MODELLING IMPACTS OF CLIMATE CHANGE ON SELECTED SOUTH AFRICAN CROP FARMING SYSTEMS

Report to the
WATER RESEARCH COMMISSION
and
DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES

by

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EXECUTIVE SUMMARY

BACKGROUND

The agricultural sector is physically and economically vulnerable to climate change (Kaiser et al., 1993; Darwin et al., 1995; IISD, 1997; IPCC, 2001; Mukheibir et al., 2003; IFPRI, 2009).

In most regions of South Africa, the availability of water is the most limiting factor for agricultural production. RSA experiences a high risk climatic environment, with a highly variable and spatially uneven rainfall distribution, as well as climate-related extremes. Any change in rainfall attributes could have wide-ranging implications for commercial and subsistence food and fibre production, as well as for the GDP, employment and foreign exchange earnings.

At present RSA's agricultural sector experiences multiple stressors, including (but not limited to) variable rainfall, widespread poverty, environmental degradation, uncertainties surrounding land reform, limited access to capital, including markets, infrastructure and technology, and HIV/AIDS. Climate change is superimposed upon all these stressors and is anticipated to exacerbate these issues, and in combination with low adaptive capacity, the South African agriculture sector through the value chain is highly vulnerable to effects of climate change and the associated increase in climate variability.

There has been limited research on climate change and related impacts on livelihood and the natural resources in some African countries (Environmental Alert, 2010; Louw et al., 2012). However, evidence from global climate models developed thus far suggests that the agricultural sector in the Southern African region is highly sensitive to future climate shifts and increased climate variability (Gbetibouo et al., 2004). Therefore, Schulze (2011) suggests that because of the complexity of South Africa's physiography, climate and socio-economic milieu, detailed local scale analyses are needed to assess potential impacts of climate change.

RATIONALE

There is a gap in research with regard to integrated economic modelling at farm level. This includes the linkages between changing projected climates, changing yield and quality of produce, hydrology (availability of irrigation water), changing crop irrigation needs (with new projected climates), financial vulnerability and financial sustainability of farming systems. The Water Research Commission (WRC, 2010) therefore initiated a project on "Adaptive interventions in agriculture to reduce vulnerability of different farming systems to climate change in South Africa." The project addresses the knowledge gaps by making a contribution to integrated climate change modelling and this report documents the research work done as part of the project.

PROBLEM STATEMENT AND AIMS

The general aim of the project was to investigate the financial impact of projected climate change on agriculture, assess the vulnerability of crops, rangelands and farming households and enterprises, identify and suggest appropriate adaptive techniques and practices in selected catchments and farming areas.

The specific aims required to accomplish this were:

AIM 1: To access and utilise existing downscaled climate change scenarios at a fine-grained spatial scale to determine the potential impacts of climate change and associated changes in climate variability on the agricultural sector.

AIM 2: To identify, describe, motivate and select at least two appropriate case-study areas with reference to:

- Winter and summer rainfall areas;
- Agricultural areas with active farming enterprises;
- Semiarid and sub-humid climate;
- Rain-fed and irrigated agriculture; and
- Areas prone to extreme climatic events

AIM 3: To identify, describe, motivate and select two relevant farming systems within the selected case study areas. In selecting the relevant farming systems, the following were to be considered:

- Current subsistence, emerging or commercial farming activities;
- Existing household needs, livelihood options and management objectives;
- Production of crops of significance economically; and
- Differing agro-ecosystems incorporating homogeneous farming areas and land-types

AIM 4: To perform a sensitivity assessment and vulnerability analysis for the selected farming systems within the case study areas through the use of appropriate crop/grazing/pasture models and 'on-the-ground' interviews and data collection. The following would be taken into consideration:

- The existing sources of livelihoods;
- Current and projected future crop yields and carrying capacities;
- Projected shifts in optimum cropping areas;
- Current and future farming management practices (e.g. fertilizer/manure application, irrigation, tillage practices);
- Appropriate household and whole farming systems modelling;
- Organization of farmers in formal and informal groups; and
- Existing support services

AIM 5: To undertake a scoping exercise to identify the existing strategies, practices and techniques that are currently being used in the selected case study areas to cope with climate variability, review literature to identify adaptation and coping strategies, practices and techniques (both indigenous and science-based knowledge) which may be appropriate for selected case study areas, and if necessary, to develop innovative, appropriate and sustainable interventions. including

- Internal management measures; and
- External policy measures.

AIM 6: To explore, assess and document linkages of vulnerability, adaptation and coping strategies, practices and techniques at farm level, to the food value chain.

AIM 7: To interpret and extrapolate the case-study findings to achieve effective knowledge dissemination regarding the impact of climate change on vulnerability of, and adaptive interventions in, the agricultural sector, to relevant agricultural stakeholders within and beyond the study areas.

APPROACH AND METHODOLOGY

In order to determine possible impacts of projected future climates on the financial vulnerability of selective farming systems in South Africa, a case study methodology was applied. The integrated modelling framework consists of four modules, viz.: climate change impact modelling, dynamic linear programming (DLP) modelling, modelling interphases and financial vulnerability assessment modelling.

Prior to selecting the case study areas, a comprehensive review of existing downscaled climate change scenarios was undertaken, where an understanding of the projections for future climates was developed. Following this, potential case study areas with active farming enterprises were identified and a motivation for each developed. The identified potential case study areas covered differing present climatic regimes (i.e. summer rainfall vs. winter rainfall, semi-arid vs. sub-humid), differing climatic projections for the future, were areas that are prone to extreme events and incorporate different farming activities (i.e. dryland vs. irrigated, subsistence vs. commercial).

Statistically downscaled climate data from five global climate models (GCMs) served as base for the integrated modelling. The APSIM crop model was applied to determine the impact of projected climates on crop yield for selected crops in the study. In order to determine the impact of projected climates on crops for which there are no crop models available, a unique modelling technique, Critical Crop Climate Threshold (CCCT) modelling, was developed and applied to model the impact of projected climate change on yield and quality of agricultural produce.

The model produced a set of valuable results, viz. projected changes in crop yield and quality, projected changes in availability of irrigation water, projected changes in crop irrigation needs, optimal combination of farming activities to maximise net cash flow, and a set of financial criteria to determine economic viability and financial feasibility of the farming system. A set of financial criteria, i.e. internal rate of return (IRR), net present value (NPV), cash flow ratio, highest debt ratio, and highest debt have been employed to measure the impact of climate change on the financial vulnerability of farming systems.

Adaptation strategies to lessen the impact of climate change were identified for each case study through expert group discussions, and included in the integrated modelling as alternative options in the DLP model. This aimed at addressing the gap in climate change research, i.e. integrated economic modelling at farm level; thereby making a contribution to integrated climate change modelling.

RESULTS AND DISCUSSION

1. OLIFANTS WEST – LORWUA IRRIGATED AREA

The modelling results for the LORWUA case studies can be summarised as follows:

- Climate information from four GCMs was applied in the APSIM modelling. All the GCMs project a 20-year average decrease in yield, varying from 9% to 18%.
- Information from five GCMs was applied in the CCCT model. All five models project a decrease in yield for wine grapes, table grapes and raisins and a decrease in quality for table grapes.
- A 10% average annual increase in irrigation requirements is projected for table grapes for intermediate future climates in order to obtain the same yield as with present climates. For wine grapes and raisins, an 11% average increase in irrigation requirements is projected.
- Both climate change financial modelling techniques (APSIM crop modelling and CCCT modelling technique) indicate that intermediate climate scenarios from five different GCMs pose a threat to the financial vulnerability of farming systems in the LORWUA grape producing area.
- Several adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:
    - Shift wine grape cultivars towards cultivars that are more tolerant towards projected climate change
    - Increase raisin and table grape production
    - Install shade nets over table grapes production areas.

2. OLIFANTS EAST – BLYDE RIVER IRRIGATED AREA

The modelling results for Blyde River WUA case studies can be summarised as follows:

- Empirically downscaled climate values of five GCMs were applied in the CCCT model. Although, only one out of five GCMs projects a decrease in yield for citrus, all models project a negative impact on quality. For mangoes the models project a negative impact on both yield and quality.

- An 8% average annual increase in irrigation requirements is projected for both citrus and mangoes for intermediate future climates in order to obtain the same yield as with present climates.
- The projection of the Blydepoort Dam level was done by UKZN, using the ACRU model. All indications are that the availability of irrigation water for the Blyde River WUA area irrigators (in terms of quota consistency) will not be negatively affected by the projected climate scenarios.
- The CCCT modelling results indicate that intermediate climate scenarios from different GCMs pose a threat to the financial vulnerability of farming systems in the Blyde River mango and citrus producing area.
- The impact of intermediate climate scenarios on financial vulnerability will be more severe on farming systems that are highly geared (high debt levels).
- An adaptation strategy to counter the impact of climate change on financial vulnerability is to install shade nets over mango and citrus production areas. The installation of shade nets proves to lessen the impact of climate change on financial vulnerability to a certain extent and seems worthwhile to investigate further.

3. MOORREESBURG DRY LAND FARMING

The modelling results for the Moorreesburg case study can be summarised as follows:

- Climate data from four GCMs were applied in the APSIM modelling to project intermediate future yield for wheat. The different GCM projections (20-year average) range from a 4% decrease to a 4% increase compared to present yield. The overall average yield between the four models equals the average present yield.
- Data from five GCMs was used in CCCT modelling. Despite relatively small variances between the different GCM projections, no major changes in yield, from the present to the intermediate future, are projected. This result concurs with the APSIM crop modelling results, which increases confidence in the CCCT modelling technique.
- Both climate change financial modelling techniques (APSIM crop modelling and CCCT modelling technique) indicate that intermediate climate scenarios from different GCMs pose a very marginal threat to the financial vulnerability of farming systems in the Moorreesburg dryland wheat producing area.
- The impact of intermediate climate scenarios on financial vulnerability will be more severe on farming systems that are highly geared (high debt levels).
- Adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:
  - Cropping systems
  - Production practices.
- The above adaptation strategies seem not only to counter the impact of climate change, but to positively impact on profitability.

4. CAROLINA DRY LAND FARMING

The modelling results for the Carolina case study can be summarised as follows:

- Climate information from four GCMs was applied in the APSIM modelling to project intermediate future yield for maize. One model projects an average decrease of 25% while three models project an increase in average yield of approximately 10%.
- Information from five GCMs was used in CCCT modelling. All five models project an average increase in yield of approximately 10%. This result correlates to a large extent with the APSIM crop modelling results where three out of four models projected similar increases in average yield.
- Both climate change financial modelling techniques (APSIM crop modelling and the CCCT modelling technique) indicate that intermediate climate scenarios from five different GCMs pose no threat to the financial vulnerability of farming systems in the Carolina summer rainfall dryland area. Please note that abnormal climate events like storms, hail, etc. are not included in the climate modelling.
- Adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:
    - Cropping systems
    - Production practices.
- The above adaptation strategies seem to not only counter the impact of climate change, but to positively impact on profitability.

5. OLIFANTS EAST/INKOMATI (SMALL SCALE/SUBSISTENCE FARMING)

Small-scale farmers in Bushbuckridge have somewhat limited capacity for dealing with current climatic stress. Climate change projections indicate that these small-scale farmers in Bushbuckridge will experience changes in rainfall patterns and increasing temperatures. This further implies that the current thresholds of what the farmers are able to deal with are at the risk of being more commonly exceeded in the future, including the summer rainfall only starting in December, heavy rainfall and flooding around planting times and more frequent days with over 40°C. This reflects the need for considerable focus on adaptation action in the Bushbuckridge area, and on strengthening the farmers' general capacity for dealing with climatic stress. Such focus would be necessary in order to shift the current thresholds to a point where they are not repeatedly exceeded in the future climate.

This study clearly indicates the importance of biophysical factors and the capacity to adapt to climate change. The Moorreesburg as well as the Carolina case study results indicated that changing to conservation agriculture (more resilient cropping system) improves the adaptive capacity of the farming systems. In the Blyde River WUA case study, shade netting improves the biophysical adaptive capacity of mangoes and citrus (in terms of yield and quality). The LORWUA case study showed similar results for table grapes under shade nets.

This site was deemed unsuitable for modelling and thus was excluded from that phase of the project

CONCLUSION

This study clearly illustrates that, without the capacity to implement adaptation strategies such as conservation agriculture (Moorreesburg and Carolina), shade netting (LORWUA and Blyde River WUA) and structural changes to land use patterns (LORWUA), the farming systems of the selected case studies will be financially highly vulnerable to climate change (as indicated by reduction in IRR and NPV, higher debt ratios and decreasing cash flow ratios).

Figure i illustrates the mapping of selective case studies included in the study, viz. LORWUA, Blyde River WUA, Moorreesburg and Carolina. The map shows the location of the case studies and the financial vulnerability towards projected future climates. The colour coding legend indicates the degree of financial vulnerability to climate change, i.e. pink – marginally vulnerable, red – vulnerable, light green – marginally less vulnerable than present scenario, and green – less vulnerable than present scenario.

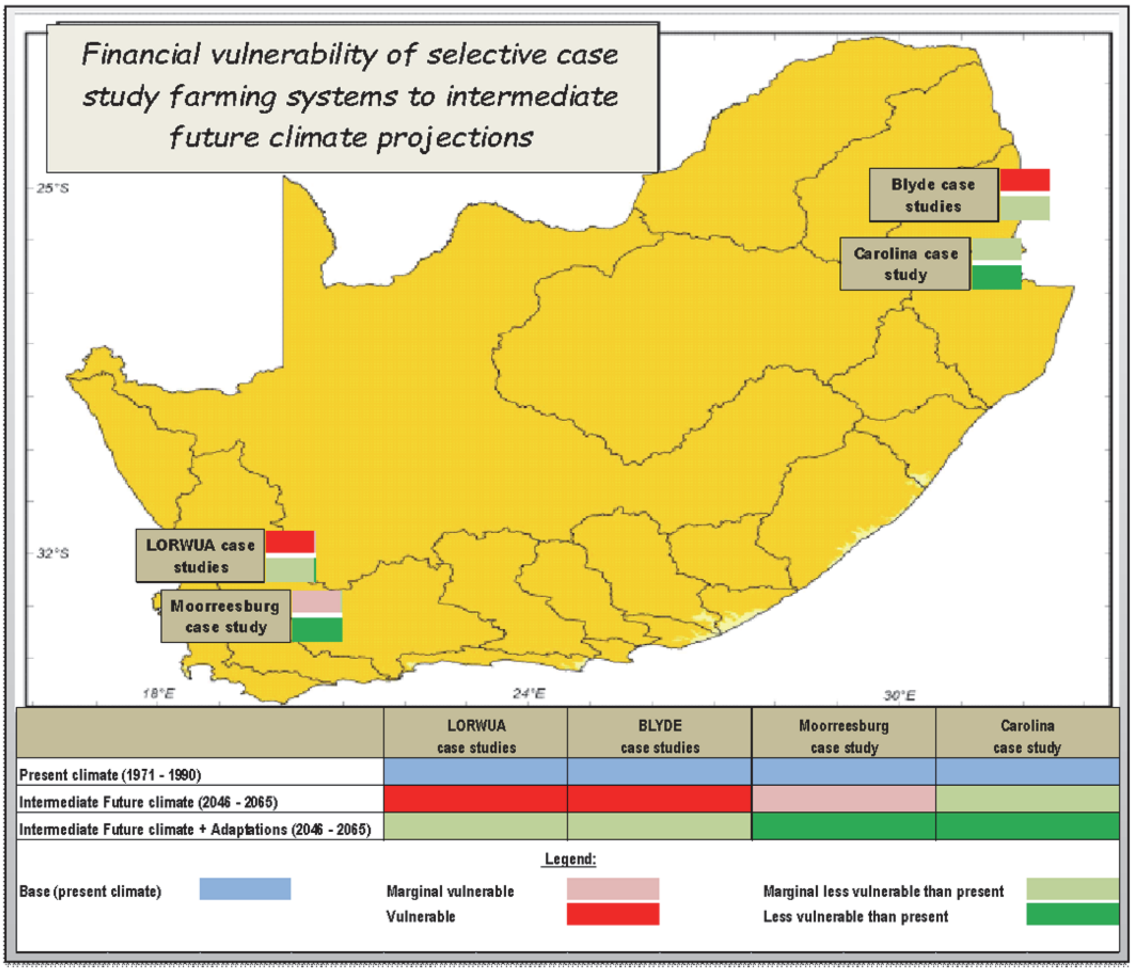

Figure i: Mapping of selective case studies and their financial vulnerability to projected future climates

The LORWUA and Blyde River WUA are more vulnerable to climate change than Moorreesburg and Carolina areas.

RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations for further research include:

- In terms of the CCCT modelling technique the critical climate thresholds for crops need to be further researched and refined. It could be worthwhile for future research to merge existing climate and existing yield data sets and deriving a variance-covariance matrix to test the assumption of independence and capture the interdependence of climate effects.
- The financial vulnerability assessment of farming systems to climate change should be executed throughout all production regions in South Africa. This will provide policy makers, industry leaders, input suppliers and researchers with valuable information for future strategizing.
- Adaptation options identified in this study need to be further researched and validated. Research should focus on a number of items, viz. cropping patterns, production practices, cultivar development, optimal irrigation equipment and practices, moisture conservation techniques and shade nets. Within the scope of this project it was not possible to do long term trials.
- The development of crop models should be a high priority on the research agenda. Models that cover more crops and more accurate models will make a significant contribution to the integrated climate change impact modelling framework that was developed through this study.
- Role players stressed the important role that Government could play in research and communication with regard to climate change research, adaptation treatments and implementation of adaptive interventions.
- Impacts further along the value chains are inevitable and need to be addressed. It is also important that climate change impacts are not just focused on the production side and are carefully considered and studied. The communication of the impacts will need to consider all the role players in the value chain and as in the case of the existing project not just focused on the case study areas.

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The authors and project team would like to acknowledge the Water Research Commission (WRC) for initiating, managing and funding this research project under the directed call for proposals and to the Department of Agriculture, Forestry and Fisheries (DAFF) for co-funding the project.

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LIST OF ABBREVIATIONS

Acronym	Description
ACM	APSIM crop model
ACRU	Agricultural Catchments Research Unit Agro-Hydrological Model
AEZs	Agro-Ecological Zones of Africa
Apr	April
APSIM	Agricultural Production Systems Simulator
APSRU	Agricultural Production Systems Research Unit
Aug	August
Blyde WUA	Blyde Water Users' Association
CAADP	Comprehensive Africa Agriculture Development Programme
CCC	General Circulation Model: CGCM3.1(T47), Canadian Center for Climate Modelling and Analysis (CCCma), Canada
CCCma	Canadian Center for Climate Modelling and Analysis, Canada
CCCT	Crop Critical Climate Threshold
CFR	Cash Flow Ratio
CH_4	Methane
CNRM	Centre National de Recherches Meteorologiques, France
CO_2	Carbon dioxide
CRM	General Circulation Model: CNRM-CM3, Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France
CSAG	Climate System Analysis Group
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization
D:A ratio	Debt:asset ratio
Dec	December
DLP	Dynamic Linear Programming
DSSAT	Decision Support System for Agrotechnology Transfer
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
ECH	General Circulation Model: ECHAM5/MPI-OM, Max Planck Institute for Meteorology, Germany
Ep	Evapotranspiration
Er	Reference potential evaporation
ET0	Reference evapotranspiration
FAO	Food and Agricultural Organization
Feb	February
FFBC	Farming for a better climate
GAMS	General Algebraic Modelling System
GCM	Global Climate Model or General Circulation Model
GDP	Gross Domestic Product
GIS	Geographic Information System
GISS	General Circulation Model: GISS-ER, NASA / Goddard Institute for Space Studies, USA

ha	Hectare
HU	Heat units
IAASTD	International Assessment of Agricultural Science and Technology for Development
ICID	International Commission on Irrigation and Drainage
IDRC	International Development Research Centre
IFPRI	International Food Policy Research Institute
IGBP	International Geosphere-Biosphere Program
IISD	International Institute for Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
IPCC SRES	Intergovernmental Panel on Climate Change – Special Report on Emissions Scenarios
IPCC TAR	Intergovernmental Panel on Climate Change, Third Assessment Report
IPS	General Circulation Model: IPSL-CM4, Institut Pierre Simon Laplace, France
IPSL	Institut Pierre Simon Laplace, France
IRR	Internal Rate of Return
ISCW	Institute for Soil, Climate and Water
Jan	January
Jul	July
Jun	June
Km	Kilometre
LDCs	Least Developed Countries
LOIS	Lower Olifants Irrigation Scheme (LOIS)
LORWUA	Lower Olifants River Water Users Association
LP	Linear programming
LSU	Large stock unit
LT	Long term
m^3	Cubic metre
MAP	Mean Annual Precipitation
Mar	March
MDGs	Millennium Development Goals
MKB	Moorreesburgse Koringboere (Edms) Beperk
mm	Millimetre
MPI-M	Max Planck Institute for Meteorology, Germany
N_2O	Nitrous oxide
NCAR	National Center for Atmospheric Research
Nov	November
NPV	Net Present Value
NRE	Natural Resources and Environment
Oct	October
ODWMA	Olifants/Doring Water Management Area
PCM	PCM General Circulation Model developed in the USA
ppm	Parts per million
QCB	Quaternary Catchments Database

QnCDB	Quinary Catchments Database
R	South African Rand (also ZAR)
RCMs	Regional Climate Models
RH	Relative Humidity
RSA	Republic of South Africa
SAD	Safari Dried Fruits
SAPWAT3	South African Plant WATer
Sept	September
SIRI	Soil and Irrigation Research Institute
SSU	Small stock unit
ST	Short term
Tmnd	Daily minimum temperature
Tmxd	Daily maximum temperature
UCT	University of Cape Town
UKCIP	United Kingdom Climate Impact Programme
UKZN	University of KwaZulu-Natal
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention for Climate Change
WMA	Water Management Area
WMO	World Meteorological Organisation
WRC	Water Research Commission
WRI	World Resources Institute
WUA	Water Users Association

CHAPTER 1 : INTRODUCTION AND OBJECTIVES

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1.1 Background

The agricultural economy of the Republic of South Africa (RSA) comprises a well-developed commercial sector as well as a subsistence and emerging orientated sector. RSA's commercial agriculture sector is an important contributor to the national economy. Although primary commercial agriculture currently contributes only ~ 2.4% of the gross domestic product (GDP) and ~ 8% to formal employment, the strong linkages of agriculture to the economy mean that the agro-industrial sector contributes 15% of GDP (Statistics SA, 2016). Of the total surface area of RSA, only 12% is suitable for crop production, and of this only 22% has a high arable potential (SA Yearbook, 2008). Currently, ~ 50% of RSA's water resources are used for agricultural production with only 1 675 822 ha registered for irrigation in 2008 (Van der Stoep and Tylcoat, 2014).

The availability of water is the most limiting factor for agricultural production. RSA experiences a high risk climatic environment, with a highly variable and spatially uneven rainfall distribution, as well as climate-related extremes. Any change in rainfall attributes could have wide-ranging implications for commercial and subsistence food and fibre production, as well as for the GDP, employment and foreign exchange earnings.

At present RSA's agricultural sector experiences multiple stressors, including (but not limited to) variable rainfall, widespread poverty, environmental degradation, uncertainties surrounding land reform, limited access to capital, including markets, infrastructure and technology, and HIV/AIDS (Adger, 2003). Climate change is superimposed upon all these stressors and is anticipated to exacerbate many of these issues, and in combination with low adaptive capacity, the South African agriculture sector through the value chain is highly vulnerable to effects of climate change and the associated increase in climate variability. This is equally applicable for rainfed agriculture and irrigated agriculture.

Farmers have developed various strategies to cope with the current climate variability experienced in South Africa. These strategies, however, may not be sufficient to cope with projected future climatic changes which could potentially increase the financial vulnerability of farming systems significantly. The identification of new adaptation strategies and in some instances the re-thinking of existing strategies to reduce financial vulnerability is of paramount importance for future sustainability of the agricultural sector in South Africa.

There are currently very few "proofs of concept", i.e. examples of agricultural decision makers that have successfully drawn on climate change projection information to take decisions that have improved agricultural productivity or human well-being. This is a function of the temporal and spatial models at which climate data are provided, as well as the way in which they are reported, perceived in terms of the reliability of the data, questions of their relevance to agriculture, and difficulty in accessing and understanding the data (Ziervogel et al., 2008).

Because of the complexity of South Africa's physiography, climate and socio-economic milieu, detailed local scale analyses are needed to assess potential impacts (Schulze, 2011). In order to address this "disconnectedness" between climate science and African agriculture, the capacity capable to link existing climate data and agricultural decision making needs to be created. This is as much an institutional challenge as it is a technical and human resource challenge. The nature of climate change adaptation demands that efforts to support African agriculture in the face of climate change incorporate a multi-disciplinary set of stakeholders including climate science experts, agricultural practitioners and technicians, local communities/civil society, donors and policy makers (Ziervogel et al., 2008).

1.2 Motivation

The Fifth Assessment Report of the IPCC states that "Increasing temperatures and changes in precipitation are very likely to reduce cereal crop productivity. This will have strong adverse effects on food security" (IPCC, 2013, p1202). As the majority of the arable land in RSA is rain-fed, with increasing variability projected under climate change conditions the livelihoods of people who depend on rain-fed agriculture will be threatened and the percentage of the population experiencing hunger and under-nourishment may increase. It is important to determine the possible impacts on the different agricultural systems under projected future climates, and evaluate the suggested adaptation strategies.

Through the development of adaptation strategies in a participatory environment, the vulnerability of the communities/societies in the selected areas, and the broader stakeholders in the agricultural sector of RSA, will be decreased through the dissemination of knowledge on projected climate change and associated anticipated increases in climate variability. Stakeholder participation in the development of the adaptation strategies will increase their understanding of and awareness to the potential impacts of climate change. Therefore, their adaptive capacity and resilience will increase as they should be able to make more informed, appropriate and pro-active decisions regarding adaptation and coping. Decision-takers will be aware of uncertainties and fields of major concern at an earlier stage, thereby offering more time to introduce adequate steps to enhance safety through detailed planning and action. The resilience against climate variability and related extreme events such as severe floods and droughts as well as the pro-active management of agricultural systems will provide greater security for SOCIETAL and ECONOMIC activities in South Africa. With resilience comes the saving of substantial financial resources, which otherwise would be lost unnecessarily due to excessive damages to the agri-environment and society, unemployment, harvest losses, regeneration of environmental services and quality, and many more. Both national and household food security will be more resilient to projected climate change, and export demand will be able to be met. The livelihoods of subsistence farmers may have more stability. By increasing the resilience of the farmer on the ground, the resilience of the larger food value chain is improved, ensuring that the important contributions of agro-industrial sector to the RSA's GDP will continue.

1.3 Aims

The **general aim** of the project was to investigate the financial impact of projected climate change on agriculture, assess the vulnerability of crops, rangelands and farming households and enterprises, identify and suggest appropriate adaptive techniques and practices in selected catchments and farming areas.

The **specific aims** required to accomplish this were:

- To access and utilise existing down-scaled climate change scenarios at a fine-grained spatial scale to determine the potential impacts of climate change and associated changes in climate variability on the agricultural sector.
- To identify, describe, motivate and select at least 2 appropriate case-study areas with reference to:
    - Winter and summer rainfall areas;
    - Agricultural areas with active farming enterprises;
    - Semiarid and sub-humid climate;
    - Rain-fed and irrigated agriculture; and
    - Areas prone to extreme climatic events
- To identify, describe, motivate and select two relevant farming systems within the selected case study areas. In selecting the relevant farming systems the following were to be considered:
    - Current subsistence, emerging or commercial farming activities;
    - Existing household needs, livelihood options and management objectives;
    - Production of crops of significance economically; and
    - Differing agro-ecosystems incorporating homogeneous farming areas and land-types
- To perform a sensitivity assessment and vulnerability analysis for the selected farming systems within the case study areas through the use of appropriate crop/grazing/pasture models and 'on-the-ground' interviews and data collection. The following were to be taken into consideration:
    - The existing sources of livelihoods;
    - Current and projected future crop yields and carrying capacities;
    - Projected shifts in optimum cropping areas;
    - Current and future farming management practices (e.g. fertilizer/manure application, irrigation, tillage practices);
    - Appropriate household and whole farming systems modelling;
    - Organization of farmers in formal and informal groups; and

    - Existing support services
- To undertake a scoping exercise to identify the existing strategies, practices and techniques that are currently being used in the selected case study areas to cope with climate variability, review literature to identify adaptation and coping strategies, practices and techniques (both indigenous and science-based knowledge) which may be appropriate for selected case study areas, and if necessary, to develop innovative, appropriate and sustainable interventions. including
    - Internal management measures; and
    - External policy measures.
- To explore, assess and document linkages of vulnerability, adaptation and coping strategies, practices and techniques at farm level, to the food value chain.
- To interpret and extrapolate the case-study findings to achieve effective knowledge dissemination regarding the impact of climate change on vulnerability of, and adaptive interventions in, the agricultural sector, to relevant agricultural stakeholders within and beyond the study areas.

1.4 Scope of research and report structure

Numerous studies indicate that the agricultural sector is physically and economically vulnerable to climate change. In order to determine possible impacts of projected future climates on the financial vulnerability of selective farming systems in South Africa, a case study methodology was applied. The integrated modelling framework consists of four modules, viz.: climate change impact modelling, dynamic linear programming (DLP) modelling, modelling interphases and financial vulnerability assessment modelling.

Prior to selecting the case study areas, a comprehensive review of existing downscaled climate change scenarios was undertaken, where an understanding of the projections for future climates was developed. Following this, potential case study areas with active farming enterprises were identified and a motivation for each developed. The identified potential case study areas covered differing present climatic regimes (i.e. summer rainfall vs winter rainfall, semi-arid vs sub-humid), differing climatic projections for the future, were areas that are prone to extreme events and incorporate different farming activities (i.e. dryland vs. irrigated, subsistence vs. commercial).

In order to determine the financial vulnerability of farming systems to climate change, research was needed to link projected climates on farm level to crop yield and quality, irrigation water availability and crop irrigation requirements.

Statistically downscaled climate data from five Global Climate Models (GCMs) served as base for the integrated modelling. The APSIM crop model was applied to determine the impact of projected climates on crop yield for selected crops in the study. In order to determine the impact of projected climates on crops for which there are no crop models available, a unique modelling technique, Critical Crop Climate Threshold (CCCT) modelling, was developed and applied to model the impact of projected climate change on yield and quality of agricultural produce. Climate change impact modelling also takes into account the projected changes in irrigation water availability (ACRU hydrological model) and crop irrigation requirements (SAPWAT3 model) as a result of projected climate change.

The models produced valuable results, viz. projected changes in crop yield and quality, projected changes in availability of irrigation water, projected changes in crop irrigation needs, optimal combination of farming activities to maximise net cash flow, and a set of financial criteria to determine economic viability and financial feasibility of the farming system. A set of financial criteria, i.e. internal rate of return (IRR), net present value (NPV), cash flow ratio, highest debt ratio, and highest debt have been employed to measure the impact of climate change on the financial vulnerability of farming systems. Adaptation strategies to lessen the impact of climate change were identified for each case study through expert group discussions, and included in the integrated modelling as alternative options in the DLP model. This aims at addressing the gap in climate change research, i.e. integrated economic modelling at farm level; thereby making a contribution to integrated climate change modelling.

Chapter One provides an introduction to the report by presenting some background to the study, the problem statement and aim and objectives of the study, and also a brief summary of the scope of the research.

Chapter Two provides a review of relevant literature to guide the authors for the purpose of analyses. The literature review contains summaries of various research reports as well as specific references to previous research that underpins and guides the development of this research project. The aim was to get a comprehensive understanding of the methodologies that already exist, a review of the current literature and a sense of the gaps that currently exist in order to be able to motivate the research objectives of this project.

The identification, description, and selection of case study areas/farming systems are covered in **Chapter Three**. This starts with a description of the different farming systems and sub-regions within South Africa and motivates for a selection of 2 systems within each selected sub-region.

Chapter Four described the selection, application and impact of the selected climate change scenarios. The motivation for the selection is presented and the difficulties and caveats association with their selection are described.

Chapter Five presents the vulnerability and sensitivity analysis for each case study area. This provides essential insight into the nature of the problems climate change may bring to each of the study sites.

The scoping of existing adaptation practices, strategies and techniques within each case study site are presented in **Chapter Six**. These provided insight and information for adding to the modelling to investigate the financial impact of such adaptations.

Linkages and associations with the food value chain of each selected commodity were investigated and presented in **Chapter Seven**. The outcomes of this spawned a further post-graduate study which will only be submitted after the completion of this project.

Chapter Eight reflects on the existing adaptation strategies and then with consultation with role players develops potential strategies which could be introduced into current farming methods and also the modelling process.

The description of the main modelling process is presented in **Chapter Nine**. Here the process of the integration of the climate, hydrological, crop and financial models is presented and the importance of the interphases discussed. The incorporation of expert analysis in the modelling is a unique input.

The financial implications for each study site are presented as part of the modelling results in **Chapter Ten**.

Chapter Eleven presents the lessons learnt and the scientific communications stemming from the project are mentioned.

Chapter Twelve concludes the report by presenting the conclusions drawn from the key findings from the case studies, and recommendations for policy and further research. The continued research gaps and shortcomings are also presented.

The Appendices in this report contains studies that can be read in conjunction with the methodologies and results presented.

CHAPTER 2 : LITERATURE REVIEW

Oosthuizen, HJ[1] & Johnston, PA[2].

1. OABS Development (Pty) Ltd/ University of Stellenbosch

2. University of Cape Town

Climate change is expected to exacerbate existing climate-related problems in Southern Africa where 38% of the population is rural (UN, 2014) and dependent on agriculture for basic livelihood. Climate change is already having an adverse impact on food security in Southern Africa, notably in the Least Developed Countries (LDCs), such as Lesotho, that have a large rural population dependent on rainfed agriculture. Projected changes in future temperature and rainfall patterns for 2030 in Southern Africa indicate a significant decline in the production of major staple crops such as maize, wheat and sorghum (Dejene et al., 2011).

A comprehensive analysis on impacts of climate change (Lobell et al., 2008) indicates that Southern Africa is likely to suffer negative impacts on several crops (e.g. maize and sorghum) that are very important to large food-insecure populations. Davis (2011) summarises the likely impact on crop and livestock production for Southern Africa in Table 1.

