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# SOUTH AFRICAN COUNTY STUDY ON CLIMATE CHANGE

# SYNTHESIS REPORT FOR THE VULNERABILITY AND ADAPTATION ASSESSMENT SECTION

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# 1 Introduction

## *1.1 Problem Statement*

Potential changes in climate may have significant effects on various sectors of South African society. The Vulnerability and Adaptation (V&A) Section of the South African Country Study on Climate Change (SACSCC) co-ordinated research efforts in several sectors to assess possible effects from a changing climate and environment. A further challenge is to identify potential measures that may alleviate adverse effects in different sectors. These adaptation options should not interfere with the successful functioning of other sectors and should reflect societal preferences and overall goals.

## *1.2 Definitions and Terms of Reference*

The following definitions provide a foundation to establish research methodologies and assessments of potentially vulnerable sectors (IPCC, 1995):

### 1.2.1 Vulnerability to Climate Change Conditions

The overall concept of climate-based challenges to human activities and natural resources can be described by two factors, sensitivity and vulnerability. The two concepts are used together to describe the overall level of risk for a specific sector or area:

> *Sensitivity is the degree to which a system will respond to a change in climatic conditions (e.g., the extent of change in ecosystem composition, structure, and functioning, including primary productivity, resulting from a given change in temperature or precipitation).*
>
> *Vulnerability defines the extent to which climate change may damage or harm a system. It depends not only on a system's sensitivity but also on its ability to adapt to new climatic conditions.*

These definitions are often used together to describe both change and a system's ability to absorb negative impacts. For example, a fifteen percent reduction in mean crop yields due to climate change may or may not be a significant amount depending on the ability of growers in the area to cope with the decrease. If the growers have significant resources available to them to cope with yield decreases, then the overall vulnerability of the area may be low. The same yield decrease in an area with resource-limited farmers may have a higher impact because of their lack of coping options. The same sensitivity level in this resource-poor area can lead to a higher level of vulnerability.

### 1.2.2 Adaptation under Climate Change Conditions

Adaptation to climate change is a broad category of actions that attempt to reduce the vulnerability caused by climate change:

> *Adaptability refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions (IPCC,1995).*

Adaptation measures can be distinguished into several categories for identification and assessment. Some adaptation options are adopted routinely by the system in question as part of its normal operation. These adaptation responses were termed "autonomous" by Parry and Carter (1998) to show the potential internal adjustments of a selected sector. Autonomous adaptation can follow three broad categories, inbuilt adjustments, routine adjustments and tactical adjustments. Inbuilt adjustments allow for the physiological or even unconscious adjustments to changed climate conditions such as a plant stomata reacting to a change in environmental conditions. Routine adjustments are more conscious adjustments that occur within the system to variations in climate conditions such as farmer altering a sowing date to take advantage of the most favourable soil moisture conditions for that season. Tactical adjustments represent a more pronounced response to climate variation that is outside the normal expectations of climatic variability. For example, a grower may decide that she/he should change crops from maize to sorghum in response to a hotter and drier environment. The autonomous adjustments represent many of the responses within a specific sector of society. More strategic adaptation responses may be formulated across societal sectors as part of a specific government plan for climate change effects.

Not all adaptation measures can be helpful to the situation in its entirety. Some measures can be made in haste or without a view to either long term or overall sustainability. The term maladaptation was created to separate out certain actions as more unproductive than others in creating resilience to adverse effects.

> *Maladaptation refers to actions that increase the vulnerability to climate change. This definition could also include making development or investment decisions while neglecting the actual or potential impacts of climate or climate change. (Burton et. al, 1998).*

These actions could represent the responses taken in the short term that satisfy an immediate need but are not productive in a longer term. For example, a farmer in a water scarce region may purchase an irrigation system to alleviate his/her own water shortage. If all the growers in this region reacted similarly, the overall water scarcity in this region may increase as a result. Maladaptation can occur at the governmental level as well by allowing development in certain regions that are known to be vulnerable to climatic events such as flood and typhoons.

### *1.3 Objectives of the SACSCC V&A Component*

The overall objectives of the South African Country Study on Climate Change Vulnerability and Adaptation study are as follows:

- Identify sectors and areas of highest vulnerability to climate change
- Propose suitable adaptation measures to offset adverse consequences
- Synthesise vulnerability and adaptation results across sectors for analysis by policy or mitigation initiatives

These objectives study the potential impacts of climate change on South African resources and resource uses. The general approach of this Vulnerability and Adaptation assessment seeks to answer *"what-if"* type questions (Burton et. al., 1998). For example, "*what if* climate was to change in a certain manner? Would current agriculture practices be adequate? *What if* growers altered planting dates to compensate? The initial answers to these questions have been addressed by researchers chosen because of their expert knowledge in certain sectors. The sector-based studies in this assessment were tasked with appraising the overall sensitivity of their sector and to propose potential adaptation responses when encountering negative effects from climate change.

A further approach beyond the scope of this current V&A assessment is to study the policy implications of the estimated impacts. Evaluations of potential outcomes are compared with the aspirations of various stakeholders. These stakeholders could be citizens, government, non-governmental organisations, businesses and other stake-holders. In the subsequent policy formation phase, researchers and experts play more of an informant role to help communicate the research results to the stakeholder forum.

### *1.4 Sectors of the Vulnerability and Adaptation Assessment*

The National Committee for Climate Change (NCCC) identified several research sectors for more detailed vulnerability and adaptation assessments. The research sectors include the following areas:

- Climate Scenarios
- Water Resources
- Agriculture
- Human Health
- Forestry
- Rangelands
- Biodiversity (Marine, Terrestrial plants and Terrestrial animals)

These sector studies formed the research base for the South African Country on Climate Change – Vulnerability and Adaptation Assessment.

### *1.5 Organisation of the V&A Synthesis Report*

This synthesis report represents a summary of the various sector studies. The executive summaries from the individual sector reports are presented in Sections 2 through 10 while the full sector reports are presented in separate volumes. The reports in the separate volumes address the levels of sensitivity and vulnerability for each sector and propose initial sector-based adaptation options. Section 11 presents some inter-sectoral linkages and effects in the vulnerability and adaptation responses. Sector results are integrated into common metrics such as potentially affected populations and possible land use changes. The section describes a methodology for transitioning the science-based results of the V&A sectors into a more inclusive and policy-based adaptation strategy. The section also reviews some of the uncertainties in the V&A process. Section 12 provides an overall summary of vulnerability and adaptation results. Sections 13 and 14 provide the references and a technical appendix, respectively.

## 2 Climate Scenarios Sector Executive Summary

Three GCMs were used in this study representing a range of complexity that encompass an older model with simplified oceans (Genesis), an earlier coupled ocean-atmosphere model (HadCM2, a leading GCM in the last IPCC assessment), and a recent current-generation fully coupled ocean-atmosphere model (CSM). An important consideration when using GCMs in climate change mode is that such simulations do not represent a *forecast*, which implies a prediction of specific atmospheric states, but are rather a projection of future climate. As such, these represent a *possible* evolution of the global climate system. Consequently, the simulations are a “best-guess” understanding of future climate. Such performance thus supports the view that the models are capturing the primary dynamical response to the increased radiative forcing from changing concentrations of atmospheric greenhouse gasses. A second point to be made is that the GCMs are most skillful in capturing the fundamental dynamics of the atmosphere represented by the synoptic, or large-scale, circulation. The variables of direct concern for regional impact assessment, most commonly precipitation and surface air temperature, are themselves derived variables, and are increasingly erroneous as spatial resolution increases, and thus individual grid cell data need to be interpreted with caution.

The coarse resolution scenarios were constructed directly from GCM output, and were monthly and seasonal aggregates of the daily grid-cell temperature and precipitation data. In general, the CSM scenario shows larger changes than both the non-sulphate and the sulphate runs from the HadCM2 scenario. In both cases the continent shows the most significant warming, with the warming greatest in the northern regions of the sub-continent. In all cases the GCMs indicate an extension of the summer season characteristics. In general, the climate projections indicate a continental warming of between 1°C and 3°C, with the maximum focused on regions of aridity, and the minimum along the coastal regions.

The GCMs show less agreement with regard to precipitation. The HadCM2 model shows smaller changes than the CSM, with the net significant impact being a broad reduction in summer rainfall, and less significant positive and negative changes in the other seasons. The sulphate simulation shows stronger changes, and in both cases the features have a general north-west/south-east alignment. Overall, the HadCM2 indicates broad reductions on the scale of 5-10% of current rainfall. The CSM model shows changes in the 5-10% range, but with greater regional structure. For summer there are indicated increases in the northeast and the southwest, with an axis of precipitation reduction from the northwest to the southeast across the center of the country. Both shoulder seasons indicate a reduction in the northeast, suggesting a reduction of the duration of summer rains in this area. The winter season has nominal increases in the northeast.

A set of high-resolution scenarios were created through the process of downscaling, which derived local climate response to the larger scale atmospheric dynamics. The methodology used regional and large-scale atmospheric dynamics (the strength of GCMs), with scale transfer functions derived from observational data, to generate local scale climate data that are directly in relation to the large scale atmospheric forcing. These changes, in conjunction with the changes in temperature and precipitation may be used to infer a number of possible consequences. (1) For the critical summer season the circulation infers greater subsidence over the continent. This is evidenced in part by the increased temperatures. However, increased subsidence also leads to enhanced inversions and greater pollution potential. More critical is the consequent suppression of convective precipitation. This is noted in the precipitation changes in the interior, but also is likely to indicate greater dry-spell duration followed by more intense convective events when they do occur, with the possibility of inducing more frequent flood events. The net effect is likely to be greater evapotranspiration and increased stress on arid and marginal zones. (2) The broad precipitation increases in early summer for the northeastern regions are likely a reflection of the increased atmospheric moisture content. Complementing this are the regional characteristics of greater atmospheric instability due to the proximity of warm sea surface temperatures and the orographic forcing. Nonetheless, the possibility of greater dry-spell lengths and intensified convective rainfall with a greater frequency of flood events, as inferred for the interior, are likely to apply in this region as well. (3) For the southwestern region the implications are increased early winter frontal and orographic rainfall, likely due to the increased moisture with warmer sea surface temperatures and an indicated increase in frontal activity. The later winter decrease is nominal.

## 3 Water Resources Sector Executive Summary

Changes in climate due to anthropogenic influences are expected to affect hydrological systems and water resources in southern Africa. To assess the potential impact of climate change on hydrological responses in the study area, which included the contiguous areas of South Africa, Lesotho and Swaziland, the *ACRU* hydrological modelling system was selected to model potential changes.

Future climate scenarios for this study were obtained from four General Circulation Models (GCMs), *viz*. the CSM (1998) GCM, the Genesis (1998) GCM and two versions of the Hadley (1995) GCM, one including and excluding sulphate forcing which has a cooling effect in the atmosphere. As the spatial resolution of the precipitation and temperature output from these GCMs was too coarse for use in hydrological impact studies of climate change there was a need to interpolate the GCM output to a finer spatial resolution. In addition, the *ACRU* model was modified and updated to enable more dynamic simulation of climate change.

Although climate change (CC) is expected to affect many sectors of the natural and man-made sectors of our environment, water is considered to be the most critical factor associated with CC impacts and adaptability. Water is becoming an increasingly scarce resource in many parts of the developing world, mostly as a consequence of demands made by increasing. Water is considered a limiting resource for development in southern Africa and changes in the water resources of this area could have major implications for the economy of the region.

The changes in hydrological responses were calculated both as absolute differences between future and present values and the ratio of future hydrological response to the present response. Identical procedures were used for all the hydrological analyses over southern Africa, with the assumption of a single land cover type, *viz*. grassland in fair hydrological condition, covering the entire study area. In addition, no anthropogenic perturbations such as abstractions from rivers or reservoirs, or inter-basin transfers were considered. The results presented in this report should be viewed as a comparative relative study, rather than assuming values to be absolute. Hydrological responses are known to be sensitive to changes in precipitation. The sensitivity of two hydrological responses, *viz*. runoff and recharge into the vadose zone were assessed. From the sensitivity studies it was concluded that runoff in the study area was highly sensitive to changes in precipitation, while the an overall sensitivity of runoff change to an effective doubling of $CO_2$ concentrations by itself, and also to a 2 °C increase in temperature by itself was not sensitive in the winter rainfall regions of the south western Cape. Recharge into the vadose zone is even more sensitive to changes in rainfall than runoff is. From a previous sensitivity study using the *ACRU* model net irrigation requirement, on the other hand, was found to be insensitive to changes in rainfall.

From the threshold study of runoff it may be concluded that the western half of the study area could experience a 10% decrease in runoff by the year 2015 using climatic output from the Hadley GCM, excluding sulphates. The year when a 10% decrease in runoff occurs moves progressively later to 2060 as one moves from the western to eastern halves of southern Africa. The threshold study of recharge into the vadose zone, however, displays a much more patchy and less systematic pattern over southern Africa.

This study, through the linking of Quaternary Catchments, has facilitated the assessment of actual catchment problems. The concept of the threshold analysis has allowed the identification of areas where changes in hydrological response could occur sooner, or later, than in other areas. The modifications to *ACRU* have allowed dynamic vegetation response to changes in temperature.

## 4 Agriculture Sector Executive Summary

South African maize production is characterized by high variations in yield due mainly to fluctuations in seasonal precipitation. Generally South African maize production is divided into two primary areas, a dry western area (western Free State and North-West provinces) and a wet eastern area (eastern Free State, Gauteng, Mpumalanga and KwaZulu-Natal provinces).

