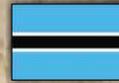




ORASECOM Document No. 009/2011



**SUPPORT TO PHASE 2 OF THE ORASECOM BASIN-WIDE  
INTEGRATED WATER RESOURCES MANAGEMENT PLAN**

**Work Package 4:**

**Climate Change in the Orange-Senqu River Basin**

# **Projection of Impacts under Plausible Scenarios and Guidelines on Climate Change Adaption Strategies**



**April 2011**

**ORASECOM**



The *Support to Phase 2 of the ORASECOM Basin-wide Integrated Water Resources Management Plan Study* was commissioned by the Secretariat of the Orange-Senqu River Basin Commission (ORASECOM) with technical and financial support from the German Federal Ministry for Economic Cooperation and Development (BMZ) in delegated cooperation with the UK Department for International Development (DFID) and the Australian Agency for International Development (AusAID). The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) implemented the study.



### Prepared by





**SUPPORT TO PHASE 2 OF THE ORASECOM BASIN-WIDE INTEGRATED WATER  
RESOURCES MANAGEMENT PLAN**

**Work Package 4:**

**Climate Change in the Orange-Senqu River Basin**

**Projection of Impacts under  
Plausible Scenarios  
and Guidelines on Climate Change  
Adaption Strategies**

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<b>Authors:</b>	Steve Crerar Jan Volkholz Julia Lutz
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**APPROVALS**

For the Consultants:

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**RS MCKENZIE**  
Managing Director: WRP Consulting Engineers

For ORASECOM:

---

**L THAMAE**  
Executive Secretary: ORASECOM Secretariat



<b>Study Name</b>	<b>Support to Phase 2 of the ORASECOM Basin-wide Integrated Water resources Management Plan</b>		
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GCC Downscaling for the Orange-Senqu River Basin	Report	008/2011	
<b><i>Projection of impacts and Guidelines on Climate Change Adaptation Strategies</i></b>	<b>WP</b>	<b>009/2011</b>	
<b>Work Package 5: ASSESSMENT OF ENVIRONMENTAL FLOW REQUIREMENTS</b>			
Literature survey and Gap Analysis	WP	008/2010	
Delineation of Management Resource Units	WP	009/2010	
Desktop Eco Classification Assessment	Report	016/2010	
Goods and Services Report	WP	010/2010	
Environmental Flow Requirements	Report	010/2011	
<b>Work Package 6: WATER CONSERVATION AND WATER DEMAND IN THE IRRIGATION SECTOR</b>			
The Promotion of WC WDM in the Irrigation Sector	Report	011/2011	
Irrigation GIS Database, Interactive Database and Irrigation Scenario Tools	WP	012/2011	
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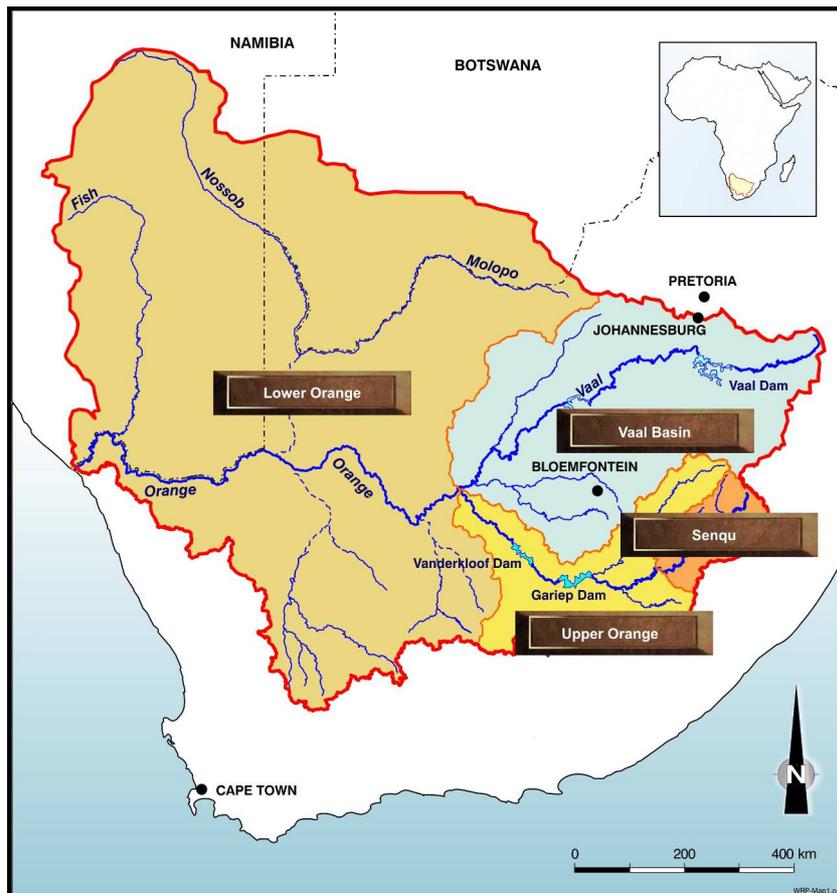
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# 1 INTRODUCTION

## 1.1 General Context

The Orange - Senqu River originates in the highlands of Lesotho some 3 300m above mean sea level, and it runs for over 2300km to its mouth on the Atlantic Ocean. The river system is one of the largest river basins in Southern Africa with a total catchment area of more than 850,000km<sup>2</sup> and includes the whole of Lesotho as well as portions of Botswana, Namibia and South Africa. The natural mean annual runoff at the mouth is estimated to be in the order of 11



500 million m<sup>3</sup>, but this has been significantly reduced by extensive water utilization for domestic, industrial and agricultural purposes to such an extent that the current flow reaching the river mouth is now in the order of half the natural flow. The basin is shown in **Figure 1**. The Orange-Senqu system is regulated by more than thirty-one major dams and is a highly complex and integrated water resource systems with numerous large inter and intra basin transfers.

**Figure 1: Orange – Senqu River Basin**

## 1.2 Management and Environmental Context

### 1.2.1 General

Management issues, including environmental protection, conservation and sustainable development have to deal with problems relating to, both, water quantity and quality, potential conflicts between users, pollution sources from industry, mining, agriculture, watershed management practices and the need to protect ecologically fragile areas. The riparian countries have for some time recognized that a basin-wide integrated approach has to be applied in order to find sustainable solutions to these problems and that this approach must be anchored through strong political will. The development of this strong political will is one of the

key initiatives of SADC, in particular the Revised Protocol on Shared Watercourses and the establishment of the Orange-Senqu River Basin Commission (ORASECOM). These initiatives are intended to facilitate the implementation of the complicated principles of equitable and beneficial uses of a shared watercourse system. It is accepted by all countries that the management of water resources should be carried out on a basin-wide scale with the full participation of all affected parties within the river basin.

Water supply in terms both of quantity and quality for basic human needs is being outstripped by the demands within and outside of the basin. Meeting the water supply needs of rapidly growing towns and cities at the same time having sufficient water of an acceptable quality to meet existing and proposed irrigation and other demands (including environmental) further downstream is a challenge for planners and decision makers and stakeholders in the Orange-Senqu River Basin.

### **1.2.2 ORASECOM**

Southern Africa has fifteen trans-boundary watercourse systems including the Orange–Senqu system. The Southern African Development Community (SADC) has adopted the principle of basin–wide management of the water resources for sustainable and integrated water resources development. In this regard, the region recognizes the United Nations Convention on the Law of Non-navigational Uses of International Watercourses, and has adopted the “Revised Protocol on Shared Watercourse Systems in the SADC Region”. Under this Revised Protocol, a further positive step has been the initiatives towards the establishment of river basin commissions in order to enhance the objectives of integrated water resources development and management in the region, while also strengthening the bilateral and multilateral arrangements that have been in existence for some time. The Orange–Senqu River Basin Commission (ORASECOM) which was established on 3 November, 2000 in Windhoek, Namibia. is a legal entity in its own right.

The highest body of the ORASECOM is the Council consisting of three permanent members, including one leader, for each delegation from the four riparian states. Support from advisors and ad hoc working groups can be established by the council. The main task of the Council is to “serve as technical advisor to the Parties on matters relating to the development, utilization and conservation of the water resources in the River System”, but the council can also perform such other functions pertaining to the development and utilization of water resources as the parties may agree.

## **1.3 Context of the Study and this Working Paper**

### **1.3.1 GIZ Support to SADC and ORASECOM**

The overall goal of the GIZ-supported ‘Transboundary Water Management in SADC’ programme is to strengthen the human, institutional, and organisational capacities for sustainable management of shared water resources in accordance with SADC’s Regional Strategic Action Plan (RSAP). The programme, which GIZ implements on behalf of the

German Federal Ministry for Economic Cooperation and Development (BMZ), and in delegated cooperation with the UK Department for International Development (DFID) and the Australian Agency for International Development (AusAID), consists of the following components:

- Capacity development of the SADC Water Division;
- Capacity development of the River Basin Organisations (RBO); and
- Capacity development of local water governance and transboundary infrastructure.