Table 1: Impacts of projected climate change on crop and livestock production for Southern Africa

Crop production	Direct impacts	• Even small increases in mean temperature between 1° and 2° C are projected to lead to a decrease in crop productivity
		• Changes in temperature regimes could affect growing locations, the length of the growing season, crop yields, planting and harvest dates
		• Increased need for irrigation in a region where existing water supply and quality is already negatively affected by other stressors
	Indirect impact	• Predicted higher temperatures are likely to negatively impact organic matter, thereby reducing soil nutrients
		• Higher temperatures may favour the spread of significant pests and pathogens to a range of agricultural systems
Livestock	Direct impacts	• Changes in forage quality and quantity (including the availability of fodder
		• Changes in water quality and quantity
		• Reduction in livestock productivity by increasingly exceeding the temperature thresholds above the thermal comfort zone of livestock which could lead to behavioural and metabolic changes (including altering growth rate, reproduction and ultimately mortality)
		• Increased prevalence of "new animal diseases"
		• Increases in temperature during the winter months could reduce the cold stress experienced by livestock, and warmer weather could reduce the energy requirements of feeding and the housing of animals in heated facilities
	Indirect impact	• Increased frequency in disturbances, such as wildfires
		• Changes in biodiversity and vegetation structure
Socio-economic/ livehood impacts		• Changes in income derived from crops and livestock production
		• Shifts in land use (including consequences of land reform)
		• Overall changes in food production and security

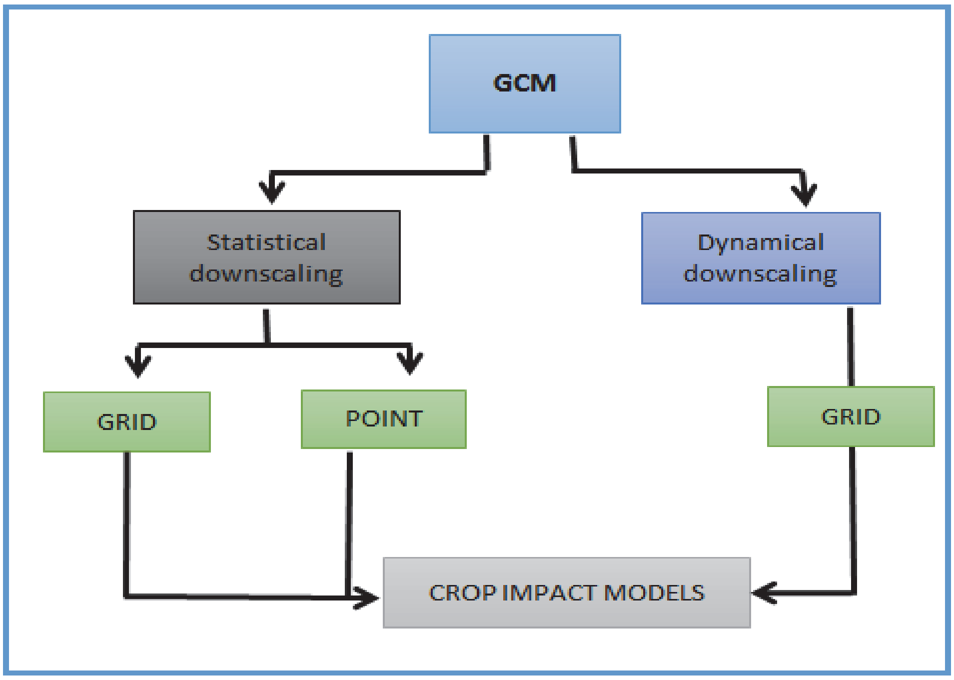
Source: Davis (2011)

Climate change is expected to not only impact on crop and livestock production, but also alter the agriculturally related socio-economic environment and general livelihood of the region.

2.1 Climate change projections – South Africa

GCMs have been developed to project future climates based on different greenhouse gas scenarios and complex earth-atmosphere interactions. As such GCMs provide the means of making climate change projections. The development of climate projections for Africa is evolving rapidly (Ziervogel et al., 2008). GCMs at the present point in time project climate parameters at a resolution of 250 km^2, while downscaled models provide projections at 50 km^2. Whilst GCMs can more accurately project changes in average global temperature, these projections are often of little use to decision makers working on regional or local scales (Ziervogel et al., 2008).

Two approaches dominate the downscaling efforts, each based on a specific set of assumptions and methodologies: statistical and dynamical downscaling (also known as Regional Climate Models or RCMs). Figure 1 shows how these different types of climate modelling approaches fit together. These downscaled climate change models take values from GCMs and interpret them in relation to local climate dynamics (Tadross et al., 2005).



Adapted from: Ziervogel et al. *(2008)*

Figure 1: Overview of different types of climate models

Statistical downscaling makes use of the quantitative relationships between the state of the larger scale climatic environment and local variations sourced from historical data. Coupling specific local baseline climate data with GCM output provides a valuable solution to overcoming the mismatch in scale between climate model projections and the unit under investigation. Statistical downscaling can be applied to a grid or to a particular meteorological station.

CSAG operates the pre-eminent statistically downscaled model for Africa and provides meteorological station level responses to global climate forcings for a growing number of stations across the African continent. The data and technical skills intensity required for statistical downscaling have resulted in no other institutions in Africa currently producing such data. Existing adaptation studies and programs outside of South Africa have had limited awareness of the availability of such data (Ziervogel et al., 2008).

Dynamical downscaling and RCMs make use of the boundary conditions (e.g. atmospheric parameters from a GCM such as surface pressure, wind, temperature and water) and principles of physics within an atmospheric circulation system to generate small scale (high resolution) datasets. Owing to its reliance on high resolution physical datasets, the approach is useful in the representation of extreme events. However, dynamical downscaling is a computationally and technically expensive method, a characteristic that has limited the number of institutions employing the approach (Ziervogel et al., 2008). Since 2009, the Council for Scientific and Industrial Research (CSIR) [Climate Studies, Modelling and Environmental Health Research Group] uses the dynamical downscaling technique to produce regional climate models (Engelbrecht, 2013).

Table 2 displays the advantages and limitations of two downscaling techniques, namely statistical and dynamical downscaling.

Table 2: Comparison of statistical and dynamical downscaling techniques

	Statistical (empirical) downscaling	RMC's (Regional Climate Models)
Definition	Large-scale climate features are statistically related to local climate for a region - historical observations are utilised	A dynamic climate model (either a limited-area model or variable resolution global model) is nested/nudged within a GCM
Advantages	• Station scale output	• 10-15 km resolution output
	• Less computational resources required	• Physical interactions and local fine-scale feedback process (not anticipated with statistical methods) can be simulated
	• Available for more GCMs, allowing an assessment of probabilities and risks	• Improved simulation of regional climate dynamics
	• Can be applied to any observed variable, e.g. streamflow	• Can include additional processes not included by the GCM simulations
		• Consistent with GCM simulations
		• Do not rely on the assumption of stationarity[1] in climate (Wilby et al. 2003)
Limitations	• May not account for some local scale interactions, e.g. between the land and the atmosphere	• Computationally demanding
	• Assume present-day statistical presentations between synoptic and local-scale climates will persist in the future (Wilby et al, 2003)	• Only a few scenarios usually developed
	• Requires high quality observations data	• Susceptible to the choice of physical parameterisations
	• Choice of predictor variables can change results	• Not easily transferred to new regions
	• Results do not feed back to the GCM	• Limited regional-to-global feedbacks may be considered, but often are not
	• Choice of statistical transfer scheme can affect results	

An important component of climate change science involves the description, understanding and representation of the inherent uncertainties in the modelling efforts. Uncertainty in climate change science is a function of the difficulties of modelling a complex and not entirely understood pair of inter-related systems (i.e. oceans and atmospheres), lack of complete knowledge on natural variability, an imperfect understanding of future greenhouse gas concentrations, and the likely impacts that surprises will bring to the climate system (Stainforth et al., 2007). Whilst it is known that specific models are more “skilled” at predicting specific parameters in certain regions, without a comprehensive exploration of multiple model outputs, choosing a single model for a specific region is not advisable (IPCC, 2007). An analysis of results from an “ensemble” of models, rather than a single model, is a sound way of addressing the uncertainty inherent in making a decision which is influenced by the future evolution of the climate system.

For the purpose of this study, values derived from statistical downscaling (done by CSAG) were used as input data to the integrated model. The focus of this study was to develop the methodology and integrated model rather than to compare results from climate model outputs.

With further projected changes in global climates into the future, changes in the South African agriculture sector will be inevitable, especially since the regional climate in South Africa is dependent on global climate, both presently and in the future (Schulze, 2012). No one knows exactly how the future global climate will develop and what the resultant consequences in South Africa will be in, for example, the agriculture sector. However, South Africa lies in one of the regions of the world that is most vulnerable to climate variability and change (IPCC, 2007).

Impacts from a changing climate can be considerable. Different regions of the country will likely be affected in many different ways. For this reason alone local scale analyses are needed to assess potential impacts (Andersson et al., 2009). Changes in optimum growing areas and yields are anticipated, and with that many knock-on effects ranging from application of new crop varieties to increased pest infestations to issues of food security and international trade (Davis, 2011; Schulze, 2011).

2.2 Dispelling misconceptions on climate change impacts over South Africa

There are many misconceptions in the popular and even the official as well as scientific literature in South Africa with regard to projected changes in magnitude and direction of key climate change variables and the associated impacts of these. They have arisen either out of ignorance, and/or by citing from dated research results, and/or having pre-conceived ideas that climate change implies only “gloom and doom” on the one hand, or is a non-issue on the other, and/or taking isolated statements/cases/criticisms out of context and disregarding the overwhelming body of evidence on climate change, and/or having been “conditioned” by what turns out to be very broad generalizations contained in IPCC reports (Schulze, 2011).

South African research

Climate change studies conducted in South Africa (including Africa wide studies) focus on:

- Physical impacts – implications of climate change on crop yield and production (Schulze et al., 1993; Du Toit et al., 2002; Midgley et al., 2007; Walker and Schulze, 2008; Haverkort et al., 2013).
- Economic impacts derived from yield losses (Erasmus et al., 2000; Blignaut et al., 2009; Gbetibouo and Hassan, 2005; Kurukulasuriya et al., 2006).
- More comprehensive economic studies including vulnerability (Daressa et al., 2007; Seo et al., 2009; Gbetibouo et al., 2010; Hassan et al., 2010) and adaptation options (Deressa et al., 2005; Gbetibouo and Hassan, 2005; Benhin, 2008).
- Advanced integrated climate change modelling linking statistically downscaled climate models, a hydrological module and dynamic linear modelling to contribute to water resources policy, planning and management (Louw et al., 2012).

Schulze et al. (1993) developed an analysis tool to simulate primary productivity and crop yields for both present and possible future climate conditions. Southern Africa was delineated into 712 relatively homogeneous climate zones, each with specific climate, soil and vegetation response information. The primary productivity and crop yield models were linked with the climate zones via a cell-based agro-hydrological model, with the final output coordinated using a Geographic Information System (GIS). The results of this preliminary study show a large dependence of production and crop yield on the intra-seasonal and inter-annual variation of rainfall. The most important conclusion from the study is the readiness of the developed tool and associated infrastructure for future analysis into social, technological and political responses to food security in Southern Africa.

Erasmus et al. (2000) link two different methodologies to determine the effects of climate change on the Western Cape farming sector. First, it uses a general circulation model (GCM) to model future climate change in the Western Cape, particularly with respect to precipitation. Second, a sector mathematical programming model of the Western Cape farming sector is used to incorporate the predicted climate change, specifically rainfall, from the GCM to determine the effects on key variables of the regional farm economy. In summary, results indicate that future climate change will lead to lower precipitation, which implies that less water will be available to agriculture in the Western Cape. This will have a negative overall effect on the Western Cape agricultural economy. Both producer welfare and consumer welfare will decrease. Total employment in the farming sector will also decrease as producers switch to a more extensive production pattern. The total decline in welfare, therefore, will fall disproportionately on the poor, including, but not limited to, farm workers.

Deressa et al. (2005) employed a Ricardian model that captures farmers' adaptation to analyse the impact of climate change on South African sugarcane production under irrigation and dryland conditions. The study utilised time series data for the period 1977 to 1998 pooled over 11 districts. Results showed that climate change has significant non-linear impacts on net revenue per hectare of sugarcane in South Africa with higher sensitivity to future increases in temperature than precipitation. Irrigation did not prove to provide an effective option for mitigating climate change damages on sugarcane production in South Africa. The study suggests that adaptation strategies should focus special attention on technologies and management regimes that will enhance sugarcane tolerance to warmer temperatures during winter and especially the harvesting phases.

Gbetibouo and Hassan (2005) employed a Ricardian model to measure the impact of climate change on South Africa's field crops and analysed potential future impacts of further changes in the climate. A regression of farm net revenue on climate, soil and other socio-economic variables was conducted to capture farmer-adapted responses to climate variations. The analysis was based on agricultural data for seven field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower and soybean), climate and edaphic data across 300 districts in South Africa. Results indicate that production of field crops was sensitive to marginal changes in temperature as compared to changes in precipitation. Temperature rise positively affects net revenue whereas the effect of reduction in rainfall is negative. The study also highlights the importance of season and location in dealing with climate change; showing that the spatial distribution of climate change impact and consequently needed adaptations will not be uniform across the different agro-ecological regions of South Africa. Results of simulations of climate change scenarios indicate many impacts that would induce (or require) very distinct shifts in farming practices and patterns in different regions. Those include major shifts in crop calendars and growing seasons, switching between crops to the possibility of complete disappearance of some field crops from some regions.

Kurukulasuriya et al. (2006) used data from a survey of more than 9000 farmers across 11 African countries and a cross-sectional approach to estimate how farm net revenues are affected by climate change compared with current mean temperature. With warming, revenues fall for dryland crops (temperature elasticity of -1.9) and livestock (-5.4), whereas revenues rise for irrigated crops (elasticity of 0.5) that are located in relatively cool parts of Africa and are buffered by irrigation from the effects of warming. At first, warming has little net aggregate effect as the gains for irrigated crops offset the losses for dryland crops and livestock. Warming, however, will most likely reduce dryland farm income immediately. The final effects will also depend on changes in precipitation, because revenues from all farm types increase with precipitation. Because irrigated farms are less sensitive to climate, irrigation is a practical adaptation to climate change in Africa, if water is available.

Benhin (2008) assesses the economic impact of the expected adverse changes in the climate on crop farming in South Africa using a revised Ricardian model and data from farm household surveys, long term climate data, major soils and runoffs. Using selected climate scenarios, the study predicts that crop net revenues are expected to fall by as much as 90% by 2100, mostly affecting small-scale farmers. Policies therefore need to be fine-tuned and more focused to take advantage of the relative benefits across seasons, farming systems and spatially, and by so doing climate change may be beneficial rather than harmful.

Walker and Schulze (2008) modelled nine plausible future climate scenarios over a 44-year period, using the CERES-maize model. The results showed that climatic changes could have major negative effects on the already drier western, and therefore more vulnerable, areas of the South African

Highveld. An increase in temperature increases the variability of yields in the relatively moist Piet Retief area (MAP 903 mm), while at the more sub-humid Bothaville, with a MAP of only 552 mm, the inter-annual variability remains the same, but mean yield over 44 seasons is reduced by 30%. Seo et al. (2009) examines the distribution of climate change impacts across the 16 Agro-Ecological Zones (AEZs) of Africa. They combine net revenue from livestock and crops and regress total net revenue on a set of climate, soil, and socio-economic variables with and without country fixed effects. Although African crop net revenue is very sensitive to climate change, combined livestock and crop net revenue proves to be more resilient to climate change. With the hot and dry CCC climate scenario, average damage estimates reach 27% by 2100, but with the mild and wet PCM climate scenario, African farmers will benefit. The analysis of AEZs implies that the effects of climate change will be quite different across Africa. For example, currently productive areas such as dry/moist savannah are more vulnerable to climate change while currently less productive agricultural zones such as humid forest or sub-humid AEZs become more productive in the future.

Blignaut et al. (2009) employed a panel data econometric model to estimate how sensitive the nation’s agriculture may be to changes in rainfall. Net agricultural income in the provinces, contributing 10% or more to the total production of both field crops and horticulture, is likely to be negatively affected by a decline in rainfall, especially rainfed agriculture. For the country as a whole, each 1% decline in rainfall is likely to lead to a 1,1% decline in the production of maize (a summer grain) and a 0,5% decline in winter wheat. These results are discussed with respect to both established and emerging farmers, and the type of agriculture that should be favoured or phased out in different parts of the country, in view of current and projected trends in climate, increasing water use, and declining water availability.

Hassan (2010) measured the economic impacts of climate change on crop and livestock farming in Africa based on a cross-sectional survey of over 8000 farming households from 11 countries in East, West, North and Southern Africa. The response of net revenue from crop and livestock agriculture across various farm types and systems in Africa to changes in climate normals (i.e. mean rainfall and temperature) is analysed. The analyses controlled for effects of key socio-economic, technology, soil and hydrological factors influencing agricultural production. Results show that net farm revenues are in general negatively affected by warmer and drier climates. The small-scale mixed crop and livestock system predominantly typical in Africa is the most tolerant whereas specialised crop production is the most vulnerable to warming and lower rainfall. These results have important policy implications, especially for the suitability of the increasing tendency toward large-scale mono-cropping strategies for agricultural development in Africa and other parts of the developing world in light of expected climate changes. Mixed crop and livestock farming and irrigation offer better adaptation options for farmers against further warming and drying predicted under various future climate scenarios.

Gbetibouo et al. (2010) examined climate adaptation strategies of farmers in the Limpopo Basin of South Africa. Survey results show that while many farmers noticed long-term changes in temperature and precipitation, most could not take remedial action. Lack of access to credit and water were cited as the main factors inhibiting adaptation. Common adaptation responses reported include diversifying crops, changing varieties and planting dates, using irrigation, and supplementing livestock feed. A multinomial logit analysis of climate adaptation responses suggests that access to water, credit, extension services and off-farm income and employment opportunities, tenure security, farmers' asset base and farming experience are key to enhancing farmers' adaptive capacity. This implies that appropriate government interventions to improve farmers' access to and the status of these factors are needed for reducing vulnerability of farmers to climate adversities in such arid areas.

Gbetibouo et al. (2010a) analysed the vulnerability of South African agriculture to climate change and variability by developing a vulnerability index and comparing vulnerability indicators across the nine provinces of the country. Nineteen environmental and socio-economic indicators were identified to reflect the three components of vulnerability: exposure, sensitivity, and adaptive capacity. The results of the study show that regions most exposed to climate change and variability do not always overlap with those experiencing high sensitivity or low adaptive capacity. Furthermore, vulnerability to climate change and variability is intrinsically linked with social and economic development.

An International Development Research Centre (IDRC) study "Managing climate risk for agriculture and water resources development in South Africa: Quantifying the costs, benefits and risks associated with planning and management alternatives" (Louw et al., 2012) was concluded in 2012. The objective of the project was to develop the capacity of South African and regional institutions in the private and public sectors, in order to better integrate information about climate change and climate variability into water resources policy, planning and management, as well as demonstrate how this information can be used to evaluate alternative strategies and projects for adjusting/adapting to climate change and climate variability for application in other regions.

The objective was accomplished through the development of three key modules to integrate information about climate change and climate variability in a systematic way to be used to influence water resources policy, planning and management. They are:

- The regional climate change module by downscaling GCMs.
- A hydrological module by using the ACRU model to estimate incremental runoff at specific locations within the study region.
- A dynamic programming module with three components, viz.
    - Regional typical farm models (21 farms) to simulate the demand for agricultural water under different climate regimes (scenarios).
    - An inter-temporal spatial equilibrium model to simulate the bulk water infrastructure (main storage dams, canals, pipelines and tunnels) and farm dams.
    - An urban demand module to simulate the demand for urban water use sectors.

In addition, the integrated framework also made provision for external inputs such as:

- Policies, plans and technology options for increasing water supplies (input by various stakeholders, amongst others the Department of Water Affairs, Western Cape Systems Analysis, Water Users Associations and the Berg River Catchment Management Agency).

- Reducing water demand through water demand management options (input by all stakeholders in the region).
- The output of the model consists of:
- Benefits and costs of structural and non-structural water management options.
- Water values and water tariffs (prices).
- Reservoir inflows, storage, transfers, releases and evaporation.
- Water use by the urban and agricultural water use sectors.

The integrated modelling framework which was developed by Louw et al. (2012) is unique in that it had not yet been done anywhere else in Africa and in very few other places in the world. The project contributed towards the improvement of the methodologies to study the impact of climate change, climate vulnerability and evaluation methodology of adaptation strategies. The project focused on a macro level and did not include detailed farm-level integrated modelling.

2.3 Other literature

The following reports also offered valuable insights into the current research:

McCartney, M. P.; Arranz, R. 2007. Evaluation of historic, current and future water demand in the Olifants River Catchment, South Africa. Colombo, Sri Lanka: International Water Management Institute. 48p. (IWMI Research Report 118)

Water resources development has played a significant role in the expansion of agriculture and industry in the Olifants River Catchment. However, currently, water resources are severely stressed and water requirements continue to grow. Water deficit is one of the major constraints hampering development in the catchment; both the mining and agricultural sectors are producing below optimal levels because of their reliance on insufficient supplies. Furthermore, the colonial and apartheid regimes have left a legacy of inequity. There is inadequate water supply to many households and now there is a considerable effort to improve the basic supply in lots of places. Against this background, the Water Evaluation and Planning (WEAP) model was applied to evaluate: i) an 'historic' (1920-1989) scenario of water resources development; ii) a 'baseline' (1995) scenario of current water demand; and iii) a set of three plausible 'future' (2025) scenarios.

South African River Health Programme, 2001. State of the Rivers Report: Crocodile, Sabie-Sand and Olifants River Systems, 2001

The cumulative effects of poor river health upstream will have a far greater impact on downstream stretches, and if downstream stretches are themselves compromised, the river may not be able to tolerate and recover from the effects. For this reason, it is important to monitor the pressures and the management responses as well as actual river conditions, in order to establish if conditions are likely to improve or worsen, and if the responses are being effective.

The importance of sustainable water use cannot be over-emphasised for long term economic, social and environmental security.

Shewmake, S, 2008. Vulnerability and the impact of climate change in South Africa's Limpopo River Basin. IFPRI.

This paper uses farmers' responses to exogenous weather shocks in South Africa's Limpopo River Basin to gauge how farmers are apt to respond to future climate change-induced shocks, in particular drought. Droughts are expected to increase in both frequency and intensity as a result of climate change. This study examines the costs of drought today and who it affects the most, in an effort to guide policy adaptations in the future. A combination of descriptive statistics and econometric analysis is used to approximate the potential impact of droughts on rural South African households. This paper also estimates household vulnerability. After controlling for household heterogeneity using propensity score matching, it is noted that there is no statistically significant impact of droughts on income, thus suggesting households have already adapted to living in a drought-prone environment. The types of households that were more vulnerable to climate shocks are analysed using two measures of vulnerability: the probability of falling below income of 7,800 South African Rand (R), and the probability of income falling below 16,000 R. Residents of the Limpopo province were the least vulnerable under both metrics. Setswana and SeSwati households were more vulnerable than other ethnic groups. Households that do not own livestock and households that rely on rainfed agriculture were also more vulnerable than other households.

Zhu, T and Ringler, C, 2010. Climate change implications for water resources in the Limpopo River Basin. IFPRI

This paper analyses the effects of climate change on hydrology and water resources in the Limpopo River Basin of Southern Africa, using a semi-distributed hydrological model and the Water Simulation Module of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). The analysis focuses on the effects of climate change on hydrology and irrigation in parts of the four riparian countries within the basin: Botswana, Mozambique, South Africa, and Zimbabwe. Results show that water resources of the Limpopo River Basin are already stressed under today's climate conditions. Projected water management and infrastructure changes are expected to improve the situation by 2030 if current climate conditions continue into the future. However, under the four climate change scenarios studied here, water supply situations are expected to worsen considerably by 2030. Assessing hydrological impacts of climate change is crucial given that expansion of irrigated areas has been postulated as a key adaptation strategy for Sub-Saharan Africa. Such expansion will need to take into account future changes in water availability in African river basins.

Community Implemented Projects in the Olifants-Doorn Water Management Area, Western Cape, South Africa 2009, Report on the Department of Water Affairs' Integrated Water Resources Management IWRM1 Programme Fund

This IWRM programme works with beneficiaries to design and implement a broad spectrum of projects that include: water awareness and conservation, food security, wetland conservation, water reuse, grey-water irrigation systems, and support to emerging farmers and water reform. The more than 40 projects in the Olifants-Doring Water Management Area display the role that water and an integrated approach to resource management has in rights-based development. The projects range from building community awareness, through fixing taps and leaks, to water harvesting and monitoring ground water and climate change. Many of the projects involve emerging farmers, and address land and water reform issues. These invariably deal with food security and sustainable farming practices. In addition, a number of projects are concerned with food security for vulnerable groups such as orphans, the elderly and HIV/AIDS affected families. Appropriate technologies are being introduced to the projects to demonstrate various aspects of IWRM at the community level.

Arranz, R., McCartney, M. 2007. Application of the water evaluation and planning (WEAP) Model to assess future water demands and resources in the Olifants Catchment, South Africa. Colombo, Sri Lanka: International Water Management Institute (IWMI). 91p. (IWMI Working Paper 116)

The model results show that for the different scenarios considered in this study the implementation of the Environmental Reserve (an instream requirement to guarantee the health of the riverine ecosystems) will increase the shortages for other sectors. The construction of the main water storage infrastructure proposed by the Department of Water Affairs and Forestry, in conjunction with the application of Water Conservation and Demand Management practices, can reduce the unmet demands and shortfalls to levels lower than, or similar to, those experienced in the 1995 baseline. However, in all cases these interventions will be insufficient to completely meet the demands of all the sectors. A tight control of the growth in future demands is essential, although this may be difficult in a rapidly developing country like South Africa

Heath R; Engelbrecht J; Coleman J. 2010. Water quality overview and literature review of the ecology of the Olifants river WRC Report TT 452-10.

This report is a summary of the status of the water quality data and is further a synthesis of the available aquatic ecology literature in the Olifants River.

Hughes DA, Smithers J, Kapangaziwiri E and Mallory SJL. Identification, Estimation, Quantification and Incorporation of Risk and Uncertainty in Water Resources Management Tools in South Africa.. Current Water Research Commission Project No: K5/1838

Uncertainty assessment has become a critical issue in hydrological and water resource estimation and is largely related to the confidence that can be expressed in the results of models and other data analysis methods. This confidence (or lack of) translates into risk when the model results are used in decision making and has largely been ignored, or not quantified, in the past. The uncertainty is associated with the fact that we do not have access to perfect data and the models themselves are simplifications of reality.

Machethe CL, NM Mollel, K Ayisi, MB Mashatola, FDK Anim and F Vanasche 2004. Smallholder Irrigation and Agricultural Development in the Olifants River Basin of Limpopo Province: Management Transfer, Productivity, Profitability and Food Security Issues. WRC report 1050/1/04.

This study was undertaken with the objective of contributing to rural poverty alleviation by improving productivity, profitability, gender equity and environmental sustainability of smallholder irrigation. The specific objectives of the study were to (a) to assess productivity and profitability of smallholder irrigation and the potential for achievement of food security; (b) identify cropping and irrigation management practices; (c) determine the effects of irrigation practices on soil salinity; and (d) examine the institutional and organizational arrangements affecting smallholder irrigation.

Manuel S Magombeyi and Akpofure E Taigbenu, 2008.Simulation of smallholder farming systems in the Olifants River Basin, South Africa. www.fao.org

Smallholder farming systems are characterised by low yields and high risks of crop failure, thereby threatening family food security. A farming systems simulation model, OLYMPE, is used to improve understanding of the existing farming practices in semi-arid Olifants River Basin, South Africa, and identify opportunities for improvements. The socioeconomic analysis component of OLYMPE is used to explore, over a 10-year period, farmer income subject to constraints of capital, land, water availability, labour, and market price dynamics. Five farming systems types were identified from surveys and these were refined and validated with farmers and extension officers. Farms with high livestock units were the most resilient to climatic variability and market shocks, followed by farms with crop diversification. Extreme events, however, such as cyclones affected all the farms to different degrees. Annual returns on labour ranged from 0 to ZAR 7646/person, with the highest under Type E followed by Type C, with ZAR 1822/person (US$1 = 8.28 ZAR – October 2008). OLYMPE model was able to simulate the farming systems productions in the catchment with good performance. The results indicate that livestock and crop diversification are most adept strategies to ensure stable income and food security for smallholder farmers. Hence, technology innovations and policies should articulate solutions to poor yields based on these two farm types in the Olifants Basin.

National Water Resource Strategy, First Edition, September 2004

Considering the possible implications of climate change, and indications that its impacts may be manifest first in the south-western parts of the country, it is important that the hydrological parameters in the Berg and Breede water management areas are monitored closely. No development or investment decisions should be made that neglect to take into account the actual or potential effects of climatic change on water resources.

From the international, African and South African research it is clear that there is a gap in the research in regard to integrated economic modelling at micro level. This includes the linkages between changing projected climates, changing yield and quality of produce, hydrology (availability of irrigation water), changing crop irrigation needs (with new projected climates), financial vulnerability and financial sustainability of farming systems.

CHAPTER 3 : IDENTIFICATION, DESCRIPTION, AND SELECTION OF CASE STUDY AREAS/FARMING SYSTEMS

Johnston, PA[1]; Oosthuizen, HJ[2]; Schulze, RE[3]; Louw DB[2]; Waagsaether, K[1].

1. University of Cape Town

2. OABS Development (Pty) Ltd/ University of Stellenbosch

3. University of KwaZulu-Natal

The final selection of the four case study areas was based upon feedback and comments suggested at the Inception Workshop which was held at the commencement of the project, at which both the Reference Group and Stakeholders were present.

For each of the identified potential case study areas the different farming systems within the area were identified. To identify these farming systems, the following were considered:

- Current subsistence, emerging or commercial farming activities
- Existing household needs, livelihood options and management objectives
- Production of crops of significance economically
- Differing agro-ecosystems

Once the different farming systems were identified, a selection of two of the farming systems per case study region was motivated.

3.1 Lower Olifants River Basin Western Cape – "Olifants West"

The Olifants/Doring Water Management Area lies on the west coast of South Africa along the Atlantic Ocean and is shared by the Western Cape and Northern Cape provinces. It is one of the most diverse water management areas in the country with respect to its natural characteristics and water resources. Prominent topographic features are the Cederberg range and the narrow Olifants River valley. Rainfall varies from over 1000 mm/a in the extreme south to less than 100 mm/a in the north, and a harsh and arid climate prevails over most of the water management area.

Virtually all the surface flow originates from the small, high-rainfall area around the Cederberg and is carried to the ocean by the Olifants River and its main tributary, the Doring River (see Fig. D17). A unique flow and water quality regime is created by the natural characteristics of the region, which provides a habitat for aquatic species of high conservation importance.

Economic activity in the Water Management Area is centred on irrigated agriculture and 95 per cent of total water use is for irrigation. Intensive production of deciduous fruits, citrus and grapes occurs in the Koue Bokkeveld and along the Olifants River. The arid areas remote from the rivers are sparsely populated, with sheep and goat farming as the main activity. There are no large towns or urban areas in the water management area.

Surface water in the Olifants River is regulated by the Clanwilliam Dam and the Bulshoek Barrage. There are no large dams on the Doring River, although a large number of farm dams have been constructed on the upper tributaries. Significant potential for further water resource development exists, mainly on the Doring River, but is tempered by serious concerns about the potential impacts of such development on the sensitive ecosystems. Groundwater is used extensively in the water management area. In particular, large quantities are abstracted for irrigation in the Sandveld area. The potential has also been identified for the possible abstraction of sizeable quantities of water from the deep Table Mountain Group aquifers.

Demographic projections show a future population decline in the water management area. Economic development is likely to be modest and will depend mainly on further irrigation development and the development of tourism.

The requirement for and availability of water are generally in balance over most of the water management area. Exceptions are in the Olifants River valley upstream of Clanwilliam Dam, where irrigation requirements have outstripped availability, and in the Sandveld area where some over-exploitation of groundwater is known to occur.

The study area proposed to focus on the region around Klawer, Vredendal and Lutzville. This is irrigated land surrounding the lower Olifants River. Lower downstream are the towns of Ebenhaeser and Papendorp. Some emerging agriculture is evident in Ebenhaeser.

Since there is little rain-fed agriculture in this region, it was decided to include the nearby northern winter wheat growing region around Moorreesburg (see Figure 3). Although, strictly speaking the wheat region is not in the Olifants Basin, it was considered to be similar in climate and it was agreed to include it as a sub-region for the purposes of this study.

Motivations for this region as a case study area include:

- It is a water stressed region – semi arid – with relatively low assurance of water supply
- The impact of the current plans to increase assurance of supply through a higher dam wall be interesting from a cost – benefit point of view for a supply management adaptation strategy
- The contribution of long-term crops to total area irrigated is relatively high (68%) – this will impact on some of the adaptation strategies
- There is a large variety of crops. The main crop is grapes (43%) followed by citrus (25%) and the remainder mainly vegetables.
- Livestock farming is also a significant industry in the region – mainly sheep, goats and cattle
- There is a large variety of irrigation technologies – canal, sprinkler, drip, micro, flood
- In the area, there are small, medium and large commercial farms, as well as emerging farmers
- It is located in a winter rainfall region

Figure 2: The Olifants West agricultural region

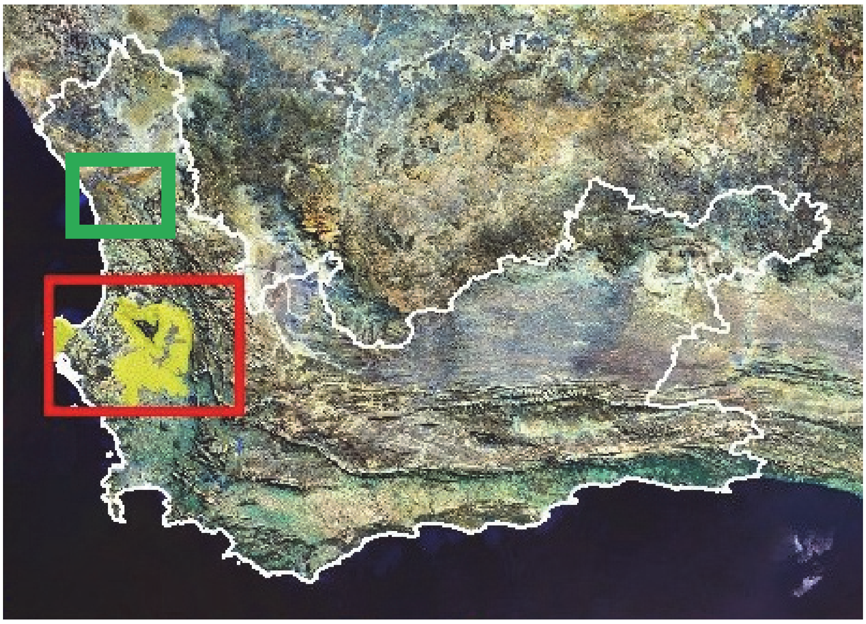


Figure 3: The Olifants West (green rectangle) and the wheat growing region centred on Moorreesburg (red rectangle).

3.2 Lower Olifants/Blyde River, Mpumalanga/Limpopo – "Olifants East"/Carolina

The Olifants Catchment covers about 54 570 km^2 and is subdivided into 9 secondary catchments. The total mean annual runoff is approximately 2400 million cubic metres per year. The Olifants River and some of its tributaries, notably the Klein Olifants River, Elands River, Wilge River and Bronkhorstspruit, rise in the Highveld grasslands.

The upper reaches of the Olifants River Catchment are characterised mainly by mining, agricultural and conservation activities. Over-grazing and highly erodible soils result in such severe erosion, in parts of the middle section, that after heavy rains the Olifants River has a red-brown colour from all the suspended sediments.

Thirty large dams in the Olifants River Catchment include the Witbank Dam, Renosterkop Dam, Rust de Winter Dam, Blyderivierspoort Dam, Loskop Dam, Middelburg Dam, Ohrigstad Dam, Arabie Dam and the Phalaborwa Barrage. In addition, many smaller dams in this catchment, have a considerable combined capacity.

The Olifants River meanders past the foot of the Strydpoort Mountains and through the Drakensberg, descending over the escarpment. The Steelpoort and Blyde tributaries, and others, join the Olifants River before it enters the Kruger National Park and neighbouring private game reserves. Crossing the Mozambique border, the Olifants River flows into the Massingire Dam.

The Steelpoort River joins the Olifants River where it meanders through the mountainous landscape of the Drakensberg. The stony riverbed varies between 50 and 80 m wide at the confluence with deep alluvial sands and silt deposits. In some areas the river forms secondary channels, floodplains and woody islands. The Ohrigstad River joins the Blyde River at the Blyderivierspoort Dam in the Blyderivierspoort Nature Reserve. Soils in this ecoregion are highly erodible. The situation is worsened by intensive cultivation and grazing, which have caused general degradation of land cover. Cultivation and grazing also causes the riverbanks to destabilise, undercutting occurs and riverbanks are swept away by floods.

Agricultural activities next to the Blyde River include commercial citrus irrigation. Runoff contaminated with agro-chemicals may result, as well as increased erosion and sedimentation due to clearing of land under the fruit trees. Many weirs impact the river flow and change the habitat. In spite of this, the water quality is very good. The Blyde River gorge has been cleared of alien species like wattles and pines, and water from the Blyde River generally improves the water quality in the Olifants River downstream of their confluence.