Using the CERES-Maize crop simulation model, four potential climate scenarios were tested for nineteen individual sites representing most of the current maize production area. These site-based simulations covered a 30 year climate period (1966 – 1996) and explored potential grower-level vulnerability and adaptation to climate change conditions. To reflect potential crop yield responses at a regional scale, the same maize model was linked with a national-scale Geographic Information System (GIS) database and simulated for a period of 42 years (1951 – 1993). In addition, simulations were conducted with simplified cropping models to explore potential climate change effects on more specialty crops grown in certain environmentally-favorable areas.

The results of the crop model simulations showed that maize yields will either remain at current levels or decrease ten to twenty percent according to the climate scenario used. Some of the marginal western areas may become unsuitable for maize production under current management strategies while some of the eastern production areas may remain unchanged or increase production levels. Specialty crops grown in specific environmentally favorable areas may also be at risk as both rainfall and temperature effects may cause changes in areas suitable for specialized production. Some of the negative crop growth effects may be mitigated by the "fertilization effect" of $CO_2$ gas on plant physiology, although scientists are currently divided on the scale and longevity of these benefits.

Adaptation responses can be catagorized into two scales, grower-level responses and government level responses. Grower-level adaptation measures such as changing planting dates may be suitable for growers in specific areas and circumstances but may not alleviate maize yield reductions in more marginal areas. Irrigation is a traditional adaptation strategy that may be costly or may demand already scarce water resources. Possible adaptation strategies for marginal areas may mean that growers may have to switch to more water efficient crops such as sorghum or millet or change production entirely from crops to livestock. Government-level adaptation measures will most likely be limited by financial resources and should be focused to aid both commercial and subsistence growers in currently marginal areas to respond adequately to a more challenging cropping environment.

# 5 Forestry Sector Executive Summary

1. The South African forestry industry is sensitive to climate, for better or for worse. Only 1.5% of the country is suitable for tree crops under the current climate. Much of this area is relatively marginal. The relatively long period between planting and harvest makes tree plantations vulnerable to environmental change. Shifts in the optimum tree-growing location can have a big impact on the profitability of fixed capital investments, such as sawlog and pulp mills.

2. Significant climate change is likely within the next 50 years, as a consequence of human-induced changes in the composition of the atmosphere. An increase in the atmospheric concentration of carbon dioxide is already apparent, and will contrive to grow. The predicted changes are of a sufficient magnitude to affect the plantation forestry industry. Many of the potential impacts are negative, and some are positive. Climate change will become an increasingly important issue to the forestry industry, but will remain secondary to the more important changes brought about by political, economic and land-use changes.

3. General Circulation Models (GCM) predict scenarios of mean annual temperature increases of 2.5 - 3.5º C and reduced rainfall during the 21st century. The rainfall predictions are less reliable than temperature predictions. These changes have the potential to alter the distribution of optimum planting areas for current cultivars of the major tree crop species (e.g. *Pinus patula, Pinus elliottii, Pinus taeda, Pinus radiata, Eucalyptus grandis, Eucalyptus saligna, Eucalyptus nitens, Accacia mearnsii*), and the competition for land with other potential users (e.g. subtropical fruits, dryland agriculture, biodiversity conservation, etc.) will increase. Greater clarity on the location and intensity of climate change will be forthcoming in the next decade as better models become available. Immediate action to alter the current distribution of tree plantation land is premature. Instead increased effort should be focused on developing new genetic hybrids (e.g. resistance to heat stress and drought tolerance) and in understanding site-species-climate relationships needed to take rational planning decisions once better climate predictions become available.

4. The results of forest growth models suggest that if the climate changes to the degree predicted, and if no action is taken to select and plant heat tolerant cultivars, there will be substantial loss of production in the core area of current forestry, particularly in *Pinus patula* and *Pinus radiata* plantations.

## 6 Rangelands Sector Executive Summary

Rangelands are defined as those natural and semi-natural ecosystems in which the husbandry of large herbivores is the principal economic activity. Altogether, rangelands occupy over 70% of the land surface of South Africa (1 219 000 km$^2$ ), making them the largest single land use. The climate change scenarios yielded by the GCM simulations suggest a general aridification of rangelands over southern Africa. This is especially true of marginal rangelands, ie where climate variability (mainly of rainfall) results in periodic drought conditions. General aridification, due to lower rainfall and higher air temperatures, will affect fodder production by vegetation, and impact the marginal costs associated with ranching. The potentially positive effects of increased minimum temperature (reduction in the area prone to killing frosts) and the fertilising effect of higher atmospheric $CO_2$ are important ameliorating influences. Temperature, atmospheric $CO_2$ and rainfall predictions are all critical in forecasting changes in vegetation structure (for example, bush encroachment into former grasslands). Structural changes affect the type and amount of forage produced, which determines how the rangelands can be used and managed.

The model used for this analysis was CENTURY. It is a model of carbon and nitrogen dynamics in grasslands, and has been extensively used and validated around the world. Three sites were chosen to represent different rangeland types in South Africa, and because soil data and some validation data was available for them. The sites included a semi-arid, "sweet" grassland site near Bloemfontein, a moist, "sour" grassland site near Pietermaritzburg and a savanna site at Nylesvley. The CENTURY model simulations were conducted with climate change conditions from the HADCM2 model. The model was tested with climate change only and climate change coupled with the effects of elevated $CO_2$ concentrations to explore the possible mitigating effects of higher $CO_2$ levels.

The simulations for three study sites suggest no change in the forage production potential over most of the grassland area of South Africa, due to the cancellation of the drying effect of higher temperatures and lower rainfall by the water use efficiency increase due to elevated $CO_2$. Over the savanna regions in the northeast of the country, forage production may decrease by about one fifth. This would impact largely on the cattle ranching industry, reducing the carrying capacity on savanna rangelands by a similar amount. Since about half of the cattle in South Africa are located in savannas, the reduction in the national free-range cattle herd would be about 10%. Beef production would be affected less, since an increasing fraction of the beef herd is fattened in feedlots before slaughter.

A changed climate would increase fire intensities by about 20%. An increase in air temperature of 2°C by itself would increase the intensities by 7% in an average savanna fire. An increase or decrease in grass fuel load would have an essentially proportional effect on fire intensities; production increases of the order of 15%, as predicted, would raise fire intensities by a similar amount if the extra fuel is not grazed. A cumulative increase of around 20% will increase the fraction of tree biomass killed aboveground by fires by a similar proportion, but is unlikely to substantially affect woody plant demography.

Conclusions from the study include the following:

1. Net primary production in South African rangelands is only marginally affected by the anticipated climate changes, because the rise in temperature and slight fall in rainfall are offset almost exactly by the rising $CO_2$.

2. Increased runoff and drainage are only a possibility in the wettest parts of the country. Elsewhere the increased water use efficiency will simply translate into a slightly longer growing season.

3. The grassland biome will become more favourable for tree growth due to higher temperatures, and possibly due to elevated $CO_2$.

4. Soil organic carbon stocks are likely to increase by a small amount (1%) in the east and north of the country, and decrease in the west.

5. There is likely to be an increase in the emissions of methane from ruminants, of possibly up to 20%.

## 7 Human Health Sector Executive Summary

The Human Health sector concentrates on the two main vector-borne diseases in South Africa, malaria and schistosomiasis.

**Malaria.** Malaria is the eleventh most important cause of death globally, claiming an estimated 856 000 lives each year. Of these, it is believed that 90% now occur in sub-Saharan Africa, the greatest toll falling on children below the age of five.

In the late 1920's and early 1930's, malaria in South Africa was intensely endemic: in Northern Province for instance 86% of 2-3 year old children and 20-40% of adults were infected at one point in time. Systematic control has reduced malaria dramatically: in the two districts with highest risk, annual incidence between 1987 and 1993 were on average 1.5%, in most other districts less or much less than 0.1%. In the last decade malaria has once again been on the increase. This has been attributed to failing drugs, increase of HIV/AIDS and recent evidence of insecticide resistance. Thus in South Africa neither the present distribution and intensity of malaria nor the recent increase is solely attributable to climate.

Nevertheless, malaria is strongly affected by many environmental factors, which affect the distribution, transmission intensity, disease outcome, small-scale variation and seasonality. Climate is considered the most important in limiting malaria at a global scale. In this study, potentially “malaria-receptive” areas, climatically suitable for sustained malaria transmissions, were examined under present climatic conditions and future climate predictions for South Africa. The models assumed no anthropogenic or other effects at all, but simulated malarial areas as function of climatic constraints only.

A climate-based model of malaria distribution was used to predict distribution, using present and future climate data, and the number of people at risk in each case was estimated. In both the sulphate and no sulphate options of the HADM2 scenario, the malaria-prone areas would more than double following projected climate changes. The number of people potentially at risk of malaria would increase from 7,819,266

(1996 census data, using Schulze's climate data) to 23,038,318 or 36,300,636 (2010 population, according to the sulphate and no sulphate HADM2 scenarios respectively). Of these, 9,672,597 (2010 population figures) will have lived in previously unaffected areas (where climatic suitability was less than 10%), while 14,495,061 people will have lived in areas where climate change would increase suitable periods from less than 5 months (too short) to 5 months or more. Areas in northern KwaZulu-Natal and eastern Swaziland would experience longer transmission seasons (1 to 4 months longer than at present) with predicted climate change. However, only about 1.5 to 2 million people presently live in theses areas, and the majority of these would only see an increase in the transmission season of 1 or 2 months. With an incidence in these parts of around 1%, this outcome would only result in an extra 1000 or so cases.

The projected numbers of people at risk are based on the potential maximum distribution of malaria. In southern Africa malaria lies at the edge of its natural distribution, and malaria control has reduced malaria northwards. Control efforts in South Africa have been effective because malaria was marginal to start off with, and because tremendous resources have been poured into the effort. Even under present climatic conditions, if the control operations were to collapse, malaria could spread again to its former level. Indeed, national malaria case numbers have been increasing over the last few years, as mentioned, but it is difficult to foresee the trends in future. On the other hand, malaria control today is more likely to succeed than in the past, because we know more about malaria today than we did then, and we have a greater choice of tools available to us today.

Future scenarios based on global warming need to be balanced by a clear consideration of the many other factors that affect the potential outcome. If the number of people living at risk were to double, the incidence of malaria would certainly increase, aggravated by the other confounding factors mentioned before, such as drug resistance. As the burden of malaria increases, and control with large-scale eradication methods becomes more difficult (a situation common in our malaria-infested northern neighbours), more emphasis will need to be placed on community involvement and personal protection.

**Schistosomiasis**. The tropical, parasitic disease schistosomiasis is second to malaria in contributing to the overall chronic disease burden in the developing world. It has been reported that 120 million people are symptomatic and 20 million people harbour severe schistosome infections. It is estimated that between 3 and 4 million people infected with one or more species of schistosome in South Africa. Prevalence ranges were reportedly between 10% in some areas and 80% in the lowveld and east coast. The disease is virtually endemic in KwaZulu-Natal and has been found along the coastal belt of the province, in the Eastern Cape, in parts of Mpumalanga, as well as the North and North-west provinces.

The link between climate and schistosomiasis transmission may be utilised to allow scientists to establish stable and unstable transmission seasons and to quantify the risk of infection within populations in particular localities. A geographical information system's (GIS) approach to linking environmental factors, climatic change and schistosomiasis contributes to our current understanding of the disease by facilitating the creation of predictive models to reflect its epidemiology within the country.
The results of the theoretical model suggest that there will be a broadening of the area that is currently suitable for transmission of both *S.haematobium* and *S.mansoni* in the future. Given this, it is not surprising that the total population at risk according to the future predictions increase for *S.mansoni* compared with that predicted for the present climate. The potential for schistosomiasis will exist in areas that are currently free of the disease if the temperature parameters described in this study are considered. This is especially evident in the Western regions of the country. However, it becomes necessary to assess the impact of other variables affecting the epidemiology of the disease to explain the possible occurrence or recurrence of the disease where there is currently little or no transmission.

With these model results, the following recommendations are offered:

1. Our foremost recommendation is to establish a monitoring system made up of scientists who collect disease data, health care professionals, climatologists, GIS scientists and statisticians. This system will be enhanced by using tools like GIS that facilitate our further understanding of the disease at a local level. Using

spatial analysis to study schistosomiasis in South Africa is new, and presents possibilities for future research.

2. The global circulation models that were used in this study were downscaled to a local level, and major anomalies may exist at a focal level where schistosomiasis presents itself. Thus, it would be better to use climate models that were based at a more localised level.

3. Efforts to control the disease in identified high risk areas should be proactive and direct. This should include the use of drugs, improving sanitation and educating the population at risk.

4. We need to evaluate and monitor the effect of other environmental parameters that affect the transmission of schistosomiasis.

5. Climate-based spatial disease models are valuable to the health sector as they can predict where outbreaks of disease occur after extreme climate events. In the case of schistosomiasis, such information is valuable in allowing health care professionals time to prepare for control and prevention.

# 8 Terrestrial Plants Biodiversity Sector Executive Summary

This report attempts to predict how plant biodiversity in South Africa will be affected, given climate change scenarios generated by three general circulation models. A combination of approaches is used, based primarily on bioclimatic modeling techniques, to provide spatially explicit predictions of the future distributions of South African biomes and selected key plant species, and to quantify and assess threats to current centres of plant endemism and nature reserve areas. These approaches rest heavily on the availability of extensive geospatial databases.

