SCOPING OF THE APPROXIMATE CLIMATE CHANGE ADAPTATION COSTS IN SEVERAL KEY SECTORS FOR SOUTH AFRICA UP TO 2050

environmental affairs

Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

Scoping of the Approximate Climate Change Adaptation Costs in Several Key Sectors for South Africa up to 2050

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2011

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Foreword

From 3 to 6 March 2009, South Africans from all spheres of life came together for the national Climate Change Summit 2009 in Midrand to initiate a consultative process to develop the South African Climate Change Response Policy. Although the Summit yielded wide-ranging consensus on a number of proposed climate change responses, it also identified various areas of divergence that required further discussion. With this, the Summit agreed, amongst others, that the National Climate Change Response Policy will be developed through a participatory, multi-stakeholder, consultative and iterative process and that issues raised during the Climate Change Summit 2009 must be addressed in a transparent manner and fed into the policy development process.

During the participatory, multi-stakeholder, consultative and iterative policy development process initiated at the Summit, certain specific issues appeared to be raised again and again in various policy development stakeholder engagements. These recurring areas of concern and/or uncertainty included: Climate Finance; Human Resources and Technology; Adaptation; Mitigation; and Governance.

In keeping with the Summit decisions and with a view to informing and enriching the debates around these issues, the Department of Environmental Affairs commissioned focussed research into these focus areas and used the findings of this research to focus and inform discussions in key stakeholder workshops on each of the topics in February and March 2011.

Although the independent research and findings contained in this publication do not necessarily represent the views, opinions and/or position of Government, the department believes that this research is an important addition to the evolving climate change discourse. Hence, the department is happy to make this work publicly available and accessible.

With this, I would like to thank everyone who contributed to the research papers presented in this book as well as everyone who contributed to the various stakeholder workshops on the topics covered by this research.

Finally, I would also like to thank our German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) partners and their local agent, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), for their generous support for this research and its publication.

Peter Lukey

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Department of Environmental Affairs

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Abbreviations

CO_2	Carbon Dioxide
CRED	Centre for Research on the Epidemiology of Disasters
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DRR	Disaster Risk Reduction
DST	Department of Science and Technology
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EbA	Ecosystem-based Adaptation
EbA	Ecosystem-based adaptation
FAO	Food and Agriculture Organisation of the United Nations
GCM	General Circulation Model
GDP	Gross Domestic Product
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
NPAES	National Protected Areas Expansion Strategy
SNC	Second National Communication
SRES	Special Report on Emissions Scenarios
UNFCCC	United Nations Framework Convention on Climate Change
ZAR	South African Rand

Summary

This report provides quantitative economic analyses of climate change impacts and the inferred estimated adaptation costs in key sectors, including water, agriculture and biodiversity and ecosystem services, up to 2050. It highlights that the costing of climate change adaptation responses and their benefits (calculated in terms of avoided damages) is still in its infancy, especially when compared to the advances made with respect to determining mitigation costs, and further outlines some of the challenges particular to economic analyses of adaptation. The report draws attention to the unique challenges of developing adaptation responses in the face of climate uncertainty, as well as the opportunities and benefits that adaptation responses can potentially provide, particularly in terms of local economic development. It concludes with recommendations of the conditions and actions required for an effective integrated adaptation response in the short, medium and long term.

The report was a collaboration between SANBI, CSIR, ASSET Research, Beatus and the Department of Economics, University of Pretoria.

The sections below provide an overview of what is contained in the main report.

The challenges of calculating costs and benefits of climate adaptation

According to the report, costs and benefits of climate adaptation should ideally be calculated using bottom-up data, i.e. building up from individual actions towards a big picture. However, since this level of detailed information was not available, the authors had to undertake a top-down sector-based assessment that was as informative as possible, based on basic information provided in South Africa's Second National Communication (SNC) to the United Nations Framework Convention on Climate Climate (UNFCCC) and selected published and unpublished literature. The SNC provides climate scenarios for the period 2045 - 2065 with quantification of various ranges of uncertainty due to incomplete knowledge of the climate system. This allows an estimation of the risk of likely rainfall and temperature change for one of the "Special Report on Emissions Scenarios" (SRES A2 emissions scenario) (Nakicenovic, et al., 2000), which projects a global temperature increase in the 2045 - 2065 time period of about 0.4°C above the target of the Copenhagen Accord. The authors also developed a tool from this that allowed uncertainties of the risk of rainfall and temperature change on the agriculture sector to be quantified.

According to Stern et al. (2006), assessing the relative costs and benefits of adaptation requires the projection of four costs, namely: i) cost increases in the infrastructure/process that would have occurred in the absence of climate change; ii) the damage costs of climate change without adaptation measures; iii) damage costs after adaptation investments have been made; and iv) the cost of adaptation investments. Benefit is calculated as the value of avoided damages that would have resulted without the adaptation intervention. The authors either use an optimality argument, which assumes that the adaptation costs would rise to equal the impact costs (Hughes et al., 2010), i.e. they do not quantify adaptation costs and avoided damages, but discuss them qualitatively.

Costing was not possible in all cases, and where it was done, these figures should be regarded as provisional first estimates, with the main intention of providing a sense of relative costs.

Estimated costs and benefits for key sectors

The economic analysis on the water sector highlighted that the biggest projected cost impact will be damage to infrastructure resulting from more frequent and intense flood events. This, combined with increased water scarcity in many parts of the country, will result in increased prices for water. In smaller towns and municipalities, it is likely that the cost burden will fall mainly on middle and low-end users, and the delivery of free basic water to households will be potentially compromised.

Analysis of the impact of climate change on profits of the commercial agriculture sector estimate significant negative impact on the national economy by 2050 (up to about 9% of sectoral GDP), with field crops (predominantly cereals) facing the greatest losses, as they are generally not irrigated.

Adaptation costs relating to biodiversity and ecosystem services accrue primarily as a result of the need for acquiring additional land for conservation, combating alien invasive plant species, replacing lost profits from wildflower harvesting and additional costs associated with increased incidents of wildfires. Ecosystem based adaptation was identified as a potential adaptation strategy that can help people adapt to the adverse effects of climate change by generating significant social, economic and cultural co-benefits, while simultaneously contributing to biodiversity conservation, and building on traditional and local knowledge and practices.

The report highlights that many adaptation strategies have the potential to align with key environmental and socio-economic policy directions. However, these potential synergies require further integrated and in-depth analysis.

It should be noted that these costs are an incomplete estimate of the total potential impact of climate change in these sectors, and are benefits of adaptation responses.

Recommendations

Since uncertainty regarding the extent of damages rises steeply over the longer term, adaptation objectives must be able to adjust to a moving target, within which timeframe is important. There is a need to plan flexibly for a wide range of possible responses over the medium to long term, and to have in place focused monitoring systems for updating information on how rapidly the change is occurring, and about the effectiveness of specific adaptation responses.

