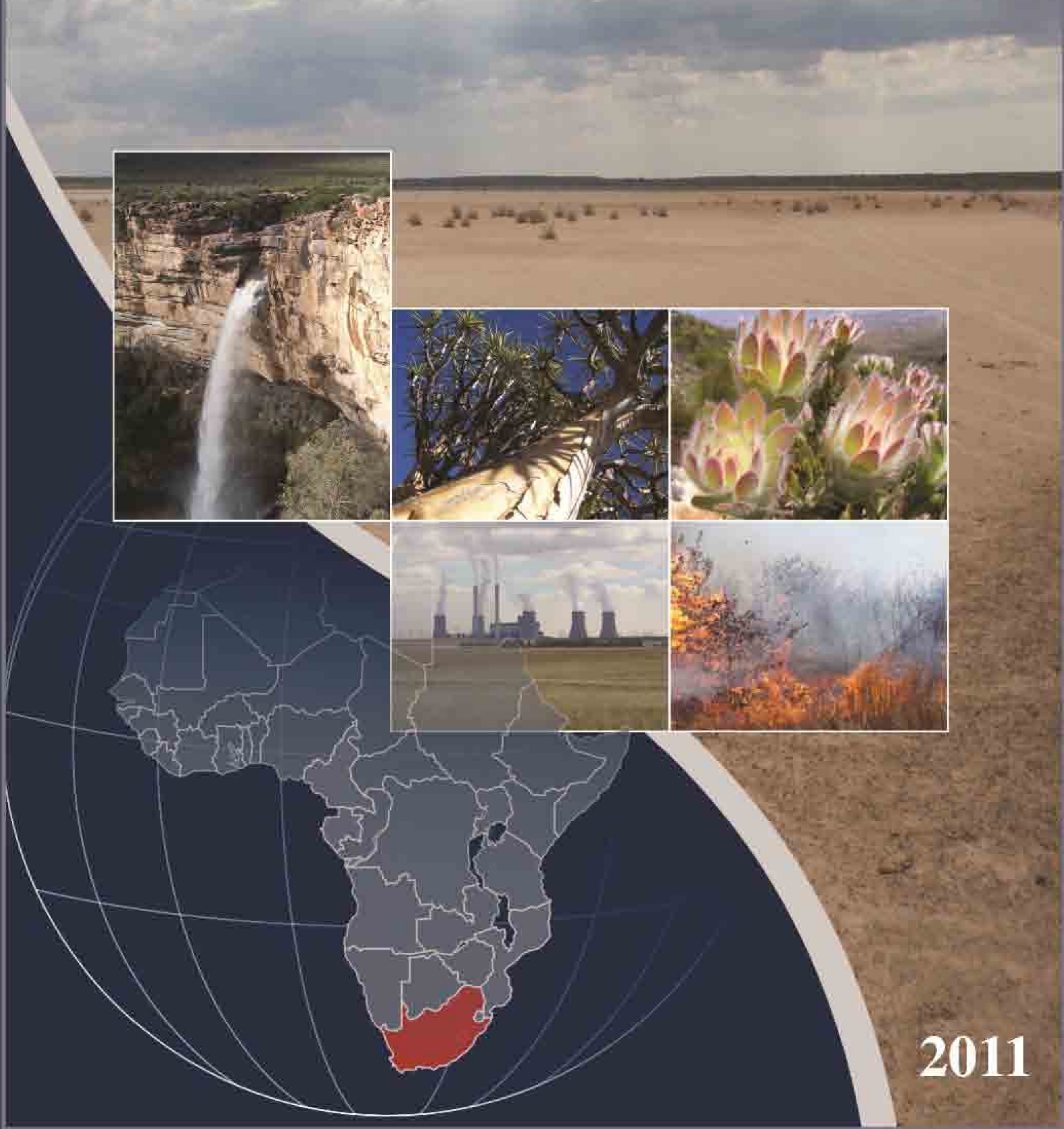
South Africa's Second National Communication under the United Nations Framework Convention on Climate Change



2011

environmental affairs

Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

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

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

Department of Environmental Affairs
Republic of South Africa

Pretoria
November 2011

Recommended citation format:

DEA 2011. *South Africa's Second National Communication under the United Nations Framework Convention on Climate Change.* Department of Environmental Affairs, Republic of South Africa, Pretoria.

Published by:

The Department of Environmental Affairs
Fedsure Building, 315 Pretorius Street, Pretoria, 0002
Private Bag X447, Pretoria, 0001 SOUTH AFRICA
Tel: +27 (0)12 310 3911
Fax: +27 (0)12 322 2682
Website: www.environment.gov.za

Printed in 2011 in the Republic of South Africa by
The Bureau Digital Media Johannesburg
www.bureau.co.za

ISBN 978 1 919976 65 5

Table of Contents

Executive Summary

In 2004, South Africa prepared its Initial National Communication in accordance with Article 12 of the United Nations Framework Convention on Climate Change (UNFCCC). This document constitutes South Africa's Second National Communication (SNC), in which several substantive advances in the national understanding of climate change-related issues are reported. The document follows suggested UNFCCC SNC guidelines for developing countries in reporting on national circumstances, and a national greenhouse gas (GHG) inventory for the year 2000. It includes a general description of steps taken or envisaged to implement the Convention; measures to facilitate adequate adaptation to climate change; measures to mitigate climate change; and other information (including technology transfer; systematic observation; monitoring and research; public awareness, training, and capacity building). The latter part of the SNC documents constraints, gaps, and related financial, technical, and capacity needs.

National circumstances

South Africa is a middle-income developing country, whose economy has historically been built on its wealth of mineral resources and its primary sectors, but which is now shifting towards an ever greater GDP share in tertiary sectors. Since the establishment of a democratic government in 1994, South African national policy has strived to address the legacy of Apartheid, including high levels of poverty combined with social inequity, high unemployment, and associated social ills. While progress has been made in this regard, significant development challenges remain. There is high social inequality in the population of about 50 million people, revealed by a Gini coefficient of between 0.66 and 0.69; and several poverty and human development indices emphasise this. These disparities, together with a high unemployment rate, are reflected in rural–urban migration trends, with negative consequences for human quality of life indicators and exposure to environmental risks in informal settlements. Health and education indices also emphasise these disparities, which are contributing factors to severe skills shortages in several sectors.

National greenhouse gas inventory for 2000

South Africa's GHG inventory has been developed for the year 2000 in four categories: energy; industrial processes and product use; waste; and agriculture. Results are given that both include and exclude emissions from forestry and other land uses, to allow for comparison with previous inventories that did not follow the Intergovernmental Panel on Climate Change's (IPCC) revised 1996 *IPCC Guidelines for National Greenhouse Gas Inventories*.

South Africa's total emissions in 2000 are estimated to be 461 million tonnes of carbon dioxide equivalents (CO_2e). Eighty-three percent of emissions are derived from energy supply and consumption, 7% from industrial processes, 8% from agriculture, and 2% from the waste sector. Forestry and other land uses currently provide a net sink for greenhouse gases, and thus reduce land-derived emissions to about 5% when they are included in the inventory.

Between 1994 and 2000 (excluding forestry and other land use emissions), energy sector emissions increased by 28%, industrial processes and other product use emissions increased by 6%, and emissions from agriculture increased by 9%, on the other hand, emissions from the waste sector decreased by 43%.

Excluding forestry and other land uses, CO_2 was the main greenhouse gas emitted, contributing 79% of emissions (362 071 Gg CO_2e). Methane (CH_4) contributed 16% of emissions (75 062 Gg CO_2e); Nitrous oxide (N_2O) contributed about 5% of emissions; and other gases (hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride (SF_6)) contributed less than 1% of emissions.

General description of steps taken or envisaged to implement the Convention

In developing appropriate policy responses to climate change, the South African government recognises the need to make a transition to a climate-resilient and low-carbon economy and society. This will be achieved by balancing mitigation and adaptation responses and, in the long-term, redefining competitive advantage and facilitating structural transformation of 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. This would be supported by building the knowledge-base and capacity to adapt to the inevitable impacts of climate change in key affected sectors, including, and by enhancing, early warning and disaster reduction systems.

Measures to facilitate adequate Adaptation to climate change

South Africa has, on average, a semi-arid and warm climate, but strong gradients in both temperature and rainfall lead to a wide variety of regional and local climatic conditions. Widespread aridity renders South Africa prone to limitations in water supply as a key vulnerability.

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

Observed trends and projections

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.

There is some evidence that rainfall 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), but inter-annual variability does not yet allow a clear overall signal to be identified.

Sea-level is rising around the South African coast, but there are regional differences. On the west coast, the sea level is rising by 1.87 mm per year; on the south coast by 1.47 mm per year; and on 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.

Research currently in progress includes a focus on the high inter-annual, decadal, and multi-decadal variability often associated with global weather patterns such as the *El Niño* phenomenon, which have had major socio-economic impacts throughout the world.

Future warming due to increased international GHG emissions is projected to be greatest in the interior of South Africa and least along the coast. Assuming a moderate to high growth in GHG concentrations, the coast is likely to warm by around 1 to 2°C by mid-century, and the interior by around 2 to 3°C. After 2050, under emissions scenarios that represent little international mitigation effort, the level of warming is projected to reach around 3 to 4°C along the coast, and 6 to7°C 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 climate models. Projections for the winter rainfall region consistently suggest future rainfall decreases, while summer rainfall region projections deviate less from present rainfall, with possible increases in rainfall amounts. With locally-developed regional downscaling techniques, rainfall projections for eastern reaches of the summer rainfall region show a strong tendency towards increased rainfall.

Socio-economic impacts and adaptation

Climate change impacts are not likely to be experienced evenly throughout the country. However, as a large proportion of South Africa's society is impoverished, it is rendered particularly vulnerable to impacts of climate change. At least 30% of South

Africa's 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 sanitation, water-borne disease and malnutrition. Without adequate adaptation strategies, the impacts would manifest as worsening food security, exacerbation of existing disease burdens, and increased vector-borne and emergent diseases and destructive social consequences.

Understanding of the impacts of climate change on human livelihoods in South Africa has developed over the past five 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, as well as on stronger links to disaster risk reduction.

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 suggests that adaptation capacity to such events is challenged by compounding factors such as pervasive social vulnerability, inadequate planning, constrained integrated and spatial development, as well as poor climate and disaster risk management.

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 is a combination of 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 droughts and floods, also affect assets.

Progress on adjustment to climate variability in South Africa has been made in the following 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 (such as 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.

Many economic sectors and ecosystems are climate- and water dependent. Water is arguably the primary medium through which climate change impacts will be felt by people, the economy, and natural ecosystems. Water resources are limited in South Africa, and thus constitute a major constraint to continued economic development and the sustainable livelihoods of people. Surface water resources are already fully allocated in many catchments, and these catchments are additionally experiencing high levels of pollution from wastewater treatment works, mining, industry, and agriculture. Changes in hydrological responses in South Africa have major associated implications for the following sectors: agriculture, health, coastal management, and disaster risk management sectors. 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 adaptation measures is well established, they are not always well executed or monitored.

Adaptation and agriculture

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

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

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

There is some evidence that small-scale and urban homestead dryland farmers are most vulnerable, while large-scale irrigated production is least vulnerable to projected climate change—given sufficient water supply for irrigation. Intensive livestock production systems are under pressure to both reduce their water use as well as contain the GHG emissions they emit.

Current projections of climate change suggest that the area potentially suitable for plantation forestry is likely to remain constant or even expand in the eastern part of the country, and conditions to favour an increase in productivity.

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

Many adaptation options in the agriculture sector have been identified, including those related to climate *per se*; to water availability and management; to hazards; the natural resource base; 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.

Adaptation and biodiversity

There is much evidence that South Africa's unique and rich biodiversity is at risk from projected anthropogenic climate change by 2050. 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 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 climatic conditions by 2050. Some impacts on species are already observable, including a notable increase in fire frequency that may be linked to observed climate change trends.

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 (that were not originally designed with climate change trends in mind) in line with the most robust knowledge of climate change impacts. Monitoring efforts and some key experimental studies at national and sub-national scale will be critical for evaluating future risk, improving model projections of impacts, and designing and assessing adaptation responses.

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

South Africa is substantially affected by invasive alien species in the terrestrial, freshwater, and marine realms, and their considerable biodiversity and socio-economic consequences are well-established. Climate change is likely to interact in various ways with the challenge of managing invasive alien species. The prevention and management of invasive alien species form integral parts of South African policy, legislation, and government action.

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 is still to be undertaken in almost all marine systems. The production of accurate regional climate models, which adequately consider ocean, atmospheric, and terrestrial influences, as well as the production of 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 limited.

Measures to mitigate climate change

With more than 80% of the country's GHG emissions 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 and 2008 Review, the development of the Long Term Mitigation Scenarios (LTMS), and the 2011 National Climate Change Response policy.

South Africa's baseline describes a scenario where there is no change from the country's current trends not even existing policy is implemented. GHG emissions in this scenario start from 446 Mt CO_2e in the 2003 base year, and increase about four-fold by 2050 to 1 637 Mt CO_2e.

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.

One-hundred-and-twenty-five 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, 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_2e between 2000 and 2050.

Other information

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.

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

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 organisations have the interest, the potential, and in many 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 realised.

Constraints, gaps, and related financial, technical, and capacity needs

Despite a great deal of progress, many gaps in understanding still exist, and these need to be addressed if appropriate 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 ten years.

The plan has identified the following 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 understanding of the links between processes on the land, the oceans and the atmosphere; 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 impact simulation models; improved forecasting and early warning systems; building capacity through education and training at all levels; and improving awareness through better communication among scientists, journalists, policy-makers, and other stakeholders.

1 National circumstances

1.1 Background

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 and respective capabilities to limit or reduce greenhouse gas (GHG) emissions that contribute to anthropogenic climate change, and to co-operate in adapting to the impacts of climate change. The government of the Republic of South Africa signed the convention in June 1993, and ratified it in August 1997. In 2004, South Africa submitted its Initial National Communication in accordance with Article 12 of the convention. This document serves as South Africa's Second National Communication.

1.1.1 Regional and national context

South Africa is a significant industrial and economic power in Africa, and especially in southern Africa, with well-developed mining, transport, energy, manufacturing, tourism, agriculture, and services sectors. South Africa has the largest economy in southern Africa, with a gross domestic product (GDP) in 2007 of R1 750 billion (US$248 billion), and is a net exporter of energy, food, telecommunications, and many other goods and services to neighbouring countries. South Africa's ports provide an important gateway for some of the landlocked countries of the region. South Africa shares borders with six countries: four to the north (Namibia, Botswana, Zimbabwe, and Mozambique); and two effectively landlocked within South Africa (Lesotho and Swaziland, which also shares a short border with Mozambique). Two of these neighbouring countries are classified as Least Developed Countries (Mozambique and Lesotho, the latter situated at high altitude on the Drakensberg Mountains in the eastern interior of South Africa).

South Africa's historical development and the attraction of its economic strength and stability have resulted in a diverse resident and immigrant population profile. Since South

Africa's first democratic elections in 1994, the country has developed its position as a regional economic leader, and has taken a stronger strategic political lead in both a southern African and African context. Since 1994, South African national policy has strived to address the legacy of apartheid, including high levels of poverty combined with social inequity, high unemployment, and associated social ills. While progress has been made in this regard, significant development challenges remain, as outlined below.

1.1.2 Geographic profile

The Republic of South Africa covers roughly 1 221 000 km^2 of the southernmost part of the African continent, and is situated at sub-tropical mid-latitudes, bordered by the Atlantic Ocean on its west coast, and the southern Indian Ocean on its south and east coasts. Its coastline stretches more than 2 500 km from Namibia in the west, southwards to the Cape and then northwards to the border with Mozambique. Fairly narrow coastal plateaus in the south and west are edged by coastal mountain ranges; and further to the interior an escarpment borders on the extensive elevated interior plateau of much of central South Africa. The eastern reaches of the escarpment include the Drakensberg Mountain Range, which has the highest peaks in South Africa. One result of this geography is a generally dry but diverse climate, ranging from a temperate Mediterranean-type climate in the south-west to a warm sub-tropical climate in the north-east, and a warm, dry, desert environment in the central west and north-west, where South Africa borders on the Namib Desert of Namibia and the Kgalagadi (Kalahari) Desert of Botswana respectively. The highlands of the Drakensberg Mountains (also home to the land-locked country of Lesotho), have a cool, wet climate relative to the rest of South Africa.

South Africa has nine provinces (each with its own provincial government), varying in size from the small but highly urbanised Gauteng province (home to major urban centres) in the north-east, to the vast and arid Northern Cape province in the north-west (see figure 1.1). The provinces are generally geographically and climatically distinct, and this, in addition to the historical development of mineral resources, is partly instrumental in determining sub-national socio-economic diversity.

Finally, in the Southern Ocean, the sub-Antarctic Prince Edward and Marion Islands (46°46'S, 37°51'E) are politically part of South Africa, and South Africa maintains a manned weather station on Gough Island (40°20'S, 10°0'W) that serves as an important remote weather station for South Africa, being situated in the path of rain-bearing cold fronts that sweep eastwards towards South Africa. While South Africa does not have a territorial claim in Antarctica, it is a founding member of the Antarctica Treaty, and maintains a non-permanent team conducting research in the natural sciences and meteorology at the South African National Antarctic Expedition (SANAE) IV base.

Figure 1.1—Map of southern Africa showing South Africa, its provinces, neighbouring countries, major towns, and roads.

1.1.3 Population profile

The South African population is estimated at roughly 50 million people (Statistics SA 2010), with an annual population growth rate of 0.5% projected for 2010–2015; a median age that has risen from 21.9 to 24.9 years between 1990 and 2010; a fertility rate that has declined from 3.3 to 2.4%; and a dependency rate that has declined from 72.7 to 53.6% (UNDP 2010). Eleven languages are officially recognised, indicating South Africa's cultural diversity. The spatial distribution of people is geographically skewed; partly as a legacy of spatial planning under apartheid, that marginalised a large proportion of the population by locating them in mostly rural areas that were geographically dispersed, spatially fragmented, and remote from economic opportunities. One result of this is concentrated rural populations in these historical 'homeland' areas, with a high reliance on subsistence activities and on grants, remittances, and other forms of transferable income[1].

Strong socio-economic and policy drivers of migration into urban centres have been at play, especially since 1994 (Roux 2009), as indicated by the urban population increase from 52 to 62% over the past two decades (UNDP 2010); and migration is significant in shaping the age structure and distribution of provincial populations (Statistics SA 2009). Rapid urbanisation and the growth of informal settlements mainly on urban fringes of both major cities and secondary towns (*e.g.* Roux 2009) have led to a range of challenges. These include the location of settlements in areas prone to flooding, difficulties in achieving the delivery of basic services (water, sanitation, and electricity), inadequate housing, and other related problems that exacerbate poverty. Up to half of all informal dwellings in South Africa are vulnerable to environmental risk factors (DEAT 2007). On the back of historical urban planning approaches, these urbanisation trends have also resulted in low income groups being marginalised from employment opportunities. In combination with high levels of poverty and unemployment, this growth in informal settlements and attendant poor living conditions and service delivery challenges, all add to the exposure and vulnerability of millions of South Africans to environmental change (*e.g.* Pelser & Redelinghuys 2009).

1.1.4 Health and well-being

Human health indicators have generally declined since 1990, but are seeing some improvements relating to efforts to achieve Millennium Development Goals (Draft MDG Report 2010), and there has been significant progress since the mid-1990s (Pelser & Redelinghuys 2009). Life expectancy at birth is currently 52.0 years (UNDP 2010), a decline from 61.5 years since 1994 (Statistics SA 2009) that is mostly due to effects of the HIV/AIDS pandemic. The infant mortality rate per 1 000 live births in the country, on the other hand, has declined marginally from 54 to 33 between 2001 and 2007, but the mortality of children under five years old increased from 59 to 104 per 1 000 between 1998 and 2007 (Draft MDG report 2010).

According to the Joint United Nations Programme on HIV/AIDS (UNAIDS 2008), 5.7 million people live with AIDS in South Africa, and the country has the highest number

---

[1] Peter Jacobs, Michael Aliber, Tim Hart, and Michael O'Donovan, *Review of rural development: 15 year review of economic and social sector programme*, prepared for the Presidency's Fifteen Year Review Process, p.52.

of HIV infections in the world. The total number of new HIV infections for 2009 is estimated at 413 000, of which an estimated 59 000 are children (Statistics SA 2009). Tuberculosis and malnutrition are the current major health threats to people living in poverty, in many cases exacerbating the HIV/AIDS pandemic. The high prevalence of HIV/AIDS compromises not only the capacity of the health sector to deliver services, but also the economy as a whole and the achievement of the Millennium Development Goals (MDGs). The National Treasury allocation to HIV and AIDS, TB and Maternal, Child and Women's Health had a budget of R8 billion (~US$1 billion) in 2011/12, which is expected to reach about R11 billion (~US$1.3 million) in 2013/14 (National Treasury 2011: 315). This represents an increase from 0.6% of total government spending in the 2005 financial year to over 1% in 2011. The 2009 antenatal care survey reflected that the occurrence of HIV infection stabilised at around 29.4 per cent among pregnant women, indicating some progress in addressing this issue (National Treasury 2011: 323).

There are several emerging and potential links between climate change and human health, particularly in the water sector; including water scarcity and the related issue of reduced water quality. Flooding and droughts, which are common seasonal occurrences, exacerbate these health challenges partly by reducing access to potable water. These impacts may therefore increasingly compromise some notable successes of government policy in increasing water delivery to poor households during the past decade (Pelser & Redelinghuys 2009).

Other climate-relevant health concerns are the geographical spread of vector and water-borne diseases, as well as reduced air quality in major urban centres in zones of subsidence. While in general, South Africa's air quality cannot be regarded as being poor; there are a number of localised areas that are exposed to extremely poor air quality, which is harmful to health. These are mostly urban areas where there are concentrations of heavy industries such as refineries and power generating plants, as well as poor residential dwellings where coal is the main fuel used for space-heating and cooking. The Air Quality Act (AQA,Act no. 39 of 2004) provides for a 'priority area approach' whereby the different spheres of government can jointly pool resources to develop strategies to address air quality issues in a cost-effective manner. Under the AQA, the South African Weather Service (SAWS) and the Department of Environmental Affairs and Tourism (DEAT), renamed Department of Environmental Affairs (DEA) in 2010, established the South African Air Quality Information System (SAAQIS) with the objective of developing the necessary information systems to set air quality improvement targets and to inform decision-making.

According to the UNDP's Human Development Index (HDI), South Africa's HDI has decreased significantly since 1990, after a marginal increase from 1990 to 1995. Its

2010 ranking at 110th out of 169 countries places it at fourth position in sub-Saharan Africa (including Mauritius), but represents a decline of seven in rank since 2005 (UNDP 2010). Social inequality has remained high since 1993, with a Gini coefficient of between 0.66 and 0.69 using the standardised All Media Products Survey (AMPS) of the South African Advertising Research Foundation (SAARF); and with poverty indices indicating an upward trend in the 1990s, followed by a declining trend in the early 2000s, and little change between 2005 and 2008 (Yu 2010). The 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, and about 13% on or below US$1 per day per person for a family of four (Statistics SA 2008).

South Africa's high unemployment rate (23.5% in 2009) has led to the growth of a large informal economy, particularly in the retail and service sectors, as well as a significant dependence on government grants including disability, child support, and old age pensions. The unemployment rate has dropped from 28.4% in 2003. 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%. The size of South Africa's emerging Black middle class has also grown from 6.3 million in 2001 to 9.3 million in 2007 (Udjo 2008).

1.1.5 Education

Several policy interventions are focused on enhancing education and education opportunities, including through addressing gender bias, such as the National Qualification Framework (NQF), Adult Basic Education and Training (ABET), skills development programmes, 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%, and 28% of adults had completed at least secondary education. Those over 20 years of age with no schooling had declined from 14.1% in 1998 to 10.5% in 2006 (Department of Education 2009). For the period 2005–2009, primary school enrolment was reported at 87%, and for 2005–2008 the adult literacy rate (ages 15 and older) was reported to be 89%[2].

It is acknowledged that, although South Africa's education system is reaching most children of school-going age and primary school enrolment should be 100% by 2015, actual learning in schools has not kept pace (Department of Education 2009). While

---

[2] http://www.mcm-deat.gov.za/about/index.html

the number of learners in the 14–18 year age-group receiving secondary education has increased, there is a higher drop-out rate before completing school education; and between 1994 and 2000 the number of matriculation endorsement annual passes declined from 88 497 to 68 626 (Department of Education 2009). There remains a disparity between schools in resourced areas and in poor areas (and between provinces) with respect to educator:learner ratios, and school:learner 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 seven universities of technology. A restructuring of the tertiary institutions took place between 2003 and 2005; reducing, through consolidation, the number of higher education institutions from 36 to 23 (Department of Education 2009). At tertiary level, South Africa's participation rate (using the 20–24 year-old age-group as the common denominator), which stood at 16% in 2005, was relatively low by international standards, although it had improved from 13% in 2000 to just over 16% in 2007. Recent expansions in enrolment applications have resulted in consideration of capping enrolment (Department of Education 2009).

1.1.6 Technical skills and capacity

South Africa currently faces significant skills shortages in many sectors, as shown by the Scarce Skills List (Department of Labour 2008), which indicates a need for 12 600 industrial and mechanical engineers and technologists; 5 000 electricians; 7 000 specialist managers, including environmental, arts and culture, office, and quality managers; 6 000 agricultural and forestry scientists; 7 000 and 9 365 teachers for Grades 4–9 and Grades 10–12 (including technical colleges) respectively; 9 000 training and development professionals; and 13 000 professionals in the human resources sectors, amongst others.

The South African Institute of Civil Engineers (SAICE) undertook a comprehensive municipal skills survey in 2007, finding that of all 283 municipalities surveyed, 83 had no civil engineers, technologists, or technicians on their staff. A further 48 employed only one civil technician, and municipalities with civil engineering staff reported 35% vacancies (over 1 000 professionals). These skills shortages are likely to constrain innovation and implementation relating to climate change adaptation and mitigation actions in urban settings.

Environmental sector skills are also critical in the context of pursuing climate-change related objectives such as meeting adaptation needs and pursuing nationally appropriate mitigation actions. The most recent South African Industrial Policy Action

Plan (IPAP 2), for example, includes an important focus on the emergence of a green economy, including addressing key issues relating to South Africa's energy future. The clear shortage of environmental sector skills, including the current high vacancy rate in national and provincial environment-related departments, has been identified by, and is considered in the Environmental Sector Skills Plan (ESSP) for South Africa (DEA 2010).

South Africa spends relatively little on research and development (0.92% of GDP in 2007), and has a low rate of research practitioners per 1 000 population (0.61%). Despite a relatively low investment in tertiary education and research, there are 73 'A-rated' researchers (considered world-class leaders in their fields by their peers) in South Africa, according to the National Research Foundation (NRF). A variety of research institutions carry out 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, the number of researchers and the number of peer-reviewed publications produced 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 2009a).

The Department of Science and Technology (DST) 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 development, knowledge generation, investment in infrastructure, and improving the strategic management of the public science and technology system. 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 (TIA) is expected to narrow this gap[3].

1.2 Economic and industry profile

South Africa is a middle developing country with well-developed financial, legal, communications, energy, and transport sectors, mainly in the urban areas. South Africa's national GDP was R1 750 billion (US$248 billion) in 2007, which translates to *per capita* GDP of R36 461 (US$5 168). From 2000 to 2008, GDP growth ranged roughly between 2.7 and 5.6%, dropped to -1.8% during the 2009 financial crisis, and recovered to 3.0% in 2010 (IMF 2010). Economic reforms since 1994 have contributed to a reduction in the budget deficit, and a budget surplus of 0.3% was achieved in 2006/7. To some extent, these gains have led to some declines in poverty measures

[3] http://www.mcm-deat.gov.za/about/index.html

after 2000, although a lack of reliable data has constrained a clear analysis (Draft MDG Report 2010).

Since 1994, growth in *per capita* expenditure has been pro-poor in an absolute sense, with individuals across the income spectrum experiencing positive income growth, irrespective of gender. However, the total number of people living in relative poverty has risen by 31.5%, linked to increasing inequality in the share of income or expenditure (Pelser & Redelinghuys 2009). High relative growth for high income levels has therefore increased the Gini coefficient (Bhorat & Van der Westhuizen 2006). The share of GDP due to social grant expenditure has increased markedly since 1994, including an increase from 2.5 to over 3% of GDP between 1997 and 2005; with numbers of social grant recipients more than tripling to more than nine million (Bhorat & Van der Westhuizen 2006), driven mostly by the extension of the child support grant (Pauw & Mncube 2007). Without social grants, the calculated Gini coefficient for 2005/6 would have increased from 0.72 to 0.76 (Statistics SA 2008).

South Africa has seen a shift in sectoral share of GDP in the past few decades that mirrors those of many developing countries and is in line with global trends of greater relative activity in services-oriented sectors (Table 1.1). Tertiary sectors have increased GDP share from about 55% in 1970 to just over 65% in 2007, with declining shares mainly in the primary sector, and to a lesser extent in the secondary sector. Nonetheless, mining-based products contribute more than 50% of the value of South Africa's exports in 2009[4].

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, but the industry has seen the loss of several thousand jobs over the past few years. South Africa's mining industry remains, however, one of the country's main employers. The coal industry is the second largest mining sector after gold. Currently, 33% of the coal mined in South Africa is exported. Although mining output has declined in general, coal mining has seen an increased output, with annual coal sales topping R70 billion. The coal mining industry contributes 70 000 jobs and the mining sector overall almost 500 000 direct jobs (Chamber of Mines 2009), making the extractive mining sector a significant job creator in South Africa.

---

[4] Wesgro trade fact sheet: www.wesgro.co.za/exporter/files/useruploads/user_anon/files/SA_Trade.pdf.

Table 1.1. Contribution (% of total value added) of different sectors of the South African economy between1980 and 2011, annual figures except for 2011, first quarter only). Source: SA Reserve Bank Quarterly Bulletins.

Sector	*1980*	*1990*	*2000*	*2007*	*2011 (Q1)*
Primary:	14.3	12.9	10.8	8.5	12.7
Mining, quarrying	11.2	9.3	7.6	6.1	10.1
Agriculture, forestry, and fishing	3.5	3.7	3.3	2.4	2.6
Secondary:	28.7	25.6	24.2	23.7	20.5
Manufacturing	20.3	20.0	19.0	17.7	14.2
Construction	4.2	3.3	2.5	3.8	3.5
Electricity, gas, water	1.9	2.6	2.7	2.3	2.6
Tertiary:	55.0	60.9	64.9	67.8	67.0
Financial services, real estate, business services	14.5	16.4	18.6	22.2	21.8
Community, social, and personnel services (incl. government)	19.8	23.5	22.0	19.4	22.2
Wholesale/retail trade, catering, and accommodation	12.7	13.7	14.6	15.4	13.9
Transport, storage, communication	7.2	7.2	9.6	10.7	9.1

Trends show that South Africa's economy has diversified in the past few decades, and new growth sectors are emerging. In particular, 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, and an increase in tourism related jobs of 10% in 2008. Growth has also been strong in the financial services sector.

In response to challenges of inequality, poverty, and high unemployment, successive governments since 1994 have put in place initiatives that aimed to reduce poverty and unemployment, primarily through targeting higher GDP growth rates. Initiatives include the National Spatial Development Perspective (NSDP) that sets out principles to guide government allocation of resources between development in strong economic centres and the provision of basic services in areas of lower economic potential; the Expanded Public Works Programme (EPWP) launched in 2004 and aimed at creating one million job opportunities over five years; an infrastructure investment programme; and education and skills development. 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, the National Planning Commission (NPC), released its Medium-Term Strategic Framework (MTSF) 2009–2014. This document outlines the government's 'Vision 2025', pursues these objectives further, and encompasses a set of objectives based on the electoral mandate, with a fifteen-year time horizon from 2010. The MTSF 2009–2014's main economic priorities are to accelerate economic growth and transform the economy to create decent work and sustainable livelihoods; elaborate 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.

The recent SAICE report card[5] ranks South Africa's infrastructure overall as a C-, where C indicates that it is satisfactory but stressed at peak periods, and D that it is at risk due to being over-stressed and poorly maintained. Rankings for ten major infrastructure types range from E- to B+, with rankings lower for locally *vs.* nationally maintained infrastructure. Key issues identified are the severe shortage of skills and its impact on planning, procurement, design, construction, and care of infrastructure; as well as inadequate funding for maintenance of existing and newly built infrastructure.

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 patterns are characterised by large distances between settlements and places of employment, and low density settlement patterns. South Africa has a higher than world average car ownership ratio, which can be attributed partly to the legacy of historical spatial

[5] http://www.saice.org.za/pdf/IRC2011-landscape-1-final-lr.pdf

planning at an urban and regional level. 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% is due to private vehicle trips, and 11.5% due to minibus-taxis. 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 formalise the taxi industry. Some major metropolitan areas are adopting Bus Rapid Transport (BRT) systems along the most centralised and congested routes and integrating these with the existing taxi industry where possible.

The South African National Roads Agency (SANRAL) oversees a national roads network of approximately 750 000 km. While road transport offers greater convenience than rail transport and other forms of public transport, it is responsible for air pollution, congestion, and fossil fuel consumption. The road-based freight sector causes damage to road surfaces, and efforts are being made to regulate overloading in road transport and to better integrate the secondary economy into the freight services industry. SANRAL estimates that there is currently a R50 billion backlog on key national and provincial roads, with an associated annual maintenance budget of R12 billion[6].

There is significant potential for freight and passenger rail to enhance their contribution within the transport sector. Only 13% of freight tonnage is moved by train, and potential for expansion of the rail freight industry is significant as the existing infrastructure is extensive and technologically advanced, with strong regional links and interests. The Transnet Freight Rail (TFR) network comprises 21 000 km of rail, with 800 trains running daily for both domestic and cross-border trade. An upgrade strategy is being implemented that will invest R80.5 billion in the next five years, building on the R53.5 billion invested since 2005. Metrorail, a division of the Passenger Rail Agency of South Africa (PRASA), is a state-owned enterprise that operates commuter rail services in the major urban areas of South Africa. The state-subsidised Metrorail system transports an average of 1.7 million passengers per working day[7]. The recently completed Gautrain Rapid Rail Link (GRRL) between Johannesburg and the Tshwane Metropolitan is anticipated to reduce related commuter road traffic by 20%.

South Africa has eight international coastal ports, among the best developed network in Africa. About 98% of South Africa's exports are conveyed by sea. Transnet spent R19.4 billion in 2009 on maintenance and development of ports alone. The air travel industry was deregulated in the early 1990s, which along with increased international

---

[6] *ibid*

[7] http://www.metrorail.co.za/national_facts.html

travel, has resulted in a 10% increase in air travel per annum over the last three years, to 32.8 million passengers in 2008.

Telecommunication 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 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 telecommunications network in Africa. Wider access to broadband (*e.g.* ADSL and 3G) 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. Access to telecommunication services is generally limited to the more populated areas. The government has committed to increasing accessibility and reducing costs, and this sector appears to offer mitigation potential and further economic development opportunities.

Following the world-wide trend, waste processing and disposal are growing challenges related to population and economic growth in South Africa. The regulation of waste disposal has been strengthened by the DWAF Minimum Requirements (second edition, 1998) for waste disposal by landfill (DWAF 1998a); the handling, classification, and disposal of hazardous waste (DWAF 1998b); and water monitoring at waste management facilities (DWAF 1998c). The Environmental Impact Assessment (EIA) regulations (managed by DEA), also curtail the environmental impact of waste management activities (DEAT 2009b). The National Environmental Management: Waste Act (Act no. 59 of 2008) (NEMWA), came into effect in 2009[8], and a draft National Waste Management Strategy (NWMS) has also been published. The NWMS emphasises international best practice that prioritises waste avoidance and reduction with potentially substantive sustainability implications. The SAICE finds that households with adequate refuse removal services have remained at approximately 60% since 2006, but are over 80% in urban areas, and as low as 20% in rural areas. Changing perceptions about waste management recognise income generation potential at a municipal, community, and household level. Sustainable waste management services in municipalities are compromised by a lack of skills, for example, 87% of municipalities do not have the skills capacity to implement waste minimisation responses as advised by the NWMS. Many recycling projects that have been launched by over 80% of municipalities have failed due to unpredictable market demand, skills challenges, and high costs.

---

[8] www.sawic.org.za/documents/429.pdf

1.3 Energy profile

South Africa has abundant energy resources in the form of fossil fuels (mainly coal), and renewables (mainly localised wind and biomass, and solar), but limited hydro-power. The main sources of supply to the energy grid are currently coal and nuclear. Biomass forms an important energy source in the rural domestic sector, while other renewable energy development opportunities are being explored in the fields of solar power, wind power, pumped storage, and in hydropower schemes. South Africa's economy is heavily dependent on coal. South African coal reserves have been estimated at roughly 30 billion tonnes, accounting for 95% of African coal reserves and 4% of world reserves. Coal provided an estimated 72% share of the country's total primary energy supply in 2007 and accounts for approximately 85% of electricity generation capacity. Coal is also a major feedstock for the country's synthetic fuel industry. Energy supply is therefore carbon-intensive.

The Department of Energy (DoE) is the entity responsible for defining and implementing the policy framework for the energy sector, while the National Energy Regulator of South Africa (NERSA), an autonomous entity, is responsible for regulating the sector, including the establishment of an overall electricity tariff regime. Eskom Holdings Ltd (Eskom), which is a vertically integrated public utility, is responsible for 96% of South Africa's electricity generation, all transmission, and 60% of distribution. Private generators account for about 3% of generation (mostly for their own consumption), and municipalities account for the remaining 1%. The balance of electricity distribution is undertaken by the local authorities (about 185 in total) that buy in bulk from Eskom.

The electricity sector of South Africa includes roughly 42 GW of installed power generating capacity providing electricity to 81% of South Africa's population through 28 000 km of high voltage transmission lines (Eberhard 2006). A public entity, the South African National Energy Research Institute (SANERI), was established in October 2004 as a subsidiary of CEF (Pty) Ltd, a private energy company incorporated in terms of the Companies Act, with 100% share-holding by the state, and governed by the CEF Act. SANERI is entrusted with the co-ordination and undertaking of public interest energy research, development, and demonstration. The DST and the DoE are joint custodians of SANERI and provide its political and strategic focus.

Table 1.2. Total additional new and existing electricity generation capacity (in GW) as per the national IRP 2010; CCGT = Closed-Cycle Gas Turbine, OCGT = Open-Cycle Gas Turbine.*

	Coal	Nuclear	Hydro	Gas-CCGT	Peak-OCGT	Renewables
New capacity (Policy-adjusted IRP)	6.3	9.6	2.6 (import)	2.4	3.9	17.8
Committed new builds	10.1	0.0	0.05	0	1.0	1.0
Existing fleet (2010)	35.5	1.8	2.1	0	2.4	0.0
Energy share 2010 (%)	90	5	5	0	<0.1	0
Energy share 2030 (%)	65	20	5	1	<0.1	9

* http://www.energy.gov.za/IRP/2010/IRP2010.pdf

South Africa's proposed electricity supply development is outlined in the gazetted Integrated Resource Plan (IRP) for Electricity (IRP 2010[9]), which went through a process of public consultation and revision of the initially proposed revised balanced scenario, referred to as the policy-adjusted IRP. The plan (Table 1.2) outlines energy efficiency demand-side management measures of 3.4 GW by 2030, and a new fleet build for 2010–2030, which has an emission constraint of 275 MT CO_2 per year after 2024. This includes a nuclear fleet of 9.6 GW to account for uncertainties related to the costs of renewables and fuels, 6.3 GW coal (in addition to an already committed 10 GW build underway), 17.8 GW of renewables (which installation was advanced to stimulate local industry), and 8.9 GW from imported hydro and gas turbines (Table 1.2). By 2030, this plan will increase South Africa's electricity generation capacity from the current 260 TWh to 454 TWh. The IRP is seen as a living plan, with review and revision expected on a two yearly basis.

1.3.1 Electricity supply, demand, and consumption

South Africa's electricity needs are met predominantly through the exploitation of its substantive coal reserves. A brief load-shedding period in January 2008, due to a temporarily constrained supply, was estimated to have decreased economic growth

[9] http://www.energy.gov.za/IRP/2010/IRP2010.pdf

by 0.4% of GDP, largely as a result of shutting down mines and smelters. This event highlighted the vulnerability of the South African economy to energy constraints.

The main supplier of electricity is the state-owned utility Eskom, generating about 96% of South Africa's electricity. Eskom is also the sole transmitter and distributor to corporations, municipalities, households, and villages at national level (Eberhard 2006). Eskom manages a nominal capacity of about 42 GW, and also supplies a sizeable fraction of the electricity needs of several of its southern Africa neighbours, including Botswana, Mozambique, Namibia, Swaziland, Lesotho, Zambia, and Zimbabwe (Eskom 2008). The highest electricity demand is from industry, consuming more than 51% of the country's total energy, double that of domestic households. Transport and Services consume about 27% and 8% respectively, with Agriculture's proportional consumption lowest at 2.6%.

After 1994, South African government policy was realigned to provide electricity to rural and urban low-income households that have been deprived of access to electricity under apartheid. The Integrated National Electrification Programme (INEP) was implemented between 1994 and 1999, including a Free Basic Electricity (FBE) programme providing qualifying households with 50 kWh per month at no cost. In 1998 an Energy White Paper (EWP) was issued regarding energy supply and consumption for the next decade. An Integrated Energy Plan (IEP) was published in 2003, providing a framework for energy policy, energy sources development, and energy technologies (DME 2003a). By 2004 approximately 77% of urban households were electrified (an increase in access to electricity from 36 to 71% of urban populations). In 2003, this was extended to areas not on the national grid through the Free Basic Alternative Energy (FBAE) programme. However, no major investments had been made to increase supply, and in 2008 Eskom experienced a considerable shortage of capacity that resulted in power outages and ultimately in electricity tariff increases. This represented a shift from the historical pattern of low electricity prices as a major national competitive advantage (between 1998 and 2007 the real price of electricity had declined by 12%, before tariffs increased after 2008).

A reserve margin below 15–19% has raised concerns about sustaining economic growth. Steps have been taken to add base-load capacity by building two coal-fired stations, Medupi and Kusile, with capacities of 4 788 MW and 4 800 MW respectively (as reflected in IRP 2010[10]); to re-commission three 'moth-balled' coal-fired stations; and to build two additional open-cycle gas turbines. With respect to fossil fuel energy sources, clean coal technologies are under consideration by the South African

[10] http://www.energy.gov.za/IRP/2010/IRP2010.pdf

Government and the coal-mining industry, and Eskom has commissioned an underground coal-gasification pilot plant—both are technology issues identified in the IRP2010 as research and development priorities. Biomass is currently estimated to meet about 8% of South Africa's primary energy supply, mainly in rural areas but also produced for own use by pulp mills and sugar refineries—this source is also identified as a research priority in IRP2010. South Africa has high potential for solar and wind energy, but so far only between 2 and 5 MW of electricity in the national grid is generated from wind. South Africa has 661 MW of domestic installed hydropower.

The Government's electricity policy includes three important pro-poor components: (i) accelerated access to electricity; (ii) subsidised electricity for the poor; and (iii) a pro-job strategy for economic growth supported by reliable, low cost electricity supplies. The Government entered into an important electrification programme as part of its post-apartheid programme designed to improve the distribution of incomes. The programme started in 1993 with electrification levels of 34% and reached 81% by 2007. Electrification rates have decelerated in the recent past, as financial issues have limited the sector's implementation capacity.

In 2003, the Government launched the Free Basic Electricity (FBE) programme (targeted at the poor), which is financed by the national government, managed by Eskom and local governments, and aims to provide a minimum of 50 kWh of energy free per month to each qualifying household. The local government decides within each respective municipality who qualifies for free basic services. At present, the FBE covers approximately three million households, 1.2 million (mostly rural) customers of Eskom, and the remainder through municipal distribution companies. The FBE system is supplemented by cross-subsidies from large customers to households using less than 350 kWh per month. The FBE system also extends to off-grid energy systems, largely Solar Home Systems (SHS) intended to facilitate the provision of basic lighting and media access. There are also other special reduced 'life-line tariff' arrangements for customers consuming less than 350 kWh/month.

The third, and arguably most important component of the pro-poor policy associated with electricity supply, is the need for electricity to support labour intensive economic growth. Given South Africa's unemployment rate, this represents one of the largest socio-economic issues that the Government needs to address.

1.3.2 Non-renewable energy reserves

South Africa has an abundance of coal (Table 1.3), which currently meets the bulk of South Africa's primary energy needs. In terms of energy reserves, South Africa is estimated to have about 30 billion tonnes of coal, with well-developed extractive and beneficiation technologies. Oil reserves are sufficient for four years' production, with further deep-water potential, but 95% of South Africa's needs are met by imports.

Table 1.3. Energy resources and reserves in South Africa (values estimated with probability greater than 50% on 1 April 2011). Tcf = trillion cubic feet, Mt = Megatonne, kt = kilotonne.

	Oil (million barrels)	*Gas (Tcf)*	*Coal bed methane (Tcf)*	*Shale gas (Tcf)*	*Coal (Mt)*	*Uranium (kt)*
Current	4.57	1.1906	-	-	30 408	205
Contingent	8.75	5.262	1	-	-	56
Prospective	18 975	55.4	>5	5–485*	-	-

* Lower estimate: agency conservative estimate; upper estimate published by EIA

South Africa leads the world in coal-and-gas-to-liquid fuel technologies. Sasol has two large units that produce about 23% of South Africa's liquid fuel. The Mossgas plant on the south coast makes liquid fuel from an off-shore natural gas field, producing about 7% of South Africa's liquid fuel. Natural gas reserves are estimated at 11.8 million barrels of condensate, and additional reserves are newly under production license at Ibhubesi on the north-west coast of South Africa. Ibhubesi Gas is expected to produce 2.8 million m^3 of natural gas a day from 2012, increasing to a peak production of 6.4 million m^3.

The beneficiation (conversion and enrichment) of locally mined uranium and nuclear fuel fabrication is not carried out in South Africa. South Africa has an estimated reserve of 205 000 tonnes of 'reasonably assured resources' of uranium and a further 56 000 tonnes of 'estimated additional resources' (SA Mineral Industry 1996/7, Minerals Bureau, Department of Minerals and Energy (DME)). For conventional nuclear power reactors, using a figure of 0.6048 PJ per tonne of natural uranium, this gives an energy reserve of 157 853 PJ for conventional nuclear power reactors, and 7 893 000 PJ for fast-breeder nuclear reactors.

1.3.3 Renewable energy potential

Fuel wood is the most widely used form of renewable energy in South Africa, with more than one third of the population relying on it for their energy needs (ERC 2007). Commercially viable renewable energy capacity is not yet well developed or exploited relative to fossil and nuclear sources, but there is a growing national focus on renewable energy sources. Theoretical renewable energy potential in South Africa is vast, with about 280 TW of solar energy typically impinging on South Africa's land surface (Eberhard & Williams 1988)—more than 6 000 times the country's current capacity of 41 GW. Solar photovoltaic panels are widely used in rural areas, with an estimated 70 000 households, 250 clinics, and 2 100 schools employing photovoltaic panels for their energy needs (ERC 2007). Western and north-western parts of South Africa are particularly well-suited to solar energy, due to the high incidence of cloud-free days.

Wind energy resources of South Africa are estimated by the South African Wind Energy Association (SAWEA) to exceed 30 GW. While South Africa only has 10 MW of installed wind energy capacity at this time, wind energy is projected to contribute 700 MW by 2013 to the 10 000 GWh target stipulated in the White Paper on Renewable Energy (DME 2003b). About 2% of South Africa's current energy mix is provided by hydroelectric and pumped storage schemes. South Africa has only a few small rivers suitable for generating hydroelectricity, mainly along the eastern escarpment and suitable only for mini-hydropower generation (ERC 2007). With current and projected future water limitations, South Africa therefore has limited further hydropower potential.

The national biofuels policy (DME 2007) sets a target of 2% of fuel supply from biofuels by 2013 (*vs.* a 4.5% target proposed in an earlier draft version of the plan). The policy excludes maize as a feedstock initially, and restricts the 2% target to bio-diesel made from soybeans, canola or sunflower oils, or ethanol from sugar cane or sugar beet. The policy will implement a 50% fuel tax exemption for bio-diesel and a 100% exemption for ethanol. Policy concerns relate especially to jeopardising food security, and thus apart from excluding maize, there is a focus on developing new and additional agricultural land. This will require about 1.4% of arable land in South Africa, targeted in former homelands.

Biomass is currently used for co-generation of heat and electricity in the paper and sugar industries, and bio-gas is generated from waste biomass in breweries and other private institutions, but the potential for biomass exploitation and co-generation is substantially higher. The development of biomass energy is being highlighted in 'Working for Energy' (WfE), South Africa's national renewable energy programme[11]. The purpose of the programme is to develop and apply practical approaches for sustainable, labour intensive, renewable energy and energy management type projects in rural areas. The programme is cabinet-endorsed and was granted an initial

[11] http://www.wfe.org.za/

funding allocation in 2009. The WfE programme is positioned to assist local authorities by relieving increasing pressure to reduce electricity demand, diversify, and increase their own generation of electrical energy, provide free basic services to indigent households, and provide sustainable energy to rural South Africa. The programme interactively addresses job creation and poverty alleviation; skills development and enterprise development; reduction of electricity demand and overall energy utilisation; development and enhancement of co-generation projects; development of new energy sources and efficiency enhancements; enhancement of existing infrastructures; development of new green field projects for low cost housing electrification; and reduction of environmental impact and green-house gas emissions.

1.4 Natural resources and related sectors

1.4.1 Climate

With a sub-tropical location, South Africa's generally warm climate is moderated by oceanic influences along its extensive coastline and by the altitude of the interior plateau. South Africa is renowned for its abundant sunshine. Air temperatures in South Africa tend to be lower than in other countries at similar latitudes due mainly to greater elevation above sea level. On the interior plateau, the high altitude prevents average summer temperatures from exceeding 30°C, and in winter, night-time temperatures in the interior can drop below freezing, but this is very seldom the case for coastal regions. While snow frequently occurs on the escarpment in winter, no part of the escarpment is permanently snow-covered. Average annual temperatures differ strongly between west and east coasts, due mainly to the influences of the northward-flowing, cold Benguela Current on the west coast and the tropical, warm, southward-flowing Agulhas Current on the east and south coast.

South Africa has a generally dry climate (especially towards the north-west), with an average annual rainfall of about 450 mm[12] (compared to a world average of about 860 mm). While the Western Cape gets most of its rainfall in winter, the rest of the country generally has summer rainfall, with a small southern region of all-year rainfall. Rainfall is variable between years. South Africa's climate is influenced by multi-year *El Niño/La Niña* climatic cycles that tend to cause dry conditions in the summer rainfall areas during *El Niño* years, while *La Niña* conditions are often associated with increased summer rainfall. Rainfall is generally variable, especially in the arid west and north-west, with both periodic drought and flood conditions not uncommon through most of the country.

[12] http://www.dwaf.gov.za/documents/policies/NWRS/Sep2004/pdf/Chapter2.pdf

1.4.2 Water

South Africa is a water-scarce country (annual freshwater availability is less than 1 700 m^3 *per capita*), with limited average rainfall of about 450 mm/yr and unevenly distributed water resources. South Africa has an annual mean-runoff value of 40 mm, one seventh of the global average of 260 mm, and rainfall and river flow are variable, erratic, and seasonal. Less than 9% of rainfall converts to river flow. South Africa's average river runoff is currently about 49 040 Mm^3/yr, including 5 500 Mm^3/yr from Lesotho and Swaziland. South Africa's dam storage capacity is 66% of this volume with the reliable surface-water yield at 82% of its maximum capacity under current rainfall and evaporation conditions (De Villiers & De Wit 2010). 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.

Water has historically been allocated to meet the demands of irrigated agriculture, mining projects, and urban growth. More recently, government has strived to allocate water resources to meet the needs of a growing economy, to ensure food security, and to maintain ecological integrity and environmental quality. In pursuit of the Millennium Development Goals (MDG), the state has provided access to basic water services for 9 million people since 1994, but this has been concentrated in the urban areas. The Free Basic Water (FBW) policy of 2001 provides the first six kilolitres of water free to all households. By 2006, however, 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).

Within the national department, the country is divided into 19 Water Management Areas (WMAs), with the aim of decentralising the management of water to stakeholders who are directly affected by water resource management decisions. Ten of the 19 WMAs have water deficits and there is competition between utilisation for agricultural, industrial, and social demand, and meeting the legal requirement to maintain the ecological integrity of the system (estimated at 20% of natural river flow)—with adverse effects on the statuses of natural river systems. The sustainable use of several trans-boundary aquifers would benefit from improved forms of management and investment in scientific understanding. Several large dams and inter-basin transfer schemes have been installed to address various needs such as urban development areas, water requirements of thermal power generation, mining centres, and some regions of agricultural activity.

South Africa's groundwater aquifers are estimated to store roughly 235 000 Mm^3 of water (DWAF 2004), but the quality and availability of data on groundwater resources and their recharge rates compromise sound management decisions. Current estimates of exploitable groundwater are variously 4 800 Mm^3/yr (Scholes & Biggs 2004), 6 000 Mm^3/yr (DWAF 2004), 10 000 Mm^3/yr (Haupt 2001) and 19 000 Mm^3/yr (DWAF 2004), the latter of which is accepted by the National Water Resource Strategy (NWRS)[13]. Groundwater is used extensively in rural and more arid parts of South Africa. It is a significant resource to many irrigation farmers, small towns in more arid parts of the country, and areas 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 reliance on groundwater is indicated by the constant slow decline in groundwater levels, despite the seasonal fluctuations, attesting to unsustainable rates of use. Monitoring programmes in some regions are not adhered to and there is a lack of proper management of groundwater resources at national and local levels. Impacts of mining projects and their practice of groundwater removal are severe. Acid mine drainage is almost certainly the biggest threat to groundwater, especially in the vicinity of coal and gold mining activities (De Villiers & De Wit 2010). Further such exploitation of groundwater could have significant adverse environmental effects (DWAF 2004: 14).

Official estimates suggest that South Africa faces shortages of between 2 and 13% of total water requirements by 2025, but some estimates that include climate change projections and other uncertainties, suggest that these could run to as high as 19–33% by 2025 (De Villiers & De Wit 2010). The agricultural sector uses most of the available surface-water resources in South Africa, estimated at about 60%, using various irrigation practices. Plantation forestry uses significant amounts of water, sometimes creating tensions with other stream-flow users downstream, and forestry has been declared a stream-flow reducing activity, with licenses issued by the Department of Water Affairs (DWA). Invasive alien trees, sometimes associated with commercial forestry, consume about 3 000 Mm^3/yr, equivalent to about 7% of total available runoff (Van Wilgen *et al.* 2007). Water demand is growing most rapidly in the main metropolitan centres, indicating a need for municipalities to manage and co-ordinate both demand and supply. Generally, however, they are under-resourced, and this is likely to put them in competition with their hinterlands (DWAF 2004: 38). Treatment of wastewater has not tracked growth in demand and use, and poor quality of surface-waters is increasingly a problem in much of the country. While there is limited undeveloped surface-water resource potential, there is potential for increasing re-use of return-flows in some coastal cities, where wastewater is currently discharged into the ocean.