Under the scenarios postulated, it appears that a number of key generalizations can be made with regard to future patterns of plant distribution and diversity. Firstly, the bioclimate of the country shows warming and aridification trends which are sufficient to shrink the area amenable to the country's biomes to between 38 and 55% of their current combined areal coverage. The largest losses occur in the western, central and northern parts off the country. These include the virtual complete loss or displacement of the existing Succulent Karoo Biome along the west coast and interior coastal plain, an extensive eastward shift of the Nama-karoo Biome across the interior plateau, and contraction of the Savanna Biome on the northern borders of the country, and its expansion into the Grassland Biome. The species rich Fynbos Biome does not suffer extensive loss of areal cover but may nevertheless lose many species. Analyses of species range shifts concur generally with these biome-level patterns, with the majority of 44 species analysed showing reduced range sizes. However, the species level analysis also indicates that species composition is likely to change in all biomes and even areas apparently "vacated" by biomes should continue to support a noticeably impoverished species mix. The change in species composition will also lead to major vegetation structural changes in some biomes, notably in the Grassland Biome where virtually the entire existing biome will be susceptible to a potentially large number of invading savanna tree species. The majority of the 16 centres of endemism studied also show significant deterioration of bioclimate, with more than half predicted to experience bioclimatic conditions completely unlike those of today. Nature reserves of the arid west and central parts of the country also experience a complete alteration of bioclimate, while those of the eastern and highland regions are better buffered.

We propose seven possible adaptation strategies. These include: the establishment of a biodiversity monitoring network, the application of sound vegetation management policies, the wise use and possible expansion of the protected area networks, focused attempts at ex-situ conservation, the refinement of national contributions to global greenhouse gas emission policy, future possible plant translocation action, and finally, tolerating loss, a mechanism for assessing the value of biodiversity elements to assess their relative importance in the event of unavoidable sacrifices.

# 9 Terrestrial Animal Biodiversity Sector Executive Summary

This study of the likely impacts of climate change on South African fauna is an exploratory assessment of the responses of animal species to a climate change scenario brought about by the doubling of atmospheric $CO_2$ concentrations. This scenario is predicted to lead to an increase of average temperatures by approximately 2 $^\circ$C. We employed a modified climate envelope model (Jeffree & Jeffree 1994) to explore the consequences of climate changes for the geographic distribution ranges of 179 South African animal species. The species used in this study were selected, by a panel of taxonomic experts, using criteria such as the accuracy of their distribution ranges, different types of geographic ranges, sound taxonomy and reasonable numbers of records to broadly represent the range of distribution types encountered in South African animal species.

Known species distribution ranges were modeled to generate interpolated distribution ranges. The ability of the model to accurately predict accurate distribution ranges of species was assessed using bird data for which we have the most comprehensive distribution data. The results were largely encouraging but some areas of the country appeared more problematic than others (e.g. the east coast region), possibly due to topographical, habitat and vegetation complexity which confounds climate-driven interpolations. The following main conclusions were reached during this study:

- The levels of climate change induced impacts on the fauna of South Africa range from minimal (6 species showed no change in range size) to severe (4 species were predicted to go extinct).

- Of the 179 species examined, 17% expanded their ranges, while 80% displayed range contractions varying from 0 - 98%. Only 3% of the species failed to show any response.

- Species rich areas contracted from existing patterns and were concentrated around the eastern highlands following climate change. This pattern could be attributed to extensive range shifts and contractions and led to a decline of maximum richness.

- The majority of range shifts were in an easterly direction (41% of taxa) reflecting the east-west aridity gradient across the country and the increased pattern of aridity in the western zones predicted by climate change models. Species losses are likely to be highest in the west.

- Substantially smaller westward shifts were also documented in some taxa. These may reflect altitudinal gradient responses and/or model artefacts.

- Geographic range contractions were documented for 72% of all species whereas 25% displayed range expansion (no response 3%).

- Species range change (composite measure reflecting range decline and displacement) identified selected species from each taxonomic group that could potentially act as climate change indicator taxa (see McGeoch 1998).

- Red-data and vulnerable species responded in a similar fashion to the other species investigated, but were more likely to display range shifts. Moreover, a larger proportion of red-data and vulnerable species (58%) were susceptible to range change (decline and displacement) compared to all other species investigated (43%).

- A Kruger National Park case study revealed that 66% of all species found in the KNP and included in this study were lost (< 50 % probability of occurrence). This included 97% of the bird species and 52% of the Red-data and vulnerable species. This case study emphasises the extensive range shifts that are likely to take place as a consequence of climate change, and underlines the importance of extending conservation mandates to areas outside existing protected areas (matrix).

- An assessment of existing land transformation patterns indicated significant spatial congruence between areas presently more than 50% transformed and areas likely to harbour large numbers of species after climate change (richness hotspots). This indicates that land-use conflicts between conservation advocates and land transformation enterprises are likely to escalate under conditions of climate change.

- Interactions between land transformation and predicted range shifts suggest that predicted range contractions may well be underestimates. Given the strong negative relationship between range size and the likelihood of extinction, this phenomenon is of considerable conservation concern.

- Although vector species, agricultural pests, and biological control agents were not specifically investigated in this study, it seems likely that climate change will have a profound influence on them. Such changes will have significant implications for agriculture and human and veterinary health.

- Mitigation of the impacts of climate change is ultimately a function of political will to confront difficult issues such as land-use planning. Nonetheless, from a conservation and research perspective several actions can be taken. These center around the need for a substantial improvement in the quality of information on animal diversity in South Africa, the need for continual updating of this information, its integration into land-use planning, and the need for a substantial improvement of local knowledge of the causal links between climate and animal distributions.

## 10 Marine Biodiversity Sector Executive Summary

Several conclusions can be drawn from the preceding studies on the likely effects of climate change on the marine environment. In the first instance, it is clear that our ability to predict how marine ecosystems are likely to respond in the face of a changing climate is extremely poor. Most of the scenarios regarding the impact of climate change on the respective marine ecosystems described, were ‘what if’ scenarios. In very few instances was it possible to provide a definitive prediction about a cause and effect relationship.

Our ability to predict future changes in the atmosphere has increased enormously over the last decade but our understanding and hence our ability to predict what effect this will have on oceanic processes remains mostly speculative. Huge advances have been made in our understanding of how pressure systems and hence wind fields are likely to change over time, but our understanding of how this might affect currents and other oceanic processes (which are really important for marine biota) is almost non-existent. Improving our understanding of the processes that couple the ocean and atmosphere, particularly those that influence the transfer of heat, momentum and greenhouse gases between these two entities is of paramount importance. The worlds ocean covers over 70% of the earth's surface and exerts a powerful influence on the earth's climate and vice versa. It is also important to improve our understanding of how marine organisms, communities and ecosystems are likely to respond to future changes. Emphasis should be placed on examining responses to scenarios that most accurately describe ocean atmosphere changes. Reconstruction and analysis of ecosystems associated with past climates can assist greatly in this field. Monitoring of marine ecosystems can also make an important contribution toward understanding and evaluating the impacts of global climate change. Simple monitoring should focus on the continuation and/or initiation of long-term studies to discriminate direction change vs. year to year variability.

The marine environment is extremely robust, being able to absorb an enormous amount of punishment with little or no apparent change, before major changes start to occur. Many of the changes we are likely to experience as a result of changing climates will be relatively small. A few changes of colossal proportions can be expected, however, and it is these that we should concern ourselves with. We simply need to consider what happens during an El-Nino event in order to be convinced of this. Contraction or expansion in the range occupied by a few species is unlikely to have a great impact on a global or even regional scale unless these species are of great economic value or social importance. A change in the passage or volume transport of the Agulhas current on the other hand, is likely to have enormous implications for marine biota living along the whole of the east, west and south coasts of South Africa, and potentially much further afield. The species composition and trophic functioning of rocky shore, sandy beach, estuarine and subtidal communities along these shores is likely to be altered dramatically. It is imperative that we are able to anticipate these changes before they occur or at least identify them in their early stages. This will assist both in developing effective mitigation but also in convincing those in authority of the magnitude of the problem we are facing. Coastal communities in southern Africa depend heavily on the harvesting and sale of marine resources for their livelihood and/or income. The collapse of the sardine stock off Namibia in the 1960s had an enormous impact on the people living along the coast. Coastal towns were literally abandoned as people were forced to move on or starve.

Regrettably, in this case much of the damage has already been done. In many instances there is virtually nothing that can be done at this stage to halt the change in climate. Sea level rise is a case in point. An immediate and complete cessation in the production of greenhouse gases probably would not even fully avert the crisis we find ourselves in. At best we can attempt to minimize the effects of climate change by, for example, reducing outputs of greenhouse gases and through effective management of existing anthropogenic threats (a complete cessation in the production of greenhouse gases is not realistic). Slowing global warming and other forms of global change in the first place would do far more than any after-the-fact measures could do to conserve biodiversity in the long-term. Some effects of global climate change can still be mitigated, however. Consider the case of a potential reduction in freshwater runoff reaching southern Africa estuaries (which in many cases seems likely). This has greater implications for estuaries in southern Africa than any other single factor, and it can be mitigated to a certain extent at least. Consideration must therefore be given to identifying where and to what extent mitigation is possible, and then must be applied in the most appropriate manner.

Any system that is already compromised by existing impacts is less likely to be able to deal with new threats. Where it seems likely that existing threats will be exacerbated (e.g. in the case of volumes of freshwater runoff reaching estuaries), they need to be dealt with immediately rather than waiting until the problem becomes worse. We simply cannot afford to continue ignoring the problem because soon we will not be able to ignore it any longer.

## 11 Inter-Sectoral Linkages and Effects

Each of the various sector studies studied sensitivity, vulnerability and potential adaptation within their area of expertise. In reality, South Africa has shared resources including water, land and markets. This section attempts to integrate some of the sector results into a broader context for overall assessment. In addition, linkages between sectors will be explored where a significant resource is shared. For example, the linkage of water resources and the agricultural sector may show how a shortage in surface water resources may negate a potential adaptation response such as irrigation. Overall, this integration is preliminary as the sector results provide a basic scientific platform on which to add further information concerning societal preferences, economic information and policy considerations.

### *11.1 Inter-sectoral vulnerability*

This section examines the various sector vulnerabilities to begin the process of building an overall picture of climate change effects across sectors. This integration represents a first step comparison of sectors and serves to begin the discussion of potential action measures to alleviate adverse outcomes. The sector results are described in intentionally vague and subjective language (more vulnerable, moderately vulnerable, less vulnerable) to highlight some of the overall responses of the section to changes in climate.

#### 11.1.1 Comparisons of sector vulnerabilities

The following sections highlight some of the primary areas of vulnerability within the various sector reports.

As described in the Water Resources Sector Report (Section 3), catchment runoff and groundwater recharge are highly sensitive to changes in precipitation. While all the GCM scenarios analysed agreed on some level of increase in the temperature regime, there were significant differences in the predicted precipitation amounts in both spatial and temporal patterns with substantial disagreement on the whether precipitation would increase or decrease in some areas. Mean annual simulated runoff and other hydrological outputs either increased or decreased depending mostly on the precipitation predictions from the different GCM scenarios with lesser effects due to increased temperature regimes. In simulating the sensitivity for mean annual runoff under the Hadley (no sulphates) scenario, model results showed that western catchments of South Africa could experience a 10% decrease in mean runoff as early as 2015 with the eastern areas of South Africa possibly realising a 10% runoff decrease by 2060. Simulations of large (Orange) and medium (Mgeni) river systems show that significant decreases (10 – 20%) in stream flow could be realised under the Hadley (no sulphates) scenario. While the Hadley (no sulphates) scenario was one of the more hotter and drier scenarios, model results highlight that water resources such as stream flow and ground water recharge may be quite sensitive to climate changes. As water resources are often limited in South Africa, potential decreases may increase vulnerability levels. This high sensitivity to climate effects would tend to result in the Water Resources sector being described as more vulnerable to potential climate change effects.

The results from the agriculture sector (Section 4) have varied findings depending on the GCM scenario, the farm location and the resource level of the farmer. As with the water resources sector, yield simulation results were highly dependent on predicted precipitation patterns. Under the hotter and drier Hadley (no sulphates) scenario, currently marginal western production areas become unsuitable for maize production. Some of the negative crop growth effects may be mitigated by $CO_2$ effects on plant physiology, although researchers are divided over its scale and longevity. Under simulations of potential farm-level adaptations, growers with high resources (capital, inputs and expertise) and relatively good growing areas are less vulnerable to adverse climate effects. Growers with low resources in marginal areas are may be significantly more vulnerable to yield decreases due to shifts in temperature and rainfall patterns. Given the large differences in crops, locationa, resources and expertise of the people in this sector, agricultural groups may range from moderately vulnerable for higher input growers to more vulnerable for lower input growers or growers operating within a limited climate suitability for their crop.

The Forestry sector report (Section 5) described an industry with significant sensitivity to potential climate effects but with a moderate overall vulnerability given its financial resources to adjust to adverse conditions. The forestry sector represents an industry that occupies specific environmental niches within South Africa that are favourable for plantation tree growth. Current suitable production areas are quite small (approximately 1.5% of South Africa) with a relatively long period between planting and harvest. Potential shifts in production areas could be an expensive liability as processing mills may have to move in response to climate change.

One of the less vulnerable sectors is described in the rangelands study. Grassland production under climate change decreases but is offset by $CO_2$ effects on plant physiology. Tree (or bush) encroachment could be an increasing problem as climate change and $CO_2$ effects may favour tree production in some situations. Often natural rangelands serve as a “baseline” land use where most current land uses could switch to with relatively low resources. Within communal and resource poor rangelands, alternative land use practices such as ecotourism could reduce reliance on over-stocked areas and provide additional income sources.