In order to plan and co-ordinate an effective integrated adaptation response, actions need to be informed by:

- Early warning and forecasting for Disaster Risk Reduction (DRR);
- Medium-term (decade-scale) climate forecasting to identify potential resource challenges well in advance (e.g. droughts); and
- Long-term climate projections that define the range of future climate conditions.

These actions need to be reinforced by research, capacity development and technology development, responding to the needs of DRR in the short term, and integrated resource and development planning in the medium and long term.

An indicative set of actions is provided in Table 6 of the main report, organised in terms of short-, medium- and long-term actions.

Government departments have begun working on sectoral adaptation plans. These should include job creation and growth strategies, especially in terms of green economy objectives. These will be incorporated into an integrated adaptation strategy and action plan with specific interventions and projects. A key component of this would be targeted funding for key sectors to conduct research into climate change impacts, vulnerability and adaptation, with a socio-economic focus. In addition to a refinement of top-down approaches such as has been attempted in this study, more detailed project-specific analyses should be conducted to provide more accurate figures than is currently possible.

An integrated long-term adaptation strategy should be developed that co-ordinates responses between sectors and departments, and which reviews responses in terms of their progress and effectiveness in relation to the unfolding understanding on climate scenarios every two years. This review cycle should allow responses to be adjusted appropriately.

1. Introduction

The costing of climate change adaptation responses and their benefits in terms of avoided damages is in its infancy, especially when compared to the advances made with respect to mitigation cost during the past decade. This necessitates an urgent assessment of the adaptation cost to guide coherent national climate policy in a way that integrates both mitigation and adaptation actions and aspirations with developmental priorities. The leading international assessment on this issue, the Stern Review (Stern et al., 2006), estimates that damages from climate change could range from 5 to 20% of the Gross Domestic Product (GDP) annually by 2100. Such levels of damages would certainly threaten and even reverse many development gains made in the developing world. The Stern Review uses this estimate of damage costs to assess the ultimate economic benefits of mitigation investments in terms of avoided damages, but does not attempt to factor in the benefits of adaptation investments. Given that a certain level of continued anthropogenic climate change is unavoidable regardless of internationally aggregated mitigation efforts, it is useful to quantify the relative effectiveness of such investments. It would also be useful to quantify this cost:benefit ratio nationally in relation to evolving global mitigation targets, such as the 2˚C target accepted in the Copenhagen Accord (United Nations Framework Convention on Climate Change (UNFCCC), 2009).

It is less useful to assess at a national level the relative cost:benefit ratio of mitigation actions for any country except for major greenhouse gas (GHG) emitters. This is because an individual country's relative contributions to aggregated global warming trends fall rapidly with country rankings in emissions terms, but the costs of mitigation actions is likely to fall much less rapidly. This means that for most individual countries the apparent relative benefits of investments in an energy transition fall with emitter ranking, assuming roughly equivalent anticipated climate damages. As the 13th highest emitter in the world (based on total annual CO_2 emissions for 2007 (United Nations Statistics Division, 2011)), South Africa contributes roughly 1.5% to anthropogenic GHGs; thus its global potential mitigation contribution is small.

The costs of adaption impacts will likely scale with the relative national level of warming and precipitation change experienced. This relates mainly to latitude and continentality[1], and national exposure to specific impacts such as sea level rise (i.e. small island states and continental states with significant coastal exposure would be significantly more prone to these damages in relation to the global average). As a country in the sub-tropics, South Africa is exposed over the medium term (until 2050) to the adverse impacts of climate change, mainly through increasing temperature and changing patterns of rainfall, both of increasing intensity of individual rainfall events and possible increases in dry spells and drought events. South Africa is thus a "climate taker"[2], but has a strong interest in avoiding high levels of global warming. This report attempts to quantify damage costs for some key sectors to a greater degree than have been previously achieved, in order to provide greater clarity on the value of avoided damages as a result of international climate change mitigation action.

There have been relatively few studies published on the costs of projected climate change impacts in South Africa. Some sector-based estimates are available (Turpie et al., 2002), but are based on earlier-generation impacts assessments. Even fewer have attempted to cost adaptation measures and there are no known studies that calculate the economic benefit of such investments. As a consequence, the Second National Communication (SNC) to the UNFCCC (Department of Environmental Affairs (DEA), 2010c) provides narrative-type descriptions rather than quantitative estimates of damage costs (with the exception of the impacts of extreme events, which were specifically assessed from an economic perspective), and provides only general descriptions of potential adaptation measures, often on a case-study basis. Adaptation responses to climate change have a local bias, unlike mitigation responses, which can be quantified in national and international emissions targets or actions. While mitigation actions can be assessed economically from a top-down perspective and using sector based analyses, the costing of adaptation responses and their potential benefits flows ideally from aggregated assessments of adaptation actions, which are generally specific to different sites, areas or regions. However, given the lack of information currently available for such an aggregated assessment, the authors have attempted to conduct a top-down assessment that is as informative and detailed as feasible.

1 *"Continentality" is a measure of the difference between continental and marine climates characterised by the increased range of temperatures that occurs over land compared with water.*

2 *A "climate taker" is a country that it does not stand to benefit from its own efforts on climate mitigation.*

2. Aims

The initial stated aims of this study were to:

a. Undertake a comprehensive overview of adaptation extracted from the SNC, including measures that are currently being implemented, identify geographically specific strategies that are under consideration, and opportunities and constraints in terms of the scale of specific adaptation measures;

b. Undertake an assessment of synergies and conflicts between current and future adaptation strategies, with a focus on identifying strategies that serve both adaptation and mitigation needs; and

c. Locate climate change adaptation within the broader context of sustainable development by identifying the costs and benefits of different adaptation strategies in relation to the South African government's developmental priorities for job creation and service delivery, and to explore the role and socio-economic consequences of economic measures such as pricing in adaptation strategies.

During the course of the study it became clear that there was a lack of detailed information about adaptation strategies for most sectors outlined in the SNC (DEA, 2010c), and a paucity of quantitative costing information due to the poorly developed literature base. In particular, there were very few impacts assessments that could be related to projected global climate change as is currently understood, because likely changes in climate under a range of emissions scenarios have only recently been made available by the climate modelling community. The result is that the climate impacts community has not developed a clear understanding of the relationship between aggregate global climate change and national level impacts.

For these reasons, basic information provided in the SNC (DEA, 2010c) and selected published and unpublished information was used where feasible to develop high-level and top-down sector based assessments. This requirement to develop or access the necessary data to achieve the aims stated above had unavoidable implications for how those aims were addressed. These are detailed in Section 5. Undertaking this study also provided the authors with insights into how the impacts and adaptation community could focus its efforts to achieve these aims more comprehensively in future national assessments. These are documented in Section 6.