The proposed study area in this summer rainfall region focuses on the region around Hoedspruit, which includes large irrigation areas, and adjacent rainfed pasturelands.

Although there is an unknown amount of emerging agriculture in this particular region, there are significant amounts of emerging agriculture within the Acornhoek and Bushbuckridge areas (formally contained in a homeland).

Motivations for this region include:

- There is a large variety of crops such as subtropical long term crops as well as citrus
- There is a variety of vegetables grown for both commercial and subsistence use
- There is a variety of irrigation technologies including drip, micro, flood, central pivot, dry land (to a lesser extent ~ 7% of area).

- There is open land agriculture as well as under net irrigation (shadow net covering) – irrigation and production efficiency
- Three different water sources are used: river, piped and canal – each varies in efficiency of water conveyance
- Agriculture in the region occurs on a small, medium and large scale
- It is a summer rainfall region
- The agricultural industry in the region makes a substantial socio-economic contribution – it employs about 5000 permanent equivalent labourers
- Labour usage is relatively evenly spread through the year compared to Western Cape – socio economic impact positive
- Water is relatively expensive – 17% of total direct costs – this increases vulnerability
- The main irrigation source (the Blyde River Dam) has an extremely high current assurance of supply compared to 'West' Olifants – this makes for an interesting comparison on the impact of this factor to be expected from the study
- Short-term versus long-term crop contribution to farming structure differs substantially from the Olifants 'West' in the Western Cape – this will also reveal interesting adaptation strategies

Figure 4: Hoedspruit region – Olifants East

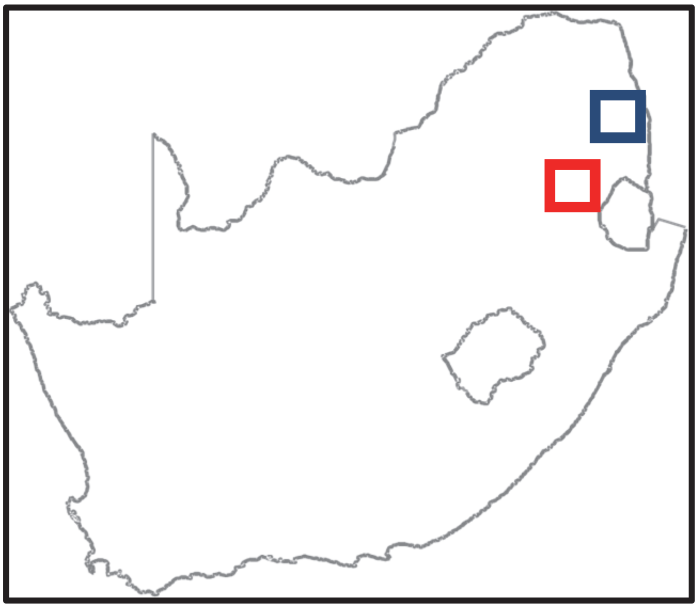


Figure 5: Olifants E case study area (blue square), Carolina (red square)

After initial scoping it was determined that the extent of commercial rainfed crops in this region was unsuitable for modelling purposes. With the approval of the reference group the selection of an alternative region in the Carolina District of Mpumalanga was motivated for and made.

Agriculture in the Carolina region is generally dominated by extensive grain production and the grazing of beef cattle and sheep. Mainline grain production includes maize, sugar beans, soybeans and sunflowers. The selection of this site was based on:

- It is a dryland rainfed production area.
- Maize, soybeans, sugar beans, mutton and beef production are the main enterprises.
- It is located in a summer rainfall region.

In the selected case study areas, a comprehensive scoping exercise was undertaken to gather available literature, to collate previous and ongoing research results in those areas, and to gain insight into the current farming management and cropping/grazing practices, existing support and extension services, current coping and adaptation practices to current climate variability, and understanding the resilience of the agricultural systems in the selected areas. Interviews were conducted with the stakeholders in the case study areas, these stakeholders include commercial and emerging/subsistence farmers, agricultural extension officers, local water authorities, community leaders and local government officials. After collation of the information gleaned from the interviews, the stakeholders were grouped strategically, and feedback sessions were held to validate the authenticity of the information gathered. Through the above gathering of information and interviews, the current databases for the selected areas were updated, extended and improved upon.

3.3 Selection of Farming Systems

In selecting the appropriate farming systems for the study, the following criteria were considered;

- Subsistence, emerging or commercial farming activities
- Existing household needs, livelihood options and management objectives
- Production of economically significant crops
- Differing agro-ecosystems

With the above in mind, it was endeavoured to locate appropriate farming systems within each of the case study areas. Since the criteria could not all be fulfilled by one type of agricultural activity, within each case study region, a selection of crops were available and these needed to be assessed within the parameters of the criteria to determine if they would be acceptable.

Olifants West

The agro-ecosystem in Olifants West is dominated by the stark difference between the irrigated land and the surrounding area. The latter is very arid reflecting the average rainfall of less than 250 mm per annum. The soil is infertile and the only economic activity, marginal as it is, is small stock farming. As an ecosystem it is distinctly hot and arid, but lying in the winter rainfall region, the rain received is less prone to evaporation than in a summer rainfall region. The water available for irrigation, on the other hand is mostly susceptible to evaporation during the dry season when it is most needed. This creates a unique conundrum in terms of future climate, as this area is projected to become even drier and hotter. The presence of a river may alleviate or mitigate any CC impacts in the future, unless the supply to the river is affected. The motive for a proposal to raise the Clanwilliam Dam wall needs to be analysed to determine whether this is an adaptation action.

Within the Olifants West study area, the predominant agricultural activities under irrigation, are grapes (for wine and table), citrus, lucerne and vegetables (including seed). The rainfed areas around Moorreesburg are predominantly wheat with some canola. These crops are all economically significant, forming a central part of the agricultural produce shown in Table 3.

The existing household needs, livelihood options and management options in the Olifants West region are difficult to evaluate without intensive field work, but preliminary research has revealed, obviously, that they differ according to the nature of the farming enterprise. The commercial farmers are focused on export and as such are more vulnerable to the foreign exchange rate, while emerging and subsistence farmers are more vulnerable to local conditions such as market access and local prices. The scale of their investments, returns and net profits (if any) are also proportional to their land holdings and capital.

Considering the above characteristics of the region, the selection of farming systems in this case study region resulted in the following description:

In the Olifants West, the region will be roughly viewed from 2 types of farming systems:

- The commercial irrigated agriculture within the Vredendal and Lutzville agricultural area (grapes, citrus and vegetables)
- The commercial rainfed region around Moorreesburg (wheat and canola).

Figure 6: Irrigated vines, showing the canal near Vredendal

The nature of the farming activities is predominantly commercial in terms of net value and area under crops in the Olifants West region. The area under irrigation available to emerging and subsistence farmers is limited. The significance of the changing ownership and the impacts of climate change influencing this, adds to the importance of this region as a case study.

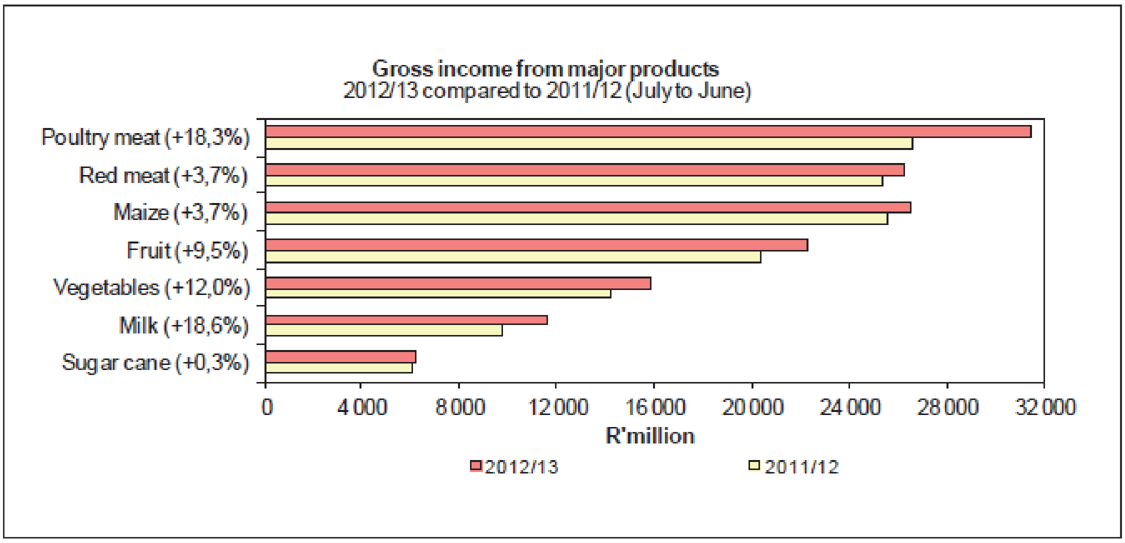
Two case studies that are representative of the study area were selected. The case studies were selected in association with Vinpro who runs several study groups in the area. Case Study 1 represents a typical small farm of 22 ha of wine grapes, raisins and table grapes. Case Study 2 represents an 86 ha farm which produces wine grapes, raisins and vegetables

In the wheat growing region of Moorreesburg, the extent of non-commercial farming is negligible, but attempts are still being made to determine the situation regarding land claims (if any) by, and transfers to Previously Disadvantaged Individual (PDI) farmers.

A case study farm was selected in Moorreesburg, to model the impact of climate change on a typical winter rainfall dryland mixed farming system. The selection of the case study was done in conjunction with the Moorreesburgse Koringboere (Edms) Beperk (MKB), who also assisted with the provision of data, information and study group results. The participating case study farm has a high level of record keeping and provided, with assistance of the MKB, most of the information needed to do the modelling.

Figure 7: Vines growing in the river floodplain, near Vredendal

Table 3: Value of production (2012/13) for leading South African agricultural commodities (millions ZAR)



Source: DAFF 2014

<u>**Olifants East**</u>

Within the Olifants East study area, the predominant agricultural activities are, under irrigation, citrus, mangoes and vegetables. The rainfed areas around Hoedspruit are predominantly used by very small scale farmers growing vegetables and maize for their own use. Further south in the Dingleydale and New Forest areas, emerging farmers are using some irrigation to grow vegetables, maize and mangoes on a larger scale. These crops are all economically significant, forming a central part of the agricultural produce table shown in Table 3. The commercial rain-fed crops in the area were determined insignificant for the purposes of this research and an area was selected approximately 180 km South West in the Carolina District.

Figure 8: Irrigated maize in the Hoedspruit area

The nature of the farming activities is predominantly commercial in terms of net value and area under crops in the Olifants East region. The area under irrigation available to emerging and subsistence farmers is limited (30% in Hoedspruit) and undetermined amount in Dingleydale and New Forest, as much of the area is also under land claims. In some cases, where land transfers have already happened, black owners are renting the land to independent contractors (not always local) who are part owned by the owners and who hire locals to work there (Personal communication, Blyde River WUA). The significance of the changing ownership and the impacts of climate change influencing this, adds to the importance of this region as a case study.

Figure 9: The Blyde River Dam, upstream from the Hoedspruit irrigation scheme

The agro-ecosystem in Olifants East is also conspicuous by the difference between the irrigated land and the surrounding area. The latter is relatively infertile considering the average rainfall of less than 450 mm per annum. As an ecosystem it is distinctly hot and sub-humid, but lying in the summer rainfall region, the rain received is more prone to evaporation than in a winter rainfall region. The water available for irrigation, on the other hand is still susceptible to evaporation during the dry season when it is most needed. This area is projected to become drier and hotter. The presence of an irrigation system river may alleviate or mitigate any CC impacts in the future, unless the supply to the river is affected. There are also plans for a hydro-electrical scheme, which may have an impact on the economic environment of the region.

The existing household needs, livelihood options and management options in the Olifants East region are equally difficult to evaluate without intensive field work, but preliminary research has revealed, obviously, that they differ according to the nature of the farming enterprise. The commercial farmers are focused on export and as such are more vulnerable to the foreign exchange rate, while emerging and subsistence farmers are more vulnerable to local conditions such as market access and local prices. The scale of their investments, returns and net profits (if any) are also proportional to their land holdings and capital.

Considering the above characteristics of the region, the selection of farming systems in this case study region resulted in the following description:

In the Olifants East, the region will be viewed from **three types of farming systems**:

1. The commercial irrigated agriculture within the Hoedspruit agricultural area (grapes, citrus and vegetables)

2. The emerging and subsistence irrigated agriculture around Dingleydale and New Forest and the rainfed options in the surrounding areas (vegetables)
3. The commercial rainfed agriculture in the Carolina District of Mpumalanga

Two case studies that were representative of the commercial irrigated agriculture in the study area were selected. The selected case studies were selected from the survey which was undertaken during 2011. Case Study 1 represents a typical farm of sixty-five hectares of mangoes and citrus. Case Study 2 represents a bigger farm (130 ha) farm which produces citrus and mangoes.

For the emerging and subsistence agricultural area, Bushbuckridge Local Municipality was chosen because, firstly, it is one of the areas in South Africa where climate change projections indicate quite significant increases in temperatures as well as some indications of drying in the middle of the rainy season (Tadross et al., 2011). Secondly, because it has a large number of small□scale and subsistence farmers, practicing both rain-fed and irrigated agriculture, as well as commercial farmers. The area also has a complex background and many socio-economic challenges. It was important to locate villages that featured irrigation agriculture, as well as villages that featured rain-fed agriculture, as the research aimed to investigate both farming systems. Two villages featuring irrigation schemes, New Forest and Dingleydale, were therefore identified and chosen based on the researcher's ability to establish reliable contacts within the schemes. Accordingly, two villages featuring rain-fed agriculture, Motlamogatsane and Phelandaba, were identified and chosen based on the researcher's ability to establish reliable contacts in the villages.

A dryland rainfed case study farm was selected in Carolina, Mpumalanga to model the impact of climate change on a typical summer rainfall dryland farming system. The participating case study farm has a high level of record keeping and provided most of the information needed to do the modelling.

Figure 10: Maize field near Carolina

CHAPTER 4 : CLIMATE CHANGE SCENARIOS

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4.1 Global Climate Models (GCMs)

The resolving scale of GCMs has improved significantly in the past 10 years with many state of the art GCMs able to resolve at a scale of around 100 km (Louw et al., 2012). Downscaling is a concept based on the assumption that local scale climate is largely a function of the large scale climate, modified by some local forcing such as topography. Downscaled climate data (rainfall and temperature) were obtained from the Climate System Analysis Group (CSAG) at the University of Cape Town.

Table 4 provides a condensed description of the information on GCMs, the global climate change scenarios of which were statistically downscaled by CSAG to point scale for application in this study. The climate change scenarios developed by CSAG for application in this project were derived from global scenarios produced by five GCMs, all of which were applied in the IPCC's (2007) Fourth Assessment Report [AR4] (Schulze et al., 2011).

Table 4: Global Circulation Model (GCM) description

Institute	GCM
Canadian Center for Climate Modelling and Analysis (CCCma), Canada ***Abbreviation: CCC***	**Name: CGCM3.1(T47)** **First published: 2005** Website: http://www.cccma.bc.ec.gc.ca/models/cgcm3.shtml
Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France ***Abbreviation: CRM***	**Name: CNRM-CM3** **First published: 2004** Website: http://www.cnrm.meteo.fr/scenario2004/indexenglish.html
Max Planck Institute for Meteorology (MPI-M), Germany ***Abbreviation: ECH***	**Name: ECHAM5/MPI-OM** **First published: 2005** Website: http://www.mpimet.mpg.de/en/wissenschaft/modelle.html
NASA / Goddard Institute for Space Studies (GISS), USA ***Abbreviation: GISS***	**Name: GISS-ER** **First published: 2004** Website: http://www.giss.nasa.gov/tools/modelE
Institut Pierre Simon Laplace (IPSL), France ***Abbreviation: IPS***	**Name: IPSL-CM4** **First published: 2005** Website: http://mc2.ipsl.jussieu.fr/simules.html

The statistically downscaled climate data from the various GCMs include daily minimum and maximum temperatures and rainfall. The climate change scenarios were developed for the "present" (1971-1990) and "intermediate future" (2046-2065).

These statistically downscaled GCMs values were used in various modelling phases including determining:

- Climate change impacts on yield and quality of crops

- Climate change impacts on crop irrigation requirements
- Climate change impacts on irrigation water availability.

4.2 A note of caution on the GCMs used in this study

Overall changes in future scenarios of climate depend strongly on (Schulze et al., 2011):

- which GCMs were used, and
- how many GCMs were in the ensemble used.

The five GCMs which were available for use in this study, viz. CGCM3.1(T47), CNRM-CM3, ECHAM5/MPI-OM, GISS-ER and IPSL-CM4 are considered by climatologists to produce rainfall output possibly on the wetter side of the spectrum (Hewitson, 2010. Personal communication with Prof Schulze), and this has to be borne in mind in interpreting any impacts in which rainfall is an input variable. Furthermore, an error in GISS GCM's rainfall values for parts of South Africa was reported during the course of the project and all statistics from multiple GCMs involving rainfall had to be re-calculated in order to eliminate the known error from that GCM (Schulze et al., 2011).

However, the reader should note that the main contribution of this study is to develop the methodology to analyse the financial vulnerability of farmers on a micro level. The accuracy of the selected GCMs and the error which was discovered in one of the GCMs is therefore irrelevant for the purpose of this study – the methodology developed in this study can use the data/information generated by any existing/future GCM. However, at the time of this analysis, the GCMs used remain the only credible tools we had for climate change impact studies (Schulze, 2014).

4.3 Climate projections

The climate projections for the study regions for the period 2040-2060 are presented in Figures 11-13. They are median results from multiple models of the IPCC 4AR, nine downscaled in the case of rainfall and thirteen in the case of temperature.

The projections are presented for the four seasons and in the case of rainfall the 10th and 90th (extreme) percentiles are also given to indicate the range within the model projection outputs.

In the case of temperature, it can be seen that, during all seasons, increases in average temperature of around $2^{o}C$ is projected. It is also inferred that the frequency of very hot days will increase significantly.

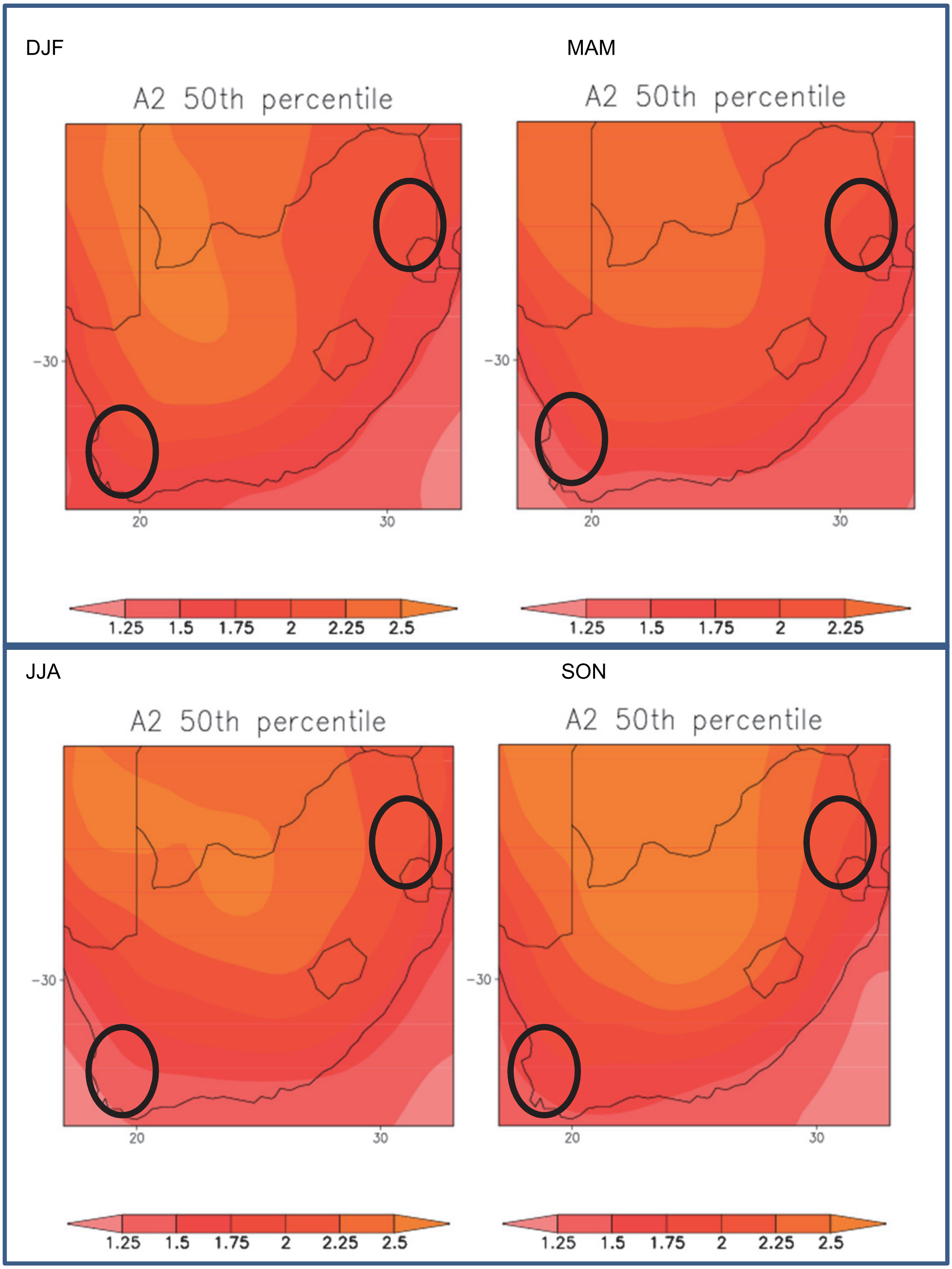
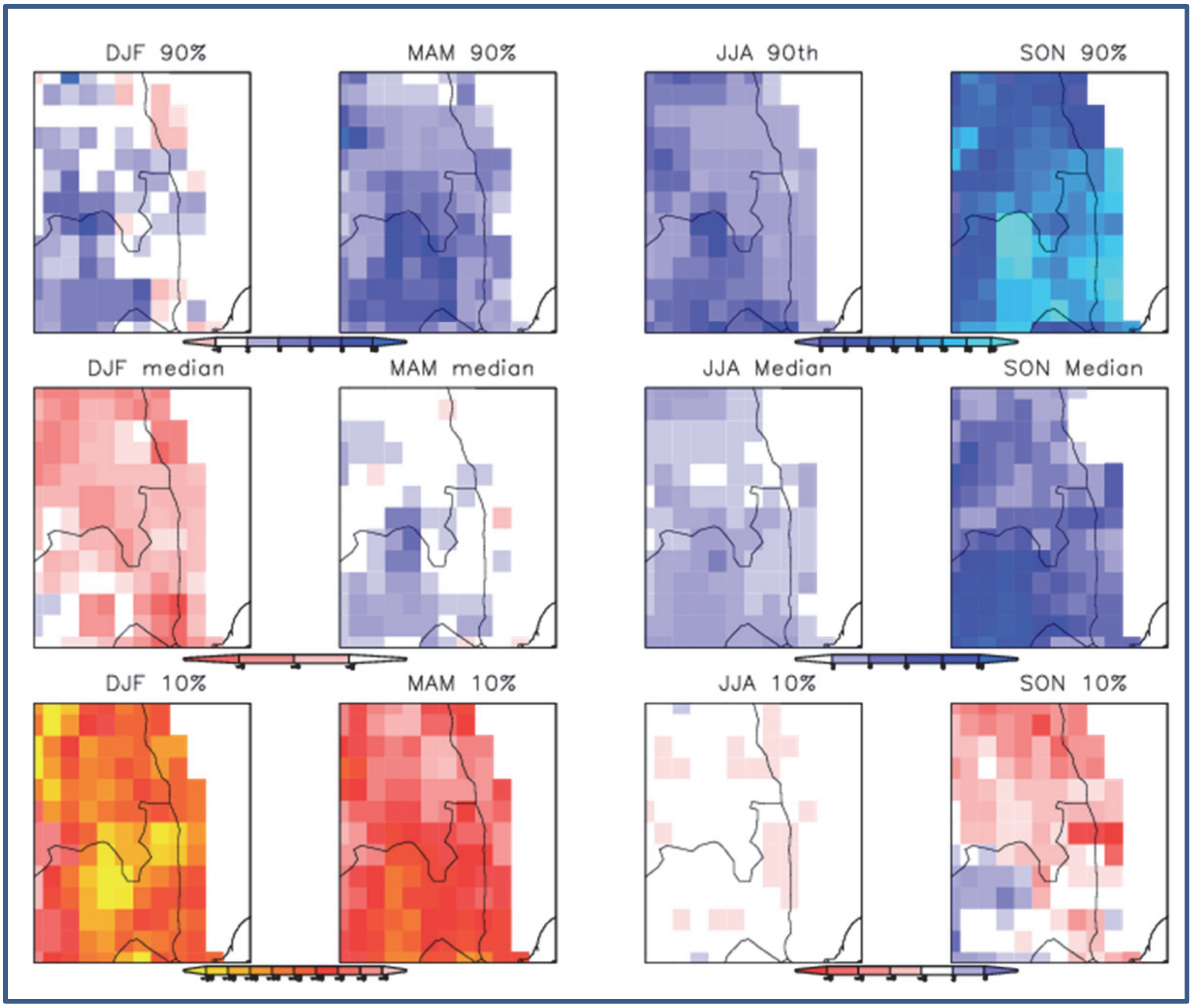


Figure 11: Median of 2040-2060 average seasonal temperature anomalies for the SRES A2 scenario



Yellow indicates 50 mm or more per month less, red 10-20 mm per month less, light blue 10 mm per month more, dark blue 10-20 mm more, and turquoise 35 mm or more per month more.

Figure 12: Rainfall projections for the eastern study area showing the median and 10th and 90th percentiles

The rainfall projections show a range of possibilities for each season indicate uncertainty but the median values indicate a drying in DJF and a wetting in SON, with little change in the other 2 seasons. The high variability of the region and its current exposure to droughts and floods is thus likely to continue.

The sensitivity of the summer rainfall crops to these changes will be further explored with the help of crop modelling.

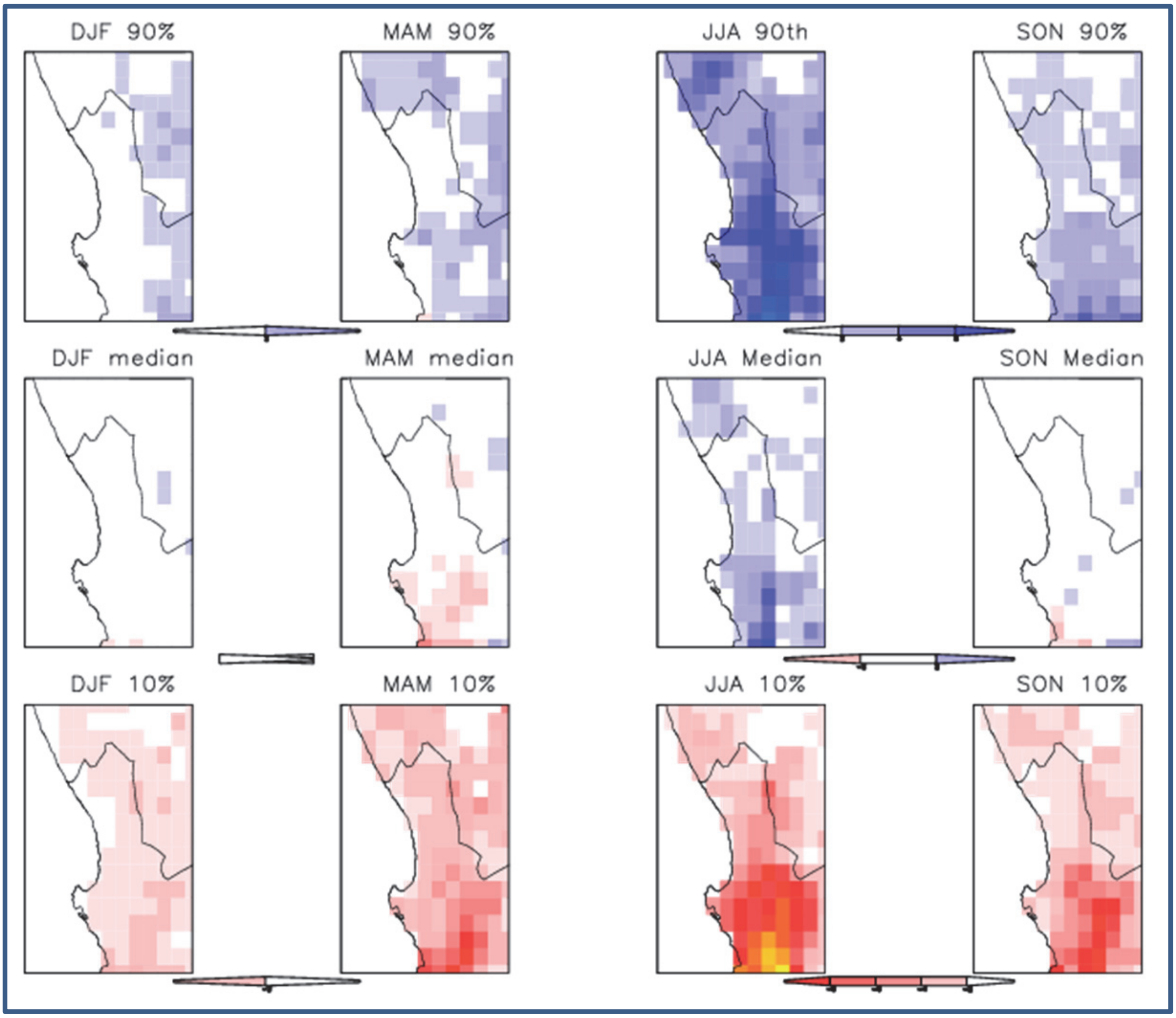


Figure 13: Rainfall projections for the western study area showing the median and 10th and 90th percentiles. Yellow indicates 50 mm or more per month less, red 10-20 mm per month less, light blue 10 mm per month more, and dark blue 10-20 mm more.

The rainfall projections show a range of possibilities for each season indicate uncertainty but the median values indicate a drying in MAM, that is early winter, and a slight wetting in JJA (midwinter), with little change in the other 2 seasons. The high rainfall variability of the region and its current exposure to droughts is unlikely to change.

The early season drying will be a factor in determining the sensitivity of winter crops and the availability of irrigation during the dry season of early and middle summer in this region.

CHAPTER 5 : VULNERABILITY AND SENSITIVITY ANALYSIS

Oosthuizen, HJ[1]; Johnston, PA[2] ; Crespo, O[2]; Waagsaether, K[2].

1. OABS Development (Pty) Ltd/ University of Stellenbosch

2. University of Cape Town

5.1 Olifants West

5.1.1 The existing sources of livelihoods

Within the Olifants West study area, the predominant agricultural activities are, under irrigation, grapes (for wine and table), citrus, lucerne and vegetables (including seed). The rainfed areas around Moorreesburg are predominantly wheat and medics with some canola. These crops are all economically significant, forming a central part of the agricultural produce table.

The nature of the farming activities is predominantly commercial in terms of net value and area under crops in the Olifants West region. The area under irrigation available to emerging and subsistence farmers is limited. The significance of the changing ownership and the impacts of climate change influencing this, adds to the importance of this region as a case study.

In the wheat growing region of Moorreesburg, the extent of non-commercial farming is negligible, but attempts are still being made to determine the situation regarding land claims (if any) by, and transfers to, PDI farmers.

The agro-ecosystem in Olifants West is dominated by the stark difference between the irrigated land and the very arid the surrounding area. The soil is infertile and the only economic activity is small stock farming.

The presence of a river may alleviate or mitigate any CC impacts in the future, unless the supply to the river is affected. The motive for a proposal to raise the Clanwilliam Dam wall needs to be analysed to determine whether this is an adaptation action.

Main long term crops produced in the area include wine grapes (7 175 ha), table grapes (900 ha) and raisins (694 ha). Tomatoes for processing (215 ha), fresh tomatoes (166 ha) and other vegetables (615 ha) constitutes the majority of cash crops produced in the area. The extent of vegetable seed production (high value crop) is 95 ha (for the current year it is 135 ha according to the contract agent Syngenta). Other crops produced on a smaller scale include, amongst others, lucerne, potatoes, vegetables (mainly butternuts, gem squash and sweet potatoes) and tunnel/hydroponic production for mainly English cucumbers and peppers. The hydroponic production is destined for mainly niche markets, e.g. Woolworths, Pick & Pay, Freshmark, Spar, etc. Production of tomatoes under shade nets for summer production and in the open for winter production is a practice that a very small number of farmers follow.

Table 5 illustrates the crop composition for the area (LORWUA survey, 2007).

Table 5: Types of crops planted in the Lower Olifants River Scheme (ha)

Cash crops	Hectare (ha)	%
Tomatoes processing	215	2%
Tomatoes table	166	2%
Tomatoes tunnels	14	0%
Seed production	95	1%
Pastures		0%
Vegetables (open)	615	6%
Vegetables (protected)	60	1%
Total	**1 165**	**11%**
Perennial crops		
Table grapes	900	9%
Wine grapes	7 175	70%
Raisins	694	7%
Lucerne	130	1%
Other	164	2%
Total	**9 063**	89%
Total crops planted	**10 228**	**100%**

Source: Survey by LORWUA (2007)

Table 6 below reflects the increase of wine grape production from the period 1937 to 2011 according to VINPRO, 2012. (Please note that the area represents a bigger area than the Scheme and serves as an indicator to the reader to illustrate the increase of wine grape production in the broader region).

Table 6: Wine grape production 1937-2011

Year	Hectare (ha)
1937	209
1965	1 538
1990	7 000
2011	9 996

(Source: VINPRO, 2012)

Wine grapes are by far the most dominant crop in the Scheme area and occupy more than 70% of hectares planted.

5.1.2 Current and projected future crop yields and carrying capacities

5.1.2.1 Current yields

The current observed average crop yield for wine grapes is shown in Table 7 below. It is clear that production peak in year 5 and then shows a steady decline from year 17 to 20. Theoretically the grapes must be replaced every 20 years. However, in practice the replacement rate has slowed down due to a depressed marketing environment for wine during the last couple of years.

Table 7: Observed average crop yield – wine grapes

Age of vineyards	Yield/ha	Age of vineyards	Yield/ha
Year 1	0	Year 11	30
Year 2	0	Year 12	30
Year 3	9	Year 13	30
Year 4	21	Year 14	30
Year 5	30	Year 15	30
Year 6	30	Year 16	30
Year 7	30	Year 17	24
Year 8	30	Year 18	21
Year 9	30	Year 19	21
Year 10	30	Year 20	18

Table 8 below shows the observed yield for table grapes in the region. It is clear that the table grapes come into production year 3 and peaks in year 5 where after the production steadily decrease from year 17. In the case of table grapes, the marketing lifespan of the cultivar is more important compared to the biological lifespan. Experience has shown that the marketing lifespan of most table grape cultivars is about 17 years.

Table 8: Observed average crop yield – table grapes

Age of vineyards	Yield/ha	Age of vineyards	Yield/ha
Year 1	0	Year 11	20
Year 2	0	Year 12	20
Year 3	6	Year 13	20
Year 4	14	Year 14	20
Year 5	20	Year 15	20
Year 6	20	Year 16	20
Year 7	20	Year 17	16
Year 8	20	Year 18	14
Year 9	20	Year 19	14
Year 10	20	Year 20	12

The raisins follow more or less the same yield production cycle as wine grapes. However, the estimated tonnage harvested for raisins is approximately 15 tons wet harvested per ha which converts to about 3.5 tons dry.