The human health sector described in Section 7 shows a moderate level of vulnerability to health effects from malaria and schistosomiases under climate change conditions. Although malaria is marginal in most of South Africa, specific areas can have quite serious health risks associated with them. Under climate change conditions, malarial areas have the potential to increase. These potential increases may be suppressed with current control mechanisms. The report maintains that control mechanisms must be maintained and new strains controlled to maintain current levels of control and vulnerability. Within the schistosomiases study, climate scenarios also show a potential for disease spread. Current development initiatives (piped water and better sanitation) can be effective control mechanisms to reduce vulnerability.

The plant, animal and marine biodiversity sectors described in Sections 8, 9 and 10 point out significant levels of sensitivity for species and habitat changes under climate change conditions. These biodiversity changes may be even more transformed when cross-sectional issues are taken into account. Within all biodiversity sectors, researchers point out potential conflict areas between species habitat and areas under significant human development. While the biodiversity sectors show negative trends throughout the country, some of the most dramatic biodiversity decreases were realised in the western part of South Africa. As the suitability of various plant, animal and marine/estuarine habitats may be considerably altered under most climate scenarios with few inherent options for adaptation, these sectors could be described as highly vulnerable to climate change.

### 11.1.2 Linkages that may affect overall vulnerability

Inter-sectoral vulnerabilities can be explained by the different influences various sectors have on one another. Adverse effects of climate in one sector can be dampened or exaggerated by coping mechanisms in another sector. An example of the inter-relatedness of sectors is shown in the interaction between the water resources sector and other V&A sectors. In most years water resources are limited in South Africa and may be under close observation by stake-holders. Any negative change in the availability of water resources can have far reaching effects on both human activities and ecosystem function. In this respect, water resources can serve as a linkage between other related sectors and can influence vulnerability levels in other sectors.

The forestry sector has a strong linkage with the water resources sector as changes in forested area can have an effect on the overall catchment stream flows. Currently, the forestry sector is being scrutinized for its effects on stream flow reduction in terms of the South African government's Water Act of 1998. Any further expansion of plantation forestry will be subject to governmental review for potential stream flow impacts. The limitation of newly available land for afforestation may mean the forestry industry must remain in current locations (or expand areas outside of South Africa). Options to reduce vulnerability may mean development of new cultivars or changing water management in current production areas.

For the agricultural sector, an important measure to alleviate adverse climate effects is the introduction of irrigation. This option has a direct dependence (and impact) on water resources since often irrigation water is stored in dams or is drawn directly from rivers. As with the forestry sector, irrigated agriculture areas may also be subject to governmental assessment on its water resources use. With the interdependence on water resources, areas that once may have been irrigated may have alternative crops or land uses that are more drought-tolerant. Given that irrigation is usually only open to higher input growers, options for smaller-scale or limited input growers may be more limited. The availability of water resources may become even more important complicated as provincial agricultural departments introduce community-based, irrigation schemes to allow lower input growers access to irrigation technology.

Within the rangelands sector, over-utilisation of land areas could mean increased degradation and erosion from some areas which subsequently, may have a negative feedback effect on the water resources in some catchment areas. These negative impacts could stem from increased siltation in storage dams or increased price in water treatment.

A significant cross-sectional impact is the influence that the human-based sectors may have on the biodiversity sectors. Expansion or alteration of current land uses in response to changing agricultural, forestry or range potential may have significant effects on species habitat. In addition, significant alterations to water resource allocation may have adverse effects on estuarine habitats.

The linkage of water resources with other sectors can also be used to alleviate vulnerability. For example, savings in water resources may be used in another sector to promote certain land uses for development. Or conversely, increased efficiency in existing irrigated agriculture areas may lower production costs for growers and may add to overall water resource availability. Land use changes that reduce erosion and degradation may be beneficial to reducing costs for water treatment.

### *11.2 Integration of sector results into common metrics*

One approach to linking sectoral results could be through chosen "integrators" (Cohen and Tol, 1998) to focus various sector results on a single topic of interest to stakeholders or government. Section 11.1 described the water resources sector as having links with other sectors' vulnerability and potential to climate change conditions. Integrators could be one of the previously studied sectors like water resources or could be an important encompassing area such as tourism. In addition, regional or national development plans can serve as an integrator as they can be used as a platform to weigh various trade-offs between governments or stakeholders. Once again, the integrators presented in this report are preliminary and serve to begin discussions on linking the elements of the sector reports with areas of interest to stakeholders.

#### 11.2.1 Potential populations affected as an integrator

One of the primary questions of integrating the various sector results is*, "who will be more affected and what can they do?"* This question introduces the concern that that certain populations may experience more vulnerability than others depending on their location and available resources. Under this section, additional questions are posed to highlight specific points of interest within the integrating area.

*Western before eastern?* Under some climate scenarios such as the Hadley scenario (excluding sulphates), people in the more marginal areas of the western parts of the country may face more climate-based effects than people in eastern areas. Both the water resources and the agriculture sector reports mentioned that currently marginal western areas may encounter more variation in some climate scenarios. There is no exact line delineating the more "at risk" areas than the less risky areas. One limitation of the climate scenarios used in the sector studies was that the overall confidence decreases as one moves to higher spatial and temporal detail.

Some of the more impacted populations in the west may have to change land uses as maize production may be less viable in currently marginal areas. Land use changes may include a move to more drought tolerant crops for those groups that wish to stay with crop production or could shift to rangeland/livestock production. These shifts may have significant local impacts as the profitability of some agricultural sectors may be affected. In some extreme cases, people may leave non-viable areas for more opportunities in less impacted areas.

*People currently at risk, may be more at risk?* Most sector reports point out a relatively common occurrence that currently marginal areas may become even more at risk under climate change conditions. Thus populations in currently marginal areas may require more aid in coping with increased vulnerability. This point was seen in the human health sector where people currently living in malaria and schistosomiases zones may have increasing health risks under climate change.

*Resource poor before resource rich*? Burton et. al (1998) noted that wealth is one of the strongest descriptive variables in predicting the capacity to adapt. South Africa's population is characterised by large differences in the resources available to people to react to adverse events. Prioritisation of resources may be used to identify and aid specific, resource poor populations. Given that the South African government has been working actively in development of resource poor areas, some cognisance of potential climate change effects may help to set priorities among different regions and sectors.

*Stay the course?* In some sectors, current government policy and activities towards presently vulnerable populations may also be appropriate in terms of climate change. For example as reported in the human health sector report, one of the most potentially effective controls for schistosomiases is the introduction of piped drinking water and effective sanitation measures. These options are currently a high priority on the current governmental development efforts. As a result, one of the more effective adaptation measures for this health effect may already be underway. These type of responses form part of the 'no regrets" style of options where current and future concerns intersect to such a degree that current aid programs may only need to be altered in some degree so that climate change effects are considered in offering support and services.

### 11.2.2 Potential land use changes as an integrator

Even under present climate conditions, land use changes can have a strong impact on natural resources and social activities. Land uses tend to change over time in both normal activities and as a result of climate change effects. Climate change effects may accelerate some land use changes while retarding others. Sector results can give some indications to the direction of land use change may take as a result of climate change.

*Maize to what?* One potential outcome of the agriculture sector report was the non-viability of some of the more marginal western maize production areas. If climate change effects do move maize production areas eastward, what options are left for people who remain? Growers could decide to grow more drought tolerant crops such as sorghum or millet or may opt for converting cropping areas to rangelands. Other growers may leave production altogether and move to urban areas.

*Eastern land in demand?* Given that most sector reports show eastern areas of South Africa being less affected by climate change, there may be more demand on the existing higher production areas as land uses may compete for adequate cropping areas. Certain resource rich industries may have advantages over others and this may affect the land use patterns in an area. An economic analysis of current land prices may give some indication to the level of potential sector movement.

*Where are the new niches?* Even within the less affected land areas, certain speciality crops grown in selected environmental niches may shift to other areas. These specific environments may not be as prevalent under climate change conditions and some land uses may simply cease to be viable anywhere in South Africa. This same effect could be used to describe natural ecosystems and the overall effect on biodiversity resources within a region.

*Where did the plants/animals/fish go?* Given that various land uses may undergo significant spatial shifts in production areas, additional effort may be necessary to protect natural resources. Given that some natural areas within South Africa are important tourist destinations and/or biodiversity reserves, considerable resources may have to be allocated to maintain these protected areas under increasing human pressure.

### *11.3 Possible inter-sectoral adaptation options*

The issue of adaptation responses has progressed from initial questions concerning the likelihood and magnitude of climate change effects to the questions concerning the most appropriate responses to adverse climate effects. At its core, adaptation responses are employed to reduce the vulnerability caused by current climate conditions and may also provide additional protection against climate change conditions. In addition, adaptation options may be used to capitalise on any new opportunities that may arise from beneficial effects. This section provides a large list of potential options for the various sectors (found in the Technical Appendix) and also reports on some of the options described in the sector reports.

#### 11.3.1 Types of Adaptation Measures

Adaptation options can have many forms and can be implemented a variety of levels. The Second Assessment Report of the IPCC Working Group II mentions over two hundred different adaptation measures that could be considered (IPCC, 1995). Generally adaptation options fall under several broad categories that aid both researchers and stakeholders in grouping and subsequently assessing their potential benefits (Carter and Parry, 1998; Burton, Smith and Lenhart, 1998). The following paragraphs give brief descriptions of the groupings.

*Tolerating losses.* These options represent a baseline or “do nothing” alternatives or situations where short-term losses do not affect overall vulnerability. Other adaptation options can often be compared with this option to analyze various costs and potential benefits. This option may be the only alternative for resource-poor areas or areas where the cost of adaptation measures are too high in relation to the risk or expected damages.

*Spreading or sharing of losses.* Many societies have mechanisms for reducing individual suffering by sharing damages or hardships over a wider community. Spreading losses can be a common activity in traditional societies where groups may co-operate among extended family, villages, or throughout a small community. Losses may also be shared in more complex, high-tech societies through public relief, rehabilitation, and reconstruction paid from public funds. In addition, private insurance policies held by individuals or businesses may provide loss-sharing mechanisms.

*Prevention of losses.* These activities are often used to reduce the risk exposure of a selected area or sector. The activities may be extensions of current management or may be new to the sector. For example, within the agricultural sector, crop management activities, increased irrigation, additional fertilisation, pesticides and disease control could either be managed differently or introduced to prevent potential yield losses.

*Changing use or activity*. If the viability of an activity is rendered unprofitable by climate effects, changing activities may provide a mechanism to preserve the current community structure. For example, agricultural communities may change crops to more drought tolerant species to maintain an agriculture-based, local economy. More significant land use changes may see crop land returned to natural rangeland for livestock production or for wildlife refuges to drive a tourism-based development initiative.

*Changing location.* This option is described by Parry and Carter (1998) as "where the preservation of an activity is considered more important than its location…" This adaptive response is often mentioned when analysing the viability of specific agricultural crops that are valued for their economic or food security value. Within the South African agriculture sector, potential shifts in maize production may be of high interest.

*Adaptation-focused research.* Burton et. al (1998) mention this option to generate new developments in technologies that may lead to new methods of adaptation.

*Educate, inform and encourage behavioural change. .* Burton et. al (1998) mention this option as a newer activity to both inform and involve communities, sectors and regions so that behavioural change is possible and that stake-holders are involved in the overall process of adaptation strategies.

11.3.2 Adaptation options arising from current responses to climate conditions

The various adaptation options described above can be analysed with respect to past experience current responses to adverse climate effects (Parry and Carter, 1998) to help identify potentially useful options. Burton et. al (1998) names this methodology "Forecasting by analogy." By carefully choosing past events, these "analogue" models can help stakeholders to assess whether current measures and policies may be adequate for future challenges. The main logic of this approach maintains that if current readiness and reaction to adverse events are inadequate, then potential future climate-related challenges may strain existing support structures even further. The following paragraphs in this section provide sets of questions that can be asked about the current or past situation within a presently vulnerable area. While analogue models and analysis do not allow a total view of all possible adaptation options, they do provide policy-makers and stakeholders with a means of quickly assessing current approaches to climate-based vulnerability.

One section of the analogue methodology focuses on communications between service providers and the various stakeholders in an area. Communications-based questions that could be addressed are as follows: How much warning of past events was available? Was the warning given to those who likely to be impacted? Did those who receive the warning act upon it? Did they know what to do and were they assisted in taking action? Could forecasting and warnings and their dissemination be improved?

Another section of the methodology focuses on the levels of damage incurred by various stakeholders. Questions that focus on the impact levels are as follows: What longer anticipatory actions were taken to prevent such impacts or to reduce their impacts? How much damage was caused? Can the damage be broken down into categories such as fatalities, malnutrition, damage to crops etc...? What steps were taken before, during and after the events to reduce their impact?

The actions by various stakeholders can be included in the analogue methodology by addressing questions such as: What action was taken by governments at national, regional or local scale? What actions were taken by individuals? What actions were taken by the private sector? How successful were these response actions? What obstacles were encountered in attempting to respond to the events?

### 11.3.3 Potential, sector-based, adaptation measures

This section describes the various potential adaptation measures for the sectors in the assessment. A more comprehensive list of adaptation measures is included for each sector in the Technical Appendix. These larger lists in the Appendix are the products of literature reviews and the sector reports. This section describes three primary groups of potential adaptation options that were addressed in the sector reports; autonomous adaptation, strategic adaptations and potential maladaptation responses.