3. Climate scenarios

Climate scenarios were taken from the climate chapter of the SNC (DEA, 2010c) where possible, or were interpreted based on the literature cited in the SNC, where previous generation scenarios had been used. In the SNC, climate changes are modelled that result from the realisation of the Special Report on Emissions Scenarios (SRES) A2 emissions scenario (Nakicenovic et al., 2000). This scenario results in a projected warming by 2050 of above 1.8˚C above 1980 - 1999 averages (i.e., about 2.4˚C above pre-industrial temperatures, or 0.4˚C above the Copenhagen Accord target). Impacts of this level of climate change therefore provide an indication of the appropriateness of the Copenhagen Accord global temperature target for South Africa's sustainable development aspirations, especially given that there is only a 50% chance of staying below 2˚C if the Intergovernmental Panel on Climate Change (IPCC) estimates of required emissions are met.

The SNC (DEA, 2010c) provides scenarios of seasonal rainfall and temperature for the country, based on the results of nine General Circulation Models (GCMs)[3] downscaled[4] for South Africa. The results are aggregated and presented as 25th, 50th and 75th percentile changes in the SNC, which encompass about half of the expected structural uncertainty due to incomplete scientific understanding in the various modelling approaches. A product was developed from this dataset that presents the 10th and 90th percentiles, thus encompassing about 80% of the structural uncertainty, and providing a useful tool for robust risk assessment or sensitivity analysis using impacts models.

Temperature changes are expressed as anomalies for 2046 - 2065 relative to a baseline of 1961 - 2000 (See Figure 2.11 of the draft SNC (DEA, 2010b)). For rainfall, two sets of scenarios were presented in the SNC, one representing direct output from the same nine GCMs used for temperature scenarios (see Figure 2.12 of the draft SNC (ibid)), and a second set using statistical downscaling techniques to account for local climatological drivers for South Africa that refine these coarser global projections (see Figure 2.13 of the draft SNC (ibid)).

Surface air temperature, a spatially continuous parameter relative to rainfall, shows warming everywhere, but most strongly in the interior. Coastal warming is of the order of 1 - 2˚C, increasing to around 3 - 4˚C towards the northern interior by 2050.

Table 1: Provincial projections of rainfall (percentage of 1971 - 2003 baseline) and temperature change (˚C above 1971 - 2003 baseline) by 2050

	Projected changes in rainfall (%)			Projected changes in temperature (˚C)		
Province	**10th**	**median**	**90th**	**10th**	**median**	**90th**
Western Cape	-8.2	-1.5	2.0	2.9	2.6	1.3
Eastern Cape	-7.1	1.4	6.5	2.3	2.1	1.1
Northern Cape	-14.8	0.2	9.3	2.5	2.3	1.1
Free State	-9.0	1.9	9.1	2.8	2.7	1.5
Kwazulu Natal	-6.2	1.3	6.5	2.3	2.1	1.3
Northwest	-10.4	0.4	7.2	3.2	2.9	1.8
Gauteng	-7.9	0.6	5.8	2.9	2.5	1.6
Limpopo	-9.7	-0.6	5.2	2.9	2.5	1.6
Mpumalanga	-7.9	0.0	4.6	2.7	2.4	1.5

3 General Circulation Models are computer-based tools that model atmospheric behaviour to project future climates, using a physical understanding of the atmosphere and climate, and how these are affected by changing concentrations of GHGs. Several research groups around the world have developed models more or less independently that allow projections to be made.

4 Downscaling involves increasing the spatial resolution from the models to a scale that can be used for local impacts assessments (Hewitson and Crane 2006).

Median rainfall changes modelled by GCMs indicate increased summer rainfall in the summer rainfall region with the exception of Limpopo Province, which shows some drying. Median winter rainfall over the southwest is projected to decrease. The 25th percentile changes indicate widespread autumn, winter and spring drying, and summer drying in the northern half of the country. The 75th percentile changes indicate significant wetting in the summer rainfall region, slight drying in winter in the Western Cape, and neutral to slightly wetter conditions throughout the country in the autumn and spring trimesters.

Jointly, the raw GCM rainfall and temperature changes suggest a potential for decreased soil moisture as a result of the increased temperatures and the drying tendency for much of the region.

Downscaled rainfall scenarios diverge somewhat from the raw GCM projections, with similar spatial patterns of wetting and drying, but a generally greater tendency towards wetter projections. For example, the median downscaled winter rainfall scenario for the Western Cape is for slight wetting, as opposed to significant drying for the raw GCM. However, when expressed as percentages of current baseline averages of rainfall for provinces, the projected downscaled changes are relatively small (see Table 1).

4. Economic methods

As mentioned in Section 1, due to insufficient information required to follow a bottom-up approach (i.e. an aggregated assessment), a top-down approach for assessing impacts and adaptation costs was followed in this report. Detailed bottom-up approaches are preferable because adaptation responses are often locally relevant and site specific. However, in reality, the level of detailed information required for aggregating assessments in most sectors would require significant additional research.

To assess the relative costs and benefits of adaptation, it is necessary to project four costs, namely: i) cost increases in the infrastructure or process considered that would have occurred in the absence of climate change; ii) the damage costs of climate change without adaptation measures; iii) damage costs after adaptation investments have been made; and iv) the cost of adaptation investments (Stern et al., 2006). For the purposes of this work, the authors used either an optimality argument (Hughes et al., 2010)[5] or did not quantify adaptation costs and avoided damages, but rather discussed them qualitatively.

5 In basic terms, the economic optimality argument assumes that the adaptation costs would rise to equal the impact costs – a fair assumption for a resource that is in limited supply. As a result, it was further assumed that the residual impacts after adaptation were zero – a far less justifiable assumption for issues such as damage to infrastructure, for which it is seldom possible, at any cost, to reduce the impacts to zero (even the incremental impacts) (Stern et al., 2006).

5 Sector-based scoping of approximate climate change impacts and adaption costs

This section provides an estimate of the approximate impacts and adaptation costs in selected key sectors affected directly by climate change, namely water, agriculture, forestry, biodiversity and ecosystem services, and wildfires. Other sectors, such as human health and urban and rural settlements could also be explored in a similar way in South Africa. However, this was beyond the scope of this study.

5.1 Water sector

Water quantity and quality are critical for its sustainable economic development. South Africa is already close to the limit of surface water available for allocation. Agriculture consumes roughly 60% of the water currently available, and urban and rural domestic use consumes 25% and 4% respectively (DEA, 2010c). According to the 2001 census, 84% of South Africans have access to piped water, but only 32% receive water in their homes (StatsSA, 2003). National development imperatives provide for the free delivery of the first 6 kilolitres per household per month, a policy that resulted from a severe cholera epidemic in 2000 in several provinces and towns, including parts of Johannesburg. The outbreak has been linked by some to Government's full cost recovery policy for water, and the resulting lack of access to water in afflicted areas (Budds and McGranahan, 2003).