The activities of this Consultancy, “Support to Phase II of the ORASECOM Basin-wide Integrated Water Resources Management Plan”, being undertaken by WRP (Pty) Ltd and Associates, contributes to Component 2 above. The work of Phase 2 comprises of six work packages, as briefly outlined in **Section 1.3.2** below

### **1.3.2 Support to Phase 2 of the ORASECOM Basin-wide Integrated Water Resources Management Plan**

#### **1.3.2.1 Objectives of the Overall Consultancy**

The main objectives of this consultancy, are to enlarge and improve the existing models for the Orange-Senqu Basin, so that they incorporate all of the essential components in the four Basin States and are accepted by each Basin State. These models must be capable of being used to meet the current and likely future information needs of ORASECOM. These needs will likely encompass additional options to achieve water security in each Basin State (including changing configurations for water supply and storage infrastructure) and ensure that ORASECOM is able to demonstrate that its operations are aligned with the principles embodied in the SADC Water Protocol.

#### **1.3.2.2 The Six Work Packages**

In order to contribute to the realisation of the above-mentioned objectives, the project includes six work packages, as outlined in **Table 1**. The first of these work packages is central to Phase 2 of the IWRM Plan and will also be at the core of the final plan to be developed in Phase 3. Under Work Package 1, the WRYM water resources simulation model was updated and expanded to cover the entire basin.

**Table 1: Summary of Work Package Objectives and Main Activities**

<b>Work Package</b>	<b>Main Objectives</b>	<b>Main Activities</b>
WP 1: Development of Integrated Orange-Senqu River Basin Model	To enlarge and improve existing models so that they incorporate all essential components in all four States and are accepted by each State	<ul style="list-style-type: none"> <li>• Extension and expansion of existing models.</li> <li>• Capacity building for experts and decision-makers.</li> <li>• Review of water balance and yields.</li> <li>• Design/initiation of continuous review process.</li> </ul>
WP 2: Updating and Extension of Orange-Senqu Hydrology	Updating of hydrological data, hands-on capacity building in each basin state for generation of reliable hydrological data including the evaluation of national databases,	<ul style="list-style-type: none"> <li>• Assessment of Required Improvements to the Existing Gauging Networks.</li> <li>• Capacity Development.</li> <li>• Extension of Naturalized Flow Data.</li> <li>• Review of Existing Data Acquisition Systems, proposals on basin-wide data acquisition and display system.</li> </ul>
WP 3: Preparation and development of integrated water resources quality management plan	Build on Phase 1 initial assessment to propose water quality management plan, based on monitoring of agreed water quality variables at selected key points	<ul style="list-style-type: none"> <li>• Establishment of protocols, institutional requirements for a water quality monitoring programme, data management and reporting.</li> <li>• Development of specifications for a water quality model that interfaces with the systems models.</li> <li>• Capacity building to operate the water quality monitoring system and implement the water quality management plan.</li> </ul>
WP 4: Assessment of global climate change	Several objectives leading to assessment of adaptation needs	<ul style="list-style-type: none"> <li>• Identification of all possible sources of reliable climate data and Global Climate Model downscaling for the Orange-Senqu Basin.</li> <li>• Scenario assessment of impacts on soil erosion, evapotranspiration, soil erosion, and livelihoods.</li> <li>• Identification of water management adaptation requirements with respect to observed/ expected impacts on water resources.</li> <li>• Assessment of major vulnerabilities and identification of measures for enhancing adaptive capacities.</li> </ul>
WP 5: Assessment of Environmental Requirements	Several objectives leading to management and monitoring system responsive to environmental flow allocations	<ul style="list-style-type: none"> <li>• A scoping level assessment of ecological and socio-cultural condition and importance.</li> <li>• Delineation into Management Resource Units and selection of EFR sites.</li> <li>• One biophysical survey to collate the relevant data at each EFR site and two measurements at low and high flows for calibration.</li> <li>• Assessment of the Present Ecological State and other scenarios.</li> <li>• Assessment of flow requirements, Goods and Services, and monitoring aspects.</li> </ul>
WP 6: Water Demand management in irrigation sector	To arrive at recommendations on best management practices in irrigation sector and enhanced productive use of water	<ul style="list-style-type: none"> <li>• Establish a standard methodology for collecting data on irrigation water applied to crops, water use by crops and crop yields.</li> <li>• Document best management practices for irrigation in the basin and finalise representative, best-practice demonstration sites through stakeholder consultation.</li> <li>• Consider and assess various instruments that support water conservation/water demand management.</li> </ul>

The other work packages are both self-standing and intended to provide inputs to an improved and more complete water resources simulation model, for the whole basin. The model will be enhanced by a more complete hydrology (WP2), better and more complete water quality information (WP3), allowance for climate change impacts and adaptation (WP4), inclusion of environmental flow requirements at key points (WP5) and modelling of scenarios with improved water demand management in the key irrigation sector (WP6).

### **1.3.3 Background to Work Package 4 and this Working Paper**

#### **1.3.3.1 Work Package Objectives**

The Overall objective of Work package 4 is to carry out a detailed assessment of the occurrence, extent and possible effects of climate change in the Orange-Senqu River Basin. Sub-objectives include:

- detection of statistically significant change in the climate;
- assessment of, to which extent the detected climate change is consistent with the predicted climate change;
- if there is an inconsistency, identification of physically plausible explanations of the detected climate change; and
- assessment of major adaptation needs in terms of water resource management, communities and economic activities, with a view to countering observed and/or expected impacts of climate variability and change on the hydro-climatology and water resources.

#### **1.3.3.2 This Working Paper**

This working paper provides details of the potential impacts of the predicted climate change, as indicated in the Regional Downscaling work carried out under this work package.

## 2 RESULTS OF DOWNSCALING

### 2.1 Introduction

As presented in detail in Report ORASECOM 008/2011, GCC Downscaling for the Orange – Senqu River Basin, both dynamic and statistical downscaling approaches were applied.

Climate projections with the statistical model STAR II, are based on historical weather records available for the region and on data from the PIK-dataset. On the other hand, the dynamic model, CCLM, uses the results of a global circulation model (ECHAM5). The statistical method uses the regional temperature trend, supplied by global circulation models (GCMs), and derives changes in other climate variables, from patterns between temperature and other variables recorded in the past. The A1B emissions scenario, which assumes a globalised world emphasising economic growth, was used.

In view of the fact that the results of the dynamic downscaling for precipitation proved unsatisfactory, it was decided to use the results of the statistical regional downscaling using STAR, for the investigation of climate change impacts and adaptation strategies. However, the results of the dynamic downscaling for temperature have been utilised, due to the fact that it is only the dynamic downscaling that provided results for all four seasons of the year.

To extract the future changes in temperature and precipitation in the Orange River Basin, the projections for the time period from 2051 to 2060 were compared with the observed historical data. The results of three realisations (runs) were presented - corresponding to wet, dry and median realisations<sup>1</sup>.

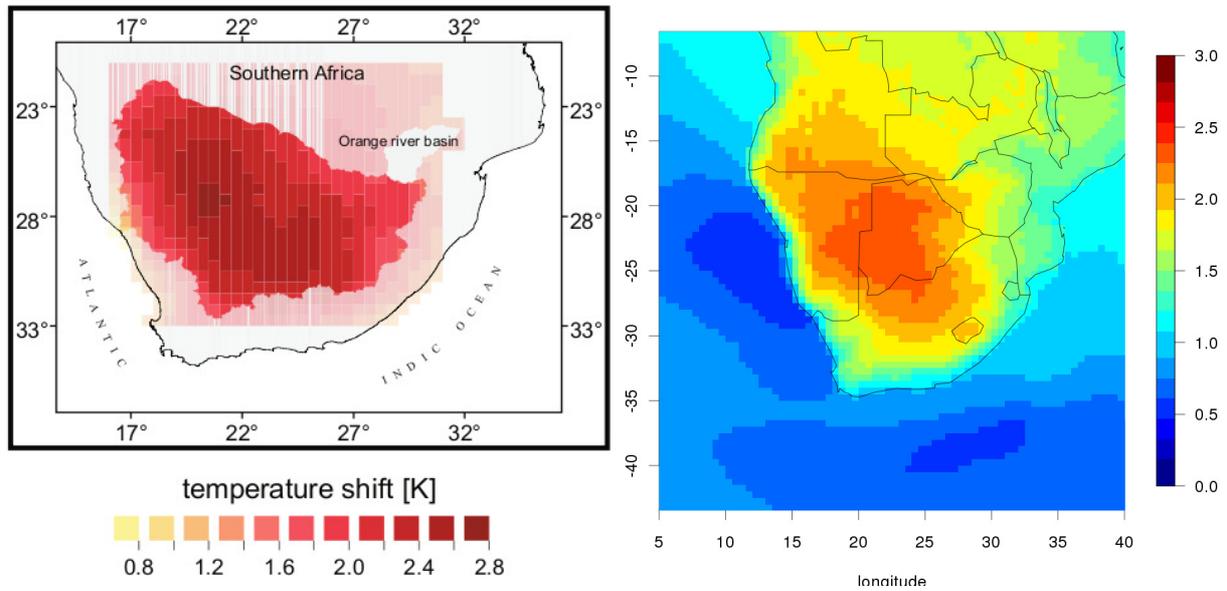
### 2.2 Temperature

#### 2.2.1 Annual Temperature

**Figure 2** shows the shift in annual temperature, when comparing the period 2031 – 2060 with 1971 – 2000. On the left is the result as derived from the statistical downscaling approach using STAR, while on the right is the result given by the dynamic downscaling using the CCLM model. Both approaches indicate that there will be an increase in temperature throughout the basin, varying from around a 1 °C increase at the coast (mouth), to a maximum of around 2 °C in the Kalahari Desert. The increase in the source areas, such as the Lesotho Highlands, is between 1.5 and 2 °C. Both the STAR and CCLM models provide similar results in this case.