#### 11.3.3.1 Autonomous adaptation

Autonomous adaptations refer to responses to climate variation that may occur in a social or ecosystem without purposeful intentions. As described in Section 1.1.2, these adaptation measures can occur as a human or an ecosystem response to climate changes.

One of the most important inbuilt, adaptation mechanisms is the $CO_2$ “fertilization effect” on plants. Various research efforts have shown that higher $CO_2$ levels can biophysically influence net photosynthetic rate and transpiration. Depending on the plant species and environmental conditions, net photosynthetic rate can increase substantially while decreasing transpiration losses. For some agricultural plants, this effect can be quite favorable as crops can grow more on less water. In theory, this effect may be a strong counter-balance to negative effects from climate scenarios with increased temperature and decreased precipitation. The “fertilization effect” on natural ecosystem plant species can be variable one species may have a new advantage where its population was previously held in check by environmental factors.

The sector researchers were divided on the strength and longevity of the $CO_2$ effects on plants. Each V&A sector that related in some way to plant production (rangelands, agriculture, forestry and water resources) included the $CO_2$ photosynthesis and transpiration effects in their models. The effects vary with the assumptions made in each model. The results vary from small effects on water resources to almost complete mitigation of negative climate effects as found in the agriculture and rangelands. While some $CO_2$ effects on plants are expected under climate change conditions, the magnitude of these effects especially in mitigating adverse climate effects is unclear. While this adaptation will occur largely beyond any human manipulation, further research and understanding are important for assessing its affects on many sectors. The effect can be literally the difference between high vulnerability and low vulnerability of entire sectors such as agriculture. Until researchers have more confidence in understanding this autonomous adaptation effect, it will continue to be a large source of uncertainty in V&A analysis.

In each V&A sector, a selection of routine adaptation measures were described. Logically, stakeholders in each sector will attempt routine adaptation measures as a normal reaction to climate variation. Within the agriculture sector study, routine changes were enough to alleviate initial negative yield responses to climate conditions in many areas. Given that climate change effects may occur progressively, many of the individual sector reports focused on the use of routine adjustments as a first line of defense to adverse climate conditions. One primary concern is that these routine adjustments do not become maladaptive as to cause negative effects in other sectors.

#### 11.3.3.2 Potential, strategic, adaptation responses

Within the individual sector studies, uncertainty about the model predictions combined with relatively coarse climate scenarios have created a conservative approach in suggesting the most appropriate adaptation responses. Even relatively vulnerable sectors such as water resources still advise a more “no regrets” style approach where measures that are currently underway as development initiatives are modified only slightly for potential climate change effects. This strategy is also reflected in the human health sector report where increasing vulnerability levels in both malaria and schistosomiases are countered with current levels of control mechanisms. Almost all of the sector reports cautioned against large-scale expenditures on “climate change alone“ adaptation measures because of the inherent uncertainties in the model results.

Not entirely surprising is the support of continued and expanded research as a viable adaptation strategy in most sector reports. Almost all the sectors recommend some form of active research effort to determine “new options” where currently there are few. A good example of this adaptation need is found in the forestry sector and its limitation/linkage with the water resources sector. If current production areas become less productive and new land areas are limited by water-conserving legislation, then a logical alternative would be to stay in current production areas and develop new tree species that are more adapted to the new climate regime. Given the high resource base of the forestry sector, a genetic engineering program to develop new tree cultivars may be a viable adaptation alternative to the expense of shifting production areas.

Another potential research-based adaptation is the use of climate forecasting systems to provide information to various stakeholders. In the agriculture sector report’s appendix, a report from the Free State Department of Agriculture shows maps of current rainfall levels, simulated maize and wheat yield potentials and the current state of the ENSO/SOI to allow a basic level of forecasting. Several sector reports mention the adaptive benefits of having timely information on the state of the climate.

#### 11.3.3.3 Potentials for maladaptation

As many sector reports mentioned the benefits of routine (small-scale) adaptation measures to adjust to adverse climate change effects, the potential for maladaptation may rise as individuals may act in their own best interest at the expense of other sectors. Lack of adequate co-ordination and communication among sectors may cause different groups to act without consideration of others. For example, forestry sectors may require new higher altitude and cooler temperature sites for tree production. Expansion into these new areas may conflict with water resources and biodiversity groups as stream flows may be reduced and natural forest areas may be cleared.

This same maladaptive effect may be propagated by agricultural shifts to more suitable areas. In addition, farmers may install more irrigation systems to place an increased demand on already vulnerable water systems.

Within the rangeland sector, ranchers may burn more frequently to control encroaching trees, but this cause conflicts with international or mitigation agreements. Maladaptive strategies may be cultural as stakeholders in communal areas may resist de-stocking due to personal beliefs or traditions.

Maladaptive strategies may arise from a variety of causes including economic incentive structures, lack of regulation or communications. Given the various adaptation strategies that may be proposed, it is probably equally important to list potential maladaptive strategies that should be avoided through effective climate change action plans.

### *11.4 Evaluation of Potential Adaptation Responses*

The methodology described in this section was provided by Mr J Smith (Stratus Consulting) as a consultant to the United States Country Studies Program. Elements of this methodology are included in Smith and Lenhart (1996) while other portions are currently in press. The methodology for evaluating potential adaptation options is divided into four phases:

- Identify Potential Adaptation Measures
- Screen Adaptation Measures for Each Vulnerable Sub-Sector
- Preliminary Cost-Effectiveness Evaluation of Selected Measures
- Identification of Potential Barriers to Implementation

At this stage of the V&A study, the various sector s have attempted to analyse the first two phases (Identification and Screening) of the methodology. Identification of potential costs and overall effectiveness as well as potential barriers should be decided later in some form of stakeholder workshops. The primary result at this point is to have one methodology where all V&A sectors are able to comment on the general viability of adaptation responses that may be useful in counteracting negative climate effects. An explanation of the remaining two phases is included to give an overall view of the evaluation process.

### 11.4.1 Identify Potential Adaptation Measures

The first step is for sector teams to identify adaptation measures to be considered. This list should only include measures to ***anticipate*** climate change (e.g., developing drought tolerant crop varieties) because the methodolgy addresses what can be done now to adapt to climate change. Reactive adaptations (e.g., farmers planting more drought tolerant cultivars or crops) should not be on the list, but anticipatory adaptations that make it easier to implement reactive adaptations should be included. These adaptation responses may be justified by considering the risks of climate change or may be justified even without considering the risks of climate change. The Technical Appendix contains potential adaptation measures in a "laundry list" form for giving a broad range of potential choices. Other measures may be appropriate depending on particular national, cultural, geographical, or other circumstances. From the longer lists, several of the most applicable adaptation responses are chosen for further analysis. An example of potential agriculture adaptation options from the US Country Study is found in Table 11.1.

Table 11.1. An example of potential agricultural adaptation reponses.

| Agricultural Sector<br>Agricultural Adaptation Measures | |
|---|---|
| **Adaption Measures** | **Application Examples** |
| *Enhance Seed Banks and Develop New Crop Types*. Seed banks that maintain a variety of seed types preserve biological diversity and provide farmers an opportunity to diversify, allowing them to both counter the threat of climate change and to develop a profitable specialization. Development of more and better heat- and drought-resistant crops will help fulfill current and future world food demand by improving production efficiencies in marginal areas. Improvements will be critical because the world population continues to increase, with or without climate change. | In the U.S., hard red winter wheat has been adapted to drier conditions (15 percent drier) and cooler temperatures (6 degrees F cooler) in the north (OTA, 1993a). |
| *Encourage Farmers to Plant Heat and Drought Resistant Crops and Avoid Monoculture*. Growing of single crops such as maize increases farmers' vulnerability to climate variability. This vulnerability will increase if climate change leads to more frequent extreme weather events such as drought. One adaptation option is for farmers to plant a wider variety of crops to reduce the risks of crop failure. Through its agricultural extension service, the government of Malawi has been advising farmers to grow drought-resistant food crops such as cassava, millet, sorghum, etc. | Through its agricultural extension service, the government of Malawi has been advising farmers to grow drought-resistant food crops such as cassava, millet, sorghum, etc. (Theu et al., in press). |

### 11.4.2 Screen Adaptation Measures for Each Vulnerable Sub-Sector

Large lists of adaptation measures are too large to be effectively considered in a more detailed analysis of adaptation measures. As a result, these lists should be screened to identify some of the most potentially effective adaptation measures. The screening should be based on the following criteria (Smith, 1999 in press):

1. Does the adaptation measure address high priority adaptation? High priority adaptations address:

    a. **Irreversible or catastrophic consequences of climate change.** Drought-induced crop losses in many developing and transition countries can result in starvation.

    b. **Unfavorable trends.** Urban and suburban expansion can reduce availability of productive agricultural land and irrigation water; overgrazing may make grasslands or rangelands more vulnerable to climate changes.

2. Does the adaptation measure address targets of opportunity? In particular, are decisions being made now on:

a. infrastructure decisions (e.g., irrigation system development)

b. plans being revised (e.g., National Environmental Action Plans, contingency plans, sustainable development plans)

c. research and development investments or priority setting.

3. Is the adaptation measure likely to be effective? Specifically:

   a. Does it increase the flexibility and capabilities of stakeholders' responses to climate and/or market signals under a wide range of potential climate changes?

   b. Does it complement a long term development or resource strategy?

4. Are there other benefits to the economy or environment? In particular, is the measure justified under current climate conditions? Many adaptation measures may be justified even without considering climate change.

5. Will the measure be inexpensive to implement? Adaptation measures generally should have minimal or low cost. Given the long time frame and uncertainty about climate change, it is difficult to justify significant costs that *only provide benefits if climate changes*. Large costs could be justified based on other benefits.

6. Is the measure feasible? Can it gain support for adoption? Are there significant barriers to implementation? Barriers can be:

   a. **Institutional/legal**. Extension programs and research activities are limited to available funding; land use planning is subject to local, regional and national jurisdiction; water supply may be subject to international agreements.

   b. **Social and cultural**. Existing cropping systems may be based on traditional practices, which may be hard to change.

   c. **Market** (e.g., pricing, availability of capital). Agricultural production may be subsidized, creating a disincentive to adapt to climate changes at the farm level.

   d. **Technological** (existence, access). Access to technologies such as drought resistant cultivars or efficient irrigation may be limited by lack of financial resources or information.

7. Is this measure consistent with mitigation measures or adaptation measures in other sectors? Will this measure make it more difficult to adapt to changes in other sectors? Will it make it more difficult to mitigate greenhouse gas emissions or achieve other goals?

The above screening process uses expert judgment to develop answers to these questions. Example answers to these screening criteria are displayed in a table as shown in Table 11.2. Those measures with the most "yes" answers should be the ones that are analyzed in the next step. Given that different experts will have varied opinions on the merits of the measures, it is critical to share these results with decision makers and key stakeholders to ensure they agree with the selection of adaptation measures for further analysis.

Table 11.2. An example of screening agricultural adaptation options.

| **Adaptation Option** | **High Priority** | **Target of Opportunity** | **Effectiveness** | **Other Benefits** | **Low Costs** | **Low Barriers** |
|---|---|---|---|---|---|---|
| Expand Irrigation | Yes | Yes | Yes | Yes | No | No |
| New Cultivar | No | Yes | Yes | Yes | No | No |
| Remove Subsidies | No | Yes | Yes | Yes | Yes | No |
| Extension Program | No | No | Yes | Yes | Yes | Yes |
| Displacement Program | No | No | No | Yes | No | No |

In this example, the sector team has identified five potential adaptation measures: expanding irrigation through infrastructure development; developing a more drought-tolerant variety of maize; removing government subsidies for growing maize; implementing an extension program to help farmers identify and adopt farm-level adaptation measures; and implementing a program to provide relocation/training assistance to the farm population that will be displaced by reduced productivity. The screening analysis in Table 11.2 suggests that the most promising measures are expanding irrigation, removing subsidies, and implementing an extension program.

The reponses of the various Vulnerability and Adaptation sectors are found in the Technical Appendix Section 14.2. Given that most of the V&A sector groups were comprised of research scientists, these results can be used as an initial framework or starting point for a more broadly representative, stakeholder group. The next two sections describe the methodology that these stakeholder groups may use to further evaluate adaptation options with respect to governmental and societal goals.

### 11.4.3 Evaluation of Selected Adaptation Measures

After having identified two to five adaptation measures for each sector, larger stakeholder groups teams may wish to analyze them in more detail. The goal of this analysis should be to rank the measures based on their effectiveness (or cost-effectiveness) in fulfilling policy goals and in their relative ease of implementation. The analysis of fulfilling policy goals is called effectiveness analysis.

#### 11.4.3.1 Identify Policy Objectives

Stakeholder groups should begin the effectiveness analysis by identifying policy objectives. For example, agricultural policy may have maintaining food security and producing crops for export as some of its objectives. Group members should try to identify quantitative or at least ordinal measures of how well these objectives are satisfied. Ideally, the same metric, such as monetary value, is used to measure this success. This will enable team members to compare success across different objectives. For example, an agricultural stakeholder group may select the following policy objectives: protecting national/local food security; enhancing economic development; producing export products; and maintaining traditional culture.

#### 11.4.3.2 Select Method for Evaluating Measures

Having identified the policy objectives, group members will need to select a method to examine how well current policy and the adaptation policy measures perform in fulfilling the objectives under a variety of climate change scenarios. Whatever method is used, the process should build a consensus among decision makers and key stakeholders. Workshops or meetings should be held in which the decision makers and key stakeholders discuss the vulnerability of sectors and evaluate the adaptation options.