Table 9: Observed average crop yield – raisins

Yield	
15 tonne wet delivers 3.5 tonne dry (conversion ratio = 0.23333 of wet yield)	
t/ha (choice grade) [dry]	80%
t/ha (industrial grade) [dry]	7%

The observed yield for tomatoes is 80 tons, for butternuts 20 tons and for gem squash 30 tons.

5.1.2.2 Simulating future grape yields in Vredendal with APSIM

The crop model used in this study is the Agricultural Production systems SIMulator (APSIM), developed in Australia at a venture of different research institutions. APSIM has been intensively experimented in Australia, including in the South Western Australia which conditions are often highlighted as of significant similarities with Southern Africa, as well as across the world, including Africa (see for instance on-going modelling efforts in southern Africa, Masikati et al., 2015, Beletse et al., 2015). Though it does require detailed input parameters that range from the soil data layers' description to the cultivar used, the model allows for the exploration of biophysical outputs in connection to the variation of inputs such as climate. It makes it a very useful tool to simulate and explore future yield projections under future climate scenarios.

A numerical analysis of simulated biophysical indices in response to various future climate scenarios, is presented here to gauge the yield response to varying temperature and rainfall.

The authors acknowledge modelling limitations and consequent expectations. Crop systems are highly variable systems that may differ simultaneously in space and in time. In order to focus on climate change impacts and more especially on the sensitivity of these systems to temperature and rainfall, the model is set up at the station level, which allows for high resolution modelling (in terms of soils, management, daily weather, etc.). Although the outcome allows for some spatial extrapolation, such exercise would have to be dealt with local knowledge and care.

5.1.2.3 Simulation of grape

Grape modelling and perennial crops in general are still difficult to model. In the case of the grape, the limited validation of the existing model and prior interactions with the modellers, guided the research in using the berry size, berry number and berry weight as proxy for the yield. In order to present a descriptive interpretation of various future climate projections, the following results for the A2 and B1 CO_2 emission scenarios (SRES), and for 15 GCMs (9 with A2 and 6 with B1) are presented.

Figures 14 to 17 show the simulated output (berry number or berry size) on the y-axis, against the its ranked occurrence (percentile) on the x-axis. Hence the reader can appreciate the response to multiple GCMs and multiple years, the worst possible output under percentile 0, the best possible output under x-axis percentile 1, and the evolution from the former to the latter, particularly taking not of the median case for percentile 0.5. The statistical plots provide a general sense as well as a sense of variability of the biophysical response of grape to future climate.

For Vredendal, Figure 14 shows the range of berry size, Figure 15 the range of berry number and Figure 16 the range of berry weight simulated in response to observed climate (1979-1999), control climate (1961-2000) and future climate (A and B1 scenarios separately).

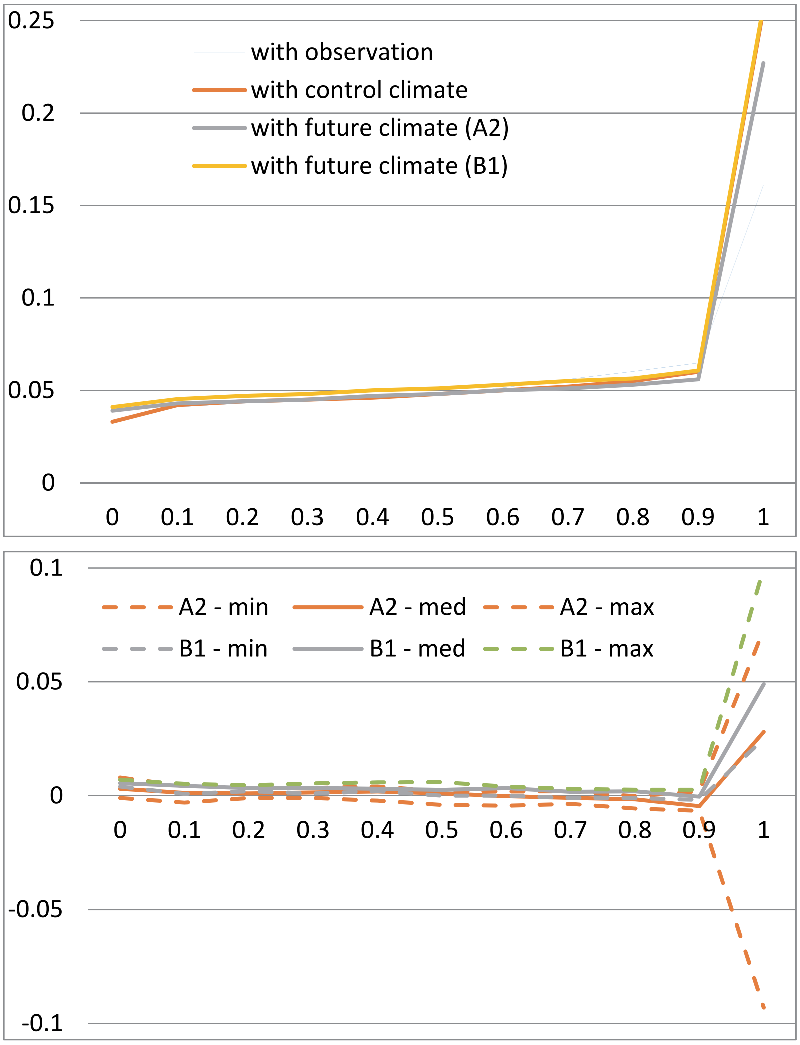
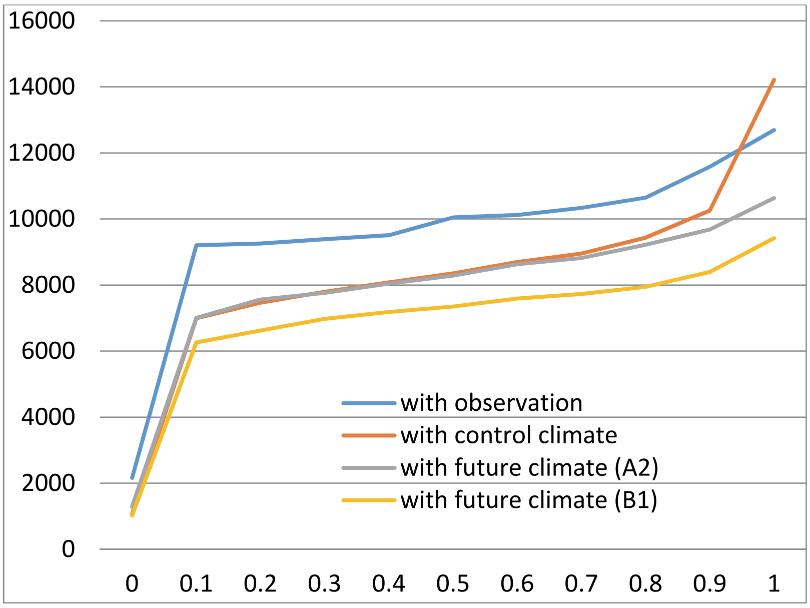


Figure 14: **(Top) Berry size simulated for observed (1979-1999), control (1961-2000) and future (2046-2065). (Bottom) Summary minimum, median and maximum changes (future minus control)**



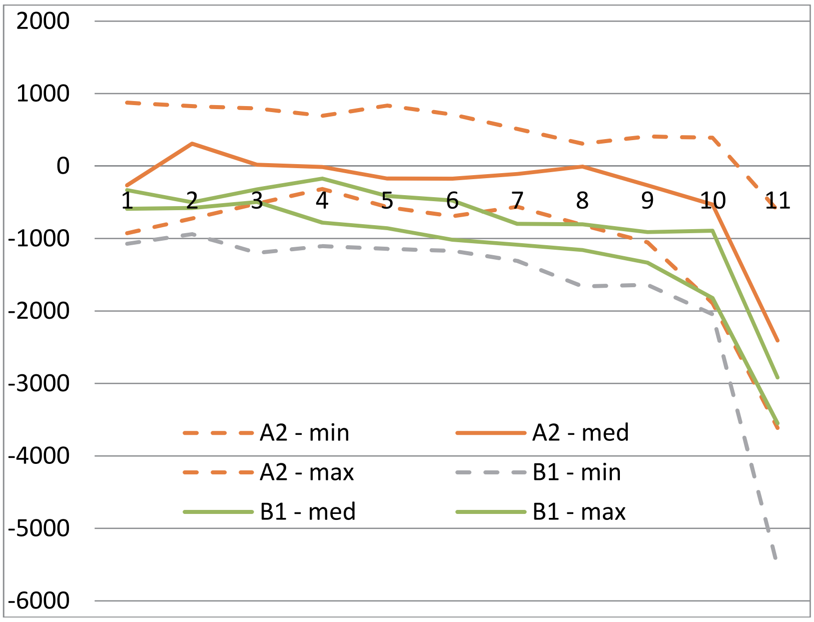
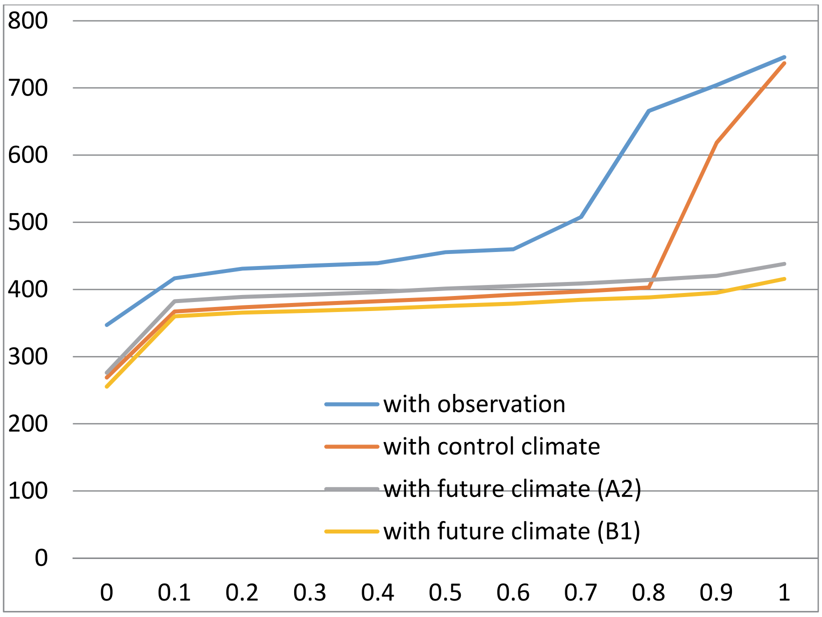


Figure 15: (Top) Berry number simulated for observed (1979-1999), control (1961-2000) and future (2046-2065). (Bottom) Summary minimum, median and maximum changes (future minus control).



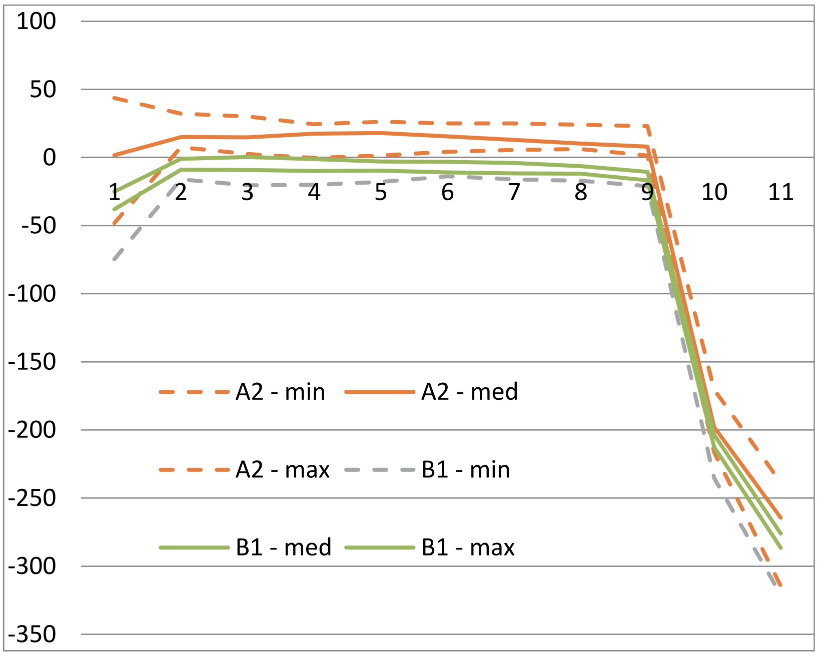


Figure 16: (Top) Berry weight simulated for observed (1979-1999), control (1961-2000) and future (2046-2065). (Bottom) Summary minimum, median and maximum changes (future minus control)

On the basis of the 3 biophysical variables simulated above, the grape future yields were approximated by applying the following empirical linear relationship : BerrySize*BerryWeight*BerryNr/10000. Figure 17 present the changes (future minus control) observed under SRES A2 and SRES B1 emission scenarios, detailing all available GCMs projections.

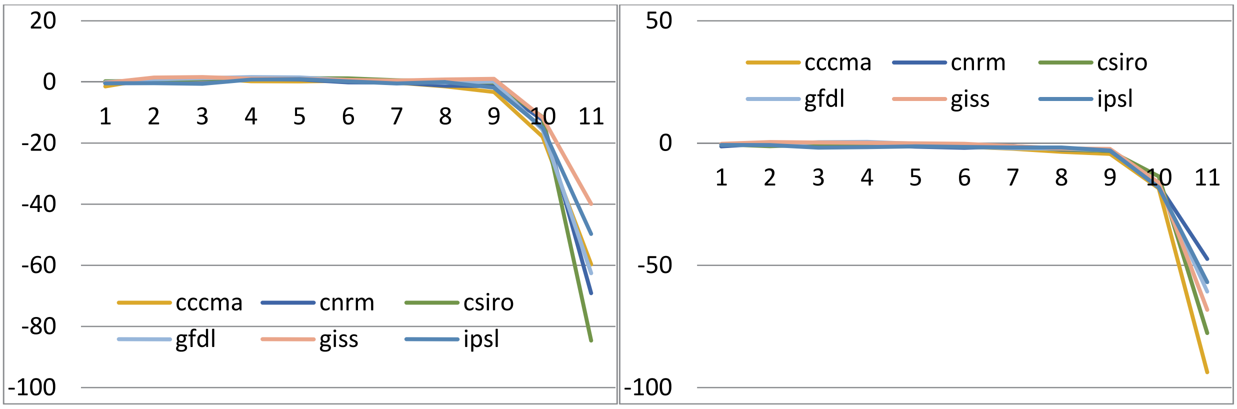


Figure 17: Grape yield approximation change, from control (1961-2000) to future (2046-2065) for 9 GCMs under SRES A2 (Left) and 6 GCMs under SRES B1 (Right).

The first observation allows for confidence in the results presented. Indeed, the proximity of response patterns in between observation outputs (simulated with recorded historical climate) and control outputs (simulated with modelled historical climate) is appropriate for berry size and berry number and acceptable for berry weight. Though the response pattern is consistent under observed and control, we note that the control set is overall underestimating the outputs (especially for berry number and berry weight). In addition, the extreme behaviour observed for high outcomes (>90th percentile) is questionable. At this stage there is not enough evidence to suggest that this singularity is associated with acceptable representation of the modelled grape, or result of the prototypal status of the APSIM wine grape module. Further study and additional data would allow for a better understanding of this occurrence, but is not available at the time.

Individual changes show no significant change in berry size independently of SRES or GCMs; a decline of berry number aggravating with larger numbers, and an indecisive change for berry weight. The extrapolated yield outcome (Figure 17) shows 9% increase for low yields (20th percentile), a 2,7% increase for median yields (50th percentile) and a 1,9% decrease for higher yields (80th percentiles). Overall the simulated outcomes suggest a consistence of this descending change from an increase for low outcomes, down to a slight decrease for high outcomes.

5.1.2.4 ACRU model

While the ACRU modelling undertaken here is not for any crop it is used to project run-off, which will determine irrigation availability.

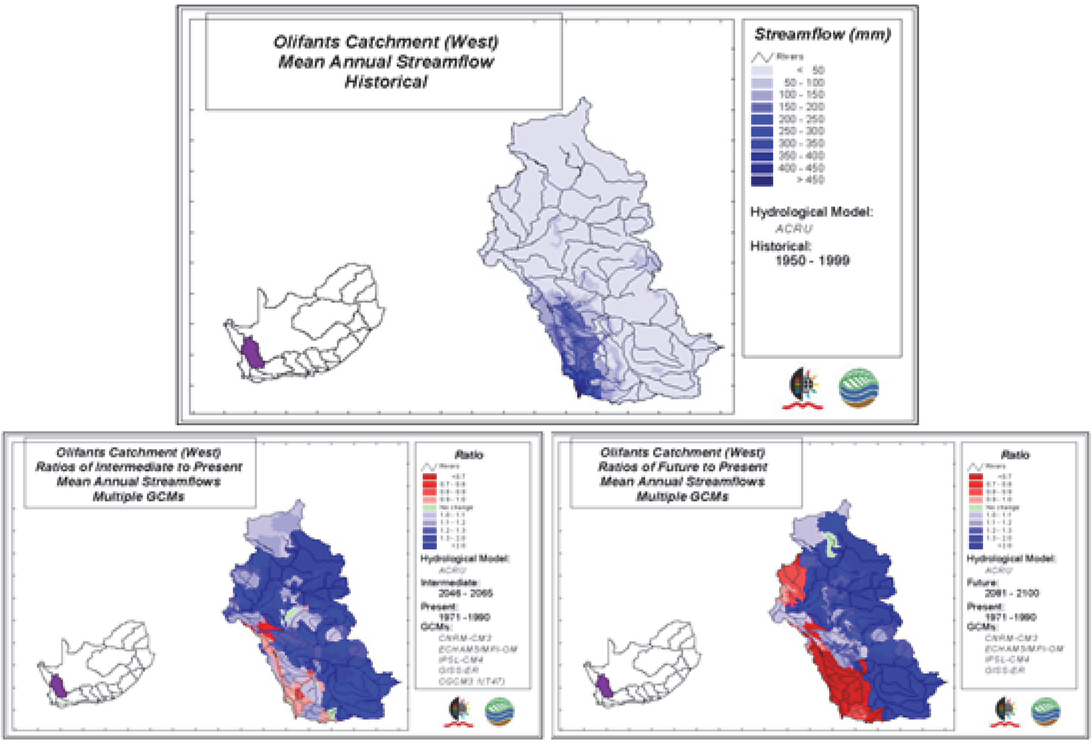


Figure 18: Means of annual accumulated streamflows under historical climatic conditions (top) and projected changes into the intermediate future (bottom left) and the more distant future (bottom right) in the Olifants (West) catchment

With the overall low rainfall experienced in the Olifants (West) it stands to reason that most of the catchment yields less than an equivalent of 50 mm of accumulated streamflow per annum under historical climatic conditions. The exception is the wetter southwestern Cederberg area, where up to 200 mm equivalent streamflow is generated in an average year (Figure 18, top). In the Blyde, by contrast, the entire eastern half of the catchment generates the equivalent of 150+ mm of streamflow (see Appendix), with parts of the escarpment yielding up to 350 mm / annum. The western areas produce somewhat less streamflow at between 50 and 150 mm equivalent in an average year.

Under climate change conditions in the Olifants (West) catchment the means of annual streamflows derived with the ACRU model from climate projections of multiple GCMs display a distinct zone of projected decreases into the intermediate future (IF) of up to 20% in the high runoff areas of the southwest, with the area of decreasing streamflows expanding northwards and eastwards as well as intensifying into the more distant future (MDF) (Figure 18, bottom). The remainder of the Olifants (West) shows increases of streamflows into the future, but it should be remembered that these projected increases are off a low base. The Blyde, on the other hand, displays spatially consistent increases in mean annual streamflows into the IF of 10-30%, while into the MDF the projections show a clear north-south split in changes, with the western parts of the catchment displaying increases of 20-30% and the eastern and northern parts 10-20%.

In water management terms for the agriculture sector in the Olifants catchment the significance of the above findings lies in the high runoff yielding southwestern parts, which makes up the “water tower” of the catchment's irrigation water supply further downstream, which experiences the most pronounced projected decreases in streamflows in future.

5.1.3 Projected shifts in optimum cropping areas

Possible projected shifts in cropping areas/patterns were discussed at a validation workshop on the 17th September 2012 with an expert group. The following were highlighted:

- The farming structure in the Olifants River region will not change easily since it is tied to the infrastructure for grape farming which was developed over many years. It is expected that most of the change will be directed at improved irrigation and other production practices.
- Shade nets can eliminate many climate change problems. The capital cost of this is, however, very high.
- Soil preparation and site selection will become more and more important for future plantings.
- Regarding increases in table grapes and raisins, new cultivars perform very well.
- Micro irrigation should be used instead of drip – to cool down vineyards

The reader must note that the objective here was not to develop optimum cropping patterns as an adaptation to climate change. That analysis will be done in the next part of the study since a change in cropping patterns in itself is an adaptation strategy.

The key objective in this part of the study was to establish the vulnerability of case studies with existing cropping patterns. The current farm structure was basically fixed with calibration constraints and the model was not allowed to make crop changes since the objective was to establish if the vulnerability will increase over time with no adaptation. As this case study site is dependent upon irrigating the available suitable arable land (limited mostly to alluvial soil), the situation required that the hypothetical future climate scenarios drive the hydrological run-off model to determine the impacts of water availability in the future,

A set of scenarios were analysed where the calibration constraints fixing the farm structure to the observed were released to a 50% up and down variation. The same set of scenarios were analysed to see what the projected change in cropping pattern would be with no technological adaptations. The result indicates a significant shift towards supplemental irrigation as the water supply variability increases for both the large and the small farm. In addition, with no adaptation the total irrigated area on the large farm decrease with about 5% as the supply variability increases and with about 8-10% as when both the water supply and the yield variability increase. There is no significant change in the cropping structure on the large farm. However, it seems as if there is a larger proportional decrease in the area cultivated with short-term crops which can be explained by the fact that the demand elasticity for water on short term crops is more elastic compared to long-term crops.

The trend on the small farms is approximately the same. However, the relative decrease in short-term crops seems to be higher compared to the large farms. The explanation for this trend is that the small farm grows table grapes which must be irrigated optimally. If water shortages occur, it is therefore obvious that the only alternative for the farmer is to reduce the short-term crop area and to use the water on the table grapes.

5.1.4 Current and future farming management practices (e.g. fertiliser/manure application, irrigation, tillage practices)

Overall, irrigation needs for crops are less in the Lutzville area than in the Klawer and Vredendal area (LOP, 1991).

5.1.4.1 Soil characteristics

Table 10 illustrates the soil characteristics in the Lower Olifants Irrigation Scheme (LOIS) area.

Table 10: Soil characteristics – Lower Olifants Irrigation Scheme

Location (Quinary nr.)	Thickness of Topsoil (m)	Thickness of Subsoil (m)	Wilting Point of Topsoil (m/m)	Wilting Point of Subsoil (m/m)	Field Capacity of Topsoil (m/m)	Field Capacity of Subsoil (m/m)	Porosity of Topsoil (m/m)	Porosity of Subsoil (m/m)	Saturated Drainage (fraction/ day)
2511	0.26	0.31	0.101	0.108	0.19	0.204	0.45	0.445	0.51

Source: School of Agricultural, Earth and Environmental Sciences, UKZN (2012)

The soils characteristics in Table 10 are area weighted from the land type information of the Institute for Soil, Climate and Water (ISCW) Land Type Survey Staff: 1972-2002 soils database for the Quinary Catchment in which the location of interest is sited. The 4-digit number (location) is the Quinary number in the SA Quinary Catchments Database (Schulze et al., 2010). The methods by which these characteristics for a 2-horizon soil have been derived are described in Schulze and Horan (2008) using the AUTOSOILS decision support system developed by Schulze and Pike (1995 and updates). Values of wilting points, field capacities and porosities (i.e. at saturation) imply the soil water content (in metre of water per metre thickness of soil) at those thresholds. Saturated drainage implies the fraction of soil water above field capacity that drains into the next horizon (i.e. from the topsoil to the subsoil or from the subsoil out of the active rooting zone) per day. The soils at LORWUA tend to be well drained and relatively sandy.

5.1.4.2 Crop irrigation requirements

Table 11 gives monthly and annual crop irrigation requirements for wine grapes, raisins and table grapes.

Table 11: Crop water requirements (m3/ha)

Month	Wine grapes (m^3/ha)	Raisins (m^3/ha)	Table grapes (m^3/ha)
Jan	1 400	1 400	1 700
Feb	1 100	1 100	1 300
Mar	1 000	1 000	1 300
Apr	600	600	700
May	400	400	400
Jun	200	200	200
Jul	200	200	200
Aug	300	300	300
Sep	400	400	400
Oct	600	600	1 200
Nov	800	800	1 000
Dec	1 000	1 000	1 200
Total	8 000	8 000	9 900

Source: Joubert (2012)

5.1.4.3 Current cultivation practices

Table 12 summarises current cultivation practices of dominant crops for the LOIS study area.

Table 12: Current cultivation practices

Cultivation practice	Wine grapes	Raisins	Table grapes
Optimum planting dates	Jul - Aug (If not enough water: Sept - Oct)	Jul - Aug (If not enough water: Sept - Oct)	Jul - Aug (If not enough water: Sept - Oct)
Lifespan of vineyard	20 years	20 years	20 years
Harvesting dates	Jan - Mar	Jan - Mar	Dec - Feb
Nitrogen application	Sept - Jan - 80 kg/ha Mar - Apr - 30 kg/ha	Sept - Jan - 80 kg/ha Mar - Apr - 30 kg/ha	Sept - Jan - 90 kg/ha Mar - Apr - 40 kg/ha

Source: LOIS workshop and expert group discussions (2012)

5.1.4.4 Crop rotation

Crop rotation, also called crop sequencing, is an agricultural system in which dissimilar crops are grown in the same region in consecutive seasons for various beneficial reasons such as the avoidance of producing pests and pathogens. Crop rotation is also intended to balance the fertility requirements of various crops to ensure that nutrients in the soil aren't exhausted. Fertility and soil structure can be improved by the crop rotational methods of alternating shallow and deep rooted plants. Crop rotation can be applied to a massive range of crop types and occurs all over the world in various forms.

Typical crop rotation systems include the following:

- Replace 5% of vineyards each year. Use land for vegetable production for one year and thereafter commence with planting of new vineyards.
- Tomato production two consecutive years, thereafter production of cucurbits, e.g. butternuts, gem squash and sweet potatoes.
- For tomato production only, fields are used for two consecutive years and thereafter rested for 2-3 years.

5.1.4.5 Possible alternative crops

A number of possible alternative crops came to the fore during the survey, which were debated by the Expert Group. Possible alternatives include citrus, mangoes, olives, apricots, peaches and date fruit production.

After much debate, the Expert Group deemed date fruit production as the only viable alternative crop on a large scale for the region.

5.1.5 Appropriate household and whole farming systems modelling

5.1.5.1 Case study farms

Two case studies that are representative of the study area were selected. The case studies were selected in association with Vinpro who runs several study groups in the area. Case Study 1 represents a typical small farm of 22 ha of wine grapes, raisins and table grapes under irrigation. Case Study 2 represents 86 ha under irrigation which produces wine grapes, raisins and vegetables (see Table 13).

Table 13: Description of case study farms: LOIS

Description	Case study 1	Case study 2
Farm size	92 ha	26 ha
Irrigable	86 ha	22 ha
Actual irrigated	86 ha	22 ha
Wasteland	6 ha	4 ha
Total farm size	**92 ha**	**26 ha**
Land use		
Perennial crops		
Wine grapes	71 ha	16.6 ha
Raisins	6 ha	1.8 ha
Table grapes		3.3 ha
Total area perennial crops	**77 ha**	**22 ha**
Cash crops		
Vegetables	9 ha	
Total area cash crops	**9 ha**	**0 ha**
Total area perennial and cash crops	**86 ha**	**22 ha**
Irrigation system (total area)		
Drip	86 ha	22 ha
Total	**86 ha**	**22 ha**
Water sources		
Canal	86 ha	22 ha
Entitlement per ha per annum	12,200 m^3	12,200 m^3
Valuation of farm	**(R)**	**(R)**
Fixed improvements	3 775 200	1 652 000
Vehicles, machinery, implements, livestock & other	3 813 000	962 000
Land	10 967 455	2 594 805
Total assets	**18 555 655**	**5 208 805**
Liabilities	**(R)**	**(R)**
Short term	0	0
Medium term	800 000	87 000
Long term	3 000 000	800 000
Total liabilities	**3 800 000**	**887 000**
Net asset value	**14 755 655**	**4 321 805**
Debt ratio	**20%**	**17%**

Source: Case study farmers' records (2012)

5.1.5.2 Crop enterprise budgets

Tables 14 and 15 summarise the crops enterprise budgets that were used in the modelling.

Table 14: Crop enterprise budget summary: Perennial crops

Red wine grapes Year	0	1	2	3	4	5 - 20
Yield (tonne/ha)		0	0	6	13	19
Gross income (R)		0	0	17 600	41 600	59 200
Yearly cash expenditure (R)	120 000	12 000	11 820	18 910	21 274	23 687
Margin above specified costs (R)	-120 000	-12 000	-11 820	-1 310	20 326	35 513
White wine grapes Year	**0**	**1**	**2**	**3**	**4**	**5 - 20**
Yield (tonne/ha)		0	0	11	26	30
Gross income (R)		0	0	21 450	50 700	58 500
Yearly cash expenditure (R)	108 000	12 000	10 745	17 191	19 340	21 534
Margin above specified costs (R)	-108 000	-12 000	-10 745	4 259	31 360	36 966
Table grapes Year	**0**	**1**	**2**	**3**	**4**	**5 - 20**
Yield (tonne/ha)		0	0	12	28	40
Gross income (R)		0	0	20 700	48 300	69 000
Yearly cash expenditure (R)	136 800	12 000	19 230	25 640	28 845	32 050
Margin above specified costs (R)	-136 800	-12 000	-19 230	-4 940	19 455	36 950
Raisins Year	**0**	**1**	**2**	**3**	**4**	**5 - 20**
Yield (tonne/ha)		0	0	11	25	36
Gross income (R)		0	0	26 169	59 475	85 644
Yearly cash expenditure (R)	136 800	12 000	20 287	27 050	30 431	33 812
Margin above specified costs (R)	-136 800	-12 000	-20 287	- 881	29 044	51 832

Source: Own calculations based on information from Vinpro, SAD and individual farmers (2012)

Table 15: Crop enterprise budget summary: Cash crops

Item	Tomato	Butternut	Gem squash
Yield (tonne/ha)	60	20	30
Gross income (R)	180 000	25 400	39 900
Yearly cash expenditure (R)	139 938	21 271	37 383
Margin above specified costs (R)	40 062	4 129	2 517

Source: Own calculations based on information from individual farmers (2012)

5.1.6 Organisation of farmers in formal and informal groups and existing support services

5.1.6.1 Organisation of farmers in formal and informal groups

In 1999 the Vredendal Irrigation Board was converted to the Lower Olifants River Water Users' Association (LORWUA) through Ministerial approval (Department of Water Affairs and Forestry, 2004:18). The main function of the LORWUA is to effectively supply water to its members and manage the water resources, ensuring maximum utilization of available water (Department of Water Affairs and Forestry, 2004a:37).

Three agricultural associations are active in the LORWUA area (here referred to as LOIS) namely: Vredendal Agricultural Association, Lutzville Agricultural Association and Trawal Agricultural Association. These agricultural associations are linked to Agri Wes Cape.

The data gathered through the fieldwork were validated by the Reference group during a workshop which was held at Vredendal on 11 April 2012. The workshop was attended by various role-players and representatives including, amongst others, Western Cape Department of Agriculture, Department of Water Affairs, LORWUA (Lower Olifants River Water Users Association), VINPRO, Kaap Agri, University of Stellenbosch, University of KwaZulu-Natal, University of Cape Town, Bokomo Foods, SAD, Kynoch, Vititec and various farmers (including leader farmers and representatives of Agricultural Associations). Several farmers were also visited beforehand for discussions on a one-on-one basis.

The basic data for this study that were validated by the Reference Group at the Workshop (11 April 2012) are: the selected farm case studies, representative crops for the region, crop budgets, crop rotation, planting & harvesting times, crop water needs, nitrogen application and thresholds for crop production (with reference to climate change).

5.1.6.2 Existing support services

Government and/or private extension and training

The Department of Agriculture has a team of multidisciplinary agriculturalists providing a comprehensive farm advisory service for farmers. This team is based in Vredendal and its main aim is to promote efficient resource utilization in the fields of viticulture, fruit and other horticultural crops, small grain production, small stock, dairy and the grazing of veld cultivated pastures for the various livestock (Agricultural Digest, 2006). Specialist extension services are provided in the field of plant pathology, entomology, milk production, deciduous fruit production, ostrich farming and irrigation.

Agribusiness or cooperative service units or depots, etc. (commercial services)

The following organisations are key players in the agricultural value chain in the area:

Kaap-Agri, Andrag Agrico, SAD, Dalmark, Tiger brands, VINPRO, Kynoch, Omnia, Nexus, Terason, Wenchem, Spilhaus and Syngenta. Several other smaller organisations are also active in the area.

The major wine cellars are: Namaqua Wines (Vredendal), Lutzville Cape Diamond Wines, Klawer Cellars and Stellar Organic Winery. A number of smaller boutique cellars are also operational in the area.

Suppliers of repair and maintenance services

There are several companies offering repair and maintenance services in Vredendal. For example, Andrag Agrico supplies agricultural machinery and irrigation equipment and Spilhaus provides the following services:

- Survey, design, quotation, sales, installation and maintenance of irrigation systems
- Survey, design, quotation, sales and installation of dam material compressions
- Sales of agricultural and turf irrigation parts
- Equipped workshop.

A number of suppliers to cater for the basic needs of farmers are active in the area.

Access to schools, clinics, hospitals, etc. (social services)

All the schools, clinics and hospitals in Matzikama Municipality's Management area have enough and safe water supply and sanitation services (Matzikama Municipality, 2011:7).

In Lutzville, Ebenhaeser and Koekenaap people have access to one Municipal Satellite Clinic. People in Klawer have access to one Satellite Clinic and one Mobile Clinic (Urban-Econ: Development Economists, 2006:11). In the Vredendal, area there is one Mobile Clinic and one District Hospital or Provincially Aided Hospital. Various clinics provide HIV/AIDS awareness programmes in the Matzikama Municipal area (Urban-Econ: Development Economists, 2006:11).

In the Matzikama Municipal area there is one crèche, one pre-primary school, 22 primary schools, three high/secondary schools and one college (Urban-Econ: Development Economists, 2006:5-2). In Vredendal, there is one crèche, eight primary schools and one high school. There are two primary schools in total in Ebenhaezer and Koekenaap. Klawer and Luztville each have four primary schools and the latter has one high school (Urban-Econ: Development Economists, 2006:5-17). People also have access to adult learning centres in Lutzville, Ebenhaezer, Koekenaap and Vredendal.