Thus, even in the absence of climate change, significant water sector changes will need to be implemented over the next few decades to ensure minimum supplies for satisfying basic human needs in all parts of the country, while maintaining the ecological reserve, and allocating the remaining water to best economic use. The changes required would benefit from a consideration of climate change imperatives to ensure that the strategies developed are robust to the projected impacts of climate change. Since water is essential for virtually every economic activity and for life itself, its total value is infinite. In scenarios of climate change, water availability changes mainly through its spatial distribution, frequency and intensity of precipitation. It is therefore water's attributes "at the margin" that matters, and it is this incremental change that this study attempts to quantify.

Water was estimated to be worth ZAR77 per kilolitre to the economy in the year 2000, and accounted for about 1.2% of the intermediate costs in GDP (StatsSA, 2006). However, these aggregate numbers conceal the fact that the water intensities of South Africa's respective economic sectors vary widely. In 2000, it required 1 kilolitre to generate a GDP of ZAR2.40 in agriculture, while 1 kilolitre was estimated to have generated a GDP of ZAR654 in trade and services, ZAR250 in industry and ZAR64 in mining (ibid). Within-sector differentiation is also important: for example, the marginal revenue of water varied between crops in agriculture sector, from ZAR2.00 – 30.00 per kilolitre. It is therefore necessary to apply caution when using high-level national statistics to consider local-level and sub-sector-specific water allocation trade-offs. Matters are further complicated by the fact that the water tariff framework[6] makes provision for tariff tiers to reflect different water qualities and different levels of infrastructure requirements.

Given these different requirements, water in the agriculture sector is priced at a much lower level than other sectors, ranging from being freely available to about ZAR1.00 per kilolitre, whereas within the other sectors water tariffs vary between ZAR3.00 per kilolitre to ZAR40.00 per kilolitre. In some cases, the cost of delivering water can be much higher (e.g. ZAR180.00 per kilolitre using a water tanker for delivery), although in these cases, the end user cannot be charged the full cost of delivery. The spectrum of costs, tariffs and the contribution to the economy therefore varies greatly.

Comprehensive climate change adaptation strategies relating to water allocation should ideally consider these complexities. To this end, this study focuses on high-level, top-down scenarios to provide some indication of climate change impacts on the water sector as a whole, and then considers two case studies that illustrate the complexities related to impacts and adaptation in the water sector at the local level.

Three main mechanisms through which climate change will affect the water sector are:

- Changes in surface water supply as a result in changes in mean rainfall and evaporative demand;
- Changes in the costs of water purification as a result if rising water temperatures; and

6 *See Water Services Act No. 108 of 1997, and the National Water Act No. 36 of 1998.*

- Increased damage to infrastructure (including but not restricted to water supply infrastructure) as a result of flooding, due to more extreme rainfall events.

Water supply projections are particularly susceptible to the large uncertainties in future rainfall. Changes in rainfall have a two- to five-fold multiplier effect on changes in surface water flows (de Wit and Stankiewicz, 2006). For the purpose of this analysis it was assumed that for the eastern part of the country net water supply would remain about the same or increase (taking into account increases in both rainfall and evaporation), while for the interior and Western Cape, the net effect would be an approximately 30% shortfall by 2030 (based on estimates for Johannesburg and Cape Town of remaining perennial drainage in Table 1 of de Wit and Stankiewicz, 2006). The current cost of supplying water, calculated at about ZAR2.2 billion per year, was estimated by adding up the public sector expenditure on water infrastructure (at local, provincial and national levels), and averaging the cost over a four-year period (2004 - 2007). This figure does not include operating costs, although some of these costs are included in the calculations made here for maintaining water quality. The overall cost was assumed to increase 3% per annum into the future, in parallel with economic growth.

The costs of water purification were ZAR90 per megalitre in 2006 (i.e. 9c per kilolitre) (Gebremedhin, 2009). It is known that the costs of purifying water increase with water temperature, largely because of the increased incidence of eutrophication. The mean water temperature in South Africa is about 18°C, and is projected to rise by about 3°C by 2050 (2010c). It was assumed that the increase in biological activity followed an exponential function, corresponding to a Q_{10} of 2, with proportional increased treatment costs.[7]

Damage caused by severe floods and storms in South Africa over the period 2000 - 2008 averaged ZAR563 million per year (2010c). This is a conservative estimate, since data for less severe damage are not included, and the data relating to damages from extreme events are incomplete at the national scale. Severe weather events have been increasing globally. According to the Centre for Research on the Epidemiology of Disasters (CRED) weather-related disasters have been rising by 6% per year since such events were first recorded in the 1950s (Guha-Sapir et al., 2011). Some of the observed increases are due to more people living in disaster-prone areas. However, due to the time constraints of this study, it was not possible to factor this aspect out. The authors therefore applied this 6% growth rate to the damage costs derived for storms in South Africa.

There is some information available to quantify adaptation costs on a project-by-project basis (i.e. bottom-up data). For example, building storage capacity in the form of dams costs approximately ZAR4.00 - 8.00 per kilolitre, recharging groundwater aquifers ZAR3.00 - 5.00 per kilolitre, desalination ZAR6.00 - 15.00 per kilolitre, and recycling ZAR5.00 - 7.00 per kilolitre (Ninham Shand, 2008). However, this data was not included in this study as there is currently no basis for predicting what specific climate change response projects would be undertaken at different locations.

Since it was impossible to estimate the adaptation costs using an aggregation approach, the authors used the assumption of economic optimality, defined in Section 4 (Hughes et al., 2010).

Table 2: Costs associated with the water sector in South Africa, for the period 2011 to 2050

	ZAR Millions per year, 2010 equivalent	
Impact mechanism	Future costs without climate change	Additional future costs due to climate change, assumed equal to adaptation costs required to counter impacts
Flood and storm damage	667	2793
Water supply security	2261	805
Water purification costs	471	60
All sources	3399	3657

7 The Q10 temperature coefficient is a measure of the rate of change of a biological or chemical process as a consequence of increasing the temperature by 10 °C

The authors' estimates are presented in Table 2, which indicates that the additional costs due to climate change in the water sector (levelised between 2010 and 2050 and brought to 2010 values) will be approximately ZAR3.6 billion per year. Maintaining a sustainable supply of water of current quality nationally could increase annual costs by about 30%, from ZAR2.7 billion to approximately ZAR3.5 billion per year. This excludes the cost of clearing alien invasive plant species that consume significant amounts of water, which is estimated to increase by 50 - 100% under climate change, from a current level of ZAR300 million per year (See Section 5.4). The biggest anticipated additional cost in the water sector will be to infrastructure damage due to flooding. Costs are estimated to increase by up to 400%, from a conservative current estimate of ZAR670 million per year to ZAR3.5 billion per year (or approximately 0.6% of GDP). If extreme events continue to increase at the current global rate of 6% per annum, this becomes important for infrastructure planning and management, and the insurance industry. This projection almost certainly represents a high estimate, as a part of the damage costs experienced historically are due to inadequate planning and could be avoided when infrastructure is rebuilt. Also, there is a large degree of uncertainty regarding the rate of increase in extreme weather events.