[13] www.dwaf.gov.za/documents/policies/NWRS/default.htm

1.4.3 Terrestrial environment

South Africa is one of the richest countries in the world in terms of diversity of plants and animals (marine and terrestrial), and levels of endemism. Three of 34 biodiversity 'hotspots' identified internationally are in South Africa (the Cape Floristic Region in the Western Cape, the succulent Karoo region in parts of the Western and Northern Cape provinces and extending into Namibia, and the Maputoland-Pondoland-Albany region in parts of KwaZulu-Natal, the Eastern Cape, Swaziland, and extending into Mpumalanga and the southern-most part of Mozambique). These 'hotspots' contain high concentrations of endemic plant and animal species, in areas most threatened by human activity. South Africa's biodiversity is exposed to significant risks with 44% of river ecosystems, 23% of estuarine ecosystems, 12% of marine ecosystems, and 5% of terrestrial ecosystems in South Africa all critically endangered (Driver *et al.* 2005). 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 3 000 Mm^3 of water per year, equivalent to about 7% of the country's annual surface-water resources (Van Wilgen *et al.* 2007). The White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity (1997)[14] seeks to improve capacity to conserve and use biodiversity, address threats, and create conditions and incentives that support conservation and sustainable use of biodiversity.

Natural land-cover types are shrublands (~40%), savanna woodlands (~33%), and grasslands (~27%), with forests and deserts making up a small fraction of less than 1% together. Roughly 11% of land is formally cultivated, and 1.5% is covered by cities and towns (Van den Berg *et al*. 2008). The extent of woodlands has increased in the past few decades, due to colonisation of previously grassy ecosystems by shrubs and trees (termed 'bush-encroachment'). There is some evidence that bush-encroachment is partly as a result of the direct effect of rising atmospheric CO_2, which favours the growth of woody plants (Bond *et al.* 2003; Wigley *et al*. 2010).

South Africa has a long history of introductions of alien species, with a pronounced increase following the arrival of European settlers in the 17th century. South Africa currently hosts approximately 8 750 alien plant species, 180 of which are invasive (*i.e.* have established themselves and are spreading into natural vegetation) and have invaded about 8% of South Africa's surface area. Future expansion of invasive plants could reduce the integrity of all South African biomes by reducing indigenous species

---

[14] http://www.environment.gov.za/soer/nsoer/Issues/land/response.htm

richness by roughly 60–80% (Van Wilgen *et al*. 2007). Freshwater ecosystems are also at risk, with 37 invasive alien species of freshwater fish currently recorded

Natural biodiversity is conserved in an extensive protected areas system as recognised in the National Environmental Management: Protected Areas Act (NEMPAA) (Act no. 57 of 2003), that covers roughly 7% of the terrestrial surface area. Over the next five years, in order to move a quarter of the way to meeting the 20-year protected area targets according to the National Protected Area Expansion Strategy (NPAES) (DEAT 2009), a further 2.7 million ha must be added to the land-based protected area network.

1.4.4 Marine environment and coastal zones

South Africa has more than 2 500 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. Vulnerabilities include seasonal cyclonic activity along the north-eastern coast, seasonal storm activity on the south-west coast, and anticipated sea level rise.

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), due largely due to the diversity of environments provided by two major current systems: the warm Agulhas Current along the east coast, and one of the major upwelling regions of the world, the Benguela system (Hutchings *et al.* 2009) along the 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. 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; and changes in the salinity levels of estuaries, which will affect breeding grounds of many marine species. A significant proportion of South Africa's metropolitan areas, as well as numerous towns and smaller settlements, are situated along the coast, making them vulnerable to any dramatic sea level rises. South Africa has 259 estuaries, most of which show high vulnerability to current human pressures (Turpie 2004). Increasing human pressure on coastal areas gives rise to the need for sustainable coastal development through an integrated coastal management approach (SANBI 2007)[15].

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 bio-zones 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[16]. In order to meet biodiversity conservation targets (DEAT 2010), 88 km of coast line needs to be added to the inshore marine protected area network (including 59 km of coastline in 'no-take' zones), 52 500 km^2 to the offshore marine protected area network in South Africa's mainland Exclusive Economic Zone (EEZ), and 23 300 km^2 to the offshore marine protected area network in the Prince Edward Islands EEZ that forms part of South Africa's territory.

1.4.5 Agriculture, forestry, and fisheries

Agriculture, forestry, and fishing together account for less than 3% of GDP in 2006 (Table 1.1), following a downward trend in the past few decades (DAFF 2009), and currently employ 618 000 people in the formal and informal sectors (Statistics SA 2010). The agriculture sector is described as dualistic[17], dominated in economic output terms by sophisticated, large-scale commercial farming, but with an important small-scale and subsistence sector. The total contribution of agriculture to the economy increased from R27 billion in 2001 to R36 billion in 2007. The total gross value of agricultural production for 2007/08 is estimated at R112 billion compared to R93 billion the previous year[18]. 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: 28). South Africa's largest agricultural commodity by mass in 2007 was sugarcane. Cattle meat produce is also a significant agricultural commodity, followed by chicken meat, grapes, and dairy[19]. 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. Farm land is undergoing a process of redistribution, with 4.3% of commercial agricultural land having changed

---

[15]http://soer/deat/gov/za/themes/land/land use and productivity

[16] http://soer.deat.gov.za/themes.aspx?m=523
[17] http://www.southafrica.co.za/about-south-africa/environment/agriculture-forestry-and-land
[18] *ibid*
[19] http://faostat.fao.org/site/339/default.aspx

hands through the land restitution and land redistribution programme against a goal of transferring 30% of land by 2014 (DEAT undated). By 2008, 74 747 land claims had been settled, involving more than 1.4 million beneficiaries[20].

The Department of Agriculture (DoA) drafted a food security strategy for South Africa in 2002 in response to the lack of both co-ordination 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; 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 (DoA 2002:6).

South Africa's plantation forests are based on non-native 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. It currently employs close to 170 000 people and contributes more than R16 billion to the South African economy, with an annual production of 2.2 million m^3 of commercial round wood with a calculated value of R5.1 billion. 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. The private sector currently owns 70% of the total plantation area, as well as virtually all the processing plants. The DAFF is currently involved in a process of restructuring the state's commercial forests and transferring ownership of these forests to the private sector or other forms of land use, mainly conservation. The afforestation rate is declining (DWAF Timber Statistics 2005: xiii).

South Africa has about 530 000 ha of indigenous forests, found mainly along the southern and eastern escarpment, along the coastal belt, and in fire-protected ravines in the mountains of the southern and south-western Cape. A detailed inventory monitors changes in forested areas, classified into 24 broad forest types. The Natural Forests Protected Areas System (NFPAS) guides the designation of natural forests as protected areas. Natural forests serve as increasingly important sources of building material, fuel wood, food, and medicine (as roughly 80% of South Africa's people rely on medicinal plants[21]).

[20] http://www.southafrica.co.za/about-south-africa/environment/agriculture-forestry-and-land
[21] *ibid*

The commercial and recreational fishing industries are a relatively small economic sector, contributing about 1% of GDP, valued at approximately R4–5 billion annually, and providing employment for an estimated 27 700[22] individuals, with secondary industries such as fish processing, transporting of fish products, and boat building employing a further 60 000 (Kashorte 2003). South African marine fisheries are diverse and dependent on different ecosystems (from coastal to offshore), but the main commercial stocks are sardine and anchovy, Cape hake, horse mackerel, rock lobster, tunas and shark, *Loligo* squid, and a composite group of so-called 'line-fish'[23]. The anchovy and sardine fishery is the largest by volume, and is strongly dependent on the status of upwelling in the west coast region of the Benguela Current ecosystem, while the south coast Agulhas Current ecosystem is important for spawning these species.

South Africa has experienced significant declines in catches and the loss of many species both as a result of over-fishing, and due to the natural migration of fish populations related to environmental changes, prompting government to apply controls to the fishing sector. The Marine Living Resources Act (MLRA) (Act no. 18 of 1998) resulted in a significant restructuring of the commercial fishing industry, and had mixed impacts on the small and subsistence fishing sector. Subsistence fishing and marine resource harvesting practices, although small and localised, are important for some coastal subsistence livelihoods. Despite the legislation, poorly controlled poaching and illegal fishing are adversely affecting high-value species.

The aquaculture industry is small but growing. Mariculture developments include abalone, black mussel, oyster, prawn, finfish, and seaweed production. Abalone farming, mainly on the Cape south coast in South Africa, supplies 21 % of the global market, and is expanding rapidly. Experimental offshore salmon and cob 'cage' farming in south coast areas is underway, and indications are that mariculture production could increase substantially[24].

[22] ftp://ftp.fao.org/FI/DOCUMENT/fcp/en/FI_CP_ZA.pdf
[23] *ibid*
[24] *ibid*

2 National greenhouse gas inventory

2.1 Introduction

South Africa's national greenhouse gas (GHG) inventory has been developed for the year 2000 using the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines. The 2000 GHG inventory is the third to be prepared for 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 United Nations Framework Convention on Climate Change (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 (excluding emissions from the combustion of fuel in industries that 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); including 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

such as 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 at 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 lower tier (tier 1) calculation methods therefore had to be used. In a number of cases no information was available, which has lead to the omission of some sources; for example the electronics industry, health sector, and some industrial activities.

2.2 Total emissions

South Africa's total emissions in 2000 were estimated to be 461 178.5 Gg CO_2 equivalents (461 million tonnes CO_2e). Eighty-three percent 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) (see figure 2.1). 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 from LULUCF for the 2000 inventory 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 were 20 022 Gg CO_2e or 20.0 Mt CO_2e (see figure 2.2).

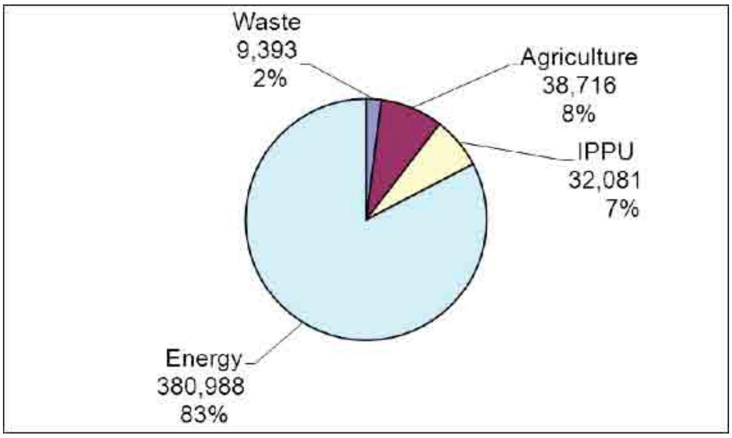


Figure 2.1—Total greenhouse gas emissions by sector in South Africa, *without* land use, land use change, and forestry (LULUCF) ($GgCO_2e$).

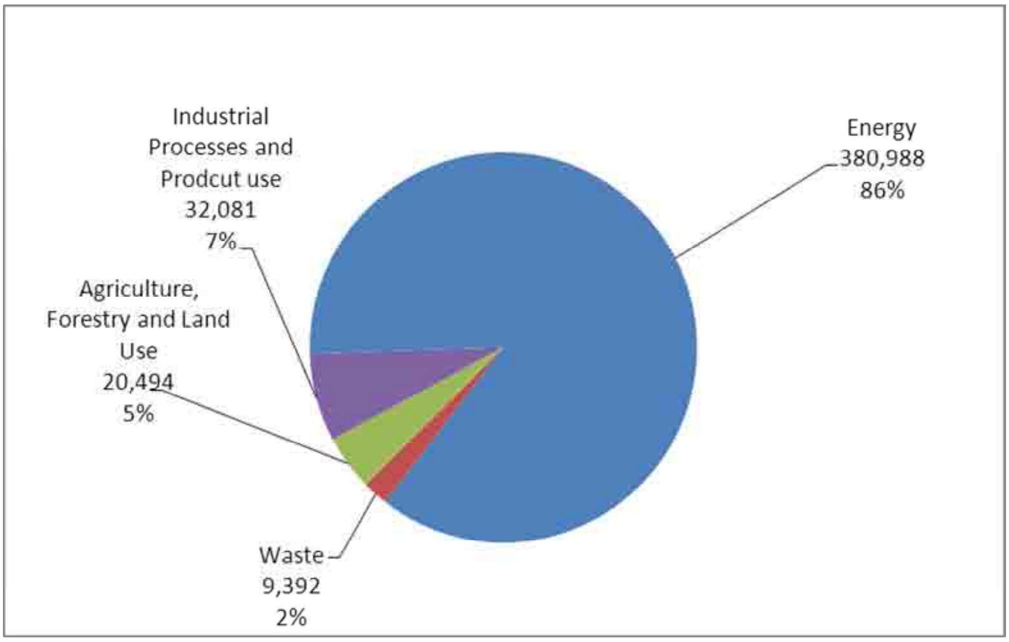


Figure 2.2—Total greenhouse gas emissions by sector in South Africa, *including* land use, land use change, and forestry (LULUCF) ($GgCO_2e$).

South Africa is using 1990 as the base year, and therefore emission trends to the 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 decreased between 1990 and 2000, depending on the sector (Tables 2.1 and 2.2). 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 was an increase of 46%. IPPU 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 can be attributed to a higher number of sources and better quality data, as well as to changes in emission calculation methods and allocation of source categories, and not necessarily to increased levels of sector activities. The use of 2006 IPCC guidelines for the 2000 inventory may make emission trend comparisons difficult for some sectors, particularly emissions or sinks from LULUCF.

Table 2.1. Greenhouse gas emissions by sector in South Africa, without land use, land use change, and forestry (LULUCF).

Sector	*Gg CO_2e in 2000*	*% of total*	*% change from 1994*	*% change from 1990*
Energy	380 988	83	28	46
Industrial processes and product use (IPPU)	32 081	7	6	4
Agriculture	38 716	8	9	-4
Waste	9 393	2	-43	-38
Total	461 178	-	21%	33%

Table 2.2. Greenhouse gas emissions by gas in South Africa, without land use, land use change, and forestry (LULUCF).

Greenhouse gas	Gg CO_2e 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	461 179	-	21	33

Carbon dioxide (CO_2) was the main GHG contributing 79% of total emissions with methane (CH_4) contributing 16%, nitrous oxide (N_2O) 5%, and perfluorocarbons (PFCs) from alu-minium 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-gasses) will require an in-depth research study. The GHG emissions trend from 1990 shows uniform increase in emissions for CO_2 and CH_4. Carbon dioxide emissions increased by 15% between 1994 and 2000, and showed a general increase of 29% between 1990 and 2000. Methane emissions showed 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 2.3 summarises total GHG emissions in South Africa by sector for 2000.

Table 2.3. Total greenhouse gas (GHG) emissions (Gg CO_2e) 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 & 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				40 390.49
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
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
E. Wetlands		190.89					190.89
F. GHG emissions from biomass burning	IE	1 072.26	793.6				1 865.86
G. Indirect N_2O emissions from managed soils			17 427				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. wastewater 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_2e emissions without LULUCF							463 235.22
Total CO_2e emissions with LULUCF							442 484.54

2.3 Emissions by sector

2.3.1 Energy

The energy sector was the largest contributing sector in the South African GHG inventory and was responsible for 83% of emissions (380 988 Gg CO_2e) in 2000 (Table 2.4). Fuel combustion produced 81% of the energy emissions, with fugitive emissions from fuel contributing the remaining 19%.

Table 2.4. Energy sector emissions (Gg CO_2e) of greenhouse gasses (GHG) in South Africa in 2000. NA = Not Applicable; NO = Not Occurring.

Sector	*Subsector*	*CO_2*	*CH_4*	*N_2O*	*Total*
Fuel combustion	All	307 132	529	2 150	380 988
	Energy industries	218 314	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 & 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 emitted 71% of the combustion emissions and 58% of the energy sector emissions; manufacturing industries and construction contributed 13% of the combustion emissions and 10% of the energy sector emissions; transport contributed 13% of the combustion emissions and 10% of the energy sector emissions; and all other combustion subsectors contributed the remaining 3% of the combustion emissions as illustrated in figure 2.3.

Emissions in the energy sector increased by 46% since 1990. In terms of combustion emissions, the energy industry sub-sector (predominantly public electricity production and refineries) saw the largest increase in emissions of 37% between 1990 and 2000, followed by the transport sector, which showed an increase of 25%. The highest emission decrease (62% between 1990 and 2000) was recorded in commercial emissions. Emissions from manufacturing industries and construction showed a decrease of 17% between 1990 and 2000. Residential energy emissions showed 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% were from 'other energy industry'.

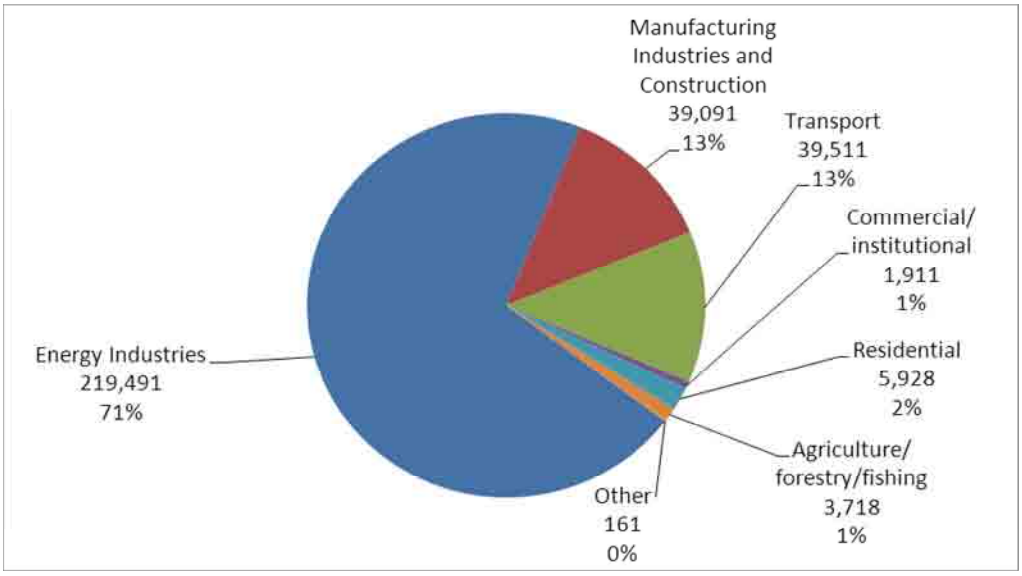


Figure 2.3—Energy sector emissions (Gg CO_2e) from fuel combustion in South Africa in 2000.

Fugitive emissions from fuels (mainly coal mining and synthetic fuels) appear to reflect an increase of 947% in comparison to the 1990 baseline. This is attributed to more accurate fugitive emissions quantification and reporting in the 2000 GHG inventory, as well as to the fugitive emission factors used for the 2000 GHG inventory (from 2006 IPCC guidelines) that were comparatively higher than in previous inventories. Further, the inclusion of emissions from coal-to-liquid (CTL) processes significantly increased the amount of fugitive emissions from solid fuels in the 2000 inventory. The inclusion of the CTL emissions therefore does not constitute a direct increase in fugitive emissions, but is merely a result of a re-allocation of emissions based on IPCC recommendations.

In the transport sector, there was an emissions 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 during the same time period. It can therefore be said that the recorded decrease in transport emissions between 1994 and 2000 can be 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 have incorrectly inflated emissions estimates in the transport sector. While this difference complicates sub-sector analysis, it does not affect the grand total.

2.3.2 Industrial processes and product use

Emissions from the Industrial Processes and Product Use (IPPU) sector amounted to 32 0816 Gg CO2e, 7% of total GHG emissions in the 2000 GHG inventory. Since 1990, IPPU sector emissions have increased by 4%. The IPPU sector was the third largest source of emissions in 2000 (Table 2.5). 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 mineral products, and 6% from chemical industry (see figure 2.4).

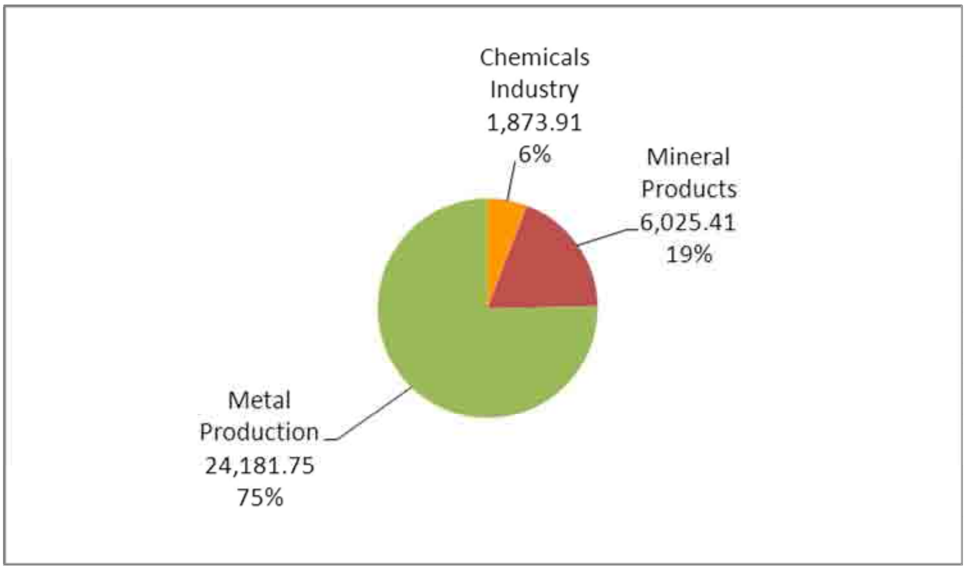


Figure 2.4—Industrial Processes and Product Use (IPPU) emissions (Gg CO_2e) in South Africa in 2000.

Table 2.5. Industrial Processes and Product Use (IPPU) emissions (Gg CO_2e) 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, N E	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

The overall GHG emissions from IPPU increased from 1990 to 2000 (Table 2.6). However, at sub-sector level there are both increasing and decreasing trends. The highest increase between 1990 and 2000 was from metal production, recording an increase of 11%. Between 1994 and 2000, metal production emission increased by 16%. Between 1994 and 2000 mineral products emissions showed a decrease of 13%, and a general increase of 10% between 1990 and 2000. The inventory for the chemical industry emissions records a decrease of 56% between 1994 and 2000. This decrease is mainly attributed to the re-allocation of a large proportion of chemical CTL emissions into the energy sector, based on IPCC recommendations.

Table 2.6. Trends in the emission of Industrial Processes and Product Use (IPPU) 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

2.3.3 Agriculture, forestry, and other land use

In the 2000 GHG inventory, activities in the agriculture, forestry and other land use (AFOLU) sector 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 the AFOLU sector in 2000, contributing 42.7% and 46.5% respectively of the sector emissions. Methane was the dominant GHG in AFOLU, contributing 54.3% and N_2O contributing the remaining 45.7%. Sinks came from forest- and crop land, respectively at 62.7% and 27.3% of the total CO_2 sequestration.

After separating AFOLU categories on the basis of 1996 IPCC guidelines, emissions from agriculture in 2000 are seen to have been 38 716.19 Gg CO_2e, whereas the land use, land use change, and forestry (LULUCF) category was a net sink of 18 693.25 Gg CO_2e. On this basis, agriculture emissions decreased by 4% between 1990 and 2000, whereas LULUCF sinks increased by 11.8%, from 16 982.37 Gg CO_2e.

The 'land use' sub-class was divided into six classes namely forestry, croplands, settlements, wetlands, grasslands, and other lands according to the IPCC 2006 guidelines. The forestry class includes 'forest lands 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 are reported for the first time. Three types were considered: wetlands, water bodies, and peat-lands. 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.

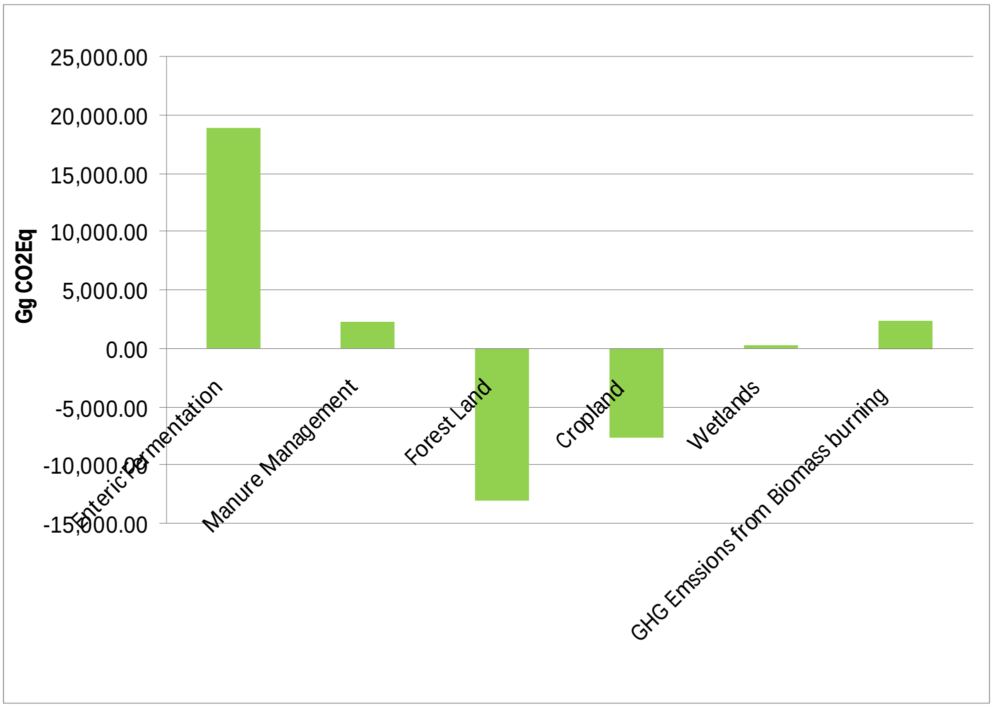


Figure 2.5—Greenhouse gas (GHG) emissions from the agriculture, forestry, and land use (AFOLU) sector in South Africa in 2000.

The Department of Agriculture, Forestry, and Fisheries (DAFF) has initiated development of an AFOLU sector inventory based on the IPCC 2006 guidelines. Hence the 2000 National Inventory Report (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 therefore not be directly comparable.

2.3.4 Waste

The disposal of solid waste contributed less than 2% of total GHG emissions in South Africa mainly through emissions of 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.

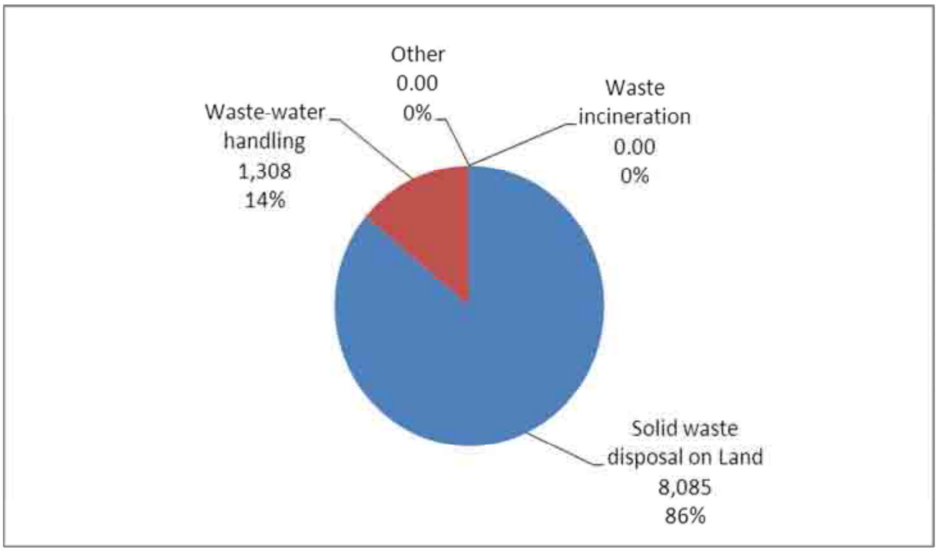


Figure 2.6—Emissions from waste activities (Gg CO_2e) in South Africa in 2000.

Only GHGs 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 are scattered throughout rural and semi-urban areas across South Africa. These unmanaged and uncategorised disposal sites are also generally shallow (*i.e.* less than 5 m 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 13.5–15 million tonnes annually. In addition, industrial waste that is generally handled and disposed of on-site was 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 CH_4 (or 8.09 Mt CO_2e) was estimated as being generated from landfills for the year 2000 (see Table 2.7). 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 2.7. Methane emissions from solid waste disposal in South Africa between 1990 and 2000.

Year	*Ch_4 (Gg)*	*CH_4 (Tg CO_2e)*
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	7.60
2000	385	8.09

Table 2.8. Emissions from wastewater handling in South Africa, 1990–2000.

Year	CH_4 (Gg)	CH_4 (Tg CO_2e)	N_2O (Gg)	N_2O (Tg CO_2e)
1990	26	0.546	1.57	0.488
1991	26.7	0.561	1.59	0.494
1992	27.5	0.577	1.64	0.507
1993	28.3	0.594	1.68	0.52
1994	29	0.608	1.72	0.533
1995	29.8	0.625	1.76	0.546
1996	30.4	0.638	1.8	0.556
1997	31	0.652	1.83	1.567
1998	31	0.66	1.85	0.572
1999	32.4	0.68	1.89	0.587
2000	32.9	0.691	1.99	0.618

In South Africa, most of the wastewater generated from domestic and commercial sources is treated through Municipal wastewater Treatment Systems (MWTS). Data on industrial categories with high organic content is very limited. Some data exists on wastewater in sectors such as vegetables, fruits, 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 and N_2O emissions from domestic sources are presented (Table 2.8). However wastewater from commercial and industrial sources discharged into sewers is accounted for, so the term 'domestic wastewater' refers to the total wastewater discharged into sewers from all sources.

2.4 Emissions by major greenhouse gas

2.4.1 Carbon dioxide

Carbon dioxide (CO_2) is the main GHG, contributing 79% of total emissions (362 071 Gg CO_2e, without LULUCF). The trend for CO_2 emissions shows a uniform increase in emissions with no decreases from 1990 (see Table 2.2). Within fuel combustion, the greatest emissions by a significant margin were from energy industries (219 491 Gg 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_2e; 12% of sector CO_2 emissions and 11% of total CO_2 emissions each). IPPU produced approximately 28 641 Gg CO_2e (8% of total CO_2 emissions) with the metal production sub-sector contributing approximately 21 959 Gg CO_2e (6% of total CO_2 emissions and 77% of sector CO_2 emissions). IPPU mineral products' contribution to CO_2 emissions was 6 025 Gg CO_2e, which was 2% of total CO_2 emissions and 21% of CO_2 emissions in IPPU. AFOLU produced a sink of approximately 21 000 Gg CO_2e, and a net emission of 20 000 Gg CO_2e.

2.4.2 Methane

Methane (CH_4) contributed 16% of total emissions to the 2000 GHG inventory (75 062 Gg CO_2e, without LULUCF). The trend for CH_4 emissions shows a continuous increase from 1990 to 2000, with a slight increase of 0.2 % between 1990 and 1994 (see Table 2.2). CH_4 showed the highest increase of more than 74% between 1990 and 2000. The greatest CH_4 emissions were 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 were produced from fugitive emissions from solid fuels (40 366 Gg CO_2e; 90% of fugitive CH_4 emissions), which resulted mainly from coal mining activities.

The agriculture sector produced 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.

2.4.3 Nitrous oxide

Nitrous oxide (N_2O) contributed 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 2.2). There was an overall decrease of 6% between 1990 and 2000. The greatest N_2O emissions were produced from the agriculture sector (17 842 Gg CO_2e; 82% of total N_2O emissions, without LULUCF), whereby 98% of these emissions came from indirect N_2O emissions from managed soils (approximately 17 400 Gg CO_2e). The IPPU sector produced 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.

2.4.4 Other

Gases that fall under this category include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6); and contributed 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 amounts 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).

3 General description of steps taken or envisaged to implement the convention

South Africa has made significant advances in climate policy since the publication of the Initial National Communication (INC). A far more comprehensive set of information on climate scenario development, impacts, and adaptation assessment, as well as in mitigation (including an updated greenhouse gas (GHG) 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, while national policy efforts in adaptation are relatively undeveloped by comparison. Given the apparent vulnerability in many sectors of the South African economy and their associated livelihoods implications, this issue is now receiving far greater attention in the current development of adaptation policies in different sectors, as well as in the development of a national climate policy process. The current policy imperatives have been informed by several key stakeholder engagements since the production of the INC and a maturing national awareness of the climate change issue. Key elements of this process, and the evolution of measures that South Africa is employing to implement the convention, are summarised in this section.

3.1 The 2005 'Climate Action Now!' conference

Figure 3.1—The 2005 national climate change conference branding.

Although the National Climate Change Response Strategy (NCCRS) for South Africa, published in September 2004, was the 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, during October 2005—known as the 2005 'Climate Action Now!' conference (DEAT 2005a). 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 as well as the key responses to the potential social and economic impacts associated with the compelling scientific evidence of climate change. The gathering was broadly considered a reflection of the 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. 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 GHG in the atmosphere—the ultimate objective of the UNFCCC—and called on all nations to join in support of the international effort to reduce GHG emissions, with developed countries taking stronger action.

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, as well as 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 (DNA), which was hoped would realise 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. There was agreement to intensify efforts to use the best available science to address adaptive and mitigation actions in a co-ordinated 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 programs. It was affirmed that the nature of climate change and the issues associated with it, lend themselves to a multi-disciplinary approach to research and development.

Importantly, the conference also compiled and published a number of 'statements of intent' by the key constituencies, including Business Unity South Africa (BUSA), Congress of South African Trade Unions (Cosatu), and civil society 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. These included statements by BUSA, the South African Climate Action Network (SACAN), and South African scientists. The conference resolved to take urgent action to meet the shared challenges in order to guarantee the nation's common future.

3.2 Government's statement of intent—the '2005 Midrand Plan of Action'

The '2005 Midrand Plan of Action' is a published undertaking by the government resulting from the 2005 national climate change conference. It describes a number of activities intended to lead the country's climate change programme. These activities include:

- Ensuring the alignment, cohesion, and coherence of government responses to climate change by co-ordinating and driving its responses and interventions through the Inter-Ministerial Committee on Climate Change (IMCCC), its associated inter-departmental committee, and the multi-stakeholder National Committee on Climate Change (NCCC).
- Continuing the review of the NCCRS.
- Initiating a detailed scenario building process to map out how South Africa could meet its UNFCCC Article 2 commitment to GHG stabilisation whilst ensuring its focus on poverty alleviation and job creation.
- Initiating a participatory climate change policy development process.
- Using the AQA to regulate GHG 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 NCCRS.
- Initiating a participatory national climate change research and development strategy development process that would co-ordinate 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 program, 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 co-ordinating 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 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 (Conference of the Parties serving as a Meeting of the Parties) 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 (NEEA) to co-ordinate public and private investment in energy efficiency.
- Considering climate change impacts on 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.
- 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.

3.3 The Long-Term Mitigation Scenario (LTMS) process

In March 2006, prompted by the 2005 Midrand Plan of Action, Cabinet mandated a national process of building scenarios of possible GHG 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. The LTMS process was launched in mid-2006.

The primary focus of the LTMS process was mitigation, although a limited vulnerability and adaptation assessment was also conducted. DEAT, as the focal point for climate change in South Africa, convened and managed the process, which was overseen by the IMCCC. DEAT appointed the Energy Research Centre (ERC) at the University of Cape Town (UCT), to manage the entire process and they, in turn, convened and contracted the process specialists and set up the personnel for four focused Research Support Units (RSUs). 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, and 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.

3.4 Government's 2008 policy directions

In July 2008, following deliberation on climate change related developments including the LTMS findings; Cabinet approved a climate change policy development process and associated development timeframes, and provided six broad policy themes to focus the development of the policy:

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 GHG emissions peak in 2020–25, plateau for approximately a decade, and decline in absolute terms thereafter. These aspirations were enunciated in South Africa's submission to the UNFCCC in January 2010, which states that 'the extent to which this action will be implemented depends on the provision of financial resources, the transfer of technology, and capacity building support by developed countries' (RSA 2010).

Theme 2: Build on, strengthen, and/or scale-up current initiatives

That current energy efficiency and electricity demand-side management initiatives and interventions would be scaled-up and reinforced through available regulatory instruments and other appropriate mechanisms that would be made mandatory. That, based on the electricity-crisis response, government's energy efficiency policies and strategies would be continuously reviewed and amended, as appropriate, to reflect national aspirations. That Treasury would explore implementation of a carbon tax in a range informed by various considerations, including the range modelled by the LTMS, starting at low levels and escalating to higher levels by 2018/20, 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 would be identified as a key 'business unusual' growth sector, and that policies and measures would be 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 would 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 would take this commitment into regard. That the transport sector would be identified as a key 'business unusual' growth sector and that policies and measures would be 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 be 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. 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 South Africa describes and prioritises what adaptation interventions would be initiated, who should be driving these interventions, and how implementation would be monitored. That affected government departments would ensure that climate change adaptation interventions in their sectors are included as departmental key performance areas.

Theme 6: Alignment, co-ordination, and co-operation

That the roles and responsibilities of all stakeholders, particularly the organs of state in all three spheres of government, would be clearly defined and articulated. That the structures required to ensure alignment, co-ordination, and co-operation would be clearly defined and articulated. That climate change response policies and measures be mainstreamed within existing alignment, co-ordination, and co-operation structures.

3.5 The 2009 Climate Change Summit

Figure 3.2—The 2009 climate change summit branding.

In accordance with Cabinet's mandate, from 3 to 6 March 2009, South Africans from all spheres of life came together in Midrand to initiate a consultative process to develop South Africa's National Climate Change Response Policy (NCCRP). The 'Climate Change Summit 2009' involved 900 representatives from government, business, the scientific and academic communities, and civil society, as well as over 150 'virtual participants' linked through the Internet.

The 'Climate Change Summit 2009':

- Considered the IPCC's fourth 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 GHG 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 LTMS's, the Climate Change Research & Development Strategy (CCRDS), the technology needs assessment, the 2000 GHG inventory, and the initiation of the Second 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.

- Discussed and debated the process of developing an integrated, cohesive, coherent, and effective NCCRP.

Broad-based consensus was achieved on:

- Making a contribution to the goal of limiting global temperature increase to below 2°C above pre-industrial levels.
- Making 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.
- Maintaining 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.
- Scaling-up of renewable energies and energy efficiency.
- Defining energy efficiency standards for industrial equipment and processes.
- The need for integrated energy planning.
- The need for enhanced government co-ordination 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.
- 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 CDM 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. There were also concerns about ear-marking of revenues. Some participants proposed a pilot phase for domestic emissions trading, which could be voluntary initially and later developed into a mandatory cap-and-trade system.

In taking the policy development process further, the summit participants agreed that:

- The NCCRP 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 NCCRP that fall within their mandates, jurisdictions, or spheres of influence.
- Local government, through the South African Local Government Association (SALGA) and associated provincial associations, must initiate and facilitate the development of the municipal components of the NCCRP that fall within their mandates, jurisdictions, or spheres 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 NCCRP that fall within their mandates, jurisdictions, or spheres of influence, in particular the integration of climate change issues into provincial spatial and strategic plans.
- The DEA will co-ordinate the policy development process using established Intergovernmental and multi-stakeholder co-ordination 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 GHG emissions, and to adapt to the adverse impacts of climate change; and will continue 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; to determine key vulnerabilities in affected sectors and communities; and to explore 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 Green Paper on the National Climate Change Response in December 2010.

3.6 The 2010 climate change policy round table

Following a period of ongoing policy discussions 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 NCCRP development process, and to provide a platform for these stakeholders to respond to and discuss the most recent NCCRP 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.

3.7 Private sector activities

Companies, particularly in the energy- and carbon intensive sectors, have been actively engaged in developing a good understanding of the relative contributions of sectors and companies to both direct and indirect GHG emissions through data gathering initiatives and the identification of potential mitigation activities. GHG emissions data continues to be provided to government on a voluntary basis.

These efforts have now been extended to ensure that all emissions from the industrial processes and product use sectors are identified. The development of a more accurate emissions profile for this sector would facilitate the identification of a more comprehensive set of mitigation actions.

A number of company and sectoral initiatives have been established to collect data and report on GHG emissions. The most comprehensive of these is the global Carbon Disclosure Project (CDP) in which South Africa participated for the first time in 2007.

In 2007, the top-40 companies (based on market capitalisation), listed on the Johannesburg Stock Exchange, were targeted. Since 2008, the project targeted the top-100 companies. The number of companies disclosing their GHG emissions has continued to increase from 2007, with many companies providing quantitative information on Scope 1, 2, and 3 emissions.

Industry associations have also developed carbon footprint guidance for smaller non-listed companies. These initiatives have enabled companies to refine the collection of data and thus improve the quality of the data. The need to refine emission factors in some cases has also been identified. A number of companies have implemented CDM projects to reduce direct process emissions and indirect emissions as a result of the use of fossil fuel electricity.

There is an increasing trend of the integration of climate change companies' governance structures, and an increasing number of companies are reporting the development of specific performance targets relating to GHG emissions reduction.

Given that South Africa's main energy carriers are electricity (generated from coal) and fossil fuel-based liquid fuel, these remain the primary drivers through which to alter the country's carbon emissions profile. In the case of energy efficiency therefore, over 30 of the country's most intensive energy users are supported by industry associations committed to a voluntary energy efficiency accord between business and government.

Participating businesses were initially drawn largely from the mining and industrial sectors, and were later joined by a number of commercial industries. Operating on this platform, these companies invested over R10 billion in improving their energy efficiency. Further opportunities in energy efficiency and renewable energy projects have been identified. These projects are expected to be supported by an energy efficiency savings incentive, which is currently under development.

A range of energy efficiency measures like more efficient management of air conditioners, lighting, geysers, and extraction fans; installing lighting retrofits, smart energy meters, motion sensors, waste heat recovery units, and heat pumps; specifying energy and water efficient air-conditioning and/or refrigeration units in stores and offices; implementing energy saving settings and remote shutdown of all computers, lighting, and temperature controls; installing building insulation such as double glazing to reduce heating and cooling energy requirements; switching to solar water heating; upgrading equipment to more energy efficient models; and engaging staff in order to ensure effective implementation of efficiency strategies.

Business has collaborated with government in the development of a measurement, reporting, and verification standard for energy efficiency savings, and is currently working on the accompanying accreditation standard for measurement and verification agencies.

Many of the direct emissions from the industrial processes sector (metals, minerals, and chemical) result from the use of carbon reductants in the process, or carbon-containing raw materials, which release CO_2 during the production process The amount of CO_2 released under these circumstances is determined by the stoichiometric requirements of the process reactions. There is currently very limited potential for emissions reduction under these circumstances. Direct emissions can therefore only be reduced through lower production or through carbon capture and storage technology, which has not yet been demonstrated as viable in these sectors.

The co-generation of electricity through the combustion of waste gas has become increasingly feasible in a number of industrial subsectors. Projects in this area have already been implemented and contribute to the reduction in demand on fossil fuel derived electricity, thus reducing indirect emissions. Feasibility studies are being undertaken with regard to the harvesting of waste heat from a number of industrial processes for generation of electricity.

Initiatives for improved efficiency in transportation and logistics activities include improving maintenance and operating practices for trucks and introducing computerised routing systems to optimise routes; converting used cooking oil into bio-diesel for use in truck fleets; enhancing the provision of public transport for staff; sourcing locally to reduce air freighting; and introducing video conferencing facilities and being more stringent on office flight travel.

Although mitigation actions dominate company level climate change activities, South Africa is a water-stressed country and access to water for industrial processes remains a key imperative for business. As a result, significant attention is paid to water resource management.

3.8 Current policy status

South Africa has taken substantive and sustained steps to implement the convention, to ensure that its climate change policy is informed by science and developed through participatory process.

Although the NCCRP is still under development and is unlikely to be finalised 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, as well as the inter-generational commitment of the environmental right contained in the country's constitution, has the climate change response objectives of:

- Making a fair contribution to the global goal of stabilisation of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.
- Effectively adapting to already unavoidable and potential projected climate change impacts through interventions that build and sustain South Africa's social, economic, and environmental resilience and emergency response capacity.

In respect of mitigation and adaptation efforts and as a developing country, the scale and ambition of South Africa's contribution will also be dependent on the scale of international support, such as through funding, capacity building, and technology transfer.

3.9 Institutional arrangements and policy co-ordination

The development of the NCCRP, GHG mitigation, and climate change adaptation related actions are specifically included in the President's list of service delivery agreements with Cabinet Ministers. This facilitates the process of regular reporting and monitoring of progress against the agreed climate change outputs.

3.10 Intergovernmental Committee on Climate Change (IGCCC)

In order to facilitate co-operative governance in the area of climate change, the Intergovernmental Committee on Climate Change (IGCCC) was established in 2008. This committee aims to foster the exchange of information, consultation, agreement, assistance, and support among the spheres of government with respect to climate change, and facilitate the policy development process and its implementation. The IGCCC serves as the 'delivery forum' for the President's climate change outputs.

The terms of reference for the IGCCC include:

- 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 co-ordinating the alignment of all policies, strategies, action plans, legislation, regulations, systems, implementation projects, and 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.* the national GHG inventory, and the NCCRP development process).
  - 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 co-ordinating 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.

4 Measures to facilitate adequate adaptation to climate change

4.1 Climate

South Africa has on average a semi-arid and temperate climate, but strong gradients in both temperature and rainfall lead to a wide variety of regional and local climatic conditions. Average annual rainfall is about 460 mm (compared to a world average of about 860 mm), but rainfall amount is lowest in the arid north-west, and increases southwards towards the Western and Eastern Cape provinces and eastwards towards the coast of the KwaZulu-Natal province (Figure 4.1.1).

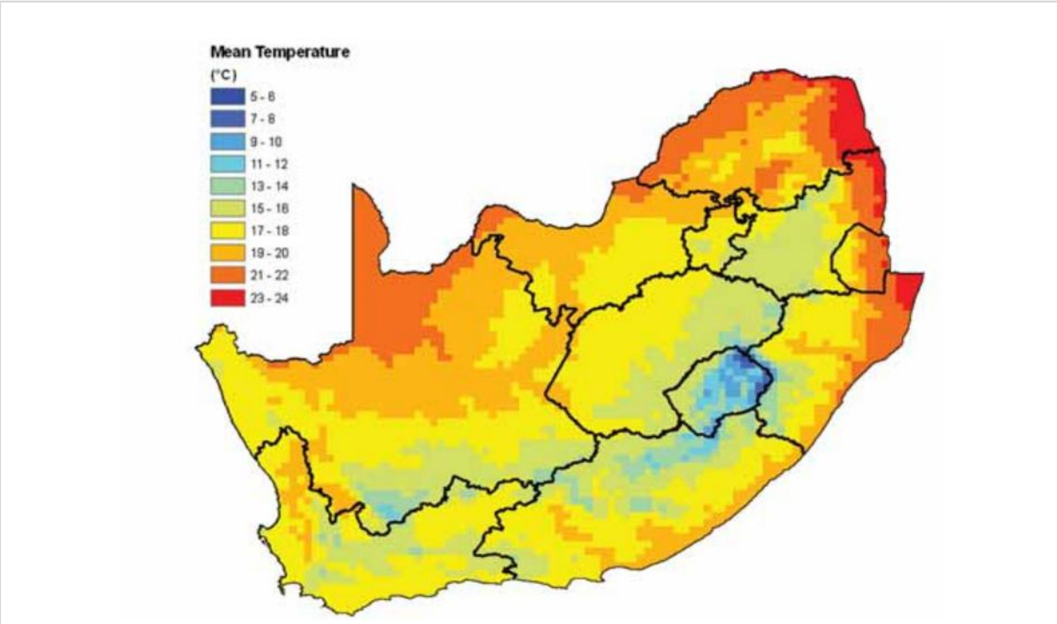


Figure 4.1.1—Mean annual temperature in South Africa.

Rainfall seasonality also varies, with winter rainfall dominant in the west and south-west, and more evenly distributed in the south. Summer rainfall dominates over much of the interior and the eastern regions. Rainfall is variable between years, especially in arid summer rainfall regions of the western interior, with fairly strong influences from multi-year *El Niño/La Niña* climatic cycles. Drier than average conditions tend to occur in the summer rainfall areas during *El Niño* years, while *La Niña* conditions are often associated with increased summer rainfall. Periodic drought and flood conditions are not uncommon through most of the country. Mean annual temperatures range from temperate to sub-tropical, with strong oceanic influences contributing to tropical conditions along the north-east coastal regions, and arid conditions associated with the cold waters of the Benguela Current along the west coast (Figure 4.1.2).

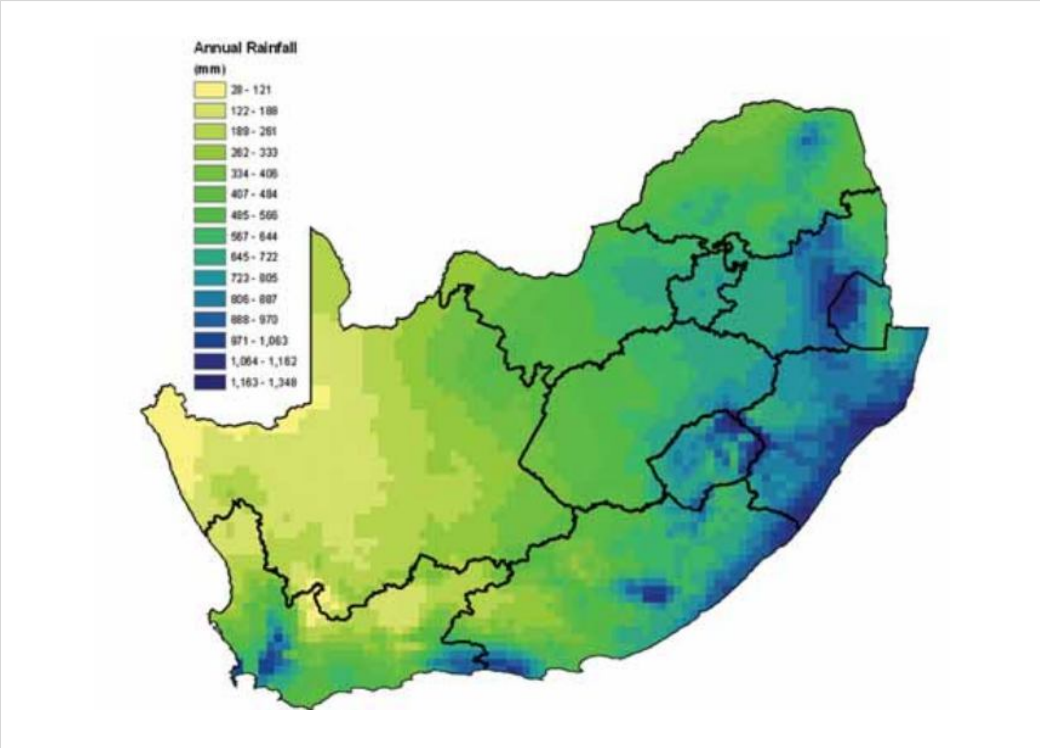


Figure 4.1.2—Mean annual rainfall in South Africa.

4.1.1 Climate variability

Climatic conditions in South Africa are determined mainly by hemispheric-scale atmospheric circulation, together with effects due to ocean circulation patterns. South Africa is located at sub-tropical mid-latitudes that are subject to subsiding air and high pressures, the result of large-scale 'Hadley cells' that transport surface air from Earth's warmer equatorial regions to sub-tropical latitudes where the air subsides towards the surface. This tends to result, as a general rule, in a dry climate relative to the global average. However, latitudinal atmospheric pressure gradients 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.

Regional climate variability in southern Africa is affected by several major atmospheric processes, some that have their origin remotely (mainly over the surrounding oceans) and others that originate locally over the land surface. These processes cause variability over seasonal, inter-annual, and longer time scales.

Seasonality is an important feature throughout South Africa. South Africa's geographic location results in an annual seasonal temperature cycle that peaks in the austral summer during January, and reaches a minimum during July. Averages of near surface daily maximum temperatures for January peak at over 30°C in the north-western arid areas of the country and Limpopo province, while milder maximum temperatures are recorded over the east, south-east, and southern parts of the country. Winter months are normally cold, with averages of near surface daily minimum temperatures for July of below -2°C over Lesotho and extensive parts of the central Highveld. The coastal belt is somewhat warmer in winter (generally above 6°C), with lower Karoo minimum temperatures ranging between 0 and 8°C.

During summer, differences in heat between the warmer southern African continent and colder surrounding oceans can lead to the development of continental surface troughs of lower pressures. These troughs allow transport of moist air from wetter equatorial African regions towards the eastern parts of South Africa where most rain falls during the summer months. The western parts of the country generally do not experience this type of rainfall in summer, but cold fronts periodically sweep over the southern coastline of Africa or even over the southern African continent during winter. These bring cold conditions to South Africa, more winter rainfall to the south-west of the country, and less winter rainfall towards the north-west. The interaction of warmer tropical air with these heavy cold air masses as they move eastwards results in rising air which can cause rainfall to spread along the southern coastline of South Africa. The eastward movement of a cold front is usually followed by the onshore flow of moist air, and 'post-frontal' rain. This can extend from the southern coastline towards the coast of KwaZulu-Natal, and to the Mpumulanga province, where cloud development and rainfall can occur as this air rises over the steep slopes of the escarpment. South Africa's mean annual rainfall ranges from less than 100 mm in the north-west to almost 1 200 mm over the east and on the southern margins. Rainfall variability is high over much of the country, though somewhat lower in the winter rainfall zones of the west; and this represents a challenge for forecasting weather, and even more so for projecting the impacts of future climate change for rainfall.

Inter-annual and longer term climate variability remains incompletely understood, although several advances in understanding have been made and a productive climatological science community has contributed to a sizeable literature over several decades. The notion of a 'quasi-periodic' rainfall cycle of about 18 years, which weakly explained roughly decadal variability in the summer rainfall region during the 20th century (Tyson & Preston-Whyte 2004), is not well supported. On the whole, 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 Niño*. Despite this apparent pattern, it is important to note that there is no evidence of a linear relationship between the *El Niño* Southern Oscillation (ENSO) index and southern African rainfall, and ENSO is thus far from a perfect predictor of rainfall variability in South Africa.

4.1.2 Historical climate change

Historical context is important in assessing the significance of observed and projected change, particularly when considering anthropogenic impacts. Identifying historical trends and changes in climate is strongly dependent on the length of time period being assessed, choice of start and end date, and climate variability—including the frequency of extreme events. South Africa's history of systematic observation of climate (rainfall in particular) dates from as early as the middle 19th century, but a well-developed national network that would support robust analysis of industrial-era trends is only available from about the mid-20th century for temperature, and the early 20th century for rainfall. A substantive and developing literature relating to the palaeo-climate of South Africa and regional southern African and southern hemispheric changes, provides useful context for recently observed changes.