5.2 Moorreesburg

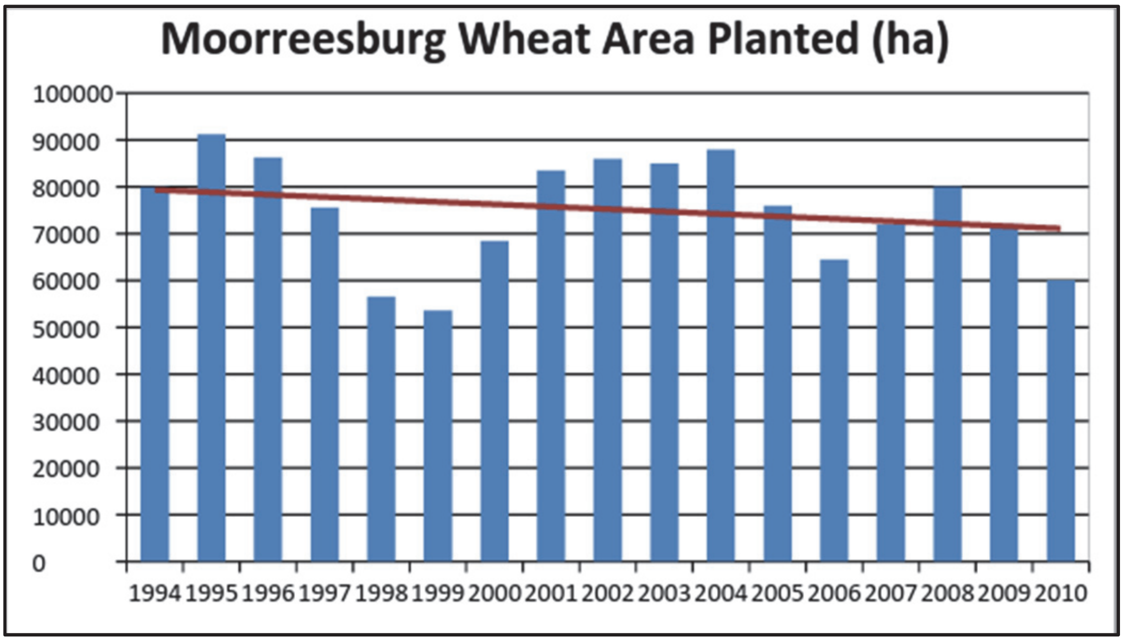
A case study farm was selected in Moorreesburg, Western Cape to model the impact of climate change on a typical winter rainfall dryland farming system. The selection of the case-study was done in conjunction with MKB, who also assisted with the provision of data, information and study group results. Owing to the TOR of the project and budget constraints, no survey was done in the surrounding area of the farm. The participating case study farm has a high level of record keeping and provided (with assistance of MKB) most of the information needed to do the modelling.

5.2.1 The existing sources of livelihoods

Wheat is by far the dominant crop produced in the area and accounted for 96% of crop production in 1996 (MKB, 2012). Crops of lesser importance include medics, canola, oats and triticale. Livestock production consists mainly of sheep (mutton and wool production). The case study farm shows typical Swartland mixed farming activities consisting of wheat and livestock (mutton and wool production).

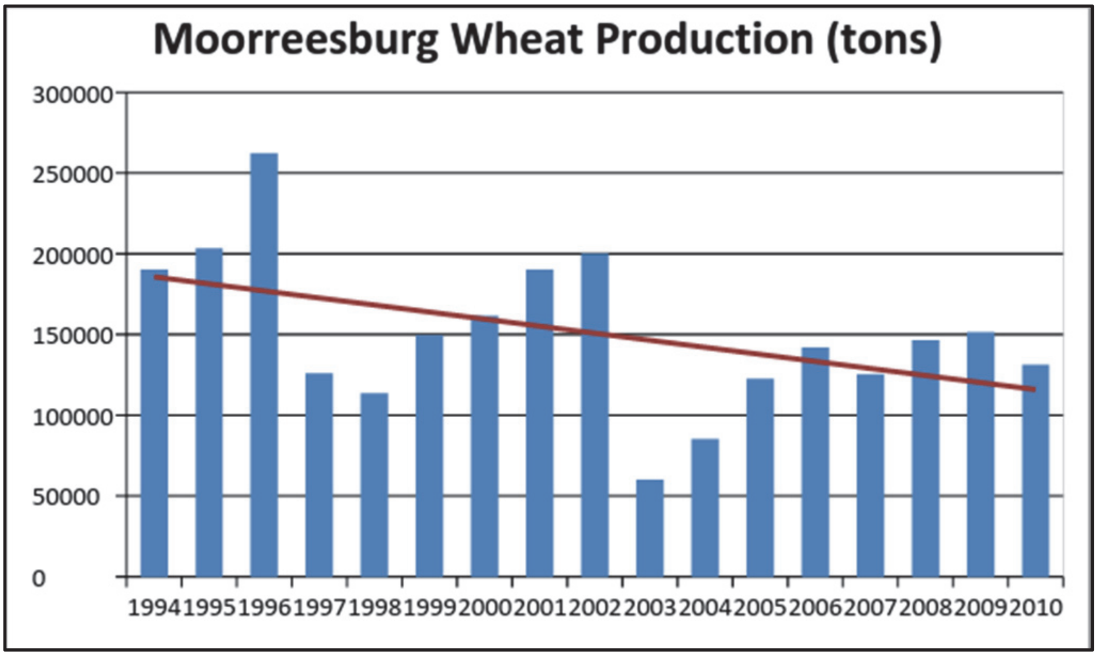
Crop statistics

Figures 19 to 22 display some wheat and rainfall statistics for the area Moorreesburg area.



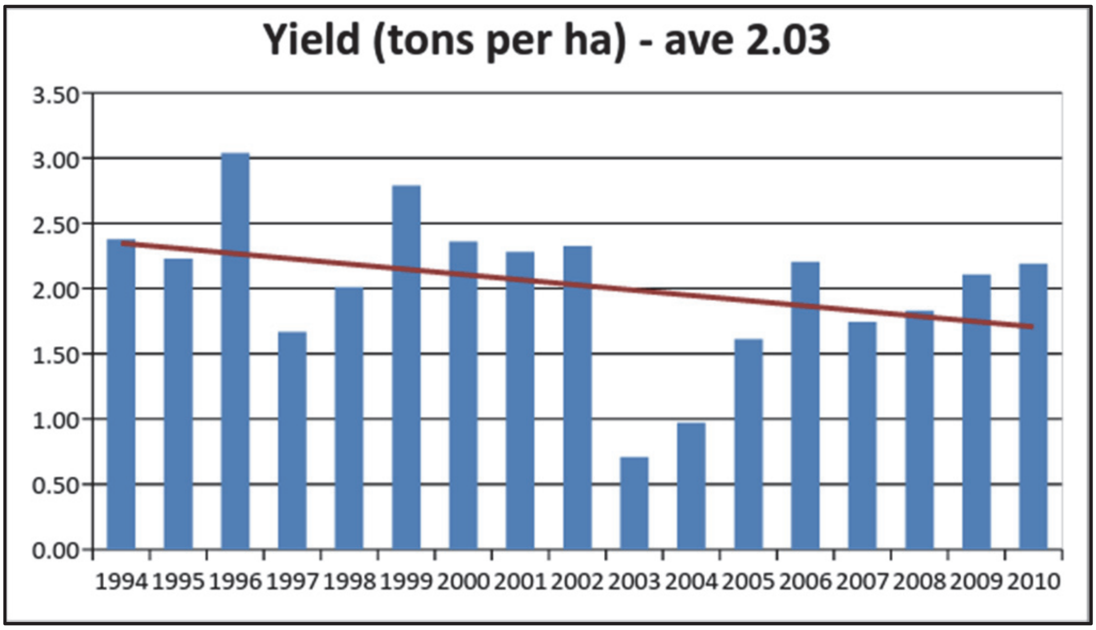
(Source: MKB, Moorreesburg)

Figure 19: Wheat Area planted by year 1994-2010



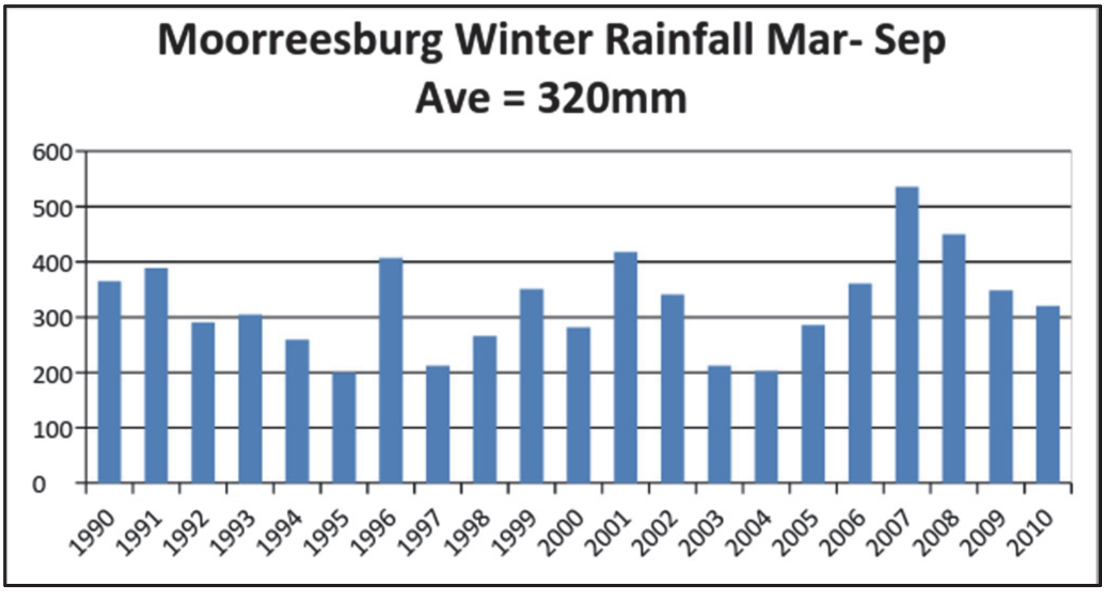
(Source: MKB, Moorreesburg)

Figure 20: Wheat production by year 1994-2010



(Source: MKB, Moorreesburg)

Figure 21: Wheat yield by year 1994-2010



(Source: MKB, Moorreesburg)

Figure 22: Winter rainfall for Moorreesburg by year 1994-2010

5.2.2 Current and projected future crop yields and carrying capacities

5.2.2.1 Current yields

Table 16 displays the average yield per hectare for Langgewens Research farm.

Table 16: Average wheat yield – Langgewens

Year	Yield (t/ha)
1997	2.2
1998	1.9
1999	2.6
2000	3.4
2001	3.3
2002	3.1
2003	1.7
2004	1.9
2005	3.6
2006	4.6
2007	3.9
2008	4.3
2009	3.5
2010	3.2
2011	3.4
Average yield (t/ha)	**3.1**

(Source: Strauss, 2012)

Table 17 summarises the average yield per hectare for wheat in different crop combinations based on data from 18 years' trial results.

Table 17: Current yields for crop combinations

Crop Combination	Yield (t/ha)
Wheat + Wheat	2.4
Wheat + canola	3.0
Wheat + Medics	3.0
Wheat + Lupins	3.0
Wheat + medics + medics	3.5
Wheat + Wheat + medics	3.2
Wheat + fallow	3.0

(Source: Strauss, 2012 & case study farmer)

5.2.2.2 Future yields

Barry Smith Model

Smith developed a suite of rule based models to estimate yields over South Africa for a range of crops according to:

- climatic criteria, using climate variables with limits for each specific crop, adjusted first for
  - different levels of management and, secondly, for
  - soils characteristics.

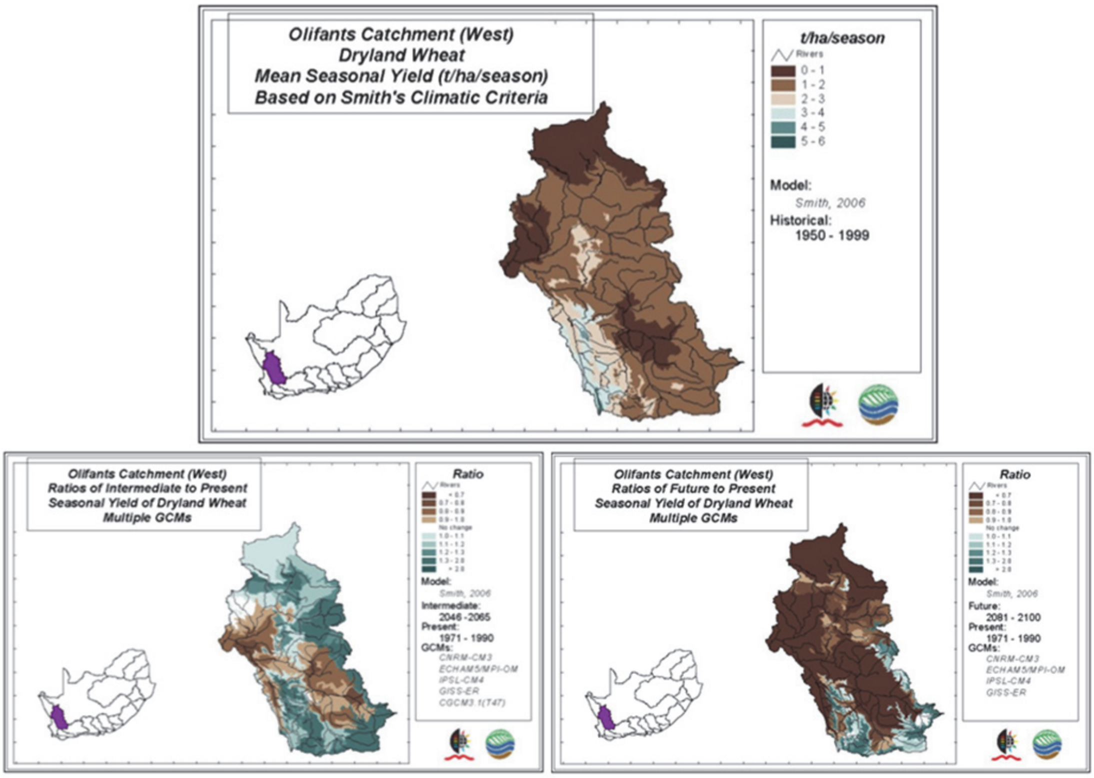
The climatic criteria in the Smith models consist of the product of

- the growing season accumulated rainfall,
- an effective rainfall fraction for the growing season, which depends on classes of rainfall amounts within crop specified limits, and
- a dry matter yield index for that crop, which is a function of classes of growing season heat units between crop related upper and lower limits.

The Olifants (West) catchment is, for the most part, on the fringe of the so-called 'Swartland' winter wheat producing area of South Africa, and the map of present-day yields (**Error! Reference source not found.** top), derived from historical climate records with the Smith rule based dryland winter wheat model shows the bulk of the catchment with mean yields ~ 1 t/ha/season, with only the south-western higher winter rainfall region at 2-3 t and in places up to 4 t/ha/season. Note that these are climatically derived yields with no account taken of soil or management conditions.

Under conditions of climate change, based on projections from the multiple GCMs used in this study, the eastern, southern and southwestern perimeter areas of the Olifants (West) catchments are expected to increase yields into the IF by 10-100% (Figure 23, bottom left). However, this is mostly off a low base yield.

The southwest, with an already reasonable present day yield potential, could become an area of relatively high yields in the IF. Into the MDF very abrupt yield changes are projected, with most of the Olifants (West) at < 70% of present yields, but again the perimeter areas showing possible increases of up to 30% from the present (Figure 23, bottom right).



(Mean seasonal dryland winter wheat yields estimated by the Smith rule based model under historical climatic conditions (top) and projected changes into the intermediate future (bottom left) and the more distant future (bottom right) in the Olifants (West) catchment)

Figure 23: Smith rule based model – Moorreesburg results

Simulating future wheat yields in Moorreesburg with APSIM model

The data available to set up the model were sufficient to run the model and to present the following results. However, these data are not representative of the fine scale APSIM can deal with, and translate generic soil conditions and generic crop managements. Hence we advise any user of this data not to extrapolate information from a resolution higher than the data resolution inputs.

In order to present a descriptive interpretation of various future climate projections, we present the following results for the A2 and B1 CO_2 emission scenarios (SRES), and for 15 GCMs (9 with A2 and 6 with B1).

Figures 24 to 29 show the simulated wheat yields on the y-axis, against its ranked occurrence (percentile) on the x-axis. Hence the reader can appreciate the response to multiple GCMs and multiple years, the worst possible output under percentile 0, the best possible output under x-axis percentile 1, and the evolution from the former to the latter, particularly taking not of the median case for percentile 0.5. We expect this statistical plots to provide a general sense as well as a sense of variability of the biophysical response under future climate.

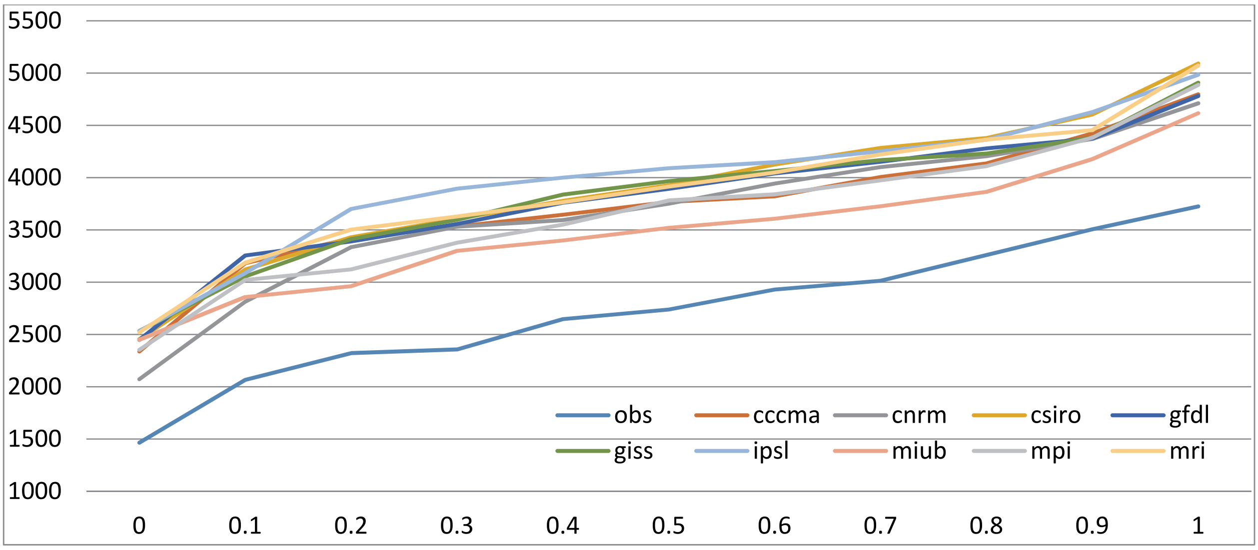


Figure 24: Simulated wheat yield under observed (1979-1999) and control (1961-2000) climates

The control simulations represent closely the yield variability from worst to best case scenarios. However, a significant overestimation in the yields amounts shows and may be explained by the close yet different spatial location of the weather data used to downscale the GCMs weather data, compared to the historical weather data used. Though at this stage the former observation decrease our confidence in the yield amount itself, it does not impact the projected changes and especially the low to high yield variations.

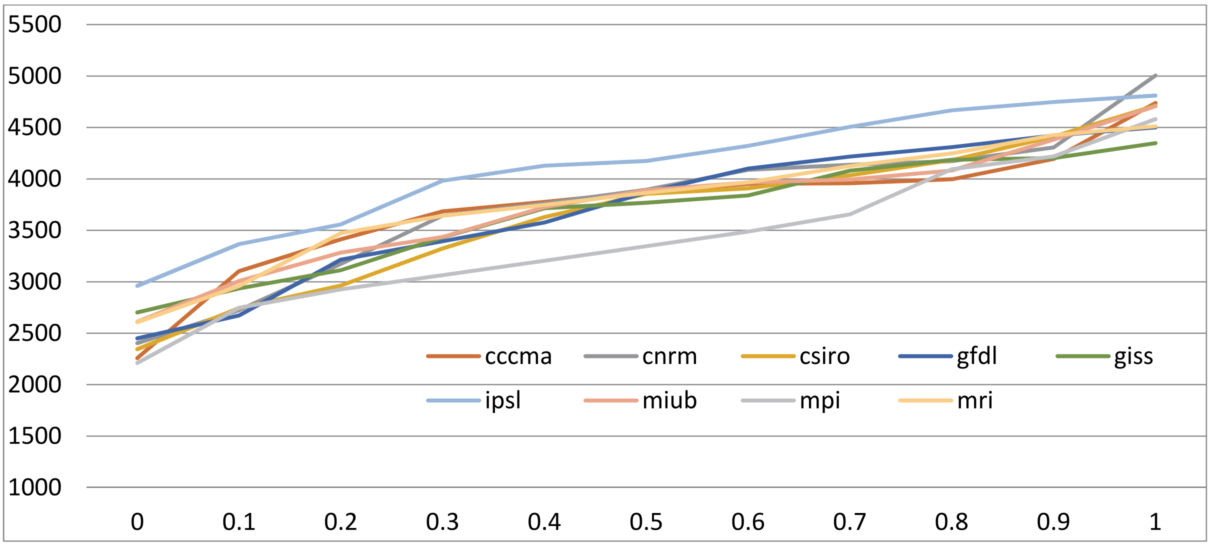


Figure 25: Simulated wheat yield under future climate (2046-2065) for 9 GCMs driven by SRES A2 emission scenarios.

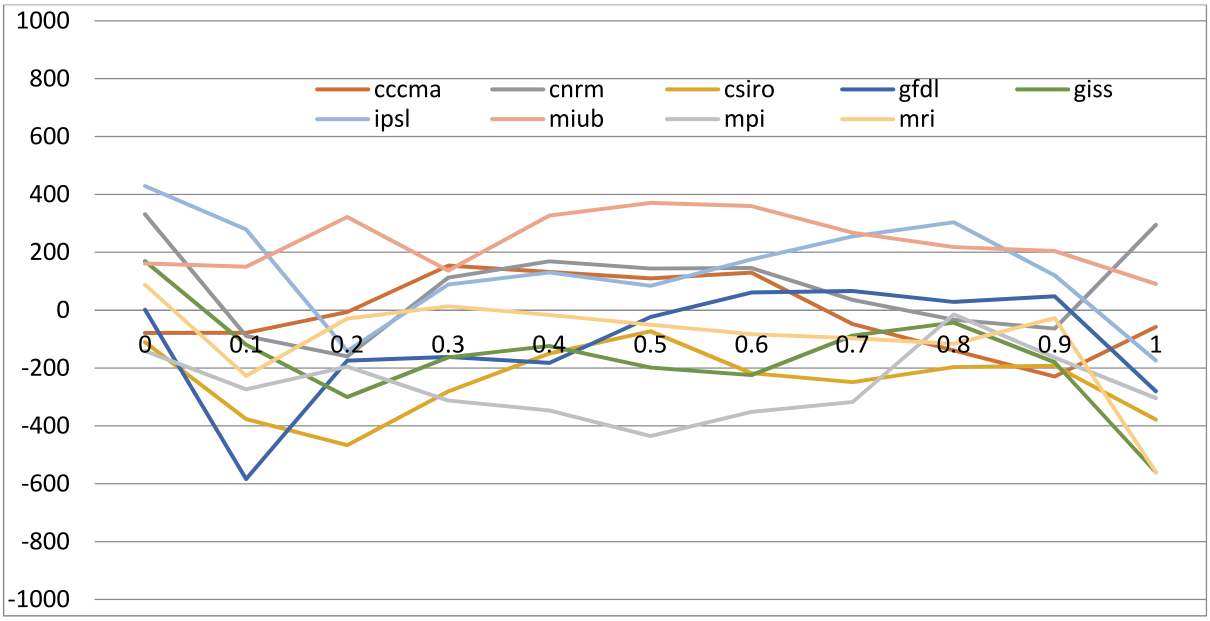


Figure 26: Changes in wheat yield (future minus control) under SRES A2 emission scenario

The changes projected in the mid-century following a CO_2 SRES A2 emission scenario varies from one to another GCM. Responses show a range of increase to decrease, more or less consistently across the worst to best yields simulated. At this stage and under the limitation of the data used for these simulations, there is no evidence of a consistent change in yield outcomes for that location.

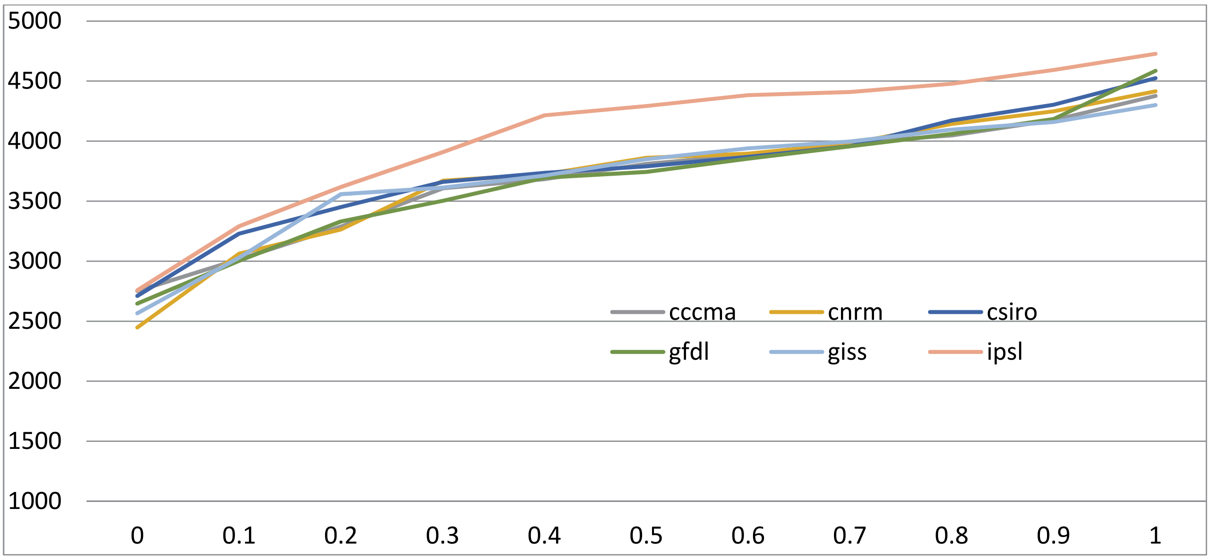


Figure 27: Simulated wheat yield under future climate (2046-2065) for 6 GCMs driven by SRES B1 emission scenarios.

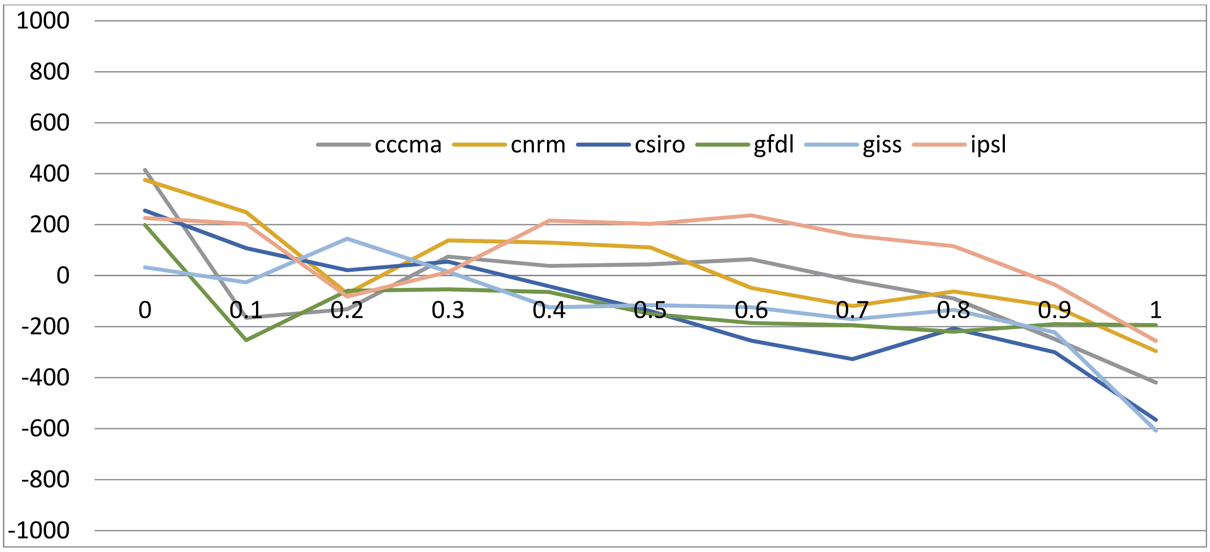


Figure 28: Changes in wheat yield (future minus control) under SRES B1 emission scenario

The changes projected in the mid-century following a CO2 SRES B1 emission scenario varies from one to another GCMs as well. Responses show a range of increase and decrease declining from increase for low yields to decrease for high yields. This decline seems consistent across GCMs, yet it mostly affects extremely low (0 to 0.1 percentile) and extremely high (0.9 to 1 percentile). Hence at this stage, and under the limitation of the data used for these simulations, there is no evidence of a consistent change in yield outcomes for that location.

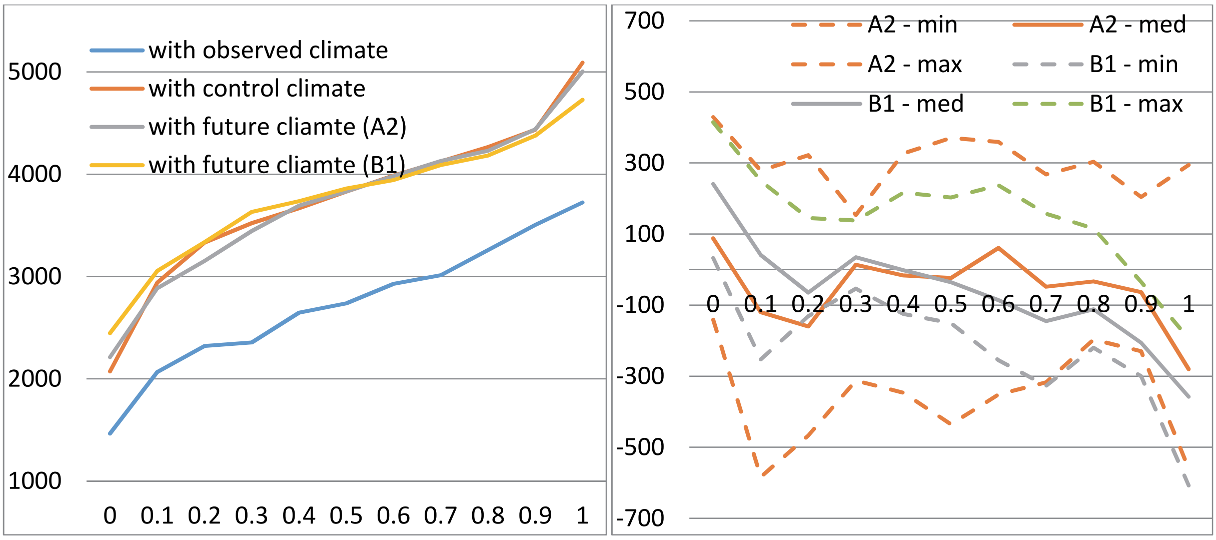


Figure 29: On the left, simulated low to high rainfed wheat yields in Moorreesburg under observed (1979-1999), control (1961-2000) and future (2046-2065) for 9 GCMs driven by A2 scenario and 6 GCMs driven by B1 scenario. On the right, minimum, median and maximum changes simulated (future minus control).

As an attempt to summarise the former results, we show in Figure 29 the average simulated yield for observed, control and futures under SRES A2 and B1, as well as a detailed minimum-median-maximum changes from control to futures (A2 and B1). The average production shown on the left

confirm the overestimation of simulation outputs independently of time period and SRES scenario. Despite the overestimate, the representation of low to high yields is satisfactory.
The changes on the right hand side of Figure 29 show a range of increases and decreases with no clear pattern. In the light of the data input resolution used, we conclude that those results present no consistency of change in the rainfed wheat production from now into the middle of the 21st century.

5.2.3 Projected shifts in optimum cropping areas

One model run (Schulze et al., 2016) shown in Figure 30 displays shifts in optimum growing areas and shows the scenario for irrigated wheat in the SW Cape. It can be assumed that dryland wheat will be similar.

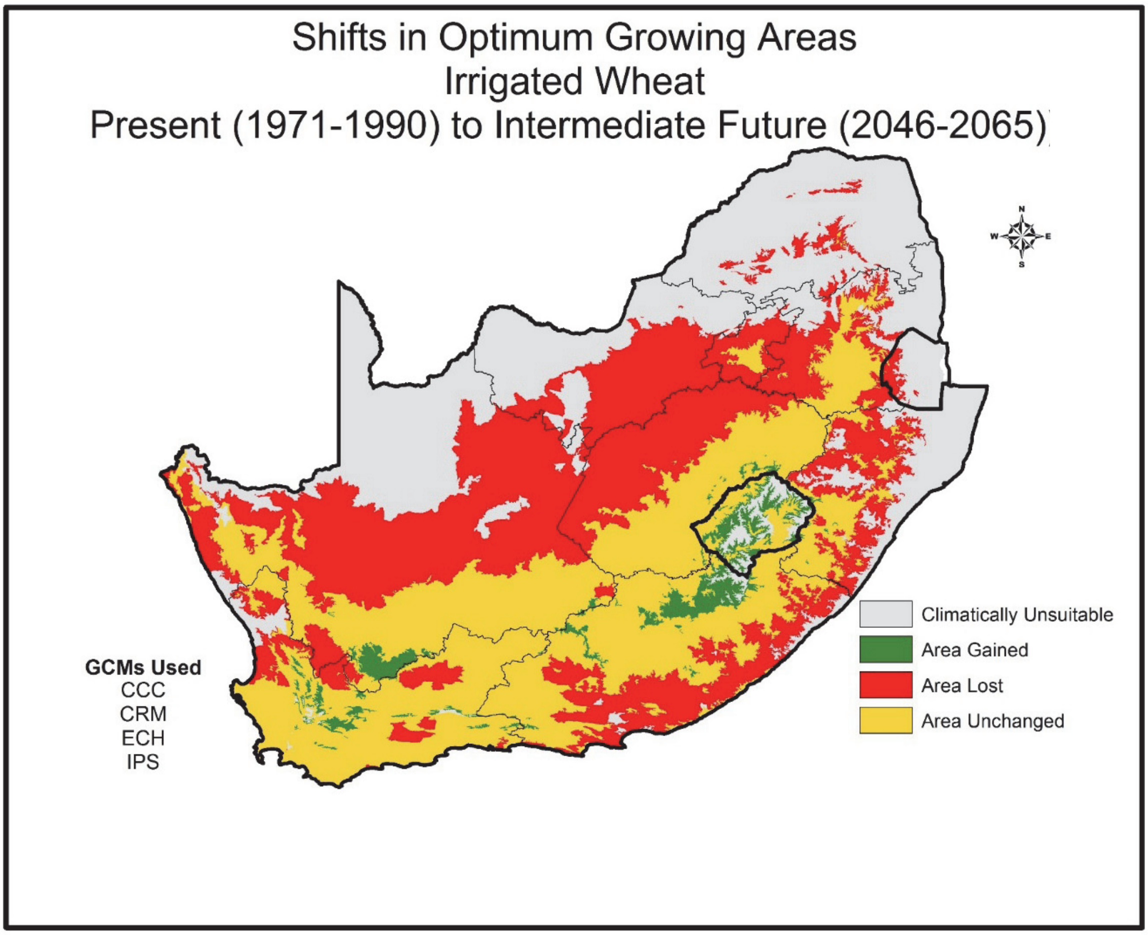


Figure 30: Shifts in optimum growing areas for Irrigated Wheat (Schulze et al., 2062)

Projected shifts in optimum cropping areas were discussed in a session with MKB experts during April 2012 and followed up by a validation workshop on 10 September 2012 with an expert group the following key elements were highlighted:

- In general, the experts were of the opinion that even with climate change, they do not foresee major shifts in farm structure.

- It is expected that temperature is going to increase with 2-3°C during the winter months. This will result in an increase in crop water requires and an increase in the risk for plants to be stressed during critical periods. However, this will not necessarily induce major shifts in cropping areas. Farmers will rather change their cultivation practices – conservation tillage to conserve the available moisture.
- Experts also indicated that if warm weather is accompanied by rain, the impact will be minimal.
- There is a huge difference between conventional and no-till cultivation practices. With no-till plants can still survive after 14-days with no rainfall with the exception of August/September when even with no-till cultivation there will also be losses.
- Adaptations to existing cropping patterns may include:
  - No-till
  - More livestock
  - Possible use of GM seed
  - More medics pasture grass and less wheat
  - Change to low cost-low yield system
- Farmers are tied to their system – difficult to change
- SAFEX trading can help to reduce risk.