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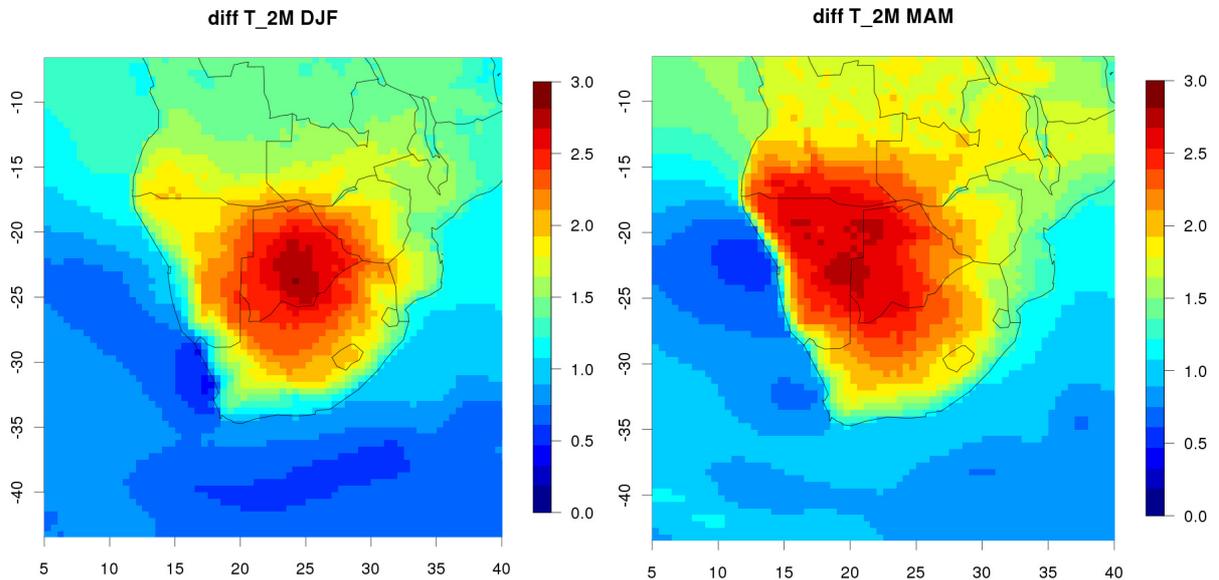
<sup>1</sup> These three realisations were chosen according to the annual area averaged precipitation. The 0.05-quantile of the precipitation represents a dry realisation, the median represents a moderate realisation and the 0.95-quantile represents a wet realisation. This approach ensures that the range of possible climate variations for the future is taken into account.



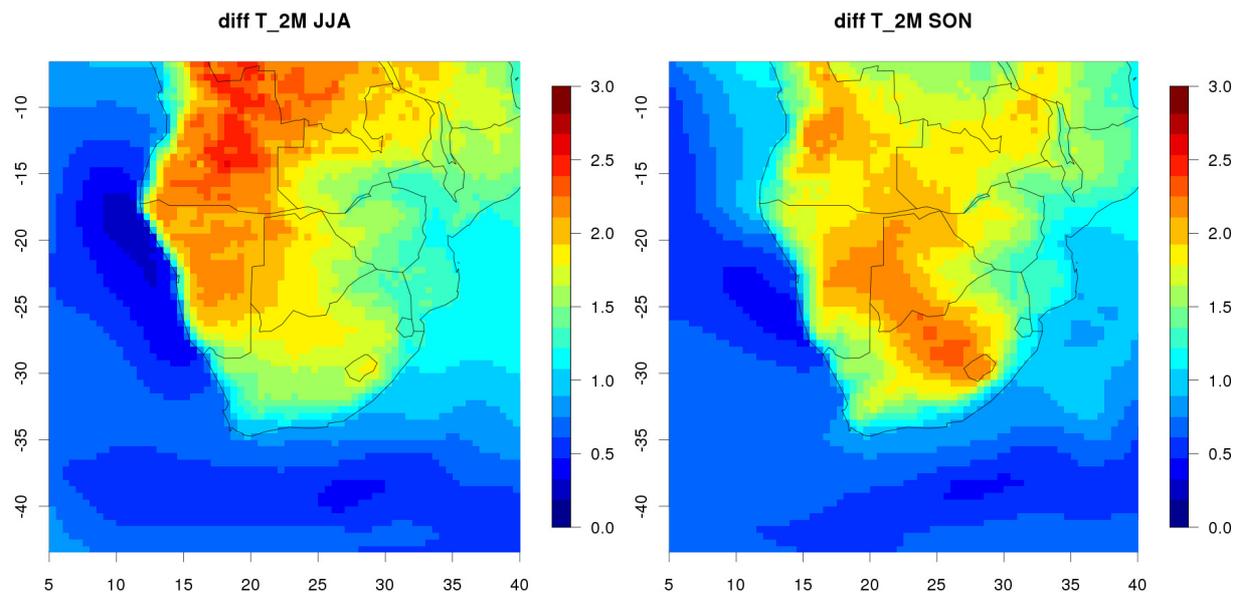
**Figure 2: Temperature Shift between Present and Future under A1B Emissions Scenario using STAR (left) and CCLM (right) Models**

**2.2.2 Seasonal Temperature**

**Figure 3** and **Figure 4** provide estimates of change in average seasonal temperature, for the four quarters of the year. These results were derived using the CCLM model.



**Figure 3: Temperature Shift between Present and Future under A1B Emissions Scenario using CCLM for December-January and March-May**



**Figure 4: Temperature Shift between Present and Future under A1B Emissions Scenario using CCLM for June-August and September-November**

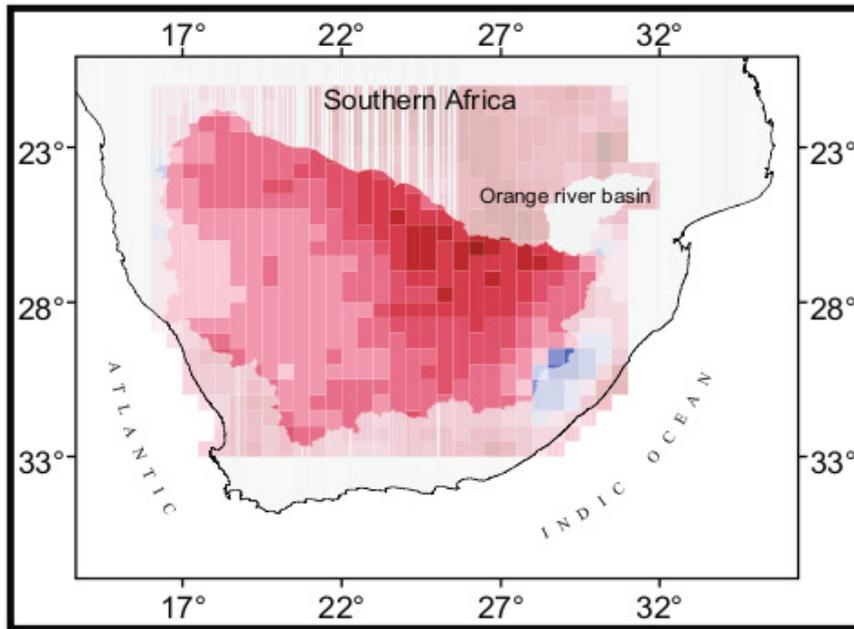
Considering the individual seasons, it is evident that the projected temperature increase is unevenly distributed across the seasons. In summer (DJF) and autumn (MAM) a temperature increase of more than 2.5°C was predicted for the northern Orange River Basin and Namibia. The largest increase of 3°C is predicted for the summer months around the Kalahari Desert. During the initial summer period, the increase in temperature over the Lesotho Highlands is also at its highest. For the autumn and winter season, an increase in temperature is still predicted, albeit not as extreme. The temperature increase in these cases is more evenly distributed across the Orange Basin, and not as high. In autumn and winter, the temperature increases is predicted at between 1°C and 2°C.