Palaeo-climatic analyses and historical reconstructions indicate that climate has showed periodic changes in historical times and in the deeper past. Before formal climatic records were kept, droughts and flood events have had significant impacts in southern Africa (e.g. Vogel 1989), including the abandonment of settlements in the Kalahari in AD 1200–1500 due to drought and overgrazing. Several records indicate damaging droughts in the 1700s and 1800s (Vogel 1989; Holmgren *et al.* 1999). In the early 1800s, widespread drought contributed to several years of famine (Denbow 1986; Vogel 1989). Subsequent records have shown that the droughts may reflect wet and dry phases that have occurred periodically for at least the previous 250 years (Nash & Endfield 2002), but there is also evidence that droughts follow large volcanic eruptions that inject dust and aerosols into the southern hemisphere's upper-atmosphere (Holmgren *et al.* 1999).

The historical flood record is less well documented than that for drought, due to flooding events' local and more transient effects. Local flooding may occur when intense storm activity affects single river systems or catchments. Regional flooding may occur when large weather systems, such as tropical cyclones, make landfall, or when the Inter-Tropical Convergence Zone (ITCZ) shifts further south than usual.

Palaeo-flood analysis on the lower Orange River indicates a flood of about 28 000 m^3/s somewhere between AD 1444 and 1462 (Zawada 1996), while the largest measured flood in modern times is only 8 330 m^3/s by comparison. Other large floods also occurred during the time span AD 1453–1785; but from 1785 to present, floods have not been larger than about 9 500 m^3/s in the lower Orange River.

Reconstructions of global and hemisphere-scale climate change spanning several thousand years have been derived from ice-core records mainly in polar regions (*e.g.* European Project for Ice Coring in Antarctica (EPICA)). These long term records display, for the past 1 000 years (Holmgren *et al.* 1999), some significant changes such as the Little Ice Age ((LIA) AD 1300–1800) and the Medieval Warm Period MWP (MWP : about AD 800–1200). The LIA is the dominant deviation, and is associated with a period of low solar activity termed the Maunder Minimum, and may have been about 2°C cooler than pre-industrial climate, and there is evidence that the MWP may have been periodically warmer but with cooler interludes (Holmgren *et al.* 1999).

The Pleistocene era (the past two million years) consisted of mainly of long periods (tens of 1 000s of years) of cold conditions interspersed by short warm intervals (of 1 000s of years), called inter-glacials. Temperatures in the last glacial, which lasted about 100 000 years, were generally 4–5°C colder than the pre-industrial mean, with low atmospheric CO_2 levels of roughly half the current values (*ca.* 180 ppm). The interior of the country was probably mainly drier (Tyson & Preston-Whyte 2000), while the winter rainfall zone appears to have been much wetter (Stuut *et al.* 2002).

The last 9 000 years have been a naturally warm interlude in relation to much of the past two million years, at least. Anthropogenic warming is thus overlain on an already 'naturally' warm climate. Recent analysis of palaeo-climate using fossilised rock hyrax middens from the Namib Desert (Chase & Meadows 2007) suggests rapid transitions (within a few centuries) between wet and dry phases over the past few thousand years; with humid conditions reigning from 8700 to 7500, 6900–6700, 5600–4900, and 4200–3500 calendar years before present (BP), and very dry conditions only from 3500 until *ca.* 300 calendar years BP, with transitions often within <200 years. The study also suggests an important influence of solar forcing on climate in this region, and indicates that a better developed understanding of these influences is needed for anticipating future climate change.

4.1.3 Recent climate trends

Within the subcontinent, the most comprehensive analysis of recent trends is the outcome of a 2004 workshop held by the World Meteorological Organisation (WMO) / Climate Var-iability and Predictability (CLIVAR) expert team on climate change detection, monitoring, and indices (New *et al.* 2006). This study reported that temperature extremes show patterns consistent with warming over most of the regions analysed, with a large proportion of stations showing statistically significant trends for all temperature indices. From 1961 to 2000, the occurrence of extreme cold days and nights has decreased by 3.7 and 6.0 days/ nights per decade, respectively, and the occurrence of extreme hot days and nights has increased by 8.2 and 8.6 days/nights per decade, respectively. The diurnal temperature range (DTR) shows consistent increases in a zone north of South Africa, with more rapid increases in maximum temperature than minimum temperature extremes. Annual rainfall has shown no consistent trends across the southern African region, but there have been statistically significant increases in daily rainfall intensity and dry spell duration over the region. These changes are consistent with current theoretical understanding of human-caused climate change (Dai *et al.* 2004; Zhang *et al.* 2007). Many studies have assessed different climate measures (*e.g.* Hulme *et al.* 2001;Unganai & Mason 2001; Fauchereau *et al.* 2003; Kruger & Shongwe 2004; Malhi & Wright 2004;). There is some evidence for statistically significant increases in precipitation since the 1950s observed in the south-west of South Africa, and significant decreases in the north-east (Warburton & Schulze 2005). In certain sub-regions in South Africa, climate station data displays 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. Overall, the region displays clear detectable signals of warming and increasing frequency of rainfall extremes, but few clear trends in average rainfall.

The most complete recent study on South African temperature trends is that of Kruger & Shongwe (2004). Temporal and spatial linear trends were derived for annual, seasonal, monthly, and diurnal temperatures from a 44-year record (1960–2003), and for a total of 26 stations that are distributed all over the country. They detected a positive annual average temperature trend at 24 out of 26 stations, with 18 stations having significant trends. Warming trends are more obvious over the western interior, western and southern coastal regions, and less so over the central interior. Almost 90% of the stations recorded positive annual mean maximum temperature trends. 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. Trends suggest that most of this warming occurred during the early 1980s.

Observed minimum temperature trends generally appear to be higher than maximum temperature trends, and therefore negative trends in the diurnal temperature range are observed. Hot days have increased in frequency over the past 44 years, while days with cooler temperatures have decreased in frequency (Kruger & Shongwe 2004). Hoffman *et al.* (2011) have shown that evaporation and windiness have both declined significantly in the Western Cape, in contrast to the positive linear trend in surface wind speeds observed in South Africa's southern coastal regions from 1982 to 2007 (Rouault *et al.* 2009). Together with the New *et al.* (2006) study for southern Africa, the key messages are that clear, large-scale changes exist, especially a pattern of increased hot days with, to a lesser degree, decreased frequency of extremely cold days.

Natural cycles and events such as solar energy cycles, and unpredictable events such as volcanic eruptions, have important impacts on global and regional climate. For South Africa, the ENSO cycle appears to trigger many regional climate impacts, including dry conditions in much of southern Africa, and also impacts on average temperatures. Lean & Rind (2008) distinguished natural temperature variability from anthropogenic effects using the observed surface temperature record from 1889 to 2006. Natural influences caused as much as a 0.2°C warming during major *El Niño* events, 0.3°C of cooling followed large volcanic eruptions, and 0.1°C warming was 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 produced by all three natural influences are at least an order of magnitude smaller than the observed surface temperature trend reported by the Intergovernmental Panel on Climate Change (IPCC 2007).

4.1.4 Relevant oceanic trends

The warming of the Indian Ocean appears to have increased the spatial extent and intensity of droughts in southern Africa since the mid-1970s (Richard *et al.* 2001; Rouault & Richard 2003, 2005). This recent warming may also have caused a closer association between inter-annual rainfall variability and the ENSO phenomenon (Richard *et al.* 2000). Low frequency changes in sea-surface temperatures in the Pacific Ocean (the Pacific Decadal Oscillation, Mantua *et al.* 1997) could affect rainfall variability over southern Africa (McCabe & Palecki 2005). Reason & Rouault (2005) and Rouault *et al.* (2003) have found links between rainfall regimes in South Africa and fluctuations in the low frequency cycle represented by the Antarctic Oscillation, as described by Thompson & Wallace (2000). There is some evidence of synchronised variability in summer within southern Africa's ocean–atmosphere system (Fauchereau *et al.* 2003) due to large scale ocean influences on climate variability in South Africa.

4.1.4.1 The Agulhas system

The Agulhas Current has an impact both on the coastal climate of South Africa and on the global climate, because of its role in the circulation of water between ocean basins in the southern and northern hemispheres. The Agulhas Current flows along the east coast of South Africa before moving offshore, southwards, near 34°S and then flows back toward the Indian Ocean after 'retroflecting' south of the Cape. Measurements have shown large 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 this 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

The Agulhas Current system has warmed significantly (+1.5°C) between 1985 and 2007, and 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 pole-ward shift in the westerly wind belt in the south Indian Ocean. This also led to higher evaporation rates and a 50% increase in the transfer of warm Agulhas Current water into the colder southern Atlantic Ocean, and a cooling in the surface ocean along parts of the eastern coast. The cooling trends in the south coast surface waters may be 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 sub-tropics of the southern Atlantic and Indian Oceans, including at the origin of the intensification of the Agulhas Current system (Rouault *et al.* 2009). Observed changes in sea level pressure and wind speed are consistent with a suggested pole-ward shift of the westerly jet in the southern hemisphere and an increase of the southern Atlantic and Indian Ocean high pressure systems due to the intensification of the Hadley circulation. It also shows a trend towards a positive phase of the Antarctic Oscillation. These shifts are consistent with projected Hadley Cell intensification under climate change, and related southerly shifts in winter-rainfall bearing cold fronts.

4.1.4.2 The Benguela system

The Benguela Current is one of four eastern continental shelf upwelling systems in the world, but has key features that make it unique (Shillington *et al.* 2006). The current is driven by south-easterly trade winds that also cause upwelling of cold waters along the west coast of South Africa, Namibia, and Angola, and that support productive fisheries. Off the southern Cape, the northward flowing Benguela borders on and interacts with the Agulhas Current where the south-western flow of the latter 'retroflects' to the south and then back to the east. This interaction is important in the exchange of heat and salt between the Indian and Atlantic oceans *via* Agulhas rings (eddies). These eddies are formed in the area of the Agulhas retroflection, flow north in the Benguela, and are believed to be important in global oceanic behaviour (Lutjeharms 1996). Large-scale, multi-year variations in the Benguela have been observed and are now termed 'Benguela *Niños*', being analogous to Pacific *El Niño* patterns of response in the Humboldt Current on the coast of Peru (Shannon *et al.* 1986), and which also have significant impacts on their dependent fisheries.

Rouault *et al.* (2010) has reported a statistically significant negative sea surface temperature trend between 1989 and 2009 of up to 0.5°C per decade in the southern Benguela from January to August. Other smaller-scale temperature trends include the cooling of 0.5°C per decade along the west coast due to a pole-ward shift in westerly winds during winter (Rouault *et al.* 2009). Surface cooling along the west coast may also be due to the positive linear trend in surface wind speed in the region from 1982 to 2007 (Rouault *et al.* 2009).

4.1.5 Future projections

Future climate projections are not forecasts, but a description of possible future conditions based on the current physical understanding of the climate and assumptions about changing greenhouse gas (GHG) emissions and their atmospheric concentrations. The skill of projections (*i.e.* their accuracy) depends strongly on how far into the future projections are made, which GHG emissions pathway is considered, and on the projected climate variable (temperature projections are generally thought to be more skilful than rainfall projections). Deriving key regional messages about future potential change requires assessing multiple lines of evidence. Climate projections are assessed here from a range of models, as it is not possible to identify a 'best' model for all relevant climate variables for South Africa.

Global Climate Models (GCMs) are most skilful with respect to simulating circulation and large area averages of surface variables, and valuable information can be drawn from understanding how such large-scale processes are projected to change. The projections of GCMs are least skilful at their original spatial resolution—typically around 250 km^2 for a single grid cell. This is especially so for grid cell-level rainfall, which reveals wide differences in projection by currently available GCMs for much of southern Africa. One approach to selecting a preferred GCM for a region is to weigh models by their skill in simulating the observed climate during the 20th century, but such skill does not guarantee that the model is skilful at capturing the projected *change* factor for the future. Likewise, agreement between models on whether the projected change (e.g. rainfall) is positive or negative (an approach such as is used in the fourth Assessment Report of the IPCC (IPCC AR4 2007), Chapter 11) also does not imply correctness.

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, large scale changes are also *downscaled*—whereby the large scale features simulated by the GCMs are translated to the local scale. Downscaling has been accomplished here through statistical downscaling and by using a Regional Climate Model (RCM). These different downscaling approaches have relative merits and shortcomings, but are, in principle, considered to be of comparable skill (See Chapter 11 of IPCC AR4 (2007)). Downscaling is especially important for South Africa as the GCMs fail to adequately capture the detailed spatial gradients and strong topographical forcing that are so important to South Africa's climate.

The results of three types of projection are described here; those from GCMs themselves (raw GCM projections), and two forms of spatially downscaled projections. The GCM data used here are drawn from the World Climate Research Programme (WCRP)'s Coupled Model Inter-comparison Project phase 3 (CMIP3) multi-model dataset, which forms the foundation of the 2007 IPCC AR4.

At present, comprehensive multi-model dynamical downscaling for southern Africa is a work in progress within the Co-ordinated Regional Downscaling Experiment, or CORDEX[25]. Thus the statistically downscaled information reported here is primarily based on the method of Hewitson & Crane (2006). This approach uses nine GCMs that are downscaled to a 25 km^2 grid resolution and to station locations across 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 results using an RCM approach are derived directly from Engelbrecht *et al.* (2009).

4.1.6 Role of emission scenarios

The GCM simulations are forced by emission scenarios that describe the possible anthropogenic changes in future GHG concentrations, based on a range of emission scenarios from the IPCC Special Report on Emissions Scenarios (SRES). The difference in

[25] http://wcrp.ipsl.jussieu.fr/SF_RCD_CORDEX.html

projected climate change due to different emissions scenarios is small up to the mid-21st century. The difference is only appreciable in the latter half of the 21st century, and does not change the pattern of modelled response. The SRES A2 emissions scenario is used here, which is close to current emissions trends and represents a moderate-to-high emissions scenario resulting from a heterogeneous world with an increasing global population and regionally-oriented economic growth. The focus in this chapter is mainly on projections for mid-21st century, where the choice of emissions scenario has limited impact.

4.1.7 Global circulation model projections

The primary large scale circulation changes as projected by GCM include:

- An increase in the intensity of the continental surface low pressure trough associated with increased surface warming.
- A regional strengthening of wind velocity along the west coast, especially during the summer.
- 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 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, which is of key relevance in that it enhances the moisture transport into the region of air that is also becoming more moisture laden as the world warms.

These circulation changes imply 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 atmospheric moisture content over the continent, which could translate to potentially more intense precipitation and a likely increase in orographic cloud cover and topographically-induced rainfall.
- Weaker frontal systems to the south, which could translate to weaker penetration of fronts onto the continent, drier conditions in the Western Cape (possibly compensated for by an increased orographic rainfall on mountain ranges).

Projections for the end of the 21st century show an enhancement of mid-century changes. These results reflect a robust first-order response of the regional circulation to the global scale changes.

Key climate responses that are affected by topography are likely to be inadequately represented in the GCM grid cell values for these regions, including rainfall. With this understanding in mind, only some general insights are described. For rainfall, projected changes indicate drying to the north-west, contrasted in the east of the country either with increased summer rainfall, or smaller decreases in rainfall than in the west. Winter rainfall over the south-west is projected to decrease. It is not possible from these projections to determine the position of the boundary between regions with projected increases and decreases in rainfall.

Surface air temperature, a more spatially continuous parameter, shows warming everywhere, but most strongly in the interior. Coastal warming is in the order of 1°C, increasing to around 3°C in the northern interior by the middle of the 21st century. By the end of the 21st century, the warming is greater still, but at that time-scale, the degree of warming is strongly dependent on the GHG emissions scenario—for the SRES A2 scenario temperature increases in the interior are projected as high as 6°C. Jointly, 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.

4.1.8 Downscaled projections

Assessment of statistical downscaling is accomplished by applying the technique to historical atmospheric circulation and comparing the results with high resolution observations (see Hewitson & Crane (2006) for details). Validation shows that the observed accumulated precipitation downscaled from the National Centre for Environmental Prediction (NCEP)'s re-analysis atmospheric data (Kalnay *et al.* 1996) are similar to observed values, and indicate the robustness of the technique in downscaling from atmospheric fields. Downscaling using the RCM approach has also been validated (Engelbrecht *et al.* 2009), indicating that the approach simulates the regional rainfall and circulation patterns over the subcontinent with a high level of fidelity.

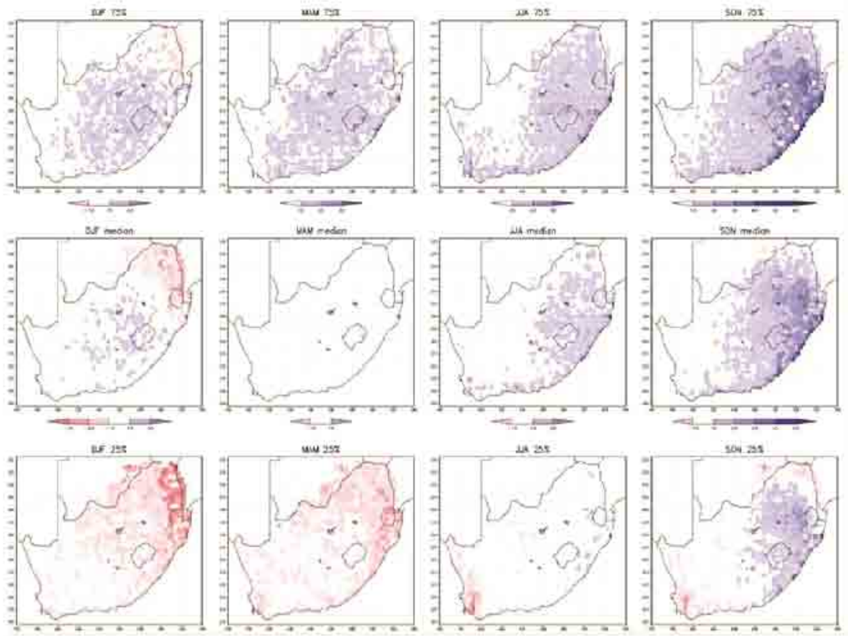


Figure 4.1.3—Downscaled projections of change in average precipitation (mm/season) from 10 GCMs of the CMIP-3 archive. Anomalies are the difference between 2046–2065 and 1961–2000, based on the SRES A2 emissions scenario. The columns are for each three month season of the year (DJF, MAM, JJA, SON). The upper row shows the 75th percentile of the model range, the middle row is the median, and the lower row the 25th percentile.

Figure 4.1.3 shows the precipitation change downscaled statistically from nine GCMs and representing the median, as well as the 25th and 75th percentiles of the projected change per season. The downscaled results support raw GCM projections of increased rainfall along the eastern coastal regions, but extend the region of increased rainfall further into the interior of the country than is the case for raw GCM projections. Similarly, drying trends projected over the south-western winter rainfall region is less extreme than that suggested by raw GCM projections and appears to be modulated by the mountains in the region after statistical downscaling is applied. These differences seem due to the fact that 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 and greater onshore flow, it is reasonable to anticipate an increased precipitation response in these regions. Further derived attributes of the downscaled rainfall—intensity, dry-spell duration, and the frequency of rain days—are physically consistent with the findings above. These suggest that an increase in the frequency and intensity of rainfall, concentrated mostly in the early summer (September–November), might be expected by mid-century. A less certain expectation is that of an increase in dry spell duration in the western regions of the country.

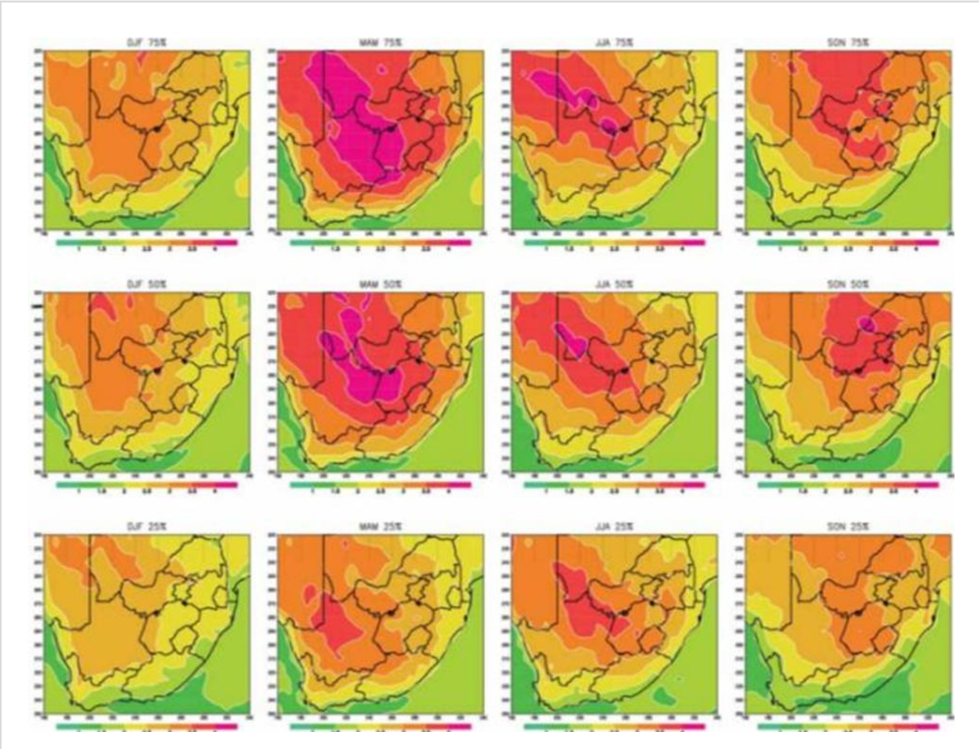


Figure 4.1.4—Projected seasonal temperature change (°C) by a dynamic regional climate model for the periods 2070–2100 *vs.* 1975–2005 under the SRES A2 scenario. The upper row shows the change in the 75th percentile (calculated separately for each model grid point) of the simulated seasonal temperatures over the period 2070–2100 relative to the 1975–2005 time series. The middle and bottom rows are similar, but represent the change in the median and 25th percentile of the seasonal temperatures respectively. Data source: WRC, UP.

Engelbrecht *et al.* (2009) simulated climatic conditions for the end of this century (2070–2100), as driven by the SRES A2 emissions scenario, using a RCM approach (figure 4.1.4 and figure 4.1.5). Their results show somewhat less warming at the end of this century than those projected by statistical downscaling—around 4°C in the interior (*vs.* 6°C for statistical downscaling) and under 2°C in coastal regions (*vs.* 2–3°C for statistical downscaling). Rain-bearing frontal systems were simulated to be displaced to the south during winter months due to higher atmospheric pressure in the sub-tropical belt. This trend would imply drying trends over winter months in western and south-western regions of South Africa. In 'shoulder-season' months (spring and autumn), high pressure systems at mid- and upper-level highs were simulated to intensify over eastern and central parts of southern Africa, resulting in generally lower rainfall totals over much of the south-eastern subcontinent. In mid-summer, the Indian Ocean high pressure system was projected to intensify most over the south-western Indian Ocean, resulting in increased occurrence of cloud bands over the south-eastern subcontinent and generally wetter conditions over this region. The most striking difference between statistical downscaling and RCM projections for rainfall is a much higher certainty of winter drying over the Western Cape, west coastal regions, and the central and eastern interior, as well as more certain increased rainfall in summer months over the eastern interior.

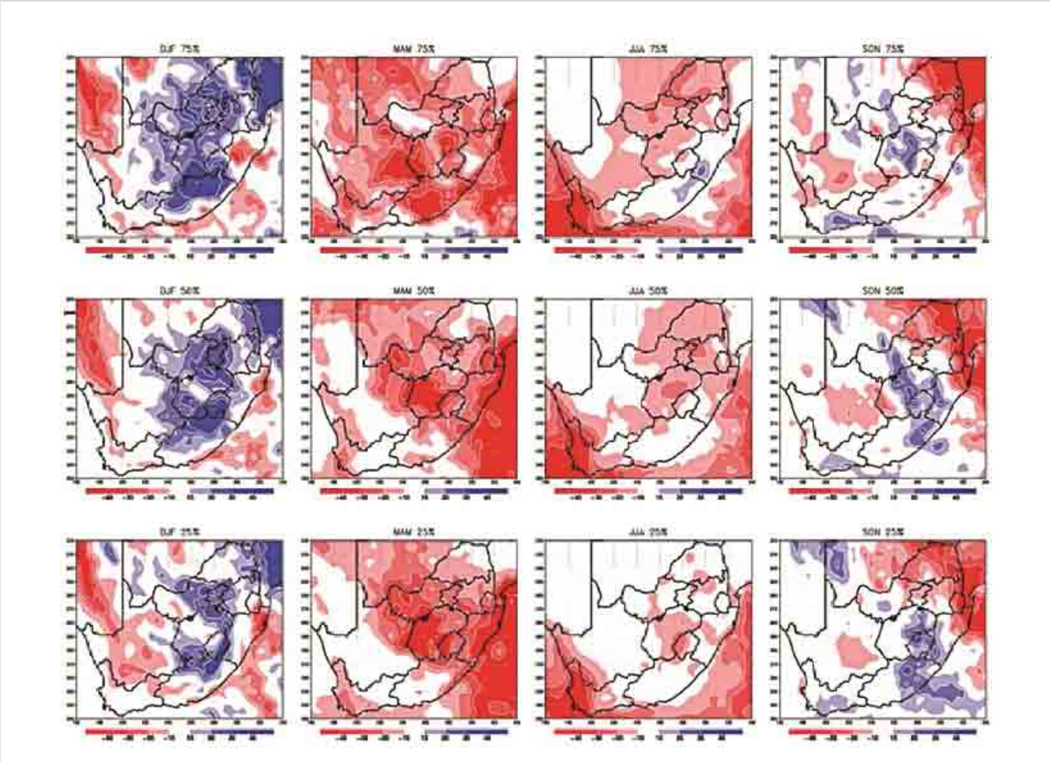


Figure 4.1.5—Projected seasonal rainfall change (mm) by a dynamic regional climate model for the periods 2070–2100 vs. 1975-2005 under the SRES A2 scenario. The upper row shows the change in the 75th percentile (calculated separately for each model grid point) of the simulated seasonal rainfall over the period 2070–2100 relative to 1975-2005 time series. The middle and bottom rows are similar, but represent the change in the median and 25th percentile of the seasonal rainfall respectively. Data source: WRC, UP.

4.1.9 Conclusions

The current understanding of regional climate change for South Africa is based on assess-ments of past changes in surface temperature and rainfall, projections of changes in large scale processes using GCMs, and downscaled projections of regional change. Scientific understanding of regional climate change is incomplete, but does

not preclude some general conclusions about future changes projected under a relatively high GHG emissions scenario.
Recent past and projected future climate changes are generally consistent with the physical understanding of global anthropogenic forcing, but climate models have not yet been fully tested in relation to climatic changes observed over deeper historical time for which appreciable independent observations are still emerging. There is evidence of recent changes in synoptic scale processes that match the understanding of an intensified Hadley circulation, and the regional details are consistent with these changes. Observations of increased historical temperatures across the country, and those projected for the future, are in agreement with current physical understanding and provide a robust message of warmer temperature conditions and extreme hot days increasing in frequency and intensity towards the end of this century. Rainfall trends are complicated by low frequency drivers such as ENSO, and lag in response to anthropogenic forcing in comparison with the driving circulation, atmospheric humidity, and temperature

As anthropogenic forcing becomes more dominant in relation to natural variability over the coming decades, changes are likely to become more apparent. Rainfall is likely to increase over the eastern portion of the country during summer months, and is indicated to decrease for the Limpopo province in summer and for the Western Cape in winter. Regional details of projections in the Western Cape are complicated in mountainous regions where the drying trend will likely be less marked.

Taken together, these findings suggest that:

- The distinct pattern of decreasing winter rainfall in the west and increasing summer rainfall in the east seems stable and physically consistent with the projected circulation changes, yet with uncertainty in the magnitude of the response and with some local scale deviations.
- All regions are very likely to be warmer in the future.
- There is uncertainty about the location of the boundary between regions that show less rainfall in the west and greater rainfall in the east.
- The role of topography is critically important, especially in enhancing the east coast increase in precipitation and slowing the rate of rainfall loss on the Cape Mountains in the west.
- A decrease in rainfall in the extreme south-west is a consistent message across GCM, RCM, and statistically downscaled scenarios, although this was least strongly projected by statistical downscaling approaches.

Overall, this level of understanding is a significant advance on South Africa's Initial National Communication (INC), and notable advances are continuing. 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 in terms of regional details of change.

4.2 Water resources

4.2.1 Current vulnerabilities

Because of South Africa's generally arid to semi-arid climatic characteristics (see Chapter 4.1), on average less than 9% of the annual rainfall ends up in rivers, and about 5% recharges groundwater in aquifers (Midgley *et al.* 1994; GRA2 2005; Schulze 2005). Together with high rainfall variability, especially in drier areas (Schulze 2008), this means that rainfall and river flow are unpredictable in time and very unevenly distributed in space, with only 12% of the land area generating 50% of stream-flows. Apparent multi-year pseudo-cycles in rainfall also result in extended dry and wet periods across the country (Tyson 1971; Tyson *et al.* 1997).

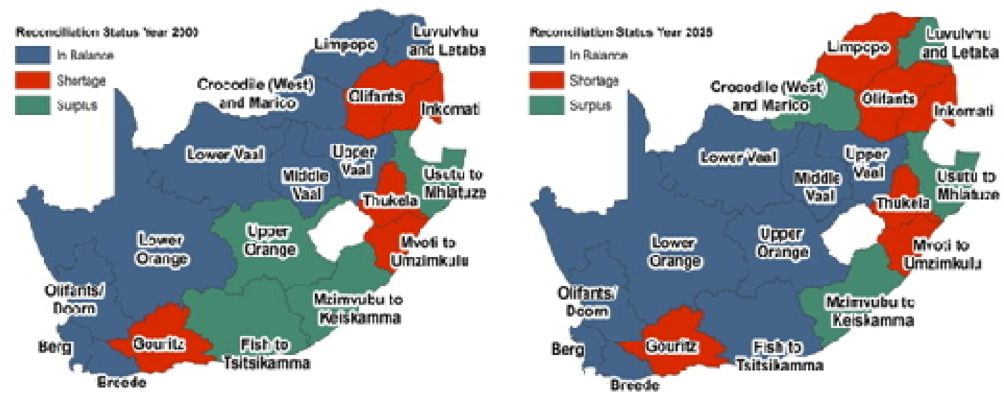


Figure 4.2.1—The reconciliation status of water resources in South African Water Management Areas (WMAs) in 2000 (left) and projected future water status by 2025 if current trends of use continue. Future reconciliation does not account for climate change.

Climate change is only one of several drivers currently informing water resource planning and decisions in South Africa. Most critically, surface water resources were already over-allocated and experiencing water stress by the year 2000 in five of 19 Water Management Areas (WMAs) (figure 4.2.1). 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, as well as 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.

The volumes of river flows are driven by rainfall and are amplified by climate variability by a factor of two to five 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 abstracts much of the early season rainfall, resulting in river flows thus responding relatively slowly and later.

The high variability in surface runoff reduces the usable yield, *i.e.* the amount of stored water that 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% (DWAF 2009). 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 water 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 (Ashton *et al.* 2008). 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 Africa's 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 times in most river and reservoir systems (Nationamaster.com 2003; Du Preez & Van Baalen 2006; Oberholster & Ashton 2008). This presents a risk to non-serviced households that 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, 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 4.2.2).

Groundwater quality is variable across the country with incidences of contamination most often caused by on-site sanitation and industrial and mining effluent (Usher & Vermeulen 2006). Arid and semi-arid areas of South Africa, in common with Botswana and Namibia, often have naturally high nitrate levels, which render the water unsafe to drink without treatment. Twenty seven percent of abstracted groundwater sources have nitrate levels that exceed the World Health Organisation (WHO)'s safe limit of 10 mg/l N-NO_3, and extremely high levels of 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 have only been a handful of reported incidences (Colvin & Genthe 1999).

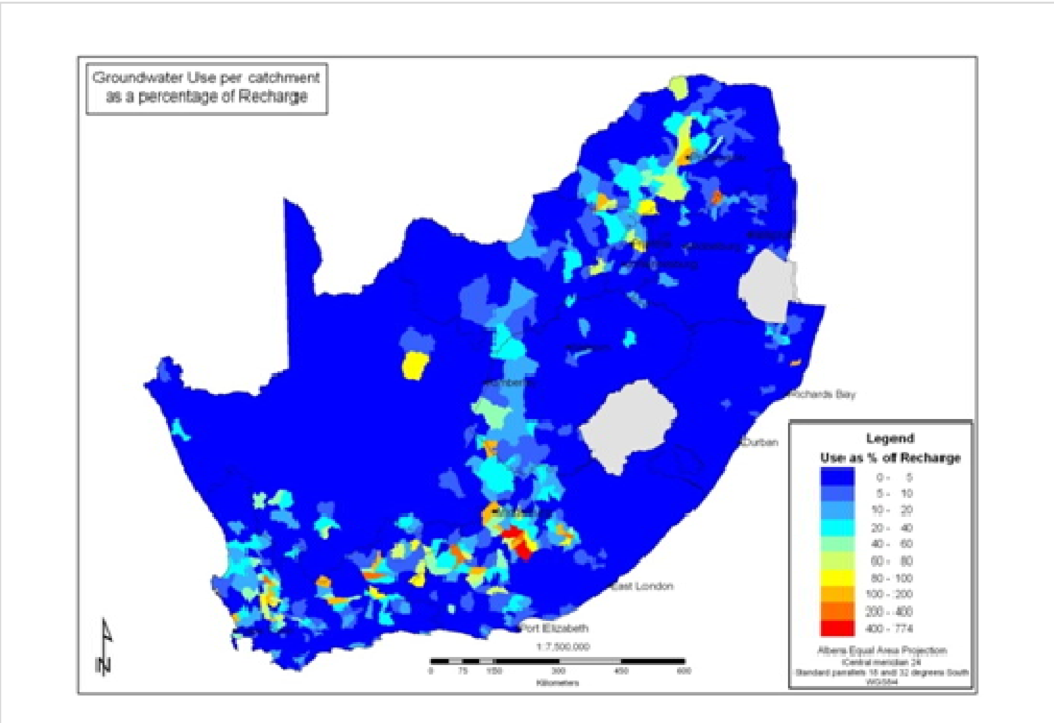


Figure 4.2.2—Groundwater use as a percentage of mean annual recharge in South Africa per Quaternary Catchment (DWAF 2005).

4.2.2 Observed trends

Observed temperature and rainfall trends are summarised in Section 4.1. In certain sub-regions in South Africa, climate station data displays spatially coherent, and in some cases statistically significant, drying trends (Kruger 2006). These areas include some of the key upland watersheds for the major river systems. Near-surface air temperatures have significant impacts on the hydrological cycle and therefore on water resources. The warming of the atmosphere could therefore potentially change 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; and increasing evapotranspiration—consequently impacting on soil moisture, irrigation demand, and runoff. However, Hoffman *et al.* (2011) have shown that evaporation and windiness have both declined significantly over land in the Western Cape, contradicting expectations of increases in evaporation. Evidence of changes occurring within the hydrological cycle in South Africa over the past century due to climate change is ambiguous, and it is likely that related trends in the hydrological cycle are currently masked by natural variability and other human impacts.

4.2.2.1 Projections of impacts on water resources

Predicted increases in temperature would in theory lead to linear changes in hydrological processes such as increased evaporation; though as discussed above, these have not been observed in Western Cape records according to Hoffman *et al.* (2011). Projections of precipitation change and consequent runoff changes are even less certain. It is well-established in South Africa that changes in rainfall would be amplified by the response of surface and groundwater resources (Schulze 2005; De Witt & Stankiewicz 2006), and be modified by intensification of land uses or alterations to the complex interactions between vegetation, soil moisture, evapotranspiration, and water resources (Schulze 2003).

Modelled hydrological projections presented here assume that projected 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; 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, rainfall seasonality, and patterns of extreme rainfall events; with indications that rainfall intensity would be likely to increase over the summer rainfall region (*e.g.* Tadross *et al.* 2006; Engelbrecht *et al.* 2009; Schulze 2010).

4.2.2.2 Quantity of water resources

The projected increase in temperature would partially offset any increase in rainfall, as it would increase potential evaporation by about 5% per 1°C (Schulze 2010). Combined temperature and precipitation changes would have significant impacts on accumulated stream-flows. These impacts are reflected in the projected relative changes in median annual stream-flows (broad understanding indicates that stream-flow would increase in the east and decrease in the west), and in similar patterns of projected changes in the year-to-year variability of stream-flows derived from multiple GCMs for the intermediate future (2046–2065) and more distant future (2081–2100) (Schulze 2010; and see figure 4.2.3). Some of the increases in river flows projected for the more arid areas would be so small in absolute quantities (because they come off a low base) that the effect for water resource management would be minimal.

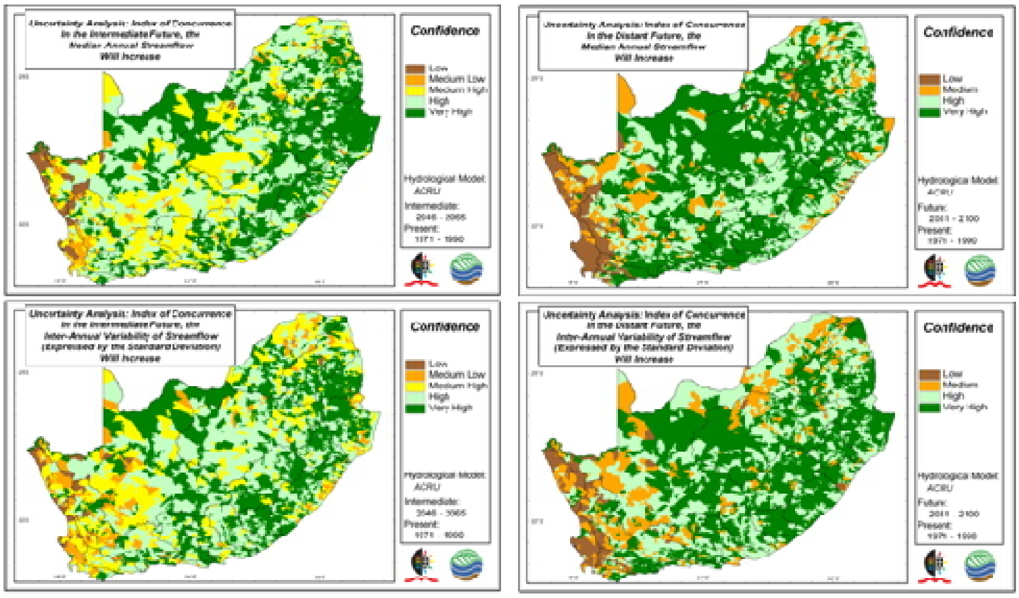


Figure 4.2.3—Output from multiple GCMs implying that median annual stream-flows are projected (top left) to increase in the east and decrease in the west by the intermediate future (2046–2065), with (top right) this trend amplifying into the more distant future (2081–2100), while (bottom left and right) the inter-annual variability of stream-flows shows similar spatial patterns (Schulze 2010).

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 KwaZulu-Natal provinces by mid-century (Figure 4.2.4). This implies that there could 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 would have negative impacts on water quality (see below) as well as on disaster risk management. On the other hand, flows are predicted to decrease markedly (Figure 4.2.4) both in years of high and low flows in the Western Cape (and particularly some of the catchments that supply Cape Town's water), and in parts of Limpopo. Such changes could lead to severe water management challenges, with potential socio-economic repercussions.

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 4.2.5). By implication, in the northern, central, and south-western areas of the country where rainfall is currently around 500 mm/year, 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 4.2.2.

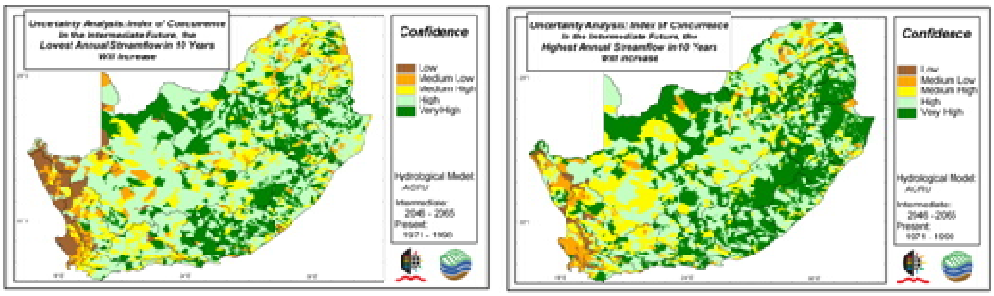


Figure 4.2.4—Output from multiple Global Circulation Models (GCMs) imply that both years of low annual stream-flows (left) and high annual stream-flows (right) are projected to increase in the east and decrease in the west by the intermediate future around mid-century (Schulze 2010).

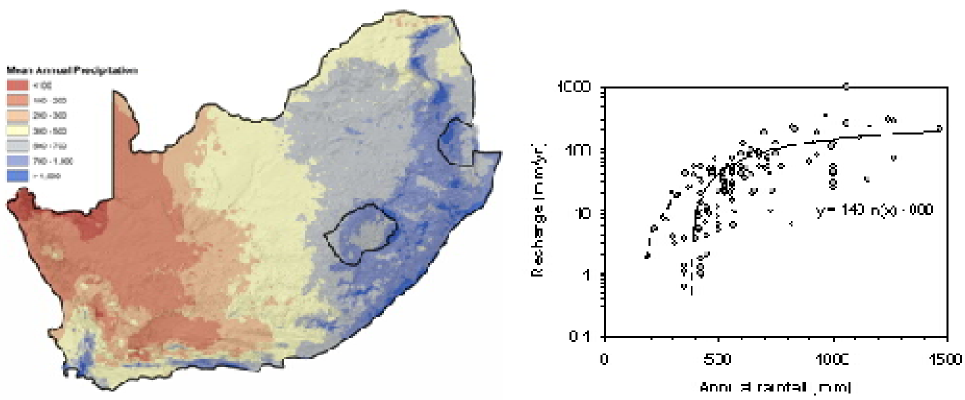


Figure 4.2.5—Non-linear relationship of annual groundwater recharge to rainfall in semi-arid areas, with the tipping point at less than 500 mm rainfall per annum (Beekman *et al*. 2003; with the map of mean annual precipitation from Lynch 2004).

Less recharge would result in declining groundwater levels. Groundwater-fed base flow to rivers would decrease (in duration and volume), impacting on 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 groundwater 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 (Tredoux *et al*. 2003). It is therefore difficult to predict the net effect of climate change on groundwater levels, because even in areas where total rainfall declines, a greater proportion of the annual rainfall may recharge aquifers if extreme storms become more frequent. 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, there is high confidence that predicted heavy rainfall events (in excess of 25 mm/day) would increase in the eastern part of the country and less so for the more arid western areas (Figure 4.2.6).

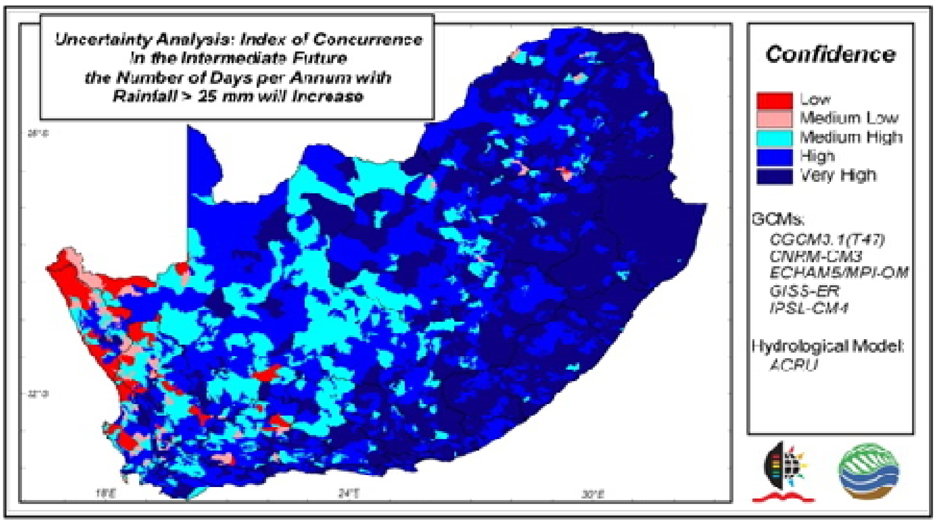


Figure 4.2.6—Concurrence between multiple Global Circulation Models (GCMs) shows a higher confidence in projected increases in the frequency of days with heavy rainfall in the eastern parts of South Africa, with areas of low confidence in the west implying fewer heavy rainfall days (Schulze 2010).

4.2.2.3 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), would 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. Predicted climate change is expected to increase mean annual sediment yield in the east and to reduce it in the north-west of South Africa by mid-century (Figure 4.2.7; Schulze 2010a). Increased turbidity would alter the albedo (reflectance) characteristics of rivers and reservoirs, and exacerbate the impact of higher temperatures. Changes in the water temperature regime would alter the conditions that promote or retard algal (phytoplankton) growth. Reduced light penetration would alter the suitability of conditions for many types of phytoplankton. Suspended sediments 'attract' metal ammonium and other 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 characteristics too dramatically. Reservoirs and rivers with low turbidity would change in unanticipated ways. All of these have important implications for water treatment processes and ultimately sludge disposal systems.

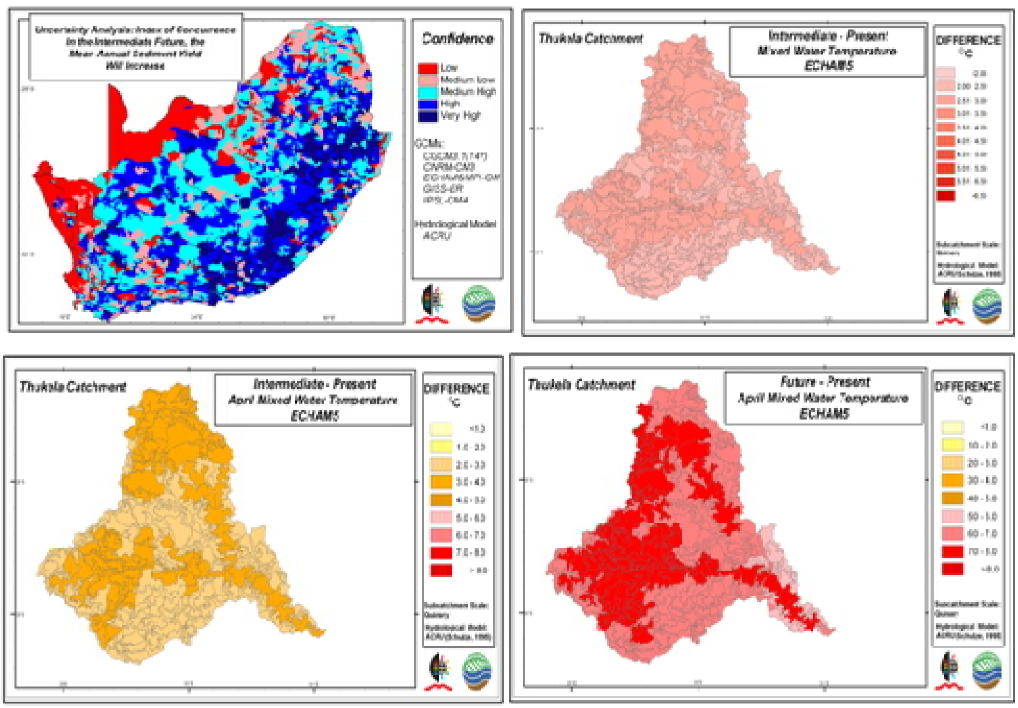


Figure 4.2.7—Potential impacts of climate change on water quality indicators, with (top left) output from multiple Global Circulation Models (GCMs) implying projected increases in mean annual sediment yield in the east and reductions in the north-west of South Africa by mid-century (Schulze 2010), and (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).

Increased water temperature creates optimal conditions for blue-green algae (cyanobacteria), which could 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 becomes dominated by toxic forms of cyanobacteria for longer periods of the year, it would pose additional (costly) implications for potable water treatment works, because tertiary treatment with activated carbon would become necessary to remove the toxins. Predicted increases in annual water temperature by mid-century in the Thukela catchment, are in the order of 2–3°C (Figure 4.2.7, top right). April water temperatures could increase by 2–4°C by the middle of the century (Figure 4.2.7), or even double that by the end of the century according to some models (Barichievy *et al.* 2010).

Denser phytoplankton blooms would 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 would promote denitrification, resulting in loss of nitrogen to the atmosphere. This would, 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 affect aquatic ecosystems markedly, particularly in dams and lakes. In the case of fish, it would be difficult to distinguish between the effects 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 is 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 the water that 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, and fluoride) in the soil profile. When rainfall events in these areas are intense, the accumulated salts are leached from the soil and unsaturated zones 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). If recharge events become more episodic and extreme, these arid and semi-arid areas would be impacted. Such changes 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 the flushing of elevated concentrations of salts into the aquifer.

4.2.2.4 Vegetation responses to climate change and impacts on water resources

Direct effects of climate change on hydrological processes are likely to be modified by more indirect effects that have not been well considered, and may have important implications for the future availability of water resources. Changes in the interactions between woody plants and grasses may cause an increase in tree cover in previously grass-dominated ecosystems, driven by increased CO_2 concentrations and changing wildfire regimes (Bond *et al.* 2003a). Atmospheric CO_2 increases enhance the competitiveness of woody plants and may already account for much of the observed increases in woody plant densities recorded in South Africa during the 20th century (Wigley *et al.* 2010). While much of the bush encroachment observed in South Africa has been ascribed to overgrazing and reductions in fire intensity and frequency (which favour woody plant proliferation), it is clear that 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 would lead to the loss of more deep soil moisture and groundwater by transpiration. The net impacts are speculative, but increased tree cover driven by rising CO_2 and climatic changes could have adverse impacts on surface water flows in the currently grassland-dominated catchments of the Drakensberg (Scheiter & Higgins, 2009)—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 would alter vegetation growing seasons and growth patterns, as has been shown by Schulze & Perks (2000). Frequent and severe frosts are characteristic of the elevated interior plateau of South Africa (Schulze 2008). The die-off of grass cover due to frost significantly reduces transpiration during the winter months (Everson *et al.* 1998). 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 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 & Perks (2000) 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.

Finally, invasion of many catchment areas, wetlands, and riparian zones by alien plants, especially trees and shrubs, poses a significant threat to water resources (Görgens & Van Wilgen 2004). These invasions currently reduce surface water runoff by an estimated 7% (Le Maitre *et al.* 2000), and this could increase significantly in future (Van Wilgen *et al.* 2008). The implications of climate change for this phenomenon are discussed in Section 4.5.

4.2.3 Vulnerability and future risks

Decreasing water availability, flooding, droughts, eutrophication, and contamination would impact all sectors of the South African economy. However, the most vulnerable sectors 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 (DWAF 2009). In many rural areas, 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 4.2.8) 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 4.2.8). 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.

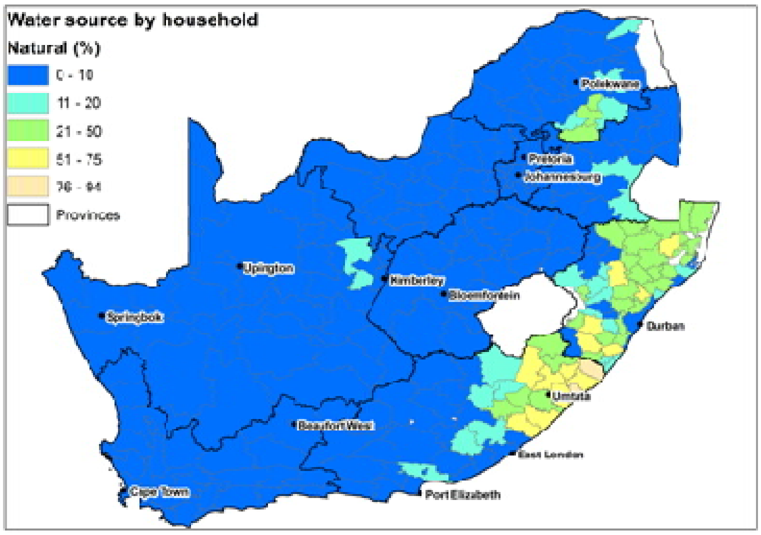


Figure 4.2.8—Percentage of households reliant on natural water sources such as springs, rivers, and wetlands (Statistics South Africa 2007).

Agriculture currently utilises roughly 60% of available surface water resources (DWAF 2009). 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 and 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 (*e.g.* salad vegetables), as the uptake of these toxins will contaminate crops.

4.2.4 Adaptation

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 would 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) is 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, whether up or down, would be 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 likely to become real 'hotspots of concern'.
- Climate change would not occur on a 'clean sheet' of virgin catchments not yet impacted upon by human interventions on the land and in the channel, but would 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 imperative—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 characterised by capacity constraints, inadequate funding, a reliance on an ageing bulk infrastructure, and erratic water quality in smaller municipalities and rural areas (WISA 2008; Stuart-Hill & Schulze 2010). Potential 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 prioritise risks and put adaptation measures in place.

With both increased and decreased rainfall projected over different parts of South Africa, water demand management (WDM) would be an important primary measure to conserve the country's water resources. 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, and technical means, instead of developing new water resources' (Van der Merwe 1999). Care is required in making technology choices with water use implications, including those relating to emissions controls. 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 (McKenzie *& Wegelin* 2009). In line with this, the Department of Water Affairs (DWA) 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).

In western and central South Africa, water service providers would most likely need greater water storage to buffer the projected higher extremes of projected 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 2004a). Dams would likely become more vulnerable to losses from evaporation, siltation, and contamination from algal blooms; and water suppliers would benefit from diversifying water storage strategies. Most water stored naturally in catchments is stored in underground aquifers; 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 seven times the volume of groundwater stored in aquifers (*ca.* 235 000 million m^3) than surface water stored in major dams (DWAF 2005). DWAF is already developing a national groundwater strategy and plans to enable water service providers to 'diversify the water mix' by using more groundwater (DWAF 2009).

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 Council for Scientific and Industrial Research (CSIR) has pioneered artificial recharge to groundwater in southern Africa in Cape Town, the west coast, and Windhoek (Namibia). Excess storm water from the winter rainy season is captured, treated, and infiltrated or injected into the aquifer. The DWA 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 would need to be implemented in areas with increasing vulnerability to floods. Environmental management of potential contaminants in the industrial and mining sectors would need to become a priority. Municipal wastewater treatment plants would require stricter enforcement of effluent standards and significant investment in aging infrastructure.