5.2.4 Current and future farming management practices (e.g. fertiliser/manure application, irrigation, tillage practices)

5.2.4.1 Soil characteristics

Table 18 illustrates the soil characteristics in the Moorreesburg area.

Table 18: Soil characteristics – Moorreesburg

Location (Quinary nr.)	Thickness of Topsoil (m)	Thickness of Subsoil (m)	Wilting Point of Topsoil (m/m)	Wilting Point of Subsoil (m/m)	Field Capacity of Topsoil (m/m)	Field Capacity of Subsoil (m/m)	Porosity of Topsoil (m/m)	Porosity of Subsoil (m/m)	Saturated Drainage (fraction/ day)
2625	0.29	0.77	0.069	0.076	0.163	0.18	0.455	0.466	0.63

The soils characteristics supplied in Table 18 are area weighted from the land type information in the ISCW soils database (ISCW, 2005) for the Quinary Catchment in which the location of interest is sited. The 4-digit number (location) is the Quinary number in the SA Quinary Catchments Database (Schulze et al., 2010). The methods by which these characteristics for a 2-horizon soil have been derived are described in Schulze and Horan (2008) using the AUTOSOILS decision support system developed by Schulze and Pike (1995 and updates). Values of wilting points, field capacities and porosities (i.e. at saturation) imply the soil water content (in metre of water per metre thickness of soil) at those thresholds. Saturated drainage implies the fraction of soil water above field capacity that drains into the next horizon (i.e. from the topsoil to the subsoil or from the subsoil out of the active rooting zone) per day. The soils in the Moorreesburg area tend to be well drained and relatively sandy.

5.2.4.2 Current cultivation practices

Wheat is by far the dominant crop produced in the area and accounted for 96% of crop production in 1996 (MKB, 2012). Other crops grown on smaller areas include canola, lupines, oats and triticale. Livestock production consists mainly of sheep (mutton and wool production).

Table19 reflects the physiological lifecycle of wheat, while Table 20 summarises the current cultivation practises for wheat in the Moorreesburg area.

Table 19: Physiological lifecycle of wheat

Wheat	
Planting	May
Germination	May
Tillering stage	Jun - Jul
Jointing and booting stage	Jul
Heading and flowering stage	Aug
Harvesting	Oct - Nov

Source: Moorreesburg workshop and expert group discussions (2012)

Table 20: Current cultivation practices

Cultivation practice	Wheat
Optimum planting dates	May
Lifespan	1 year
Harvesting dates	Oct - Nov
Nitrogen application	May - 15 kg/ha Jun - 20 kg/ha Jul - 20 kg/ha

Source: Moorreesburg workshop and expert group discussions (2012)

The case study farm shows typical Swartland mixed farming activities consisting of wheat and livestock (mutton and wool production). Table 21 reflects the carrying capacity for the farm.

Table 21: Carrying capacity for the Moorreesburg case study

Carrying capacity	
Medics	1.25 SSU/ha/year
Wheat stubble	5 SSU/ha for 90 days

Source: Moorreesburg workshop and expert group discussions (2012)

5.2.4.3 Crop rotation practices

According to the experts at MKB the rotation of crops depends on the farming system selected by the individual farmer. As there is a tendency to move away from broadcast sowing to mechanised planting, these systems are changing, but currently can be divided into 7 annual sequences, i.e.:

- Wheat-Wheat (decreasing)
- Wheat-Canola (constant)
- Wheat-Medics (increasing most)
- Wheat-Lupins (increasing)
- Wheat-Medics-Medics (increasing)
- Wheat-Wheat-Medics (decreasing)
- Wheat-Fallow (constant)

5.2.4.4 Possible alternative crops

While no specific crops were listed as alternatives by the stakeholders they did refer to changes in cropping systems that would possibly be adopted in the region

- Wheat-medics-wheat-medics (with old man saltbush)[1]
- Wheat-medics-medics-wheat
- Wheat-wheat-wheat-wheat (mono cropping system with no sheep)
- Wheat-lupin-wheat-canola (no sheep).

While these cropping alternatives were still focused on wheat, it was also clear that diversification was also a clear recommendation, where farmers utilised any available water to grow grapes, rootstocks, and fava beans. The livestock option was also used as a counter to droughts. In this region full scale canola was not regarded as an option as it required more rainfall than the region received, on average.

5.2.5 Appropriate household and whole farming systems modelling

5.2.5.1 Case study farm

A case study farm was selected in Moorreesburg, Western Cape to model the impact of climate change on a typical winter rainfall dryland farming system. The selection of the case study was done in conjunction with MKB, who also assisted with the provision of data, information and study group results. Owing to the TOR of the project and budget constraints, no survey was done in the surrounding area of the farm. The participating case study farm has a high level of record keeping and provided (with assistance of MKB) most of the information needed to do the modelling.

Table 22 reflects the composition of the selected winter rainfall case study farm.

[1] Old man saltbush provides a useful forage resource particularly in times when other feed is scare.

Table 22: Description of case study farm: Moorreesburg

Description	
Farm size	1 010 ha
Dryland	445 ha
Pastures	445 ha
Veldt	107 ha
Waste land	13 ha
Total farm size	**1 010 ha**
Land use	
Perennial crops	
Medics	445 ha
Total area perennial crops	**445 ha**
Cash crops	
Wheat after medics	445 ha
Total area cash crops	**445 ha**
Total area perennial and cash crops	**890 ha**
Livestock	
Sheep (producing ewes)	1 300
Valuation of farm	**(R)**
Fixed improvements	2 600 000
Vehicles, machinery, implements, livestock, etc	7 235 800
Land	9 520 000
Total assets	**19 355 800**
Liabilities	**(R)**
Short-term	1 570 000
Medium term	750 000
Long-term	630 000
Total liabilities	**2 950 000**
Net asset value (R)	**16 405 800**
Debt ratio	**15%**

Source: Case study farmer's records (2012)

5.2.5.2 Crop Enterprise budgets

Tables 23 and 24 summarise the crop enterprise budgets for wheat, medics, mutton and wool production for the Moorreesburg case study.

Table 23: Crop enterprise budget summary: wheat and medics

Item	Wheat after medics	Medics yearly cost
Yield (tonne/ha)	3	0
Price per tonne (R)	2 500	0
Income/ha (R)	7 500	0
Total cash expenditure/ha (R)	3 940	459
Margin above specified costs (R)	3 560	- 459

Source: Hough and Coetzee (2012)

Table 24: Crop enterprise budget summary: mutton and wool production

Assumptions	
Weaning %	90%
Weaning weight (kg)	20 kg
Price/kg (R)	R42
Kg wool/ewe	2 kg
Price/kg (R)	R75
Income and cost (gross margin)	
Income per ewe (R)	R906
Total cost per ewe (R)	R284
Gross margin per ewe (R)	R622

Source: Hough and Coetzee (2012)

5.2.6 Organisation of farmers in formal and informal groups. Existing support service.

5.2.6.1 Organisation of farmers in formal and informal groups

The reader is referred to Appendix C for details regarding the discussions with farmers and cooperative members. Farmers belong to study groups.

5.2.6.2 Existing support services

Farmers study groups are organised by MKB, the local silo/cooperative which offers assistance in respect of seed, pesticide, herbicide and fertiliser requirements.

5.3 Olifants East (Blyde River WUA) – Commercial farmers

5.3.1 The existing sources of livelihoods

Main crops produced in the area includes citrus (3 700 ha) and mangoes (3 500 ha). Other crops produced on a smaller scale include, amongst others, vegetables (open & protected), sweet corn and maize seed. The production of peppers under net irrigation constitutes approximately 50 hectares but cannot be regarded as typical for the region. During the past couple of years there seems to be a shift in production patterns. Citrus production increased and vegetable production decreased substantially when Tiger brands decided to close down their tomato processing plant in Hoedspruit.

Table 25: Types of crops planted in Blyde River (ha)

Cash crops	Hectare (ha)	%
Sweetcorn	200	2%
Seed production (maize)	200	2%
Vegetables (open)	550	7%
Vegetables (protected)	50	1%
Total	1 000	12%
Permanent crops		
Citrus	3 700	45%
Mangoes	3 500	43%
Total	7 200	88%
Total crops planted	**8 200**	**100%**

(Source: Own estimates based on interviews with industry leaders, i.e. representatives of WUA, growers associations (citrus and mangoes) and farmers association)

5.3.2 Current and projected future crop yields and carrying capacities

5.3.2.1 Current yields

Citrus

Table 26 displays the average observed yield for citrus.

Table 26: Average yield (tonne/ha) – Citrus

Age of orchards	Yield/ha	Age of orchards	Yield/ha
Year 1	0	Year 15	60
Year 2	0	Year 16	60
Year 3	5	Year 17	60
Year 4	10	Year 18	60
Year 5	20	Year 19	60
Year 6	40	Year 20	60
Year 7	60	Year 21	60
Year 8	60	Year 22	60
Year 9	60	Year 23	48
Year 10	60	Year 24	43
Year 11	60	Year 25	39
Year 12	60	Year 26	35
Year 13	60	Year 27	31
Year 14	60	Year 28	28

(Source: Own calculations with inputs from Citrus Growers Association, 2012)

Table 27 displays the average harvest distribution and price per tonne for citrus.

Table 27: Harvest distribution and price per tonne – Citrus

Harvest distribution	%	Price/tonne	Weighted price
Export market	65%	3 333	2 166
Local market	0%	1 133	0
Juice market	35%	550	193
Average weighted price/tonne	**100%**		**2 359**

(Source: Own calculations with inputs from Citrus Growers Association, 2012)

Mangoes

Table 28 displays the average observed yield for mangoes.

Table 28: Average yield (tonne/ha) – Mangoes

Age of orchards	Yield/ha	Age of orchards	Yield/ha
Year 1	0	Year 15	30
Year 2	0	Year 16	30
Year 3	3	Year 17	30
Year 4	5	Year 18	30
Year 5	7	Year 19	30
Year 6	12	Year 20	30
Year 7	18	Year 21	30
Year 8	22	Year 22	30
Year 9	27	Year 23	30
Year 10	27	Year 24	30
Year 11	30	Year 25	30
Year 12	30	Year 26	24
Year 13	30	Year 27	18
Year 14	30	Year 28	16

(Source: Own calculations with inputs from Mango Growers Association, 2012)

Table 29 displays the average harvest distribution and price per tonne for mangoes.

Table 29: Harvest distribution and price per tonne – Mangoes

Harvest distribution	%	Price/tonne	Weighted price
Export market	1%	9 100	91
Niche market (supermarkets)	8%	6 000	480
Local market	20%	7 000	1 400
Juice market	31%	1 900	589
Atchar market	15%	1 100	165
Drying market	25%	2 200	550
Average weighted price/tonne	**100%**		**3 275**

(Source: Own calculations with inputs from Mango Growers Association, 2012)

5.3.2.2 Future yields

No crop models currently exist for mangoes and citrus. **Expert opinions were used to determine the possible impact of climate change on these crops in Blyde River**. In the words of Prof Stephanie Midgley (University of Stellenbosch):

"This is a difficult topic (crop models and climate change) since modelling approaches work well for annual crops with simple growth phases such as vegetables, but no models have yet been found to capture the complex multi-year climatic responses of perennial tree crops. The most important impact on deciduous fruit is on chill units and the effects of heat stress on sunburn and loss of red skin colour (quality attributes). It is almost impossible to capture the effects of temperature on fruit growth and yield since this is highly regulated by other farming interventions such as fruit thinning. Farmers pre-determine their crop load and manage the tree accordingly. The crop load determines the final fruit size, with some influence of temperature in the early fruit growth phases (first 40 days after fertilisation) but not much later. The economic impacts will thus be on fruit quality rather than tonnage. Tonnage will, however, be affected by lack of chilling and inadequate flowering. There are no easy temperature thresholds since so many other factors play a role and the impacts are not linear".

The project team believes that this a serious shortcoming in the field of climate change adaptation research. However, it is believed that expert local knowledge, although not substantiated by scientific proof or evidence, could go a long way to capture the potential impact of climate change in the case study regions.

Expert opinions were used to determine the possible impact of climate change on the crops in Blyde River region. It is for this reason that the Crop Critical Climate Threshold technique was developed by Oosthuizen (2014).

5.3.2.3 Crop Critical Climate Threshold technique (CCCT)

The CCCT modelling technique is based on the following pillars (Oosthuizen, 2014):

- Statistically downscaled daily climate values (rainfall, minimum and maximum temperatures).
- Physical/biological critical climate thresholds for different crops.
- Expert group discussions (for guidance on crop critical climate thresholds and also the impact on yield and/or quality should a threshold be exceeded).

The use of expert group discussions, as a research method is suitable, firstly, for gathering information in a meaningful manner and, secondly, to stimulate individual creativity by presenting alternative perspectives provided by various participating experts (Hoffmann, 2010). However, due to the various uncertainties in the models, when analysing CCCT modelling results the emphasis should be on trends in projected yield and quality, rather than absolute values (Oosthuizen, 2014).

The CCCT modelling consists of the following steps (Oosthuizen, 2014):

- The crop critical climate thresholds for different crops were determined during workshops with farmers and experts. This includes the impact on yield and/or quality of the crop if the threshold is breached.
- These thresholds are then applied to different climate scenarios (present and intermediate) of the downscaled GCMs to determine the number of breaches per threshold for the different climate scenarios.
- The effects of critical climate threshold breaches (which can be positive or negative) are then calculated to determine the impact on yield and/or quality of crops.

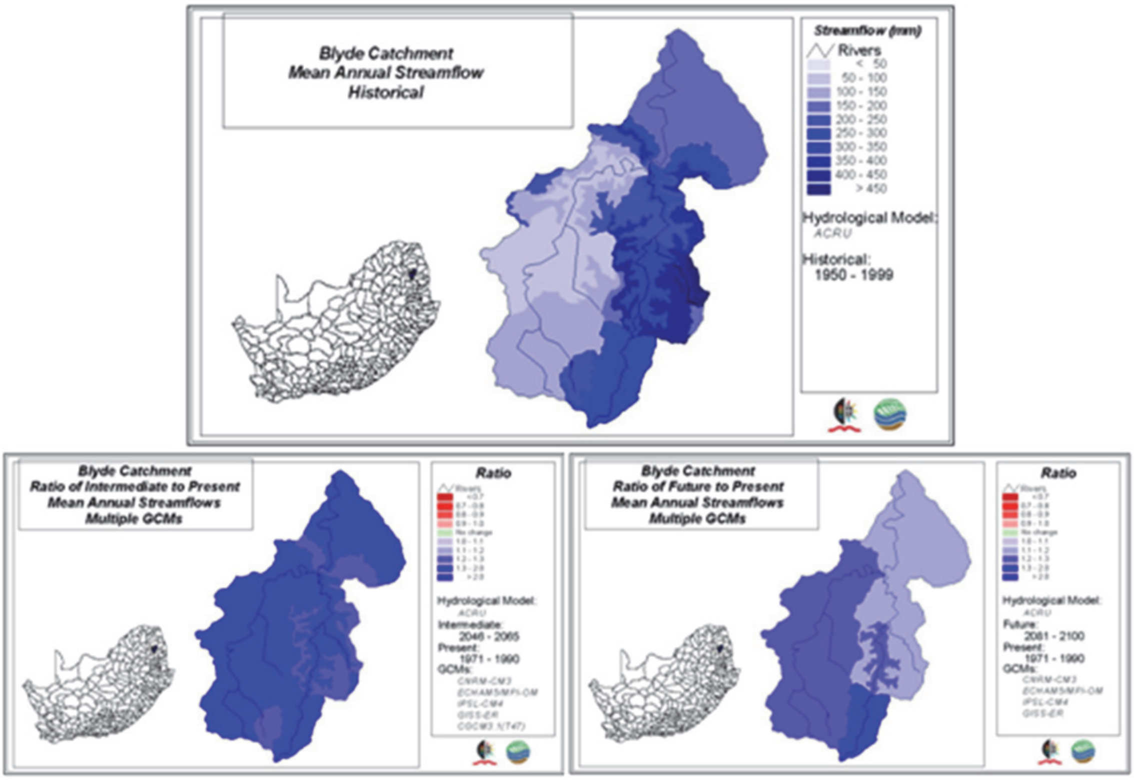
The results of the crop critical threshold modelling are integrated into the DLP model through an interphase. The CCCT modelling results are discussed in Chapter 9 (see also Appendix C).

5.3.2.4 ACRU Model results

While the ACRU modelling done here is not for any specific crop, it is used to project run-off, which will determine irrigation availability.

In the Blyde river basin the entire eastern half of the catchment generates the equivalent of 150+ mm of streamflow, with parts of the escarpment yielding up to 350 mm / annum (Figure 31, top). The western areas produce somewhat less streamflow at between 50 and 150 mm equivalent in an average year.

The Blyde displays spatially consistent increases in mean annual streamflows into the IF of 10-30%, while into the MDF the projections show a clear north-south split in changes, with the western parts of the catchment displaying increases of 20-30% and the eastern and northern parts 10-20%.



(Means of annual accumulated streamflows under historical climatic conditions (top) and projected changes into the intermediate future (bottom left) and the more distant future (bottom right) in the Blyde catchment)

Figure 31: Means of annual accumulated streamflows in the Blyde catchment

More details on Irrigation demand projections and variability can be found in the Appendix.

5.3.3 Projected shifts in optimum cropping areas

Possible future farming operations were discussed during a workshop in Hoedspruit on the 16th of April and followed up with discussions with experts after the workshop. Mr. Gerhard Mostert (a consultant for the sub-tropical industry), in particular made very useful inputs especially with regard to potential future practices. These are:

- In general, the Hoedspruit farmers do not foresee a major shift in cropping areas. They are of the opinion that most of the impact will be countered by a shift to other cultivars and through production practices. These will be modelled in the next phase of the project as adaptation strategies.
- If the season shifts forward by a week or two for Mangoes, it will have major price implications since the highest prices occur between Christmas and New Year. A decrease of 30-40% will not be uncommon especially for the Tommy Atkins cultivar. **It will be necessary to switch to other cultivars**.

- The quality of Navels will drop if climate change result in warmer winter temperatures and it will **also be necessary to consider other cultivars to counter this impact**.
- There seem to be an increase in the occurrence of hail storms which is disastrous for any producer affected by this. **The only adaptation is to construct hail nets which are extremely expensive (R130 000 per ha).**
- The only **alternative crop** which may be considered in this region is **sugarcane**. Paw-paws are not an option if the temperature if there is an increase in temperature and if there is more wind.
- They already experience problems with but break since the change from winter to summer is not as smooth compared to what it used to be (stop/go impact). However, this can be **countered by using but break agents (chemicals)**.
- If they experience problems with a rise in minimum temperature it will result in colouring problems and a loss in quality grading.
- In general farmers are of the opinion that more mangoes will be planted compared to citrus if there is an increase in rainfall and temperature.

Optimal cropping patterns will be calculated in the next phase of the project when adaptation strategies are modelled.

5.3.4 Current and future farming management practices (e.g. fertiliser/manure application, irrigation, tillage practices)

5.3.4.1 Soil characteristics

Table 30 illustrates the soil characteristics in the Blyde River WUA area.

Table 30: Soil characteristics – Blyde River WUA

Location (Quinary nr.)	Thickness of Topsoil (m)	Thickness of Subsoil (m)	Wilting Point of Topsoil (m/m)	Wilting Point of Subsoil (m/m)	Field Capacity of Topsoil (m/m)	Field Capacity of Subsoil (m/m)	Porosity of Topsoil (m/m)	Porosity of Subsoil (m/m)	Saturated Drainage (fraction/ day)
0675	0.3	0.31	0.117	0.146	0.205	0. 230	0.454	0.442	0.43

Source: School of Agricultural, Earth and Environmental Sciences, UKZN (2012)

The soils characteristics given in the table are area weighted from the Land Type information in the ISCW soils database (ISCW, 2005) for the Quinary Catchment in which the location of interest is sited. The 4-digit number (location) is the Quinary number in the SA Quinary Catchments Database (Schulze et al., 2010). The methods by which these characteristics for a 2-horizon soil have been derived are described in Schulze and Horan (2008) using the AUTOSOILS decision support system developed by Schulze and Pike (1995 and updates). Values of wilting points, field capacities and porosities (i.e. at saturation) imply the soil water content (in metre of water per metre thickness of soil) at those thresholds. Saturated drainage implies the fraction of soil water above field capacity that drains into the next horizon (i.e. from the topsoil to the subsoil or from the subsoil out of the active rooting zone) per day. The soils tend to gradually become sandier and less clayey in the Blyde River WUA area.

5.3.4.2 Crop irrigation requirements

Table 31 illustrates annual crop water requirements for mangoes and citrus.

Table 31: Crop water requirements (m^3/ha)

Item	Mangoes	Citrus
Jan	840	1 020
Feb	840	1 020
Mar	525	935
Apr	525	510
May	233	425
Jun	233	255
Jul	233	255
Aug	525	425
Sep	525	765
Oct	840	850
Nov	840	1 020
Dec	840	1 020
Total	7 000	8 500

Source: Du Preez (2012)

5.3.4.3 Current cultivation practices

Table 32 summarises the current cultivation practises for citrus and mangoes in the Blyde River WUA area.

Table 32: Current cultivation practices for citrus and mangoes

Cultivation practice	Citrus	Mangoes
Optimum planting dates	Feb - Apr	Sept - Feb
Lifespan of orchards	25 years	35 years
Harvesting dates	Apr - Aug	Jan - Mar
Nitrogen application	Oct - Dec - 30 kg/ha Jul - Sept - 90 kg/ha	Jan - Mar - 35 kg/ha Jul - Sept - 15 kg/ha

Source: Blyde River WUA expert group discussions (2012)

5.3.4.4 Crop rotation practices

Citrus and mangoes are long term crops – crop rotation practices are not applicable.

5.3.4.5 Possible alternative crops

A number of possible alternative crops came to the fore during the survey, which were debated by the Reference Group. Possible alternative crops include sugarcane, paw-paws, macadamias, pomegranates and table grapes.

The Reference Group indicated (after much debate) that the regional infrastructure is developed for citrus and mangoes and it would make sense to develop cultivars that can cope with higher temperatures and make use of alternative cultivation practices rather than changing to alternative crops.

5.3.5 Appropriate household and whole farming systems modelling

Two case studies that are representative of the study area were selected. The selected case studies were selected from the survey which was undertaken during 2011. Case Study 1 represents a typical farm of sixty-five hectares of mangoes and citrus. Case Study 2 represents a bigger farm (130 ha) farm which produces citrus and mangoes.

5.3.5.1 Case study farm

Table 33 describes the case study farms for the Blyde River WUA.

Table 33: Description of case study farms: Blyde River WUA

Description	Case study 1	Case study 2
Farm size	70 ha	140 ha
Irrigable	65 ha	130 ha
Actual irrigated	65 ha	130 ha
Waste land	5 ha	10 ha
Total farm size	**70 ha**	**150 ha**
Land use		
Perennial crops		
Mangos	55 ha	10 ha
Citrus	10 ha	120 ha
Total area perennial crops	**65 ha**	**130 ha**
Cash crops		
	0 ha	0 ha
Total area cash crops	**0 ha**	**0 ha**
Total area perennial and cash crops	**65 ha**	**130 ha**
Irrigation system (total area)		
Drip	65 ha	130 ha
Total (ha)	**65 ha**	**130 ha**
Water sources		
Pipeline	65 ha	130 ha
Total (ha)	65 ha	130 ha
Entitlement per ha per annum	9 900 m^3	9 900 m^3
Valuation of farm	**(R)**	**(R)**
Fixed improvements	1 140 000	2 940 000
Vehicles, machinery, implements, livestock, etc	560 000	1 500 000
Land	5 950 000	13 150 000
Total assets	**7 650 000**	**17 590 000**
Liabilities	**(R)**	**(R)**
Short term	1 050 000	2 000 000
Medium term	200 000	500 000
Long term	2 000 000	2 000 000
Total liabilities	**3 250 000**	**4 500 000**
Net asset value (R)	**4 400 000**	**13 090 000**
Debt ratio	**42%**	**26%**

Source: Case study farmers' records (2012)

5.3.5.2 Crop Enterprise budgets

Tables 34 and 35 summarise the crop enterprise budgets for mangoes and citrus for the Blyde River WUA case studies.

Table 34: Crop enterprise budget summary: mangoes

Item Year	0	1	2	3	4
Yield (tonne/ha)		0	0	3	5
Gross income (R)		0	0	10 914	18 190
Yearly cash expenditure (R)	41 433	10 500	30 705	36 048	41 948
Margin above specified costs (R)		- 10 500	- 30 705	- 25 134	- 23 758
Item Year	**5**	**6**	**7**	**8**	**9 - 30**
Yield (tonne/ha)	7	12	18	22	27
Gross income [R]	25 466	43 656	65 484	80 036	98 226
Yearly cash expenditure (R)	43 843	49 489	55 174	58 964	63 702
Margin above specified costs (R)	- 18 377	- 5 833	10 310	21 072	34 524

Source: Own calculations with inputs from Mango Growers Association (2012)

Table 35: Crop enterprise budget summary: citrus

Item Year	0	1	2	3
Yield (tonne/ha)		0	0	5
Gross income (R)		0	0	11 795
Yearly cash expenditure (R)	55 134	10 200	13 116	25 515
Margin above specified costs (R)	- 55 134	- 10 200	- 13 116	- 13 720
Item Year	**4**	**5**	**6**	**7 - 30**
Yield (tonne/ha)	10	20	40	60
Gross income (R)	23 590	47 180	94 360	141 540
Yearly cash expenditure (R)	36 769	50 720	77 709	104 737
Margin above specified costs (R)	- 13 179	- 3 540	16 651	36 803

Source: Own calculations with inputs from Citrus Growers Association (2012)

5.3.6 Organisation of farmers in formal and informal groups. Existing support service.

5.3.6.1 Organisation of farmers in formal and informal groups

There is only one active agricultural association in the Blyde River area namely Blyde River Agricultural association, which is linked to AgriSA.

South African Mango Growers Association's (SAMGA) history dates back in the early 1970s when a forum was formed to solve producer problems through research and to facilitate communication between researchers and producers. SAMGA is a producer association representing about 80% of all mango growers in South Africa (SAMGA, 2009).

When the fruit industry was deregulated in 1997, the citrus growers formed the Citrus Growers Association (CGA). CGA represents the interests of citrus growers and it has a membership of about 1400 growers throughout Southern Africa (including Zimbabwe and Swaziland) (CGA, 2010).

5.3.6.2 Existing support services

Government and/or private extension and training

As of January 2007 the total number of extension workers in the Limpopo was 666 (William et al., 2008:15). In order to improve the extension and training support services, the Limpopo province launched the Limpopo Agribusiness Development Academy (LADA), a program established and funded by both the Limpopo Department of Agriculture (LDA) and the Flemish government through the Flanders International Cooperation Agency (FICA) (William et al., 2008:21).

Citrus Growers Association (CGA) employ two extension personnel committed to helping emerging growers from in the Mpumalanga, Limpopo, KwaZulu-Natal, Eastern Cape and Western Cape (CGA, 2010:29). CGA has since asked the provincial Departments of Agriculture, Forestry and Fisheries and Rural Development and Land Affairs to give them government extension workers who will be trained as Citrus specialists to provide support to all growers in the regions (CGA, 2010:29).

Suppliers of repair and maintenance services

Over the past years the town of Hoedspruit has grown rapidly with a number of new and innovative businesses offered with more traditional options as well (Hoedspruit, 2011). Services provided by the businesses include finance, hardware and construction, applies, maintenance and repairs, farming input suppliers, security and equipment hire, just to mention a few.

Access to schools, clinics, hospitals, etc. (social services)

In the Maruleng Municipality, Hoedspruit is considered as the economic centre, has two secondary and four primary schools (Hoedspruit, 2011; Maruleng Municipality, n.d:48). There is a critical shortage of schools, and more particularly, classrooms in both primary and secondary schools. Many schools need infrastructure like electricity, water, sanitation (Maruleng Municipality, n.d:48).

There is one clinic in Hoedspruit (Maruleng Municipality, n.d:48). Even though Hoedspruit does not have direct and immediate access to a closely located hospitals and emergency services, there are a number of medical services available in Hoedspruit from paramedic services, general practitioners, physiotherapists, dentists, etc. (Hoedspruit, 2011).

Hoedspruit Training Trust (HTT) has a running project named “Hlokomela”, which targets seasonal and permanent workers on 38 farms in the Hoedspruit. This project’s main aim is to provide sustainable HIV prevention and care services to farm workers (Eye on Migration Health, 2009:1).

The Hoedspruit community established a number of voluntary organizations that works closely with the police and other emergency services to provide a variety of safety, security and medical emergency services (Hoedspruit, 2011). Organizations involved in helping the community are Hoedspruit Plaaswag/Farmwatch, Hoedspruit Victim's Support Unit and Africa Safe-T.

5.4 Olifants East/Inkomati (small scale/subsistence)

One of the objectives of the project proposal was to include emerging/small-scale farming systems in the project to determine the (financial and socio-economic) impacts of climate change, and this was done in the Dingleydale area (North-east Mpumalanga) at 2 distinct sites. Upon review of the results and conclusions it was felt by the reference group that these farming systems were not financially functional and as such may not prove to be useful for the study. The results do, however, display interesting and unique challenges facing very many small scale farmers and are thus presented in this section of the report. It must be noted that NO modelling was performed for this site and it is therefore not discussed any further.

5.4.1 The existing sources of livelihoods

The data collection from the field work completed in Dingleydale and New Forest areas is shown below. This includes detail of the farming systems and economic activities. A total of 42 farmers were interviewed in the 4 villages. The groups comprised small scale farmers with varying sized plots and included those with and without access to irrigation (see Table 36).

Approximately half of the farmer households had at least one person who was actively employed in off-farm activity. Government support is made available to some of the community by way of tractor time, and extension officers are also available.

Table 36: Overview of the sources of alternative income in different villages

Type of Household	Motlamo-gatsane (n=9)	Phelandaba (n=10)	New Forest (n=12)	Dingleydale (n=11)	All (n=42)
Households with one or more family members with off-farm employment	7	6	2	5	20
Households regularly receiving remittances from families or friends	1	0	4	1	6
Households receiving monthly government grants	8	9	6	7	30

Remittances from families or friends are not very common amongst the farmer in Bushbuckridge, with only one seventh of the farmers interviewed saying that they regularly (varying from once a year to once a month) receive remittances. Off-farm employment is a more common way to support livelihoods, with nearly half of the households of the farmers interviewed having one or more family members with employment off the farm. Out of the 20 households three are family businesses such as sewing, and three are just temporary employment. Permanent employment jobs mentioned include plantation and security work, teaching, taxi driving and road maintenance work. It should also be mentioned that some farmers gave the impression that even though someone in the household have off-farm employment they don't necessarily use their income to support the household.

Government grants, more specifically child grants and pensions, are by far the most common way interviewees were found to support their livelihoods as farmers. While providing something to fall back on, the use of children grants for farming and food in times of crisis raises the question of how this impacts the children's ability to go to school and to buy necessary material and uniforms. As was found in a study in Lesotho, some people indicated how they might take their children out of school in drought years, using the school fee money to feed the family. While keeping the family alive, this can have detrimental effects in that without education children are less likely to get out of the poverty trap.

The farmers in New Forest sell their crops at markets and supermarkets in nearby towns and villages, including Thulamahashe, Bushbuckridge, Hazyview, Hluvukani, Hoedspruit and Graskop. They also sell their crops at the local market in New Forest, along the road or to people come to their field to buy.

Table 37: New Forest Irrigation Scheme

Farm	Plot size (ha)	Carrot	Cabbage	Tomato	Chilli	Spinach	Lettuce	Onion	Butternut	Peanuts	Pumpkin	Sweet potato	Sugarcane	Dry beans	Beetroot	Green pepper	Green beans	Maize	Bambara nuts	Cassava	Matlapala	Madombe	Potato	Cow peas
1	**3**		√	√		√		√	√	√	√				√			√	√					
2	**5**			√		√		√	√	√				√				√	√					
3	**3**			√		√		√	√					√				√						
4	**2**			√					√						√			√						
5	**2**		√	√														√						
6	**3**		√	√						√								√	√					
7	**8**					√					√	√		√				√						
8	**1**		√	√		√				√	√			√	√			√	√					√
9	**-**		√			√		√			√			√				√						√
10	**1**			√					√		√							√		√				
11	**1**			√		√					√	√		√				√						
12	**2**			√							√							√						

Most of the farmers interviewed in Motlamogatsane cultivate both in the wetland and the homestead, while three of them also have a field in the mountain close to the village. It was difficult to estimate the size of their fields, as they themselves did not know. Two of the farmers interviewed occasionally sell their crops in Acornhoek, but the majority either just farm for their own subsistence or they sell a little at the local markets or to people in the neighbourhood.

Table 38: Wetland and homestead plots (no irrigation)

Farm	Plot size (ha)	Carrot	Cabbage	Tomato	Chilli	Spinach	Lettuce	Onion	Butternut	Peanuts	Pumpkin	Sweet potato	Sugarcane	Dry beans	Beetroot	Green pepper	Green beans	Maize	Bambara nuts	Cassava	Matlapala	Madombe	Potato	Cow peas
13	**-**	√	√	√		√		√				√			√						√	√		
14	**-**	√	√	√		√					√		√		√			√		√	√	√		
15	**-**					√					√							√				√		
16	**-**																					√		
17	**-**	√	√	√		√									√								√	
18	**-**		√	√		√	√	√							√			√			√	√		
19	**-**		√	√		√		√										√				√		
20	**-**			√				√		√		√						√		√		√		
21	**-**		√	√				√			√							√				√		

The farmers in Dingleydale sold their crops at supermarkets and markets in in Acornhoek, Bushbuckridge, Belfast, Hazyview, Phalaborwa, Nelspruit, They also sold their crops at the local market in Dingleydale, along the road or to people who come to their field to buy.

Table 39: Dingleydale Irrigation Scheme

Form	(ha)	Carrot	Cabbage	Tomato	Chilli	Spinach	Lettuce	Onion	Butternut	Peanuts	Pumpkin	potato	Sugarcane	Dry beans	Beetroot	pepper	beans	Maize	nuts	Cassava	Matlapala	Madombe	Potato	Cow peas
22	**3**		√	√	√	√		√	√		√			√	√			√						
23	**15**			√		√			√		√	√		√	√			√		√				
24	**1**			√		√		√		√	√			√	√			√						
25	**1**																	√						
26	**1**			√	√						√	√		√	√			√		√				
27	**2**			√	√	√			√		√			√	√		√	√						
28	**1**													√				√						

Form	(ha)	Carrot	Cabbage	Tomato	Chilli	Spinach	Lettuce	Onion	Butternut	Peanuts	Pumpkin	potato	Sugarcane	Dry beans	Beetroot	pepper	beans	Maize	nuts	Cassava	Matlapala	Madombe	Potato	Cow peas
29	**1**			√		√									√	√		√						
41	**3**		√	√				√	√			√		√	√			√						
42	**5**		√	√	√										√			√						
43	**1**			√		√					√				√			√						

As in Motlamogatsane, most the farmers interviewed in Phelandaba cultivated in both the wetland and the homestead, and two of the farmers also have a third field up in the mountain close to the village. Fields size estimates for the wetland ranged from 1 to 15 beds. Though the beds seem to differ in size, it is estimated that they were +/- 2x3 metres. The farmers in Phelandaba either just farmed for their own subsistence or they sold a little at the local markets or to people in the neighbourhood.