5.1.1 Berg River Catchment case study

A case study by Callaway et al. (2006) is of relevance to this report. The study explored the costs and benefits of two distinct adaptation strategies for the Berg River catchment in the Western Cape, in the context of projected reductions in water yield of up to 25% due to climate change and increased demand (200% in 30 years). The two strategies examined were the building of a dam and the implementation of water markets. The results are summarised in Table 3.

While either strategy on its own shows significant net present value, it is clear that by adopting both strategies simultaneously climate change may be more efficiently addressed. Liberalising the market for water results in a more efficient and resilient distribution of water, which reduces water demand and thus the ultimate cost of dam construction.

5.1.2 Access to water in small municipalities

Small municipalities are less able than large ones to implement and maintain a rising block tariff that allows cross-subsidisation of the poor, as the revenue generated by these municipalities is limited by the relatively low numbers of high end users in their user profile (Pape, 2002). A detailed study of the Bredasdorp Municipality by (Mukheibir, 2007) explored how climate change would compromise the ability of small municipalities to supply water and to subsidise the provision of free basic supply of 6 kilolitres to poor households. This has important implications for the allocation of the Equitable Share Grant provided by Government for compensating municipalities for the delivery of such services, but which is subject to many competing priorities. The study found that the additional burden of climate change would be felt in the

Table 3: Net present value estimates for costs and benefits of adjustments for increasing development pressures and climate change in the 2080s (Callaway et al., 2)

	Adaptation strategy A	Adaptation strategy B
Respond to development imperative (no climate change)	Construct dam	Implement water market
Net benefits	ZAR15 billion	ZAR17 billion
Respond to climate change with additional adaptation action	Increase dam capacity	Construct dam
Net benefits of adaptation	ZAR0.2 billion	ZAR7 billion
Cost of not adapting for climate change that occurs	ZAR0.2 billion	ZAR7 billion
Cost of adapting for climate change that does not occur	ZAR0.2 billion	ZAR1 billion

increase in unit cost of supply, due to an 8% reduction in projected rainfall by 2035, which in turn would lead to a 30 - 36% reduction in available water. This would quadruple capital investment costs relative to a base case scenario of consumption growth of 2.3% per year to 2035 and would result in an average tariff increase of approximately 25% over the period 2006 - 2035, a burden that would fall mainly on middle and low-end users who currently make up the majority (66%) of consumers in this municipality.

5.2 Agriculture

Given the lack of quantified estimates of impact costs in the SNC for this sector, algorithms developed in published models of climate impacts on agricultural sectors were applied, based on historical analysis of agricultural yield and profit data in relation to variances in rainfall and temperature (Blignaut et al., 2009). Expressed simply, the authors used a sectoral production function approach that attributed changes in production and profit to changes in a variety of explanatory variables, including climate data. The analysis assesses the role of a wide range of drivers of agricultural profit in three sub-sectors, namely field crops, horticulture and animal husbandry, which, together, comprise the entire spectrum of commercial agriculture, which contributes approximately 2.4% to national GDP.

The value of this approach is in the resulting ability to assess a broad range of rainfall and temperature change scenarios and thus capture the full range of possible climate outcomes as currently understood by the climate modelling community. No attempt has been made to estimate the replacement cost, cost in avoiding the loss of the service, or the consequences of such service losses in the agriculture sector. Table 4 shows the impact of climate change on net profit in three agriculture sub-sectors as a percentage change by 2050, with negative numbers indicating a drop in profits. The 10th, 50th and 90th percentile changes combine best, median and worst-case projected impacts of temperature and rainfall on agricultural sub-sectors that were projected at the provincial level, and aggregated to the national level. Negative impacts on profits are expected from projected climate change for all three modelled sub-sectors. These drops in profit translate to the risk of national annual monetary losses of up to ZAR3.9 billion (field crops), ZAR1.4 billion (horticulture), and ZAR2 billion (animal husbandry), for a total aggregated cost of ZAR7.3 billion, or about 1.2% of GDP by 2050. These results are in line with published studies on changes in agricultural yields based on warm, dry future climate scenarios, as opposed to impacts resulting from marginal warming associated with an increase in rainfall (Seo et al., 2009).

The results presented in this report indicate that the effects of the expected temperature rise will far outweigh the effect of the anticipated rise in rainfall in the eastern portions of the country. Field crops would be most severely impacted (13 - 66% drop in profits). Horticultural profits would be least adversely affected on average, although its profits appear to be the most sensitive of the three sub-sectors to different climate scenarios (ranging from a 4% increase to a 32% drop in profits). The animal husbandry sub-sector shows appreciable projected profit losses of 12 - 32%.

The differences amongst these sub-sectors can mainly be attributed to the fact that horticultural production is predominately buffered against adverse climate effects, as most of the industry is irrigated. However, the modelling approach used assumes that there are no critical threshold effects that might cause non-linear responses of horticultural crop profits to rising temperature. An example that would violate this assumption is the dependence of some horticultural crops on chilling units, a measure that may decline abruptly above certain temperature thresholds. The projected lower impact on horticultural profits also assumes that increased irrigation carried out by producers in the past under warmer and drier conditions is simply enhanced further. This is in contrast with field crops, which are predominately dry field production and do not enjoy the same level of buffering from irrigation. Animal husbandry largely takes on the form of feedlots, with water being provided to the animals from various sources other than rainwater, and result in the intermediate but meaningful changes that are projected. As in the case of horticultural production, it is assumed that increased watering carried out in the past by producers under warmer and drier conditions is simply enhanced further, and that no temperature thresholds come into play.

The fact that the economic costs of the implicitly assumed irrigation adaptation options are not included in these estimates identifies an important need to recognise and account for such "embedded" autonomous adaptation options that are assumed in this kind of impacts modelling approach. Furthermore, given that a national scarcity of water is projected even in the absence of climate change, a reduction in the water allocated to agriculture and a

Table 4:The impact of climate change on net profit in three agriculture sub-sectors

Climate scenario	Field crops	Horticulture	Animal husbandry	Aggregated
10th	-66.21%	-32.27%	-31.95%	-44%
50th	-36.66%	-9.82%	-20.81%	-24%
90th	-12.89%	3.70%	-11.94%	-8%

concomitant increase in price of water seems inevitable. These factors are likely to exacerbate the negative effects of climate change on net profitability of both horticulture and animal husbandry by a considerable margin.