4.3 Agriculture, rangelands, and forestry

4.3.1 Current vulnerabilities

4.3.1.1 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[26].
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, to a large extent, important in determining potential agricultural activities and suitability across the country, especially in small-holding 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

---

[26] http://www.info.gov.za/aboutsa/agriculture.htm

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 into a commercially-oriented sector that services national food requirements and export earnings; and a small-scale and homestead farming sector that constitutes a high proportion of the (mainly subsistence) farming population that rely 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, 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. Livestock also has a socio-cultural, in addition to its monetary, value.

Small-scale and homestead food production is practiced in rural areas on both high potential and marginal agricultural land, with roughly 1.3 million small-scale farm units country-wide. Seventy percent of the country's poorest households live in these areas and few of these households are food self-reliant throughout the year. 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 fertilisation and seed, and in weed, pest, and disease control. Programmes 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 roughly 60% of total available water, and with all agriculture-related activities consuming roughly 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 7 630 million m^3 in 1995 to 7 921 million m^3 in 2000; 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, which means 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) that adversely affect 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 *et al.* 2003); potentially adversely affecting topsoil *via* nutrient depletion and land degradation.

Some evidence suggests that increasing population pressure, unsustainable land use, and 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).

4.3.1.2 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). 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 an apparent status of being food-secure as a country (De Klerk *et al.* 2004), it has been estimated that about 1.5 million South African children are malnourished, 14 million people are prone to food insecurity, and 43% of households suffer from 'food poverty' (National Treasury 2003). 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).

South Africa's concern about 'food security and the environment' (including climate change-related risk of increased hunger), 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 *et al.* 2010).

4.3.1.3 Rangelands

South African rangelands (un-transformed ecosystems that support extensive grazing and browsing) 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 that may initiate desertification processes are exceeded. 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.

4.3.1.4 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 and 14%, and 12 and 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.

4.3.2 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% 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 (ERC 2007). Rural rooibos tea farmers have been adversely affected by recent drought impacts (Oettle 2006).

Non-climatic land-use trends such as urbanisation 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 south-western Cape and a drier and warmer trend in the north-east 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.

4.3.3 Projections and future risks

4.3.3.1 Climate projections and agricultural responses

The INC (DEAT 2004a) interpolated climate projections for 2050, which indicated a decrease in rainfall by *ca.* 15% in the summer rainfall area, and by *ca.* 25% in the winter rainfall area; temperature increases of between 2.5 and 3°C; 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). These projections contrast to some extent with the more recent projections being applied by current impacts assessments. Major climate change impacts on, and implications for, agriculture projected in the INC included:

- 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 ecto-parasites change.

More recent studies largely support, but significantly extend, these predicted effects, and indicate in more depth where the specific vulnerabilities might lie (Benhin & Hassan 2006; Midgley & Thuiller 2007; Molope 2006; Oettle 2006; Schulze 2006, 2010 (for South Africa); and Nelson 2009 (for sub-Saharan Africa)). Some regional studies (*e.g.* Pan African Climate Justice Alliance (2009)) project significant future economic costs of climate change in many regions of Africa, including a drop in crop revenues by *ca.* 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 less extreme projections for South African agriculture, but they may serve as a potential warning of regional impacts under worst case scenarios.

Projections of impacts in these sectors in South Africa are complicated by the application of a wide range of climate scenarios and modelling approaches, making it extremely challenging to extract coherent key messages. Projections of agricultural impacts 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. Published projections therefore 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 scenario, and based on the Commonwealth Scientific and Industrial Research Organisation

(CSIRO) and the National Centre for Atmospheric Research (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 (1971–2090), intermediate future (2046–2065), 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 (ERC 2007; Schulze 2010).

4.3.3.2 Key summer rainfall crops

Maize

Local consumption of maize amounts to about eight million tonnes annually, and surplus is exported with a gross value of R21 billion (Department of Agriculture 2009; South Africa's Farming Sector 2009). As South Africa's staple food crop, maize has been under the spotlight since the late 1990s, both in vulnerability research (Du Toit *et al.* 1999, 2002) and in regard to productivity (Schulze *et al.* 1995), as well as 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 fertilisation, 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 2008). 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 (South Africa's Farming Sector 2009). Sugarcane is grown in the northern parts of the Eastern Cape through KwaZulu-Natal to the Mpumalanga Lowveld. An estimated 2.5 million tonnes of sugar are produced per season. Some 50% is marketed in southern Africa with the rest exported. Analysis indicates positive dryland sugarcane yield increments of *ca.* 5.0–5.5% 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 *ca.* 7% for a 10%

reduction in rainfall, and to increase by a similar percentage for a 10% increase in 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.

4.3.3.3 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 for the period to 2050 were identified in the LTMS (2007) as:

- Those reliant on rainfall (small grains, rooibos tea, stock on western arid rangelands).
- Those that require significant chill units (*e.g.* apples, pears).
- Irrigated agricultural crops, especially during drought periods.
- 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 that 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 such as fynbos and cut flowers.

Apples

South Africa currently ranks 15th in global apple production and in 2006 produced 1.25% of the global supply (DFPT 2007), as one of the top six apple exporters. Total production in 2005/2006 was 780 000 tonnes, 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 number of 'on-farm' jobs is generated in related industries and service companies.

Future temperature increases are projected to cause a 28% reduction of the area suitable for apple production by as early as 2020, with suitable apple producing climates limited 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 are 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 ninth 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 tonnes, 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 (ERC 2007). 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 capitalise 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.* ten 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 (ERC 2007). Preliminary analysis demonstrates that both timing and amount of rainfall are good predictors 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.

4.3.3.4 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 *Chilo 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.

4.3.3.5 Livestock production

Livestock and livestock products contribute an estimated 51% of the agricultural income, mainly from the intensive livestock sector (Department of Agriculture 2009).

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 I_{TH}) 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 the following:

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 counteract 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 2.5–3°C rise in temperature, substantial mortality can be expected. Options to be considered by farmers would be a reduction of stocking density by 12%, thereby 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 temperatures, 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, northern 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 jeopardising milk production, high milk-producing exotic breeds have been cross-bred with heat-tolerant indigenous breeds.

4.3.3.6 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 (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 the *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 south-west 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.

4.3.3.7 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 increase the cover of shrubs and trees in grassland and savanna, with mixed effects on biodiversity and possible positive implications for carbon sequestration (Bond *et al.* 2003a). 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 as well as livestock water requirements in the extensive livestock production that takes place in rangelands.

4.3.3.8 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 and 5% for the whole of South Africa, by between 1 and 4% for irrigated farms, 26 and 28% for dryland farms, 6 and 14% for large-scale farms, and 10 and 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 severely affected. This compares well with Pan African Climate Change Justice Alliance (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% (rain fed) 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 52–55% for maize, 94–111% for wheat, and 11–14% for soybeans. Carbon dioxide fertilisation 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 *ca.* 2 300 kcal/day to *ca.* 1 900 kcal/day by 2050. By 2050, the world-wide 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 US$3 billion (2000 equivalent) would be needed annually in sub-Saharan Africa to counteract these negative trends, with about US$2 billion needed for road development, US$300 million for agricultural research, US$500 million for irrigation expansion, and US$200 million for irrigation efficiency. A major constraint to irrigation expansion is soil suitability for irrigation and water availability (De Villiers *et al.* 2005).

4.3.4 Adaptation

4.3.4.1 Broad 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 optimising climatic conditions to maximise 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 programmes and information are initiated at high levels in government for regional implementation and are not always adapted to local conditions. However, all agricultural programmes 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).

Farmers will need to adapt to the following climatic changes, 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.
- 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 with 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, and conservation tillage and water harvesting.
- Wetlands conservation as they perform vital ecosystems functions and provide a wide range of agricultural goods and services in supporting livelihoods in many rural communities.
- Competition 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.
- 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 soil suitability studies prior to future land use decisions.
- Adopting a soil protection ethos to underpin land use decisions in the future.
- Local-area-specific soil husbandry.

Dryland crop-related adaptation embraces:

- The overall promotion of best management practices (BMPs) based on the principles of the least possible soil disturbance, permanent soil cover, multi-cropping, and integrated crop and livestock production to optimise yields as well as sequestering carbon and minimising 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 practising no-till as a soil conservation measure.
- 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, irrigation practices being efficient, and expansion not leading to negative repercussions downstream.
- Integrated water use planning.
- 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 fertiliser losses from irrigated lands.
- Use of mulching/crop residue as a water saving mechanism.

Livestock-related options include:

- Adapting livestock (and game) densities to changing grassland carrying capacities.
- Minimising 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.
- Minimising weed infestations in grasslands because weed infestations, being mostly pioneer species, tend to degrade ecosystems and adapt more rapidly to environmental changes.

- Practising fodder storage for livestock.
- Shifting of livestock to land with higher carrying capacity.
- 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 commercialisation, poor infrastructure, and low farm productivity, which largely implies eliminating the poverty trap that 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.
- 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.
- The importance of integrated planning, especially with regard to agriculture and mining uses in relation to municipal needs.
- 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 use current and new technology and practices.
- Considering climate change implications in land reform and land redistribution policy and practice.

- 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 increased rainfall variability and its impacts on multiple year droughts and long cycle crops (*e.g.* commercial timber species or deciduous fruit trees), persistence of rain days, or the onset and duration of the rainy season.
- Better understanding the CO_2 fertilisation 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, grass/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 ecto-parasites change.
- Evaluating potential changes in pest/disease distributions since more pest attacks are likely, the distributions of plant and animal diseases and insects are projected to change, the dynamics of insect pests and disease complexes are likely to be perturbed, new pests are emerging, and currently effective biological control agents/predators are losing their efficacy.
- Better understanding of weed control, including weeds as hosts and changing costs of weed control.
- Undertaking 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) are long.
- Re-assessing plant needs, for example, in regard to water requirements, pH, or fertiliser requirements.
- 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 that are climatically suitable for specific crops and growing indigenous species.

- 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.
- The need for market projections into the future.
- The potential repercussions that changing climate might have on government re-looking at forms of subsidisation of key agricultural commodities.
- Changing markets within South Africa (*e.g.* from dairy farming to sugarcane).

Culture and tradition-related issues on adaptation would include:

- Re-assessment of communal land ownership and land distribution/sub-delineation policies that may result in unprofitable activities.
- The culture of maintaining large numbers of cattle, with respect to potential challenges relating to climate change.

Communications-related adaptation will require:

- A clear communication strategy with regard to climate issues.
- 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.
- Improved authorities-to-farmer communication and trust building.
- Inter-farmer communications through organised and operational networks of communication on climate change and information sharing with one another.

4.3.4.2 Specific adaptation 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 and precision farming. The benefits of CA are well established at small scales, and are currently being quantified at commercial farm level and compared to conventional production methods (Smith *et al.* 2010). Adoption of CA practices by the commercial and household food security sectors is 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 input costs and thus larger profit margins, 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, are well-documented for sub-Saharan Africa and form 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, groundwater management systems, the artificial recharge of aquifers, rainwater harvesting, as well as farming operations adaptations 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 practised to ensure general environmental health and in providing food and water security, notably to the rural poor (Kotze & Silima 2003; Swanepoel 2006; Grundling 2008; Mondi 2009).

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 minimise the adverse impacts of negative events, while benefitting from positive events. Climate information on a day-to-day basis is vital for farm operational procedures such as irrigation scheduling, timing of fertiliser applications, in-field traffic control, cultivar and variety selection, 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 (SAWS) and the Agricultural Research Council (ARC), which maintains 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, as well as diminishing soil productivity and land degradation, will add an additional stress layer.

Progress has been made with the development of genetically modified crops with regard to 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 minimise 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 (*e.g.* to minimise 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 who are 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. Programmes 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 encourage the sector to adapt to climate change and, most importantly, 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.

4.3.4.3 Specific adaptation 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 provide 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 optimise 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 meet all 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.

4.3.4.4 Specific adaptation options—rangelands

Adaptation interventions in rangeland systems would benefit from an integrated approach that 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 as 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 would 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.

4.4 Terrestrial biodiversity

4.4.1 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 2005b).

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 (Scholes & Biggs 2004; Hassan *et al.* 2005). 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. More recently, the unintended consequences of mitigation responses have emerged as a concern (see Box 4.4.1).

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 recognised 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 and smoke from residential areas, but pollution impacts also extend to areas of Mpumalanga and the North West province, and to the vicinities of urban centres nationally (Van Tienhoven & Scholes 2006).

Box 4.1.1 Biodiversity-mitigation interactions—wind energy development, vulnerability, and reducing risk

Wind energy is a fast-developing economic sector in South Africa, as in many other countries. An important initiative between two of South Africa's most important conservation non-governmental organisations (NGOs), the Endangered Wildlife Trust (EWT) and BirdLife South Africa (BLSA), has led to the formation of a joint specialist task team, the Birds and Wind Energy Specialist Group (BAWESG). BAWESG also includes scientists working on bats, which are also harmed or killed by wind turbines. Seeking proactive engagement between specialists, the wind energy industry, and government, BAWESG has developed three useful products to inform and support sustainable energy development in the country:

- A **national sensitivity map** of areas with low and high risk for negative bird impacts based on a detailed and quantitative species risk assessment combined with expert-driven identification of high-risk areas for threatened or vulnerable birds (see the draft map at http://www.birdlife.org.za/component/content/article/19-birds-and-wind-energy/151-google-map).
- A **best-practice guidelines document for wind energy impact assessments on birds** (see https://www.ewt.org.za/Portals/0/ewt/workgroups/WEP/BAWESG_Monitoring%20guidelines_Version%201_04042011.pdf).
- A **best-practice guidelines document for wind energy impact assessments on bats** (see https://www.ewt.org.za/Portals/0/ewt/workgroups/WEP/SA_Wind_Survey_Guidelines_FINAL_April%202011.pdf).

Together, these products seek to support economic development of sustainable energy options in South Africa by identifying areas where wind energy facilities can be most likely established with minimal biodiversity consequences, as well as areas where the financial and biodiversity impacts could make projects non-viable. They also provide best-practice guidelines following international standards to ensure that appropriate data is collected to fully inform the EIA process.

Here are also some useful references from Megan Diamond, Wildlife and Energy Programme Manager, EWT, and Dr Hanneline Smit, Conservation Manager, BirdLife SA, from EWT's and BLSA's websites:

- NERSA's proposed new tariffs for wind and solar energy: https://www.ewt.org.za/Portals/0/ewt/workgroups/WEP/Sake24%2024%20March%202011%20Tariffs.txt.
- The EWT & BirdLife SA's position statement on bird and bat impact assessment and monitoring at wind energy facilities: https://www.ewt.org.za/Portals/0/ewt/workgroups/WEP/EWT-BLSA%20Position%20statement%20on%20bird%20&%20bat%20EIA's_240311.pdf.
- Further reading on cumulative impacts of wind energy on birds: https://www.ewt.org.za/Portals/0/ewt/workgroups/WEP/Cumulative%20impact%20assessments%20&%20wind%20farm%20bird%20interactions.pdf and http://www.birdlife.org.za/conservation/birds-and-wind-energy.

The distribution of biomes is thought to be controlled to a large extent by both climate and natural disturbance by wildfire (Bond *et al.* 2005). 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 2007a). 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 roles 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 INC on climate change, but assessments used modelled climate projections (Perks *et al.* 2000) driven by the IS92a GHG emissions scenarios used in the IPCC's second assessment report, and 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 bio-climate 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 bio-climates were projected in the western, central, and northern parts of the country, including the almost complete displacement of bio-climatic 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 bio-climate across the interior plateau, and the contraction of the Savanna biome bio-climate on the northern borders of the country and its expansion into the Grassland biome bio-climate. The species-rich Fynbos biome bio-climate 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 bio-climate 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 contraction variation 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, with a decline of total country-level richness.
- The majority of the 16 centres of endemism studied also showed significant change of bio-climate according to the model projections, with more than half predicted to experience bio-climatic 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 bio-climate, 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 (these are discussed further in section 5.2).

4.4.2 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 2007b) showed clearly that there were 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.

The secular trends in temperature-related impacts on key life stages observed in organisms at high latitudes are, furthermore, not likely to be as obvious in the sub-tropics. This is because disturbance and water availability are relatively more important in driving ecological processes in the sub-tropics, and directional changes may be obscured by climate variability on a range of temporal scales (Tyson & Preston-Whyte 2000), driven most notably by *El Niño* cycles (Diaz *et al.* 2001; Glantz 2001). Fire regime is an important determinant of ecosystem structure and function in this region (Bond & Van Wilgen 1996; Bond *et al.* 2003c; Bond & Keeley 2005), 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.* 2009), which threatens plant species with long juvenile periods, and 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 1990s and SABAP2 currently ongoing) indicates changes in phenology (timing of seasonal activities such as migration) and geographic ranges. Phenological responses of barn swallows (*Hirundo rustica*) show that they are now leaving northern parts of South Africa on their northward migration eight days earlier than they did 20 years ago (Altwegg *et al.* submitted). 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 fertilisation of trees and shrubs, providing them with a competitive advantage in relation to grasses (Bond *et al.* 2003b).
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 the climate warms and dries. Certain seabird species on Marion Island show population declines driven especially by changes in frontal tracks and storm intensity.

4.4.3 Projections and future risks

4.4.3.1 Species

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. They further support the suggestion that projected climatic and atmospheric change may induce significant spatial shifts in optimal bio-climatic conditions for southern African species (Rutherford *et al.* 2000; Erasmus *et al.* 2002; Broennimann *et al.* 2006) and may alter controls on ecosystem structure and function (Bond & Midgley 2000; Hulme *et al.* 2001; Bond *et al.* 2003a; Woodward & Lomas 2004; Thuiller *et al.* 2006a), which may themselves affect 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 as 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 bio-climatic 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 that 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 could on average be reduced by about 40% in endemic species richness even under the most optimistic SRES scenario (B1). Varied 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 how these are incorporated or ignored by methods for estimating species vulnerability. A continent-wide study at rather coarse resolution using HadCM3 scenarios of potential geographic shifts of 5 197 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 bio-climatic (niche-based) modelling. This shortcoming requires that experimental and ongoing monitoring programmes 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 sensitivity to extended drought that contrasts with high drought tolerance of desert sclerophylls (Midgley & Van der Heyden 1999). 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).

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 (Hulme *et al.* 1996) suggested a prevalence of range size decreases over range size 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), along with 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 ranges 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, which is 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 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 (1977–1996) 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, which is a concern as model projections suggested near-extirpation (local extinction) 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 *et al.* (2006), who found that ant assemblage structure in the Cape Floristic Kingdom responded to site temperature characteristics that, together with area and vegetation variables, contributed significantly to species mix in major vegetation types and biomes on a bio-climatic 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 are important determinants of future retention of biodiversity. However, findings such as these based on species range modelling are limited in that they fail 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.

4.4.3.2 Ecosystems

Changes to major vegetation types have been modelled in South Africa using correlative and mechanistic techniques. 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.* 2003a,b; Scheiter & Higgins 2009), has allowed far more useful and credible projections to be made. By contrast, correlative bio-climatic niche-based approaches are limited in that they do not account for the effects of CO_2 fertilisation 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 (ERC 2007). 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 also imply the invasion of adjacent biomes (Savanna, Succulent Karoo, and Grassland) by more arid-adapted Nama-Karoo elements.

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, 2003c; Scheiter & Higgins 2009) have concluded that 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 *ca.* 500 mm mean annual rainfall (MAR); somewhat affected by disturbance regime within MAR limits of 650 plus/minus 134 mm MAR; and strongly disturbance-determined above *ca.* 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 2009a), 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 fertilisation 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 bio-climatic modelling application, little spatial modelling work has been done on its vulnerability to climate change. One bio-climatic niche-based study 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 utilisation, and thus subject to water stress. Projected shifts in climate have significant implications for the persistence of these systems and their 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 need to keep wetlands intact wherever possible, because of the vital role they play in contributing to consistency of water availability and water quality.

4.4.3.3 Ecological processes and ecosystem services

There is a significant information gap with respect to the impacts of climate change on South African ecosystem processes and related ecosystem services. Two processes that emerge above as critical are wildfire and 'fertilisation' of photosynthesis and plant growth as a result of rising CO_2. Both are widely pertinent to the structure and function of South African ecosystems. Changes to both have the potential to cause major changes in ecosystems over vast areas, and these changes may already be underway.

4.4.3.3.1 CO_2 fertilisation

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 1990s, 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 fertilisation 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 fertilisation effects included, the more mesic and tree-dominated seasonal forest vegetation types more than doubled their extent at the expense of arid vegetation types.

More recent studies using HadCM3 climate projections for 2050 (Thuiller *et al.* 2006b) also found a strong sensitivity of vegetation structure and function to CO_2 enrichment, with Net Primary Production (NPP) reductions due to climate change almost negated by CO_2 fertilisation, 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, 2003c). 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 in below- and above-ground growth to atmospheric CO_2 levels (Kgope *et al.* 2010). C_4 grassland species' responses to elevated CO_2 show increased water-use efficiency, but no increase in growth (Wand *et al.* 2000, 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 (Wand *et al.* 2000, 2002; Motete *et al.* 2005; 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, no empirical field experiment exists in southern Africa to confirm or refute it.

4.4.3.3.2 Fire

Fire is a key determinant of vegetation structure and function in African ecosystems (Van Wilgen & Scholes 1997; Bond *et al.* 2005), 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.* 2003c, 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 *ca.* 3–4% to South Africa's mitigation potential through increasing the size and permanence of the terrestrial sink (ERC 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.* (2000), 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 in Fynbos has been shown to be a key driver of large fires, which are responsible for the vast majority of area burned annually in this biome (Southey 2009). 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 that may be a result of a regional change in climate (Southey 2009). A separate analysis has shown that, overall, fire intervals in Fynbos have shortened by about five years over the past 30 years on an original average of roughly 20 years (Wilson *et al.* 2009).

4.4.4 Adaptation

4.4.4.1 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, biome, 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 (NPAES) has made most use of the projections of climate change impacts on biodiversity (DEAT 2009). 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 maximising 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.

4.4.4.2 Adaptation options

Most focus on adaptation in the biodiversity sector has been on conservation strategies to minimise 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 recognised and explored (CBD 2009), but this is not considered here due to a lack of local information (as highlighted in the previous section).

Adaptation planning for biodiversity recognises 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) (see Table 4.4.1).

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 (Cropp & Gabrica 2002; Tompkins & Adger 2003). 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.

Table 4.4.1. 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 programmes 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.

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 *et al.* 2002; Hannah & Lovejoy 2003). 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 prioritising 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 utilisation. This argument is based on the observation that greater species diversity occurs outside larger protected areas (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 African 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 (summarised by Archibald *et al.* 2009). In general, it has been shown that fire suppression and control have 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. 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 colonisation 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 programmes 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 Global Environment Facility (GEF)-funded AIACC programme (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.

4.5 Coastal and marine environment

Depending on the extent to which human interference in the climate system progresses, profound consequences for marine and coastal ecosystems of South Africa may result from the associated changes in air and water temperature, precipitation and evaporation rates, sea level rise and increased storminess, winds, and even CO_2 concentration and ocean circulation changes (Roessig *et al.* 2004). Southern Africa experiences strong oceanic influences on its weather and climate patterns, and derives significant socio-economic benefits from marine and coastal resources, and thus the link between climate change and the marine and coastal environment is a critical one for projecting impacts on South Africa and its southern African neighbours. Very little detail on these sectors was provided in South Africa's INC, and while there is a significant scientific information base relating to ocean/climate interactions, and marine fisheries resources and regional climates, there is not yet a clear picture of the potential impacts of projected climate change for South Africa.

4.5.1 Observed trends

Trend information is available for several measures for South Africa, including sea surface temperatures, wind, oceanic upwelling, and sea level rise. Analysis of sea surface temperatures (SST) from satellite data *vs. in situ* measurement gives spatially distinct trends. Using optimally interpolated SST data, Rouault (2007) 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. This was accompanied by an increasing trend in southerly winds. High resolution SST records from 1982 onwards 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.
- A corresponding increase of approximately 1.0°C in the Agulhas retroflection area just south of the Agulhas bank.
- A decrease of 0.2–0.3°C near the coast along the west and south coast.

Rouault *et al.* (2009) confirmed that since the 1980s, Agulhas Current SST (from AVHRR satellite SST data) had increased significantly, by up to 0.7°C per decade. Their analysis produced similar results for the west and south coasts, but they also indicated that along the west coast near-shore SST are cooling between -0.2 to -0.5°C per decade, with isolated pockets of cooling in the region between Cape Agulhas and Cape St Francis (South Coast) of about -0.2°C per decade. A larger region of cooling ranging from -0.2 to -0.7°C was identified between East London and Port Elizabeth centred in the Port Alfred dynamic upwelling cell. In the sub-tropical bio-geographical province, a very thin strip of near-shore water as far south as Port St. Johns, has cooled at a rate of -0.6 to -0.8°C per decade.

Sea surface temperatures measured *in situ* off Port Elizabeth over a 25 year period on the south-east coast of South Africa, have been increasing by *ca.* 0.25°C per decade for the past four decades (Schumann *et al.* 1995). Similarly, despite considerable variation between years, there has been a significant increase 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) hypothesised that intensified long shore winds, due to warming land masses, would lead to more frequent and intense seasonal upwelling events. An increasing trend in upwelling intensity has been reported for the Benguela system over the last four decades (Shannon *et al.* 1991; Scavia *et al.* 2002). Recently, significant changes to southerly and westerly wind regimes have been reported in South Africa (Reason & Rouault 2005; Rouault *et al.* 2009), together with an intensification of the Atlantic and Indian high pressure systems (Rouault *et al.* 2009). Shifts in westerly wind patterns have been identified as indicative of global climate change (Trenberth *et al.* 2007).

Sea-level has risen over the past decades 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 east (+3.55 $mm.yr^{-1}$) 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 seem to be increasing (Theron *et al.* 2010), in alignment with projections (IPCC 2007). Precipitation and runoff into South African rivers are expected to change, with greater variability of flow expected and possible increases in the frequency of high flow events—especially along the east coast (See sections 4.1 and 4.2). Such changes would impact on the functioning of estuaries and the near-shore 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 would 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.

4.5.1.1 Biophysical implications of trends and projections

The physical trends observed above are likely to have direct impacts on the habitats, animals, and plants of the coastal and marine zones; and there is some early evidence to quantify this. A useful review of the current *status quo* of South Africa's marine and coastal resources is given by Griffiths *et al.* (2010), and a review of marine environmental monitoring programmes is given by Hutchings *et al.* (2009).

Hard and sandy shores

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 by rising sea level. Ancient primary dunes would experience slips along the steep seaward-facing slope (*e.g.* The Bluff at Durban). Mildly sloping sandy shores would be subject to the greatest landward migration of the shoreline due to sea level rise (Brown & McLachlan 2002). Small increases in sea level rise would result in significant regression of the high water mark (*e.g.* on the Cape flats). Sandy beaches would erode with rises in sea level, reducing their surface area, while increasing storm intensity would require more coastal defence systems. Changes in the sand budget would affect estuary mouth dynamics, resulting in changes in the open/closed mouth status of estuaries.

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 (Harris 2008; Mather *et al.* 2009). Early indications are that sea level rise in KwaZulu-Natal would result in the loss of backshore beach and upper intertidal areas due to '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).

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. This 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 SST in the cool-temperate region and adjacent transition zone, and shifts in circulatory and upwelling patterns. 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. For example, long term monitoring of the fishes in the warm-temperate East Kleinemonde Estuary near 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 (James *et al.* 2008). Mean annual SST 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).

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 a reef at St Lucia. Sea temperatures at the site were shown to have risen by 0.15°C per year up to 2000, but have subsequently decreased by 0.07°C per year. Bleaching in the region was not significant during the 1998 ENSO event, in contrast to coral reefs globally, but bleaching did occur during an extended period of warming in 2000 associated with increased radiation in exceptionally clear water (Celliers & Schleyer 2002). During 2005 a warm-water anomaly in the southern Indian Ocean caused coral bleaching to reach unprecedented levels in southern Africa (Ruiz Sebastian *et al.* 2009). Ongoing monitoring is essential to develop a better understanding of the trends in risk facing these high latitude coral reefs (*e.g.* McClanahan *et al.* 2005)

The greater Agulhas Current

The Agulhas Current has a marked influence on the local atmosphere (*e.g.* Lee-Thorp *et al.* 1998) that 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 SST 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 & Mulenga 1999; Reason 2001). 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 into the Atlantic 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 Oceans, the equator-ward shift in the sub-tropical convergence will close off the inter-ocean leakage south of Africa.

The Benguela system

One of the strongest offshore trends observed (*ca.* 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 (*ca.* 10-fold), caused by changes in productivity and upwelling-favourable winds. Pelagic fish stocks have declined, resulting in the collapse of sardine fisheries in the 1960s. This could be attributed to fishing pressure, warming trends, competition with the increased horse-mackerel stocks, or suppression by predators. By contrast, southern pelagic stocks have increased, accompanied by an eastward (perhaps cyclic) shift in sardine and anchovy. Horse-mackerel 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 penguins have declined considerably in the north.

4.5.2 Current vulnerabilities, projections, and future risks

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, University of Cape Town). Changes in ecosystem stressors (*e.g.* changes in air temperatures, sea surface temperatures, storm intensity, sea level rise, and upwelling) associated with climate change would 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 DWA's 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 simulate 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 molluscs (USEPA 2009). Estuarine acidification would 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'.

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 SST would 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 events that shape 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 would have a serious effect on beaches as insufficient time (between storms) would be available for recovery from a preceding storm event. In South Africa, the increased intensity and frequency of storms, coupled with sea level rise, would present a synergistic erosive force that could remove large quantities of sand off the beach face. This would 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 long shore drift of sediment and connectivity of populations that are connected by pelagic larvae. It is unlikely that temperature would 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, and a similar pattern would 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 would result in increased turbulence and sediment movement. The latter have a profound influence on coral distribution and survival (Schleyer 2000; Schleyer & Celliers 2003). 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). 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 pole ward 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 controls 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 would 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 thermo-haline circulation.

The Benguela system

The status of, and trends in, the major Benguela ecosystem components have been reviewed by Hutchings *et al.* (2009). 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 would be integrated ecosystem-level biogeochemical modelling that takes into consideration terrestrial, oceanic, and atmospheric forcing.

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, and stock levels and recruitment. These factors are likely to be influenced by climate change drivers such as changes in SST, currents, and wind regimes. 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 sub-tropical region off Angola and a cool temperate upwelling region in the south, separated by the powerful Luderitz upwelling cell at 26°S, 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, and the frequency and intensity of storms and wave heights to increase, 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 & Brundrit 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 the KwaZulu-Natal coast from Port Edward to Richards Bay (Smith *et al.* 2007; Mather 2008a, 2008b; Phelp *et al.* 2008).

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).

4.5.3 Adaptation

Biodiversity & fisheries

South African adaptation strategies to protect marine and coastal biodiversity from climate change would need to be centred on sound integrated ecosystem management practices. Key to this would be to ensure that existing non-climate stressors (such as habitat destruction, fisheries, and pollution) are managed as best possible as a reduction in their impact would 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. 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 inter-annual 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 10–100 (globally), and that adaptation would come at a minor cost compared to the damage done without adaptation. This strongly emphasises 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 would 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 & 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 programme utilising 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 (Bruun 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', '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 are essential components of ongoing shoreline management plans (Midgley *et al.* 2005).
- Design coastal protection/developments/structures specifically to compensate for effects of climate change.

4.6 Invasive alien species

4.6.1 Current vulnerabilities

South Africa includes a section focused on invasive alien species because of their significant current and projected impacts on ecosystems and on the biodiversity of the country, and because of likely interactions between the invasiveness of introduced species and projected climate change (Walther *et al.* 2009). These impacts often translate into a loss of ecosystem services and even direct economic damages and effects on human livelihoods (Van Wilgen *et al.* 2008). Few studies have examined the ways in which alien and invasive species would respond to climate change in South Africa (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 would 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 would 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 with jump dispersal and movement *via* corridors (Tolley *et al.* 2008; Wilson *et al.* 2009) 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 would 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 would appear in the well-populated eastern parts of the country (*i.e.* tropical species) compared with the western, sparsely populated, arid parts of the country (Rouget *et al.* 2004). This is not to say that western South Africa would be immune to a future increase in invasive species.

Climate change is likely to cause some alien species to become drivers in ecosystem conversion by enhancing their competitiveness, while others would become passengers, because climate would 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 would 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 would change the representation of C_3 and C_4 plants, which would drive crucial changes in fire regimes that could induce non-linear threshold effects (Richardson *et al.* 2000). Increases in CO_2 concentration are likely to have major effects on tree-grass dynamics in grasslands and savannas because of the different photosynthetic pathways and relative carbon requirements of the different growth forms (Bond *et al.* 2003). Subsequently these life forms would respond differentially to increased levels of CO_2. Generally, C_3 plants show increased photosynthetic efficiency with carbon fertilisation 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 (*e.g.* 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, would change as humans adapt to novel climatic conditions (Galil *et al.* 2007). Globalisation together with climate change would add new trade paths and alter existing ones, across the oceans as well as across land, which would 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[27]. This cargo is then dispersed across land routes, contributing to increases in road and rail traffic. Furthermore, with increased urbanisation, economic growth, and infrastructure development; human disturbance of natural ecosystems is expected to increase and

[27] www.transnetnationalportsauthority.net

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 would not be utilised any longer and new natural habitats in climatically more suitable areas would 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 indigenous birds and frogs, implying that people 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 well-known 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 would mean that most aliens are 'change passengers' because natural ecosystems would 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 would the direct effects of climate change.

4.6.2 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 (e.g. grasshoppers—Samways & Moore 1991; ground-living invertebrate assemblages—Samways *et al.* 1996; dung beetles—

Steenkamp & Chown 1996; spiders—Van der Merwe *et al.* 1996; and 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 stream-flow reduction (De Wit *et al.* 2001). Invasive plants currently reduce the grazing potential by *ca.* 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 (Van Wilgen *et al.* 2011) and a provincial programme in KwaZulu-Natal spend *ca*. US$80 million per year 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 year, 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 would 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] promote bush encroachment in grasslands and savannas (Bond & Midgley 2000). Not only indigenous woody species would 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.

4.6.3 Projections and future risks

4.6.3.1 Terrestrial

Changes in temperature and rainfall regimes together with changes in atmospheric composition are likely to restructure the composition of the indigenous and non-indigenous biota of South Africa (Richardson *et al.* 2000; Erasmus *et al.* 2002; Foden *et al.* 2007). Bio-geoclimatic 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). Woody plants, alien and indigenous, would benefit from CO_2 enrichment (Bond & Midgley 2000). The subsequent increased growth rates of woody species are 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 would 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 utilised 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; but see Piao *et al.* 2007), further exacerbating the effects of climate change.

With increased urbanisation 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 would significantly affect propagule pressure (Lockwood *et al.* 2005). In the absence of effective policy implementation, increasing demands for goods and services would therefore lead to increasing pressure from invasive alien species (Hulme *et al.* 2008). Furthermore, with increased urbanisation, economic growth, and infrastructure development, an increase of goods being imported and transported along land routes would 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 bio-control 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 would respond. Some bio-control 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 bio-control agents to climate change and their effectiveness in managing their hosts remain 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 utilised 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, emphasising the need for stringent risk assessment and for effective early detection and rapid response programmes.

4.6.3.2 Freshwater

Climate change would 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 would boost dam construction, and inter-basin transfers would consequently assist in the transfer of species between regions and increase the spread of indigenous as well as alien invaders (Kolar & Lodge 2000; Johnson *et al.* 2008). Changes in land use and the increased conversion of natural environments for agriculture would place increasing pressure on aquatic systems by increasing the runoff of agricultural effluent into rivers and dams, which would 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 dragon- and damselflies (Samways & Taylor 2004). However, increased evaporation and increased aridity in the western parts of the country would decrease annual runoff and river flow (Magadza 1994). Increases in the 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 would 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.

4.6.3.3 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, would all influence indigenous as well as non-indigenous biodiversity.

Changes in precipitation patterns across the country would 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 would significantly affect the marine and estuarine environments (Clark 2006). The greatest effect on South Africa's marine biota due to climate change would 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 would 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 sub-tropical 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 & Chícharo 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).

4.6.3.4 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 would 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 would sporadically result in eutrophication of coastal zones and freshwater systems through increased runoff, as seen elsewhere (Carlton 2000; Zhang *et al.* 2009). These areas would 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 areas invaded by *Prosopis* species in the Northern 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 have 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 (Zimmerman & 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 would negatively affect indigenous flora, favour alien invasions, and change the tree:grass balance in savannas.

4.6.3.5 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 that 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 would 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 would 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, would 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 that 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).

4.6.3.6 Indigenous species' range expansions and invasiveness

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 species have already spread through inter-basin transfers, and are 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 trans-located 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 trans-located 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, trans-frontier approaches, and managed relocation.

4.6.4 Adaptation

4.6.4.1 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), would 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.

4.6.4.2 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 minimise 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 form 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). Despite its size and national coverage, the Working for Water programme is not currently able to cope with infestations of all invasive plant species. In an estimate of progress in 2004, Marais *et al.* (2004) concluded that, for many species, 'the indications are that, even with the existing generous levels of funding, it is unlikely that the problem will be contained within the next half century, and clearly other solutions need to be found'. A later assessment (Van Wilgen *et al.* 2011), concluded that the area invaded by alien Australian *Acacia* species had doubled in the past fourteen years, 'despite substantial mechanical and biological control effort, with an estimated 300 000 ha cleared between 1999 and 2010, largely through the Working for Water programme'.

Capacity building initiatives include the government-supported Centre for Invasion Biology[28], a partnership between government and the tertiary education sector. Effective implementation of the legislation, sufficient capacity to undertake the

[28] http://academic.sun.ac.za/cib/

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.

4.7 Human health

4.7.1 Current vulnerabilities

4.7.1.1 Climate variability and human health

Climatic perturbations are injurious to humans either directly (*e.g.* 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 (Burke *et al.* 2009; Smith *et al.* 2009; Butler & Harley 2010). 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 water-borne 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 accounts 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 require concerted public health initiatives. Vulnerable sectors of society would be susceptible to adverse climatic changes, with implications for poverty, food insecurity, and demographic imbalances (Gommes *et al.* 2004). 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).

4.7.1.2 Key preconditions contributing to current vulnerabilities

Nutrition

Protein Energy Malnutrition (PEM) lowers immunity and predisposes people to infection. Evidence now clearly demonstrates that people with an infection have 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 (De Waal & Whitehead 2003), due to an inability to mount an immune response to the invading organism (Chatraw *et al.* 2008). Furthermore, infection would cause further deterioration of the existing nutritional status, ushering in a vicious cycle of progressive malnutrition, fading immune status, and super infections or even death. 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). Children are particularly prone to the effects of PEM, and infection in childhood requires higher supplementation with protein and calories (Keusch 2003).

These preconditions demonstrate the profound relationship between environment, food security, and the infection profile of a community and region. 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). In the context of the AIDS pandemic, under-nutrition would facilitate 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 *et al.* 2003). In some locations like South Africa, where food is not technically in short production, adequate nutrition is not accessible to populations most vulnerable to PEM, who may depend on rain-fed agricultural traditional systems for subsistence. Macro-economic factors associated with the diverse economic landscape are partly responsible for this dichotomy (De Waal *et al.* 2003; McMichael *et al.* 2008a; SADB 2008).

HIV/AIDS

HIV is now the largest health burden confronting South Africans. With national average prevalence rates of 10–15%, 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. This threatens to compromise economic, social, and developmental gains achieved in the last century (UNAIDS 2008; Harrison 2009). 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. AIDS has resulted in the deaths of at least 2.6 million South Africans, many of them young adults and children under the age of five (Harrison 2009; Avert 2010). Over 250 000 South Africans died of AIDS in 2008 (Statistics SA 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.* 2005). 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 six and ten million South Africans are infected with *Myobacterium tuberculosis*—a bacterium that causes TB. As a result of HIV and living conditions, TB is resurging in South Africa (Harrison 2009). Confined living conditions with indoor pollution in the setting of malnutrition and HIV facilitate the spread and new infections (Gommes *et al.* 2004; McMichael *et al.* 2008). 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; Andrews *et al.* 2007; DOH 2008)

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 socio-economic profile, are especially vulnerable (Bambrick *et al*. 2008). Most humans function comfortably at environmental temperatures between 17 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 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 four decades indicates that the number of hotter days and nights are increasing, especially in the interior, while cooler days and nights are decreasing (see section 4.1), suggesting that warming may result in increased casualties from heat stress.

Water and wind induced weather-related events

The health impacts of 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 in comparison with developed nations. Disaster occurs when a climate hazard converges with a vulnerable population, and severe structural damage and social disruption can ensue that 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 as a result of such catastrophic events (ERC 2007).

Water-borne diseases

Water-borne 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 adverse weather patterns and disaster situations that can have long-term socio-dynamic consequences (McMichael *et al.* 2008). Water-borne infectious diseases pose an acute problem in areas where populations are expanding and the water supply and sanitation infrastructure is poorly developed.

The most common water-borne infectious diseases in South Africa include cholera, dysentery, typhoid, and other rotavirus infections. Climate change would directly or indirectly affect factors that influence outbreaks of these water-borne 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 unseasonal extreme events such as floods or droughts (Patz 2002).

It is difficult, however, to establish a link between long-term climate change and environment-related diseases because of the lack of sufficiently long- and well-documented health data that are recorded at appropriate spatial and temporal scales. Strong confounding factors including human migration and travel patterns, erratic intervention strategies, emerging drug resistance, demographic changes in the human population, and development of immunity in the human population also contribute to the complexity of detecting and attributing climate-related drivers of such trends (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 (Cash *et al.* 2009), where almost three quarters of the variation in disease prevalence could be explained by the El Nino Southern Oscillation index for the period 1980–2001.

Exploitable water supplies in South Africa are confined to rivers, artificial impoundments, and groundwater. The total capacity of impoundments is greater than half of South Africa's total average annual river runoff (Oberholster *et al.* 2005; Wilson *et al.* 2005). Urban complexes and farmland runoff in South Africa generates large amounts of sewage and effluents that are high in salts, phosphates, and nitrates that stimulate the 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 bio-toxins 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 *et al.* 2004). A significant air-related health effect of pollution is in relation to the ozone, particulate matter, and brown haze content of the tropospheric or near-surface level (especially in urban areas), and all resulting from fossil fuels. Ozone at even at relatively low levels, when inhaled, has been associated with pulmonary damage and asthma attacks (Mittal *et al.* 2007). Ultra-fine particles demonstrate very high capacity to penetrate and deposit deep in human lungs and alveoli, potentially leading to enhanced biological toxicity (Brook *et al.* 2004). All these pollutants are dependent on, amongst others factors, meteorology and the relationship and dynamics of the planetary boundary layers. Therefore, changes in meteorology would lead to potential changes in the particulate matter concentrations. In particular, precipitation acts as the main sink for particulate matter (Jacob & Winner 2009). Stagnant air episodes occur primarily in winter when inversion conditions occur, trapping pollutants and increasing their concentrations. Climate change projections may possibly impact on the number and intensity of air pollution events (Midgley *et al.* 2005).

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 five years (WHO 2008; IPCC 2007; Keiker 2000). While models and some observations in key locations support a potential risk for malaria resurgence, observation and data suggest that this has not manifested in the last decade (Rogers *et al.* 2002; Thompson *et al.* 2005). 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 on prevailing factors, but not every year.
- Malaria free: conditions unsuitable for transmission at any time.

In perennially and seasonally endemic zones, residents have high levels of immunity within the community, while in the other zones, communal immunity is weak or absent. 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. 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 2009). 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 (Small *et al.* 2003; Thompson *et al.* 2006), but a concerted cross-border prevention programme has offset the trend.

Malaria-HIV interactions

Malaria and HIV have considerable geographic overlap in Africa (WHO 2004). People with HIV suffer increased frequency and severity of malaria attacks, and during such episodes, elevated HIV viral load levels increase the risk of sexual transmission of HIV (Froebel *et al.* 2004; Abu-Raddad 2006). 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.* 2001). Modelling has suggested that the four million people 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 two million excess cases of malaria per year. Recent significant declines in malaria cases in the Limpopo area due to adaptive measures may have mitigated this scenario (Abu-Raddad 2006).

4.7.2 Observed trends, projections, and future risk

HIV/AIDS

The HIV prevalence among people older than two has stabilised at about 11%, and is likely to remain stable for at least five years (Scott & Harrison 2009). 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 also likely peaked and should decline further with increasing availability of treatment. The decline in prevalence of HIV/AIDS in younger age groups is linked to better access to prevention of mother-to-child transmission, and much higher (self-reported) condom-use. Large populations in crowded, high density, and informal settlements with poor amenities, contribute to social interaction epidemics such as HIV and TB. Lack of organised infrastructure in these localities results in increased indoor and outdoor air-, water-, and environmental pollution, further aggravating those produced by motorisation and industry (Gommes *et al.* 2004; McMichael *et al.* 2008).

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.

Water-borne diseases

The first confirmed case of cholera in South Africa was in 1973 (Mugero & Hoque 2001), and the first major outbreak started in 1980, peaked in 1982/1983, 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 1990s until a devastating outbreak started in South Africa in 2000, during which nearly 146 000 cholera cases were reported between 2000 and 2005 (WHO Weekly Epidemiological Reports on cholera 2001, 2002, 2003, 2004, 2005, 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 putative cost of the outbreak in 2008/2009 in South Africa ranges between R40 million and R67 million (Kirigia *et al.* 2009).

South Africa is at risk of further cholera outbreaks due to its history of cholera outbreaks, its proximity to areas where the bacteria are known to be endemic, the movement of people between these areas and South Africa, the number of poor people dependent on natural water, and environmental conditions conducive to the survival and growth of the bacteria. These include 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, and 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 (Lucas *et al.* 2005; Soto 2009).

Air quality

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 would be within the 60 ppb contour (Anderson *et al.* 2001). In addition, wildfires that are common in South Africa (Carter *et al.* 2008), may cause increases in ground-level ozone (Liao *et al.* 2006) and particulate matter concentrations (Maenhaut *et al.* 1996).

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 (Keiker 2000). Predictions suggested an increase in the range of the malaria zone along South Africa's north-east borders, affecting the most vulnerable non-immune population. A projection of a four-fold increase in populations susceptible to malaria in South Africa, translating into a cost burden of R1 billion per year by 2010 if no adaptive strategies were adopted (Turpie *et al.* 2002), has not materialised, with the Department of Health citing increasing success in managing malaria incidence and achieving a 60% decrease in case load reports in 2008 compared to previous years (DOH 2007 Malaria day reports; Ledford 2010).

4.7.3 Adaptation

HIV/AIDS and tuberculosis

Efforts focused on the management of HIV and tuberculosis will clearly be important in reducing the vulnerability of those susceptible to future climate change-related impacts.

Water-borne 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. 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 cyanobacteria, new molecular assays, applied directly to environmental samples, provide a useful indicator that the analysed strains have the genetic potential to produce microcystin. Detection of toxic *Microcystis aeruginosa* strains through molecular markers for bio-toxins 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 al.* 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 (SAAQIS)[29] provides all information relevant to air quality and climate change initiatives and legislation. The National Framework on Air Quality Management (NFAQM) (2007) provides the medium- to long-term plan to improve air quality and thus meet the objectives of the Air Quality Act (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 NFAQM state that air quality measures should take cognisance of climate change, there is no directive or guidance on how this can be achieved (Mitchell & Johns 1997; Manahan 2004; Leiman *et al.*2007).

Malaria

The number of malaria cases in South Africa decreased by 65%, and deaths by 73%, between 2006 and 2007 (Statistics 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 *ca.* 125 000 km^2 inhabited by about four million people (Sharp *et al.* 2007). The LSDI was launched in October 1999 to control vectors by indoor residual spraying using DDT or pyrethroids; to control parasites 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 five-fold since the inception of the LSDI (Figure 4.7.1).

[29] www.saaqis.org.za

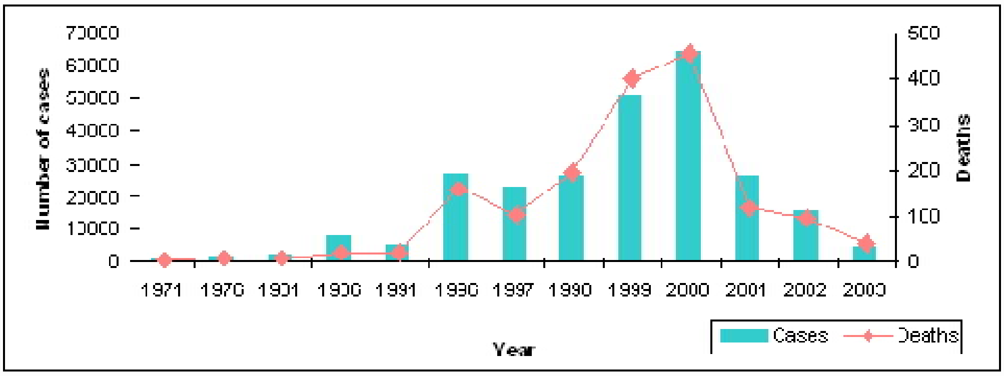


Figure 4.7.1—Annual malaria notifications, South Africa, 1971–2003.

These results show the significant health benefit of active control programmes in these endemic zones, which may have offset the earlier predictions attributable to environmental changes (Ledford 2010). The successful campaign against malaria described above is partly due to the continued use of DDT for indoor residual spraying.

Nutrition and health infrastructure

The interaction between malnutrition and infection requires focused attention on prevailing and potentially emerging infectious epidemics in areas subject to high levels of poverty (De Waal *et al.* 2003; Keusch 2003; Macallan 2010). Health care capacity in these areas is a key component of developmental growth and stability, and central to all adaptation strategies. Addressing poor infrastructure and inadequate human resources would be beneficial for both rural and urban welfare goals under future climate change scenarios.

4.8 Human livelihoods and social aspects

4.8.1 Current vulnerabilities

Effective adaptation[30] to climate change and climate variability requires an understanding of vulnerability of human livelihoods, and especially those factors that

[30] Adaptation refers to initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected *climate change* effects. Various types of adaptation exist, *e.g. anticipatory* and *reactive*, *private* and *public*, and *autonomous* and *planned* (IPCC 2007: 76).

contribute to susceptibility to climate change, including exposure to the hazard (*e.g.* storm), and the coping capacity that a unit or system possesses (*e.g.* coastal zone, farming community). The current vulnerability of urban and rural settlements and livelihoods to climate change is shaped by various complex current arrangements (such as the interaction of legislation, urban planning guidelines, resource allocation *etc.*) that configure the context of various risk environments in which vulnerable sectors and societies are located. Many of these arrangements can exacerbate or amplify the impacts of severe climate events, especially in informal urban and rural settings. Current climate stresses already expose a number of these vulnerabilities. As shown below, once these interacting stresses are understood, effective risk reduction to both current climate stress and slower, but equally important, 'creeping' climate changes (*e.g.* possible sea level rise, longer term temperature increases *etc.*) is possible.

In the Initial National Communication (DEAT 2004a), social vulnerability and adaptation to climate change and climate variability were not strongly profiled. Urban and rural livelihoods were subsequently addressed as a concern at a national level in the LTMS (ERC 2007), which identified that a 'nested approach' in adaptation, that attempts to link activities in policy, planning standards, and regulations (*e.g.* Integrated Development Plans (IDPs); Disaster Risk Reduction, Republic of South Africa 2003, 2005; National Environmental Management Act (NEMA); and the constitutional mandate) may be emerging nationally. However, the focus of adaptation efforts has been primarily on limited adjustment activities that are reactive, rather than larger-scale planned or anticipatory adaptation activities (see Burton *et al.* 1993) for discussion on adaptation *versus* reactive adjustments). There is currently a paucity of quantitative, modelled information available on the projection of future risks for urban and rural settlements. There are, for example, currently few integrating reviews available for South Africa that allow coherent and comprehensive assessment of current vulnerabilities to climate variability and climate change in rural and urban settlement settings, and a significant effort will be required to draw together the wide variety of information types to achieve such an integrated view. At this time, we point to selected sources that illustrate some key points.

4.8.1.1 Human settlements

The understanding of vulnerabilities and impacts of current climate stresses on rural and urban settlements in South Africa is improving (Nhemachena & Hassan 2007; Bryan *et al.* 2007; Archer *et al.* 2008; Ziervogel & Taylor 2008; Gbetibuou 2009; Vogel 2009). There is clear evidence that climate related stresses, if not addressed, can have severe adverse impacts on livelihoods and inhibit development (*e.g.* DiMP 2007).

Box 4.8.1 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 prioritising intervention, has been outlined (Mukheibir & Ziervogel 2007). 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 Enviromentek 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 (Phalatse & Mbara 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 characterised 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 (Phalatse & Mbara 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.

Urban settlements

Several larger municipalities have begun to address climate change as an integrated development planning issue, with adaptation plans already developed in some. In many cases, current activities in urban settings are motivated by mitigation concerns that do not take advantage of the clear links to the ancillary adaptation benefits (*e.g.* installation of ceilings in low-cost housing). A more concerted effort to identify such co-benefits would be beneficial. Critical links are, nonetheless, being made between climate risks, and climate change adaptation and planning (*e.g.* Roberts 2008). Efforts to better climate-proof cities (*e.g.* coastal cities) are being undertaken assisted by advances in research on storm surges and other developments in marine science (see section on marine sciences). A number of climate change adaptation plans and strategies are in the process of being developed. In some of the larger municipalities, several adaptation plans have been prepared (see Box 4.8.1).

The convergence of intensifying weather events with the trend of rapidly expanding and densifying informal settlements have generated specific new challenges for development planning, disaster risk management, and climate change adaptation constituencies. The links between climate variability, change, and disaster risk reduction, notably flood and fire risks, have been increasingly researched (*e.g.* DiMP at UCT—www.riskreductionafrica.org). Field research undertaken in numerous informal settlements (Benjamin 2008; Holloway & Roomaney 2008), including during actual severe storm events, has underlined the emergence of 'new' flood risk configurations that are not easily studied with conventional flood hydrology methods. Many vulnerabilities arise from the location in flood-prone areas (*e.g.* coastal and marine flooding; riverine and estuarine flooding; and ponding (Holloway & Roomaney 2008)). Poor drainage, settlements located in wetlands and ponding areas, poor building materials used for housing, and structures built on sand dunes close to the coastal areas, can all exacerbate risks to weather and climate, particularly severe weather.

Benjamin (2008), for example, identified six distinct forms of localised flood exposure in Thembelethu informal settlement in George associated with damaging cut-off low events. These included ponding, overland surface runoff, upwelling (seepage or 'rising flood'), riverine/stream flooding, wetland flooding, overtopping of storm-water channels, and rain leakage into houses. Furthermore, specific purposive ('adaptive') and reactive ('coping') adjustments made by residents of informal and low-cost RDP houses exposed to these specific flood hazards, along with their respective effectiveness and costs (Benjamin 2008), were investigated.

Concerted efforts are also underway to better understand several other dimensions of climate risk management in city environments, including energy and urban food security challenges (Ziervogel *et al.* 2010) and the role that the business sector can play in enhanced adaptation efforts. Some limited evidence of the business community engaging in adaptation is noted (*e.g.* Vogel 2009). Many of these adaptation efforts are still in early phases and are not actively linked to activities in planning of effective water, food, and energy provisioning in a changing climate-risk environment.