### 2.3 Precipitation

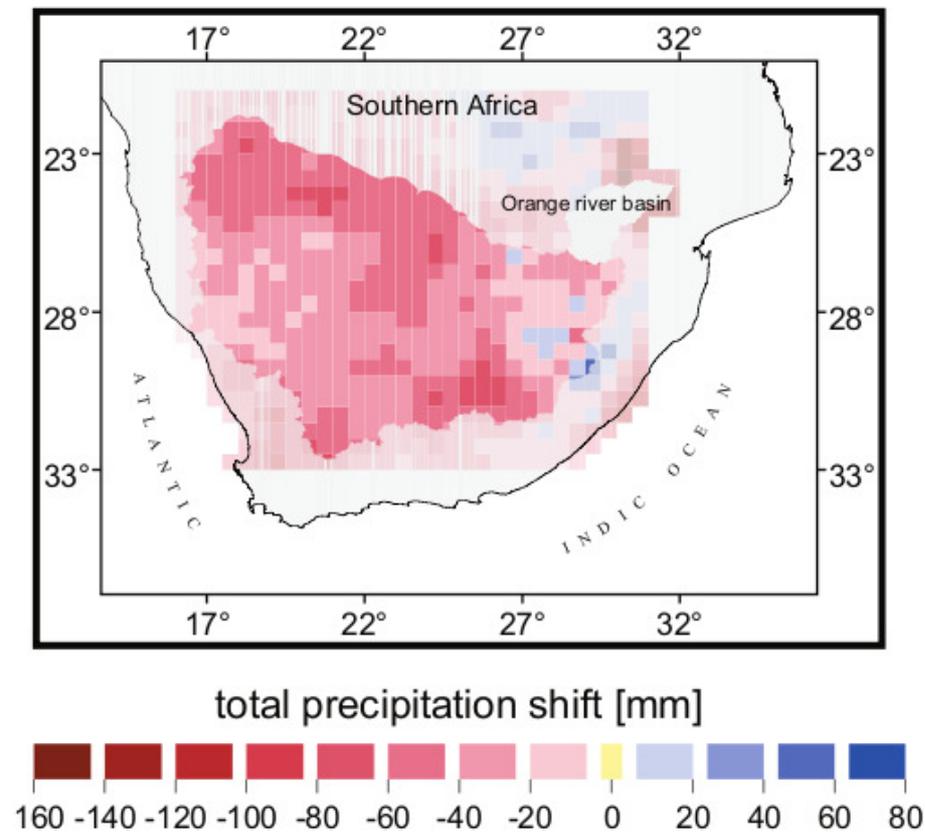
As already indicated, the poor level of validation meant that the CCLM predictions of precipitation were unusable., STAR was therefore used for future precipitation projections since the validation process yielded more realistic results

To extract the future changes in temperature and precipitation in the Orange River Basin, the projections for the time period from 2051 to 2060, are compared with the observed historical data. The key results from the three realisations (wet, dry and median) are illustrated in **Figure 5**, **Figure 6** and **Figure 7** respectively. The dry realisation shows the largest changes, reaching values of down to -140mm per annum in the northeast of the basin. An increase in precipitation of between 20mm and 60mm per annum is predicted for the southeast of the basin in Lesotho. This increase is particularly evident in the wet realisation where it stretches further north into the Vaal River basin. In this realisation in the remainder of the Orange-Senqu basin, the reduction in precipitation is more moderate, with values of down to -80mm

per annum. The median realisation shows a precipitation decrease of down to -60mm for the river basin.



**Figure 5: Precipitation Shift under Dry Realization**



**Figure 6: Precipitation Shift under Median Realizations**

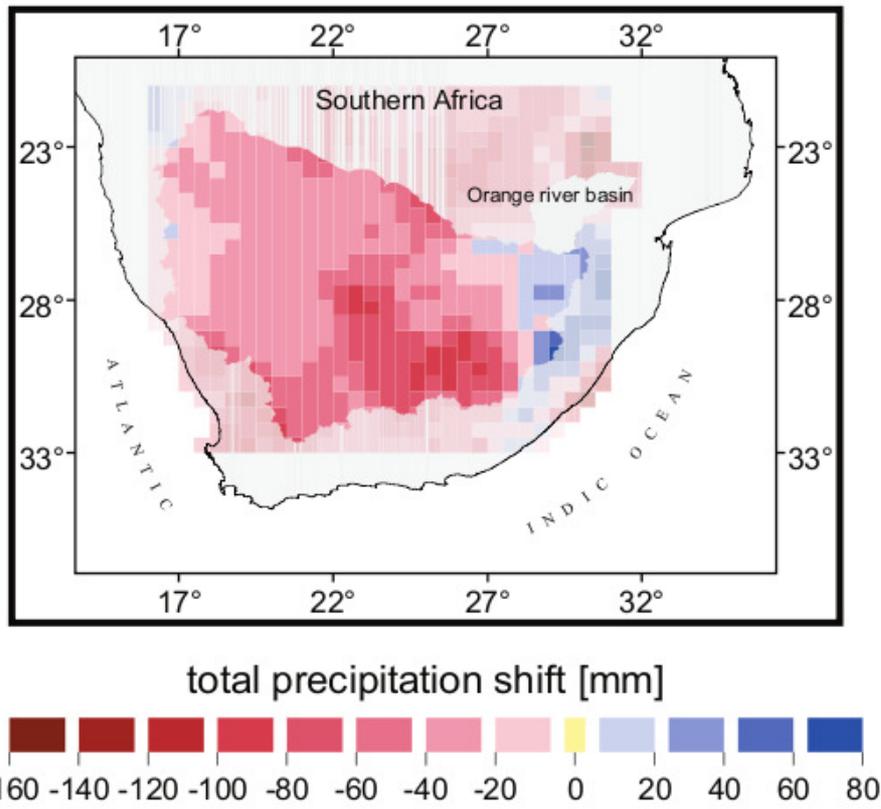


Figure 7: Precipitation Shift under Wet Realization

### 3 VULNERABILITY TO CLIMATE CHANGE

#### 3.1 Introduction

The Inter-governmental Panel on Climate Change (IPCC), in its Second Assessment Report, defined vulnerability as:

*“the extent to which climate change may damage or harm a system.” It adds that vulnerability “depends not only on a system’s sensitivity, but also on its ability to adapt to new climatic conditions” (Watson et al. 1996: 23).*

Possibly a more useful definition in the current context is:

*“the extent to which a natural or social system is susceptible to sustaining damage from climate change, and is a function of:*

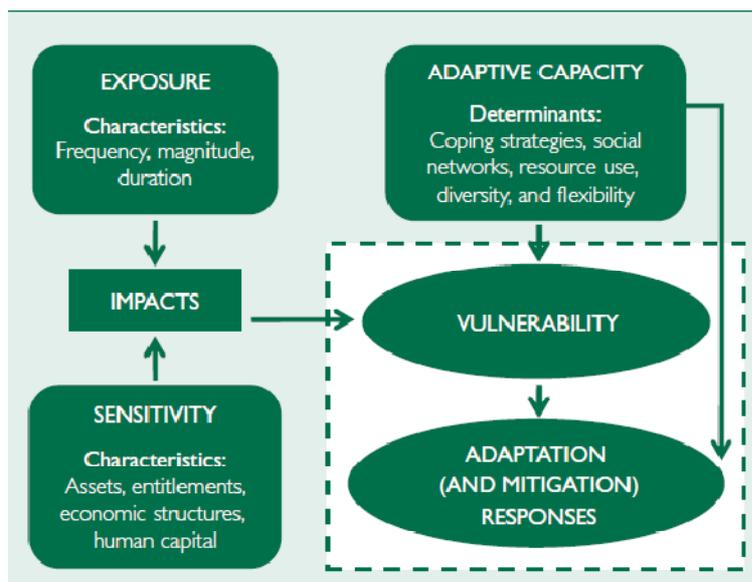
- *the magnitude of climate change;*
- *the sensitivity of the system to changes in climate; and*
- *the ability to adapt the system to changes in climate.*

*Hence, a highly vulnerable system is one that is highly sensitive to modest changes in climate and one for which the ability to adapt is severely constrained.”*

The IPCC report, *The Regional Impacts of Climate Change: An Assessment of Vulnerability* (Watson et al.1998), argues that the vulnerability of a region depends (to a great extent) on its wealth, and that poverty limits adaptive capabilities. In simple terms, ***vulnerability is highest where there is “the greatest sensitivity to climate change and the least adaptability.”***

It is well recognised that the poor are likely to be the most severely affected by climate change. It is also known that the capacity to respond to climate change is lowest in developing countries and among the poorest people in those countries. It seems clear that vulnerability to climate change is closely related to poverty, as the poor are least able to respond to climatic stimuli.

**Figure 8** shows how sensitivity and exposure influence the level of impact and how the vulnerability to this impact is further tempered by adaptive capacity



**Figure 8: How Vulnerability is influenced by Impact Exposure and Adaptive Capacity**

### 3.2 Current Hydro-climatic Conditions (overview of current climate)

Both climate and the related hydrological regime in Southern Africa, are highly variable. Precipitation over the basin varies from more than 2 000mm in the Lesotho Highlands, down to less than 25 mm towards the river mouth in the dry desert areas. The resultant runoff generated over the whole Orange-Senqu River Basin is relatively small with a highly skewed distribution where most of the runoff originates in the eastern portion of the basin.

Precipitation is highly variable, both spatially and temporally and is typical of an arid to semi-arid climate. This variability is amplified in the hydrological cycle, with periods of both high flood and very low flow and drought periods of up to 20 years can be expected in some areas.

This naturally high inter-annual and intra-annual variability, of both precipitation and runoff, makes it very difficult to detect subtle climate change trends, which can easily be masked by the natural variability.

In some respects, the high natural variability of the climate has forced many stakeholders (especially farmers) to develop an adaptive capacity to climate change, due to the fact that the types of management systems that are required to deal with a highly variable climate, are already similar to those required to adapt to climate change. It could therefore be argued, that some of the basin's stakeholders are less vulnerable than might be expected.

### 3.3 Vulnerability of different Sectors

#### 3.3.1 Introduction

The table overleaf, which applies to the African Continent in general, provides a useful summary of vulnerability and adaptive capacity to key climate change variables (temperature, precipitation and extreme events).