It is very unlikely that adjustment of input costs would be able to compensate for losses, at least in the field crop sub-sector. In addition, the prospect of such losses will likely put downward pressure on wage costs. Spatial shifting of crop-growing areas could partially compensate for these losses, but it is unknown how much land in South Africa would be available with the suitable climate in the future to allow such shifts to occur. Far more beneficial would be a shift to sustainable farming methods such as low-till practices that encourage increased water conservation and nutrient exchange capacity in soils, and reduce input costs. These would have additional mitigation benefits in terms of emissions reductions. It is also clear that impacts of this severity and the adaptation strategies required, would place a premium on skills in the agriculture sector.

It is further unlikely that an increase in irrigation will completely compensate for the impacts on animal husbandry, as these effects experienced are mainly due to temperature rise and not rainfall impacts. Adjustment in input costs and intensive responses are more feasible for the livestock industry. However, the most obvious adaptation responses in this sub-sector (namely climate control and feedlots) come with large implications for energy and water demands, and with implications for agricultural emissions.

The results outlined above have significant implications for national food security, given the increase in catastrophic losses in international food production capacity between 1990 and 2011 and the resulting increases in food prices (Food and Agriculture Organisation of the United Nations (FAO), 2011). The cost of not having access to food and the possible consequences thereof with respect to malnutrition, morbidity and mortality and, in the extreme, food riots, have also not been estimated. The damage cost, as observed through the impact of climate change, is therefore likely to far exceed the effect on profits only. Nevertheless, these estimates provided above indicate that adaptation to climate change is a key factor to consider, even under a global temperature change that does not far exceed the Copenhagen Accord target.

5.3 Forestry

The current value of the forestry industry in South Africa has been variously estimated by a number of sources. According to South Africa Online[8] commercial forestry plantations cover 1.1% of South Africa's land surface, accounting for production of 2.2 million cubic metres of commercial round wood, with a calculated value of ZAR5.1 billion. Total industry turnover is estimated at ZAR15 billion, including ZAR6.8 billion worth of wood pulp. The South African Risk and Vulnerability Atlas states that the export of forestry products accounted for ZAR15 billion in foreign exchange in 2008 (Warburton, 2010). Industries associated with commercial forestry add significantly to this GDP contribution, with the Department of Water Affairs and Forestry (DWAF) estimating the value of forestry, and associated processing industries at 4.5% of South Africa's GDP (Bethlehem and Dlomo, 2003).

The SNC projects likely loss of productivity in current areas of plantation forestry, particularly in the Western Cape, due to potential decreases in rainfall in that region (2010c). However, in the medium and long term, the findings regarding the forestry sector are complex, and more difficult to translate into costed impacts (Warburton and Schulze, 2008). This is mainly because the total area of

8 http://www.southafrica.co.za/about-south-africa/environment/agriculture-forestry-and-land/

potential afforested land is projected to change, but it is not currently possible to project if areas of new forestry potential would be re-allocated to forestry activities. For example, changes in the optimum growth area for four *Eucalyptus* species and one hybrid, and for three *Pinus* species and one hybrid have been estimated using simple modelling approaches (Warburton and Schulze, 2008). For both genera, an increase in temperature results in a slight growth in optimum growth area for Mpumalanga and the Eastern Cape Provinces, and a slight decrease for Kwazulu Natal. For *E. nitens*, an increase of 2˚C results in an 80% reduction in climatically optimal area, and a 50% reduction for a 1˚C increase. The greatest impacts are seen with an increase in temperature and a reduction in precipitation. These projections have not yet been translated into production changes and economic impacts.

5.4 Biodiversity and ecosystem services

South Africa is widely cited as the third most biologically diverse country in the world (Wynberg, 2002). Natural and semi-natural ecosystems and their biodiversity yield valuable and often irreplaceable ecosystem services[9] to human society. Their value has been estimated at roughly 7% of GDP in South Africa (Turpie et al., 2008), although the full value of ecosystem services to all South Africans is certainly larger (Shackleton, 2009). Significant progress is being made in quantifying and mapping the value of these ecosystem services (Egoh et al., 2008). However, this information was incomplete at the time of this study and so could not be used for analysis. Nature-based tourism is likely to make a substantial contribution of roughly ZAR50 billion (international market) and ZAR30 billion (domestic market) in tourism industry turnover (Shackleton et al., 2007).

Biodiversity loss as a result of climate change is projected in South Africa, especially in regions with high levels of endemicity (i.e. species that are found nowhere else globally), such as South Africa. Roughly 20 - 30% of all species assessed so far for climate change impacts are projected to be at increased risk of extinction if Copenhagen Accord targets are exceeded (IPCC, 2007). South Africa is particularly vulnerable to biodiversity loss and previous generation assessments have suggested that a number of South African biomes are likely to be in part displaced, with their overall area being restricted (Rutherford et al., 2000). The Succulent Karoo, Grassland and Fynbos Biomes were projected to show the highest impacts, although more recent work using updated climate scenarios has reduced the severity of these projections substantively for the Succulent Karoo (Midgley and Thuiller, 2011). More detailed studies focusing on the Proteaceae in the Western Cape found that while most of the *Protea* species are projected to persist in the predicted climate of 2050, about 11% of species have no future habitat and 6% will need to be moved to new locations (Williams et al., 2005). The on-going impact of climate change is well illustrated using the charismatic and easily visible desert tree-succulent *Aloe dichotoma* (kokerboom, quiver tree). Dieback of adult plants and lack of recruitment of juvenile plants have been identified at the warmer extremes of the species' habitat, whilst healthy populations are found at the cooler extremes of the habitat, a result in keeping with climate model predictions (Foden et al., 2007). Extensive research has been conducted on the *A. dichotoma* populations, and to date anthropogenic climate change remains the most plausible explanation for the observed dieback (ibid).

Developing conservation strategies for adaptation to climate change requires rethinking conservation strategies, which have traditionally assumed a stable climate. Potential adaptation options have been identified (Von Maltitz et al., 2007) and are extended in the SNC (DEA, 2010c) as options to prevent extinction of biodiversity given projected climate change. These include the following:

- Manage and reduce the impacts of non-climate related stressors on ecosystems (e.g. pollution, overharvesting, inappropriate management, invasive alien species);
- Reconfiguration of the reserve system to strategically conserve areas that accommodate climate change;
- Design corridors that link protected areas effectively;
- Matrix management: i.e. managing the biodiversity in areas outside of reserves;
- Translocation of species into new habitats; and
- Ex-situ conservation: e.g. gene banking, cryopreservation, zoos and botanical gardens.