Rural settlements

Our understanding of the links between climate and rural livelihoods since the INC has grown particularly in understanding the connection between various hazards (*e.g.* drought) and socio-economic contributing factors (*e.g.* access to markets, infrastructure), and access to climate information. Vulnerabilities to climate risks, in the context of a range of other stresses, are shown to impact the rural poor sector hardest—especially those who depend heavily on the environment for their livelihood (*e.g.* Ziervogel *et al.* 2003, 2006, 2010a). An overall vulnerability index of agriculture to climate change compiled for the country (Schulze 2010) shows, for example, that vulnerability to climate change is highest in the Eastern Cape, KwaZulu-Natal, and Limpopo provinces. The exposure to climate stress together with underlying contributing factors that enhance vulnerability (*e.g.* many small holder producers; high dependency on rain-fed agriculture; high levels of land degradation; and high rural population densities), all combine to create high vulnerabilities to climate change (see sections 4.2, 4.3, 4.5, 4.6 and 4.7).

A range of adaption or adjustment options is currently being piloted, including the use of climate information. Seasonal climate forecasts of how much rain can be expected over the season can be useful in enabling farmers to respond, adjust, and adapt to climate variability in various time frames. Much research has been undertaken in this area of adaptation, supporting the work and activities of the South African Weather Service (SAWS) (Vogel 2000; Archer 2003; Klopper *et al.* 2005; Vogel & O'Brien 2006; Ziervogel *et al.* 2006; Vogel *et al.* 2010). Seasonal climate forecasts, for example, have been tried to assist in managing the impacts of climate variability on agriculture and water resources (Stuart-Hill & Schulze 2010). Better understanding of the use of seasonal climate forecast information in the water sector, including the challenges to such usage, has prompted several research projects funded by the Water Research Commission (WRC), to explore processes and products that might facilitate increased uptake of seasonal climate forecasts among water resource managers (*e.g.* Reid *et al.* 2005; Schulze 2007, 2008; Ziervogel *et al.* 2009). More, however, needs to be done in this field of research.

Assessing dynamic vulnerability is also crucial in ensuring enhanced adaptation. As indicated above, poor and vulnerable communities are likely to be some of the most seriously affected by climate changes (Reid *et al.* 2005)—largely because they do not have access to large financial resources, livelihoods are precarious, and in many cases are constrained by limited safety nets and insurance options. A careful assessment of local vulnerabilities and how these can inform adjustment and adaptation options are therefore required. Such assessments are already being prompted through the Disaster Management Act and can also be supported through the South African Risk and Vulnerability Atlas (SARVA).

Some adaptation options are being undertaken, including providing better climate information services in many rural and peri-urban areas, and through integrated water management activities. There are few examples however, of actual planned or purposive adaptation activities for the longer term (*e.g.* technological changes coupled to, for example, improved irrigation systems). Most adaptations that are being observed (these may well be adjustments rather than adaptations) include diversification of activities, planting different crops, mulching, and other farm management activities. There may be some potential in considering the possible synergies and co-benefits that could be derived from existing activities not necessarily designed for climate adaptation, but with added benefits *e.g.* land care activities[31], Working for Water, and various conservation actions (*e.g.* eco-corridors—enhancing adaptation in biodiversity 'hotspots').

4.8.2 Adaptation

In some settlement- and municipality planning arenas, climate change adaptation is being considered. Relatively few detailed climate change plans and implementation strategies exist, however, particularly those that show synergistic efforts between existing planning efforts and climate change adaptation activities.

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).

While some activity is underway for adaptation in larger-sized municipalities; much of this remains focused on a mitigation-led approach. More effort and research are thus required in this arena, including advocacy on improved climate risk management at all decision-making levels.

---

[31] *e.g.* www.landcareinternational.net and www.nda.agric.za.

The development of the SARVA (data platform: www.dst.gov.za), may generate useful data and tools for municipalities and rural settlements to become more active in adaptation planning.

4.8.2.1 Enabling factors for adaptive capacity

Enabling factors that shape adaptive capacity comprise the 'whole of the capabilities, resources, and institutions of a country or region to implement effective adaptation measures' (IPCC 2007: 76). Adaptive capacity is dynamic and is usually influenced by a society's productive base (natural and human-made assets), including social networks and entitlements, human capital and institutions, and governance and national income (IPCC 2007: 56). These factors, moreover, can either enhance or severely constrain adaptation to climate change.

Since the INC, the science of the social dimensions of adaptation has been enriched and has become much more nuanced by focusing on such themes. The following section is thus a significant new addition to the state of climate change activity in South Africa. Selected examples are provided of the role that each of these determining factors (*e.g.* the role of institutions and governance, technology, and social networks) is playing in shaping emerging adaptive capacity in disaster risk reduction and early warning.

4.8.2.2 Institutions and governance

Institutional relations play a major role in enhancing overall governance and adaptive capacity. Two levels or types of institutions are elaborated on below, namely formal, 'state' driven institutions, and more informal, or 'community-linked' institutions.

Climate change is a multi-dimensional issue and will require adaptation inputs from both the state and non-state actors, and would benefit from integration across various government departments and between actors at various levels of governance. An assessment of some of the wider institutional challenges facing adaptation to climate change at the local (Reid & Vogel 2006; Stuart-Hill & Schulze 2010; Ziervogel *et al.* 2010), national, and wider scales (*e.g.* Vogel *et al.* 2010) shows that some departments are, for example, focused on mitigation and on climate change activities undertaken independently. Inadequate integration between departments and various stakeholders may frustrate adaptation efforts. A recent assessment of the history of drought risk management and the role of policy and institutions for the past two hundred years for South Africa and the wider region (Vogel *et al.* 2010), also shows a lack of integration across actors involved in droughts in the region—particularly for undertaking effective risk reduction to drought. Multiple policies and other requirements (*e.g.* disaster risk reduction and various disaster management plans; integrated water resource management; Integrated Development Planning (IDP); and inputs and outcomes for the new National Planning Commission), may overload formal administrative capacity and compromise active policy implementation. Finding ways to 'mainstream' climate change and such activities may result in some reduction of such burdens.

One of the persistent challenges emerging from much of the adaptation work to date is therefore assigning practical responsibilities and mandates for mobilising and shaping adaptation efforts. In the study of adaptation activities in Ethekwini, for example, it was initially noted that 'little internal institutionalisation momentum and knowledge' is being built around climate change (Roberts 2008). Subsequently, efforts made to purposively build a meaningful appreciation of climate change science, have 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).

Research in the Cape Town water sector also suggests that there are a small number of champions highlighting the need to integrate climate change concerns (Ziervogel & Erikson 2010). Although it is evident that adaptation to climate change is urgently needed, this needs to be sensitively integrated, where appropriate, with immediate development and planning challenges such as improved service delivery and increased security of water supply. This approach will help to ensure that climate change responses are not seen as competition for immediate development priorities, but as part of the development solution at the national and local level (Vogel *et al.* 2007; Ziervogel *et al.* 2009; Ziervogel *et al.* 2010a, 2010b).

These observations and perceptions of actors within the institutional system can usefully also be seen in the context of wider management, governance, and decision making arenas, including wider policy and regime changes (Vogel *et al.* 2007; Vogel *et al.* 2010). In the water sector, for example, a number of diverse challenges frustrate local management and have the potential to also frustrate future climate change adaptation efforts.

Synergies could be achieved by linking planning efforts in sectors (*e.g.* water sector) in urban areas with climate risk reduction. Integrated Water Resource Management (IWRM), for example, promotes a strategic water allocation policy that aims at efficient investments across collaborating sectors and at gaining benefits from water resources (TEC GWP 2004a). Therefore, IWRM is an iterative and hence responsive system that cannot be prescribed, but, to a certain extent, is a process of trial and error (TEC GWP 2004b). Linkages and synergies with such approaches, and through various adaptive management approaches, may enhance local adaptation to climate change.

Research in the water sector shows that climate change adaptation planning requires dynamic organisations that are well-informed and offer leadership that can create effective strategies when adjusting to changing circumstances (Pahl-Wostl 2007, 2008; Stuart-Hill & Schulze 2010). Successful uptake of new information must usually be internally coherent (across sectors and between government levels), as well as externally coherent (stakeholders using and impacting water directly and indirectly) (*e.g.* Vogel *et al.* 2010; Ziervogel 2010a, 2010b). These processes will only be efficient when awareness has been created within all affected groups. In summary, integrating climate information calls for essential mechanisms such as dialogue and effective co-ordination (TEC GWP 2004a, 2004b).

4.8.2.3 Early warning systems

Linked to the institutional dimension of adaptation to climate change, is also the critical role of effective integration across existing activities (*e.g.* climate change and Disaster Risk Reduction (DRR)). Climate change and DRR activities could be better aligned through early warning systems and planning (*e.g.* Klopper *et al.* 2005; Vogel & O'Brien 2006, see also several Disaster Mitigation for Sustainable Livelihoods Programme (DiMP) outputs *e.g.* DiMP 2003, 2007, 2010). As part of the requirements of the Disaster Management Act (Act No. 57 of 2002), for example, the SAWS has completed their Disaster Risk Management Plan (SA Weather Service 2006). The institutional structure of one form of early warning system (EWS), weather and climate related EWSs, has already been planned and includes a network of forecasting offices. The process of implementing a fully-fledged Severe Weather Warning System (SWWS, see Poolman *et al.* 2008) is also underway.

4.8.2.4 Current vulnerabilities and adaptation responses

Notwithstanding the existence of the Disaster Management Act and some attempts to begin to put in place an EWS architecture, evidence from various parts of the country shows that implementation and uptake of early warning information can be slow. In the Western Cape, South Africa, for example, during severe flooding triggered by cut-off low systems, warning of the heavy rainfall periods did not reach communities timeously. Assessments of repeated flooding events in the Western Cape such as occurred in 2006, showed that despite the establishment of 'Flood Committees' and SMS cellular phone text warning messages, potential users of such information were 'desensitised' to SMS warnings. Messages were received too often and did not match weather subsequently experienced. In several cases, despite the implementation of the SMS system, several residential, urbanised communities also either did not receive the message at all, or did not receive the message in time. When messages were received from the Weather Service to the municipality for wider distribution, these were not rapidly disseminated because municipality staff did not know procedures to follow. Many private sector enterprises were also not informed of the warning. Several residential settlements in the wider area reported not receiving any messages. Such a lack of effective preparedness in 'taking up' the 'available' climate information could severely retard evacuation, relief, and effective response activities (for more details see DiMP Report, October 2007 and other related reports[32]).

4.8.2.5 Future vulnerability and adaptation requirements

A variety of data and process development efforts to improve early warning systems are underway (*e.g.* SARVA and the SAWS Severe Weather System (see box 4.8.2)):

- The National Forecasting Centre (NFC) based in Pretoria, which is responsible for guidance on potential hazardous weather of a general and maritime nature (7 days in advance). The NFC also interacts closely with the National Disaster Management Centre (NDMC), Pretoria; and the flood forecasting room of formerly DWAF now DWEA.
- The Aviation Weather Centre (AWC) that operates on a 24-hour basis.
- Regional forecasting offices that liaise directly with Provincial and Municipal Disaster Management Centres.
- The Innovation and Research Divisions, which provides research and enhancement of early warning systems.

---

[32] www.riskreductionafrica.org

Box 4.8.2 Capacity to adapt, forecast, and respond to changing circumstances: examples of progress

Various existing planning frameworks and legislation can be used to enhance adaptation to climate change without creating new and additional activities. Some examples are provided here.

Since the promulgation of the Disaster Management Act (Act No. 57 of 2002), several disaster management plans have been completed. These are reflected especially in the finalisation and implementation of the National Disaster Management Framework (Republic of South Africa 2005; Department of Local and Provincial Government 2006) and priority guidelines, both of which placed explicit emphasis on developmental risk reduction.

By 2008, five fully functional provincial disaster management centres had been established in the Eastern and Western Cape, Free State, Gauteng, and Limpopo provinces (DPLG 2008: 21).

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

A National Weather 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-hour basis, and regional forecasting offices liaise directly with Provincial and Municipal Disaster Management Centres' Innovation and Research Divisions, 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 SAWS Severe Weather System covers potentially damaging weather events (*e.g.* heavy rain, cold weather, and heat waves) that are experienced regularly in the country, and can result in severe impacts if not well managed. Three categories of warning or advice from SAWS are being offered in various formats: an advisory providing early warning of hazardous weather in a >3 days period; an advisory and watch for weather likely to deteriorate to hazardous levels during a 2–3 days period; and finally a 'take action' warning that a hazardous event linked to weather changes are likely to occur within the following 24 hours. Various products, using such early warnings, are being designed; including web-based maps of warning and easily accessible information (*e.g.* colour coded warnings)—see for example Poolman *et al.* (2008). Such systems are key elements of an overarching climate change adaptation system.

4.8.2.6 Adaptation and disaster risk reduction

Much can be gained from the national and international disaster risk reduction community in how best to ensure community resilience to periods of climate stress and change. In South Africa, since the INC, significant national and sub-national efforts have been directed to the implementation of the Disaster Management Act (Act No. 57 of 2002). These have been measurably reflected in the finalisation and implementing of the National Disaster Management Framework (Republic of South Africa 2005; Department of Local and Provincial Government 2006) and priority guidelines, both of which placed explicit emphasis on developmental risk reduction. They are also evidenced by the incremental establishment of the institutional architecture necessary for implementation of the Act across all spheres of government. By 2008, this institutional progress was specifically reflected in the establishment of fully functional provincial disaster management centres in five provinces—the Eastern and Western Cape, Free State, Gauteng, and Limpopo provinces (DPLG 2008: 21). In addition to the above, further information is provided in box 4.8.3.

4.8.2.7 Current vulnerabilities and adaptation responses

Since the promulgation of the Disaster Management Act (Act No. 57 of 2002), several disaster management plans (as per the Act) have been completed (*e.g.* for agriculture (Van Zyl 2008)). An Agricultural Drought Management Plan that may have key implications for the agriculture sector has, for example, been drafted and refers and draws attention to various risk reduction activities.

The interface between current disaster management efforts and measures to promote climate risk management and climate change adaptation has also been clearly underlined since promulgation of the Act. This is illustrated by the severe weather events that have occurred nationwide, and particularly so in the Western Cape, where detailed *ex post* studies of seven weather events, their direct economic losses, and underlying vulnerability drivers have been undertaken from 2003 to 2007 (DiMP 2010, and see Box 4.8.3).

These studies focused primarily on cut-off low weather systems (DiMP 2003, 2005, 2007), and have provided valuable insights on sectoral and social sensitivity to climate variability at local and district scales. They have also identified and documented critical developmental and institutional risk factors that both increase and diminish susceptibility to loss. These studies, while very useful, should not be over-interpreted as giving cost estimations for adaptation. Attributing weather, climate, and climate change to such loss estimations is extremely problematic and serious attention is needed for such estimations, including adaptation cost assessments.

Box 4.8.3 Preliminary cost estimates of extreme weather-related events between 2000 and 2009

Extreme weather-related events and associated disasters may impose significant costs to South Africa. The impacts range from infrastructure damage and death (primary effects) to logistical inefficiencies, health issues, and even trauma and loss of livelihoods (secondary and tertiary affects). A reliable assessment of the national extent of these impacts and their trends is not currently possible due to a lack of robust data, but a conservative indication can be obtained from the few cases where direct costs have been assessed. This brief account is based on such reports between 2000 and 2009, and costs are expressed in 2008 Rand-values. Four major categories of weather-related events have been identified:

- Floods, associated with high and often concentrated rainfall events, have caused damage estimated at R4 700 million, and 140 deaths have resulted.
- Wildfires (termed veldfires in South Africa, and known as bushfires or wild-land fires elsewhere) are a natural phenomenon in many of South Africa's ecosystems, but they cause damage and death in areas of human settlements, and are particularly damaging to the plantation forest industry. Wildfires caused damage estimated at R1 750 million, and 34 deaths have resulted.
- Storms are associated with heavy precipitation, high winds, and flash floods, and often with coastal and landslide damage. Each component has the ability to cause extensive damage. Difficult to dissociate from floods, storms are most often considered sudden events that can come in a number of forms, most commonly associated with severe thunderstorms and cold fronts. Storms have cost South Africa R395 million, and have resulted in six reported deaths.
- Droughts are defined in South Africa as a season's rainfall of 70% less than normal (Bruwer 1990), and are considered progressive or 'slow onset' disasters. They are a temporary feature, and are typically more widespread than localised. Droughts caused damage estimated at R1 150 million between 2000 and 2009.

The total costs of weather-related disasters were therefore in the region of R8 billion. The above estimates represent direct costs, but the indirect, or knock-on, effects of climate-related disasters can be substantial. 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, a conservative estimate for total cost for the period 2000–2009 would be around R9.2 billion (in 2008 values). This would equate to R920 million per annum, which equates to 0.04% of current GDP or R21 *per capita*.

The severity of weather impacts has been shown in the Western Cape cases to be significantly compounded by pervasive social vulnerability, inadequate planning, constrained integrated and spatial development, and poor climate risk management. Direct losses of R3.2 billion from 2003 to 2008 (financial losses 'unadjusted' for inflation), are linked to failed or poor development planning in urban contexts. In the case of George, for instance, one of the Western Cape's largest secondary towns, the extent of urban development and its surrounds has nearly trebled over the 47 year period between 1957 and 2004; with the bulk of this expansion having occurred since 1985. While the overall urban area of George doubled between 1957 and 1985, from 7.39 km^2 to 15 km^2, it expanded by 600% between 1985 and 2004, reaching 90 km^2 by 2004. This represents an average annual increase of 3.9 km^2 between 1985 and 2004—fifteen times higher than the 0.3 km^2 urban growth rate for each year during the previous period (DiMP 2007). Such rapid growth has resulted in a measurable increase in hard surfaces, and with it the risk of severe rainwater runoff that now exceeds both technical and infrastructural management capacity of existing services. This recurrent finding from most *ex post* studies in the Western Cape underlines limited capacity within provincial and local government to match growth with strategic investments in the redesign and maintenance of critical infrastructure, as evidenced by repeated losses to roads and storm-water systems, as well as sewage treatment and water supply plants (DiMP 2007).

Valuable insights on managing current and future climate variability for economically at-risk households have also been drawn from these studies. For instance, the August 2006 southern Cape cut-off low (324 mm rainfall) not only destroyed dwellings, but also damaged personal possessions, identification documents, and other valuables. Flooding reduced attendance at school and workplaces. People lost between two and three days' work, and anything between one third and one half of their usual income. Those running small enterprises, or storing goods at home, also lost sources of livelihood (DiMP 2007). Small-scale farmers in one settlement alone lost livestock to the value of R39 500 (US$5 000). Local clinics also recorded higher than average numbers of children presenting with diarrhoea, which is often associated with contaminated water. This highlights not only the health implications of the flooding, but also how the existing 'everyday' hazards born of poor service delivery, such as poor sanitation and water supply, can compound the effects of larger, less frequent events (DiMP 2007).

As in the case of drought shocks, there is frequently a gendered component to severe weather risk and vulnerability. Recent research indicates that households headed by women are often worst affected. Interviews and field observations suggest that older women over the age of 50, particularly those with young children or grandchildren, were 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 the HIV/AIDS pandemic, suggesting that gender and age will become in increasing important factors in assessing and responding to risk in South Africa.

DiMP's research shows that the costs of flooding often exceed households' average monthly income and thus that it would take some time for households to save enough money to cover the extra expenses. While those living in informal dwellings reported an average income of approximately R1 000, for instance, their average monthly reported expenditure amounted to almost R900 (US$ 118), leaving little for replacing or repairing damaged property (DiMP 2007). This is exacerbated by repeated losses experienced by the same households associated with 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 over time.

4.8.2.8 Future vulnerability scenarios and adaptation requirements

Numerous insights on adaptation to increasing climate variability, as shown above, can be usefully derived from the disaster risk domain, especially in areas and settlements historically documented as disaster-prone. Detailed *ex post* studies of severe storms and associated flood events provide valuable insight on critical risk factors that generate loss and their associated causal pathways. Similarly, as illustrated by the 'purposive adjustments' referred to above, they can also highlight useful potential adaptive strategies, including infrastructural and technological adaptation, which are centrally relevant to the management of climate variability and broader climate risks.

4.8.2.9 Limits and barriers to adaptation

Limits to adaptation are usually analysed as a set of immutable thresholds either in biological, economic, or technological contexts (Adger *et al.* 2009). More recently, such approaches have been extended to include some of the social limits to adaptation. Adger *et al.* (2009), for example, show that individual and various other social factors (*e.g.* individual behaviour, underlying values, and perceptions of climate change and ability to respond) are also essential to understand at various levels (both local and amongst decision makers) if adaptation is to occur and be a sustained effort. They argue further that bottom-up efforts, if appropriately designed, can harness individual capacities and social capital that could assist in wider adaptation efforts. Few efforts to engage various other forms of 'social groups' are, however, being made (*e.g.* faith-based groups) in climate change adaptation work. This arena offers an important set of social networks and influence that could be very critical for climate change adaptation particularly in community contexts as well as in understanding the values and assumptions used to craft interventions that ultimately shape adaptive behaviour.

A relatively under-researched area in South Africa is the role of issues such as social networks, education, and adaptation with reference to climate change. The use and relevance of social networks for heightened capacity to face climate stresses are of great potential value. Social networks are critical if adaptation in urban and rural contexts is to be facilitated. Some examples of social networks (*e.g.* among farmers, water practitioners, the business community, and community-based adaptation specifically with reference to disaster risk reduction) have been provided above. Few efforts to co-ordinate such efforts *via* social platforms for the engagement of wider civic society are, however, operating. Forums for the inclusion of wider civic society, specifically on adaptation, are being established with very useful case studies emerging (see, for example, ICLEI (International Council for Local Environmental Initiatives, also known as Local Governments for Sustainability) work; Working for Water; Indigo Development and Change; Mvula Trust; and the South African Adaptation network). For details on education gaps and requirements, see the section on training in this report.

The inclusion of various forms of knowledge systems also requires more attention. Indigenous knowledge, for example, is essential in early warning systems. Traditional structures have knowledge and various sources of information as well as various indicators that have been used for many years to respond to changes in climate and weather. Local knowledge indicators could be incorporated in the design and composition of current scientific early warning systems. 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). Detailed research on this key element has been sporadic and not well co-ordinated.

Several local assessments endorse some of the concerns raised above, both in rural and urban settings (*e.g.* Archer 2003; Nhemachena & Hassan 2007; Ziervogel & Taylor 2008; Gbetibuou 2009; Vogel 2009). Repeatedly these cases show that barriers to adaptation include the following:

- Lack of information in all sectors, including interactions and feedbacks of possible activities (awareness of climate change is, for example, shown to be an important determinant of farm-level adaptation, here agricultural extension could play a major role).

- Linked to the issue of information is also better and more informed interventions that explain in accessible ways what we mean by climate change, impacts, and vulnerabilities (*e.g.* for various sectors including the private sector and government).
- Lack of credit/money (highly ranked by many respondents in a number of assessments).
- Limited access to free and reliable extension services.
- Insecure property rights.
- Lack of market access.

An additional major limitation in adaptation to climate change is also finding effective ways to cost adaptation, particularly for the future (*e.g.* planned and/or purposive adaptation). Some preliminary estimates of current disaster losses have been undertaken (see box 4.8.3 above). These, together with various other planning scenarios and cost estimations (*e.g.* a longer term adaptation plan or scenarios as undertaken for mitigation), would be a useful exercise to advance this area in South Africa.

4.8.2.10 Opportunities for effective risk reduction

Climate change and climate variability present a range of challenges to our present decision making processes (*i.e.* largely top-down, sector specific); to our information content (*i.e.* statistics, climate projections); and to our knowledge bases for action (heavy reliance on scientific knowledge). Climate stresses are now also increasingly added as an additional stressor to the number of challenges facing the country. Climate change adaptation could focus productively on resource management (*e.g.* water resources (Muller 2007)). Increasing adaptive capacity, particularly in areas with constrained resources and capacity, will require innovative ways of linking adaptation to climate change to sustainable development (Adger 2001).

Various existing planning and other useful frameworks and legislation can be used to enhance adaptation to climate change without creating new and additional silos of activity. Integrated Environmental Management (IEM) and Environmental Management Frameworks (EMF); the National Environmental Management Act (NEMA, Act no. 107 of 1998); Corporate Social Responsibility (CSR); IWRM; and DRR can all provide existing frameworks within which a range of choices for adaptation can be evaluated (Schulze 2008; Vogel *et al.* 2010; RADAR 2010).

IWRM, for example, promotes a strategic water allocation policy that aims at efficient investments across collaborating sectors and gaining benefits from water resources (TEC GWP 2004a). Therefore, IWRM is an iterative and hence responsive system that cannot be prescribed, but to a certain extent is a process of trial and error (TEC GWP, 2004b). Linkages and synergies with such approaches, and various adaptive management approaches, may enhance local adaptation to climate change.

4.8.3 Conclusions

A great deal of progress has been made since the INC in better understanding the 'human dimensions' of adaptation to climate stresses in both the shorter and longer term; and especially about social drivers that shape vulnerability to change and possible adjustments and adaptations required. In the water, agricultural, and urban planning sectors, there are increasing evidence of consideration and planning around climate change adjustment and adaptation. Likewise, major progress has been made in making early warning information more accessible to a variety of users and decision-makers both at the national and very local levels. Much progress is also being made to understand how risks to climate and other factors are configured at a number of scales (*e.g.* among local, urban residents, particularly those in poorer communities). Evidence from such work may be useful to consider when planning for future adaptation. Progress is also emerging in expanding the climate change discourse into the social arena, with examples of efforts to understand the intersection of policy, governance, and planning; and emerging evidence of efforts to include issues such as values, local knowledge systems, and cultural dimensions.

Notwithstanding the progress being made, we still require more knowledge and understanding about existing and future vulnerabilities, and adjustments and adaptation in some sectors *e.g.* various business sectors. Much of the work profiled here has been in the water, agricultural, and settlement areas. We also understand little about how adaptation planning can impact on labour and the trade union sectors, including benefits for labour and in the employment sectors. Considerable efforts have also been made to understand how climate change can weaken livelihoods, but relatively little attention has been given to the role of technologies (small and large, soft and hard) in bolstering emerging sectors: To what extent may these technologies become mal-adaptations? How can these technologies become useful and where are the synergies and the tradeoffs between adaptation and mitigation using various technologies?

The potential role of social capital and networks of various types has been repeatedly highlighted, but few studies have interrogated these dimensions and measures to prompt change. Efforts to communicate adaptation both for the shorter term and the longer term, and the governance implications for such actions, would be beneficial, but there is some uncertainty as to where this responsibility lies.

5 Measures to mitigate climate change

5.1 Introduction

Given that 79% of South Africa's greenhouse gas (GHG) emissions are attributable to energy supply and use; the focus of the tension between national development 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 elaborates on all climate change mitigation developments in South Africa.

5.2 Programmes and measures prior to 2006

Major steps have been taken by South Africa to formulate and publish national measures to mitigate 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:

- The 2003 White Paper on Renewable Energy sets a target of 10 000 GWh contribution from new renewable energy sources in 2013, while the 2007 National Industrial Biofuels Strategy (NIBS) sets a target of 2% (of the national liquid fuels supply) penetration of biofuels in 2013 (DME 1998, DME 2003b, DME 2007).
- In 2005, government published a National Energy Efficiency Strategy (NEES), 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). The NEES is currently under review and a number of energy efficiency interventions are being developed.

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, SBT 2007, ERC 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, stabilise for up to ten years, and then decline in absolute terms. The LTMS is one of the key documents on which national climate policy and strategies are based.

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

5.3 Methodological approach for the LTMS process

The LTMS was initiated with a mandate from Cabinet in March 2006, and concluded with outcomes agreed upon 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 energy technology optimisation model developed by the International Energy Agency (IEA), was used to analyse actions in energy demand and supply (Hughes *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 *et al.* 2007a) 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 & Spalding-Fecher 1999). The approach drew on international best practice as described more fully in the LTMS Technical Report (ERC 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 a comparative static computable general equilibrium (CGE) model (Pauw 2007), and subsequently a dynamic CGE model (Kearney 2008), was used.

5.3.1 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.

5.3.2 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 constraints, and that choices to supply energy to the economy are made purely on least-cost grounds, without internalising 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.

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/AIDS 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 US$30 per barrel in the base year (2003) to US$97 per barrel in nominal terms in 2030, while gas prices were assumed to rise from R28/GJ in 2003 to R140/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/GJ in 2003 to R6/GJ in 2030, after which they were assumed to increase further (ERC 2007).

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

5.3.3 Description of the baseline and emissions profiles

South Africa's emissions in the 2003 base year are at 446 Mt CO_2e, increasing about four-fold by 2050 to 1 637 Mt CO_2e (see figure 5.1). This trend is consistent with the country's latest GHG inventory that reports South Africa's emissions at 435 Mt CO_2e in 2000 (DEAT 2009c). 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 (ERC 2007).

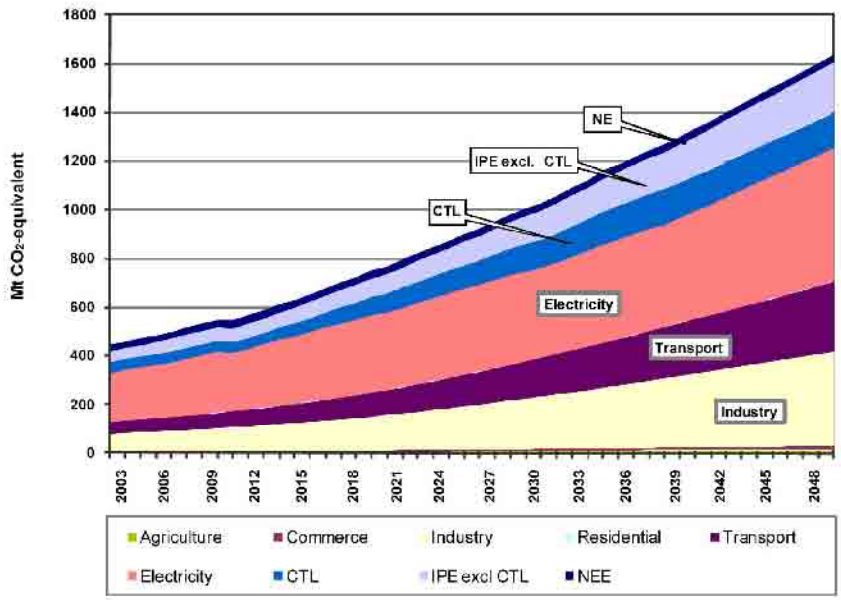


Figure 5.1—Emissions in the *growth without constraint* scenario baseline. CTL, IPE, and NE refer to coal-to-liquids, industrial process, and non-energy emissions respectively. Source: SBT 2007.

Electricity generation continues to be predominantly from coal in the baseline scenario, with all new coal-fired plants using either super-critical steam technology, which comes into the generation mix from 2016, or integrated gasification combined cycle (IGCC), which comes into the generation mix from 2020. Electricity generation from nuclear power assumes that nine new conventional nuclear plants and 12 modules of the pebble bed modular reactors are also built for electricity generation during this period. This assumption is now violated, however, as further development of the latter technology is not currently being pursued. 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 2007).

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

5.4 Assessment of mitigation options

5.4.1 Long-term mitigation options: description, reduction potentials, and costs

A wide range of mitigation actions have been identified through initiatives such as the LTMS. In addition, private sector firms have undertaken a range of mitigation actions. For the purposes of this communication, mitigation actions assessed in the LTMS are presented in some detail. Actions were considered in three categories: energy supply, energy use, and non-energy emissions. The use of this assessment does not imply that the LTMS is the only source of potential mitigation action.

Table 5.1 below presents a description of the mitigation actions that are currently under consideration, together with their status of implementation.

Table 5.1. Status of implementation of mitigation actions currently being considered OR under development.

POTENTIAL MITIGATION ACTIONS	*STATUS OF IMPLEMENTATION*
Financial measures	
Imposition of carbon tax	Levy on electricity generated from fossil fuel already in place.
	Carbon tax on new vehicles already implemented.

POTENTIAL MITIGATION ACTIONS	*STATUS OF IMPLEMENTATION*
	Universal carbon tax under consideration.
Emissions trading	Discussion paper under development.
Energy sector	
Support measures for mitigation actions in energy sector	Introduction of tax rebate for savings as a result of energy efficiency.
	Subsidy to promote installation of solar water heaters.
	Support for use of energy efficiency lighting.
Diversification of electricity generation sources	Integrated resource plan for electricity makes provision for increased contribution from renewable and nuclear energy as electricity sources.
	Renewable Energy Strategy being reviewed to support achievement of increased contribution from renewable energy sources.
	Regulations to promote the procurement of renewable energy supply will be promulgated in 2011.
	Rules to promote cogeneration currently being considered.
	Install solar water heaters.
	Cleaner coal for electricity generation.
Diversification of liquid fuel sources	Integrated Energy Plan which will promote inclusion of biofuels in the liquid fuel supply.
Carbon capture and storage	Carbon capture and storage centre funded by government and private sector has been established.
	Map of potential sites has been published.

POTENTIAL MITIGATION ACTIONS	*STATUS OF IMPLEMENTATION*
	Potential under consideration.
Energy efficiency	National energy efficiency strategy being revised to increase commitment to achieving energy savings from the introduction of energy efficiency measures in all sectors.
	Regulations on norms and standards for electricity reticulation, which include more electricity efficient measures, will come into force in 2012.
	Revised building regulations, which include energy efficient design of new buildings, will be promulgated in 2011.
	Compulsory performance management and energy efficiency labelling for domestic appliances under development.
	Industrial energy efficiency strategy under development.
Fuel switching	Change to less carbon intensive fuel sources already in place where possible.
Coal bed methane reduction	Research in progress.
Transport	Electric vehicles.
	Improved vehicle efficiency.
	Passenger modal shifts being explored.
	Freight strategy to shift freight from road to rail under development.
	Limit on less efficient vehicles.
Industrial processes sector and product use	

POTENTIAL MITIGATION ACTIONS	*STATUS OF IMPLEMENTATION*
Nitrous oxide emission reduction	Implemented in some plants.
Capture of PFC in aluminium plants	Reduction measures implemented as far as possible.
Carbon capture and storage	Being explored where potential may exist.
Agriculture, forestry and land use management	
Land use	Fire control.
	Savannah thickening.
	Afforestation.
Agriculture	Enteric fermentation.
	Reduced tillage.
	Manure management.
Waste	Implementation of recently promulgated waste act.
	Increase recycling, reuse, and energy recovery.
	Promote waste minimisation.
	Composting.

5.4.2 Description of mitigation scenarios

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

5.4.3 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 summarised in Table 5.1above.

5.4.3.1 Start now

The first option, called 'start now', is composed of all those mitigation actions in the LTMS described 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 5.2 shows that this option would save 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 would reduce the gap between the 'baseline' and 'required by science' scenarios by 43% in 2050 (SBT 2007).

Table 5.2. Indicative mitigation costs and emission reduction potentials of combined strategic actions.

Mitigation action	*Mitigation cost (R/t CO_2e)*	*GHG emission reduction, Mt CO_2e, 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%

5.4.3.2 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 listed in the LTMS.
In terms of mitigation, the biggest actions in this scenario are energy efficiency, extended renewables, extended nuclear, syn-fuels 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).

5.4.3.3 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_2e between 2003 and 2050. In 2050 the emissions are at 620 Mt CO_2e, closing the gap between 'baseline' and 'required by science' scenarios by over three-quarters (76%).

5.4.3.4 Reaching for the goal: strategic options beyond the modelled

Figure 5.2 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 5.2). This implies that a new set of options would have to be ready for implementation by this time.

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.
- Resource identification: searching for lower carbon resources.
- People-orientated measures: incentivised behaviour.
- Transition to a low-carbon economy: redefining SA's competitive advantage.

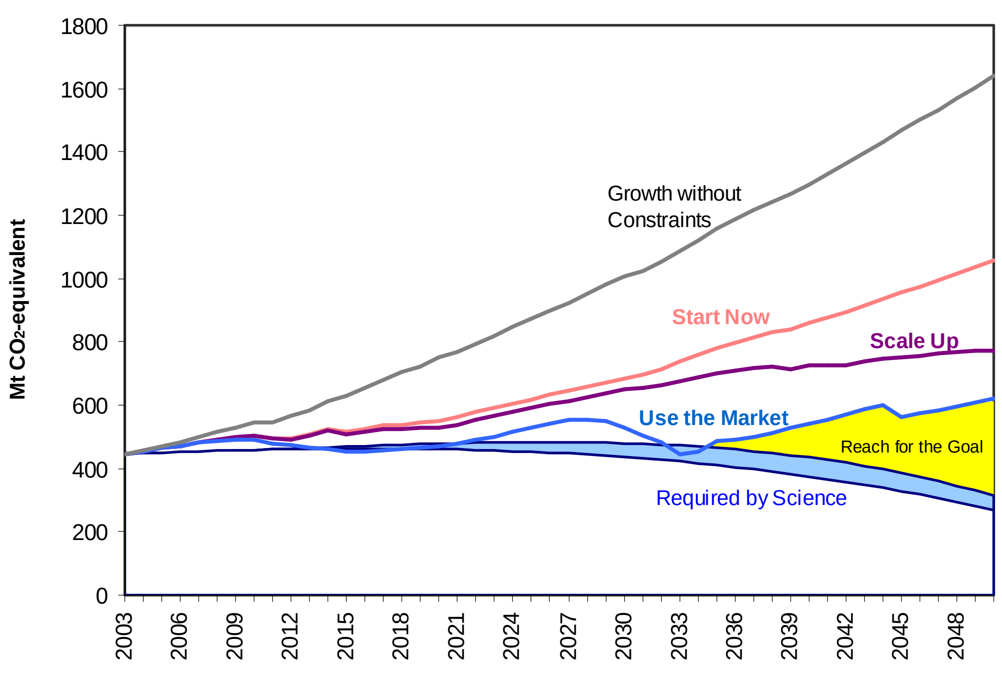


Figure 5.2—Emission pathways of *baseline*, *required by science* and *combined* strategic options.

5.5 Mitigation actions implemented and planned

A mix of economic instruments, including incentives, could be considered to move the country to a low carbon trajectory. 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 (DEA)'s National Climate Change Response Database (NCCRD), with a total emission reduction potential of 25 million tonnes of CO_2e between 2000 and 2050 (DEAT 2009d).

The Department of Minerals and Energy (DME) 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 (DoE 2009).

In 2009, the National Energy Regulator of South Africa (NERSA) 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 programme and respective tariffs are: wind, concentrated solar power, small hydro (<10 MW), landfill gas, large scale grid-connected PV (>1 MW), solid biomass, and bio-gas. 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). Regulations are being finalised to implement the REFIT programme and rules for a Co-generation Feed-In Tariff (COFIT) programme to support co-generation are under development.

In 2009, the Department of Energy acquired financing from the Global Environmental Facility (GEF), 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 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).

5.6 Barriers to and opportunities for mitigation

5.6.1 Level of financial support required for implementation

Both South Africa's Technology Needs Assessment (TNA, DST 2007) and the LTMS 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. 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 industrialised countries.

CDM as a financial incentive 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 (equivalent to 37 361 000 Certified Emission Reductions (CERs)). For consideration in international negotiations, other mechanisms such as programmatic CDMs and sectoral crediting have been proposed for the future.

5.6.2 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 suggested approaches to this challenge include the potential establishment of an international code of compulsory licensing for mitigation technologies (DST 2007: 7).

5.7 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 that will be conducive of a low-carbon development path (DST 2007: 7). International support will therefore be key in implementation, research, and development.

International cooperation on research and development could support South Africa in the following four areas identified by the LTMS (SBT 2007: 21–23):

- Support for South Africa's efforts to make a just transition to a low-carbon economy.
- Positive incentives for people-oriented measures.
- Assistance in searching for lower-carbon resources.
- New technology through joint development and transfer.

The extent to which these actions will be implemented depends on the provision of financial resources, the transfer of technology, and capacity building support by developed countries (RSA 2010).

6 Other information

6.1 Technology transfer

6.1.1 Technology needs assessment

South Africa has conducted a Technology Needs Assessment (TNA) 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 Council for Scientific and Industrial Research (CSIR). The process followed the guidelines laid out in UNDP (2003) and 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 (started in 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*. 2007b) was presented to stakeholders in August 2007. The South African TNA was published, based on this information, by the DST in September of that year (DST 2007). The TNA was approved by Cabinet in November 2007 and has since been submitted to the United Nations Framework Convention on Climate Change (UNFCCC). The Long-Term Mitigation Scenario (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).

6.1.2 The climate change technology needs of South Africa

In terms of climate change, 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, non-governmental organisations (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 (NSI). 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 of 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).

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 emissions reduction in a cost-effective manner), namely: 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 that could lead to a large reduction in greenhouse gas (GHG) emissions.

Energy efficiency was the one area not prioritised by the TNA, but identified by the LTMS as integral to all strategic options. Energy efficiency in industry shows the greatest potential emissions reduction, but energy efficiency has benefits in almost all sectors, including commercial and residential buildings and transport. Key technologies considered include, amongst 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.

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 multi-criteria analysis from over 110 options that were considered. Source: DST 2007.

Response	*Sector*	*Subsector*	*Measure/technology Options*	*Total score (% of the max 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 source reduction, recycle, and reuse	84.8
	Agriculture, land use and forestry		Conservation agriculture	83.3
			Control of biomass burning in 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-borne diseases	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 max 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

The broad prioritisation of solar power, clean-coal technologies, and wind power in the TNA can be enhanced by details from the LTMS analysis. Clean-coal by itself shows relatively modest emission reductions, unless accompanied by Carbon Capture and Storage (CCS). Concentrated Solar Power (CSP) systems, the parabolic trough, and wind turbines are three specific renewable energy technologies highlighted by LTMS. Wind power is currently more competitive cost-wise than CSP. There are some areas of medium-to-high wind power potential in South Africa. Key barriers to widespread adoption are 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 1 000 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 CCS as a key element in making the clean-coal technologies such as coal gasification climate-friendly (Table 6.2). There are significant research needs relating to CCS, and challenges regarding implementation at large scale. The largest potential reduction of industrial process emissions is from applying CCS to new coal-to-liquid syn-fuel plants, where approximately half the CO_2 emissions are already in >90% concentrated form. South Africa considers only geological carbon storage. Work is underway to produce an atlas of potential storage sites.

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/CO_2e)*	*GHG emission reduction, Mt CO_2e, 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

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 emissions reduction relative to the baseline, at a cost saving. Electric, hybrid internal combustion/electric, and hydrogen-fuelled 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 (*e.g.* from road to rail).

6.1.3 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, 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 6.3). In the South African experience, two stand out especially: 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.

Barriers	*Suggestions for enabling environment*
Physical resource constraints.	Examine possibility of applying in other Southern African Development Community (SADC) 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; research and development (R&D) for local substitutes; removal of import tariffs, international funding or subsidies.
High cost of operation and maintenance of 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.
Low savings potential.	Measure to improve productivity through streamlining of government functions.
Lack of suitable small and medium sized firms	Provision of support to small and medium-sized firms

Barriers	*Suggestions for enabling environment*
for subcontracting.	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—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.

Barriers	*Suggestions for enabling environment*
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 CSP. A 100 MW CSP demonstration plant is estimated to cost between R3 billion and R6 billion, 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 four 100 MW CSP plants (R5 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 a 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 6.3 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.

6.1.4 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 with 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 ensuring that suitable controls exist to minimise anti-competitive practices such as price-fixing, and reducing 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 (GCGC) has established a mechanism called the South African Risk and Vulnerability Atlas (SARVA), 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 technologies 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 (TAP). The system would need to be governed by an Executive Board for Technology (EBT).

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.

6.2 Systematic observation, monitoring, and research

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 geo-spatial infrastructure to co-ordinate 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 efforts to better co-ordinate and strengthen research, a 10-year research plan that provides a focussed framework for global change research has been developed. Systemic observation and monitoring form one of the key knowledge generation focus areas within that framework. In 2009, the SARVA 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 an effort to build Africa's resilience to climate variability.

South Africa's efforts in climate change science and the science-policy interface 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.
- 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.

6.2.1 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 co-ordinate 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), was launched in 2003 and 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 (DWA) assembles, curates, and monitors data on climatic and hydrological variables from selected sites across South Africa. Similarly, the Department of Environmental Affairs (DEA) has put in place the South African Air Quality Information System (SAAQIS) as a tool to comply with national and international information management requirements and commitments. A record of climate change-related projects is also maintained by this Department.

Observation, monitoring, and research programmes are generally undertaken by a variety of science councils, universities, and NGOs; often in partnership with government departments and their agencies. Some of these are mentioned below.

6.2.1.1 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, as well as 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.

6.2.1.2 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 Departments of Water Affairs (DWA) and Environmental Affairs (DEA) that are engaged in climate change-related monitoring and/or research work.

The 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 in the southern Atlantic Ocean by the SAWS every year. A comprehensively-equipped and long-established station at Cape Point is the focal point for Global Atmosphere Watch (GAW) activities in southern Africa, which include the monitoring and research of the ozone layer, solar radiation, as well as measurements of atmospheric 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. Weather forecasting research 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 the 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 (NBSAP)), whilst the work commissioned by the WRC informs the development and revision of water catchment and water resource management plans.

6.2.1.3 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, including 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, as well as the feedbacks that the region imposes on the global earth systems. It does so by addressing what has driven and drives the climate cycle in palaeo-climatic terms, and by investigating what influences its variability and trajectory.

The institutions most actively involved in meteorological and atmospheric observation, monitoring, and research programmes include:

- The South African National Space Agency (SANSA), particularly the Pathfinder satellite programme.
- South African National Antarctic programme (SANAP).
- The Climate and Environment Research and Monitoring Unit at the SAWS.
- 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.

- The 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, and 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 CSIR.
- The SAEON marine research programme at its Egagasini marine offshore node.
- The SAIAB 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, as well as conditions and productivity of marine and coastal resources. Other research themes include limnology and oceanic biogeochemistry.

6.2.2 Adaptation and mitigation research programmes

In response to the South African National Climate Change Response Strategy (DEAT 2004b), 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 (SANERI), is the public entity entrusted with the co-ordination and undertaking of energy-related public interest mitigation research, development, and demonstration.

Similarly, the SANBI plays a leading role in monitoring and reporting on the country's biodiversity, as well as in developing a climate change and biodiversity strategy.

A variety of science councils, universities, NGOs, and businesses are increasingly initiating adaptation and mitigation projects across a range of sectors.

6.2.3 Participation in international programmes

South African climate change-related observation, monitoring, and research programmes contribute to and influence programmes established as part of the Intergovernmental Panel on Climate Change (IPCC), the Earth System Science Partnership (ESSP) of the International Community of Scientific Unions (ICSU), the Group on Earth Observations (GEO), the World Meteorological Organisation (WMO), and the Global Climate Observation System of Systems (GEOSS).

South Africa is a member and contributor to the GEO. The GEO brings governments together at a high level to work towards a future in which our decisions and actions, for the broadest benefit to society, are informed by co-ordinated, 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 (GCOS). It also aims to achieve 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 ELTOSA programme for observing and monitoring of drivers of and responses to 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 India-based International Crop Research Institute for the Semi-Arid Tropics (ICRISAT); the air monitoring programme of the Norwegian Institute for Air Research (NILU); and the SADC Hydrological Cycle Observing System (HYCOS) programme.

6.2.4 Challenges and needs

Globally there is a need for better-quality, integrated information to support decision-making related to global environmental challenges. This is needed to inform key political and policy decisions, which 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 severely 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 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, as well as 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 (GNP). 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.

6.3 Public awareness, training, and capacity building

6.3.1 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 DST has developed 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 Applied Centre for Climate and Earth Systems Science (ACCESS), and the proposed Global Change and Sustainability Centre (GCSC) 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[33], 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.

6.3.2 Key civil society initiatives

Many NGOs have the interest, 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 realised (Knowles *et al.* 2009). Key locally-based examples include, but are not limited to: the Association for Water and Rural Development; the Environmental Monitoring Group; the Centre for Environment, Agriculture and Development at the University of KwaZulu-Natal; Indigo Development and Change; Drynet; and Food and Trees for Africa.

Prompted by the 2009 national climate change summit the Adaptation Network[34] provides a platform for sharing experiences and practical approaches, and for promoting focused co-ordination of national climate change adaptation planning and activities

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 (WWF), and play a key role in informing the public about climate change and appropriate individual responses.

6.3.3 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

---

[33] www.rvatlas.org
[34] http://www.adaptationnetwork.org.za/

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[35]) that has as its core mission the development of art and science journalism in the country; held a conference on 'Practicing the craft: writing about climate change and global warming' in 2008, which brought together leading national 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 (SJN), 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.

6.3.4 Key initiatives in education

6.3.4.1 School curriculum

South Africa's school curriculum does not yet 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 0–9 in which climate change could 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

[35] http://fynbosmedia.co.za/foundation.html

social science includes an outcome that 'the scholar will be able to make informed decisions about social and environmental issues and problems'.

In Grades 10–12, 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, this is not the case in the majority of schools.

6.3.4.2 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 include the Climate Systems Analysis Group at the University of Cape Town (UCT), and the Climatology Research Group (CRG), a unit that addresses the human dimensions of vulnerability, adaptation, mitigation, and planning (ReVAMP) in relation to global environmental change at the University of Witwatersrand. These hubs may also draw from experienced professionals from outside academia to add diversity to the material offered, such as the climate change module of the conservation biology Masters course at UCT, which includes co-ordination and lectures by professional scientists from the SANBI. 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 has designed a proposed Masters degree in climate change, while an M.Sc. in climate and development has been approved for inclusion at the University of the Witwatersrand).

The global change SysTem for Analysis, Research, and Training (START), is a NGO 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 Ph.D. graduates on the continent. START also established an African climate change fellowships programme in 2009 offering scholarships and training support to African early-career scientists and graduate students. The fellowship programme 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.

7 Constraints, gaps, and related financial, technical, and capacity needs

This section draws both from the Global Change Grand Challenge (GCGC) research plan (DST 2010)—as the process of developing this involved broad consultation with many appropriate stakeholders—and from knowledge gaps identified during the Second National Communication development process. 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 an inability 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.

7.1 Key major knowledge challenges identified by the Global Change Grand Challenge

The Department of Science and Technology (DST) has identified four 'knowledge challenges' that will provide the framework for addressing gaps in technical understanding and underpin a proposed research plan for global change. The knowledge challenges that have bearing on climate change-related gaps in understanding and capacity include *understanding a changing planet* and *adapting the way we live*. In the sections that follow, the themes associated with each knowledge challenge are briefly described, and the high-level research focus areas are listed.

7.1.1 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. The understanding will be necessary to improve predictive capability and to plan appropriate adaptive responses. The focus area has identified four themes, discussed below.

7.1.1.1 Observation and monitoring

South Africa shares with the Group on Earth Observations (GEO)[36], the objectives of improving and co-ordinating 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 Global Earth Observation System of Systems (GEOSS)[37], and are dealt with broadly within the South African Earth Observation Strategy (SAEOS)[38] 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 changes 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?

7.1.1.2 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.

---

[36] www.earthobservations.org
[37] www.earthobservations.org/geoss.shtml
[38] www.esastap.org.za/esastap/pdfs/spacews_saeos_dec2005.pdf

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 (CO_2) and other greenhouse gases (GHG) continue to rise at their present rates of 1–3% per annum, regional responses to such a rise remain unclear. The strong links between local climate and the three oceans surrounding the southern African landmass, make any seasonal and decade-scale forecasts dependent on the changing nature of these links. This is a key knowledge gap for South Africa and the southern African region.

The role of the region's oceans is of global importance in driving the global climate system through their biogeochemical and biophysical behaviours. For example, the Southern Ocean provides a 'sink' for some 50% of all natural and anthropogenic CO_2 taken up annually by the world's oceans—a key 'ecosystem service' providing vast carbon sequestration capacity. It is unclear how this ecosystem service will be affected by global warming. Also insufficiently understood is the role of the Southern Ocean in modulating albedo (*i.e.* the ability of the Earth to reflect solar radiation). The ocean 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.

Research focus areas include:

- How will the large-scale Southern Ocean ocean-climate systems 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 CO_2, and to 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 that modify food webs and climate feedbacks such as atmospheric albedo?

7.1.1.3 Linking the land, the air, and the sea

Although many researchers tend to work within a single domain (*e.g.* oceanographers who focus on marine ecosystems), it remains a fact that ecosystems are interconnected. To increase 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. Research focus areas address the following gaps:

- What are the priority forms of change on the land that will directly or indirectly affect atmospheric, 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?

7.1.1.4 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 understanding increased. 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 five million years that saw the rise of African hominids, 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?

7.1.2 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 on the other still being able to raise the average standard of living to an acceptable level, 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 explicit 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, discussed below.

7.1.2.1 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; as well as changes to the dynamics of diseases affecting humans and livestock.

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?

7.1.2.2 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 of the slow rate at which they adapt to change, their ever-increasing reliance on the hinterland, and their 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 would 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. It 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 as 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?

7.1.2.3 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 trans-boundary effects can be expected, considering that a number of South Africa's major river systems are shared with our neighbouring countries?

7.1.2.4 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 (*e.g.* 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?

7.2 Specific gaps identified in relation to climate change impacts and vulnerability

7.2.1 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 infrastructure upgrade or new infrastructure development. 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.

7.2.2 Capacity constraints and needs

The shortage of climate change professionals in Africa trained at the Ph.D. and postdoctoral levels 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 Ph.D. 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 DST's Global Change Grand Challenge (GCGC) human capital development foci, and the planned activities envisaged by the National Research Foundation (NRF).

7.2.3 Research and monitoring constraints and needs

Climate and oceanography

There is need to continue to 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) emphasises the need for further work to understand the way that climate events are influenced by processes in the south-east 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 drivers 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 GCGC (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 impacts assessment work is needed in these sectors to update work carried out using previous generation climate and impacts models. These assessments should be based on appropriately downscaled climate change scenarios of long and continuous time series (rather than time slices) from multiple Global Climate Models (GCMs) 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 interactions of damaging insects and especially pathogens with changes in climate are barely predictable on the basis of current knowledge. A constant monitoring of pathogens on a national spatial level seems advisable.

Key improvements needed in agriculture include utilising 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 are 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 timber and pulp quality, and also on 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 programme, as well as 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, climate variability, and extreme weather events on the spread and intensity of cholera outbreaks has 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 programme is needed to support the provision of the long-term information needed to test projections and the impacts of policy responses. 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, in order to develop appropriate adaptation responses that benefit people.

Key work on the impacts of climate change on alien invasive species 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 are 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 adverse climate change impacts on livelihoods, relatively little attention has been given to opportunities, including the role of technologies (small and large, soft and hard) in supporting emerging sectors under future climate scenarios.