A number of different approaches can be used in these meetings to help assess the effectiveness of the policy measures. Two that are briefly discussed here are benefit-cost analysis and cost-effectiveness analysis. It is important that whatever approach that is applied considers multiple climate change scenarios (e.g., hot and wet, hot and dry, mild and wet, mild and dry) in order to assess the flexibility of adaptation measures to meet policy objectives under a wide range of potential climate change conditions. The evaluation should also consider the discounted benefits and costs of the measures so as to assess the economic efficiency of measures.

**Benefit-Cost Analysis.** Benefit-cost analysis relies on monetizing all the benefits and costs of policy options in present value terms (Gramlich, 1981). The advantage of benefit-cost analysis is that it uses a common measure, monetary value of all of the benefits and costs. This enables users to determine whether policy options are efficient, i.e., are their benefits greater than their costs. The disadvantage is that it is often difficult to apply monetary values to all benefits. Although techniques exist for valuing human life and ecosystems, such techniques are quite controversial. When costs are considered, estimates based on current costs should be used due to the many uncertainties associated with projecting future costs. This holds for all evaluation methods described in this section.

**Cost-Effectiveness Analysis.** Cost-effectiveness analysis identifies the most efficient measure for reaching a goal. An example is a decision matrix which analyzes the cost-effectiveness of adaptation measures by comparing costs of adaptation measures with benefits of the measures measured in a common metric, but not necessarily rands. Such measurements can be added up across the different policy objectives (and weighted based on relative importance) and compared to costs to determine cost-effectiveness (e.g., cost per point on the ordinal scale) and rank measures.

Table 11.3 (based on U.S. Country Studies, 1994) displays the use of a decision matrix to examine adaptation measures for a hypothetical agricultural example. In the example, expert judgment is used to apply an ordinal ranking (e.g., on a 1 to 5 scale) of how well objectives are fulfilled. Expanding irrigation has the most benefits, increasing the total score of how well objectives are met to 67. But that option costs $40 million. Removing subsidies only increases the benefits score to 57, but by avoiding paying subsidies, it saves $10 million.[1] Since it results in higher benefits and saves money, removing subsidies is the most cost-effective measure.

1. The negative cost-effectiveness ratio results because this option reduces costs, while increasing benefits. In the matrix a negative value is preferable to any positive value.

Table 11.3. An example of a decision matrix to analyse agricultural adaptation options.

**Agriculture Decision Matrix Using 1-5[1] Scale**

| Measures | | Objectives: Food Security | Objectives: Economic Development | Objectives: Exports | Objectives: Tradit. Culture | Score | Total Score[2] | Cost of Measure ($M) | Cost-Effectiveness (Cost/Incremental Unit of Benefit) |
|---|---|---|---|---|---|---|---|---|---|
| | Weights: | 4 | 3 | 2 | 3 | | | | |
| | Scenario | | | | | | | | |
| Current Policy | Wet | 3 | 2 | 4 | 2 | 32 | 53 | N/A | N/A |
| | Dry | 2 | 1 | 2 | 2 | 21 | | | |
| Expand Irrigation | Wet | 4 | 3 | 5 | 1 | 38 | 67 | $40 | 2.9 |
| | Dry | 3 | 2 | 4 | 1 | 29 | | | |
| Remove Subsidies | Wet | 4 | 3 | 3 | 2 | 37 | 57 | ($10) | -2.5 |
| | Dry | 1 | 2 | 2 | 2 | 20 | | | |
| Extension Program | Wet | 3 | 3 | 4 | 2 | 35 | 63 | $7 | 0.7 |
| | Dry | 3 | 2 | 2 | 2 | 28 | | | |

1. The 1-5 scale in this matrix is an arbitrary ranking of how well objectives are met under different scenarios and policies. Five is the highest score and one is the lowest score.
2. In this example, we simply added the wet and dry scores. This assumes each scenario has the same probability of occurrence. Probabilities for individual scenarios can be adjusted.

### 11.4.4 Implementation Analysis

To analyze the effectiveness of adaptation measures in meeting policy goals, group members should also identify any barriers to implementing the measures and evaluate how difficult or easy it will be to overcome these barriers. A matrix like the one shown in Table 11.4a-c can be used to track this analysis. The tables can be used to identify barriers, actions to overcome the barriers, action, what time and financial resources are required, and an evaluation of the degree of difficulty in overcoming the barriers. A three point rating system can be used with one X being easiest to overcome and three Xs being the most difficult to overcome. The results from the analysis of barriers can be used to adjust the rankings from the results of benefit-cost analysis or the decision matrix. If the barriers, however, are only a matter of cost, the costs of overcoming the barriers can be entered into the cost calculations under benefit-cost analysis or the decision matrix.

In Table 11.4a-c, a continuation of the agricultural example, the extension program has one barrier and it is relatively easy to overcome. Expanding irrigation has two barriers that are moderately difficult to overcome, while removing subsidies only has one barrier, but it is most difficult to overcome.

**Table 11.4a**
**Example: Overcoming Barriers to Implementation**
**Expand Irrigation**

| Barriers | Response | Time | Costs | Difficulty |
|---|---|---|---|---|
| Market C farmers cannot afford irrigation | Subsidies | 2 years | $40 million | XX |
| Technological C farmers need training in efficient use of irrigation | Training | 1 year | $0.5 million | X |

**Table 11.4b**
**Example: Overcoming Barriers to Implementation**
**Remove Subsidies**

| Barriers | Response | Time | Costs | Difficulty |
|---|---|---|---|---|
| Legal/institutional C laws and institutions providing subsidies will have to be changed and potential increase in food prices must be addressed | Legislation | 18 months | | XXX |

**Table 11.4c**
**Example: Overcoming Barriers to Implementation**
**Extension Program**

| Barriers | Response | Time | Costs | Difficulty |
|---|---|---|---|---|
| Legal/institutional C extension program must be created and funded | Legislation | 1 year | $1 million | X |

### *11.5 Uncertainties in the V&A process*

Uncertainties are found at almost every level of climate impact assessment (Parry and Carter, 1998) and can be caused by two primary sources, errors and unknowns. Errors are propagated due to lack of data, inadequate parameterisation of models and faulty assumptions. Unknowns refer to factors that are not recognised or understood as being important to the analysis.

Within this assessment, most sectoral studies referred to the climate scenarios as being a major source of uncertainty as different scenarios often gave quite different scenarios of future climate.  Another source of uncertainty was the assumptions inherent in each model used in the sector studies.  Some models required a large amount of input data while others operating with only a few basic inputs.   Models are constantly being upgraded as researchers learn and apply new concepts.  Many of the individual sector reports highlighted the limitations in their model applications.

## 12 Summary of V&A Results

The South African Country Study on Climate Change (SACSCC) Vulnerability and Adaptation Assessment Section was formed to explore the potential effects of climate change on several sectors of society including, water resources, agriculture, human health, forestry, rangelands and biodiversity.   The individual sector studies addressed the sensitivity of certain system elements to climate effects.  In addition the sector studies assessed the vulnerability of sector by analysing the extent to which climate induced variations in sector activities would cause overall harm to humans, ecosystem structure or productive capacity.  The sector assessments also included potential adaptation responses for each sector and basic estimates of their potential effectiveness in reducing vulnerability.

The various sector results showed that South Africa has significant sensitivity and vulnerability to climate change effects, but also has significant adaptive resources to address potential harmful effects.  Many sector findings showed that resource-rich groups may not be under high levels of vulnerability but resource-poor groups in the same sector may encounter notable levels of vulnerability within marginal areas.  Given that some sectors have both high and low vulnerability depending on the spatial area or resource level of its constituents, the identification of "at risk" areas and populations may become important to prioritise policy and action plans.

The sectoral results for sensitivity and vulnerability show a significant amount of interdependence of sectors especially in relation to water resources.   Further integration of sector results with topics such as potentially affected populations or potential land use changes highlight different aspects of the research results. These integrative techniques may aid in the prioritisation of potential responses and areas for resource allocation. In addition, these linkages may help stakeholders to avoid potential responses that would increase overall vulnerability.

This V&A study has produced a list of potential adaptation options for further consideration by policy-makers and stakeholders. Where possible in a mainly research-based methodology, potential adaptation activities have been linked with the sensitivity and vulnerability results from each sector. Further efforts may be able to add more societal and economic descriptions to the various adaptation options.

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# 14 Technical Appendix

## *14.1 List of potential adaptation options*

These potential adaptation options were gathered from several sources including the V&A sector studies. These lists are included to give information on the wide range of adaptation options open at various levels.

### 14.1.1 Water Resources Adaptation Options

Source: (Strzepek et., al, 1998)

- Modification of existing physical infrastructure
  - Supply adaptation
    - Changing location or height of water intakes
    - Installing canal linings
    - Using closed conduits instead of open channels
    - Integrating separate reservoirs into a single system
    - Using artificial recharge to reduce evaporation
  - Possible modifications if there is increased flows due to climate change
    - Raising dam wall height
    - Adding more turbines
    - Increasing canal size
    - Removing sediment from reservoirs for more storage
  - Construction of new infrastructure
    - Reservoirs
    - Hydroplants
    - Delivery systems
    - Inter-basin water transfers
  - Alternative management of existing water supply systems
    - Change operating rules
    - Use conjunctive surface/groundwater supply
    - Change the priority of releases
    - Physically integrate reservoir operation system

        - Co-ordinate supply/demand
- Demand adaptation
    - Conservation and improved efficiency
        - Domestic
            - Low-flow toilets
            - Low-flow showers
            - Re-use of cooking water
            - More efficient appliance use
            - Leak repair
            - Commercial car washing where recycling takes place
            - Rainwater collection for non-potable uses
        - Agricultural
            - Night time irrigation
            - Lining of canals
            - Introduction of closed conduits
            - Improvement in measurements to find losses and apply water efficiently
            - Drainage re-use
            - Use of wastewater effluent
            - Better control and management of supply network
        - Industrial
            - Re-use of acceptable water quality
            - Recycling
        - Energy
            - Keeping reservoirs at lower head to reduce evaporation
            - Changing releases to match other water uses
            - Taking plants off-line in low flow times
            - Co-generation (beneficial use of waste heat)
    - Technological change
        - Domestic
            - Water efficient toilets
            - Water efficient appliances
            - Landscape changes
            - Dual supply systems (potable and non-potable)
            - Recycled water for non-potable uses
        - Agricultural
            - Low water use crops
            - High value per water use crops
            - Drip, micro-spray, low-energy, precision application irrigation systems

        - Salt tolerant crops that can use drain water
        - Drainage water mixing stations
    - Industrial
        - Dry cleaning technologies
        - Closed cycle and/or air cooling
        - Plant design with reuse and recycling of water imbedded
        - Shift the type of products manufactured
    - Energy
        - Additional reservoirs and hydropower stations
        - Low head run of the river hydropower
        - More efficient hydropower turbines
        - Alternative thermal cooling stations
        - Cooling ponds, wet tower and dry towers
- Market/price-driven transfers to other activities
    - Using water price to shift water use between sectors

### 14.1.2 Agriculture Adaptation Options

Source (Parry et al., 1998)

- Farm Level Adaptation Measures
    - Altered crop choice
        - Planting quicker or slower maturing varieties
        - Plant drought or heat resistant crops
        - Plant pest resistant crops
        - Plant a larger mixture of different crops
    - Altered management techniques
        - Use minimum or reduced tillage
        - Increased terracing or leveling
        - Change fallow and mulching practices
        - Reduce weed infestation
        - Alter planting dates to better match precipitation patterns
        - Alter row spacing and plant populations
        - Inter-cropping for maximized water use
    - Altered inputs
        - Irrigation to improve efficiency
        - Altered use of fertilizers at more optimized timings
        - Altered use of chemical control
- Village or community level adaptation measures
    - Subsistence production

        - Soil conservation
        - Water conservation
        - Irrigation
        - Multiple farms
        - Inter/relay cropping
        - Dry planting
        - Mixed livestock herds
        - Dispersed grazing
        - Fodder production
        - Drought resistant crops
    - Monetary activity
        - Local wage labor
        - Migrant wage labor
        - Permanent employment
        - Local business
        - Cash crops
        - Selling capital assets
        - Livestock sales
    - Remittance/donations
        - Relatives/friends
        - Government, NGO's or others
        - Loans/credit
- National level Adaptation Measures
    - Improved training and general education of populations dependent on agriculture
    - Agricultural research to test the robustness of new farming strategies and development of new crop varieties
    - Education of research results to farmers
    - Food programs and other social security programs to provide insurance against local supply changes
    - Transportation, distribution and market integration to provide the infrastructure to supply food during crop shortfalls
    - Removal of subsidies, which can, by limiting change in process, mask the climate change signal in the marketplace

### 14.1.3 Rangeland Adaptation Options
Source (Baker, 1998)

- Autonomous adaptations

- Rangeland ecosystems
  - Shifts in biological diversity
  - Shifts in species composition
  - Shifts in species distribution
- Livestock farmers
  - Change in grazing management (timing, duration and location)
  - Change in mix of grazers and browsers
  - Change in supplemental feeding
  - Change in location of watering points
  - Change in breeding management
  - Changes in rangeland management practices
  - Change in operation production strategies
  - Change in market strategies

- Planned adaptation
  - Farm level
    - Use windbreaks to protect soil from erosion
    - Reduce stocking rates
    - Use feed conservation techniques and fodder banks
    - Improve nutritional plane by using protein, vitamin and mineral supplements
    - Change combinations of grazing and browsing animals
    - Alter animal distribution by the use of mineral blocks, watering point and fences
    - Bush encroachment programs
    - Restoration of degraded areas
  - Governmental adaptation
    - Modify price supports and other programs (co-operatives, marketing boards, etc..) to allow farmers to quickly respond to climate change effects.
    - Encourage production in more efficient areas by discouraging the use of marginal lands and protecting degraded areas.
    - Prepare for veterinary animal health services for the spread of diseases and parasites
    - Develop breeding programs