Table 40: Phelandaba – wetland and homestead plots (no irrigation)

Form	(ha)	Carrot	Cabbage	Tomato	Chilli	Spinach	Lettuce	Onion	Butternut	Peanuts	Pumpkin	potato	Sugarcane	Dry beans	Beetroot	pepper	beans	Maize	nuts	Cassava	Matlapala	Madombe	Potato	Cow peas
30	**-**																	√				√		
31	**-**										√							√				√		
33	**-**									√	√	√						√	√	√		√		√
34	**-**									√	√							√						
35	**-**										√							√				√		
36	**-**										√							√	√			√		
37	**-**										√							√				√		√
38	**-**										√	√						√	√		√	√		√
39	**-**		√			√				√	√				√			√	√			√		
40	**-**									√	√							√	√			√		

Table 41: Overall number of farmers growing specific crops:

Carrot	Cabbage	Tomato	Chilli	Spinach	Lettuce	Onion	Butternut	Peanuts	Pumpkin	Sweet potato	Sugarcane	Dry beans	Beetroot	Green pepper	Green beans	Maize	Bambara nuts	Cassava	Matlapala	Madombe	Potato	Cow peas
3	15	26	4	20	1	12	9	10	25	8	1	13	17	1	1	39	8	6	4	17	1	5

Within the Olifants East commercial farming study area, the predominant agricultural activities are under irrigation; citrus, mangoes and vegetables. The rainfed areas around Hoedspruit are predominantly used by very small scale farmers growing vegetables and maize for their own use.

Further south in the Dingleydale and New Forest areas, emerging farmers are using some irrigation to grow vegetables, and maize on a larger scale. These crops are all economically significant, forming a central part of the income for the region's inhabitants.

The nature of the farming activities is predominantly commercial in terms of net value and area under crops in the Olifants East region. The area under irrigation available to emerging and subsistence farmers is limited (30% in Hoedspruit) and undetermined amount in Dingleydale and New Forest, as much of the area is also under land claims. In some cases, where land transfers have already happened, black owners are renting the land to independent contractors (not always local) who are part owned by the owners and who hire locals to work there. The significance of the changing ownership and the impacts of climate change influencing this, adds to the importance of this region as a case study.

Table 42: Overview of the different villages

Village	number of farmers interviewed	Number of farmers part of a farm organisation	Number of farmers with irrigation
New Forest	12	11	12
Dingleydale	11	9	11
Motlamogatsane	8	0	1
Phelandaba	11	0	0

5.4.2 Current and future farming management practices (e.g. fertiliser/manure application, irrigation, tillage practices)

<u>5.4.2.1 Irrigation practices</u>

With the exception of one farmer in Motlamogatsane, who has a drip irrigation system, it is only the farmers in New Forest and Dingleydale that have irrigation. These farmers all work with a flood irrigation system, meaning that the water is transported from dams into large canals and on into smaller canals from which the farmers then channel the water into their field. As they are sharing the water they have schedules that dictate when they can irrigate, and they are given slots either two or three times a week. The irrigation systems are old, built in the 1960s, and the farmers told of recurring problems such as broken canals, silted dams, broken valves and lack of human and financial resources to deal with the problems.

5.4.2.2 Fertilisers

With regards to fertilisers there are differences between the different villages, as can be observed in Table 43 below. The farmers in Phelandaba rely completely on cow, chicken and goat dung, while the farmers in Motlamogatsane also use on KAN as well as methods like using saw dust or dry leaves and grass. Cow dung is the most common fertiliser in both these villages though, and the farmers usually either collected it in the area or get it from their own cows.

In New Forest the farmers most commonly use KAN and 2.3.2, and some also use 2.3.4, 1.0.1. and Promis. The farmers in Dingleydale, while using all the fertilizers used by the farmers in New Forest, also use compost in the form of chicken, goat or cow dung. The costs and availability of fertiliser was a limiting and concerning factor for the villagers.

Table 43: The most common fertilisers and the number of farmers in each village applying them.

Village (number of farmers interviewed)	**KAN**	**2.3.2.**	**2.3.4.**	**3.2.3.**	**1.0.1.**	**Promis**	**Cow/ chi-cken/ goat dung**	**Dry leaves/ grass**	**Saw dust**	**No-thing**
New Forest (12)	12	11	6	0	3	2	0	0	0	0
Dingleydale (11)	11	5	3	2	1	1	6	0	0	0
Motlamogatsane (8)	2	0	0	0	0	0	8	2	1	1
Phelandaba (11)	0	0	0	0	0	0	9	0		1

5.4.3 Organisation of farmers in formal and informal groups.

There is quite a clear division between the farmers in the different villages. Neither of the farmers interviewed in Motlamogatsane and Phelandaba are members of any organisations, while 20 out of the 23 farmers interviewed in New Forest and Dingleydale are in irrigation schemes.

Through the interviews it was found that being part of the irrigation schemes has given the irrigation scheme farmers in New Forest and Dingleydale information and a support structure that the farmers in Motlamogatsane and Phelandaba don't have. For example, the irrigation scheme farmers were found to have acquired a lot more information about insurance and credit options than those farmers in the villages without irrigation, mainly because of the interaction that takes place in the irrigation schemes. Not only do the irrigation schemes seem to work closely with extension officers, but they are also approached and visited by financial institutions that provide information. The farmers in Motlamogatsane and Phelandaba, on the other hand, did not report on any interaction with extension officers, and the only financial institution they had been in touch with was the Women's Development Businesses (WDB).

5.4.4 Existing support service

The Association for Water and Rural Development (AWARD), a South African NGO in the area, had four participatory projects in the Motlamogatsane village, one that worked to limit erosion in the wetland and to help improve farming mechanisms, one that worked to limit erosion in the upland, a governance project and finally a project on intensive food security, where the farmers were encouraged and taught how to start backyard vegetable gardens. So the farmers in Motlamogatsane learned different farming mechanisms by working with AWARD, one of which is to leave the natural vegetation in the wetland and to plant vetiver (a non-indigenous, non-palatable grass) in the upland, in order to limit erosion caused by heavy rainfall and flooding. While the farmers all said that they had learned this adaptation mechanism from AWARD, the one farmer told of how she had seen her mother leaving wetland vegetation, but that she never understood why. AWARD taught her about it she said, and she could then understand why her mother had been doing it. So while it does seem like the farmers interviewed in Motlamogatsane have started using this adaptation mechanism after working with the AWARD team, there is thus also evidence that this mechanism has been used by farmers in the past.

5.4.5 Vulnerability thresholds

Table 44 below gives an overview of the three climatic stressors that were named by emerging farmers with thresholds and future projections in relation to current responses.

Table 44: Outline of current climatic stressors and related responses, thresholds and future projections for emerging farmers in Olifants East

	Late onset	Heavy rainfall/flooding	High temperatures
Nature of stressor (historical records)	High variability in the timing	Average of 18 floods (>100 mm/3 days) in the 35 year period 1960-1995	Low inter-annual variability in mean monthly temperatures
Response mechanisms	Dominated by short term coping mechanisms	Dominated by long term adaptation mechanism (mainly due to response mechanisms used in the one village after cooperation with local NGO)	Dominated by long term adaptation mechanisms, all of which are not widely available to all the farmers
Threshold	Some point in December (only for some crops; madumbis, peanuts and cowpeas)	One day of heavy rainfall can be enough to cause erosion	It becomes difficult to keep crops healthy and alive at temperatures over 40 degrees Celsius
Complicating factors	Other factors than a late onset can trigger a delay in farming activities	The planting time and the age of the crop is important for the impact caused by heavy rainfall	Impact from temperatures depends on water availability
Future projections	Projections indicate wetting in the first half of the rainy season, but the little agreement among the GCM outputs	Projections indicate increase in number of heavy rainfall events (over 50 mm in one day), but there is little agreement among the GCM outputs	Projections indicate a temperature increase of around 2 degrees through the whole year by the middle of this century, and increase in the number of days with over 40 degrees Celsius in the first half of the rainy season.
NET IMPACT	**NOT MEASURABLE**	**MEDIUM TO HIGH IMPACT**	**LOW TO MEDIUM IMPACT**

Small-scale farmers in Bushbuckridge have somewhat limited capacity for dealing with current climatic stress. Climate change projections indicate that small-scale farmers in Bushbuckridge will experience changes in rainfall patterns and increasing temperatures. This further implies that the current thresholds of what the farmers are able to deal with are at the risk of being more commonly exceeded in the future, including the summer rainfall only starting in December, heavy rainfall and flooding around planting times and more frequent days with over 40 degrees Celsius. This reflects the need for considerable focus on adaptation action in the Bushbuckridge area, and on strengthening the farmers' general capacity for dealing with climatic stress. Such focus would be necessary in order to shift the current thresholds to a point where they are not repeatedly exceeded in the future climate.

5.5 Carolina Region

A case study farm was selected in Carolina, Mpumalanga to model the impact of climate change on a typical summer rainfall dryland farming system. Owing to the TOR of the project and budget constraints, no survey was done in the surrounding area of the farm. The participating case-study farm has a high level of record keeping and provided most of the information needed to do the modelling.

Agriculture in the Middelburg region, where Carolina is located, is generally dominated by extensive grain production and the grazing of beef cattle and sheep. Mainline grain production includes maize, sugar beans, soybeans and sunflowers.

5.5.1 The existing sources of livelihoods

Main crops produced in the area include maize, sugar beans, soybeans and potatoes. Livestock production consists mainly out of cattle (weaner production), sheep (mutton and wool production) and dairy production.

The case study farm has typical Highveld mixed farming activities consisting of grain and livestock production. Activities include weaner calf, lamb and wool production.

5.5.2 Current and projected future crop yields and carrying capacities

5.5.2.1 Current yields

Table 45 displays the current average crop yield for different crops.

Table 45: Average crop yields – Carolina case study

Crop	Yield (t/ha)
Maize - dryland	6.0
Sugar bean - dryland	2.0
Soybean - dryland	2.0

Source: Own calculations, with inputs from case study farmer

5.5.2.3 Future yields

ACRU model projections

As a model of intermediate complexity in respect also of its crop yield modules, the ACRU maize yield model is phenology and daily soil water budget based.

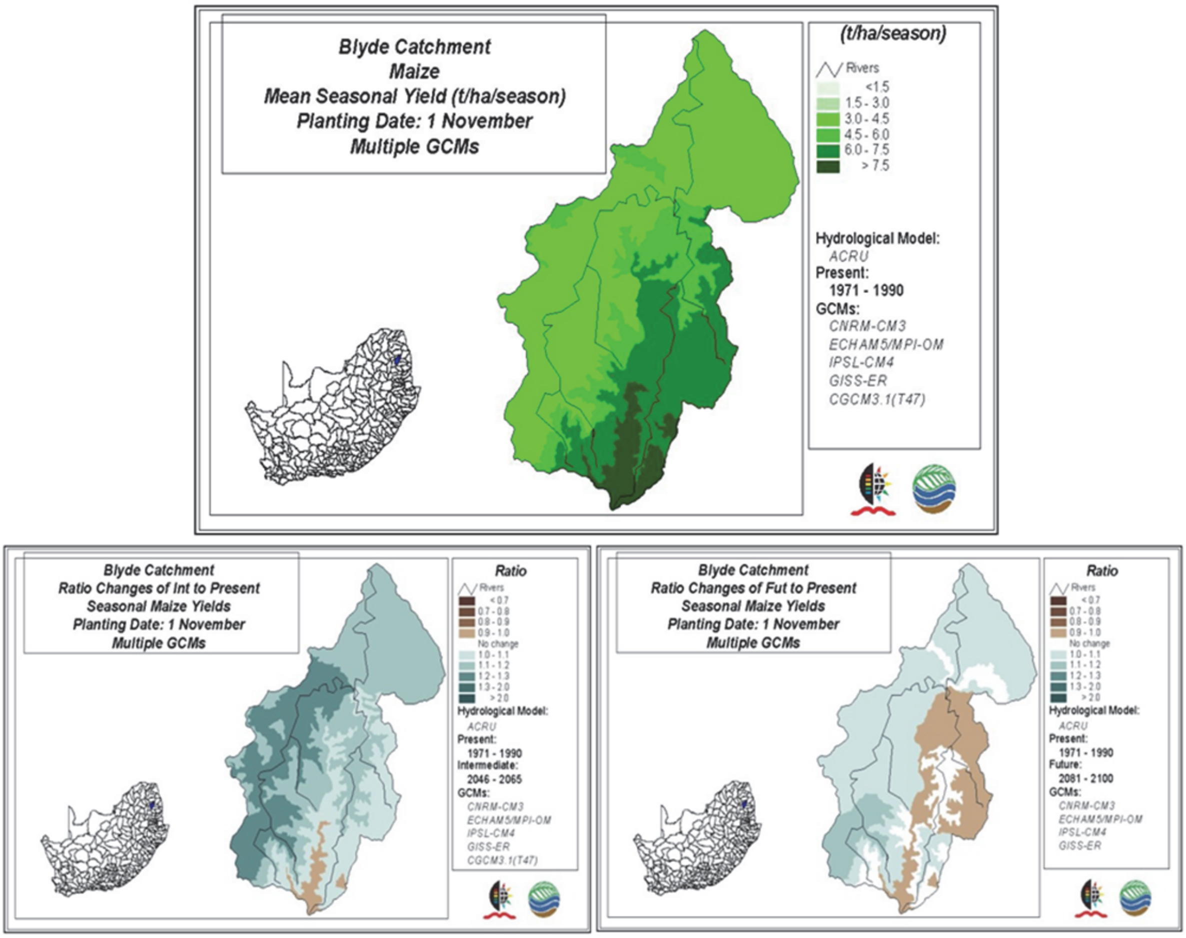
At the outset, two points should be noted from Figure 32, viz.

- For all maize yield and associated analyses in this report the baseline used for comparisons was not derived from the 50 year (1950-1999) historical record, as in other analyses, but rather the mean of values derived for the present period (i.e. 1971-1990) from the multiple GCMs used in this study.

- In all analyses on maize the option available in the ACRU model to account for the so-called CO_2 “fertilization effect”, effectively through transpiration suppression by this C4 plant, was not invoked because of uncertainties remaining on the effect on the long term and under large field conditions.

The summer rainfall Blyde catchment is clearly climatically suitable for maize production (at a 1 November plant date), with the lowest means of seasonal yields in excess of 3 t/ha/season, and parts of the southwest showing that under sound management mean yields of the order of ~ 7.5 t/ha/season could be attained.

Maize yield projections into the IF in the Blyde catchment from the climates of the multiple GCMs used with the ACRU model, on the other hand, show increases of 10-100%, with the highest projected increases in the west where yields could possibly change from ~ 3 to ~ 5-6 t/ha/season (Figure 32, bottom left). These projected increases are dampened into the MDF, with the presently high yielding southeast showing maize yield reductions of up to 10%.



(Mean seasonal dryland maize yields in the Blyde catchment, estimated by the ACRU model under present climatic conditions (top) and projected changes into the intermediate future (bottom left) and the more distant future (bottom right))

Figure 32: Mean seasonal dryland maize yields in the Blyde catchment

For further descriptions on the modelling results, see Appendix C.

Simulating future maize yields in Middelburg with APSIM

The data available to set up the model were sufficient to run the model and to present the following results. However, these data are not representative of the fine scale APSIM can deal with, and translate generic soil conditions and generic crop managements. Hence we advise any user of this data not to extrapolate information from a resolution higher than the data resolution inputs.

In order to present a descriptive interpretation of various future climate projections, we present the following results for the A2 and B1 CO_2 emission scenarios (SRES), and for 15 GCMs (9 with A2 and 6 with B1).

Figures 33 to 38 show the simulated rainfed maize yields on the y-axis, against its ranked occurrence (percentile) on the x-axis. Hence the reader can appreciate the response to multiple GCMs and multiple years, the worst possible output under percentile 0, the best possible output under x-axis percentile 1, and the evolution from the former to the latter, particularly taking not of the median case for percentile 0.5. We expect these statistical plots to provide a general sense as well as a sense of variability of the biophysical response under future climate.

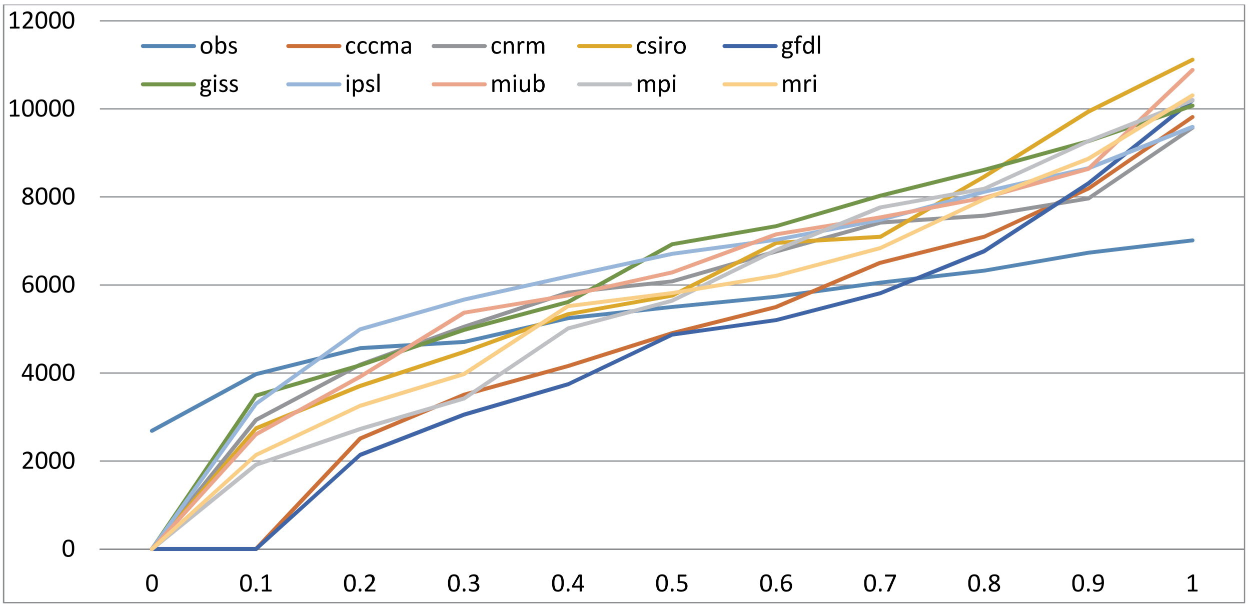


Figure 33: Simulated maize yield under observed (1979-1999) and control (1961-2000) climates

The control simulations are consistent with the simulated yield computed with observed weather data, except for worst case scenario (<= 10^{th} percentile). This is likely due to the mathematical nature of the crop model, where a crop can die simply by reaching a mathematical threshold, which in the field hardly result in a complete/total loss. The control simulations seem to increase the variability of the simulated yields, as we can see low yields being mostly underestimated and high yields mostly overestimated compared to the simulations ran with observed data.

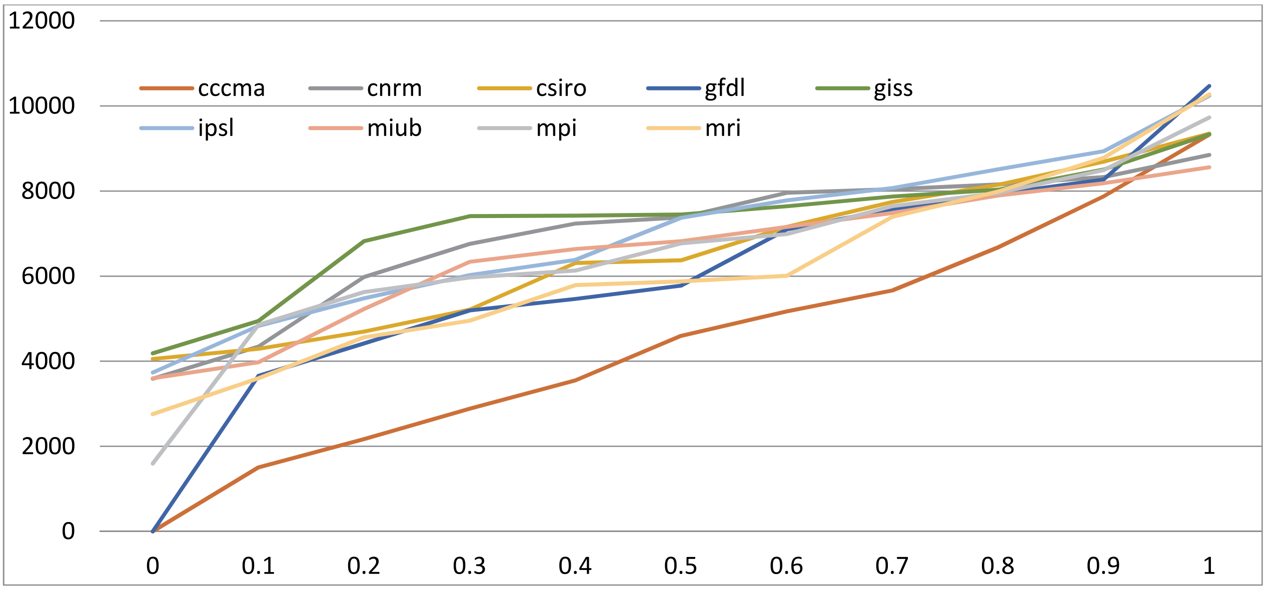


Figure 34: Simulated maize yield under future climate (2046-2065) for 9 GCMs driven by SRES A2 emission scenarios.

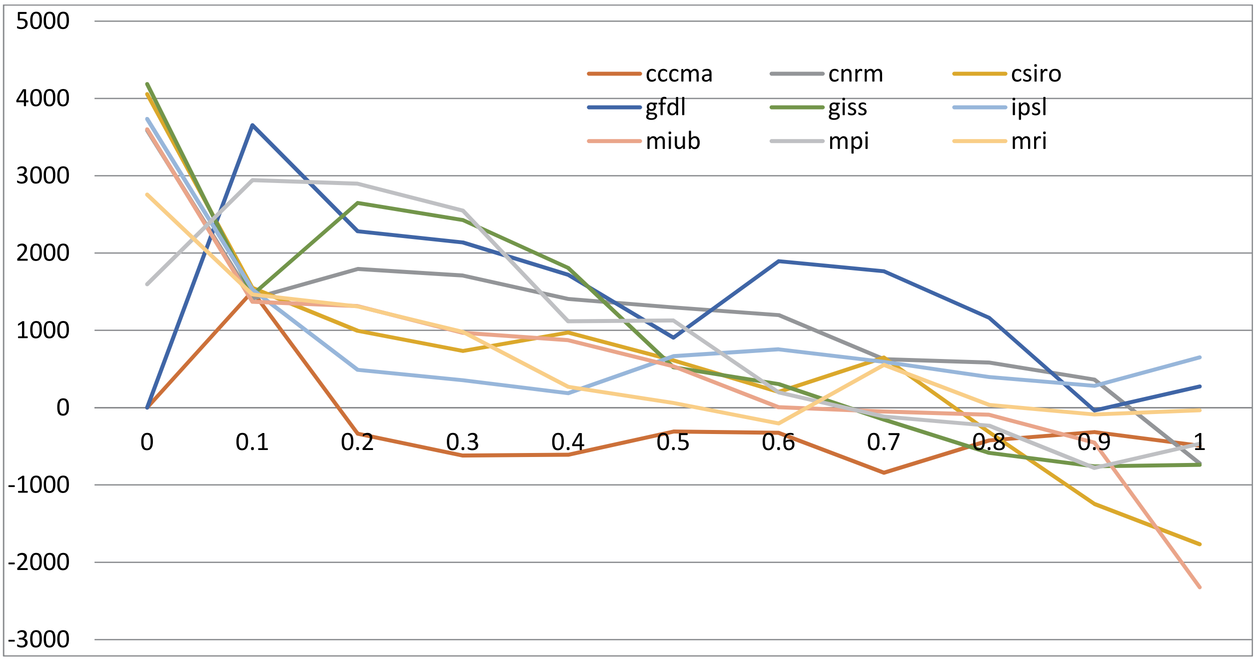


Figure 35: Changes in maize yield (future minus control) under SRES A2 emission scenario

The CCCMA GCM projections (SRES A2) stand apart from the 8 other GCMs. It shows a decline of yields simulated straight from low yields, while the 8 other GCMs project a noticeable increase for low yields and this anomaly diminishes toward higher yields, at which point there is no evidence of a change.

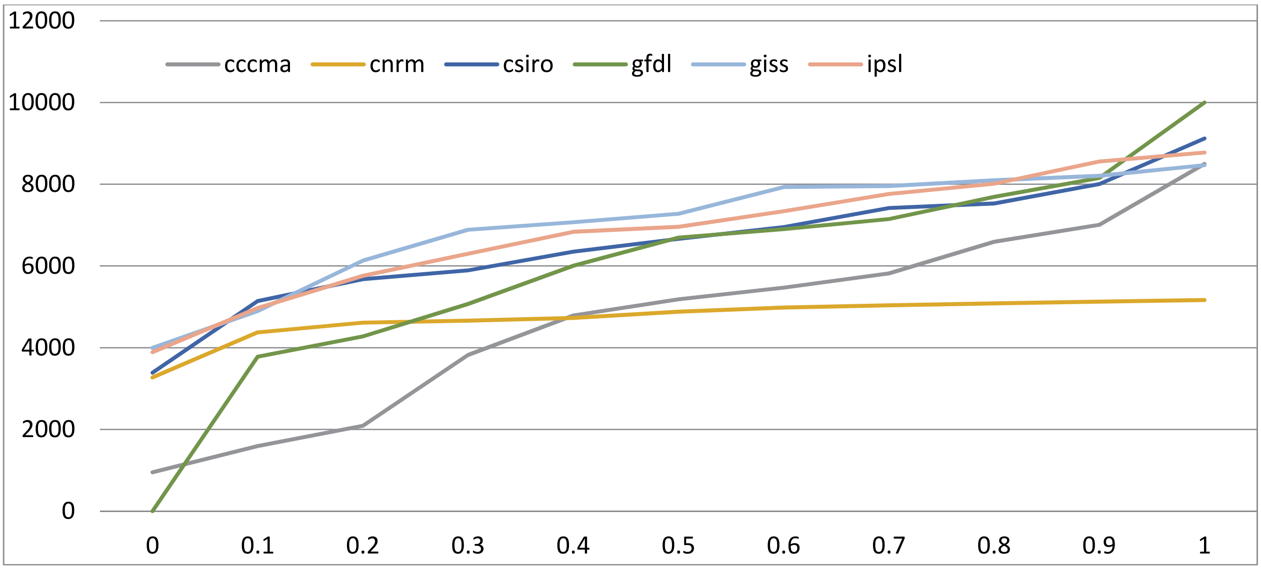


Figure 36: Simulated maize yield under future climate (2046-2065) for 9 GCMs driven by SRES B1 emission scenarios.

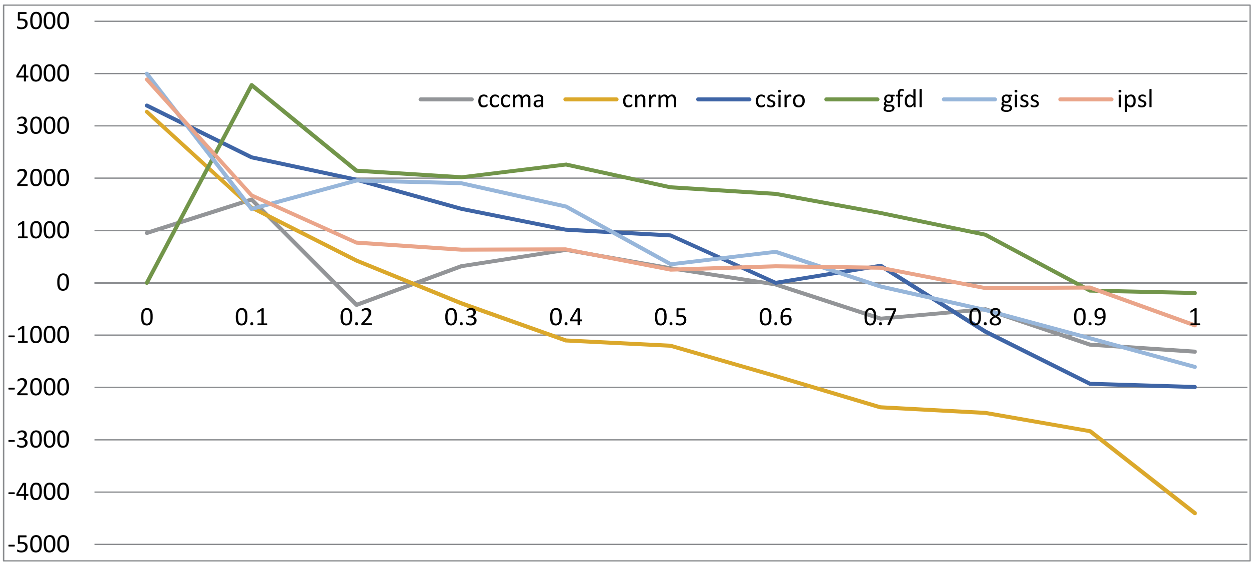


Figure 37: Changes in maize yield (future minus control) under SRES B1 emission scenario

Under SRES B1 all GCMs show a noticeable increase for low yields, no sensitive change for the median and a consistent decline of high yields.

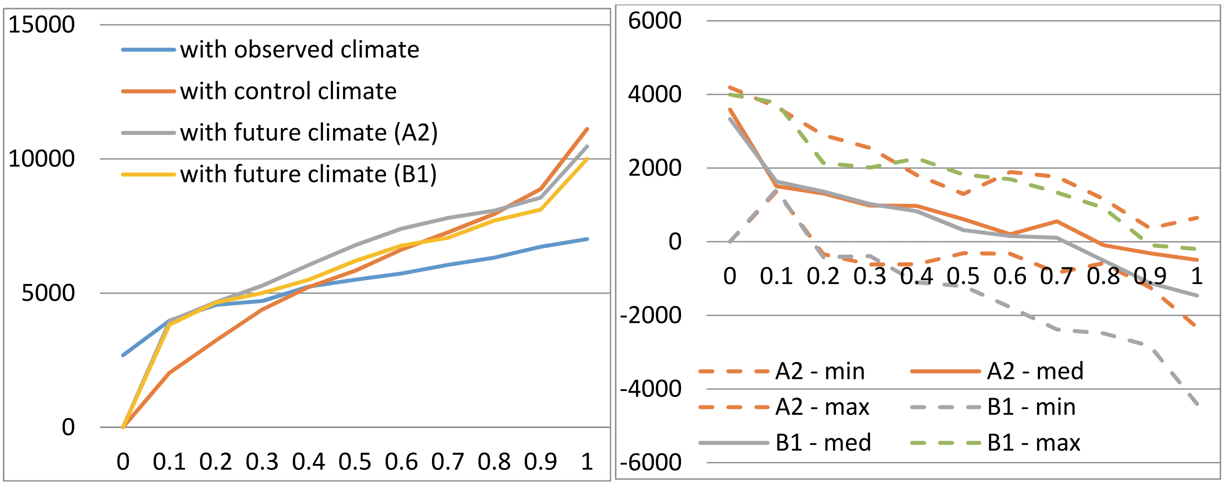


Figure 38: On the left, simulated low to high rainfed maize yields in Middelburg under observed (1979-1999), control (1961-2000) and future (2046-2065) for 9 GCMs driven by A2 scenario and 6 GCMs driven by B1 scenario. On the right, minimum, median and maximum changes simulated (future minus control).

As an attempt to summarise the former results, we show in Figure 38 the average simulated yield for observed, control and futures under SRES A2 and B1, as well as a detailed minimum-median-maximum changes from control to futures (A2 and B1).

The production variability from low to high yields shown on the left confirms that the climate baseline is less variable that the GCMs controls. This is especially true for high yields independently of the SRES scenarios. The results from the right on Figure 38, suggest a low yield increase – high yield no change linear trend. This seems to translate both SRES A2 and B1 in the same proportion, and even the various GCMs. Results show a median increase of 38% for low yields (20th percentile), a median 10% increase for median yields (50th percentile) and a median insignificant 1.9% decrease for higher yields (80th percentiles). These observations are consistent for all but one GCMs (CCCMA), and for both A2 and B1 scenarios.

5.5.3 Projected shifts in optimum cropping areas

Some preliminary model projections have been made for maize, wheat and soya by Schulze (2011) and Estes et al. (2013) and these show changes in crop suitable areas, where the largest areas of lost suitability is found in the Free State, North-West and Limpopo Provinces, while modest gains in suitable areas are to be found in the Eastern Cape and Mpumalanga. (see Figure 39)

In the Blyde and Olifants irrigated catchment areas, the suitability is merely a function of temperature and as such can be measured by changes to yield and not spatial suitability. The modelling results are covered in the above report.

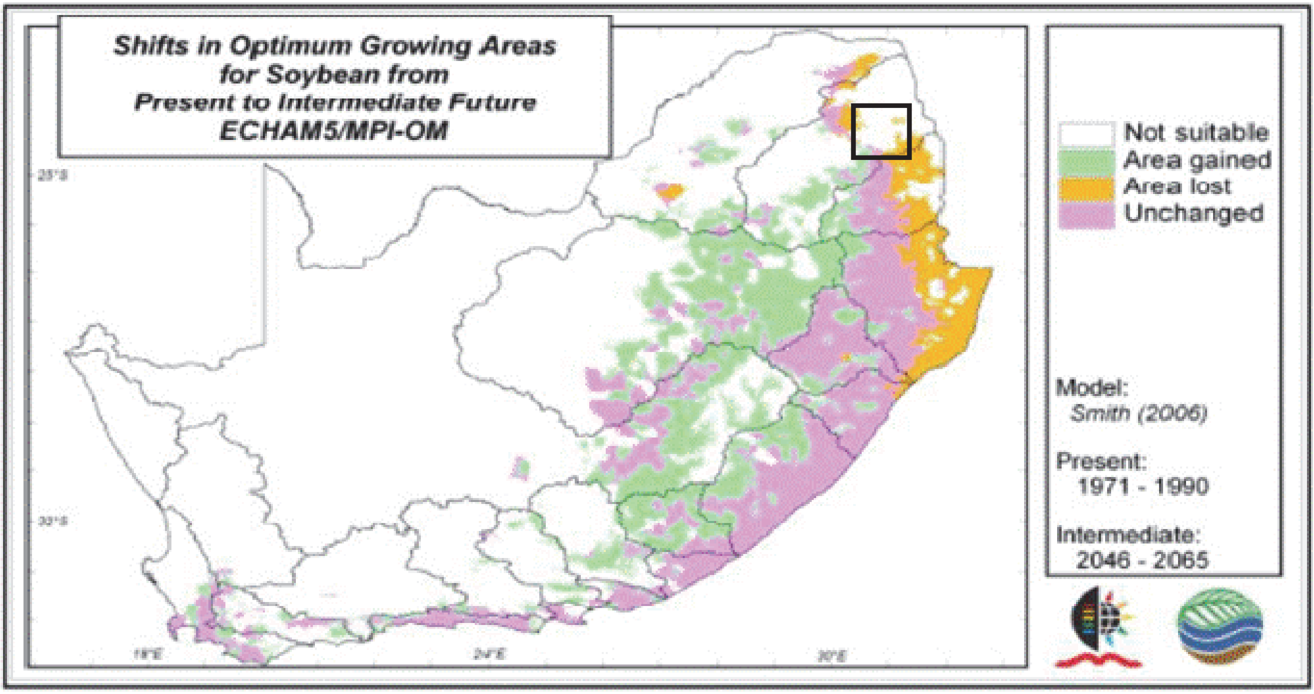


Figure 39: Shifts in optimum growing area for soya (Schulze, 2011) – case study area in block.