**Table 2: Sectoral Vulnerabilities and Adaptive Capacity**

Impact	Sectoral Vulnerabilities	Adaptive Capacity
<p><b>Temperature</b> Higher warming throughout the continent and in all seasons compared with global average. Drier subtropical regions may become warmer than the moister tropics.</p> <p><b>Precipitation</b> Decrease in annual rainfall in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean coast is approached. Decrease in rainfall in Southern Africa in much of the winter rainfall region and western margins. Increase in annual mean rainfall in East Africa. Increase in rainfall in the dry Sahel may be counteracted through evaporation.</p> <p><b>Extreme Events</b> Increase in frequency and intensity of extreme events, including droughts and floods, as well as events occurring in new areas.</p>	<p><b>Water</b> Increasing water stress for many countries. 75–220 million people face more severe water shortages by 2020.</p> <p><b>Agriculture and food security</b> Agricultural production severely compromised due to loss of land, shorter growing seasons, more uncertainty about what and when to plant. Worsening of food insecurity and increase in the number of people at risk from hunger. Yields from rain-fed crops could be halved by 2020 in some countries. Net revenues from crops could fall by 90% by 2100. Already compromised fish stocks depleted further by rising water temperatures.</p> <p><b>Health</b> Alteration of spatial and temporal transmission of disease. Vectors, including malaria, dengue fever, meningitis, Cholera, etc.</p> <p><b>Terrestrial Ecosystems</b> Drying and desertification in many areas particularly the Sahel and Southern Africa. Deforestation and forest fires. Degradation of grasslands. 25–40% of animal species in national parks in sub-Saharan Africa expected to become endangered.</p>	<p>Africa has a low adaptive capacity to both climate variability and climate change, exacerbated by existing developmental challenges including:</p> <ul style="list-style-type: none"> <li>– low GDP per capita;</li> <li>– widespread, endemic poverty;</li> <li>– weak institutions;</li> <li>– low levels of education;</li> <li>– low levels of primary health care;</li> <li>– little consideration of women and gender balance in policy planning;</li> <li>– limited access to capital, including markets, infrastructure and technology;</li> <li>– ecosystems degradation;</li> <li>– complex disasters;</li> <li>– conflicts.</li> </ul>

### 3.3.2 Agriculture

The agriculture sector is generally vulnerable to increased temperatures and reduced precipitation due to the following:

- Increased evapotranspiration would result in increased crop water requirements;
- Crop yields are likely to be affected by changes in precipitation and temperature and carbon dioxide levels. When carbon dioxide fertilisation is taken into account, losses may be less severe than anticipated;

- Increased temperature will increase heat stress on livestock and resultant water requirements. There may also be some positive aspects such as reduced winter stock losses; and
- The vulnerability of stock farmers could be partially offset by the fertilisation effect of carbon dioxide.

### **3.3.3 Health**

Potential impacts on health are significant. Human health is vulnerable to:

- Poorer sectors of the population, during water shortages, being more vulnerable to water-borne and water-washed diseases; and
- An increase in some diseases, in particular malaria.

### **3.3.4 Water Resources Sector**

- Natural adaptive capacity or regulatory functions of river systems, has been diminished by deforestation, erosion and damage or reduction wetlands;
- The availability of water will be diminished as a result of reduced precipitation; and
- The intra-annual availability of water may be affected by less frequent, but more extreme, rainfall events

### **3.3.5 Biodiversity**

Quantity and extent of biome and biodiversity are vulnerable to increased temperature and decreased precipitation with the following effects:

- Potential loss of some species
- Some biomes such as savannas are particularly sensitive to even small changes in climate.

## 4 IMPACTS AND ADAPTATION

### 4.1 Introduction

In the following paragraphs, some of the potential impacts of the climate changes, as predicted by the regional downscaling, are identified and discussed along with potential adaptive strategies and measures.

### 4.2 Runoff production in Lesotho Highlands and other Source Areas

#### 4.2.1 Potential Impacts

The majority of the Orange-Senqu water resources are generated in South Africa, the highlands of Lesotho and the uplands of the Vaal River Basin, as shown in **Figure 9** (generated in the Hydrological Studies work package).

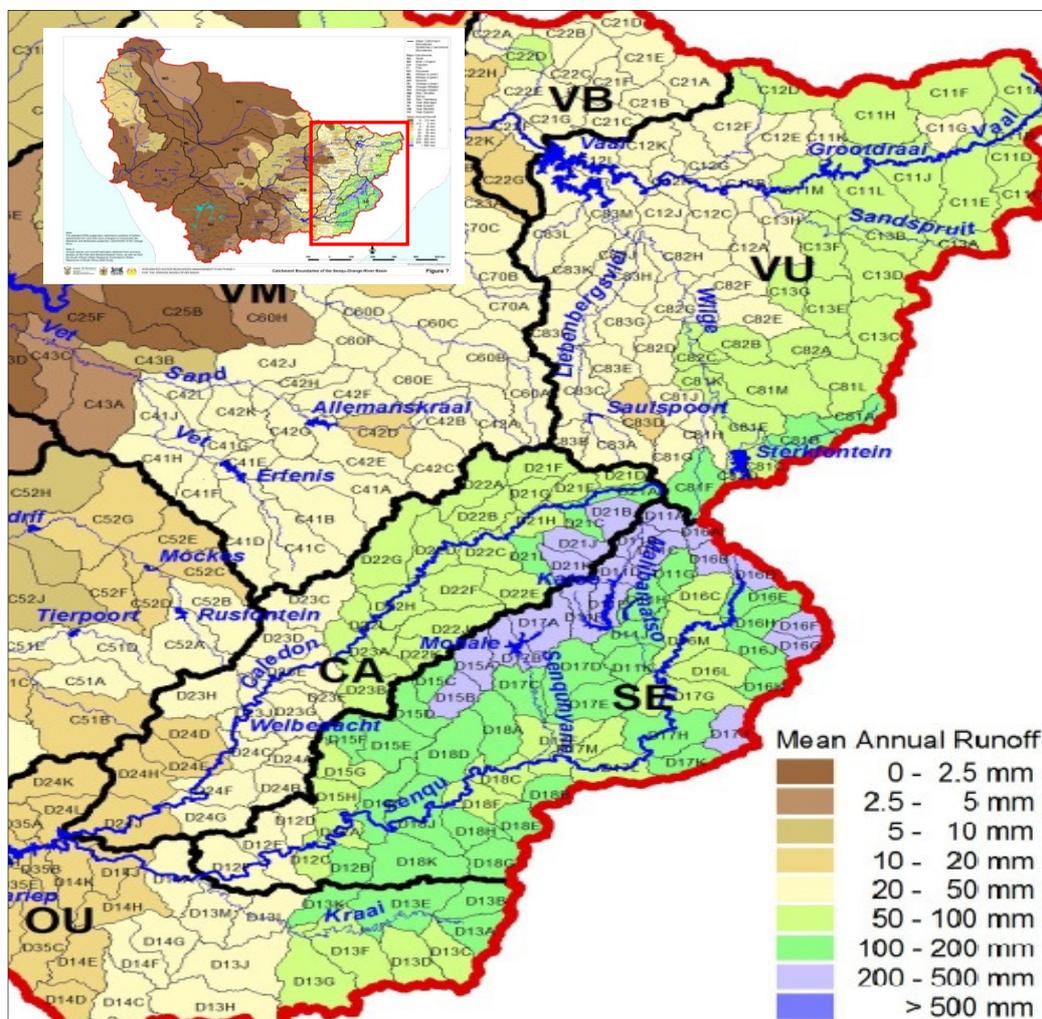
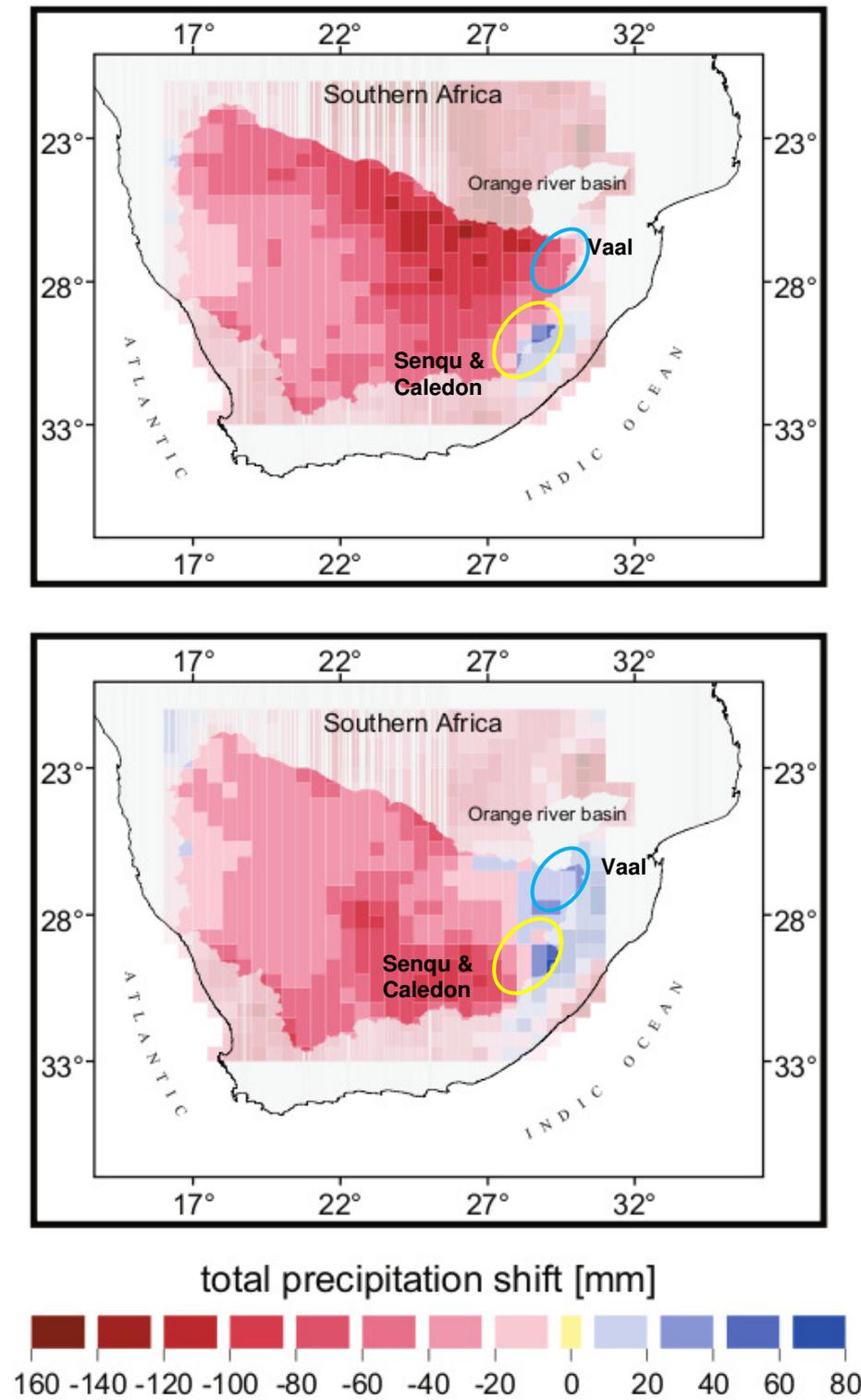