### 14.1.4 Human Health Adaptation Options

Source (Balbus, 1998)

- Autonomous Adaptation Options
  - Wearing protective clothing
  - Obtaining drinking water from different sources
  - Migration to lesser affected areas

- Planned Adaptation Options
  - Levels of prevention and hierarchy of controls
    - Primary prevention measures (reduce or prevent risk of developing a disease)
      - Immunisation
      - Use of bed nets
      - Eradication of disease vector
      - Replacement of dangerous chemicals in an industrial process
    - Secondary prevention measures (detection and treatment of a disease at early stages)
      - Screening for malnutrition or parasitic infections
    - Tertiary prevention measures (limiting long term health deterioration from a disease)
      - Treatment of infectious diseases
      - Rehydration therapy for diarrhoea
    - Public education
    - Surveillance and monitoring
      - Long term data gathering of vector-borne diseases
    - Ecosystem intervention (control)
    - Infrastructure development
      - Water treatment facilities
      - Improvement of existing water systems
    - Technological/engineering
    - Medical interventions

### 14.1.5 Forestry Adaptation Options

Source (Scholes and Linder, 1998)

- Planned adaptation
  - Change the species or varieties planted and harvested
  - Allow the size of the sector to decrease or increase by shifting land in or out of other uses
  - Increase the efficiency with which forest materials are converted to forest products
  - Shift the geographical location of the industry to match the area of optimum potential
  - Change the product mix to utilise new species or size classes.
  - Market the potential carbon sequestration potential of afforestation projects

## *14.2 Potential Adaptation Options By V&A Sector*

This section contains the summary tables for the adaptation evaluation procedure described in Section 11.4. Each V&A section has two tables associated with it, the first showing potential adaptation measures and the second showing the answers to the questions posed in Section 11.4.2. Answers that have a question mark in parenthesis (?) denote either a disagreement among the V&A team or less confidence in the answer to the question.

### 14.2.1 Water Resources Sector

Table 14.1. Draft Water Resources Adaptation Measures

| Water Resources Sector<br>DRAFT Water Adaptation Measures | |
|---|---|
| **Adaptation Measures** | **Adaptation Examples** |
| *Plan and Coordinate Use of River-Basin.* Comprehensive planning across a river basin may allow coordinated solutions to problems of water quality and water supply. Planning can also help to address the effects of population, economic growth, and changes in the supply of and demand for water. | The Water Act of 1998 requires that water use should be conducted in a sustainable and equitable manner. The Act mandates the creation of Catchment Management Authorities to manage the water resources and demands. |
| *Make Marginal Changes in Construction of Infrastructure.* In planned construction, consider marginal increases in the size of dams or marginal changes in the construction of canals, pipelines, pumping plants, and storm drainages. This change may be much less expensive than adding capacity in the future. | Specific example not available |
| *Conserve Water.* Reducing demand can increase excess supply, creating a greater margin of safety for future droughts. Demand for water may be reduced through a range of measures that encourage efficient water use including education, voluntary compliance, pricing policies, legal restrictions on water use, rationing of water, or the imposition of water conservation standards on technologies. | Specific example not available |
| *Control Pollution.* Polluting water so that it is unfit for drinking or other uses can, in many respects, have an effect that is similar to reducing water supply. Reducing water pollution effectively increases the supply of water. In turn, a larger water supply increases the safety margin for maintaining water supplies during droughts. In addition, reduced runoff from climate change will most likely increase concentrations of pollutants in the water column. | Specific example not available |
| *Allocate Water Supplies by Using Market-Based Systems.* Market-based allocations are able to respond more rapidly to changing conditions of supply and also tend to lower demand, thus conserving water. Consequently, market-based allocation increases both the robustness and the resiliency of the water supply system. | Specific example not available |
| *Adopt Contingency Planning for Drought.* Plans for short-term measures to adapt to water shortages could help mitigate droughts. Planning could be undertaken for droughts of known or greater intensity and duration. The cost of developing contingency plans is relatively small compared with the potential benefits. | Specific example not available |
| *Use Interbasin Transfers.* Transfers of water between water basins may result in more efficient water use under current and changed climate. Transfers are often easier to implement than fully operating markets for water allocation. Transfers also can be an effective short-term measure for responding to regional droughts or other problems of water supply. | Specific example not available |
| *Maintain Options to Develop New Dam Sites.* Keep options open to develop new dam sites, should they be needed. The number of sites that can be used efficiently as reservoirs is limited, and removing structures once an area has been developed may be very costly or politically difficult. | Specific example not available |

| | |
|---|---|
| *Improve Monitoring and Forecasting Systems for Flood and Droughts.* Climate change is likely to affect the frequency of floods and droughts. Monitoring systems will help in coping with these changes and will be beneficial without climate change (IPCC, 1996). | Specific example not available |

Table 14.2. Screened Water Resources Adaptation Measures

**Water Resources Sector**
**DRAFT Screening Adaptation Measures**

| Adaptation | High Priority | Target of Opportunity | Effectiveness | Other Benefits | Low Costs | Low Barriers |
|---|---|---|---|---|---|---|
| Plan and Coordinate | Yes | Yes | Yes | Yes | No (?) | No |
| Minor Infrastructure Changes | No | No | Yes | No | Yes | Yes |
| Water Conservation | Yes | Yes | Yes | Yes | No (?) | No |
| Control Pollution | No (?) | No (?) | No (?) | Yes | No | No |
| Market Allocation | No | Yes | Yes (?) | Yes | Yes (?) | No |
| Contingency Plans | Yes | Yes | Yes | Yes | Yes | Yes |
| Interbasin Transfers | Yes (?) | Yes | Yes (?) | Yes | No | Yes (?) |
| Maintain Options for New Dams | No | No | No (?) | No | No (?) | No |
| Improve Monitoring and Forecasting | No (?) | Yes | Yes | Yes | Yes (?) | Yes |

### 14.2.2 Agriculture Sector

Table 14.3. Draft Agriculture Adaptation Measures

| **Agricultural Sector<br>DRAFT Agricultural Adaptation Measures** | |
|---|---|
| **Adaptation Measures** | **Application Examples** |
| *Enhance Seed Banks and Develop New Crop Types*. Seed banks that maintain a variety of seed types preserve biological diversity and provide farmers an opportunity to diversify, allowing them to both counter the threat of climate change and to develop a profitable specialization. Development of more and better heat- and drought-resistant crops will help fulfill current and future world food demand by improving production efficiencies in marginal areas. Improvements will be critical because the world population continues to increase, with or without climate change. | *Specific example not available to author's knowledge.* |
| *Encourage Farmers to Plant Heat and Drought Resistant Crops and Avoid Monoculture*. Growing of single crops such as maize increases farmers' vulnerability to climate variability. This vulnerability will increase if climate change leads to more frequent extreme weather events such as drought. One adaptation option is for farmers to plant a wider variety of crops to reduce the risks of crop failure. For example, areas that are marginal for maize production could be encouraged to grow sorghum or millet. | *Specific example not available to author's knowledge.* |
| *Increase Efficiency and Flexibility of Irrigation*. Many farming technologies, such as efficient irrigation systems, provide opportunities to reduce direct dependence on natural factors such as precipitation and runoff. In evaluating an improvement to irrigation systems, the additional benefit of reducing vulnerability to climatic variations and natural disasters should be considered. Improvements allow greater flexibility by reducing water consumption without reducing crop yields. This will also help in adapting water resources. | *The Water Act of 1998 requires that irrigation as a water use should be conducted in a sustainable and equitable manner. Existing irrigation practices are currently under review.* |
| *Disperse Information on Conservation Management Practices*. Many practices, such as conservation tilling, furrow diking, terracing, contouring, and planting vegetation to act as windbreaks, will protect fields from water and wind erosion and can help retain moisture by reducing evaporation and increasing water infiltration. Using management practices that reduce dependence on irrigation will reduce water consumption without reducing crop yields and will allow greater resiliency in adapting to future climate changes. | *Specific example not available to author's knowledge.* |
| *Promote Agricultural Drought Management*. Encourage management practices that recognize drought as part of a highly variable climate, rather than treating drought as a natural disaster. Farmers can be given information on climatic conditions, incentives can be offered to adopt sound practices of drought management, and farmers can be discouraged from relying on drought relief. This type of policy is particularly useful if farm disaster relief and other government subsidies distort the market and encourage overly risky expansion of farming into marginal lands. | *Free State Dept of Agriculture Crop Report (van den Berg, 1999)* |

| | |
|---|---|
| *Tailor Land Use Planning to Consider Potential Climate Change*. As natural ecosystems are converted to agricultural land, or rural land is converted to urban and suburban use, consider whether high quality agricultural land is being brought into or removed from production. Land use planning programs can help distinguish trends in land use that are advantageous in the event of climate change from land use trends that are potentially damaging. | *Specific example not available to author's knowledge.* |

Table 14.4. Screened Agriculture Adaptation Measures

| **Agricultural Sector<br>DRAFT Screening Adaptation Options** | | | | | | |
|---|---|---|---|---|---|---|
| **Adaptation Option** | **High Priority** | **Target of Opportunity** | **Effectiveness** | **Other Benefits** | **Low Costs** | **Low Barriers** |
| Develop New Cultivars | Yes (?) | No | Yes | Yes (?) | No | No |
| Promote Drought Resistant Crops | No | No | Yes | Yes | No | No |
| Increase Irrigation Efficiency | Yes | Yes | Yes | Yes | Yes | No |
| Extension Program | Yes | Yes | Yes | Yes | No | No |
| Drought Management | Yes | Yes | Yes (?) | Yes | No | No |
| Tailor Land Use Planning | Yes | Yes | Yes | Yes | No | No |

### 14.2.3 Forestry Sector

Table 14.5. Draft Forestry Adaptation Measures

| Forestry Sector<br>DRAFT Forestry Adaptation Measures | |
|---|---|
| **Adaptation Measures** | **Application Examples** |
| *Develop New Tree Hybrids*. Genetic engineering may be used to develop more heat- and drought-resistant hybrids allowing the forestry industry both counter the threat of climate change and to maintain current production areas. | Specific example not available to author's knowledge. |
| *Shift the Geographical Location of the Industry to Match Areas of Optimum Potential.* As new areas become climatically suitable for forestry, shift forest production areas to the new favorable areas. Given that forestry has been designated as a streamflow reducing activity, new afforestation permits may be more difficult to obtain. This option also has cost implications for the movement of industrial capacity to accommodate the new production areas. | Specific example not available to author's knowledge. |
| *Market the potential carbon sequestration potential of afforestation projects.* As various Clean Development Mechanisms become available through international agreements (such as the Kyoto Protocol), opportunities to market the carbon sequestration potential of afforestation projects may arise. | Specific example not available to author's knowledge. |
| *Tailor Land Use Planning to Consider Potential Climate Change*. As natural ecosystems are converted to forest land, or rural land is converted to urban and suburban use, consider whether high quality agricultural land is being brought into or removed from production. Land use planning programs can help distinguish trends in land use that are advantageous in the event of climate change from land use trends that are potentially damaging. | Specific example not available to author's knowledge. |

Table 14.6. Screened Forestry Adaptation Measures

| Forestry Sector<br>DRAFT Screening Adaptation Options | | | | | | |
|---|---|---|---|---|---|---|
| **Adaptation Option** | **High Priority** | **Target of Opportunity** | **Effectiveness** | **Other Benefits** | **Low Costs** | **Low Barriers** |
| Develop New Hybrids | No | Yes | Yes | Yes | No | No |
| Shift Industry Location | No | No | Yes | No | No | No |
| Market carbon sequestration potential | No | No | Yes (?) | No | Yes (?) | No |
| Extension Program | Yes | Yes | Yes | Yes | No | No |
| Drought Management | Yes | Yes | Yes (?) | Yes | No | No |
| Tailor Land Use Planning | Yes | Yes | Yes | Yes | No | No |

14.2.4 Rangelands Sector

Table 14.7. Draft Rangeland Adaptation Measures

| **Rangeland Sector<br>DRAFT Rangeland Adaptation Measures** | |
|---|---|
| **Adaptation Measures** | **Application Examples** |
| *Improve Monitoring and Forecasting Systems for Fire Hazard and Droughts.* Climate change is likely to affect the frequency of both floods and droughts. Associated with these climate factors is the risk of events that alter rangeland viability at both seasonal and longer time periods. Monitoring systems may help in coping with these changes and may be beneficial without climate change. | Free State Dept of Agriculture Crop Report (van den Berg, 1999*)* |
| *Programs to provide/promote nitrogen-containing supplements.* Declining carbon to nitrogen ratios in the forage may be a side effect of elevated $CO_2$ conditions. While using supplements may increase livestock production and decrease methane emissions, there may be an increase in the net cost of animal production. | Specific example not available to author's knowledge. |
| *Prepare Veterinary Animal Health Services for the Potential Spread of Diseases and Parasites*. Climate change may affect the frequency and spatial extent of livestock disease outbreaks. Preventative steps in addition to current measures may be useful in limiting adverse disease effects. | *Specific example not available to author's knowledge.* |
| *Market the potential methane reduction credits of rangeland projects involving reduced stocking rates.* Decreases in stocking rate may be justifiable in terms of international agreements to reduce greenhouse gas emissions. Methane emission credits in terms of the Kyoto Protocol may allow some level of compensation to stakeholders who reduce stocking levels. | *Specific example not available to author's knowledge.* |
| *Promote Agricultural Drought Management*. Encourage management practices that recognize drought as part of a highly variable climate, rather than treating drought as a natural disaster. Farmers can be given information on climatic conditions, incentives can be offered to adopt sound practices of drought management, and farmers can be discouraged from relying on drought relief. This type of policy is particularly useful if farm disaster relief and other government subsidies distort the market and encourage overly risky expansion of farming into marginal lands. | *Specific example not available to author's knowledge.* |
| *Tailor Land Use Planning to Consider Potential Climate Change*. As natural ecosystems are converted to agricultural land, or rural land is converted to urban and suburban use, consider whether high quality agricultural land is being brought into or removed from production. Land use planning programs can help distinguish trends in land use that are advantageous in the event of climate change from land use trends that are potentially damaging. | *Specific example not available to author's knowledge.* |