These options do not represent either/or options as for some species the ex-situ option will be the only

9 *Ecosystem services are the benefits people obtain from nature, such as climate regulation, storm protection, food, clean water, fuel, shelter, amongst others.*

viable alternative; however the decision between matrix management and new reserves will be largely dependent on financial and socio-economic considerations.

Invasive alien species have significant adverse economic impacts in South Africa (Van Wilgen et al., 2001). Many of these species have been deliberately introduced for economic reasons, although some have been accidently introduced. Invasive alien plant species are able to displace indigenous species through direct competition and by altering the habitat through changes in vegetation structure and changes in disturbance regimes. Invasive alien species have adverse economic impacts across all South Africa's biomes (Vanwilgen et al., 2008), but are particularly problematic within the Fynbos Biome where they are able to alter fire frequency and intensity, which favours aliens at the expense of indigenous vegetation (Van Wilgen et al., 2001). Maintaining conservation areas that are optimal for indigenous species entails control of invasive alien species. The success of invasive alien plants is likely to become more challenging within an environment of climate change (Dukes and Mooney, 1999). For example, climate change may favour exotic nitrogen-fixing species over indigenous species, and it is likely that rising atmospheric CO_2 will further enhance their success (Dukes, 2000).

In terms of impacts and adaptation costs for conservation under climate change, the authors calculated the costs of land acquisition to maximise persistence of species in situ, the likely costs of species reductions and extinctions due to projected losses of wildflower harvesting, and the costs of invasive alien plant control.

For the protected areas expansion analysis it was assumed that the South African government would increase its conservation estate from roughly 6% of total land area to the International Union for Conservation of Nature (IUCN) norm of 10% of land area between 2010 and 2020. In addition it was assumed that an additional 2% of land would be required as a climate change adaptation strategy. This is in keeping with the revised National Protected Areas Expansion Strategy (NPAES), which is designed to take climate change into consideration and identifies 12% of the land surface for conservation (DEA, 2010a). The NPAES estimates land acquisition costs at about ZAR23 billion. For analysis, a conservative land price was used, based on the national mean land price from Greenberg (2010), extrapolated to 2010 at ZAR4,500 per hectare. Logically, however, it is the land that is undergoing rapid transformation to agriculture and forestry that will be the most important to conserve and this land is, by definition, the productive land and likely to have a value in excess of mean land values. The assumption is that this land would be acquired over a ten-year period, as it is important to secure the conservation areas as early as possible. Owning land as conservation land has a management cost which includes alien removal, fire protection and other management costs. This cost has been added to the land acquisition costs using an amount of ZAR285 per hectare (2010 value). The management rate has been used as a flat rate, despite the fact that there is a well-recognised scale factor between reserve sizes and per hectare management costs. Further, the same management cost has been applied across the country, although the authors are aware that this will vary by habitat type (Moore et al., 2004). The rates might therefore be conservative for habitats such as the Fynbos but high for some of the more arid savanna areas.

The wildflower industry and the medicinal plant industries contribute an additional approximate ZAR300 million per year (Turpie et al., 2008). The authors assumed an escalating loss up to 2050 of up to 10% of this revenue, and calculated this annually. Costs of combating alien invasive plant species were estimated to increase by about two thirds. These costs are provided in Table 5. When aggregated, these costs give a coarse estimate of an approximate 30% increase in the cost of managing natural resources under climate change.

Table 5: Annualised costs of three key elements of natural resources management under climate change up to 2050

ZAR millions per year, 2010 equivalent		
Impact mechanism	Future costs without climate change	Additional future costs due to climate change, assumed equal to adaptation costs required to counter impacts
Protected Areas Expansion	3002	1316
Alien Invasive Plant Control	300	200
Loss of Ecosystem Services	0	250
All sources	3302	1766

Restructuring reserves and alien plant control will not conserve all species in the face of climate change and alternative strategies are needed. These additional strategies have not been fully costed, but it may be possible to do so in the near future. A key precautionary strategy would be to create seed banks and/or gene banks for all plant species, as it is difficult to predict with certainty which species will be most susceptible to climate change. The current cost to establish the infrastructure and collect the necessary material is estimated at roughly ZAR4,000 per plant species. This represents a total cost of approximately ZAR96 million to create seed banks for the 24,000 plant species indigenous to South Africa, and excludes costs of infrastructure and seed bank maintenance.

5.5 Wildfire

Approximately 2.4 million hectares of vegetation burns in South Africa annually, and the damage cost of wildfires was conservatively estimated at approximately ZAR200 million per year for the period 2000 - 2008 (2010c). About 14% of all wildfires attract formal fire-control activity. The current cost of combating vegetation fires in South Africa is ZAR346 per hectare per year (J. Blignaut, pers. comm.), making the present costs conservatively around ZAR115 million per year. Fire frequencies in the Cape Peninsula have been rising at about 1.6% per year over the past four decades, while the area of plantations burned in Mpumalanga has risen over the past decade at about 6% per year. Although it is thought that increasing numbers of ignitions in the Cape Peninsula are largely a result of greater densities of people (Van Wilgen and Forsyth, 2008), an argument can be made that climate change is also an important driving factor behind these trends (Southey, 2009), although it is not yet certain if this is related to cyclical climatic shifts in the case of the Cape (Wilson et al., 2010). For this analysis, it was estimated that fires would increase by approximately 2% per year, close to the lower range estimate of current trend. The annualised cost of this additional burden is about ZAR58 million per year, based on 2010 values. It is not yet possible to estimate the efficiency of the simple adaptation measure of enhancing current fire fighting practices on reducing the projected impacts of increased fire frequency as a result of climate change. In other words, more expensive adaptation responses might be necessary that involve the introduction of additional novel fire fighting responses to reduce future impacts to current levels.

6 Ecosystem-based adaption

Ecosystem-based adaptation (EbA) has been described as the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change (Secretariat of the Convention on Biological Diversity, 2009). It uses sustainable management, conservation, and restoration of ecosystems to enhance the services that will help people, communities and societies adapt to the impacts of climate change. Ecosystem-based adaptation approaches seek to maintain and enhance resilience and reduce vulnerability in ecosystems experiencing the effects of climate change. The approach has the potential to generate significant social, economic and cultural co-benefits, while contributing to the conservation of biodiversity, and building on traditional and local knowledge and practices. As an additional co-benefit, EbA can enhance ecosystem mitigation potential, for example, through the sequestration and storage of carbon.