Figure 9: Runoff producing Areas of Senqu, Caledon and Vaal Rivers.

In **Figure 10** these key runoff producing areas have been circled on the predicted difference in precipitation maps under the dry and wet realisations.



**Figure 10: Precipitation Shift in Source Areas under dry (upper) and wet (lower) Realisations**

Some observations can be made:

- The relationship between precipitation and runoff is not linear. A 5% increase in precipitation in some areas, could produce a greater than 5% increase in runoff.
- A reduction in precipitation in the low unit runoff areas, may not result in a significant (in terms of the basin-wide water resources) reduction in runoff.
- Mean annual precipitation is only one of the variables which are related to runoff. The quantity of runoff generated also depends on rainfall intensity. Less frequent, but more extreme events, can result in an increase in mean annual runoff, although there may be many negative impacts associated with this:
  - Increased erosion and loss of soils;
  - Reduced base flow and higher flood levels and associated flooding;
  - Inappropriately sized dams (reservoirs) and spillways; and
  - Reduced groundwater recharge.

In terms of the predicted changes to precipitation, it can be seen from **Figure 10** that the precipitation in the Lesotho highlands and source of the Caledon River in South Africa may experience an increase in precipitation. A relatively small increase in precipitation in these key runoff producing areas could result in a significant increase in runoff, perhaps enough to offset the reduced runoff in the lower runoff producing areas to the west.

Runoff in the Fish River is likely to be adversely affected by significantly reduced precipitation, although this may be partially offset by more extreme rainfall events. The Fish River is almost an ephemeral system, and most of the runoff is during flood events generated during intense rain storms.

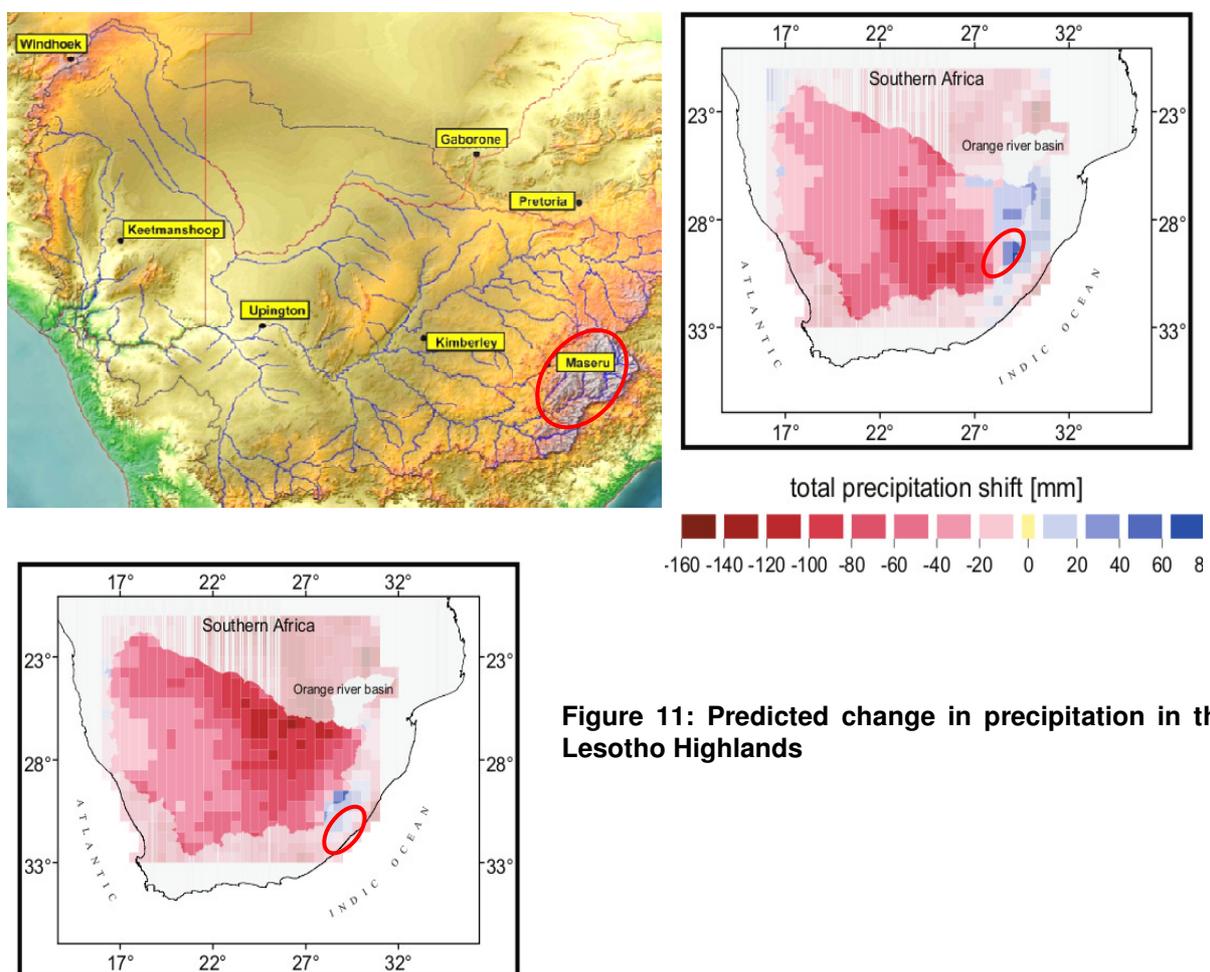
#### **4.2.2 Adaptive Measures**

- There is a high degree of uncertainty related to the predicted changes in precipitation. This uncertainty could be reduced through both further, more detailed downscaling work and greatly improved and intensified data collection efforts. Considering the potential wastage of financial resources, through poor planning, based on incorrect and inaccurate data, it is clearly justified to invest in an improved network, especially in the key runoff producing areas. It is therefore very important to maintain and if possible improve the rainfall collection network in the basin as well as improve the river gauging network, especially low flows to assess impact on base flows.
- A possible reduction in runoff in some critical areas, should be anticipated in the planning of future water resource development infrastructure. A case in point is the Fish River in Namibia where planning of the Neckertal Dam is at an advanced stage. A possible reduction in mean annual runoff, as well as a possible increase in the magnitude of extreme flood events, should be taken into account in the sizing of both the reservoir and spillway.

### 4.3 Impact on Activities and Livelihoods around the Basin

#### 4.3.1 Lesotho Highlands

The majority of farmers in Lesotho are generally smallholder subsistence farmers, with limited financial resources. Farmers with limited financial resources and farming systems with few adaptive technological opportunities available, to limit or reverse adverse climate change, may suffer significant disruption and financial loss for relatively small changes in crop yields and productivity. Or these farms may be located in areas more likely to suffer yield losses. However, the downscaling results have indicated that rainfall over the Lesotho Highlands may increase as shown in **Figure 11**, so the impact on agriculture may in fact be positive.



**Figure 11: Predicted change in precipitation in the Lesotho Highlands**

Irrigation is relatively undeveloped in Lesotho for a number of reasons. As with the rain-fed sector, the impact of climate change may be limited and therefore no specific adaptive measures are proposed. There are many other important issues unrelated to climate change which must first be addressed, to improve the productivity of irrigated agriculture in Lesotho.