Table 14.8. Screened Rangeland Adaptation Measures

## Rangelands Sector
## DRAFT Screening Adaptation Measures

| Adaptation | High Priority | Target of Opportunity | Effectiveness | Other Benefits | Low Costs | Low Barriers |
|---|---|---|---|---|---|---|
| Improve Monitoring and Forecasting | No (?) | Yes | Yes | Yes | Yes (?) | Yes |
| Promote Nitrogen-Containing Supplements | No (?) | No | Yes | Yes (?) | No | Yes |
| Prepare Veterinary Animal Health Services | No (?) | No | Yes | No | No | Yes |
| Market Methane Reduction Credits | No | No | Yes (?) | Yes | No | No |
| Promote Agricultural Drought Management | Yes | Yes | Yes | Yes | No (?) | No |
| Tailor Land Use Planning | Yes | Yes | Yes | Yes | No (?) | No |

## 14.2.5 Human Health Sector

Table 14.9. Draft Human Health Adaptation Measures.

| **Human Health Sector<br>Human Health Adaptation Measures: Malaria and Schistosomiasis** | |
|---|---|
| **Adaptation Measures** | **Application Examples** |
| *Improve Monitoring and Forecasting for Disease Warning Systems.* Climate change is likely to affect the potential extent and severity of malaria and schistosomiasis. Monitoring systems help in coping with the challenges that increasing prevalence presents. In the case of malaria such systems are already in place in two provinces and proving invaluable to the control programme. A monitoring system could also be used to keep track of environmental conditions impacting on the diseases, and may allow prediction of disease risk or the risk of epidemics occurring. | Malaria monitoring systems are used in South Africa (Sharp and le Sueur. 1996. *South Afr Med J 86* (1):83-89; Booman *et al.* 2000. In press).<br>The potential of disease prediction systems based on environmental factors (Cox, 1999, Highlands Malaria report; Patz *et al*. 1998.*Trop.Med Int.Health 3* (10): 818-827.)<br><br>The relative annual risk of bovine fascioliasis in Louisiana was predicted using climatic factors (Malone *et al.* 1987. *Am J Vet Res 48*, (7): 1167-1170). The Thornthwaite water budget system was used to measure the effect of moisture stress and flooding in snail habitats. The forecasting system could inform farmers of the relative risk of fascioliasis timeously, allowing preparation for extreme events by treating cattle at the most appropriate time.<br>Indices using temperature (Growing Degree Days) and rainfall were also used to predict the incidence of fascioliasis in Bolivia by Fuentes *et al.* (1999) *Ann. Trop. Med. Parasit. 93:* 835-850. |
| *Improved clinic treatment and prevention systems.* Continued emphasis should be placed on adequate case management and treatment of malaria and schistosomiasis in vulnerable areas. It is important that emphasis be placed on quick action, to prevent severe disease and long-term after-effects. In the case of malaria rapid diagnosis and treatment should be prioritized, and made available at the first point of contact, such as peripheral clinics.<br>Regular malaria drug efficacy testing is necessary to monitor development of drug resistance and allow timely drug policy changes, such as alternative drug use or combination therapy.<br>Infra-structure changes such as improved sanitation and water delivery systems may lower disease levels in both current and climate changed conditions | Management of malaria (WHO. 1997. *Management of uncomplicated malaria and the use of antimalarial drugs for the protection of travelers.* WHO/MAL/96.1075 Rev. 1.; Gove. 1997. Integrated management of childhood illness by outpatient health workers: technical basis and overview. *Bull.World Health Organ. 75* Suppl 1:7-24)<br>Drug resistance has a serious effect on malaria risk and mortality (Trape *et al.* 1998. *C.R Acad.Sci.III. 321* (8):689-697.) and needs to be monitored. A new potential solution for multi-drug resistance is combination therapy (White. 1999. *Philos.Trans.R Soc Lond B Biol.Sci. 354* (1384):739-749.).<br><br>A de-worming programme in KwaZulu-Natal, 1997 targets schistosomiasis (and the geohelminths) by chemotherapy, snail control, health education and sanitation.<br>Use of health promotion model to investigate risk factors and implement effective intervention strategies in KZN schools (Taylor *et al*. 1999, *SAMJ 89:* 273-279)<br>Role of human-water contact in schistosomiasis transmission may change with infra-structural changes such as the building of community swimming pools (Kvalsvig and Schutte. 1986. *Ann.Trop.Med Parasitol. 80*: 13-26). |
| *Improved access to disease-control devices.* If greater parts of the country turn into potentially | The use of insecticide-treated nets (Lengeler *et al*. 1996. *Net Gain: a new method for preventing malaria deaths.* IDRC/WHO, Geneva) and adulticiding by indoor spraying (Sharp and le Sueur. 1996. *South Afr* |

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| perennial malaria areas, the use of insecticide treated nets should be encouraged. Bed nets have proven cost-effective in various endemic settings in terms of morbidity and mortality; implementation in SA needs to go along with community education, stimulating supply by encouraging local producers of bed nets and some form of organized distribution. House spraying operations and focal larviciding should continue and be expanded where necessary.<br>If the limits of schistosomiasis-prone areas increase as a result of climate change , environmental control of snails should be investigated and encouraged. Suitable plant-based molluscicides may be used to control snail populations. | *Med J 86*: 83-89) are effective control measures against malaria. Early diagnosis and treatment remain high on the agenda (WHO. 1993. *A Global Strategy for Malaria Control*. WHO, Geneva.).<br><br>Bio-control of snails by replacement through competitor snail species (*Pomacea glauca, Marisa cornuarietis*, *Melanoides tuberculata* and *Thiara granifera*) has been successful against *Biomphalaria glabrata* (Pointier *et al.* 1991. *J. Med. Appl. Malacol. 3*, 49-52; Pointier and Guyard. 1992. *Ann. Trop. Med. Parasit. 43:* 98-101.)<br>150 of 600 molluscicidal plant species are potentially useful for control in South Africa (Clark *et al*. 1997. *J Ethnopharmacol 56:* 1-13). *Agave attenuata* is very toxic to snails but non-toxic to crop plants, invertebrates, fish and mammals (Brackenbury and Appleton, 1997. *Acta Tropica 68:* 201-213). Two applications of *Phytolacca dodecandra* (Endod) berries controlled trematode-transmitting snails for seven months in a stream in Zimbabwe. Snails only re-appeared after the next rains (Ndamba *et al*. 1989. *Acta Tropica 46:* 303-309). |

Table 14.10 Screened Human Health Adaptation Measures

| **Health Sector: Screening Adaptation Options** | | | | | | |
|---|---|---|---|---|---|---|
| **Adaptation Option** | **High Priority** | **Target of Opportunity** | **Effectiveness** | **Other Benefits** | **Low Costs** | **Low Barriers** |
| Monitoring System | No | | Yes | Yes | No | No |
| Epidemic Warning | No | | Unconfirmed | No | Yes | No |
| Vector control | Yes | | Variable | No | No | Yes |
| Disease prevention | Yes | | Yes/No | Yes | Yes | No |
| Early diagnosis | Yes | | Yes | Yes | Yes | Yes |
| Rapid and effective treatment | Yes | | Yes | Yes | Yes | Yes |

## 14.2.6 Plant Biodiversity Sector

Table 14.11. Draft Plant Biodiversity Adaptation Measures

| **Plant Biodiversity Sector<br>DRAFT Plant Biodiversity Adaptation Measures** | |
|---|---|
| **Adaptation Measures** | **Application Examples** |
| *Biodiversity Monitoring Network*. This should be focussed in a network of areas that combine a high risk of climate change with current high biodiversity, and security of land tenure. A further recommendation would be the identification of a suite of sensitive indicator species to serve as flagship warning entities. | Specific example not available to author’s knowledge. |

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| *Vegetation Management.* Current vegetation management has been based on the assumption that successional changes can be directed by adjusting herbivore numbers (livestock or game) and setting fire frequencies. Future management will need to be more opportunistic in taking advantage of rare good rainy seasons and managing extremely cautiously during, and immediately after, droughts. | Some examples from the Kruger National Park. |
| *Protected Area Networks.* The best way of using future biodiversity scenarios to ensure adequate representation of the country's floral wealth would be a strong motivation for retaining conservation areas which are predicted to show little change, and motivation for extending protected areas to adjacent land with high topographic relief (and local climate refugia) to allow for future change. | Some examples from the Addo National Park. |
| *Ex-situ Conservation. S*eedbanks and the network of national botanical gardens, is already important in South Africa. It is likely to become even more important in the future. *Ex situ* methods comprise establishing viable populations in gardens and under controlled conditions, and gene banking. | |
| *Global Greenhouse Gas Emission Policy.* Biodiversity considerations have not been a significant factor in setting greenhouse gas emissions. However, predicted biodiversity losses in South Africa are of national and international significance. They should be brought to the attention of the international community to provide additional motivation for policy measures to contain greenhouse gas emission and reduce the risk of global warming.. | |
| *Direct Intervention Actions.* For particular species, intensive rescue efforts might be warranted to the point where wild species are effectively "gardened".. | |
| *Tolerating Loss.* Given that it will probably be impossible to conserve all species in the face of climate change, a mechanism for prioritising intervention decisions will be crucial. We suggest the development of a cost-benefit analysis that takes into account such considerations as species ecological redundancy/equivalency, potential importance (e.g. keystone effects) and genetic variation and uniqueness. | |

Table 14.12. Screened Plant Biodiversity Adaptation Measures.

**Plant Biodiversity Sector**
**DRAFT Screening Adaptation Options**

| **Adaptation Option** | **High Priority** | **Target of Opportunity** | **Effectiveness** | **Other Benefits** | **Low Costs** | **Low Barriers** |
|---|---|---|---|---|---|---|
| Biodiversity monitoring network | Yes | Yes | Yes | Yes | No | No |
| Vegetation management | Yes | Yes | Yes | Yes | Yes | Yes |
| Protected area networks | Yes | Yes | Yes | Yes | No | No |
| Ex-situ conservation | Yes | Yes | Yes | Yes | No | Yes |
| Global greenhouse gas emission policy | Yes | Yes | No | No | No | No |
| Plant translocation actions | No | Yes | Yes | Yes | No | No |

| | | | | | | |
|---|---|---|---|---|---|---|
| Tolerating loss | No | Yes | Yes | No | Yes | Yes |

### 14.2.7 Animal Biodiversity Sector

Table 14.13. Draft Animal Biodiversity Adaptation Measures

| **Animal Biodiversity Sector<br>DRAFT Animal Biodiversity Adaptation Measures** | |
|---|---|
| **Adaptation Measures** | **Application Examples** |
| *Implementation of a Representative Conservation Network* . Implement a representative conservation area network for South Africa that incorporates considerable redundancy in order to buffer effects of climate change. | Specific examples and citations within the Sector Report. |
| *Establish a Species Inventory and Distribution Monitoring Network.* This activity should focus efforts on potential detector species as a point of departure and areas most likely to be susceptible to climate change (western arid zone and escarpment areas). | Specific examples and citations within the Sector Report. |
| *Promote the establishment of existing species documentation, analytical and integrated land-use planning decision making platforms*. | SA-ISIS Program. Cited web page http://www.sa-isis.co.za |
| *Land use Management for Biodiversity.* Encourage land-use practices or patterns outside conservation areas that minimize impacts on biodiversity conservation and/or future dispersal probabilities | Specific examples and citations within the Sector Report. |
| *Actively Discourage Rampant Land Transformation Practices.* | Specific examples and citations within the Sector Report. |
| *Research to Improve Understanding of Climate Limited Species Distributions.* Support greater fundamental research to improve our mechanistic understanding of the manner in which climate limits the distribution of species (directly or indirectly). | Specific examples and citations within the Sector Report. |
| *Screening Procedure for Early Detection of Invasive Species..* | Specific examples and citations within the Sector Report. |

### 14.2.8 Marine Biodiversity Sector

Table 14.14. Draft Marine Biodiversity Adaptation Measures.

| **Marine Biodiversity Sector<br>DRAFT Marine Biodiversity Adaptation Measures** | |
|---|---|
| **Adaptation Measures** | **Application Examples** |
| *Biodiversity Monitoring Network*. | Specific example not listed. |
| *Water Resources Management for Estuary Ecosystems.* | Specific example not listed. |

| | |
|---|---|
| *Resource Management for Coastline Ecosystems.* | Sardine fishery collapse off Namibia in the 1960s. |
| *Reactive Measures for Localised Species Losses.* | Specific example not listed. |
| *Fundamental Research to Improve Understanding of Marine and Estuarine Species Impacts..* | Specific examples and citations within the Sector Report |