Because of the potential value of this approach for South Africa, the authors explored an extensive piece of work by Kotze and Ellery (2009), which provides a good example of EbA in practice. The study assessed the value of restoring wetland function in rural settings in South Africa and the socio-economic value of this intervention. The pilot study implemented rehabilitation and maintenance procedures in six wetlands, contributing towards regulatory and supporting ecosystem services (e.g. flood attenuation, nitrate assimilation and erosion control), biodiversity conservation, and provisioning services (e.g. maintaining suitable sites for cultivating foods). The economic valuation undertaken indicated appreciable cost effectiveness of investment in rehabilitation of the Manalana Wetland, one of the wetlands critical for human livelihoods near Bushbuckridge on the south-western border of the Kruger National Park in Mpumalanga Province. This assessment indicated that the economic benefits were double the investment in rehabilitation over a 50-year period. This is in an area where the relative contribution of land-based activities to livelihoods is estimated at 57.5%, compared to 42.5% from cash income streams (Dovie et al., 2006), and where half of the households survive on an income of less than ZAR5,700 per year and a further 20% on less than R12,000 per year. A critical component of the value of this rehabilitation is to provide a safety-net for people during times of resource shocks, such as are likely to be experienced as a result of climate change. The savings represented by wetland provisioning services in this regard is conservatively estimated at an additional R3,466 per year to some 70% of the village households (Kotze and Ellery, 2009).

7 Adaptation priorities

As mentioned in Section 3, a challenge in planning adaptation responses to climate change is that future climate trends are uncertain, especially for southern Africa. Furthermore, uncertainty regarding the extent of damages rises steeply over the longer term. Adaptation objectives must therefore be able to adjust to a moving target, within which the timeframe is important. For this reason, there is a need to plan flexibly for a wide range of possible responses over the medium to long term, and to have in place focused monitoring systems to update our knowledge of how rapidly the change is occurring, and about the effectiveness of adaptation responses.

There are many potential positive synergies between adaptation and mitigation objectives, particularly in the agriculture and biodiversity sectors. However, these need full cost:benefit analysis to guide their prioritisation. Likewise, adaptation strategies in many sectors have the potential to align with many environmental and socio-economic policy directions, but these also require more integrated and in-depth analysis.

Increased climate variability is an important driver of damages in the short term, while the impacts of longer-term effects, such as gradual warming, will tend to emerge more slowly. There are some exceptions to this, in which sensitive or vulnerable systems that are close to their climate thresholds could show sudden effects, such as agricultural regions that become too warm for certain crops. The key message is that extreme weather-related disasters will be far more frequent and damaging, and in the absence of effective adaptation, many sectors will be compromised.

On the positive side, a key feature of adaptation responses is that they have a much stronger local context than do mitigation responses, and can show short-term benefits, such as improvement in local environmental quality. Effective adaptation responses can also provide many opportunities for job creation, particularly of "green jobs", and could contribute significantly to sustainable development goals, over and above their role of reducing the impacts of climate-related. Well-planned adaptation responses can thus be easily integrated with sustainable development policy directions. However, it is not yet possible to quantify the role and socio-economic consequences of economic measures, such as pricing in adaptation strategies.

In order to plan and coordinate an effective integrated adaptation response, actions need to be informed by:

- Early warning and forecasting for Disaster Risk Reduction (DRR);
- Medium-term (decade-scale) climate forecasting to identify potential resource challenges well in advance (e.g. droughts); and
- Long-term climate projections that better define the potential range of future climate conditions.

Effective adaptation planning needs to be reinforced by research, capacity development and technology development, responding to the needs of DRR in the short term, and integrated resource and development planning in the medium and long term. An unresolved issue with regard to the implementation of adaptation actions relates to building the case by conducting full cost:benefit analyses of potential alternative actions, because there is a lack of detailed information about potential adaptation strategies and their quantitative costing for most sectors. Because early estimates indicate large potential adverse impacts on many sectors (Stern et al., 2006), adaptation responses could therefore be highly beneficial and cost-effective.

An indicative national level prioritisation for adaptation responses and the appropriate timeframes is provided in Table 6 below. Please note that this table is far from complete, and subject additions as a result of the development of sector plans.

Table 6: Indicative national level prioritisation for adaptation responses and the appropriate time frames

Short term	Medium term	Long term
Review National Water for Growth and Development Strategy (DWA, 2009) accounting for climate change constraints.	Food security objectives should be defined and quantified, and their potential achievement analysed in the light of plausible climate change scenarios.	Integrated terrestrial, coastal and marine resource management plans to strengthen the resilience of ecosystem services and biodiversity.
Define and quantify regional and national water security objectives and adaptation responses for ground water, surface water and alternative supplies such as desalination.	Develop an understanding of the use of water by different sectors, and how this can be sustainably adjusted to optimise other sectoral objectives, such as food security.	Develop integrated catchment management planning and approaches that link the implications of land management for impacts between upper and lower reaches of catchments.
Scale up Water Demand Management Strategy (DWAF, 2004).	Agriculture sector to integrate land reform objectives with food security objectives, and with projected water supply constraints, accounting for plausible climate scenarios.	Urban and rural settlement planning needs to be as fully informed as possible about climate change and climate variability risks.
Ensure basic water needs for the poor continue to be met under plausible climate scenarios.	Health sector planning to take into account full cost:benefit analysis of managing vector borne diseases and issues relating to climate related stresses, assuming minimum levels of food security and water.	
Enhance DRR responses, adequately fund disaster management systems, improve early warning capacity, and enhance data reporting.	All relevant sectors to plan for possible periods of extended drought, based on likely scenarios over the medium-term, including projecting regional impacts and socio-economic consequences of these drought events.	
Create job opportunities around adaptation sectors.	Urban infrastructure planning to account for water supply constraints and impacts of extreme weather-related events (e.g. storm water drainage, recalculate flood lines, etc.).	
Begin enhancing ecological resilience and developing EbA responses.	Explore mitigation and adaptation synergies.	
Disaster Risk Reduction should focus on mechanisms for the poor, including micro-insurance.		

Government departments have begun working on sectoral adaptation plans. These should include job creation and growth strategies, especially in terms of green economy objectives. These will be integrated into an integrated adaptation strategy and action plan with specific interventions and projects. A key component of this would be targeted funding for key sectors to conduct research into climate change impacts, vulnerability and adaptation with a socio-economic focus, as described in the aims articulated in Section 2 of this report. In addition to a refinement of top-down approaches, such as has been attempted in this study, more detailed bottom-up approaches should also be conducted that will be able to provide results with a higher degree of confidence than is currently possible.

An integrated long-term adaptation strategy should be developed that co-ordinates responses between sectors and departments, and which reviews responses in terms of their progress and effectiveness in relation to the unfolding understanding on climate scenarios. This biennial review cycle should allow responses to be adjusted appropriately.

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