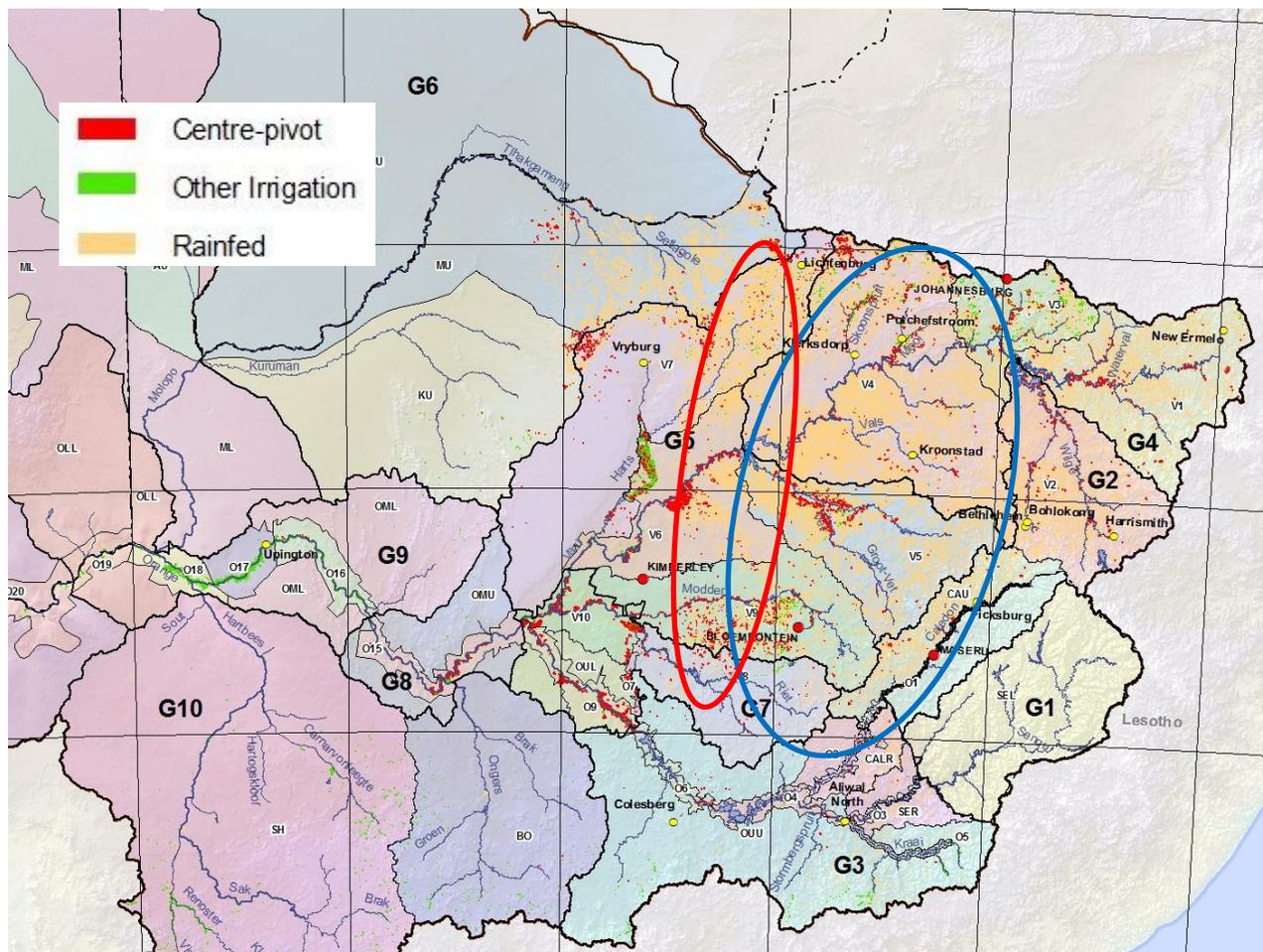
Agricultural activities in the wetter source areas are likely to be positively affected or little affected by the possible climate change. A marginal increase in precipitation over most of Lesotho, could improve the productivity of both arable agriculture and stock farming.

One possible negative impact of climate change could be an increase in rainfall intensity, or an increase in the frequency of the extreme rainfall events. This could result in higher rates of erosion and the marginalisation of farmlands on steeper slopes. The importance of catchment conservation measures (already an important activity in the Lesotho Highlands) would increase.

#### 4.3.2 Lesotho Lowlands

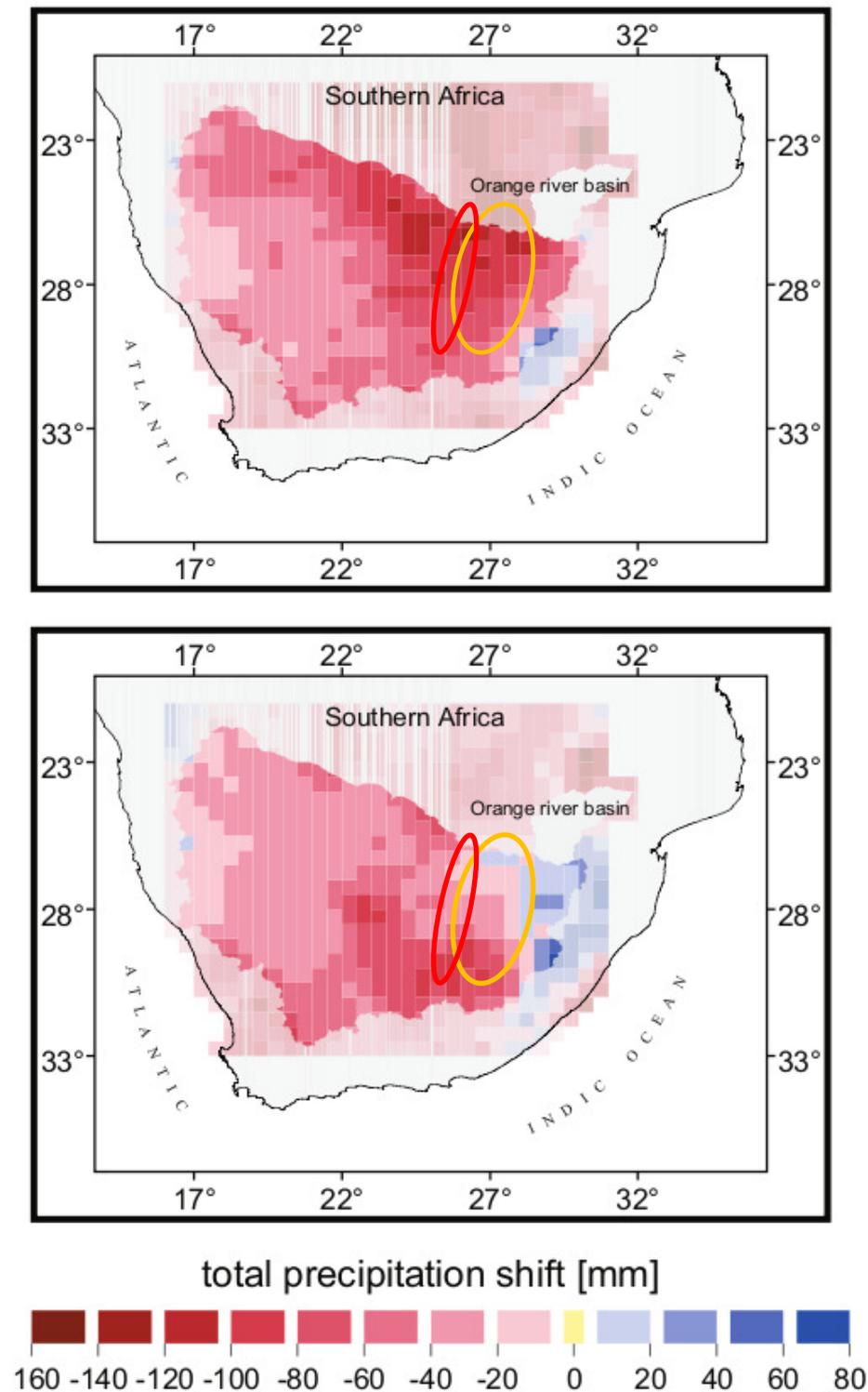
As can be seen from **Figure 10**, the Lesotho lowlands are located in an area where precipitation may not change significantly and at best may increase slightly. Based on the information currently available, the impacts of possible climate change are unlikely to be as significant as in other parts of the basin.

#### 4.3.3 Upper-Middle Catchment and Marginal Rain-fed Areas



**Figure 12: Upper-middle Catchment and Marginal Rain-fed Farming Areas**

In **Figure 12** the Upper-middle catchment is circled in blue and the marginal rain-fed area in red. These same areas are shown in the precipitation shift maps for the dry and wet realizations in the upper and lower diagrams in **Figure 13**.



**Figure 13: Upper-middle Catchment and Marginal Rain-fed Areas on Precipitation Shift Maps**

The Upper-middle catchment is dominated by rain-fed agriculture and stock-farming. Rain-fed agriculture is shown in yellow on **Figure 13**. At the western side of this area, rain-fed agriculture becomes more marginal, with rainfall becoming both too little and too variable to make rain-fed farming possible.