Few studies have explored the factors shaping adaptation and adaptive behaviours. The potential role of social capital and networks of various types is widely recognised 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. Adger *et al.* (2009), for example, show that individual and various other social factors (*e.g.* individual behaviour, underlying values and perceptions of climate change, as well as ability to respond) are essential to understand at various levels (both local and amongst decision makers) if adaptation is to occur and be a sustained effort.

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 cost/benefit 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. 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 students progress 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 co-ordination of such integration, as well as early advice on accreditation and cross-university or cross-country recognition (working, for example, within South African Qualification Authority (SAQA) standards). There is a 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 to scientists, whether by government or other sources, 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 organisations, if more appropriate). Columbia University in New York, for example, have a dual Masters degree programme in Earth and Environmental Science Journalism[39], 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 aforementioned Fynbos Foundation 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 and 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 (SALGA) has explicitly asked for climate change awareness raising and capacity building to be undertaken for municipalities in South Africa.

[39] http://www.ldeo.columbia.edu/edu/eesj/

8 Table of Figures

9 List of Tables

10 Cited references and selected further reading

ABAYOMI, E.A., SOMMERS, A., GREWAL, R., SISSOLAK, G., BASSA, F., MAARTENS, D., JACOBS, P., STEFAN, C. & AYERS, L. 2010. *Malignant lymphoma incidence and HIV-related lymphoma subtypes in the Western Cape of South Africa, 2002–2009*. International Conference on Cancer in Aids and Other Opportunistic Infections (ICMAOI), National Institute of Health, Bethesda, Maryland. http://www.ssalc.org/acsr_drupal/index.php?q=node/57.

ABU-RADDAD, L.J., PATNAIK, P. & KUBLIN, J.G. 2006. Dual Infection with HIV and Malaria Fuels the Spread of Both Diseases in Sub-Saharan Africa. *Science* 314: 1603–1606.

ACCELERATED AND SHARED GROWTH INITIATIVE FOR SOUTH AFRICA (AsgiSA). *A summary. The Presidency. Republic of South Africa.*http://www.info.gov.za/asgisa/asgisa.htm.

ACCELERATED AND SHARED GROWTH INITIATIVE FOR SOUTH AFRICA (AsgiSA). 2006. Pretoria.

ACTIONAID INTERNATIONAL. 2006. *Climate change, urban flooding, and the rights of the urban poor in Africa: Key findings from six African cities*. http://www.actionaid.org.

ADGER, W. N. 2001. Scales of governance and environmental justice for adaptation and mitigation of climate change. *Journal of International Development* 13:921-931.

ADGER, W.N., HUGHES, P.T., FOLKE, C., CARPENTER, S.R. & ROCKSTRÖM, J. 2005. Social-Ecological Resilience to Coastal Disasters. *Science* 309: 1036–1039.

ADGER, W.N., HUQ, S., BROWN, K., CONWAY, D. & HULME, M. 2003. Adaptation to climate change in the developing world. *Progress in Development Studies* 3: 179–195.

AEAEE. 2007. *Review of the South African MARKAL model*. S. Pye and H. Haydock. London.

ALBER, M. 2002. A conceptual model of estuarine freshwater inflow management. *Estuaries* 25: 1246–1261.

ALLAN, D.G., HARRISON, J.A., NAVARRO, R.A., VAN WILGEN, B.W. & THOMPSON, M.W. 1997. The impact of commercial afforestation on bird populations in Mpumalanga Province, South Africa—Insights from bird-atlas data. *Biological Conservation* 79: 173–185.

ALLAN, R.J., PARKER, D. & LINDESAY, J.A. 1996. *El Niño Southern Oscillation and climatic variability*. Unpublished report, CSIRO Australia.

ALLAN, R.J., REASON, C.J.C., LINDESAY, J.A. & ANSELL, T.J. 2003. Protracted ENSO episodes and their impacts in the Indian Ocean region. *Deep-Sea Research II* 50: 2331–2347.

ALSTON, K.P. & RICHARDSON, D.M. 2006. The roles of habitat features, disturbance, and distance from putative source populations in structuring alien plant invasions at the urban/wildland interface on the Cape Peninsula, South Africa. *Biological Conservation* 132: 183–198.

ALTWEGG, R., BROMS, R.K., ERNI, B., BARNARD, P., MIDGLEY, G.F. & UNDERHILL. L.G. 2011. Novel methods reveal shifts in migration phenology of barn swallows in South Africa. *Proceedings of the Royal Society B: Biological Sciences*. doi:10.1098/rspb.2011.1897

AMBRUS, J.L. Sr. & AMBRUS, J.L. Jr. 2004. Nutrition and Infectious Disease in Developing Countries and Problems of Acquired Immunodeficiency Syndrome. *Experimental Biology of Medicine* 229: 464–472.

ANDERSON, H.R., DERWENT, R.G. & STEDMAN, J. 2001. Air pollution and climate Change. In *Health Effects of Climate Change in the UK Department of Health*: 193–217. London.

ANDREWS, G. & PILLAY, Y. 2005. Strategic priorities for the national health system 2004–2009. In P. Barron (ed.), *Ijumba, South-African Health Review*. Health Systems Trust, Durban. http://www.hst.org.za/uploads/files/sahr2005.pdf.

ANDREWS, P. & O'BRIEN, E.M. 2000. Climate, vegetation, and predictable gradients in mammal species richness in southern Africa. *Journal of Zoology* 251: 205–231.

ANECK-HAHN, N., SCHULENBURG, G., BORNMAN, M., FARAIS, P. & DE JAGER, C. 2007. Impaired Semen quality Associated With Environmental DDT Exposure in Young Men Living in a Malaria Area in Limpopo Province, South Africa. *Journal of Andrology* 28: 423–434.

ANFUSO, G., DOMINGUEZ, L. & GRACIA, F.J. 2007. Short and medium-term evolution of a coastal sector in Cadiz, SW Spain. *Catena* 70: 229–242.

ANONYMOUS. 1999. Appendix. Releases of introduced biological control agents against weeds in South Africa. *African Entomology Memoir* 1: 175–182.

ANONYMOUS. 2008. *Combating malnutrition in South Africa Input paper for Health Roadmap.* www.dbsa.org/Research/Documents/South%20Africa%20Nutrition_%20input%20paper_roadmap.pdf.

APPEL, M. 2007. Tourism to contribute 12% of SA GDP by 2010. http://www.sa2010.gov.za/node/889.

APPEL, M. 2008. Housing, transport dominate household spending. http://www.buanews.gov.za/view.php?ID=08030416451004&coll=buanew08.

AR4. undated. Fourth Assessment Report. IPCC. http://www.ipcc.ch.

AGRICULTURAL RESEARCH COUNCIL (ARC). 2001. Crop Post-Harvest Programme outputs into small-scale food production systems in South Africa's Northern Province. http://www.arc.agric.za/uploads/documents/3129_sustainablerurallivelihoodcphppraftr2001.pdf.

ARCHER, E. 2006. 'Farming on the Edge' in arid western South Africa: adapting to climate change in marginal environments.

ARCHER, E. 2008. *Developing Doctoral and Postdoctoral Research Fellowships in Support of Climate Change Adaptation in Africa*. Position paper prepared for START, Dar es Salaam.

ARCHER, E.R.M. & TADROSS, M.A. 2009. Climate change and desertification in South Africa – science and response. *African Journal of Range and Forage Science* 26(3): 127–131.

ARCHIBALD, S., ROY, D.P. VAN WILGEN B.W., & SCHOLES, R.J. 2009. What limits fire? An examination of drivers of burnt area in Southern Africa. *Global Change Biology* 15:613-630.

ASHTON, P.J., HARDWICK, D. & BREEN, C.M. 2008. Changes in water availability and demand within South Africa's shared river basins as determinants of regional socialecological resilience. In: Burns, M.J. & Weaver, A.v.B. (Eds.) Advancing Sustainability Science in South Africa. Stellenbosch: Stellenbosch University Press. 279 – 310.

AVERT. 2010. *HIV and AIDS in South-Africa*. http://www.avert.org/aidssouthafrica.htm.

BADRI, M., CLEARY, S., MAARTENS, G., PITT, J., BEKKER, L.G., ORRELL, C. & WOOD, R. 2006. When to initiate highly active antiretroviral therapy in sub-Saharan Africa? A South-African cost-effectiveness study. *Antiviral Therapy* 11: 63–72.

BAKUN, A. 1990. Global climate change and intensification of coastal upwelling. *Science* 247: 198–201.

BAMBRICK, H., DEA, K., WOODRUFF, R., HANIGAN, I. & McMICHAEL, A. 2008. *Garnaut Climate Change Review: The impacts of climate change on three health outcomes: temperature-related mortality and hospitalisations, salmonellosis and other bacterial gastroenteritis, and population at risk from dengue.*

BARD, E. & RICKABY, R.E.M. 2009. Migration of the subtropical front as a modulator of glacial climate. *Nature* 460 (7253), 380-393.

BARICHIEVY, K.R., SCHULZE, R.E. & KUNZ, R.P. 2010. Results 3: Spatial Changes in Water Temperature Indicators with Climate Change in the Thukela Catchment Using Output from the ECHAM/MPI-OM General Circulation Model. In R.E. Schulze, B.C. Hewitson, K.R.

Barichievy, M.A. Tadross, R.P. Kunz, M.J.C. Horan & T.G. Lumsden, *Methodological Approaches to Assessing Eco-Hydrological Responses to Climate Change in South Africa.WRC Report,* 1562/1/10: 147–175. Water Research Commission, Pretoria.

BARNARD, R.O., VAN DER MERWE, A.J., DE VILLIERS, M.C., VAN DER MERWE, G.M.E. & MULIBANA, N.E. 2000. Problem soils including degraded soils: Extent, present use, management and rehabilitation in South Africa. *Proceedings FAO/ISCW Expert Consultation on Management of Degraded Soils in southern and East Africa*: 126–140.

BAZZAZ, F.A. 1990. The response of natural ecosystems to the rising global CO_2 levels. *Annual Review of Ecology & Systematics* 21: 167–196.

BEEKMAN, H.E., SAAYMAN, I. AND HUGHES, S. 2003. "*Vulnerability of Water Resources to Environmental Change in Southern Africa*". A report for the Pan African START Secretariat and UNEP. Council for Scientific and Industrial Research, Stellenbosch.

BENHIN, J.K.A. 2006. Climate change and South African agriculture: Impacts and adaptation options. *CEEPA Discussion Paper*: 21.

BENHIN, J.K.A. & HASSAN, R. 2006. Climate change and South African agriculture: A Ricardian analysis of the impacts and adaptation options (preliminary results). *Proceedings Agricultural sector Workshop on climate change*: 63–75.

BENJAMIN, M.A. 2008. *Analysing Urban Flood Risk in Low-Cost Settlements of George, Western Cape, South Africa: Investigating Physical and Social Dimensions.* MA Dissertation, University of Cape Town, Cape Town.

BENSON, C. & CLAY, E. 2004. Understanding the Economic and Financial Impacts of Natural Disasters. *Disaster Risk Management Series*: 4. World Bank, Washington.

BETTS, R.A., BOUCHER, O., COLLINS, M., COX, P.M., FALLOON, P.D., GEDNEY, N., HEMMING, D.L., HUNTINGFORD, C., JONES, C.D., SEXTON, D.M.H. & WEBB, M.J. 2007. Projected increase in continental runoff due to plant responses to increasing carbon dioxide. *Nature*: 448: 1037–1041.

BEUKES, D.J., DE VILLIERS, M.C, MKHIZE, S., SALLY, H. & VAN RENSBURG, L. 2003. The Bloemfontein Declaration on water and nutrient conservation technologies. *Proceedings symposium and workshop on water conservation technologies for sustainable dryland agriculture in sub-Saharan Africa*: viii.

BHARWANI, S., BITHELL, M., DOWNING,T.E., NEW, M., RICHARD, M.N., WASHINGTON, R. & ZIERVOGEL, G. 2005. Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo. *Philosophical Transactions of the Royal Society of London B Biological Sciences* 360: 2183–2194.

BIASTOCH, A., BÖNING, C.W., LUTJEHARMS, J.R.E. & SCHWARZKOPF, F. submitted. Increase in Agulhas leakage due to poleward shift of southern hemisphere westerlies. *Nature* 462: 495–498.

BIASTOCH, A., LUTJEHARMS, J.R.E., BÖNING, C.W. & SCHEINERT, M. 2008. Mesoscale perturbations control inter-ocean exchange south of Africa. *Geophysical Research Letters* 35: L20602.

BIGGS, R., SIMONS, H., BAKKENES, M., SCHOLES, R.J., EICKHOUT, B., VAN VUUREN, D. & ALKEMADE, R. 2008. Scenarios of biodiversity loss in southern Africa in the 21st century. *Global Environmental Change* 18: 296–309.

BINEDELL, M., MATOOANE, M., PIENAAR, M., VAN DER MERWE, M., WOODBORNE, S., TIRUSHA THAMBIRAN, T., NAIDOO, M., SOWDEN, M. & OMAR, S. 2008. *eThekwini municipality urban integrated assessment framework for climate change specialist study*. Human Health and Climate Change. http://www.csir.co.za.

BLAIKIE, P., CANNON, T., DAVIS, I. & WISNER, B. 1994. At Risk: Natural hazards, people's vulnerability, and disasters. Routledge, London. http://www.radixonline.org/at_risk.html.

BLIGNAUT, J., UECKERMANN, L. & ARONSON, J. 2009. Production's sensitivity to changes in climate in South Africa. *South African Journal of Science* 105: 61–68.

BOHLE, H.G., DOWNING, T.E. & WATTS, M.J. 1994. Climate Change and Social Vulnerability: The Sociology and Geography of Food Insecurity. *Global Environmental Change* 4(1): 37–48.

BOMHARD, B., RICHARDSON, D.M., DONALDSON, J.S., HUGHES, G.O., MIDGLEY, G.F., RAIMONDO, D.C., REBELO, A.G., ROUGET, M. & THUILLER, W. 2005. Potential impacts of future land use and climate change on the Red List status of the Proteaceae in the Cape Floristic Region, South Africa. *Global Change Biology* 11: 1452–1468.

BOND, W.J. 1997. Functional types for predicting changes in biodiversity: A case study in Cape fynbos. In T.S. Smith, H.H. Shugart & F.I. Woodward (eds), *Plant functional types: Their relevance to ecosystem properties and global change*: 174–194. Cambridge University Press, Edinburgh.

BOND, W.J. 2008. What limits trees in C_4 grasslands and savannas? *Annual Review of Ecology, Evolution & Systematics* 39: 641–659.

BOND, W.J. & KEELEY, J.E. 2005. Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. *Trends in Ecology and Evolution* 20: 387–394.

BOND, W.J. & MIDGLEY, G.F. 2000. A proposed CO_2-controlled mechanism of woody plant invasion in grasslands and savannas. *Global Change Biology* 6: 865–869.

BOND, W.J., MIDGLEY, G.F. & WOODWARD, F.I. 2003a. The importance of low atmospheric CO_2 and fire in promoting the spread of grasslands and savannas. *Global Change Biology* 9: 973–982.

BOND, W.J., MIDGLEY, G.F. & WOODWARD, F.I. 2003b. What controls South African vegetation—climate or fire? South African Journal of Botany 69: 79–91.

BOND, W. J., WOODWARD, F.I. & MIDGLEY, G.F. 2005. The global distribution of ecosystems in a world without fire. New Phytologist 165:525-537.

BOND, W.J. & VAN WILGEN, B.W. 1996. *Fire and plants.* Chapman and Hall, London.

BOND, W.J., VETTER, S., GOQWANA, W.M. & TROLLOPE, W.W. 2006. Effects of land tenure, geology and topography on vegetation and soils of two grassland types in South Africa. *African Journal of Range and Forage Science* 23: 13–27.

BOND, W.J., WOODWARD, F.I. & MIDGLEY, G.F. 2005. The global distribution of ecosystems in a world without fire. *New Phytologist* 165: 525–538.

BOTES, A., McGEOCH, M.A., ROBERTSON, H.G., NIEKERK, A., DAVIDS, H.P. & CHOWN, S.L. 2006. Ants, altitude and change in the northern Cape Floristic Region. *Journal of Biogeography* 33: 71–90.

BOUWMAN, H. 2004. South Africa and the Stockholm Convention on persistent organic pollutants. *South African Journal of Science* 100: 323–328.

BP. 2008. BP Statistical Review of World Energy June 2008. http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/downloads/pdf/renewables_section_2008.pdf.

BRADLEY, B.A., BLUMENTHAL, D.M., WILCOVE, D.S. & ZISKA, L.H. 2010. Predicting plant invasions in an era of global change. *Trends in Ecology & Evolution* 25: 310–318.

BRADSHAW, D. 2008. Chapter 4: Determinants of health and their trends. In P. Barron & J. Roma-Reardon (eds), *South-African Health Review* 2008. Health Systems Trust. http://www.hst.org.za/uploads/files/sahr2008.pdf

BRADSHAW, D., BOURNE, D. & NUNNAN, N. 2003. What are the leading causes of death among South African children? Medical Research Council Policy Brief No.3, Tygerberg, South Africa. *Circulation* 109: 2655–2671.

BRADSHAW, D., NANNAN, N., GROENEWALD, P., ET AL. 2005. Provincial mortality in South Africa, 2000 – priority-setting for now and a benchmark for the future. *South African Medical Journal* 95: 496-503.

BRANCH, G.M. & STEFFANI, C.N. 2004. Can we predict the effects of alien species? A case-history of the invasion of South Africa by *Mytilus galloprovincialis* (Lamarck). *Journal of Experimental Marine Biology & Ecology* 300: 189–215.

BROENNIMANN, O., THUILLER, W., HUGHES, G., MIDGLEY, G.F., ALKEMADE, J.M.R. & GUISAN, A. 2006. Do geographic distribution, niche property and life form explain plants' vulnerability to global change? *Global Change Biology* 12: 1079–1093.

BROOK, R.D. 2004. American Heart Association Statement. Air Pollution and Cardiovascular Disease. A Statement for Healthcare Professionals From the Expert Panel on Population and Prevention Science of the American Heart Association. *Circulation* 204: 2655–2671. http://circ.ahajournals.org/cgi/content/full/109/21/2655.

BROOK, R.D. FRANKLIN, B. CASCIO, W. HONG, Y. HOWARD, G. LIPSETT, M. LUEPKER, R. MITTLEMAN, M. SAMET, J. SMITH, S.C., JR. & TAGER, I. 2004. Air Pollution and Cardiovascular Disease: A Statement for Healthcare Professionals from the Expert Panel on Population and Prevention Science of the American Heart Association; *Circulation* 109:2655-2671.

BROOKS, M.L., D'ANTONIO, C.M., RICHARDSON, D.M., GRACE, J.B., KEELEY, J.E., DiTOMASO, J.M., HOBBS, R.J., PELLANT, M. & PYKE, D. 2004. Effects of invasive alien plants on fire regimes. *Bioscience* 54: 677–688.

BROOKS, T., BALMFORD, A., BURGESS, N., FJELDA, J., HANSEN, L.A., MOORE, J.L., RAHBEK, C. & WILLIAMS, P.H. 2001. Toward a blueprint for conservation in Africa. *BioScience* 51: 613–624.

BROWN, A.C. & McLACHLAN, A. 2002. Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. *Environmental Conservation* 29: 62–77.

BROWN-BRANDL, T.M., EIGENBERG, R.A., NIENABER, J.A. & HAHN, G.L. 2005. Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle. *Biosystems Engineering* 90: 451–462.

BRUNDRIT, G.B. 2008. *Global Climate Change: Coastal Climate Change and Adaptation—A Sea-Level Rise Risk Assessment for the City of Cape Town. Phase one: Sea Level Rise Model*. Report prepared for the City of Cape Town, Environmental Resource Management Department by LaquaR Consultants CC.

BRUUN, P. 1983. Review of conditions for uses of the Bruun rule of erosion. *Coastal Engineering* 7: 77–89.

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

BRUWER, J.J. 1990. *Drought policy in the Republic of South Africa*. Southern African Regional Commission for the Conservation and Utilisation of the Soil, Pretoria.

BURKE, M.B., MIGUEL, E., SATYANATH, S., DYKEMA, J.A. & LOBELL, D.B. 2009. Warming increases the risk of civil war in Africa. *Proceedings of the National Academy of Sciences* 106: 20670-20674.

BURTON, I., KATES, R.W & WHITE, G.F. 1993. *The Environment as Hazard*, (Second ed.), Guilford, New York.

BUTLER, C. & HARLEY, D. 2010. The primary, secondary and tertiary effects of eco-climate change: the medical response. *Post Graduate Medicine* 86: 230–234.

BYRNE, M.J., CURRIN, S. & HILL, M.P. 2002. The influence of climate on the establishment and success of the biocontrol agent *Gratiana spadicea*, released on *Solanum sisymbriifolium* in South Africa. *Biological Control* 24: 128–134.

CALDEIRA, K. & WICKETT, M.E. 2003. Anthropogenic carbon and ocean pH. *Nature* 425: 365–365.

CARLTON, J.T. 2000. Global change and biological invasions in the oceans. In H.A. Mooney & R.J. Hobbs (eds), *Invasive species in a changing world*: 31–53. Island Press, Washington DC.

CARNEY, D. 1998. *Sustainable Rural Livelihoods: What Contribution can we make? DFID's Natural Resources Advisers' Conference.* Department for International Development (DFID), London.

CARTER, T.R., PARRY, M.L., HARASAWA, H. & NISHIOKA, S. 1994. *IPCC Technical Guidelines for Assessing Impacts of Climate Change*: 59. Intergovernmental Panel on Climate Change, WMO and UNEP, Geneva.

CARTER, W., ZUNCKEL, M. & DIAB, R.D. 2008. *Generating emissions and meteorology to model the impacts of biomass burning emission on regional air quality in South Africa*. CSIR Report: http://researchspace.csir.co.za/dspace/bitstream/10204/2828/1/Carter_2008.pdf.

CARTWRIGHT, A. 2002. *When apples don't sleep: The impact of warmer climates on Braeburn apple production in the winter rainfall region of South Africa*. MSc thesis, Environmental Change Institute, Oxford University.

CARTWRIGHT, A. 2008. *Global Climate Change: Coastal Climate Change and Adaptation - A Sea-Level Rise Risk Assessment for the City of Cape Town. Phase three: Final Report, A Sea-Level Rise Risk Assessment for the City of Cape Town.* Report prepared for Prepared for the City of Cape Town, Environmental Resource Management Department by LaquaR Consultants CC.

CASH, B.A., RODÓ, X. & KINTER, J.L., III 2009. Links between tropical Pacific SST and cholera incidence in Bangladesh: role of the western tropical and central extratropical Pacific. Journal of Climatology 22:1641–1660.

CELLIERS, L. & SCHLEYER, M.H. 2002. Coral bleaching on high-latitude marginal reefs at Sodwana Bay, South Africa. *Marine Pollution Bulletin* 44:1380-1387.

CELLIERS, L. & SCHLEYER, M.H. 2008. Coral community structure and risk assessment of high-latitude reefs at Sodwana Bay, South Africa. *Biodiversity Conservation* 17: 3097–3117.

CHAMBER OF MINES. 2009. *Facts and figures.* http://www.bullion.org.za/Publications/Facts&Figures2009/F&F2009.pdf

CHAMBERS, R. 1995. Whose reality counts? *Environment and Urbanisation* 7: 173–204.

CHAPMAN, M.G., UNDERWOOD, A.J. & SKILLETER, G.A. 1995. Variability at different spatial scales between a subtidal assemblage exposed to the discharge of sewage and two control assemblages. *Journal of Marine Biology and Ecology* 189: 103–122.

CHASE, L.E. 2006. *Climate change impacts on dairy cattle*. www.climateandfarming.org/pdfs/FactSheets/iii.3Cattle.pdf.

CHASE, B.M. & MEADOWS, M.E. 2007. Late Quaternary dynamics of southern Africa's winter rainfall zone. *Earth-Science Reviews* 84:103-138.

CHATRAW, J.H., WHERRY, E.T., AHMED, R & KAPASI, Z.F. 2008. Diminished CD8 T cell response to Viral infection during PEM in mice is due to changes in the microenvironment and low numbers of Viral Specific CD8 T cell precursors. *Journal of Nutrition* 138: 806–812.

CHEGOU, N.N., BLACK, G.F., KIDD, M., VAN HELDEN, P.D. & WLAZL, G. 2009. Host markers in Quantiferon supernatant differentiate TB from latent TB infection: preliminary report. *BioMedCentral Pulmonary Medicine.* http://www.biomedcentral.com/1471-2466/9/21.

CHÍCHARO, L.M.Z. & CHÍCHARO, M.A. 2000. Estimation of the life history parameters of *Mytilus galloprovincialis* (Lamarck) larvae in a coastal lagoon (Ria Formosa—south Portugal). *Journal of Experimental Marine Biology & Ecology* 243: 81–94.

CHOPRA, K., LEEMANS, R., KUMAR, P. & SIMONS, H. 2005. *Ecosystems and human well-being*. Volume 3: 621. Island Press, Washington, DC.

CHOWN, S.L., VAN RENSBURG, B.J., GASTON, K.J., RODRIGUES, A.S.L. & VAN JAARSVELD, A.S. 2003. Energy, species richness, and human population size: conservation implications at a national scale. *Ecological Applications* 13: 1233–1241.

CHRISTENSEN, J.H., HEWITSON, B., BUSUIOC, A., CHEN, A., GAO, X., HELD, I., JONES, R., KOLLI, R.K., KWON, W-T., LAPRISE, R., MAGANA RUEDA, V., MEARNS, L., MENENDEZ, C.G., RAISANEN, J., RINKE, A., SARR, A. & WHETTON, P. 2007. Regional Climate Projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, A.B. Averyt, M. Tignor & H.L. Miller (eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge and New York.

CLARK, A. & SPALDING-FECHER, R. 1999. *Financial protocol for South Africa's climate change mitigation assessment.* Energy & Development Research Centre, University of Cape Town, Cape Town.

CLARK, B.M. 2006. Climate change: A looming challenge for fisheries management in southern Africa. *Marine Policy* 30: 84–95.
CLARK, B.M., STEFFANI, C.N., YOUNG, S., RICHARDSON, A.J. & LOMBARD, A.T. 2000. *The effects of climate change on marine biodiversity in South Africa*. Report prepared for the Foundation for Research Development, South African Country Study on Climate Change, Vulnerability and Adaptation Assessment, Marine Biodiversity Section. Pretoria.
CLEARY, S. 2009. *Long term costs and implications for sustainable budgeting*. Health Economics Unit. Presentation. http://www.alp.org.za/Presentations.
CLIMATE SYSTEMS ANALYSIS GROUP (CSAG). undated. http://www.csag.uct.ac.za/biblio.
COETZEE, B.W.T., ROBERTSON, M.P., ERASMUS, B.F.N., VAN RENSBURG, B.J. & THUILLER, W. 2009b. Ensemble models predict Important Bird Areas in southern Africa will become less effective for conserving endemic birds under climate change. *Global Ecology & Biogeography* 18: 701–710.
COETZEE, G. & KOORNHOF, H. 2006. MDR/XDR tuberculosis in South-Africa. *Southern African Journal of Epidemiology and Infection* 21: 150–151.
COETZEE, J.A., HILL, M.P. & SCHLANGE, D. 2009a. Potential spread of the invasive plant *Hydrilla verticillata* in South Africa based on anthropogenic spread and climate suitability. *Biological Invasions* 11: 801–812.
COLLINS, A.E. 1996. The geography of cholera. In B.D. Drasar & B.S. Forrest (eds),*Cholera and the Ecology of Vibrio cholerae*. Chapman & Hall, London.
COLVIN, C.A. & GENTHE, B. 1999. Increased risk of methaemoglobinaemia as a result of bottle feeding by HIV positive mothers in South Africa. In M. Fendekova & M. Fendek (eds), *XXIX Congress of International Association of Hydrogeologists (IAH) Hydrogeology and land use management. Proceedings*: 599–605. Bratislava.
COST, E. & SILVA, J. 2007. Evaluation of an international series of *Pinus kesiya* provenace trials for adaptive, growth and wood quality traits. *Forest & Landscape Working Papers* 22: 41.
COSTAS, S., ALEJO, I., VILA-CONCEJO, A. & NOMBELA, M.A. 2005. Persistence of storm-induced morphology on a modal low-energy beach: A case study from NW-Iberian Peninsula. *Marine Geology*, 224: 43–56.
COVIELLA, C.E. & TRUMBLE, J.T. 1999. Effects of elevated atmospheric carbon dioxide on insect-plant interactions. *Conservation Biology* 13: 700–712.
COWLING, R.M., PRESSEY, R.L., ROUGET, M. & LOMBARD, A.T. 2003. A conservation plan for a global biodiversity hotspot—the Cape Floristic Region, South Africa. *Biological Conservation* 112: 191–216.
COWLING, R.M., RUNDEL, P.W., LAMONT, B.B., ARROYO, M.K. & ARIANOUTSOU, M. 1996. Plant diversity in Mediterranean-climate regions. *Trends in Ecology & Evolution* 11: 362–366.
CROPP, R. & GABRICA, A. 2002. Ecosystem adaptation: do ecosystems maximize resilience? *Ecology* 83: 2019–2026.
CSIR (NATURAL RESOURCES AND THE ENVIRONMENT). 2005. *A Discussion Document for the Process of Developing a Technology Needs Analysis for South Africa.* In R.J. Scholes (ed.), Publication number: CSIR/NRE/ECO/ER/0030/C.
CSIR ENVIRONMENTEK (NATURAL RESOURCES AND THE ENVIRONMENT). 2006. Climatic future for Durban. In S. Naidu, R. Hounsome & D. Roberts (eds), *Final Report*: 199. CSIR/NRE/PW/ER/2006/0017/C.
DAFF (DEPARTMENT OF AGRICULTURE FORESTRY AND FISHERIES) 2009. Quarterly economic overview of the agriculture sector http://www.daff.gov.za/docs/Economic_analysis/EconomicOverview_Oct-Dec2009.pdf
DAI, A., TRENBERTH, K.E. & QIAN, T. 2004. A global dataset of Palmer Drought Severity Index for 1870–2002: Relationship with soil moisture and effects of surface warming. *Journal of Hydrometeorology* 5: 1117–1130.

DALLAS, H.F. & RIVERS-MOORE, N.A. 2009. *Future uncertain—Climate change and freshwater resources in South Africa.* Draft Technical Report produced for the Water Research Commission and the World Wide Fund for Wildlife, The Freshwater Consulting Group and Ezemvelo KZN Wildlife.

DBSA (DEVELOPMENT BANK OF SOUTH AFRICA). 2010. *Renewable energy market transformation (REMT).* http://www.dbsa.org/(S(jfiabt55qjt3zljxfbaycab1))/Projects/Pages/default.aspx.

DE VILLIERS, S. AND DE WIT, M. 2010. *H_20-CO_2 – Energy equations for South Africa: present status, future scenarios and proposed solutions.* Aeon Report Series No 2, 2010, 46pp.

DEA (Department of Environmental Affairs) (2010) *Environmental Sector Skills Plan for South Africa.* Department of Environmental Affairs, Pretoria.

DEAN, W.R.J. 2000. Alien birds in southern Africa: what factors determine success? *South African Journal of Science* 96: 9–14.

DEAN, W.R.J., ANDERSON, M.D., MILTON, S.J. & ANDERSON, T.A. 2002. Avian assemblages in native *Acacia* and alien *Prosopis* drainage line woodland in the Kalahari, South Africa. *Journal of Arid Environments* 51: 1–19.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2000. http://soer/deat/gov/za/themes/land/land use and productivity. South African Department of Environmental Affairs and Tourism, Pretoria.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2000. *White paper on Integrated pollution and waste management for South Africa.* South African Department of Environmental Affairs and Tourism, Pretoria. http://www.deat.gov.za/PolLeg/WhitePapers/20978.pdf.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2003. *Climate Change responsibility in South Africa.* South African Department of Environmental Affairs and Tourism, Pretoria. http://www.deat.gov.za/Documents/Documents/2003May26/climate_change_sa_responsibility_26052003.html.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2004a. *Initial National Communication*. South African Department of Environmental Affairs and Tourism, Pretoria.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2004b. *A National Climate Change Response Strategy for South Africa*. South African Department of Environmental Affairs and Tourism, Pretoria.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2005a. *Action for Climate Change*. Conference Statement, South African Department of Environmental Affairs and Tourism, Pretoria..

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2005b. *South Africa's National Biodiversity Strategy and Action Plan.* South African Department of Environmental Affairs and Tourism, Pretoria.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2006. *South Africa environment outlook: A report on the state of the environment*. South African Department of Environmental Affairs and Tourism, Pretoria.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM. 2007. *State of the Environment report*. South African Department of Environmental Affairs and Tourism, Pretoria. http://soer.deat.gov.za/58/_2517.html.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2009a. State of the Environment (SOE) Report. South African Department of Environmental Affairs and Tourism, Pretoria. http://soer.deat.gov.za/themes/land/land_reform; http://www.nbi.ac.za.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM) & SANBI (SOUTH AFRICAN NATIONAL BIODIVERSITY INSTITUTE). 2009b. *National Protected Area Expansion Strategy for South Africa*: 55. South African National Biodiversity Institute, Pretoria.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2009c. *National Greenhouse Gas Inventory South Africa: 1990–2000*. South African Department of Environmental Affairs and Tourism, Pretoria.

DEAT (DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM). 2009d. *National Climate Change Response Database*. Department of Environment Affairs and Tourism, Pretoria.

DE KLERK, M., DRIMIE, S., ALIBER, M., MINI, S., MOKOENA, R., RANDELA, R., MODISELLE, S., VOGEL, C., DE SWARDT, C. & KIRSTEN, J. 2004. *Food security in South Africa: key policy issues for the medium term.* Position paper for the National Treasury.

DE KOCK, K.N. & WOLMARANS, C.T. 1998. A re-evaluation of the occurrence of freshwater molluscs in the Kruger National Park. *Koedoe* 41: 1–8.

DE MOOR, I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

DE VILLIERS, M.C., ELOFF, J.F., BARNARD, R.O., MULIBANA, E., MKHIZE, S. & MSOMI, B. 2005. *Land and water management: South African country situational analysis*. Workshop Proceedings1: 93–112.

DE WAAL, A. & WHITEHEAD, A. 2003. New variant famine: AIDS and food crises in Southern Africa. *Lancet* 362: 1234–1237.

DE WIT, M.P., CROOKES, D.J. & VAN WILGEN, B.W. 2001. Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion. *Biological Invasions* 3: 167–178.DENNILL, G.B. & GORDON, A.J. 1990. Climate-related differences in the efficacy of the Australian gall wasp (Hymenoptera: Pteromalidae) released for the control of *Acacia longifolia* in South Africa. *Environmental Entomology* 19: 130–136.

DE WIT, M. & STANKIEWICZ, J. 2006. Changes in Surface Water Supply Across Africa with Predicted Climate Change. *Science* 311:1917-1921.

DEPARTMENT OF EDUCATION. 2009. *Trends in education macro indicators report*. Pretoria, South Africa.

DFID (DEPARTMENT FOR INTERNATIONAL DEVELOPMENT). 2001. *The potential for integrating DFID-funded*.

DFID (DEPARTMENT FOR INTERNATIONAL DEVELOPMENT). 2006. *Livelihoods Guidance Sheets*. http://www.livelihoods.org/info/info_guidancesheets.htm.

DEPARTMENT OF AGRICULTURE. 2007. *Discussion document: Climate change and the agricultural sector in South Africa*.

DEPARTMENT OF ENVIRONMENTAL AFFAIRS AND DEVELOPMENT PLANNING (DEA&DP). 2008. *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.

DEPARTMENT OF HEALTH (DOH). 2009. *Annual Report 2008/9*. Pretoria. http://www.doh.gov.za/docs/reports/annual/2009.

DESMET, P., GOODMAN, P., HARRIS, J., JONAS, Z., REYERS, B., SINK, K. & STRAUSS, T. 2005. National Spatial Biodiversity Assessment 2004: Priorities for Biodiversity Conservation in South Africa. *Strelitzia* 17. South African National Biodiversity Institute, Pretoria.

DFPT (DECIDUOUS FRUIT PRODUCERS' TRUST). 2006. *The Fruit Industry Plan: An overview and summary*. A study commissioned by Fruit SA. www.fip.co.za.

DFPT (DECIDUOUS FRUIT PRODUCERS' TRUST). 2007. *Key Deciduous Fruit Statistics*. Deciduous Fruit Producers' Trust, Paarl.

DIAZ, H.F., HOERLING, M.P. & EISCHEID, J.K. 2001. ENSO variability, teleconnections and climate change*. International Journal of Climatology* 21: 1845–1862.

DIDHAM, R.K., TYLIANAKIS, J.M., HUTCHISON, M.A., EWERS, R.M. & GEMMELL, N.J. 2005. Are invasive species the drivers of ecological change? *Trends in Ecology & Evolution* 20: 470–474.

DiMP (DISASTER MITIGATION FOR SUSTAINABLE DEVELOPMENT PROGRAMME). 2003. *March 2003 Cut-off Low: Consolidated Report*. Unpublished report prepared for the Department of Social Services and Poverty Alleviation of the Provincial Government of the Western Cape, University of Cape Town, Cape Town.

DiMP (DISASTER MITIGATION FOR SUSTAINABLE DEVELOPMENT PROGRAMME). 2004. *Pilot Study on the socio-economic impact of disasters: 1994–2004.* University of Cape Town, Cape Town.

DiMP (DISASTER MITIGATION FOR SUSTAINABLE DEVELOPMENT PROGRAMME). 2004. *Report on Fire Occurrence and Loss: Cape Town Metropolitan Area 1995–1999*. University of Cape Town., Cape Town.

DiMP (DISASTER MITIGATION FOR SUSTAINABLE DEVELOPMENT PROGRAMME). 2005. *August 2004 Severe Storm Post Flood Assessment*, Prepared for Directorate of Transport, Roads and Stormwater, City of Cape Town. Prepared by the Disaster Mitigation for Sustainable Livelihoods Programme (DiMP), University of Cape Town, Cape Town.

DiMP (DISASTER MITIGATION FOR SUSTAINABLE DEVELOPMENT PROGRAMME). 2005. *South Coast Debriefing—December 2004 Cut-off Low*. Unpublished report, University of Cape Town, Cape Town.

DiMP (DISASTER MITIGATION FOR SUSTAINABLE DEVELOPMENT PROGRAMME). 2007. *Severe Weather-Compound Disaster: August 2006 Cut-off Lows and their Consequences in the Southern Cape, South Africa*. Unpublished report prepared for the National Department of Public Works and Transport and the Department of Local Government and Housing, the Provincial Government of the Western Cape, University of Cape Town, Cape Town.

DiMP (DISASTER MITIGATION FOR SUSTAINABLE DEVELOPMENT PROGRAMME 2010. *RADAR: Western Cape 2009* - Risk and Development Annual Review, Western Cape 2010

DME (DEPARTMENT OF MINERALS AND ENERGY). 1998. *White Paper on the Energy Policy of the Republic of South Africa*. http://www.dme.gov.za/pdfs/energy/planning/wp_energy_policy_1998.pdf.

DME (DEPARTMENT OF MINERALS AND ENERGY). 2003a. *Integrated Energy Plan. For The Republic of South Africa*. http://www.dme.gov.za/pdfs/energy/planning/integrated_energy_plan_dec03.pdf.

DME (DEPARTMENT OF MINERALS AND ENERGY). 2003b. *White paper on renewable energy*. Pretoria.

DME (DEPARTMENT OF MINERALS AND ENERGY). 2006. *Digest of South African Energy Statistics*. http://www.dme.gov.za/pdfs/energy/planning/2006%20Digest.pdf.

DME (DEPARTMENT OF MINERALS AND ENERGY). 2007. *Biofuels Industrial Strategy of the Republic of South Africa.* Pretoria.

DME (DEPARTMENT OF MINERALS AND ENERGY). 2009. National Energy Efficiency Strategy of the Republic of South Africa. *Government Gazette of the Republic of South Africa*: 543.

DoA (Department of Agriculture) 2002. Census of commercial agriculture: Financial and production statistics http://www.statssa.gov.za/publications/Report-11-02-01/CorrectedReport-11-02-01.pdf

DoE (DEPARTMENT OF ENERGY) 2009. Department: Minerals and Energy annual report 08/09 http://www.energy.gov.za/files/media/ar/ar2009.pdf

DoH (Department of Health) 2007. Malaria day reports, Africa Malaria Day: South Africa records major decrease in Malaria cases. http://www.doh.gov.za/show.php?id=1697

DoH (DEPARTMENT OF HEALTH). 2008. *Integrated Nutrition Programme*. http://www.doh.gov.za/programmes/nutrition.

DPLG (DEPARTMENT OF PROVINCIAL & LOCAL GOVERNMENT). 2008. *National Disaster Management Centre: Inaugural Annual Report 2006/2007*. Pretoria.

Draft MDG Report (Draft Millennium Development Goals Country Report) 2010. http://www.statssa.gov.za/news_archive/Docs/MDGR_2010.pdf

DRAKE, B.G., GONZÀLEZ-MELER, M.A. AND LONG S.P. 1997. More efficient plants: a consequence of rising atmospheric CO2? *Annual Review of Plant Physiology and Plant Molecular Biology* 48: 609–639.

DRINKWATER, K.F., BEAUGRAND, G., KAERIYAMA, M., KIM, S., OTTERSEN, G., PERRY, R.I., PÖRTNER, H.-O., POLOVINA, J.J. & TAKASUKA, A. 2010. On the processes linking climate to ecosystem changes. *Journal of Marine Systems* 79: 374–388.

DRIVER, A., DESMET, P., ROUGET, M., COWLING R.M. & MAZE, K. 2003. *Succulent Karoo Ecosystem Plan.Biodiversity Component Technical Report*: 153. Cape Conservation Unit.

DRIVER, A., MAZE, K., ROUGET, M., LOMBARD, A.T., NEL, J.L., TURPIE, J.K., COWLING, R.M., DESMET, P., GOODMAN, P., HARRIS, J., JONAS, Z., REYERS, B., SINK, K. & STRAUSS, T. 2005. National spatial biodiversity assessment 2004: priorities for biodiversity conservation in South Africa. *Strelitzia* 17: 1–45.

DST (DEPARTMENT OF SCIENCE AND TECHNOLOGY). 2007. *South Africa's Climate Change Technology Needs Assessment: Synthesis Report.* Department of Science and Technology, Pretoria.

DST (DEPARTMENT OF SCIENCE AND TECHNOLOGY). 2010. *South African Global Change Research Plan*. Pretoria.

DST (DEPARTMENT OF SCIENCE AND TECHNOLOGY). 2010. *South African Risk and Vulnerability Atlas*. Pretoria.

DUDZAI, M. 2005. *Experience and exposure to fire risk: A comparison of Langa/Joe Slovo residents in hostels and those in wooden emergency houses*. Thesis. Department of Environmental Science and Geography. University of Cape Town.

DU PREEZ, H., & BAALEN, L. 2006. Generic incident management framework for toxic blue-green algal blooms, for application by potable water suppliers. *Water Research Commission report*: TT 263/06.65.

DURAIAPPAH, A., NAEEM, S., AGARDI, T., ASH, N., COOPER, D., DÍAZ, S., FAITH, D.P., MACE, G., MCNEILLY, J.A., MOONEY, H.A., OTENG-YEBOAH, A.A., PEREIRA, H.M., POLASKY, S., PRIP, C., REID, W.V., SAMPER, C., SCHEI, P.J., SCHOLES, R., SCHUTYSER, F. & VAN JAARSVELD, A. 2005. *Ecosystems and human well-being: biodiversity synthesis*: 100. Island Press, Washington DC.

DU TOIT, A.S., PRINSLOO, M.A., DURAND, W. & KIKER, G. 1999. *Vulnerability of maize production to climate change and adaption assessment in South Africa*. Agricultural Research Council—Grain Crops Institute, Potchefstroom.

DU TOIT, A.S., PRINSLOO, M.A., DURAND, W. & KIKER, G. 2002. *Vulnerability of maize production to climate change and adaptation in South Africa.* Combined Congress: South African Society of Crop Protection and South African Society of Horticultural Science, Pietermaritzburg.

DVORAK, W.S., LAMBETH, C.C. & BAILIAN, L.P. 1993. Genetic and site effects on stem breakage in *Pinus tecunumanii*. *New Forests* 7: 237–253.

DWAF (Department of Water Affairs & Forestry) 1998a. *Minimum requirements for waste disposal by landfill*, Second Edition, Waste management Series. Department of Water Affairs and Forestry, Republic of South Africa.

DWAF (Department of Water Affairs & Forestry) 1998b. *Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste*, Second Edition, Waste management Series. Department of Water Affairs and Forestry, Republic of South Africa.DWAF (Department of Water Affairs & Forestry) (2004) National Water Resources Strategy, 1st edition, September 2004. Department of Water Affairs and Forestry, Pretoria.

DWAF (Department of Water Affairs & Forestry) 1998c. *Minimum requirements for water monitoring at waste management facilities*, Second Edition, Waste management Series. Department of Water Affairs and Forestry, Republic of South Africa.

DWAF (DEPARTMENT OF WATER AFFAIRS & FORESTRY). 2004. *National Water Resources Strategy, 1st edition*. Department of Water Affairs and Forestry, Pretoria.

DWAF (Department of Water Affairs and Forestry) 2004a. Integrated Water Resources Management: Guidelines for groundwater resources management in water management areas, South Africa http://www.iwrm.co.za/resource%20doc/irwm%201/Groundwater/Groundwater%20Resources/GUIDELINES%20FOR%20GROUNDW%20RESOURCES%20MANAGEMENT%20LEVEL%201.pdf

DWAF (DEPARTMENT OF WATER AFFAIRS & FORESTRY). 2005. *Groundwater Resource Assessment, Phase II: Methodology. Groundwater-surface water interactions*. Department of Water Affairs and Forestry. DWAF (Department of Water Affairs and Forestry) (2009) Strategy and Guideline Development for National Groundwater Planning Requirements: A proposed GRA3 Methodology http://www.dwa.gov.za/Groundwater/Documents/GRA3Methodology.pdf

DWAF Timber Statistics Report (Department of Water Affairs and Forestry) 2005. Report on commercial timber resources and primary roundwood processing in South Africa http://ebookbrowse.com/timber-statistics-report-2005-final-pdf-d34557858

DWAF (DEPARTMENT OF WATER AFFAIRS & FORESTRY). 2007. *Timber Statistics Report 2006/7*. Forestry Economics Services CC. http://www.saasta.ac.za/antarctica/about.shtml.

DWEA (DEPARTMENT OF WATER AND ENVIRONMENTAL AFFAIRS). 2009. *Water Services National Information System (WS NIS)*. www.dwaf.gov.za/dir_ws/wsnis/.

EASTERLING, D., MEEHL, G., PARMESAN, C., CHANGNON, S., KARL, T. & MEARNS, L. 2000. Climate Extremes: Observations, Modeling, and Impacts. *Science* 289.

EBERHARD, A.A. 2006. *A study on the feasibility of establishing an independent regulator in the water services sector in South Africa, Output 3: Assessment methodology and model*, DWAF, February 2006.

EBERHARD A.A. & WILLIAMS, A.T. (eds) (1988) *Renewable Energy Sources and Technological Development in Southern Africa.* Elan Press, Cape Town

EDWARDS, M.S. 2004. Estimating scale-dependency in disturbance impacts: El Niños and giant kelp forests in the northeast Pacific. *Oecologia* 138: 436–447.

EELEY, H.A.C., LAWES, M.J. & PIPER, S.E. 1999. The influence of climate change on the distribution of indigenous forest in KwaZulu-Natal, South Africa. *Journal of Biogeography* 26: 595–617.

EIA (ENERGY INFORMATION ADMINISTRATION). 2007. *Country Analysis Briefs: South Africa*. Department of Energy, Washington DC. http://www.eia.doe.gov/emeu/cabs/South_Africa/pdf.pdf.

EIA (ENERGY INFORMATION ADMINISTRATION). 2008. *World Proved Reserves of Oil and Natural Gas, Most Recent Estimates*. http://www.eia.doe.gov/emeu/international/reserves.html.

EIA (ENERGY INFORMATION ADMINISTRATION). 2010*. Country Analysis Briefs: South Africa*. US Department of Energy. http://www.eia.doe.gov/emeu/cabs/South_Africa/Background.html.

ELLIOTT, M. 2002. An overview of the status, study and management of fishes in estuaries. In: M. Elliot & K.L. Hemingway (eds), *Fishes in estuaries*: 553–575. Blackwell Science, Oxford.

ELLIS, F. 2000. *Rural Livelihoods and Diversity in Developing Countries*. Oxford University Press, Oxford.

ENERGY MINISTER'S BUDGET SPEECH. 2009. http://www.pmg.org.za/briefing/20090623-energy-ministers-budget-speech.

ENGELBRECHT F.A., MCGREGOR J.L. & ENGELBRECHT C.J. 2009. Dynamics of the conformal-cubic atmospheric model projected climate-change signal over southern Africa. *International Journal of Climatology* 29: 1013–1033.

ENVIRONMENTAL RESOURCES MANAGEMENT (ERM), 2005. *Natural Disaster and Disaster Risk Reduction Measures*. http://www.dfid.gov.uk/Documents/publications/disaster-risk-reduction-study.pdf.

ERASMUS, B.F.N., VAN JAARSVELD, A.S., CHOWN, S.L., KSHATRIYA, M. & WESSELS, K.J. 2002. Vulnerability of South African animal taxa to climate change. *Global Change Biology* 8: 679–693.

ERC (ENERGY RESEARCH CENTRE). 2007. *Long Term Mitigation Scenarios: Technical summary*. Department of Environment Affairs and Tourism, Pretoria. http://www.erc.uct.ac.za/Research/LTMS/LTMS-intro.htm Accessed 30 October 2008.

ERIKSEN, S., O'BRIEN, K. & ROSENTRATER, L. 2007. *Climate Change in Eastern and Southern Africa: Impacts, Vulnerability and Adaptation.* Presentation made at the Department of Sociology and Human Geography (ISS), University of Oslo.

ESKOM. 2008. *Annual Report 2008*. Eskom, Johannesburg. http://financialresults.co.za/eskom_ar 2008/ar_2008/downloads.htm.

EVANS, K.L., VAN RENSBURG, B.J., GASTON, K.J. & CHOWN, S.L. 2006. People, species richness and human population growth. *Global Ecology & Biogeography* 15: 625–636.

FAIRBANKS, D.H.K. & SCHOLES, R.J. 1999. South African Country Study on Climate Change: Vulnerability and Adaptation Assessment for Plantation Forestry. *CSIR Environmentek Report ENV/C/99*. National Research Facility, Sustainable Development Program, Pretoria.

FAUCHEREAU, N., TRZASKA, S., RICHARD, Y., ROUCOU, P. & CAMBERLIN, P. 2003. Sea surface temperature co-variability in the southern Atlantic and Indian Oceans and its connections with the atmospheric circulation in the Southern Hemisphere. *International Journal of Climatology* 23: 663–677.

FAWZI, W., MSAMANGA, G., SPIEGELMAN, D. & HUNTER, D. 2005. *The challenge of nutrition and HIV/AIDS.* www.jn.nutrition.org.

FISCHLIN, A., MIDGLEY, G.F., PRICE, J.T., LEEMANS, R., GOPAL, B., TURLEY, C. ROUNSEVELL, M.D.A., DUBE, O.P., TARAZONA, J. & VELICHKO, A.A. 2007. Ecosystems, their properties, goods, and services. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability*: 102. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge.

FLETCHER IMPORTANCE OF BIOAEROLOSISED INFECTIONS. undated. www.efm.leeds.ac.uk/CIVE/aerobiology/PDFs/uv-and-airborne-hospital-infection-fletcher.pdf.

FLORENCHIE, P., REASON, C.J.C., LUTJEHARMS, J.R.E., ROUAULT, M. & ROY, C. 2004. Evolution of interannual warm and cold events in the southeast. *Journal of Climate* 17: 2318–2334.

FOCUS SOUTH AFRICA. 2009. Publication for political and socio-economic issues in South Africa http://www.fes.org.za/publications/Focus_South_Africa/fokus_sa_01_09_eng.pdf.

FODEN, W., MIDGLEY, G.F., HUGHES, G., BOND, W.J., THUILLER, W., HOFFMAN, M.T., KALEME, P., REBELO, A., UNDERHILL, L.G. & HANNAH, L. 2007. A changing climate is eroding the geographical range of the Namib Desert tree Aloe through population declines and dispersal lags. *Diversity & Distributions* 13: 645–653.

FORSYTH, G.G., VAN WILGEN, B.W., SCHOLES. R.J., LEVENDAL, M.R., BOSCH, J.M. JAYIYA, T.P & LE ROUX, M. 2006. Integrated Veldfire Management in South Africa: An assessment of the current conditions and future approaches. Report to the Working on Fire Programme. *CSIR Report*: CSIR/NRE/ECO/ER/2006/0064/C.

FRANCIS, E. 2000. *Rural Livelihoods, Institutions and Vulnerability in South Africa*. Development Studies Institute: London School of Economics and Political Science .

FROEBEL, K., HOWARD, W. SCHAFER, J.R., HOWIE, F., WHITWORTH, J., KALEEBU, J., BROWN, A.L. & RILEY, E. 2004. Activation by malaria antigens renders mononuclear cells susceptible to HIV infection and re-activates replication of endogenous HIV in cells from HIV-infected adults. *Parasite Immunology* 26: 213–217.

GAERTNER, M., DEN BREEŸEN, A., HUI, C. & RICHARDSON, D.M. 2009. Impacts of alien plant invasions on species richness in Mediterranean-type ecosystems: a meta-analysis. *Progress in Physical Geography* 33: 319–338.

GALIL, B.S., NEHRING, S. & PANOV, V. 2007. Waterways as invasion highways—impact of global climate change and globalization. In W. Nentwig (ed.), *Biological Invasions*: 59–74. Springer-Verlag, Berlin.

GANDHI, N., MOLL, A., STURM, W., PAWINSKI, R., GOVENDER, T., LALLOO, U., ZELLER, K., ANDREWS, J. & FRIEDLAND, G. 2006. Extensively drug-resistant tuberculosis as a cause of death in patients co-infected with tuberculosis and HIV in a rural area of South-Africa. *The Lancet Online*, DOI:10.1016/S0140-6736(06)69573-1.

GELDENHUYS, C.J. 1997. Native forest regeneration in pine and eucalypt plantations in Northern Province, South Africa. *Forestry Ecology and Management* 99: 101–115.

GELDENHUYS, C.J. 1998. Long-term monitoring plots show trends in the composition, growth and mortality of mixed evergreen forests in South Africa. In F. Dallmeier & J.R. Comiskey (eds), *Forest Biodiversity research, monitoring and modelling. Man and Biospehere* 20: 447–468. Parthenone Publishing, New York.

GELDENHUYS, C.J. 2000. The need for monitoring recruitment, growth and mortality in indigenous forests: Examples from Northern Province. In A.H.W. Seydack, W.J. Vermeulen & C. Vermeulen (eds), *Proceedings of the Natural Forests and Savannah Woodlands Symosium II* : 17–28. Knysna.