In the Upper-middle catchment area a significant temperature increase, coupled with a significant reduction in precipitation, will make rain-fed farming increasingly difficult.

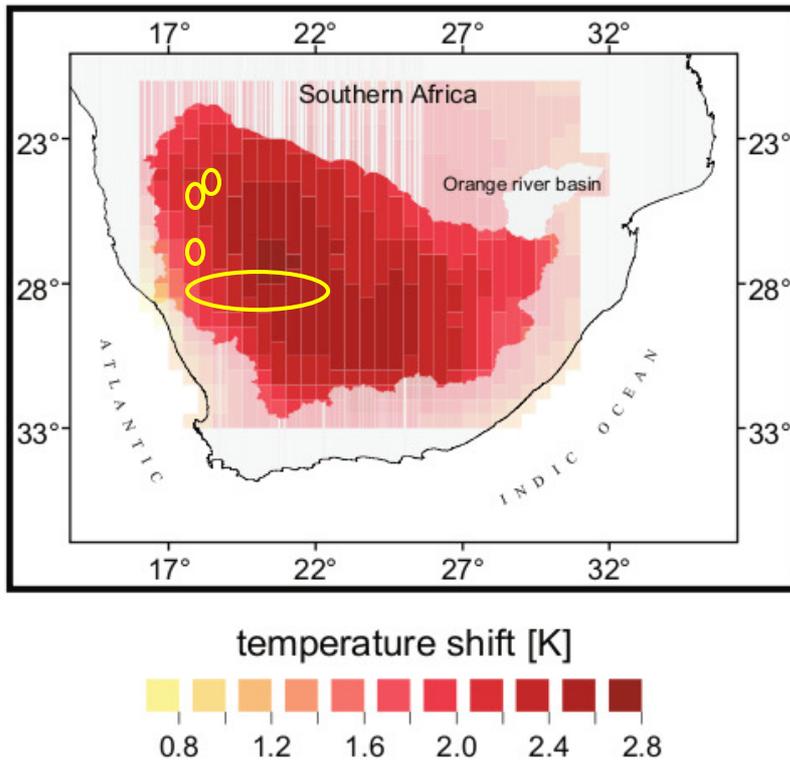
Grasslands may move eastwards and some areas where rain-fed arable farming has previously been practiced, may become more suitable for livestock production. This could result in increased cattle production.

There are a range of adaptation measures to be considered in the rain-fed sector: These can be divided into five groups:

- Genetic measures (new drought tolerant/high yielding varieties);
- Land reclamation measures (to increase soil water holding capacity – manure, increase in organic matter etc);
- Agricultural practices (soil and water conservation, soil cultivation – reduced tillage, water harvesting, mulching etc);
- Supplementary irrigation; and
- Knowledge, awareness, education and capacity building.

Certain measures can be introduced to assist farmers to adapt and continue with productive farming, but it is probable that parts of the western part of this area will become unsuitable for economic rain-fed farming. Alternative livelihoods will have to be sought.



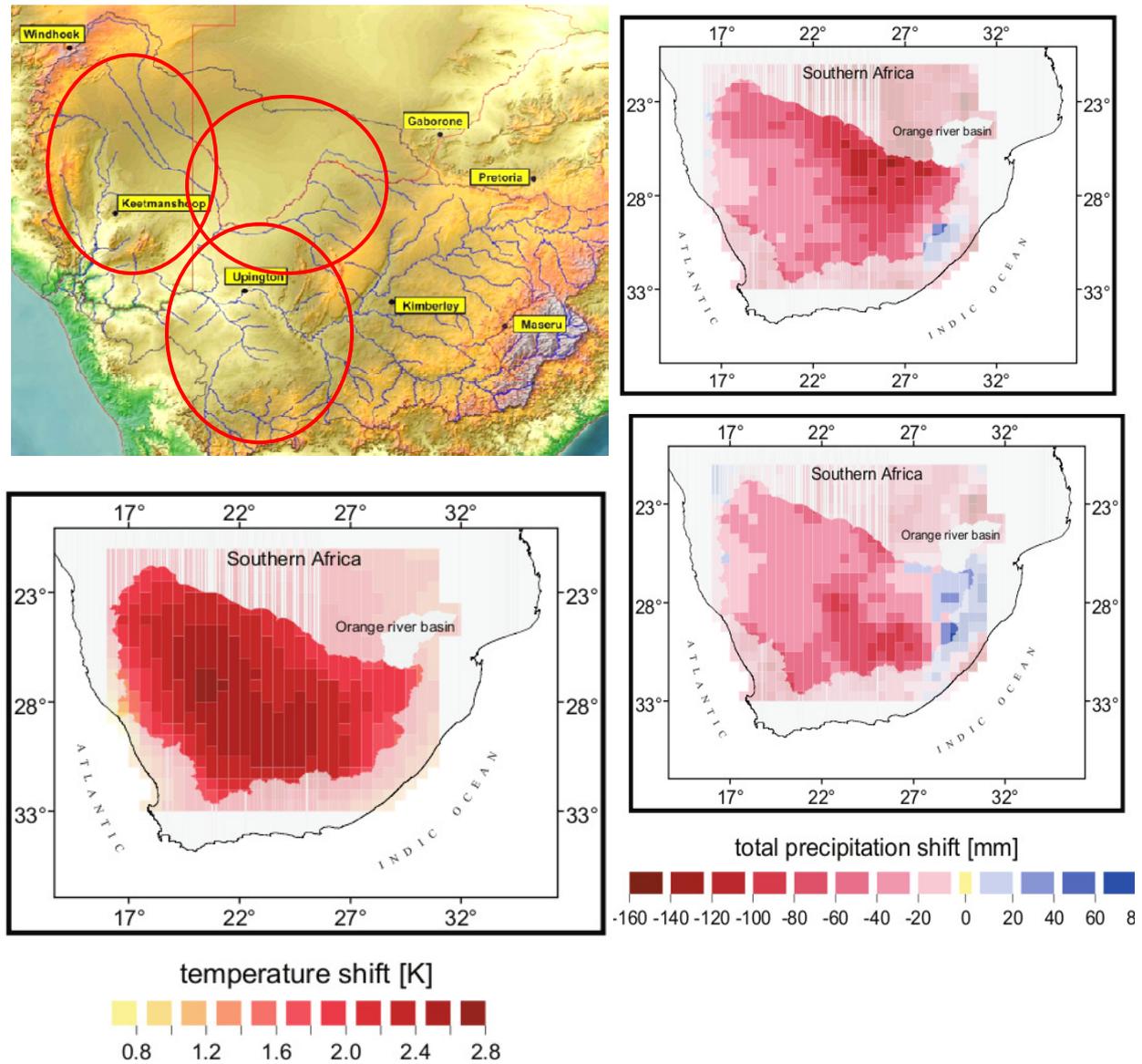


**Figure 15: Temperature Increase in the Lower Orange and Namibia**

Adaptation of the irrigation sector, to the threat of climate change, will be important. However, the promotion of the best management practices, will already aid in mitigating against climate change. Generally accepted adaptation measures for irrigated agriculture include:

- Spreading of water savings techniques (generally towards micro-irrigation);
- Rehabilitation of existing schemes;
- Defining a “real” price for irrigation water;
- Institutional and structural reform;
- Education of farmers in modern irrigation and
- Increasing of public awareness for changes in irrigation practices.

**4.3.5 Stock-farming in Lower Orange, Namibia and Botswana**



**Figure 16: Stock-farming in Lower Orange, Namibia and Botswana**

**Figure 16** indicates that there will be a major increase in temperature over these areas which will clearly increase heat stress and cattle watering requirements. Changes in vegetation are likely to occur due to reduced precipitation. It has been suggested that the reduced precipitation may be counteracted by the carbon dioxide fertilisation effect on grazing lands.

One of the positive impacts of increased winter temperatures will be the reduced losses of lambs in small stock areas during winter and spring.

## 5 CONCLUSIONS

Temperature is expected to rise significantly over all of the Orange River Basin, and impacts on all agriculture sectors will be considerable. In particular, rain-fed agriculture in all but the Lesotho Highland areas will be the most affected, with a combination of higher temperature and reduced precipitation, reducing productivity and endangering the basic viability to farm in many areas.

The irrigation sector will be adversely affected by higher crop water requirements and there will be a need to accelerate the implementation of the best management practices in the irrigation sector, if water savings are to be made. The presence of higher winter temperatures may allow the extension of double cropping into some areas where it is not currently practiced.

It is difficult to draw firm conclusions on the future status of the basin's water resources, regarding the overall mean annual runoff and it is not known if it will remain constant, increase or decrease. It does seem possible that higher rainfall in the source areas may in fact outweigh the effects of reduced rainfall over the much larger, but less productive, drier areas. A great unknown will be how rainfall patterns may change, whether rain events will become more extreme or not. In order to improve future estimates of precipitation under changed climatic conditions, it will be necessary to greatly improve the quantity of climate data being collected in the source areas, of the Orange-Senqu River Basin.

Many of the existing water resource and land use management initiatives, are already moving in the right direction due to the fact that most of the basin is already regarded as water-stressed. An awareness of climate change and its impacts can act as a catalyst to accelerate these initiatives.