GITAY, H., SUÁREZ, A., WATSON, R.T. & DOKKEN, D.J. 2002. Climate change and biodiversity. Intergovernmental Panel on Climate Change, Geneva.

GLANTZ, M.H. 2001. *Currents of change: Impacts of El Nino and La Nina on climate and society*. Cambridge University Press, Cambridge.

GOLDMAN, J.S. RUBAMBEY, G., ASIAGO, J., KINGMAN, A. & GOLDMAN, I. 2010. Experience of "hybrid" organisations in promoting meaningful rural livelihoods: Lessons from Africa, India and the Americas. Conference paper presented at 'Overcoming inequality and structural poverty in South Africa: Towards inclusive growth and development Johannesburg, 20–22 September 2010

GOMMES, R., DU GUERNY, J., GLANTZ, M.H. & HSU, L. 2004. Climate and HIV/AIDS: *A hotspots analysis for Early Warning Rapid Response Systems*. A joint publication of the UNDP, FAO and NCAR.

GÖRGENS A.H.M. & B.W. VAN WILGEN, B.W. 2004 Invasive alien plants and water resources in South Africa: current understanding, predictive ability and research challenges. *South African Journal of Science* 100:27-33.

GOVERNMENT OF SOUTH AFRICA. 2010. *National Protected Area Expansion Strategy 2008: Priorities for expanding the protected area network for ecological sustainability and climate change adaptation.* Government of South Africa, Pretoria.

GREGORY, P.J., INGRAM, J.S.I., CAMPBELL, B., GOUDRIAAN, J., HUNT, L.A., LANDSBERG, J.J., LINDER, S., STAFFORD SMITH, M., SUTHERST, R.W., & VALENTIN, C. 1999. Managed production systems. In B. Walker, W. Steffen, J. Canadell & J.S.I. Ingram (eds), *The terrestrial biosphere and global change: implications for natural and managed systems*: 229–270, Cambridge University Press, Cambridge.

GRIFFITHS, C.L., ROBINSON, T.B. & MEAD, A. 2009. The status and distribution of marine alien species in South Africa. In G. Rilov & J.A. Crooks (eds), *Biological Invasions in Marine Ecosystems*: 393–407. Springer Verlag, Heidelberg, Berlin.

GRIFFITHS, C.L., ROBINSON, T.B. LANGE L., & MEAD,A. 2010. Marine Biodiversity in South Africa: An Evaluation of Current States of Knowledge. *PLoS ONE* 5:e12008.

GROSS, R., DOUGHERTY, W. & KUMARSINGH, K. 2004. *Conducting Technology Needs Assessments for Climate Change*. UNDP, New York.

GRUNDLING, A.T. 2008. Developing practical (wise) use guidelines for sustainable agricultural practices in wetlands based on available knowledge and information. *ARC-ISCW report no.*: GW/A/2007/135.

GRÜNDLINGH, M.L. 1993. On the satellite-derived wave climate off southern Africa. *South African Journal of Marine Science* 13: 223–235.

GRÜNDLINGH, M.L. 1994. Evidence of surface wave enhancement in the southwest Indian Ocean from satellite altimetry. *Journal of Geophysical Research* 99: 7917–7927.

GUASTELLA, L.A. & ROSSOUW, M. 2009. *Trends in frequency and intensity of coastal storms along the KwaZulu-Natal coast?* KwaZulu-Natal Marine and Coastal Management Research Symposium, Durban.

GUISAN, A. & THUILLER, W. 2005. Predicting species distribution: offering more than simple habitat models. *Ecology Letters* 8: 993–1009.

GUISAN, A. & ZIMMERMANN, N.E. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling* 135: 147–186.

HALSNAES, K., CALLAWAY, J.M. & MEYER, H.J. 1998. *Economics of greenhouse gas limitations: Technical guidelines. Draft February '98*. UNEP Collaborating Centre on Energy and Environment, Roskilde.

HANNAH, L. & LOVEJOY, T.E. 2003. Climate change and biodiversity: synergistic impacts. *Advances in Applied Biodiversity Science*: 1–123.

HANNAH, L., MIDGLEY, G.F., HUGHES, G. & BOMHARD, B. 2005. The view from the Cape: Extinction risk, protected areas and climate change. *Bioscience* 55: 231–242.

HANNAH, L., MIDGLEY, G.F. & MILLAR, D. 2002. Climate change-integrated conservation strategies. *Global Ecology and Biogeography* 11: 485–495.

HAUPT C.J. 2001. Water Resources Situation Assessment. Directorate of Water Resources Planning. DWAF. Compiled by WSM Engineers.

HARDING, G.B. & BATE, G.C. 1991. The occurrence of invasive *Prosopis* species in the north-western Cape, South Africa. *South African Journal of Science* 87: 188–192.

HARLEY, C.D.G., HUGHES, A.R., HULTGREN, K.M., MINER, B.G., SORTE, C.J.B., THORNBER, C.S., RODRIGUEZ, L.F., TOMANEK, L. & WILLIAMS, S.L. 2006. The impacts of climate change in coastal marine systems. *Ecology Letters* 9: 228–241.

HARRIS, L.R. 2008. *The ecological implications of sea-level rise and storms for sandy beaches in KwaZulu-Natal.* MSc thesis, University of KwaZulu-Natal.

HARRISON, D. 2009. *An overview of health and health-care in South-Africa 1994–2010: priorities, progress and prospects for new gains*. A discussion document commissioned by the Henry J. Kaiser Family Foundation to help inform the national health-leaders' retreat in Muldersdrift, January 24–26 2010. www.doh.sa.za.

HASSAN, R., SCHOLES, R. & ASH, N. 2005. *Ecosystems and human well-being, volume 1: current state & trends.* Island Press, Washington, DC.

HELMUTH, B., MIESZKOWSKA, N., MOORE, P. & HAWKINS, S.J. 2006. Living on the edge of two changing worlds: forecasting the responses of intertidal rocky ecosystems to climate change. Annual Review of Ecology. *Evolution and Systematics* 37: 373–404.

HEWITSON, B., RAUTENBACH, C.J., DEW, ROUAULT, M., TADROSS, M. & COOP, L. 2009. *Observed trends and future projections of the South African regional climate.* Second National Communication.

HEWITSON, B.C. & CRANE, R.G. 2006. Consensus between GCM climate change projections with empirical downscaling. *International Journal of Climatology* 26: 1315–1337.

HIGGINS, S.I., BOND, W.J. & TROLLOPE, W.S.W. 2000. Fire, resprouting and variability: a recipe for grass-tree coexistence in savanna. *Journal of Ecology* 88: 213–229.

HILL, M.P. 2003. The impact and control of alien aquatic vegetation in South African aquatic ecosystems. *African Journal of Aquatic Science* 28: 19–24.

HOBBS, R.J. & MOONEY, H.A. 2005. Invasive species in a changing world: the interactions between global change and invasives. In H.A. Mooney, R.N. Mack, J.A. McNeely, L.E.

Neville, P.J. Schei & J.K. Waage (eds), *Invasive alien species: a new synthesis*: 310–331. Island Press, Washington DC.
HOCKEY, P.A.R. & MIDGLEY, G.F. 2009. Avian range changes and climate change: a cautionary tale from the Cape Peninsula. *Ostrich* 80: 29–34.
HOEGH-GULDBERG, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research* 50: 867–878.
HOFFMAN, T. & VOGEL, C. 2008.Climate Change Impacts on African Rangelands.*Rangelands* 30: 12–17.
HOFFMAN, M. T., CRAMER, M.D., GILLSON, L. & WALLACE. M 2011. Pan evaporation and wind run decline in the Cape Floristic Region of South Africa (1974–2005): implications for vegetation responses to climate change. *Climatic Change*. DOI 10.1007/s10584-011-0030-z
HOLLOWAY, A. & ROOMANEY, R. 2008. *Weathering the Storm: Participatory Risk Assessment in Informal Settlements.* Periperi Publications, Cape Town.
HOLLOWAY, A., FORTUNE, G. & CHASI, V. 2010. RADAR Western Cape, 2010, *Risk and Development Annual Review.* Disaster Mitigation for Sustainable Livelihoods Programme (DiMP).
HOLMGREN, K., KARLIEN, W., LAURITZEN, S.E., LEE-THORP, J.A., PARTRIDGE, T.C., PIKETH, S., REPINSKI, P., STEVENSON, C., SVANERED, O. & TYSON, P.D. 1999. A 3000-year high-resolution record of palaeoclimate for north-eastern South Africa. *The Holocene* 9:295–309.
HUANG, D., GUAN, P., GUO, J., WANG, P. & ZHOU, Z. 2008. Investigating the effects of climate variations on bacillary dysentery incidence in northeast China using ridge regression and hierarchical cluster analysis. *BMC Infectious Diseases* 8: 130.
HUGHES, A., HAW, M., WINKLER, H., MARQUARD, A. & MERVEN, B. 2007. *Energy emissions: A modelling input into the Long Term Mitigation Scenarios process.* Prepared by the Energy Research Centre for Department of Environment Affairs and Tourism, Pretoria.
HUGHES, L. 2000. Biological consequences of global warming: is the signal already apparent? *Trends in Ecology and Evolution* 15: 56–61.
HUGHES, P. & BRUNDRIT, G.B. 1991. The vulnerability of the False Bay coast line to the projected rise in sea level. *Transactions of the Royal Society of South Africa* 47: 519–534.
HUGHES, P. & BRUNDRIT, G.B. 1992. An index to assess South Africa's vulnerability to sea level rise. *South African Journal of Science* 88: 308–311.
HUGHES, P., BRUNDRIT, G.B. & SHILLINGTON, F.A. 1991. South African sea-level measurements in the global context of sea-level rise. *South African Journal of Science* 87: 447–453.
HUGHES, P., BRUNDRIT, G.B., SWART, D.H. & BARTELS, A. 1993. The possible impacts of sea-level rise on the Diep River/Rietvlei system, Cape Town. *South African Journal of Science* 89: 488–493.
HUGHES, T.P., BAIRD, A.H., BELLWOOD, D.R., CARD, M., CONNOLLY, S.R., FOLKE, C., GROSBERG, R., HOEGH-GULDBERG, O., JACKSON, J.B.C., KLEYPAS, J., LOUGH, J.M., MARSHALL, P., NYSTRÖM, M., PALUMBI, S.R., PANDOLFI, J.M., ROSEN, B. & ROUGHGARDEN, J. 2003. Climate change, human impacts, and the resilience of coral reefs. *Science* 301: 929–933.
HULME, M. 1996. Climate Change and Southern Africa. *A Report commissioned by WWF International*. Climatic Research Unit, University of East Anglia, Norwich.
HULME, M., DOHERTY, R., NGARA, T., NEW, M. & LISTER, D. 2001. African climate change: 1900-2100. *Climate Research* 17: 145–168.
HULME, P.E., BACHER, S., KENIS, M., KLOTZ, S., KÜHN, I., MINCHIN, D., NENTWIG, W., OLENIN, S., PANOV, V., PERGL, J., PYŠEK, P., ROQUES, A., SOL, D., SOLARZ, W. & VILÁ, M. 2008. Grasping at the routes of biological invasions: a framework for integrating pathways into policy. *Journal of Applied Ecology* 45: 403–414.
HUMAN SCIENCES RESEARCH COUNCIL. 2004. Poverty in South Africa. http://www.sarpn.org.za/documents/d0000990/.

HUTCHINGS, L., ROBERTS, M.R. & VERHEYE, H.M. 2009. Marine environmental monitoring programmes in South Africa: a review. *South African Journal of Marine Science* 105: 94–102.

HUTCHINGS, L., VAN DER LINGEN, C.D., SHANNON, L.J., CRAWFORD, R.J.M., VERHEYE, H.M.S., BARTHOLOMAE, C.H., VAN DER PLAS, A.K., LOUW, D., KREINER, A., OSTROWSKI, M., FIDEL, Q., BARLOW, R.G., LAMONT, T., COETZEE, J., SHILLINGTON, F., VEITCH, J., CURRIE, J.C. & MONTEIRO, P. in press. The Benguela Current: an ecosystem of four components. *Progress in Oceanography*.

IMF (INTERNATIONAL MONETARY FUND) 2010. World Economic Outlook Database 2010 World Economic and Financial Surveys http://www.imf.org/external/pubs/ft/weo/2010/02/weodata/index.aspx

IOL. 2009. *Opinion/Analysis: Clean power sector needs reply to loss of mine jobs*. http://www.busrep.co.za/index.php?fArticleId=5002670.

IPCC (INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE). 1996. *Revised 1996 guidelines for national greenhouse gas inventories.* Organisation for Economic Co-operation and Development, Paris. http://www.ipcc-nggip.iges.or.jp/public/gl/invs2.html

IPCC (INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE). 1997. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Vols. I-III, OCED, IEA, 1997*. http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html.

IPCC (INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE). 2001. Climate Change 2001: Mitigation. In B. Metz, O. Davidson, R. Swart & J. Pan (eds), *Contribution of WG III to the Third Assessment Report of the IPCC.* Cambridge University Press for Intergovernmental Panel on Climate Change, Cambridge.

IPCC (INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE). 2000. In R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, & D.J. Dokken (eds). Cambridge University Press, Cambridge.

IPCC (INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE). 2006. Intergovernmental Panel on Climate Change. In H.S. Eggleston, L. Buenida, K. Miwa, T. Ngara & K. Tanabe (eds), *2006 IPCC Guidelines for National Greenhouse Gas Inventories. The National Greenhouse Gas Inventories Programme.* Institute for Global Environmental Strategies (IGES), Hayama, Kanagawa.

IPCC (INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE). 2007. Climate change 2007—Impacts, adaptation and vulnerability. In M. Parry, O. Canziani, J. Palutikof & P. van der Linden (eds), *Contribution of Working Group II to the Assessment Report Four of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge University Press, Cambridge.

IPCC (INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE). 2007. *Climate Change 2007: Mitigation of Climate Change.* Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva.

IPCC (INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE). 2007. Climate change 2007: The Physical Science Basis. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor & H. Miller (eds), *Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

IRP (INTEGRATED RESOURCE PLAN) 2010. Integrated resource plan for electricity. Draft Version 8, October 2010. http://www.doe-irp.co.za/content/INTEGRATED_RESOURCE_PLAN_ELECTRICITY_2010_v8.pdf

JACOB, D. & WINNER, D.A. 2009. Effects of climate change on air quality. *Atmospheric Environment* 49: 51–63.

JAGER, C.D.E., ANECK-HAHN, N.H., SCHULENBURG, G., FARIAS, P. & BORNMAN, M.S. 2006. DDT and Male Reproductive Health in Limpopo Province, South Africa. *Epidemiology* 17: 193–194.

JAMES, N.C., WHITFIELD, A.K. & COWLEY, P.D. 2008. Preliminary indications of climate-induced change in a warm-temperate South African estuarine fish community. *Journal of Fish Biolog*y 72: 1855–1863.

JEFFREY L.S. 2005. Characterization of the coal resources of South Africa. http://www.saimm.co.za/publications/downloads/v105n02p095.pdf.

JOHNSON, P.T.J., OLDEN, J.D. & VAN DER ZANDEN, M.J. 2008. Dam invaders: impoundments facilitate biological invasions into freshwaters. *Frontiers in Ecology & the Environment*6: 357–363.

JONES, P.G. & THORNTON, P.K. 2003. The potential impacts of climate change and maize production in Africa and Latin America in 2055. *Global Environmental Change* 13: 51–59.

JOUBERT, J.R. 2008. *An investigation of the wave energy resource on the South African coast, focusing on the spatial distribution of the south west coast*. MSc thesis, University of Stellenbosch.

JUMBE, C.B.L. 2007. *Will the growing demand for biofuels lead to food crisis?*Fanrpan www.fanrpan.org/documents/.../Biofuels_food_crisis_Jumbe_Nov2007.pps.

KABAT, P., VAN SCHAIK, H. & APPLETON, B. 2003. *Climate Changes the Water Rules: How Water Managers can Cope with Today's Climate Variability and Tomorrow's Climate Change*. Dialogue on Water and Climate, Wageningen.

KADO, R. & NANBA, N. 2006. *Balanus glandula*: a new alien barnacle from the west coast of North America, established on the northeast coast of Japan. In F. Koike, M.N. Clout, M. Kawamichi, M. de Poorter & K. Iwatsuki (eds), *Assessment and control of biological invasion risks*: 210–211. Shoukadoh Book Sellers, Kyoto and IUCN, Gland.

KALNAY, E., KANAMITSU, M., KISTLER, R., COLLINS, W., DEAVEN, D., GANDIN, L., IREDELL, M., SAHA, S., WHITE, G., WOOLLEN, J., ZHU, Y., LEETMAA, A., REYNOLDS, R., CHELLIAH, M., EBISUZAKI, W., HIGGINS, W., JANOWIAK, J., MO, K.C., ROPELEWSKI, C., WANG, J., JENNE, R. & JOSEPH, D. 1996. The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological* Society 77: 437–470.

KALWIJ, J.M., ROBERTSON, M.P. & VAN RENSBURG, B.J. 2008. Human activity facilitates altitudinal expansion of exotic plants along a road in montane grassland, South Africa. *Applied Vegetation Science* 11: 491–498.

KANZLER, A. 2002. *Genotype x Environment Interaction in* Pinus patula *and its Implications in South Africa.* PhD Thesis, Graduate Faculty of North Carolina State University.

KARJALAINEN, T. & ASIKAINEN, A. 1996. Greenhouse gas emissions from the use of primary energy in forest operations and long-distance transportation of timber in Finland. *Forestry* 69(3): 215–228.

KASHORTE, M. 2003. Moving subsistence fisheries to commercial fisheries in South Africa. Final Project Report. The United Nations University, Fisheries Training Program. Reykjavik, Iceland.

KAUFMANN, G.R., FERER, H., LEDERGERBER, B., PERRIN, L., OPRAVL, M., VENEZZA, P., CAVASSINI, M., BERNASCONI, E., RICKENBACH, M., HIRCHEL, B. & BETTEGAY, M. 2005. Swiss HIV Cohort Study. Characteristics, determinants and clinical relevance of CD4 T cell recovery to <500 in HIV type-1 infected individuals receiving potent antiretroviral therapy. *Clin Infectious Disease* 41: 361–371.

KEARNEY, M. 2008*. Long-term mitigation scenarios: Dynamic economy-wide modelling. Technical discussion document*. Energy Research Centre, Cape Town.

KEDDY, K.H., NADAN,S., GOVIND, C. & STURM, A.W. 2007. Evidence for a clonally different origin of the two cholera epidemics of 2001–2002 and 1980–1987 in South Africa. *Journal of Medical Microbiology* 56: 1644–1650.

KENNEDY, V.S. 1990. Anticipated effects of climate change on estuarine and coastal fisheries. *Fisheries* 15: 16–24.

KEUSCH, G.T. 2003. *Nutrition in infection. Progress since 1968.* Proceedings of Symposium of Nutrition. www.jn.nutrition.org.
KEVANY, S., MEINTJIES, G., REBE, K., MAARTENS, G. & CLEARY, S. 2009. Clinical and financial burdens of secondary level care in a public sector antiretroviral setting (G F Jooste Hospital). *South-African Medical Journal* 99: 320–325.
KGOPE, B.S., BOND, W.J. & MIDGLEY, G.F. 2010. Growth responses of African savanna trees implicate atmospheric [CO_2] as a driver of past and current changes in savanna tree cover. *Austral Ecology* 35: 451–463.
KHANDLELA, M. & MAY, J. 2006. Poverty, vulnerability and the impact of flooding in the Limpopo Province, South Africa. *Natural Hazards* 39: 375–387.
KING, J.R. & TSCHINKEL, W.R. 2008. Experimental evidence that human impacts drive fire ant invasions and ecological change. *Proceedings of the National Academy of Sciences of the USA* 105: 20339–20343.
KIRIGIA, J.M., SAMBO, L.G., YOKOUIDE, A., SOUMBEY-ALLEY, E., MUTHURI, L.K. & KIRIGIA, D.G. 2009. Economic burden of cholera in the WHO African region. *BMC International Health and Human Rights* 9: 8.
KLAGES, N.T.W. 2008. *Draft Strategic Environmental Assessment of the North End coastline.* Report prepared for the Nelson Mandela Bay Municipality, Arcus Gibb.
KLOPPER, E., VOGEL, C.H. & LANDMAN, W.A. 2005. Seasonal Climate Forecasts—potential agricultural risk management tools. *Climatic Change* 76: 73–90.
KNOESEN, D., SCHULZE, R.E., PRINGLE, C., SUMMERTON, M., DICKENS, C. & KUNZ, R. 2009. *Water for the future: impacts of climate change on water resources in the Orange-Senqu River basin. Report to NeWater, a project funded under the Sixth Research Framework of the European Union.* Institute of Natural Resources, Pietermaritzburg.
KNOWLES, A., ARCHER, E. & TADROSS, M. 2009. *Maputaland-Pondoland-Albany Biodiversity Hotpot Ecosystem Profile: Climate Change Assessment.* Report submitted to the Critical Ecosystems Partnership Fund, Cirrus Group.
KOELLE, K. 2009. The impact of climate on the disease dynamics of cholera. *Clinical Microbiology and Infection* 15: Supplement 1.
KOELLE, K. & PASCUAL, M. 2004. Disentangling extrinsic from intrinsic factors in disease dynamics: a nonlinear time series approach with an application to cholera. *American Naturalist* 163: 901–913.
KOELLE, K., RODO, X., PASCUAL, M., YUNUS, M. & MOSTAFA, G. 2005. Refractory periods and climate forcing in cholera dynamics. *Nature* 436: 696–700.
KOLAR, C.S. & LODGE, D.M. 2000. Freshwater nonindigenous species: interactions with other global changes. In H.A. Mooney & R.J. Hobbs(eds), *Invasive species in a changing world*: 3–30. Island Press, Washington DC.
KORNELIUS, G., MARQUARD, A. & WINKLER H. 2007. *Non-energy emissions—Industrial processes: An input into the Long Term Mitigation Scenarios process, LTMS Input Report 3*. Energy Research Centre, Cape Town.
KOTZE, D.C. & SILIMA, V. 2003. Wetland cultivation: Reconciling the conflicting needs of the rural poor and society at large through wise wetland use. *Journal Ecology and Environmental Sciences* 29(1): 85–88.
KRUGER, A.C. 2006. Observed trends in daily precipitation indices in South Africa: 1910–2004. *International Journal of Climatology* 26: 2275–2285.
KRUGER, A.C. & SHONGWE, S. 2004. Temperature trends in South Africa: 1960–2003. *International Journal of Climatology* 24: 1929–1945.
KRUGER, F.J., FORSYTH, G.G., KRUGER, L.M., SLATER, K., LE MAITRE, D.C. & MATSHATE, J. 2006. Classification of veldfire risk in South Africa for the administration of the legislation regarding fire management. In D.X. Viegas (ed.), *Conference Proceedings: 5th International Conference on Forest Fire Research*. Figueira da Foz (Coimbra), Portugal.

KÜSTNER, H.G.V. & DU PLESSIS, G. 1991. The cholera epidemic in South Africa 1980–1987. Epidemiological features. *South African Medical Journal* 79: 539–544.

LAIRD, M.C. & GRIFFITHS, C.L. 2008. Present distribution and abundance of the introduced barnacle *Balanus glandula* Darwin in South Africa. *African Journal of Marine Science* 30: 93–100.

LAKE, J. C. & LEISHMAN, M. R. 2004. Invasion success of exotic plants in natural ecosystems: the role of disturbance, plant attributes and freedom from herbivores. *Biological Conservation* 117: 215–226.

LANDMAN, W.A. & MASON, S.J. 1999. Change in the association between Indian Ocean sea-surface temperatures and summer rainfall over South Africa and Namibia. *International Journal of Climatology* 19: 1477–1492.

LANDMAN, W.A. & MASON, S.J. 2001. Forecasts of near-global sea surface temperatures using canonical correlation analysis. *Journal of Climate* 14: 3819–3833.

LAWN, S. & WOOD, R. 2007. When should antiretroviral treatment be started in patients with HIV-associated tuberculosis in South-Africa?*South-African Medical Journal* 97: 414–415.

LEAN, J.L., & RIND, D.H. 2008. How natural and anthropogenic influences alter global and regional surface temperatures: 1889 to 2006. *Geophysical Resources Letters* 35: L18701, doi:10.1029/2008GL034864.

LEE-THORP, A.M., ROUAULT, M. & LUTJEHARMS, J.R.E. 1998. Cumulus cloud formation above the Agulhas Current. *South African Journal of Science* 94: 351–354.

LEIMAN, A., STANDISH, B., BOTING, A. & VAN ZYL, H. 2007. Reducing the healthcare costs of urban air pollution: The South African experience. *Journal of Environmental Management* 84: 27–37.

LE MAITRE, D.C., RICHARDSON, D.M. & CHAPMAN, R.A. 2004. Alien plant invasions in South Africa: driving forces and the human dimension. *South African Journal of Science* 100: 103–112.

LE MAITRE, D.C., SCOTT, D.F. & COLVIN, C. 1999. Review of information on interactions between vegetation and groundwater. *Water SA* 25: 137–152.

LE ROUX, J. (compiler). 2002. The biodiversity of South Africa 2002. Struik, Cape Town.

LETSOALOA, A., REYERS, B., HUGHES, G., MIDGLEY, G.F., VON MALTITZ, G. & DE WIT, M. in preparation. *Economic cost of alternative conservation response options to climate change: the case of Cape Floral Region (CFR).*

LIAO, H., CHEN, W.T. & SEINFELD, J.H. 2006. Role of climate change in global predictions of future tropospheric ozone and aerosols. *Journal of Geophysical Research and the Atmosphere* 111: D12304.

LINDESAY, J.A. 1988. South African rainfall, the Southern Oscillation and a Southern Hemisphere semi-annual cycle. *International Journal of Climatology* 8: 17–30.

LOCKWOOD, J.L., CASSEY, P. & BLACKBURN, T.M. 2005. The role of propagule pressure in explaining species invasions. *Trends in Ecology & Evolution* 20: 223–228.

LOMBARD, A.T., STRAUSS, T., HARRIS, J., SINK, K., ATTWOOD, C. & HUTCHINGS, L. 2004. *South African National Spatial Biodiversity Assessment 2004: Technical Report Volume 4: Marine Component.* National Botanical Institute, Cape Town.

LOUW, J.H. & SCHOLES, M.C. 2006. Site index functions using site descriptors for *Pinus patula* plantations in South Africa. *Forest Ecology and Management* 225: 94–103.

LOVEJOY, T.E. & HANNAH, L. 2005. *Climate change and biodiversity*. Yale University Press, New Haven.

LUCAS, M.E.S., DEEN, J.L., VON SEIDLEIN, L., WANG, X-Y., AMPUERO, J., PURI, M., ALI, M., ANSARUZZAMAN, M., AMOS, J., MACUAMULE, A., CAVAILLER, P., GUERIN, P.J., MAHOUDEAU, C., KAHOZI-SANGWA, P., CHAIGNAT, C-L., BARRETO, A., SONGANE, F.F. & CLEMENS, J.D. 2005. Effectiveness of Mass Oral Cholera Vaccination in Beira, Mozambique. *New England Journal of Medicine* 352: 757–767.

LUTJEHARMS, J. R. E., 1996: *The exchange of water between the South Indian and the South Atlantic.* In The South Atlantic: Present and Past Circulation, eds G. Wefer, W. H. Berger, G. Siedler, and D. Webb, Springer-Verlag, Berlin, pp. 125-162.

LYNCH, S.D. 2003. *Development of a RASTER database of annual, monthly and daily rainfall for Southern Africa*. Report no. 1156/ 1/03. Water Research Commission, Pretoria, 78pp.

MACALLAN, D. 2009. Infection and malnutrition. *Medicine* 37: 525–528.

MACDONALD, I.A.W., REASER, J.K., BRIGHT, C., NEVILLE, L.E., HOWARD, G.W., MURPHY, S.J. & PRESTON, G. (eds) 2003. *Invasive alien species in southern Africa: national reports and directory of resources*. Global Invasive Species Programme. Cape Town.

MACGREGOR, H., BUCHER, N., DURHAM, C., FALCAO, M., MORRISSEY, J., SILVERMAN, I., SMITH, H. & TAYLOR, A. 2005. Hazard Profile and Vulnerability Assessment for Informal Settlements: An Imizamo Yethu Case Study with special reference to the Experience of Children. DiMP, University of Cape Town, Cape Town.

MACHUTCHON, K.R. 2006. The characterisation of South African sea etorms. MSc thesis, University of Stellenbosch.

MACK, R.N. 1996. Predicting the identity and fate of plant invaders: emergent and emerging approaches. *Biological Conservation* 78: 107–121.

MAENHAUT, W., SALMA, I., CAFMEYER, J., ANNEGARN, H.J. & ANDREAE, M.O. 1996. Regional atmospheric aerosol composition and sources in the eastern Transvaal, South Africa, and impact of biomass burning, Journal of Geophysical Resources101(D19): 23,631–23,650.

MAGADZA, C.H.D. 1994. Climate change: some likely multiple impacts in southern Africa. *Food Policy* 2: 165–191.

MALARIA STATISTICS FOR SOUTH AFRICA. 2007. http://www.doh.gov.za/docs/pr-f.html.

MALHI, Y. & WRIGHT,J. 2004. Spatial patterns and recent trends in the climate of tropical rainforest regions. *Philosophical Transactions of the Royal Society of London - Series B (Biological Sciences)* 359:311-329

MANAHAN, S.E. 2004. *Environmental Chemistry 7th Edition*. CRC Press LLC.

MANTUA, N., HARE, S., ZHANG, Y., WALLACE, J. & FRANCIS, R. 1997. A Pacific inter-decadal climate oscillation with impacts on salmon production, *Bulletin of American Meteorological Society* 78(6): 1069–1080.

MARAIS, C., VAN WILGEN, B.W. & STEVENS, D. 2004. The clearing of invasive alien plants in South Africa: a preliminary assessment of costs and progress. *South African Journal of Science* 100:97–103.

MARAIS, C. & WANNENBURGH, A.M. 2008. Restoration of water resources (natural capital) through the clearing of invasive alien plants from riparian areas in South Africa—costs and water benefits. *South African Journal of Botany* 74: 526–537.

MARINDO, R., GROENEWALD, C. & GAISIE, S. 2008. *The State of the population in the Western Cape Province*. HSRC Press.

MARTÍNEZ-MÉNDEZ, G., ZAHN, R., HALL, I.R., PEETERS, F., PENA, L.D., CACHO, I. & NEGRE, C. submitted. Variability of heat and salt transport through the Agulhas corridor during the past 345 ka BP: evidence from multi-centennial planktonic d180 and Mg/Ca records. *Paleoceanography*.

MATHER, A.A, GARLAND, G.G. & STRETCH, D.D. 2009. Southern African sea levels: corrections, influences and trends. *African Journal of Marine Science* 31: 145–156.

MATHER, A.A. 2007. Linear and non-linear sea level changes at Durban, South Africa. *South African Journal of Science* 103: 509–512.

MATHER, A.A. 2008a. Coastal erosion and sea level rise: Are municipalities prepared? *Institute of Municipal Engineers of Southern Africa (IMIESA)*: 49–70.

MATHER, A.A. 2008b. Sea level rise and its likely financial impacts. *Institute of Municipal Finance Officers (IMFO)*: 8–9.

MATHER, A.A. 2009a. *Projections and modeling scenarios for sea level rise at Durban, South Africa*. Report prepared for the eThekwini Municipality.
MATHER, A.A. 2009b. *High water mark, coastal erosion and hazard delineation model for the Durban coastline*. Report prepared for the eThekwini Municipality.
MBANDE, S., WHITFIELD, A.K. & COWLEY, P.D. 2005. The ichthyofaunal composition of the Mngazi and Mgazana estuaries: a comparative study. *Smithiana Bulletin* 4: 1–22.
MBENDI INFORMATION SERVICES. Mining in South Africa. Overview. http://www.mbendi.com/indy/ming/af/sa/p0005.htm.
MCCABE, G. & PALECKI, M. 2005. Multidecadal climate variability of global lands and oceans. *International Journal of Climatology* 26: 849–865.
MCCLANAHAN, T.R. MAINA, J. STARGER, C. J. HERRON-PEREZ, P. & DUSEK,E. 2005. Detriments to post-bleaching recovery of corals. *Coral Reefs* 24:230-246.
MCCLEAN, C.J., LOVETT, J.C., KÜPER, W., HANNAH, L., SOMMER, J.H., BARTHLOTT, W., TERMANSEN, M., SMITH, G.F., TOKUMINE, S. & TAPLIN, J.R.D. 2005. African plant diversity and climate change. *Annals of the Missouri Botanical Garden* 92: 139–152.
MCKEAND, S.E., JOKELA, E.J., HUBER, D.A., BYRAM, T.D., ALLEN, H.L., LI, B. & MULLIN, T.J. 2006. Performance of improved genotypes of loblolly pine across different soils, climates, and silvicultural inputs. *Forest Ecology and Management* 227: 178–184.
McKENZIE, R.S. & WEGELIN, W. 2009. Challenges facing the implementation of water demand management initiatives in Gauteng Province. *Water SA* 35:168-174.
MCM. undated. http://www.mcm-deat.gov.za/about/index.html.
MCMICHAEL, A.J., BUTLER, C. & WEAVER, H. 2008a. *Climate Change and AIDS*. A joint working paper, UNEP and UNAIDS.
MCMICHAEL, A.J., WILKINSON, P., KOVATS, R.S., PATTENDEN, S., HAJAT, S., ARMSTRONG, B., VALJANAPOOM, N., NICIU, E., MAHOMED, H., KINGKEOW, C., KOSNIK, M., O'NEILL, M.S., ROMIEU, I., RAMIREZ-AGUILAR, M., BARRETO, M., GOUVEIA, N. & NIKIFOROV, B. 2008b. International study of temperature, heat and urban mortality: the ISOTHURM' project. *Environmental Epidemiology* 37: 1121–1131.
MCNEELY, J.A. & SCHUTYSER, F. 2003. Protected areas in 2023: scenarios for an uncertain future. IUCN—The World Conservation Union, Gland.
MEAD, A. in prep. *The rocky intertidal: Are marine introduced species and climate change forcing significant spatial and temporal community assemblage shifts in South Africa?* PhD Thesis, University of Cape Town.
MECHLER, R. 2004. *Natural Disaster Risk Management and Financing Disaster Losses in Developing Countries*. Grasser, Karlsruhe.
MEISZOKOWSKA, N. 2009. Intertidal indicators of climate and global change. In T.M. Letcher (ed.), *Climate Change, Observed Impacts on Planet Earth*. Elsevier.
MÉNAN, H., DAKOURY-DOGBO, N., ROUET, F., HUËT, C. & ANGLARET, X. 2001.HIV-1 infection and malaria parasitaemia. *The Lancet* 357: 233.
MGIDI, T.N., LE MAITRE, D.C., SCHONEGEVEL, L., NEL, J.L., ROUGET, M. & RICHARDSON, D.M. 2007. Alien plant invasions—incorporating emerging invaders in regional prioritization: a pragmatic approach for Southern Africa. *Journal of Environmental Management* 84: 173–187.
MIDDLETON, N. & THOMAS, D.S.G. (eds) 1997. *World Atlas of Desertification*. Arnold, London.
MIDGLEY, G.F., CHAPMAN, R.A., HEWITSON, B., JOHNSTON, P., DE WIT, M., ZIERVOGEL, G., MUKHEIBIR, P., VAN NIEKERK, L., TADROSS, M., VAN WILGEN, B.W., KGOPE, B., MORANT, P.D., THERON, A., SCHOLES, R.J. & FORSYTH, G.G. 2005. *A Status Quo, Vulnerability and Adaptation Assessment of thePhysical and Socio-economic Effects of Climate Change in the Western Cape. Report to the Western Cape Government, Cape Town, South Africa.CSIR Report*: ENV-S-C 2005-073.

MIDGLEY, G.F., HANNAH, L., MILLAR, D., RUTHERFORD, M.C. & POWRIE, L.W. 2002. Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. *Global Ecology and Biogeography* 11: 445–451.

MIDGLEY, G.F., HANNAH, L., MILLAR, D., THUILLER, W. & BOOTH, A. 2003. Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. *Biological Conservation* 112: 87–97.

MIDGLEY, D.C., PITMAN, W.V. & MIDDLETON, B.J. 1994. *The Surface Water Resources of South Africa 1990. Volumes 1 to 6.* Report Numbers 298/1.1/94 to 298/6.1/94 (text) and 298/1.2/94 to 298/6.2/94 (maps). Water Research Commission, Pretoria.

MIDGLEY, G.F. & THUILLER, W. 2005. Global environmental change and the uncertain fate of biodiversity. *New Phytologist* 167: 638–641.

MIDGLEY, G. F. & THUILLER, W. 2007. Potential vulnerability of Namaqualand plant diversity to anthropogenic climate change. *Journal of Arid Environments* 70:615-628

MIDGLEY, G.F. & VAN DER HEYDEN, F. 1999. Growth form and function: Perennial plants. In R.J. Dean & S.J. Milton (eds), *The Karoo: Ecological patterns and processes*. Cambridge University Press, Cambridge.

MITCHELL, J.F.B & JOHNS, T.C. 1997. On modification of global warming by sulphate aerosols. *Journal of Climate* 10: 245–267.

MITTAL, M.L., HESS, P.G., JAIN, S.L., ARYA, B.C. & SHARMA, C. 2007. Surface ozone in the Indian regions. *Atmospheric Environment* 41: 6572-6584.

MOFENSON, L. 2009. *Update on the Science of Prevention of Mother to Child HIV Transmission*. National Institutes of Child Health and Human Development. http://www.pepfar.gov/documents/organization/117839.pdf.

MOLDAN, B., PERCY, S., RILEY, J., HÁK, T., RIVERA, J. & TOTH, F.L. 2005. Choosing responses. In K. Chopra, R. Leemans, P. Kumar & H. Simons (eds), *Ecosystems and human well-being - volume 3: policy responses*: 527–548. Island Press, Washington DC.

MOLOPE, B.M. 2006. Adaptation of negative effects of climate change in the agricultural sector. *Proceedings Agricultural Sector Workshop on Climate Change*: 46–48.

MONDI. 2009. Wetlands—nature's purification works. www.wetland.org.

MOTETE, N., MIDGLEY, G.F. & PAMMENTER, N. 2005. Impact of elevated CO_2 on the phenology and canopy structure of a C4 grassland microcosm. *South African Journal of Botany* 70: 797–803.

MPANDELI, S., DE VILLIERS, M., BARANRD, R., KGAKATSI, I. & MOTSEPE, M. 2008. Climate change implications for agriculture in South Africa. *Proceedings 2nd scientific symposium Land and Water Management in southern Africa: Towards better water use in semi-arid and arid areas*:199–208.

MUCINA, L. & RUTHERFORD, M.C. 2006. The vegetation of South Africa, Lesotho and Swaziland *Strelitizia*. South African National Biodiversity Institute, Pretoria.

MUELLER, J.M. & HELLMANN, J.J. 2008. An assessment of invasion risk from assisted migration. *Conservation Biology* 22: 562–567.

MUGERO, C. & HOQUE, A.K.M. 2001. *Review of Cholera Epidemic in South Africa, with focus on KwaZulu-Natal Province.* Provincial DoH KwaZulu-Natal. http://www.kznhealth.gov.za/cholerareview.pdf.

MUKHEIBIR, P. & ZIERVOGEL, G. 2007. Developing a Municipal Adaptation Plan (MAP) for climate change: the city of Cape Town. *Environment & Urbanization* 19(1).

MULENGA, H.M., ROUAULT, M. & REASON, C.J.C. 2003. Dry summers over NE South Africa and associated circulation anomalies. *Climate Research* 25: 29–41.

MUSIL, C.F., SCHMIEDEL, U. & MIDGLEY, G.F. 2005. Lethal effects of experimental warming approximating a future climate scenario on southern African quartz-field succulents: a pilot study. *New Phytologist* 165: 539–547.

MYERS, N., MITTERMEIER, R.A., MITTERMEIER, C.G., DA FONSECA, G.A. B. & KENT, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403: 853–858.

NAKICENOVIC, N., ALCAMO, J., DAVIS, G., DE VRIES, B., FENHANN, J., GAFFIN, S., GREGORY, K., GRUBLER, A., YONG JUNG, T., KRAM, T., LEBRE LA ROVERE, E., MICHAELIS, L., MORI, S., MORITA, T., PEPPER, W., PITCHER, H., PRICE, L., RIAHI, K., ROEHRL, A., ROGNER, H.-H., SANKOVSKI, A., SCHLESINGER, M., SHUKLA, P., SMITH, S., SWART, R., VAN ROOIJEN, S., VICTOR, N. & DADI, Z. 2000. *Special Report of Emissions Scenarios: a special report of working group III of the IPCC.* Cambridge University Press, Cambridge.

NATIONAL STATE OF THE ENVIRONMENT REPORT. undated. *South African National State of the environment. Responses to changes in the state of terrestrial ecosystems.*http://www.environment.gov.za/soer/nsoer/Issues/land/response.htm.

NATIONAL TREASURY 2003. Intergovernmental Fiscal Review (2003) National Treasury, Republic of South Africa http://www.treasury.gov.za/publications/igfr/2003/title.pdf

NATIONAL TREASURY. 2011. *Annual report*. National Treasury, Pretoria.

NATIONAL WATER ACT 1998. http://www.info.gov.za/view/DownloadFileAction?id=70693

NATIONAL WATER RESoURCE STATEGY 2004. www.dwaf.gov.za/documents/policies/NWRS/default.htm

NATIONMASTER.COM. 2003. South Africa: Environment. http://www.nationmaster.com/country/sf/Environment.

NEILSON, R.P., PITELKA, L.F., SOLOMON, A.M., NATHAN, R., MIDGLEY, G.F., FRAGOSO, J.M.V., LISCHKE, H. & THOMPSON, K. 2005. Forecasting regional to global plant migration in response to climate change. *Bioscience* 55: 749–759.

NEL, E. & HILL, T. 2008. Marginilasation and demographic change in the semi-arid Karoo, South Africa. *Journal of Arid Environments* 72: 2264–2274.

NEL, J.L., RICHARDSON, D.M., ROUGET, M., MGIDI, T.N., MDZEKE, N., LE MAITRE, D.C., VAN WILGEN, B.W., SCHONEGEVEL, L., HENDERSON, L. & NESER, S. 2004. A proposed classification of invasive alien plant species in South Africa: towards prioritizing species and areas for management action. *South African Journal of Science* 100: 53–64.

NELSON, G.C. 2009. *Climate Change and Agriculture.Paper prepared for the conference on 2020 European Agriculture: Long Term Challenge, New Public and private policies*. Grouped' Economie Mondiale (GEM) at Sciences Po, Paris.

NHEMACHENA, C., HASSAN, R.M. 2007. Micro-level analysis of farmers' adaptation to climate change in Southern Africa. IFPRI Discussion Paper, 714. International Food Policy Research Institute (IFPRI), Washington, DC, 30pp.

NERSA. 2009. *South Africa Renewable Energy Feed-in Tariff (REFIT) Regulatory guidelines 26 March 2009.* National Energy Regulator of South Africa, Pretoria.

NEW, M., HEWITSON, B., STEPHENSON, D.B., TSIGA, A., KRUGER, A., MANHIQUE, A., GOMEZ, B., COELHO, C.A.S., NTIKI MASISI, D., KULULANGA, E., MBAMBALALA, E., ADESINA, F., SALEH, H., KANYANGA, J., ADOSI, J., BULANE, L., FORTUNATA, L., MDOKA, M.L. & LAJOIE, R. 2006. Evidence of trends in daily climate extremes over southern and west Africa. *Journal of Geophysical Research* 111: D14102, doi:10.1029/2005JD006289.

OBERHOLSTER, P. & ASHTON, P. 2008. State of the Nation report: An overview of the current status of water quality and eutrophication in South African rivers and reservoirs. *CSIR report* CSRI/NRE/WR/IR/2008/0075/C.

OBERHOLSTER, P.J., BOTHA, A. & CLOETE, T.E. 2005. An overview of toxic freshwater cyanobacteria in South Africa with special reference to risk, impact and detection by molecular marker tools. *Biokemistr* 17: 57–71.

OBERHOLSTER, P.J., MTHETHWA, B.L.S & BOTHA, A. 2009. Development of a rapid and sensitive battery of bioassays for risk assessment of cyanobacterial microstatin-LR in drinking water of rural water treatment plants in South Africa. *African Journal of Biotechnology* 8: 16.

OCHA (UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS). 2009. Cholera/Acute Watery Diarrhoea Outbreaks in Southern Africa. *OCHA Regional Update No*. 6.

OETTLE, N. 2006. *'Farming on the edge' in arid western South Africa: adapting to climate change in marginal environments.* WWF-SA Climate Change Program.

OGUTU, J. O. & OWEN-SMITH, N. 2003. ENSO, rainfall and temperature influences on extreme population declines among African savanna ungulates. *Ecology Letters* 6: 412–419.

ONEWORLD SUSTAINABLE INVESTMENTS. 2007. *SADC Feasibility Review Study: South Africa*.

OPDAM, P. & WASCHER, D. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale level in research and conservation. *Biological Conservation* 117: 285–297.

OPPORTUNITIES IN THE RENEWABLE ENERGY SECTOR. *2nd South African International Trade and Investment Conference*. http://www.thedti.gov.za/tradeinvestmentconference/speaker/RenewableEnergy.pdf.

PACE. 2009. *Making Carbon Work for the Poor*. PACE. http://www.carbon.org.za/category.php?catid=11.

PAHL-WOSTL, C. 2007. Transitions Towards Adaptive Management of Water facing Climate and Global Change. *Water Resource Management* 21: 49–62.

PAHL-WOSTL, C. 2008. Requirements for Adaptive Water Management. In C. Pahl-Wostl, P. Kabat & J. Möltgen (eds), *Adaptive and Integrated Water Management. Coping with Complexity and Uncertainty*: 1–22. Springer Verlag.

PAN AFRICAN CLIMATE JUSTICE ALLIANCE (PACJA). 2009. *The economic cost of climate change in Africa*. PACJA.

PATZ, J.A. 2002. A human disease indicator for the effects of recent global climate change. *Proceedings of the National Academy of Sciences* 99: 12506–12508.

PAUW, K. 2007. *Economy-wide modeling: An input into the Long Term Mitigation Scenarios process, LTMS Input Report 4*. Energy Research Centre, Cape Town.

PAUW, K. & MNCUBE L. 2007. *Expanding the Social Security Net in South Africa: Opportunities, Challenges and Constraints"*, Country Study No. 8, July 2007, IPC, Brasilia, and United Nations Development Programme (UNDP), New York.

PEETERS, F.J.C., ACHESON, R., BRUMMER, G.J.A., DE RUIJTER, W.P.M., GANSSEN, G.M., SCHNEIDER, R.R., UFKES, E. & KROON, D. 2004. Vigorous exchange between Indian and Atlantic Ocean at the end of the last five glacial periods. *Nature* 430(7000): 661–665.

PELLING, M. 2007. I*nvestigating urban risk accumulation in six countries in Africa*.

PELSER, A. & REDELINGHUYS, N. 2009. *Towards a 10-year review of the population policy implementation. Department of Social Development*, March 2009.

PERKS, L.A., SCHULZE, R.E., KIKER, G.A., HORAN, M.J.C. & MAHARAJ, M. 2000. Preparation of climate data and information for application in impact studies of climate change over southern Africa. In G. Kiker (ed.), *Climate Change Impacts in Southern Africa; Report to the National Climate Change Committee.* Department of Environmental Affairs and Tourism, Pretoria.

PHALATSE, L. & MBARA, G. 2009. Impacts of climate change and vulnerable communities at the City of Johannesburg. Fifth Urban Research Symposium 2009. http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1256566800920/6505269-1268260567624/Phalatse.pdf

PHELP, D., ROSSOUW, M., MATHER, A.A. & VELLA, G. 2008. *Storm damage and rehabilitation of coastal structures on the east coast of South Africa.* Institution of Civil Engineers Coasts, Marine structures and breakwater conference, Edinburgh.

PIAO, S., FRIEDLINGSTEIN, P., CIAIS, P., DE NOBLET-DUCOUDRÉ, N., LABAT, D. & ZAEHLE, S. 2007. Changes in climate and land use have a larger direct impact than rising CO_2 on global river runoff trends. *Proceedings of the National Academy of Sciences of the USA* 104: 15242–15247.

PIMENTEL, D. (ed) 2002. *Biological invasions: economic and environmental costs of alien plant, animal, and microbe species*. CRC Press, Boca Raton.

PIMENTEL, D., MCNAIR, S., JANECKA, J., WIGHTMAN, J., SIMMONDS, C., O'CONNELL, C., WONG, E., RUSSEL, L., ZERN, J., AQUINO, T. & TSOMONDO, T. 2001. Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems & Environment* 84: 1–20.

POLLEY, H.W., JOHNSON, H.B. & TISCHLER, C.R. 2002. Woody invasion of grasslands: evidence that CO_2 enrichment indirectly promotes establishment of *Prosopis glandulosa*. *Plant Ecology* 164: 85–94.

POOLMAN, E.M., NDABAMBI, M., VAN NIEKERK, H., NGUBANE, S., STANDER, J., MOSETLHO, F. & MALALA, R. 2008. *Modernizing the Early Warning System: The new Severe Weather Warning System.* Paper presented at the Disaster Management Institute of Southern African Conference, 8–9 October, Goudini Spa.

POPE III, A.C., BURNETT, R.T., THUN, M.J., CALLE, E.E., KREWSKI, D. KAZUHIKO ITO, K. & THURSTON, G.D. 2002. Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. *Journal of the American Medical Association* 287: 1132–1141.

PRESSEY, R.L., CABEZA, M., WATTS, M.E., COWLING, R.M. & WILSON, K.A. 2007. Conservation planning in a changing world. *Trends in Ecology & Evolution* 22: 583–592.

PYŠEK, P., RICHARDSON, D.M., REJMÁNEK, M., WEBSTER, G.L., WILLIAMSON, M. & KIRSCHNER, J. 2004. Alien plants in checklists and floras: towards better communication between taxonomists and ecologists. *Taxon* 53: 131–143.

QUEFFEULOU, P. & CROIZÉ-FILLON, D. 2007. *Investigation of large scale and regional features of wave heights from altimeter measurements.* Proceedings of the Envisat Symposium 2007, Montreux.

RAGHU, S., ANDERSON, R.C., DAEHLER, C.C., DAVIS, A.S., WIEDENMANN, R.N., SIMBERLOFF, D. & MACK, R.N. 2006. Adding biofuels to the invasive species fire? *Science* 313: 1742–1742.

RAJAGOPAL, S., VAN DER VELDE, G., JANSEN, J., VAN DER GAAG, M., ATSMA, G., JANSSEN-MOMMEN, J.P.M., POLMAN, H. & JENNER, H.A. 2005. Thermal tolerance of the invasive oyster *Crassostrea gigas*: feasibility of heat treatment as an antifouling option. *Water Research* 39: 4335–4342.

RAMSAY, P.J., SCHLEYER, M.H., LEUCI, R., MULLER, G.A., CELLIERS, L. & HARRIS, J.M. 2006. The development of an expert marine geographical information system to provide an environmental and economic decision-support system for coastal tourism and leisure developments within the Lubombo Spatial Development Initiative. *Report* 24401. South African Department of Arts, Culture, Science and Technology Innovation Fund Project.

RAU, A.J., ROGERS, J., LUTJEHARMS, J.R.E., GIRAUDEAU, J., LEE-THORP, J.A., CHEN, M.T. & WAELBROECK, C. 2002. A 450-kyr record of hydrological conditions on the western Agulhas Bank slope, south of Africa. *Marine Geology* 180: 183–201.

RAUBENHEIMER, S. 2007. *Long Term Mitigation Scenarios: Process Report*. Energy Research Centre, Cape Town.

REASON, C.J.C. 2001. Evidence for the influence of the Agulhas Current on regional atmospheric circulation patterns. *Journal of Climate* 14: 2769–2778.

REASON, C.J.C., ALLAN, R.J, LINDESAY, J.A. & ANSELL, T.J. 2000. ENSO and climatic signals across the Indian Ocean Basin in the global context: Part I, interannual composite patterns. *International Journal of Climatology* 20: 1285–1327.

REASON, C.J.C. & GODFRED-SPENNING, C.R. 1998. SST Variability in the South Indian Ocean and associated circulation and rainfall patterns over southern Africa. *Meteorology and Atmospheric Physics* 66: 243–258.

REASON, C.J.C. & MULENGA, H. 1999. Relationships between South African rainfall and SST anomalies in the Southwest Indian Ocean. *International Journal of Climatology* 19: 1651–1673.

REASON, C.J.C. & ROUAULT, M. 2002. ENSO-like decadal patterns and South African rainfall. *Geophysical Research Letters* 29: 1638.

REASON, C.J.C. & ROUAULT, M. 2005. Links between the Antarctic Oscillation and winter rainfall over western South Africa. *Geophysical Research Letters* 32: L07705.

REID, P., MASSAY, R. & VOGEL, C. 2005. Climate and development: Experiences of farmers in Kwa-Zulu-Natal, South Africa In: Schulze, R.E. (Ed) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Pretoria, Water Research Commission: Chapter 25, pp 395 - 414

REPUBLIC OF SOUTH AFRICA. 2005. National Disaster Management Framework. *Government Gazette* No. 27534, Notice 654 of 2005. http://www.ndmc.gov.za/.

RICHARD, Y., FAUCHEREAU, N., POCCARD, I., ROUAULT, M. & TRZASKA, S. 2001. XXth Century Droughts in Southern Africa Spatial and temporal variability, teleconnections with oceanic and atmospheric conditions. *International Journal of Climatology* 21: 873–885.

RICHARD, Y., TRZASKA, S., ROUCOU, P. & ROUAULT, M. 2000. Modification of the Southern African rainfall variability/El Niño Southern Oscillation relationship. *Climate Dyn* 16: 886–895.

RICHARDSON, D.M. 1998. Forestry trees as invasive aliens. *Conservation Biology* 12: 18–26.

RICHARDSON, D.M., BOND, W.J., DEAN, W.R.J., HIGGINS, S.I., MIDGLEY, G.F., MILTON, S.J., POWRIE, L.W., RUTHERFORD, M.C., SAMWAYS, M.J. & SCHULZE, R.E. 2000. Invasive alien species and global change: a South African perspective. In H. A. Mooney & R.J. Hobbs (eds), *Invasive species in a changing world*: 303–349. Island Press, Washington DC.

RICHARDSON, D.M., CAMBRAY, J.A., CHAPMAN, R.A., DEAN, W.R.J., GRIFFITHS, C.L., LE MAITRE, D.C., NEWTON, D.J. & WINSTANLEY, T.J. 2003. Vectors and pathways of biological invasions in South Africa—past, present, and future. In G. M. Ruiz & J.T. Carlton (eds), *Invasive species: vectors and management strategies*: 292–349. Island Press, Washington DC.

RICHARDSON, D.M., HELLMANN, J.J., MCLACHLAN, J.S., SAX, D.E., SCHWARTZ, M.W., GONZALEZ, P., BRENNAN, E.J., CAMACHO, A., ROOT, T.L., SALA, O.E., SCHNEIDER, S.H., ASHE, D.M., CLARK, J.R., EARLY, R., ETTERSON, J.R., FIELDER, E.D., GILL, J.L., MINTEER, B.A., POLASKY, S., SAFFORD, H.D., THOMPSON, A.R. & VELLEND, M. 2009. Multidimensional evaluation of managed relocation. *Proceedings of the National Academy of Sciences of the USA* 106: 9721–9724.

RICHARDSON, D.M., MACDONALD, I.A.W., HOFFMANN, J.H. & HENDERSON, L. 1997. Alien plant invasions. In R.M. Cowling, D.M. Richardson & S.M. Pierce (eds), *The vegetation of southern Africa*: 535–570. Cambridge University Press, Cambridge.

RICHARDSON, D.M., ROUGET, M., RALSTON, S.J., COWLING, R.M., VAN RENSBURG, B.J. & THUILLER, W. 2005. Species richness of alien plants in South Africa: environmental correlates and the relationship with indigenous plant species richness. *Écoscience* 12: 391–402.

ROBERTS, D. 2008. Thinking globally, acting locally—institutionalizing climate change at the local government level in Durban, South Africa. *Environment and Urbanization* 20: 521–537.

ROBINSON, T.B., GRIFFITHS, C.L., MCQUAID, C. & RIUS, M. 2005. Marine alien species of South Africa—status and impacts. *African Journal of Marine Science* 27: 297–306.

RODO, X., PASCUAL, M., FUCHS, G. &FARUQUE, A.S. 2002. ENSO and cholera: a nonstationary link related to climate change? *Proceedings of the National Academy of Sciences of the USA* 99(20): 12901-12906.

RODRIGUES, A.S.L., ANDELMAN, S.J., BAKARR, M.I., BOITANI, L., BROOKS, T.M., COWLING, R.M., FISHPOOL, L.D. C., DA FONSECA, G.A.B.D., GASTON, K.J., HOFFMANN, M., LONG, J.S., MARQUET, P.A., PILGRIM, J.D., PRESSEY, R.L., J., S., SECHREST, W., STUART, S.N., UNDERHILL, L.G., WALLER, R.W., WATTS, M.E.J. & YAN, X. 2004. Effectiveness of the global protected area network in representing species diversity. *Nature* 428: 640–643.

ROESIG, J.M., WOODLEY, C.M., CECH, J.J. & HANSEN, L.J. 2004. Effects of global climate change on marine and estuarine fishes and fisheries. *Reviews in Fish Biology and Fisheries* 14: 251–275.
ROGERS, D.J., RANDOLPH, S.E., SNOW, R.W. & HAY, S.I. 2002. Satellite imagery in the study and forecast of malaria. *Nature* 415: 710–715.
ROUAULT, M. 2007. The changing state of the Benguela Current large marine ecosystem. In J. Veitch (ed.), *Expert workshop on climate change and variability and impacts thereof in the BCLME region*. Climate Change workshop report.
ROUAULT, M., PENVEN, P. & POHL, B. 2009. Warming in the Agulhas Current system since the 1980's. *Geophysical Research Letters* 36: 5. L12602.
ROUAULT, M., REASON, C.J., LUTJEHARMS, J.R.E., MULENGA, H., RICHARD, Y., FAUCHEREAU, N. & TRZAKSA, S. 2003. Role of the oceans in South Africa's rainfall. *WRC Report Number*: 953/1/03.
ROUAULT, M. & RICHARD, Y. 2003. Spatial extension and intensity of droughts since 1922 in South Africa, *Water SA* 29: 489–500.
ROUAULT, M. & RICHARD, Y. 2005. Intensity and spatial extent of droughts in Southern Africa. *Geophysical Research Letters.*
ROUAULT, M., WHITE, S.A., REASON, C.J.C., LUTJEHARMS, J.R.E. & JOBARD, I. 2002. Ocean-Atmosphere Interaction in the Agulhas Current and a South African extreme weather event. *Weather and Forecasting* 17(4): 655–669.
ROUAULT, M., POHL, B. & PENVEN, P. 2010. Coastal oceanic climate change and variability from 1982 to 2009 around South Africa. *African Journal of Marine Science* 32:237-246.
ROUGET, M., RICHARDSON, D.M., NEL, J.L., LE MAITRE, D.C., EGOH, B. & MGIDI, T. 2004. Mapping the potential ranges of major plant invaders in South Africa, Lesotho and Swaziland using climatic suitability. *Diversity & Distributions* 10: 475–484.
ROUX, N. 2009. *Migration and urbanization. Towards a 10-year review of the population policy implementation.* Department of Social Development, March 2009.
RSA. (REPUBLIC OF SOUTH AFRICA) 2007. Government's vision, strategic direction and framework for climate policy. Presentation by the Minister of Environmental Affairs and Tourism on the July Cabinet lekgotla. Department of Environmental Affairs and Tourism, Cape Town.
RSA (REPUBLIC OF SOUTH AFRICA) 2010. Independent communications Authority of South Africa Annual Report 2010/2011 http://www.info.gov.za/view/DownloadFileAction?id=152680
RUIZ SEBASTIAN, C., SINK, K.J., MCCLANAHAN, T.R. & COWAN, D.A. 2009. Bleaching response of corals and their *Symbiodinium* communities in southern Africa. Marine Biology 156:2049–2062.
RUTHERFORD, M.C., MIDGLEY, G.F., BOND, W.J., POWRIE, L.W., ROBERTS, R. & ALLSOPP, J. 2000. Plant biodiversity: Vulnerability and adaptation assessment. In G. Kiker (ed.), *Climate Change Impacts in Southern Africa. Report to the National Climate Change Committee*. Department of Environmental Affairs and Tourism Pretoria, South Africa.
SACSCC (SOUTH AFRICAN COUNTRY STUDY FOR CLIMATE CHANGE). 2009. *Vulnerability and Adaptation assessment.* http://unfccc.int/files/meetings/seminar/application/pdf/sem_sup5_south_africa.pdf.
SADB (SOUTH AFRICAN DEVELOPMENT BANK). 2008. *Combating under nutrition in South Africa*.
SADC. 2007. *Feasibility Review Study 34*. IMF.
SA DEPARTMENT OF AGRICULTURE. 2000. *The Integrated Food Security Strategy for South Africa*. http://www.info.gov.za/view/DownloadFileAction?id=70243.
SA DEPARTMENT OF AGRICULTURE. 2002. *The Integrated Food Security Strategy For South Africa*. http://www.nda.agric.za/doaDev/sideMenu/foodSecurity/policies.pdf.
SA DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES. 2009. *Abstract of Agricultural Statistics*. http://www.nda.agric.za/docs/Abstract_2009.pdf.

SA DEPARTMENT OF TRANSPORT. 1998. *Moving South Africa*. http://www.transport.gov.za/projects/msa/msareport.

SA GEOGRAPHIC PROFILE. undated. http://wwwgoogle.co.za/imgres?imgurl=http://geology.com/world/south-africa-map.gif.

SANBI (SOUTH AFRICAN NATIONAL BIODIVERSITY INSTITUTE) 2007. Annual Report 2007/2008 http://www.sanbi.org/about/annual-reports/sanbi-annual-report-2007-2008

SA TOURISM. 2008. *Annual Report*. http://www2.southafrica.net/satourism/research/viewResearchDocument.cfm?ResearchDocumentID=525.

SA WEATHER SERVICE 2006. Disaster Risk Management Plan, South African Weather Service, January, 2006

SA YEARBOOK. undated. *(2007/8) Transport*. http://www.gcis.gov.za/resource_centre/sa_info/yearbook/2009/chapter21.pdf.

SA YEARBOOK. undated. *2008/9 Economy*. http://www.gcis.gov.za/resource_centre/sa_info/yearbook/2009/chapter6.pdf.

SAMWAYS, M.J., CALDWELL, P.M. & OSBORN, R. 1996. Ground-living invertebrate assemblages in native, planted and invasive vegetation in South Africa. *Agriculture,Ecosystems & Environment* 59: 19–32.

SAMWAYS, M.J. & MOORE, S.D. 1991. Influence of exotic conifer patches on grasshopper (Orthoptera) assemblages in a grassland matrix at a recreational resort, Natal, South Africa. *Biological Conservation* 57: 117–137.

SAMWAYS, M.J. & SHARRATT, N.J. 2010. Recovery of endemic dragonflies after removal of invasive alien trees. *Conservation Biology* 24: 267–277.

SAMWAYS, M.J. & TAYLOR, S. 2004. Impacts of invasive alien plants on Red-Listed South African dragonflies (Odonata). *South African Journal of Science* 100: 78–80.

SAMWAYS, M.J., TAYLOR, S. & TARBOTON, W. 2005. Extinction reprieve following alien removal. *Conservation Biology* 19: 1329–1330.

SANKARAN, M., HANAN, N.P., SCHOLES, R.J., RATNAM, J., AUGUSTINE, D.J., CADE, B.S., GIGNOUX, J., HIGGINS, S.I.L.R.X., LUDWIG, F., ARDO, J., BANYIKWA, F., BRONN, A., BUCINI, G., CAYLOR, K.K., COUGHENOUR, M.B., DIOUF, A., EKAYA, W., FERAL, C.J., FEBRUARY, E.C., FROST, P.G.H., HIERNAUX, P., HRABAR, H., METZGER, K.L., PRINS, H.H. T., RINGROSE, S., SEA, W., TEWS, J., WORDEN, J. & ZAMBATIS, N. 2005. Determinants of woody cover in African savannas. *Nature* 438: 846.

SAWIS. 2007. *Annual booklet 2006*. South African Wine Industry Information and Systems, Paarl. http://www.sawis.co.za.

SBT (SCENARIO BUILDING TEAM). 2007. *Long Term Mitigation Scenarios, Technical Summary*. Department of Environmental Affairs and Tourism, Pretoria.

SCAVIA, D., FIELD, J.C., BOESCH, D.F., BUDDEMEIER, R.W., BURKETT, V., CAYAN, D.R., FOGARTY, M., HARWELL, M.A., HOWARTH, R.W., MASON, C., REED, D.J., ROYER, T.C., ALLENGER, A.H. & TITUS, J.G. 2002. Climate change impacts on U.S. coastal and marine ecosystems. *Estuarie* 25: 149–164.

SCHEITER, S. & HIGGINS, S.I. 2009. Impacts of climate change on the vegetation of Africa: an adaptive dynamic vegetation modelling approach. *Global Change Biology* 15: 2224–2246.

SCHLEYER, M.H. 2000. South African coral communities. In T. McClanahan, C. Sheppard & D. Obura (eds), *Coral reefs of the Indian Ocean: Their ecology and conservation*: 83–105. Oxford University Press, New York.

SCHLEYER, M.H. in press. *Extreme environments: High-latitude reefs—South African coral reefs*. Oxford University Press.

SCHLEYER, M.H. & BENAYAHU, Y. 2009. *Soft coral biodiversity and distribution in East Africa: Gradients, function and significance.* Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale.

SCHLEYER, M.H. & CELLIERS, L. 2003. Coral dominance at the reef-sediment interface in marginal coral communities at Sodwana Bay, South Africa. *Marine and Freshwater Research* 54: 967–972.

SCHLEYER, M.H. & CELLIERS, L. 2005. Modelling reef zonation in the Greater St Lucia Wetland Park, South Africa. *Estuarine and Coastal Shelf Science* 63: 373–384.

SCHLEYER, M.H., KRUGER, A. & CELLIERS, L. 2008. Long-term community changes on high-latitude coral reefs in the Greater St Lucia Wetland Park, South Africa. *Marine Pollution Bulletin* 56: 493–502.

SCHOLES, R.J. & BIGGS, R. 2004. *Ecosystem services in southern African: A regional assessment—A contribution to the Millennium Ecosystem Assessment, prepared by the regional-scale team of the Southern African Millennium Ecosystem Assessment.* Council for Scientific and Industrial Research, Pretoria.

SCHOLES, R.J. & BIGGS, R. 2005. A biodiversity intactness index. *Nature* 434: 45–49.

SCHOLES, R.J., VON MALTITZ, G., DE WIT, M., HUGHES, G.O., MIDGLEY, G. & ERASMUS, B. 2004. *Helping biodiversity adapt to climate change*. Finnish Environment Institute, Helsinki.

SCHULZE, R.E. & HORAN, M.J.C. 2010. Methods 1: Delineation of South Africa, Lesotho And Swaziland into Quinary Catchments. In: R.E. Schulze, B.C. Hewitson, K.R. Barichievy, M.A. Tadross, R.P. Kunz, M.J.C. Horan & T.G. Lumsden (eds), *Methodological Approaches to Assessing Eco-Hydrological Responses to Climate Change in South Africa. WRC Report* 1562/1/10.Water Research Commission, Pretoria.

SCHULZE, R.E. & PERKS, L.A. 2000. *Assessment of the Impact of Climate Change on Hydrology and Water Resources in South Africa.* Report to SA Country Studies on Climate Change. ACRUcons Report 33. School of Bioresources Engineering and Environmental Hydrology Report to South African Country Studies for Climate Change Programme University of Natal, Pietermaritzburg.

SCHULZE, R.E. 1995. *Hydrology and Agrohydrology: A Text to Accompany the ACRU 3.00 Agrohydrological Modelling System*. Water Research Commission, Pretoria.

SCHULZE, R.E. 2003. The Thukela Dialogue: Managing Water Related Issues on Climate Variability and Climate Change in South Africa. *Proceedings of the DWC Thukela Dialogue Workshop*. School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg.

SCHULZE, R.E. 2005. *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation*. Water Research Commission, Pretoria.

SCHULZE, R.E. 2005. Setting the Scene: The Current Hydroclimatic 'Landscape' in Southern Africa. In R.E. Schulze (ed.), *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation*: 83–94. Water Research Commission, Pretoria.

SCHULZE, R.E. 2006. Climate change and agriculture: Water sector relationships in South Africa. *Proceedings Agricultural Workshop on Climate Change*:10–45.

SCHULZE, R.E. 2007. *Climate change and the agricultural sector in South Africa: An assessment of findings in the new millennium*. School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal.

SCHULZE, R.E. 2008. *South African Atlas of Climatology and Agrohydrology*. Water Research Commission, Pretoria.

SCHULZE, R.E. 2010. *Atlas of Climate Change and the South African Agricultural Sector: A 2010 Perspective*. Department of Agriculture, Forestry and Fisheries, Pretoria.

SCHULZE, R.E., *et al.*2005. An assessment of impacts of climate change on agrohydrological responses over southern Africa. In R.E. Schulze (ed.), *Climate Change and Water*

Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Water Research Commission, Pretoria.

SCHULZE, R.E., *et al.*2008. *South African Atlas of Climatology and Agrohydrology*. Water Research Commission, Pretoria.

SCHULZE, R.E., & HORAN, M.J.C.2010. Methods 2: Development of the Southern African Quinary Catchments Database. In R.E. Schulze, B.C. Hewitson, K.R. Barichievy, M.A. Tadross, R.P. Kunz, M.J.C. Horan & T.G. Lumsden (eds), *Methodological Approaches to Assessing Eco-Hydrological Responses to Climate Change in South Africa*: 63–74. Water Research Commission, Pretoria.

SCHULZE, R.E., KIKER, G.A. & KUNZ, R.P. 1995. Global climate change and agricultural productivity in southern Africa: Thought for food and food for thought. In T.E. Downing (ed.), *Climate Change and World Food Security*: 421–447. Springer Verlag, Berlin.

SCHUMANN, E.H., COHEN, A.L. & JURY, M.R. 1995. Coastal sea surface temperature variability along the south coast of South Africa and the relationship to regional and global climate. *Journal of Marine Research* 53: 231–248.

SCOTT, D.F., LE MAITRE, D.C. & FAIRBANKS, D.H.K. 1998. Forestry and streamflow reductions in South Africa: a reference system for assessing extent and distribution. *Water SA*, 24:187-199.

SCOTT, R. & HARRISON, D. 2009. A gauge of HIV prevention in South Africa. LoveLife Trust, Johannesburg. http:/www.lovelife.org.za/prevention_gauge.

CBD (CONVENTION ON BIOLOGICAL DIVERSITY). 2009. Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. *Technical Series* 41, Montreal. http://www.cbd.int/ts/.

SERVAIN, J., BUSALACCHI, A.J., MCPHADEN, M.J., MOURA, A.D., REVERDIN, G., VIANNA, M. & ZEBIAK, S.E. 1998. A pilot research moored array in the tropical Atlantic. *Bulletin of the American Meteorological Society* 79: 2019–2031.

SHACKLETON, L.Y., LENNON, S.J. & TOSEN, G.R. (eds). 1996. *Global climate change and South Africa.* Environmental Scientific Association, Cleveland.

SHANNON, L.V. 1989. The physical environment. In A.I.L. Payne & R.J.M. Crawford (eds), *Oceans of life off southern Africa*: 136–147. Vlaeberg, Cape Town.

SHANNON, L. V., BOYD, A. J., BRUNDRIT, G. B. & TAUNTON-CLARK, J. 1986. On the existence of an El Nino type phenomenon in the Benguela system. *Journal of Marine Research*, 44:495–520.

SHANNON, L.V., CRAWFORD, R.J.M., POLLOCK, D.E., HUTCHINGS, L., BOYD, A.J., TAUNTON–CLARK, K.L., BADENHORST, A., MELVILLE–SMITH, R., AUGUSTYN, C.J., COCHRANE, K.L., HAMPTON, I., NELSON, G. & SPARGO, P.E. 1991. False Bay, South Africa—An historic and scientific overview. *Transactions of the Royal Society of South Africa* 47: 363–375.

SHARP, B.L., KLEINSCHMIDT, I. & STREAT, E. 2007. Seven years of regional malaria control collaboration in Mozambique, South Africa and Swaziland. *American Journal of Topical Medicine and Hygiene* 76: 42–47.

SHELTON, J.M., DAY, J.A. & GRIFFITHS, C.L. 2008. Influence of largemouth bass, *Micropterus salmoides*, on abundance and habitat selection of Cape galaxias, *Galaxias zebratus*, in a mountain stream in the Cape Floristic Region, South Africa. *African Journal of Aquatic Science* 33: 201–210.

SHILLINGTON, F., REASON, C., DUNCOMBE-RAE, C., FLORENCHIE, P. & PENVEN, P. 2006. *Benguela: predicting a large marine ecosystem.* Large scale variability of the Benguela Current Large Marine Ecosystem (BCLME). Large Marine Ecosystems, vol.14. Elsevier B.V.. pp. 49–70 (Chapter 4)

SIMMONS, R.E., BARNARD, P., DEAN, W.R.J., MIDGLEY, G.F., THUILLER, W. & HUGHES, G. 2004. Climate change and birds: perspectives and prospects from southern Africa. *Ostrich* 75: 295–308.

SIYAWA, J.F.D., CHEGOU, N.N., VAN DE HEUVEL, M.M., DIACON, A.H., BEYERS, N., VAN HELDEN, P. & WALZL, G. 2009. Different Cytokine/chemokine and KL-6 profile in patients with different forms of TB. *Cytokine* doi: 10,1016/j.cyto.2009.05.016

SMALL, J., GOETZ, S.J. & HAY. S.I. 2003. Climatic suitability for malaria transmission in Africa 1911–1995. *Proceedings of the National Academy of Science* 100: 15341–15345.

SMITH, A.M., GUASTELLA, L.A., BUNDY, S.C. & MATHER, A.A. 2007. Combined marine storm and Saros spring high tide erosion events along the KwaZulu-Natal coast in March 2007. *South African Journal of Science* 103: 274–276.

SMITH, J.B., SCHNEIDER, S.H., OPPENHEIMER, M., YOBE, G.W., HARE, W., MASTRANDREA, M.D., PATWARDHAM, A., BURTON, I., CORFEE-MORLOT, J., MAGADZA, C.H.D., FUSSEL, H., PITTOCK, A.B., RAHMAN, A., SUAREZ, A. & VAN YPERSELE, J.P. 2009. Assessing dangerous Climate Change through an update of Intergovernmental Panel on Climate Change 'Reasons for Concern'. *Proceedings of the National Academy of Science* 106: 4133–4137.

SMITH, J., MAPENDEMBE, A., VEGA, A., HERNANDEZ MORCILLO, M., WALPOLE, M. & HERKENRATH, P. 2010. *Linking the thematic Programmes of Work of the Convention on Biological Diversity (CBD) to Poverty Reduction*. Biodiversity for Development: New Approaches for National Biodiversity Strategies. CBD Secretariat, Montreal

SMITH, K. 2001. *Environmental Hazards: assessing risk and reducing disaster*. Routldge, London.

SMITH, S.D., HUXMAN, T.E., ZITZER, S.F., CHARLET, T.N., HOUSMAN, D.C., COLEMAN, J.S., FENSTERMAKER, L.K., SEEMANN, J.R. & NOWAK, R.S. 2000. Elevated CO_2 increases productivity and invasive species success in an arid ecosystem. *Nature* 408: 79–81.

SMITH, V.R. & STEENKAMP, M. 1990. Climate Change and its Ecological Implications at a Subantarctic Island. *Oecologia* 85: 14–24.

SOTO, S.M. 2009. Human migration and infectious diseases. *Clinical Microbiology and Infection* 15: 26–28.

SOUTH AFRICA. undated. *Info. Gateway to the nation. South Africa's mineral wealth*. http://www.southafrica.info/about/416221.htm.

SOUTH AFRICAN MINERAL INDUSTRY 1996/7. Minerals Bureau. DME. Cited in: ENERGY OUTLOOK FOR SOUTH AFRICA: 2002 DEPARTMENT OF MINERALS AND ENERGY, ESKOM, ENERGY RESEARCH INSTITUTE, UNIVERSITY OF CAPE TOWN. http://www.info.gov.za/view/DownloadFileAction?id=124706

SOUTH AFRICA YEARBOOK 2006/07. *Government Communication and Information System (undated) GCIS, South Africa*. http://www.gcis.gov.za/resource_centre/sa_info/yearbook/2007/chapter23.pdf.

SOUTH AFRICAN RESERVE BANK 2009. *Inflation Rates*. http://www.reservebank.co.za/

SOUTH AFRICA'S FARMING SECTOR 2009. (Department of Agriculture) (2009) Trends in the Agricultural Sector http://www.daff.gov.za/docs/statsinfo/Trends2009.pdf

SOUTHEY, D. 2009. *Investigating fire size and fire frequency in the Fynbos Biome of South Africa*. M.Sc, dissertation. University of Cape Town, Cape Town.

SOUTHWARD, A.J. 1958. Note on the temperature tolerances of some intertidal animals in relation to environmental temperatures and geographic distribution. *Journal of the Marine Biological Association of the United Kingdom* 37: 49–66.

SPEAR, D. & CHOWN, S.L. 2009. The extent and impacts of ungulate translocations: South Africa in a global context. *Biological Conservation* 142: 353–363.

STATISTICS SOUTH AFRICA. 2006. *Census of agriculture Provincial Statistics 2002—Western Cape. Financial and production statistics.Report*: 11-02-02 (2002). Statistics South Africa, Pretoria.

STATISTICS SOUTH AFRICA. 2007. *Methodology, Processes and Highlights of Key Results. Community Survey 2007 Report: 03-01-20*. Statistics South Africa, Pretoria.

STATISTICS SOUTH AFRICA. 2007a. Causes of death 2007: Statistics South Africa. Mortality and causes of death in South Africa, 2007: Findings from death notification. Statistical release P0309.3. Pretoria: Statistics South Africa; 2009. http://www.statssa.gov.za Local copy: /indicators/StatsSA/mortality/P03093_2007.pdf

STATISTICS SOUTH AFRICA, 2008. *Income and Expenditure of Households Survey 2005/6*. Statistics South Africa, Pretoria.

STATISTICS SOUTH AFRICA. 2009. *Mid-year population estimates 2009.* http://www.statssa.gov.za/PublicationsHTML/P03022009/html/P03022009.html.

STEENKAMP, H.E. & CHOWN, S.L. 1996. Influence of dense stands of an exotic tree, *Prosopis glandulosa* Benson, on a savanna dung beetle (Coleoptera: Scarabaeinae) assemblage in southern Africa. *Biological Conservation* 78: 305–311.

STOCK, W.D., LUDWIG, F., MORROW, C., MIDGLEY, G.F., WAND, S.J.E., ALLSOPP, N. & BELL, T.L. 2005. Long-term effects of elevated atmospheric CO_2 on species composition and productivity of a southern African C-4 dominated grassland in the vicinity of a CO_2 exhalation. *Plant Ecology* 178: 211–224.

STUART-HILL, S.I. & SCHULZE, R.E. 2010. Does South Africa's water law and policy allow for climate change adaptation? *Climate and Development* 2: 128–144.

STUUT, J.-B. W. PRINS, M.A. SCHNEIDER, R.R. JAN WELTJE, G. JANSEN J.H.F. & POSTMA,G. 2002. A 300-kyr record of aridity and wind strength in southwestern Africa: inferences from grain-size distributions of sediments on Walvis Ridge, SE Atlantic. *Marine Geology* 180:221-233.

SWAIN, T.L. & GARDNER, R.A.W. 2004. Cold Tolerant Eucalypts in South Africa—Growth information for informed site-species matching. *Southern African Forestry Journal* 202: 83–84.

SWANEPOEL, C.M. 2006. Workshop report: Discussion paper on wetlands in agriculture. *ARC-ISCW Report*: GW/A/2006/185.

TADROSS, M., JACK, C. & HEWITSON, B. 2006. On RCM-based projections of change in southern African summer climate. *Geographical Research Letters*: 32 L23713, doi:10.1029/2005GL024460.

TAVIV, R., SCHOLES, R.J., PHALATSE, L. & COLLET, G. 2007. *South Africa's Climate Change Technology Needs Assessment report—Resource Document Commissioned by Department of Science and technology*. CSIR Natural Resources and Environment, Pretoria.

TAVIV, R., VAN DER MERWE, M., & COLLET, G. 2007. *Non-energy emissions—Agriculture, forestry & waste: An input into the Long Term Mitigation Scenarios process, LTMS Input Report* 2. Energy Research Centre, Cape Town.

TAYLOR, A. 2006. *Discussion paper on facilitating adaptation technology transfer*. SSN Projects (Africa).

TEC GWP (GLOBAL WATER PARTNERSHIP) 2004a.*Gender mainstreaming: An essential component of sustainable water management.* TEC Policy Brief, GWP, 2004.

TEC GWP (GLOBAL WATER PARTNERSHIP) 2004b. *Unlocking the door to social development and economic growth: how a more integrated approach to water can help*. TEC Policy Brief, GWP, 2004.

TENNANT, W.J. & C.J.C. REASON. 2005. Associations between the global energy cycle and regional rainfall in South Africa and Southwest Australia. *Journal of Climate* 18: 3032–3047.

THE PROVINCIAL GOVERNMENT OF THE WESTERN CAPE. 2008. *Western Cape Growth and Development Strategy*. http://www.dme.gov.za/pdfs/energy/planning/2006%20Digest.pdf.

THE WATER WHEEL. 2005. *New guide to managing valuable resources*: 16–18.

THERON, A.K. 2007. Analysis of potential coastal zone climate change impacts and possible response options in the Southern African region. *Proceedings, IPCC TGICA Conference: Integrating Analysis of Regional Climate Change and Response Options*. Nadi, Fiji.

THERON, A.K. & ROSSOUW, M. 2008. *Analysis of potential coastal zone climate change impacts and possible response options in the southern African region*. Science real and relevant: 2nd CSIR Biennial Conference, CSIR International Convention Centre, Pretoria.

THERON, A., ROSSOUW, M., BARWELL, L., MAHERRY, A., DIEDERICKS, G. & DE WET, P. 2010. *Quantification of risks to coastal areas and development: wave run-up and erosion*. CSIR 3rd Biennial Conference 2010. Science Real and Relevant, CSIR International Convention Centre, Pertoria 30 August – 01 September 2010, South Africa, 16pp.

THOMAS, D.S.G. & LEASON, H.C. 2005. Dunefield activity response to climate variability in the southwest Kalahari. *Geomorphology* 64: 117–132.

THOMPSON, D. & WALLACE, J. 2000. Annular modes in the extratropical circulation. Part I: month-to-month variability. *Journal of Climatology* 13: 1000–1016.

THOMPSON, M., MASON, S.J., PHINDELA, T. & CONNOR, S.J. 2005. Use of rainfall and sea surface temperature monitoring for malaria early warning in Botswana. *American Journal of Tropical Medicine and Hygiene* 73: 2145–2221.

THOMPSON, M.C., DOBLAS-REYERS, F.T., MASON, S.J., HEGEDORN, R., CONNORS, S.J., PHINDELA, T., MORSE, A.P. & PALMER, T.N. 2006. Malaria early warning based on season climate forecast from multi-model ensembles. *Nature* 439: 576–579.

THORNTON, P.K., JONES, P.G., OWIYO, T., KRUSKA, R.L., HERRERO, M., KRISTJANSON, P., NOTENBAERT, A., BEKELE, N. & OMOLO, A., with contributions from ORINDI, V., OCHIENG, A., OTIENDE, B., BHADWAL, S., ANANTRAM, K., NAIR, S., KUMAR, V. & KELKAR, U. 2006. *Mapping climate vulnerability and poverty in Africa*. Report to the Department for International Development, ILRI, Nairobi.

THUILLER, W., BROENNIMANN, O., HUGHES, G., ALKEMADE, J.R.M., MIDGLEY, G.F. & CORSI, F. 2006. Vulnerability of African mammals to anthropogenic climate change under conservative land transformation assumptions. *Global Change Biology* 12: 424–440.

THUILLER, W., MIDGLEY, G.F., HUGHES, G.O., BOMHARD, B., DREW, G., RUTHERFORD, M.C. & WOODWARD, F.I. 2006. Endemic species and ecosystem sensitivity to climate change in Namibia. *Global Change Biology* 12: 759–776.

THUILLER, W., RICHARDSON, D.M. & MIDGLEY, G.F. 2007. Will climate change promote alien species invasions? In W. Nentwig (ed.), *Biological invasions*: 197–211. Springer Verlag, Heidelberg.

TURPIE, J.K. 2004. *South African National Spatial Biodiversity Assessment* 2004: Technical Report. Volume 3: Estuary Component. Pretoria: South African National Biodiversity Institute

TOL, R.S.J. 2004. *The double trade-off between adaptation and mitigation for sea level rise: An application of ZFUND*. Research Unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science.

TOLLEY, K.A., DAVIES, S.J. & CHOWN, S.L. 2008. Deconstructing a controversial local range expansion: conservation biogeography of the painted reed frog (*Hyperolius marmoratus*) in South Africa. *Diversity & Distributions* 14: 400–411.

TOMPKINS, E.L. & ADGER, W.N. 2003. *Building resilience to climate change through adaptive management of natural resources.* Tyndall Centre for Climate Change Research, Norwich.

TREDOUX, G., MURRAY, E.C. & CAVE, L. 2003. Infiltration basins and other recharge systems in Southern Africa. Paper presented at IAH-Netherlands Workshop: "Recharge Enhancement and Sub Surface Water Storage, a Promising Option to Cope with Climate Variability", Wageningen, Netherlands, 18 to 19 December 2002.

TREDOUX, G. & TALMA, A.S. 2006. Nitrate Pollution of Groundwater in Southern Africa. In Y. Xu & B. Usher (eds), *Groundwater Polution in Africa*. Taylor and Francis, London.

TRENBERTH, K., JONES, E., AMBENJE, P.D., BOJARIU, P., EASTERLING, R., KLEIN, D., TANK, A., PARKER, D., RAHIMZADEH, F., RENWICK, J.A., RUSTICUCCI, M., SODEN, B. & ZHAI, P. 2007. Observations: Surface and Atmospheric Climate Change. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor & H.L. Miller (eds), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.Cambridge.

TURPIE, J.K., ADAMS, J.B., JOUBERT, A., HARRISON, T.D., COLLOTY, B.M., MAREE, R.C., WHITFIELD, A.K., WOOLDRIDGE, T.H., LAMBERTH, S.J., TALJAARD, S. & VAN NIEKERK, L. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. *Water SA* 28: 191–206.

TYSON, P.D. 1971. Spatial Variation of Rainfall Spectra in South Africa. *Annals of the Association of American Geographers* 61: 711–720.

TYSON, P.D. & GATEBE, C.K. 2001. The atmosphere, aerosols, trace gases and biogeochemical change in southern Africa: a regional integration. *South African Journal of Science* 97: 106–118.

TYSON, P.D. & PRESTON-WHYTE, R.A. 2000. *The weather and climate of South Africa.* Oxford University Press, Oxford.

TYSON, P.D., STURMAN, A.P., FITZHARRIS, B.B., MASON, S.J. & OWENS, I.F. 1997. Circulation changes and teleconnections between glacial advances on the west coast of New Zealand and extended spells of drought years in South Africa. *International Journal of Climatology* 17: 1499–1512.

UDJO, E.O. 2008. *The demographics of the emerging black middle class in South Africa*. Bureau of Market Research (BMR), University of South Africa.

UNAIDS. 2008. *2008 Report on the Global AIDS epidemic*. http://www.unaids.org/en/KnowledgeCentre/HIVData/GlobalReport/2008/2008_Global_report.asp.

UNDP (UNITED NATIONS DEVELOPMENT PROGRAMME) 2003. *Assessing technology needs for climate change.* National Communications Support Unit Handbook.

UNDP (UNITED NATIONS DEVELOPMENT PROGRAMME) 2008. http://en.wikipedia.org/wiki/List_of_countries_by_income_equality.

UNDP (UNITED NATIONS DEVELOPMENT PROGRAMME) 2010. *Human development report 2010. The real wealth of nations: pathways to development*. United Nations Development Programme. Palgrave Macmillan, New York.

UNEP (UNITED NATIONS ENVIRONMENTAL PROGRAMME). 1995. *UNEP decision 18/32 of the UNEP Governing Council: persisting organic pollutants*. http://www.pops.int/document/back-ground/gedecision/18-32/gcl1832en.html.

UNGANAI, L.S. &. MASON, S.J. 2001. Spatial characterization of Zimbabwe summer rainfall during the period 1920-1996 : research letter. *South African Journal of Science* 97:425-431.

UNICEF (UNITED NATIONS CHILDREN'S FUND). 2005. *Water, Sanitation and Hygiene: Common water and sanitation-related diseases.* www.unicef.org/wash/index_wes_related.html.

UNICEF/WHO (UNITED NATIONS CHILDREN'S FUND/WORLD HEALTH ORGANISATION). 2009. *Diarrhoea: Why children are still dying and what can be done*.

UNISDR (UNITED NATIONS INTERNATIONAL STRATEGY FOR DISASTER REDUCTION). 2009. *Global Assessment Report*. www.unisdr.org.

USAID. undated. Infectious Diseases, South Africa. http://www.USAID.gov.

USAID (UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT). 2000. *FEWS Monthly Country Summaries May 2000: Southern Africa*. http://www.reliefweb.int/rw/RWB.NSF/db900SID/ACOS-64BEXP?OpenDocument.

USEPA. 2009. *Synthesis of Adaptation Options for Coastal Areas*. U.S. Environmental Protection Agency, Climate Ready Estuaries Program, Washington DC.

USHER, B. H. & VERMEULEN, P. D. 2006. *The Impacts of Coal and Gold Mining on the Associated Water Resources in South Africa*. In Y. Xu, & B. H. Usher (Eds.), Groundwater Pollution in Africa (pp. 301-313). London: Tylor and Francis

VAN DEN BERG, E.C., PLARRE, C., VAN DEN BERG, H.M. & THOMPSON, M.W. 2008. *The South African National Land Cover 2000*. Agricultural Research Council—Institute for Soil, Climate and Water, Pretoria.

VAN DER LINGEN, C.D., SHANNON, L.J., CURY, P., KREINER, A., MOLONEY, C.L., ROUX, J-P. & VAZ-VELHO, F. 2006. Resource and ecosystem variability, including regime shifts, in the Benguela Current System. In V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C.L. Moloney & J. Woods (eds), *Predicting a Large Marine Ecosystem. Large Marine Ecosyste ms 14, Benguela*: 147–185. Elsevier, Amsterdam.

VAN DER MERWE, A.J., DE VILLIERS, M.C. & TANNER, P.D. 1999a. Land degradation and rehabilitation in South Africa: Opencast coal mining case study. *Proceedings World Congress on Land Use and the Sustainable Development of Resources.*

VAN DER MERWE A.J., DE VILLIERS, M.C., BARNARD, R.O., BERRY W.A.J. & WALTERS, M.C. 1999b. Successful experience in integrated soil management and conservation under dryland conditions in South Africa. *FAO/ISCW Expert Consultation on land resources inventories/SOTER, national soil degradation assessment and mapping and its impacts on soil productivity*:16–37.

VAN DER MERWE, F.P.J. 2007. Keynote paper 4: Policy and institutional aspects affecting agricultural water use in South Africa. *Proceedings 2nd scientific symposium land and water management in southern Africa: Towards better water use in agriculture in semi-arid and arid areas*.

VAN DER MERWE, M.R., DIPPENAAR-SCHOEMAN, A.S. & SCHOLTZ, C.H. 1996. Diversity of ground-living spiders at Ngome State Forest, Kwazulu/Natal: a comparative survey in indigenous forest and pine plantations. *African Journal of Ecology* 34: 342–350.

VAN NIEKERK, D., TEMPELHOFF, J., FALING, W., THOMPSON, L., COETSEE, C. & MAARTENS Y. 2009. The effects of Climate Change in two flood laden and drought stricken areas in South Africa: Responses to Climate Change—past, present and future. www.acds.co.za.

VAN ROOYEN, J.A. & VERSFELD, D.B. 2009. *Strategic planning for water resources in South Africa. A situation analysis 2009. Report No. P RSA 000/00/7809*. Department of Water and Environment Affairs, Pretoria.

VAN SEBILLE, E., BIASTOCH, A., LEEUWEN, P.J. & DE RUIJTER, W.P.M. 2009. A weaker Agulhas Current leads to more Agulhas leakage. *Geophysical Research Letters* 36: L03601.

VAN TIENHOVEN, A.M. & SCHOLES, M.C. 2006. Air pollution impacts on vegetation in South Africa. In L. Emberson, A. Ashmore & F. Murray (eds), *Air pollution impacts on crops and forests: A global assessment*: 237–262. Imperial College Press.

VAN VUUREN, L. 2008. Water & energy join hands to avert future crisis : water conservation. *Water Wheel* 7:22-23.

VAN WILGEN, B.W. 2009. The evolution of fire and invasive alien plant management practices in fynbos. *South African Journal of Science* 105: 335–342.

VAN WILGEN , B.W. BIGGS, H.C., O'REGAN, S.P. & MARÈ, N. 2000. A fire history of the savanna ecosystems in the Kruger National Park, South Africa, between 1941 and 1996. *South African Journal of Science* 96:167-178.

VAN WILGEN, B.W. & SCHOLES, R.J. 1997. The vegetation of fire regimes of southern hemisphere Africa. In B.W. van Wilgen, M. O. Andreae, J.G. Goldammer & J.A. Lindesay (eds), *Fire in southern African savannas: ecological and atmospheric perspectives*. Witwatersrand University Press, Johannesburg.

VAN WILGEN, B.W., RICHARDSON, D.M., LE MAITRE, D.C., MARAIS, C. & MAGADLELA, D. 2001. The economic consequences of alien plant invasions: examples of impacts and approaches to sustainable management in South Africa. *Environment, Development & Sustainability* 3: 145–168.

VAN WILGEN, B.W., GOVENDER, N., BIGGS, H.C., NTSALA, D. & FUNDA, X.N. 2004. Response of savanna fire regimes to changing fire management policies in a large African national park. *Conservation Biology* 18: 1533–1540.
VAN WILGEN, B. W., NEL, J.L & ROUGET, M. 2007. Invasive alien plants and South African rivers: a proposed approach to the prioritization of control operations. *Freshwater Biology* 52:711-723.
VAN WILGEN, B.W., REYERS, B., LE MAITRE, D.C., RICHARDSON, D.M. & SCHONEGEVEL, L. 2008. A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. *Journal of Environmental Management* 89: 336–349.
VAN WILGEN, B.W. & RICHARDSON, D.M. 2009. Current and future consequences of invasion by alien species: a case study from South Africa. In C. Perrings, H.A. Mooney & M. Williamson (eds), *Bioinvasions and Globalization*: 183–201. Oxford University Press, Oxford.
VAN WILGEN, B.W., FORSYTH, G.G., DE KLERK, H., DAS, S., KHULUSE, S. & SCHMITZ, P. 2010. Fire management in Mediterranean-climate shrublands: a case study from the Cape fynbos, South Africa. *Journal of Applied Ecology* 47: 631–638.
VAN WILGEN, N.J., WILSON, J.R.U., ELITH, J., WINTLE, B. & RICHARDSON, D.M. 2010. Alien invaders and reptile traders: what drives the live animal trade in South Africa? *Animal Conservation* 13: 1–9.
VAN WILGEN, B. W., KHAN, A & MARAIS.C 2010. *Changing Perspectives on Managing Biological Invasions: Insights from South Africa and the Working for Water programme*. Pp. 377-393 Fifty Years of Invasion Ecology. Wiley-Blackwell.
VAN WYK, E. & VAN WILGEN, B.W. 2002. The cost of water hyacinth control in South Africa: a case study of three options. *African Journal of Aquatic Science* 27: 141–149.
VAN ZYL, K. 2008. *A Study on a Disaster Risk Management Plan for the South African Agricultural Sector*. Agri SA, NAFU SA and TAU SA, funded by Total SA.
VASQUEZ, J.M. & DVORAK, W.S. 1996. Trends in variance and heritabilities with stand development of tropical pines. *Canadian Journal of Forest Resources* 26(8): 1473–1480.
VOGEL, C. 1989. A documentary-derived climatic chronology for South Africa. *Climatic Change* 14:291–308.
VOGEL, C. 2000. Useable Science: An assessment of long-term seasonal forecasts amongst farmers in rural areas of South Africa. *The South African Geographical Journal* 82, 2, 107-116.
VOGEL, C. 2008. *Mixing and Matching! Education, Skills and Other Requirements for Adapting to Climate Change*. Position paper prepared for START, Dar Es Salaam.
VOGEL, C. 2009. Business and climate change: Initial explorations in South Africa. *Climate and Development* 1,:1-16.
VOGEL, C., KOCH, I. & VAN ZYL, K. 2010. "A Persistent Truth"-Reflections on Drought Risk Management in Southern Africa?. *Weather, Climate and Society* 2: 9–22.
VOGEL. C., MOSER, S., KASPERSON, R. & DAEBELKO, G. 2007. Linking Vulnerability, Adaptation and Resilience Science to Practice: Pathways, Players and Partnerships. *Global Environmental Change* 17: 349–364.
VOGEL, C. & O' BRIEN, K. 2006. Who can eat Information? Examining the effectiveness of seasonal climate forecasts and regional climate-risk management strategies, *Climate Research* 33: 111–122.
VOGEL, C., KOCH, I. & VAN ZYL, K. 2010. Reflections of drought risk management in southern Africa: Past choices, current caveats and future challenges. *Weather, Climate and Society* 2 ;9–22.
VON MALTITZ, G.P., SCHOLES, R.J., ERASMUS, B. & LETOALO, A. 2007. *Adapting conservation strategies to accommodate impacts of climate change*. *AIACC Adaptation Synthesis*. Assessments of Impacts and Adaptations to Climate Change (AIACC), Washington DC.

WALENKSY, R., WOODS, R., WEINSTEIN, M. & MARTINSON, N. 2008. Scaling up antiretroviral therapy in South-Africa: The impact of speed on survival. *The Journal of Infectious Diseases* 197: 1324–1332, Doi:10.1086/587184.

WALKER, N.J. & SCHULZE, R.E. 2006. An assessment of sustainable maize production under different management and climate scenarios for smallholder agro-ecosystems in KwaZulu-Natal, South Africa. *Physics and Chemistry of the Earth* 31: 995–1002.

WALKER, N.J. & SCHULZE, R.E. 2008. Climate change impacts on agro-ecosystem sustainability across three climate regions in the maize belt of South Africa. *Agriculture,Ecosystems and Environment* 124: 114–124.

WALTHER, G.-R., ROQUES, A., HULME, P.E., SYKES, M.T., PYŠEK, P., KÜHN, I., ZOBEL, M., BACHER, S., BOTTA-DUKÁT, Z., BUGMANN, H., CZÚCZ, B., DAUBER, J., HICKLER, T., JAROŠÍK, V., KENIS, M., KLOTZ, S., MINCHIN, D., MOORA, M., NENTWIG, W., OTT, J., PANOV, V.E., REINEKING, B., ROBINET, C., SEMENCHENKO, V., SOLARZ, W., THUILLER, W., VILÀ, M., VOHLAND, K. & SETTELE, J. 2009. Alien species in a warmer world: risks and opportunities. *Trends in Ecology & Evolution* 24: 686–693.

WAND, S.J.E., MIDGLEY, G.F., JONES, M.H. & CURTIS, P.S. 1999. Responses of wild C4 and C3 grass (Poaceae) species to elevated atmospheric CO_2 concentration: a meta-analytic test of current theories and perceptions. *Global Change Biology* 5: 723–741.

WAND, S.J.E., MIDGLEY, G.F. & STOCK, W.D. 2000. Growth responses to elevated CO_2 in NADP-ME, NAD-ME and PCK C4 grasses and a C3 grass from Africa. *Australian Journal of Plant Physiology* 28: 13–25.

WAND, S.J.E., MIDGLEY, G.F. & STOCK, W.D. 2002. Response to elevated CO_2 from a natural spring in C4-dominated grassland depends on seasonal phenology. *African Journal of Range and Forage Science* 19: 81–91.

WARBURTON, M.L. & SCHULZE, R.E. 2005. Detection of trends over time in hydrological drivers and responses over southern Africa. In R.E. Schulze (ed.), *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation*. Water Research Commission, Pretoria.

WARBURTON, M.L. & SCHULZE, R.E. 2008. Potential impacts of climate change on the climatically suitable growth areas of *Pinus* and *Eucalyptus*: results from a sensitivity study in South Africa. *Southern Forests* 70: 27–36.

WARBURTON, M., SCHULZE, R.E. & MAHARAJ, M. 2005. Is South Africa's temperature changing? An analysis of trends from daily records, 1950–2000. In R.E. Schulze (ed), *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation*: 275–295. Water Research Commission, Pretoria.

WATER SERVICES ACT, 1997. www.dwaf.gov.za/Documents/Legislature/a108-97.pdf

Western Cape Provincial Development Council 2005. In pursuit of provincial growth and development through social dialogue and partnerships. Annual Report of the Western Cape Provincial Development Council. http://www.westerncape.gov.za/other/2005/12/pdc_2005_annual_finalpdf.pdf

WHITFIELD, A.K. 2000. *Available scientific information on individual South African estuarine systems. Unpublished Report No. 577/3/00*. Water Research Commission, Pretoria.

WHITWORTH, J. & HEWITT, K.A. 2005. Effect of malaria on HIV-1 progression and transmission. *The Lancet* 365: 196–197.

WHITWORTH, J., MORGAN, D., QUIGLEY, M., SMITH, A., MAYANJA, B., EOTU, H., OMODING, N., OKONGO, M., MALAMBA, S. & OJWIYA, A. 2000. Effect of HIV-1 and increasing immunosuppression on malaria parasitaemia and clinical episodes in adults in rural Uganda: a cohort study. *Lancet* 356: 1051–1056.

WHO (WORLD HEALTH ORGANISATION). 1993. *Guidelines for drinking water quality*. Second edition. Vol. II.

WHO (WORLD HEALTH ORGANISATION). 2001. Weekly Epidemiological Report—Cholera in 2000. *WER* 31(76).

WHO (WORLD HEALTH ORGANISATION). 2002. Weekly Epidemiological Report—Cholera in 2001. *WER* 31(77).
WHO (WORLD HEALTH ORGANISATION). 2003. Weekly Epidemiological Report—Cholera in 2002. *WER* 31(78).
WHO (WORLD HEALTH ORGANISATION). 2004. Weekly Epidemiological Report—Cholera in 2003. *WER* 31(79).
WHO (WORLD HEALTH ORGANISATION). 2005. Weekly Epidemiological Report—Cholera in 2004. *WER* 31(80).
WHO (WORLD HEALTH ORGANISATION). 2006. Weekly Epidemiological Report—Cholera in 2005. *WER* 31(81).
WHO (WORLD HEALTH ORGANISATION). 2009. Weekly Epidemiological Report—Cholera in 2008. *WER* 31(84).
WHO (WORLD HEALTH ORGANISATION). undated. Global Malaria Program. http://apps.who.int/malaria/wmr2008/.
WHO EPR (WORLD HEALTH ORGANISATION, EPIDEMIC AND PANDEMIC ALERT RESPONSE AVIAN FLU). 2009. The influenza outbreak in humans caused by Influenza A/H1N1 - considerations at the human-animal interface. http://www.who.int/foodsafety/fs_management/No_02_influenza_Apr09_en_rev1.pdf
WIGLEY, B.J., BOND, W.J. & HOFFMAN, M.T. 2010. Thicket expansion in a South African savanna under divergent land use: local vs. global drivers? *Global Change Biology* 16: 964–976.
WILKINSON, C.R. 1999. Global and local threats to reef functioning and existence: reviews and predictions. *Marine and Freshwater Research* 50: 867–878.
WILLIAMS, P., HANNAH, L., ANDELMAN, S., MIDGLEY, G.F., ARAUJO, M., HUGHES, G., MANNE, L., MARTINEZ-MEYER, E. & PEARSON, R. 2005. Planning for Climate Change: Identifying Minimum-Dispersal Corridors for the Cape Proteaceae. *Conservation Biology* 19: 1063–1074.
WILSON, A.E., SARNELLE, O., NEILAN, A.B., SALMON, T.P., GEHRINGER, M.M. & MARK, M.E. 2005. Genetic Variation of the Bloom-Forming Cyanobacterium *Microcystis aeruginosa* within and among Lakes: Implications for Harmful AlgalBlooms. *Applied Environmental Microbiology* 71: 6126–6133.
WILSON, A.M., LATIMER, A.M., SILANDER, J.A., GELFAND, A.E. & DE KLERK, H. 2010. A hierarchical Bayesian model of wildfire in a Mediterranean biodiversity hotspot: Implications of weather variability and global circulation. *Ecological Modelling* 221: 106–112.
WILSON, J.R.U., DORMONTT, E.E., PRENTIS, P.J., LOWE, A.J. & RICHARDSON, D.M. 2009. Something in the way you move: dispersal pathways affect invasion success. *Trends in Ecology & Evolution* 24: 136–144.
WILSON, J.R.U., ZENNI, R.D., LE ROUX, J.J., & RICHARDSON, D.M. 2009. Evaluating the invasiveness of *Acacia paradoxa* in South Africa. *South African Journal of Botany* 75(3): 485–496.
WINKLER, H. (ed.). 2007. *Long Term Mitigation Scenarios: Technical Report*. Energy Research Centre for Department of Environment Affairs and Tourism, Pretoria.
WINKLER, H. & BOYD, A. 2009. *Addendum to South Africa's Technology Needs Assessment based on the Long Term Mitigation Scenarios*. Department of Science and Technology Energy Research Centre, University of Cape Town, Cape Town.
WOLFE, D.W. & ERICKSON, J.D. 1993. Carbon dioxide effects on plants: uncertainties and implications for modelling crop response to climate change. In H.M. Kaiser & T.E. Drennen(eds), *Agricultural dimensions of global climate change*: 153–178. St. Lucie Press, Delray Beach.
WOODBORNE, S., PIENAAR, M. & VAN DER MERWE, M.R. 2008. Mitigating the future impacts of cholera. *Conference proceedings: Science real and relevant: The 2nd CSIR Biennial Conference.* CSIR, Pretoria.

WOODWARD, F.I. & LOMAS, M.R. 2004. Simulating vegetation processes along the Kalahari transect. *Global Change Biology* 10: 383–392.

WORKING GROUP ON CLIMATE CHANGE AND DEVELOPMENT. 2005. *Africa—Up in Smoke*. New Economics Foundation, London.

YU, D. 2010. Poverty and inequality trends in South Africa using different survey data. *Stellenbosch Economic Working Papers: 04/10*. Department of Economics, University of Stellenbosch.

ZAHN, R. 2009. Climate change; beyond the CO_2 connection. *Nature* 460 (7253): 335–336.

ZARDI, G.I., NICASTRO, K.R., MCQUAID, C.D. & ERLANDSSON, J. 2008. Sand and wave induced mortality in invasive (*Mytilus galloprovincialis*) and indigenous (*Perna perna*) mussels. *Marine Biology* 153: 853–858.

ZAWADA, P. 1996. Palaeoflood hydrology of selected South African rivers. Ph.D. Dissertation, Univ. Port Elizabeth, South Africa. 348 pp.

ZHANG, J.-Z., KELBLE, C.R., FISCHER, C.J. & MOORE, L. 2009. Hurricane Katrina induced nutrient runoff from an agricultural area to coastal waters in Biscayne Bay, Florida. *Estuarine,Coastal and Shelf Science* 84: 209–218.

ZHANG, X., ZWIERS, F.W., HEGERL, G.C., LAMBERT, F.H., GILLETT, N.P., SOLOMON, S., STOTT, P.A. & NOZAWA, T. 2007. Detection of human influence on twentieth century precipitation trends. *Nature* 448: 461–466.

ZIERVOGEL, G. & CALDER, R. 2003. Climate variability and rural livelihoods: assessing the impact of seasonal climate forecasts in Lesotho. *Area* 35(4): 403–417.

ZIERVOGEL, G., BHARWANI, S. & DOWNING, T.E. 2006. Adapting to climate variability: Pumpkins, people and pumps. *Natural Resource Forum*.

ZIERVOGEL, G. & TAYLOR, A. 2008. Feeling stressed: Integrating climate adaptation with other priorities in South Africa. *Environment.* 50:32-41

ZIERVOGEL, G. & ERICKSEN, .J. 2010. Adapting to climate change to sustain food security. Wiley Interdisciplinary Reviews: *Climate Change* 1:525-540.

ZIERVOGEL, G., JOHNSTON, P., MATTHEW, M., & MUKHEIBIR, P. 2010. Using climate information for supporting climate change adaptation in water resource management in South Africa. *Climatic Change*,103: 537–544.

ZIMMERMANN, H.G. & MORAN, V.C. 1991. Biological control of prickly pear, *Opuntia ficus-indica* (Cactaceae), in South Africa. *Agriculture, Ecosystems & Environment*, 37: 29–35.

ZIMMERMANN, H.G., MORAN, V.C. & HOFFMANN, J.H. 2004. Biological control in the management of invasive alien plants in South Africa, and the role of the Working for Water programme. *South African Journal of Science* 100: 34–40.

ZISKA, L.H. 2003. Evaluation of the growth response of six invasive species to past, present and future atmospheric carbon dioxide. *Journal of Experimental Botany* 54: 395–404.