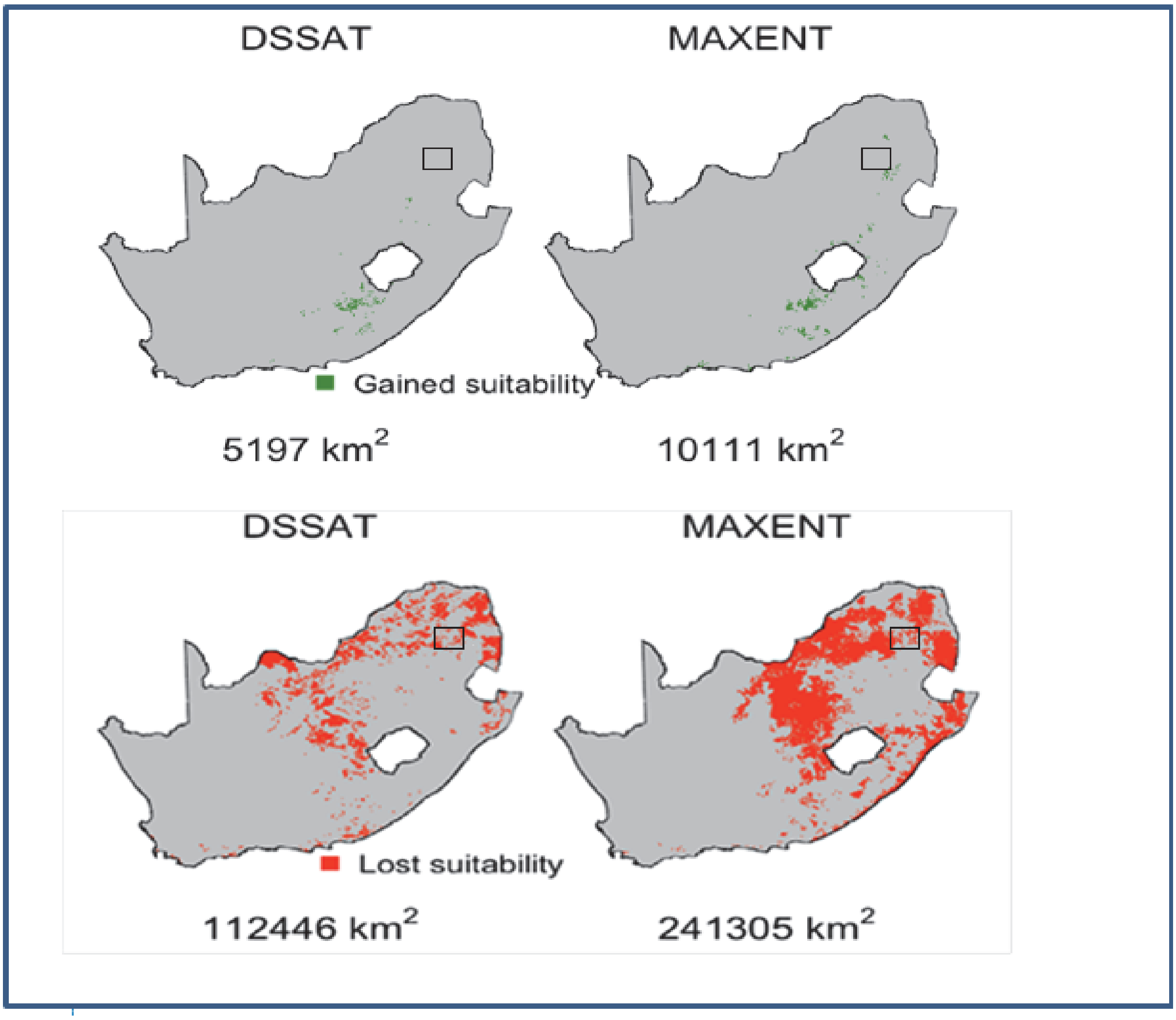


Figure 40: Gain/Loss of suitability for growing maize (Estes et al., 2013) – case study area in block

5.5.4 Current and future farming management practices (e.g. fertiliser/manure application, irrigation, tillage practices)

5.5.4.1 Soil characteristics

Table 46 illustrates the soil characteristics in the Carolina area.

Table 46: Soil characteristics – Carolina

Location (Quinary nr.)	Thickness of Topsoil (m)	Thickness of Subsoil (m)	Wilting Point of Topsoil (m/m)	Wilting Point of Subsoil (m/m)	Field Capacity of Topsoil (m/m)	Field Capacity of Subsoil (m/m)	Porosity of Topsoil (m/m)	Porosity of Subsoil (m/m)	Saturated Drainage (fraction/ day)
0429	0.3	0.58	0.116	0.158	0.205	0.243	0.456	0.433	0.44

Source: School of agricultural, earth and environmental sciences, UKZN (2012)

The soils characteristics are area weighted from the land type information in the ISCW soils database (ISCW, 2005) for the Quinary Catchment in which the location of interest is sited. The 4-digit number (location) is the Quinary number in the SA Quinary Catchments Database (Schulze et al., 2010). The methods by which these characteristics for a 2-horizon soil have been derived are described in Schulze and Horan (2008) using the AUTOSOILS decision support system developed by Schulze and Pike (1995 and updates). Values of wilting points, field capacities and porosities (i.e. at saturation) imply the soil water content (in meter of water per meter thickness of soil) at those thresholds. Saturated drainage implies the fraction of soil water above field capacity that drains into the next horizon (i.e. from the topsoil to the subsoil or from the subsoil out of the active rooting zone) per day. From the characteristics in the table the soils tend to have a sandy loam texture at Carolina.

5.5.4.2 Adapted crops for the region

Main crops produced in the area include maize, sugar beans and soybeans. Livestock production consists mainly of cattle (weaner production), sheep (mutton and wool production) and dairy production.

Table 47 reflects the physiological lifecycle of maize, sugar beans and soybeans.

Table 47: Physiological lifecycle of maize, sugar beans and soybeans

Maize	
Planting	Oct and first half of Nov
Germination	Nov
Leaf development stage	Nov, Dec to mid Jan
Plume & cob development	Mid Jan to end Feb
Harvesting	May, Jun and Jul
Sugar beans	
Planting	Mid Nov
Germination	Nov
Leaf development stage	Dec to mid Jan
Flowering stage	Mid to end Jan
Pods development	Feb
Harvesting	Mar
Soybeans	
Planting	Mid Nov
Germination	Nov
Leaf development stage	Dec to mid Jan
Flowering stage	Mid to end Jan
Pods development	Feb
Harvesting	Apr - May

Source: Carolina workshop and expert group discussions (2012)

5.5.4.3 Current cultivation practices

Table 48 summarises the current cultivation practices for maize, soybeans and sugar beans in the Carolina area.

Table 48: Current cultivation practices

Cultivation practice	Maize - dryland
Optimum planting dates	Oct
Lifespan	1 year
Harvesting dates	May - Jul
Nitrogen application	Oct - 20 kg/ha Dec - 90 kg/ha
Cultivation practice	**Soybeans - dryland**
Optimum planting dates	Nov
Lifespan	1 year
Harvesting dates	Apr - May
Nitrogen application	Nov - 10 kg/ha
Cultivation practice	**Sugar beans - dryland**
Optimum planting dates	Nov
Lifespan	1 year
Harvesting dates	Mar
Nitrogen application	Nov - 20 kg/ha

Source: Carolina workshop and expert group discussions (2012)

The case study farm has typical Highveld mixed farming activities consisting of grain and livestock production. Activities include weaner calf, lamb and wool production.

Table 49 reflects the carrying capacity for the farm.

Table 49: Carrying capacity – Carolina case study

Carrying capacity	
Natural veld	3 ha/LSU/year
Natural veld	1 SSU/ha/year
Field (post harvest)	1 LSU/ha for 75 days
Field (post harvest)	6 SSU/ha for 75 days

Source: Case study farmer (2012)

5.5.4.4 Crop rotation practices

Crop rotation includes maize and soybeans/sugar beans.

5.5.5 Appropriate household and whole farming systems modelling

5.5.5.1 Case study farm

Table 50 reflects the composition of the summer rainfall dryland case study farm.

Table 50: Description of case study farm: Carolina

Description	
Farm size	3 305 ha
Dryland	1 050 ha
Pastures	70 ha
Veldt	2 170 ha
Odd	15 ha
Total farm size	**3 305 ha**
Land use	
Cash crops	
Maize dryland	700 ha
Sugar beans dryland	50 ha
Soybeans dryland	300 ha
Total area cash crops	**1 050 ha**
Livestock	
Cattle (producing cows)	600
Sheep (producing ewes)	2 500
Valuation of farm	**(R)**
Fixed improvements	5 000 000
Vehicles, machinery, implements, livestock, etc	26 363 500
Land	57 325 000
Total assets	**88 688 500**
Liabilities	**(R)**
Short-term	11 000 000
Medium term	1 200 000
Long-term	16 500 000
Total liabilities	**28 700 000**
Net asset value	**59 988 500**
Debt ratio	**32%**

Source: Case study farmer's records (2012)

5.5.5.2 Crop Enterprise budgets

Tables 51 and 52 summarise the crop enterprise budgets for the Carolina case study.

Table 51: Crop enterprise budget summary: maize, sugar beans and soybeans

	Maize - dryland	Sugar bean - dryland	Soybean - dryland
Yield (tonne/ha)	6	2	2
Price per tonne (R)	1 800	8 000	4 500
Income/ha (R)	10 800	12 000	8 100
Total cash expenditure/ha (R)	6 062	7 352	4 890
Margin above specified costs (R)	4 738	4 648	3 210

Source: Own calculations, with inputs from case study farmer

Table 52: Crop enterprise budget summary: beef and mutton production

Assumptions - beef production	
Weaning %	80%
Weaning weight (kg)	220 kg
Price/kg [R]	R16
Income and cost	
Income per cow	R2 816
Total cost per cow	R1 000
Net income per cow	R1 816
Assumptions - mutton production	
Weaning %	90%
Weaning weight (kg)	22 kg
Price/kg [R]	R45
Kg wool/ewe	2 kg
Price/kg [R]	R75
Income and cost	
Income per ewe	R1 041
Total cost per ewe	R 340
Net income per ewe	R 701

Source: Own calculations, with inputs from case study farmer

5.5.6 Organisation of farmers in formal and informal groups. Existing support service.

5.5.6.1 Organisation of farmers in formal and informal groups

The reader is referred to Appendix C for details regarding the discussions with farmers and cooperative members. Farmers belong to study groups.

5.5.6.2 Existing support services

Farmers study groups are organised by AFGRI, the local silo/cooperative which offers assistance in respect of seed, pesticide, herbicide and fertiliser requirements as well as informal study groups.

CHAPTER 6 : SCOPING OF EXISTING ADAPTATION PRACTICES AND TECHNIQUES

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3. University of KwaZulu-Natal

6.1 Background

To assess the farming vulnerabilities farmers and experts were asked about climate related thresholds (mostly temperature and rainfall) that would cause significant reduction in crops. The results provided a very interesting range of conditions which were validated at a second interaction with other stakeholders. The next step was to determine what the likelihood is of a future climate in the study areas of breaching these thresholds.

An adjunct to these questions was a survey of any existing adaptations that farmers have made in response to existing changing conditions. These are not specifically adaptations to climate change but more responses to existing climate variability. Many stakeholders have their own opinions about climate changes that they have perceived to have occurred, and it is not part of this research to determine the validity of these perceptions, but each farmer responds to climate risk in a way that may be unique. It was found that due to communication channels and organisations, the responses by farmers were generally used throughout the communities.

The degree of climate variability ranged from extreme long-lived events such as drought and major flooding, to the individual short-lived events like very hot days (or nights), hailstorms, or very intense rainfall, or wind. In most cases farmers responded in one of two ways; as a response to an event to reduce the follow-on impact, or as a proactive measure to reduce the impact of a re-occurring future event.

“Adaptation” refers to the adoption of appropriate coping strategies to minimise any negative effects of climate change and includes a range of activities, such as response farming, crop selection and breeding, animal selection, rainfall use efficiency, timing of agricultural activities, etc.

6.2 Adaptation to climate change in the South African agricultural sector: some introductory thoughts (Schulze 2013)

- Adaptation to climate change implies a range of measures to cope with and possibly overcome the challenges of, and vulnerabilities to, climate change.
- By formal definition adaptation includes “initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types

of adaptation exist, e.g. anticipatory, and reactive, private and public, and autonomous and planned" (IPCC, 2007, p 76).

- Climate and climate change issues are superimposed upon the multiple other challenges, problems and stressors the South African agriculture sector already faces (e.g. globalisation, urbanisation, environmental degradation, disease outbreaks, market uncertainties, higher fuel and machinery costs, policies concerning water / field burning / overgrazing and land redistribution, or slow responses from authorities), and that together these affect future planning strategies (Andersson et al., 2009).
- To varying degrees, farming communities already cope with, and adapt to, a variable climate.
- The key to enabling communities to deal with an uncertain future climate is to identify their vulnerabilities and investigate ways of reducing their exposure, including existing strategies used by them and others, leading to the adoption of adaptation strategies.

Adapting to projected climate change in South Africa's agriculture sector will mean that commercial farmers optimise climatic conditions to maximise output in a sustainable manner while maintaining a competitive edge. At the rural livelihood scale, on the other hand, adaptation needs to focus on the most vulnerable groups and areas, so that livelihoods are not eroded by climate events, but rather that the affected communities become more resilient to the expected changes in climate. For both sets of farmers, adaptation will require an integrated approach that addresses multiple stressors, and will have to combine the indigenous knowledge/experiences of vulnerable groups together with latest specialist insights from the scientific community.

Most agricultural programmes and information are initiated at high levels in government for regional implementation and are not always adapted to local conditions. However, all agricultural programmes and planning strategies in regard to climate change will need to focus on local conditions, as climate change will have very local repercussions (Schulze 2011).

6.3 Existing coping strategies, practice and techniques

In each study region, workshops were held and farmers were asked about their vulnerabilities and current coping and adaptation strategies. Their strategies, practice and techniques are highlighted in **bold text** in this section

6.3.1 Olifants East (Mangoes, citrus)

The current farming management practices and possible future farming operations were discussed during a workshop in Hoedspruit on the 16th of April and followed up with discussions with experts after the workshop. The following key elements and adaptation responses were highlighted:

- If the season shifts forward by a week or two for mangoes, it will have major price implications since the highest sales and prices are obtained between Christmas and New Year. A decrease of 30-40% will not be uncommon especially for the Tommy Atkins cultivar. **It would be necessary to switch to other cultivars.**

- The quality of navel oranges will drop if climate change result in warmer winter temperatures and it will also be necessary **to consider other cultivars to counter this impact.**
- There seem to be an increase in the occurrence of hail storms which is disastrous for any producer affected. **The only adaptation is to construct hail nets which are extremely expensive (R130 000 per ha).**
- The only **alternative crop which may be considered in this region is sugarcane**. Papayas are not an option if there is an increase in temperature and if there is more wind.
- There will also be an impact on the fertiliser requirement for crops. High rainfall will increase leaching of chemicals and will result in an **increase in fertiliser application** and cost.
- More rainfall will also impact on the spraying program for pest control (**increased frequency of spraying – increased costs**).
- More rainfall will require that all trees to be planted on **ridges. Higher establishment costs (R4000 per ha for ridging).**
- In general, farmers are of the opinion that **more mangoes will be planted** compared to citrus if there is an increase in rainfall and temperature.
- **Net houses** for citrus (prevent hail, wind and decrease variation in fruit quality)
- **Seeded citrus cultivars** do better – negotiations with retailers
- **Ridging** between trees (to improve drainage)
- **Dripper irrigation** improves accuracy to control ground moisture
- **Improved rootstocks** to cope with pathogens
- **Mango caps** for sunburn (cheaper than net houses)
- **Net houses** for mangoes (to initiate earlier fruit set)
- **Improved pruning** techniques
- **Ripening rooms** for mangoes
- Alter and **change spraying programs**
- **Genetically modified cultivars**
- Spray **chemicals** to reduce temperature
- **GIP** – to get better cropset in mangoes
- **Low seeded mango cultivars**
- **De-greening rooms** for mangoes

6.3.2 Carolina (maize, soya)

The current farm management practices were discussed in a previous report. During a discussion with the case study farmer on the 17th of April 2012, and followed up by a validation workshop on the 3rd of October 2012 with an expert group the following key elements and adaptation responses were highlighted:

- They plant as soon as it is physically and climatically possible and they **plant short to medium grower cultivars to reduce risk**. There are hardly any farmers who still plant long growers.
- Adaptation strategies include the following:
  - **Decrease in row spacing to get more shade on the soil**
  - **Short growing cultivars**
  - **Low pressure pivots**
  - **Use of no-till /strip-till practices**
  - **Better moisture management**
  - **Improving soil health**
  - **Correct crop rotation**
- **Grain sorghum and sunflowers are adapted crops for the region**.

6.3.3 Olifants West (Wine grapes, table grapes & raisins)

The current farm management practices and possible future farming operations were discussed during a workshop in Vredendal on the 11th April 2012 and followed up by a validation workshop on the 17th September 2012 with an expert group. The following key elements and adaptation responses were highlighted:

- **Plastic liners** placed on the ground (improve water efficiency)
- **Cover ground** with crude material and or **mulch** (improve water efficiency)
- **Cultivar selection** – with shorter growth periods/different areas/more heat resistant
- **Scale down production** and irrigate optimally
- **Apply Dormex** to control bud break
- Increase production of **table grapes** (red seedless)
- Increase production of **currants and raisins**
- **Increase farm dam capacity** for winter storage – citrus production
- Table grapes – summer rain – **cover shade nets with plastic**
- Use less water with **crops that are physical-biological adapted** to the area
- **Plant under plastic cover** – higher soil temperature, use less water, less weed
- **Shift planting season** later
- **Sprinkler irrigation cools down temperature** – but less efficient
- To save water one can **irrigate at night** – this adaptation strategy however doubles capital cost
- **Shade nets** can eliminate a lot of climate change problems (heat, sunburn, hail) – the capital cost of this is however very high
- Mist spray under shade nets
- **Soil preparation and site selection** will become more and more important for future plantings

- **Increase table grapes and raisins** – new cultivars perform very well
- **Micro irrigation instead of drip** – to cool down vineyards
- **Date fruit production** identified as the only viable alternative crop on a large scale for the region

6.3.4 Moorreesburg (wheat)

During a discussion with MKB experts during April 2012 and followed up by a validation workshop on 10th September 2012 with an expert group the following key elements and adaptation responses were highlighted:

- The level of Nitrogen fertilization depends on the availability of moisture in the soil. If the rainfall decreases, it will result in **less nitrogen which can be applied** accompanied by a decrease in yield.
- A soil temperature of 18°C plus will result in improved germination and increase the yield potential. Farmers indicated that for about 7 out of 10 years, **farmers which were in a position to plant in April (earlier)** had a higher yield since the plants are better developed and more resilient to drought and diseases.
- There is a huge difference between conventional and no-till cultivation practices. With no-till plants can still survive after 14-days with no rainfall with the exception of August/September when even with no-till cultivation there will also be losses. **More and more farmers are switching to no-till.**
- Farmers are keeping **more livestock** as an adaptation
- Also considering **GM seed**.
- Farmers are **growing more medics and less wheat** to provide grazing instead of crop
- Changing to **low cost-low yield** system
- **SAFEX futures** can help to reduce risk.

6.3.5 Olifants East/Inkomati (small scale/subsistence)

As was outlined in section 5.4.5 farmers highlighted three climatic stressors that affect their activities:

- Delayed or unpredictable rainfall
- Heavy rainfall
- High temperatures

When considering the responses to climatic stress, the research found that farmers mainly employ short-term coping mechanisms for dealing with delays and variability in the timing of the onset. Therefore, while the farmers get by from season to season, they have few mechanisms by which they can override, and permanently reduce their vulnerability to variability and delays in the timing of the onset. There is the constant threat of experiencing crop losses if the rains do come late or at unexpected times. This is of concern, especially given that the climate is projected to change into the future. While it has been difficult to detect specific trends in the rainfall projections, there are indications that September through November could get wetter. This could be positive for the farmers, as wetting in the start of the rainy season could mean that the onset of the summer rainfall would not shift to later in the year. It would also mean that farmers would experience a good start for the season, with sufficient moisture.

The second climatic stressor investigated was heavy rainfall. Farmers were found to have a number of adaptation mechanisms to respond to this, mainly due to the work of a local NGO, AWARD. These mechanisms that limit erosion, were mainly used in Motlamogatsane, the village where AWARD had been working, and were not found to have spread across to other villages. Based on these findings it therefore seems that some of the farmers, more specifically those from Motlamogatsane, are more capable of dealing with erosion than are farmers from the other villages.

Rainfall projections indicate, with relatively low confidence, that the number of rainfall events with over 50 mm in one day could increase slightly in parts of the first half of the rainy season. If this was to happen, there should be concern, as this is the time of the season when crops are young and weak. As the farmers interviewed highlighted, young crops are more likely to erode than older crops when exposed to heavy rainfall.

Due to the low confidence found in the rainfall projections, there should be caution with regard to how rainfall related issues are addressed. Research, projects and other interventions focusing on promoting adaptive actions, should thus be cautious with introducing adaptation mechanisms concentrating on specific changes in the rainfall. Rather than for example focusing on heavy rainfall in the first part of the season specifically, there should be a focus on managing heavy rainfall and erosion through the whole rainy season. Generally speaking, this reflects the need to shift from a deterministic view on seasonal rainfall patterns, towards strengthening farmers' capacity to deal with more unpredictable rainfall patterns.

For dealing with high temperatures, farmers were found to have a number of adaptation mechanisms, some of which are not accessible to many of the farmers due to the related costs. Importantly, many of the farmers said that there is nothing they can do about high temperatures, as they cannot afford options such as nets, which is not to say that there are no affordable adaptation mechanisms. The work that AWARD did on erosion with the farmers from Motlamogatsane shows how affordable and accessible adaptation options can be discovered through a process of reflection and knowledge sharing within the community.

As has been outlined above, small-scale farmers in Bushbuckridge have somewhat limited capacity for dealing with current climatic stress. Climate change projections indicate that small-scale farmers in Bushbuckridge will experience changes in rainfall patterns and increasing temperatures. This further implies that the current thresholds of what the farmers are able to deal with are at the risk of being more commonly exceeded in the future, including the summer rainfall only starting in December, heavy rainfall around planting times and more frequent days with over 40 degrees Celsius. Projections, together with the fact that historical data from the area are also showing trends of temperature increases and drying, reflect the need for considerable focus on adaptation action in the Bushbuckridge area, and on strengthening the farmers' general capacity for dealing with climatic stress. Such focus would be necessary in order to shift the current thresholds to a point where they are not repeatedly exceeded in the future climate.

6.4 Adaptation and coping strategies, practices and techniques (both indigenous and science-based knowledge) which may be appropriate for the selected case study areas.

Adaptation plans in the South African agriculture sector aim at identifying existing climate related problems and current mechanisms of coping with those, then undertaking local assessments of vulnerability to projected changes in climate and, on the basis of those, to make recommendations on adaptation strategies for action in the future.

Adaptation plans need to be joint productions of various stakeholder groups in agricultural and water resource management, with climate/agriculture/water resource experts acting as information providers and facilitators.

According to Andersson et al. (2009), the rationale behind adaptation plans is that:

- adaptation strategies emanating from authorities and/or experts should be ratified by local actors; that
- knowledge and information should be multi-directional between agricultural stakeholders, planners and researchers; and that
- the process must be seen to increase understanding between involved groups.

This adaptation and mitigation plan must not be seen as an end in itself, but rather as constituting one step in an ongoing process of refinement and enhancement of needing to cope with projected future climates in the South African agricultural sector.

ICLEI (2012) have proposed a schematic to represent the stakeholder adaptation cycle, involving authorities and scientists as well as SMART[2] goals (see Figure 41).

[2] SMART stands for Specific, Measurable, Achievable, Realistic and Time-framed, and is a tool to set feasible goals and to identify the different steps that are necessary for the implementation of adaptations

Figure 41. The stakeholder adaptation cycle (from ICLEI, 2012)

Below is a summary of recommendations on adaptation options for the South African agriculture sector, adapted from Schulze (2013).

6.4.1 Introduction to adaptation and coping

It is important to extend focus to all vulnerable groups, and vulnerable areas, so that livelihoods are not eroded by climate events, and that the affected communities rather become more resilient to the expected changes in climate. This requires an integrated approach that addresses multiple sectors, whilst combining the indigenous knowledge/experiences of farming communities, together with latest specialist insights from the scientific community.

Most farmers, who are adapting, are adapting to climate variability and some observed climate change that is being detected now, whereas changes in the future may require completely different adaptations.

Many agricultural programmes and information are initiated at high levels in government and are not always adapted to local conditions. Agricultural programmes and planning strategies need to focus on local conditions, especially in regard to climate change which will have a very specific spatial character.

6.4.2 Climate related changes

Farmers in the study areas of this project will need to adapt to (or continue to have to cope with) the following projected climate changes, which are likely to vary from region to region within South Africa:

- **Increased unpredictability and variability of rains**: There are signs that some locations will experience an overall earlier or later start to the rainy season (with a threshold date after which planting can no longer take place), too little rain at planting and critical phenological stages (e.g. flowering in maize), or increases in season-to-season rainfall variability.
- **Increased temperatures** across the board. The intricacies of this increase are not always obvious. For example, grape farmers in the Vredendal district remarked that the maximum temperature is not necessarily a threat unless the corresponding minimum is also high. The lack of cooling overnight is, for them, a bigger issue.
- **Frost days**: Projections show changes in the beginning and end of the frost season and in numbers of days with frost, with knock-on effects on climatic suitability of crops, plant dates or pest/disease incidence and adaptation in regard to the use of shade cloths being used to minimise frost damage.
- **Chill units**: chill units being recorded later and fewer in total, with farmers possibly having to change fruit types (e.g. from apples to pears) which require fewer chill units or move upslope to cooler microclimates or move to colder areas within South Africa.
- Increased **exposure to erosion**: Where soils are projected to dry out more frequently or for longer periods at a time, measures will be required to prevent and reduce enhanced wind and water erosion.

6.4.3 Conservation agriculture

Conservation agriculture (CA) is an integrated approach addressing multiple sectors, including in-field rainwater harvesting, roof and road runoff water collection to supplement irrigation, and organic and precision farming. The benefits of CA are well established at small scales, and are currently being quantified at commercial farm level and compared to conventional production methods (Smith et al., 2010). Adoption of CA practices by the commercial and household food security sectors is comparatively low (Smith et al., 2010), as the adoption process is intricate and as on-farm experimentation and demonstrations are limited. However, those who have adopted and expanded these practices are reporting benefits such as crop yield even during periods of drought, productive soils, minimum input costs and thus larger profit margins, less soil degradation, better soil water-holding capacity, and all-year-round household food security. Evidence form wheat farmers in the Moorreesburg district reveal that changing farming systems to incorporate CA is critical in maintaining good soil health and higher yields.

The CA adoption rate needs to be increased significantly by concerted and joint awareness campaigns and on-farm application by all agricultural stakeholders, as it is quite impossible for the limited number of extension officers to reach all food producer levels. It is true, unfortunately, that CA is not a quick fix as it takes time to restore natural biological processes conducive to CA benefits. This affects the rate of uptake by farmers who are looking for immediate gains.

6.4.4 Water infrastructure

More impoundments: Construction of larger dams and even farm dams has become a sensitive issue mainly for environmental reasons. However, in certain areas more water might have to be impounded (either as new dams or heightened dam walls) as an adaptation strategy in order to cope with increased flow variability and higher irrigation demands, conditional upon required environmental flow releases being made and more impoundments not being a maladaptive practice in regard to downstream riparian water users. Currently the Clanwilliam dam wall is due to be raised, but the EIA is not yet complete. The Blyde river dam is regarded as being sufficiently capable of meeting current demand, but the increase of mining activities in the region may change this.

Re-evaluation and/or infrastructure modifications of dams: Existing dams were dimensioned on historical hydrological records (regarding sizing, dam safety). They will not necessarily be able to deal with future climate conditions in regard to increases in design floods or lower inflows. Climate change therefore needs to be included as one of the factors to be taken into account when assessing the safety of current dams and in the design of new structures.

6.4.5 Water conservation

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

- **Wise use of water and nutrient conservation technologies (WNCTs)**: Attention must focus on water productivity, i.e. the so-called ‘more crop per drop’. As an adaptation strategy WNCTs have the potential to make better use of precipitation and contribute substantially to reducing food insecurity and poverty by reducing vulnerability to risk and uncertainty. As WNCTs are agro-ecosystem specific, these technologies must be adapted to suit the biophysical and socio-economic conditions of target areas and take cognizance of the effects of climate change. Examples include
    - Promotion of water use efficiency related technologies, i.e. technologies to promote

- o water use efficiency,
  - o irrigation efficiency,
  - o reduction in reticulation losses,
  - o water recycling and
  - o groundwater management systems (notably the artificial recharge of aquifers);
- Conservation Agriculture, i.e. tillage practices conducive to soil water conservation and a soil with desirable water holding capacity; Water harvesting in its many forms.

● **Wetlands Conservation**

Wetland conservation should be practised to ensure general environmental health and in providing food and water security, notably to the rural poor. Wetlands need to be conserved as an adaptation measure as they:

- Perform vital ecosystems functions such as water storage, storm protection, erosion control and groundwater recharge / discharge, but they also
- Provide a wide range of agriculturally related goods and services in supporting livelihoods in many rural communities, including provision of hydrological buffers and providing food, livestock grazing, domestic water, construction material and other natural products.

● **Water allocation**

Many areas in South Africa (e.g. the Berg river catchment in the Western Cape) are characterised by strong competition for a finite quantity of water with a highly unequal seasonal distribution between the agriculture sector, urban demands and the environmental reserve. In the interests of future national food security careful consideration has to be given to an equitable share of that water being allocated to an efficient and productive agricultural sector.

● **Flood and Drought Management**

- Curtailment during droughts: Water for agricultural purposes is often re-allocated to other sectors during a drought. The extent to which this is done will have to be thought through carefully, depending on the crop’s value as a staple food or foreign exchange earner or its physiological response to reduced water, e.g. deciduous fruit trees may suffer for up to 5 years later after severe drought.
- Flood protection: With flood magnitudes projected to increase over many parts of South Africa under future climatic conditions, the protection of agricultural lands will become an important component of adaptation.

● **Groundwater**

Dependence on boreholes: With many farmers dependent on borehole water drawn from widely varying depths, these will be impacted upon in different ways under conditions of climate change and farmers will need to adapt to revised groundwater recharge rates in order for the boreholes to remain sustainable. As temperatures increase and dry spells lengthen the pressure on groundwater supplies will increase.

- **Water Quality**
  - Reduction of high salinity levels: Salination is largely due to the injudicious management of soil and water by agriculture, and is likely to continue into the future. Where salinity levels are already high (e.g. in the Berg catchment) these will need to be reduced, elsewhere irrigation practices will need to adapt to prevent salination, especially where future climates may result in widespread rains which mobilise salts.
  - Sewage works overloading: As an adaptation measure, the reduction in water quality for irrigation resulting from municipalities' sewage works being overloaded, no longer functioning properly and discharging sewage into rivers (as experienced in parts of the Western Cape) should be unacceptable.

6.4.6 Natural Resource Base

- **Soil suitability studies**: In order to adapt to local climatic conditions soil suitability studies need to be undertaken prior to future land use change and land use decisions.

- **Adopting a soil protection ethos**: As an adaptation strategy a soil protection ethos needs to be adopted to underpin land use decisions in the future. This would prevent (or at least reduce) conflicts related to pressure on the land, competition for land, land use change and the depletion of the natural resources and environmental services if all land users are committed to living in harmony with the land and thus prevent soil degradation and exploitation.

- **Local area specific soil husbandry**: Soils will need to be utilised in accordance with local properties in conjunction with projected climatic regimes, e.g. areas with shallow soils which saturate rapidly when it rains and result in high surface runoff will need protection.

6.4.7 Dryland crop

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

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

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

Depending on their resilience, small-scale and urban homestead dryland farmers tend to be most vulnerable, while large-scale irrigated production is least vulnerable to projected climate change – given sufficient water supply for irrigation.

- **Overall Promotion of Best Management Practices**: As an overall adaptation strategy, a concerted promotion is required of best management agriculture practices based on the principles of the least possible soil disturbance, permanent soil cover, multi-cropping and integrated crop and livestock production in order to optimise yields, as well as sequestering carbon and to minimising methane and nitrous oxide emissions. Examples are given below, many of which have been implemented to varying degrees in the study sites.
    - Shifts in optimum growing areas: Changes in the geographic locations crops and cultivars will need to be identified, with heat / drought tolerance and water use efficiency being paramount considerations in new or alternative crop selection, such as changing to yellow maize or late maturing fruit trees;
    - Climatically marginal land (e.g. in the west) should be identified and crops (if grown at all) selected accordingly, as such areas are likely to be more prone to reduced yields (e.g. maize) and even complete crop failures in light of projected increases in climatic variability, with a view to maintaining soil productivity and preventing (further) land degradation;
    - Climate-specific farms: As an adaptation strategy, farmers may need to procure “climate specific” farms for specific crop, as well as looking to other African countries to produce their crop;
    - Growing indigenous species suitable for local conditions should be encouraged;
    - Altering plant times, on a year-by-year basis by considering seasonal climate forecasts is another adaptation strategy,
    - Altering harvest times
    - Diversifying crops
    - Harvesting less often in drier regions to prevent nutrient depletion should be promoted;
    - No-till: Practicing no-till as a soil conservation measure and following conservation laws and polices is already accepted by progressive farmers. However, many small scale farmers have limited resources and pressing needs and priorities that constrain their possibilities and motivation to put efforts into soil conservation practises as an adaptation measure;

- Water harvesting, in its many forms, to capture additional rainfall for utilisation by crops;
- Cover crops should be encouraged in wide row crops (e.g. vines) to reduce soil water evaporation;
- Decreasing wind erosion (e.g. by mulch strips or shelter belts of natural vegetation) should become standard practice.

- **Consolidation of small plots of land**, for example for small scale farmers, is an adaptation option with respect to profit, obtaining maximum production and environmental sustainability.

- **Genetically modified crops**: Progress has been made with the development of genetically modified crops with regard to heat resistance, drought tolerance, and water use efficiency. These include potatoes, sweet potatoes, soybeans, indigenous vegetables, maize, and wheat. Other notable developments include those to minimise crop failure under harsh climate conditions, low-cost alternatives to chemicals for organic production, a reduction in water consumption by vegetables, the production of indigenous and other vegetables crops under low input-cost conditions, and hydroponics. The public debate and controversy around these GM seeds and crops needs to be addressed.

6.4.8 Irrigation farming

- **Increasing the area under irrigation**: Where climate scenarios project a lowering of rainfall (and elsewhere) increasing the area under irrigation is an adaptation option, but only subject to water and suitable soils being available, farming practices being efficient and expansion not leading to negative repercussions downstream (e.g. regarding environmental flow requirements or reductions to other users).

- **Integrated water use planning** is essential as an adaptation strategy, with due consideration given to

  - Decreased water supplies from single dry seasons (i.e. during winter in the summer rainfall region and vice-versa) as a result of projected increases in the number of single years with insufficient streamflows being generated, with significant economic impacts;
  - Decreased water supplies from multiple dry seasons, where these are projected and continuous periods with insufficient streamflows are experienced, with more catastrophic economic and environmental consequences;
  - Upstream dams, and abstractions from these, which can have severe downstream repercussions;
  - Multi-purpose dams with curtailment rules during droughts, which could affect irrigators severely; and/or

- Dependence on external water sources, where irrigated areas are actually in semi-arid areas, but with an apparent abundance of water for irrigation as a result of the water being conveyed in from external sources (as in parts of the Western Cape), and where such external water dependent areas are highly vulnerable to changes in water supply/demand elsewhere and the abundance of water in such areas being a delusion.

- **Conversion to drip irrigation**: Conversion to drip irrigation (from overhead or flood methods) is an obvious adaptation strategy because of its high water use efficiency, but it comes with expensive capital outlays in infrastructure and installation, for which government subsidies should be considered. With regard to drip irrigation:

  - water is used by the plant, not by inter-row weeds
  - it works well for certain crops (e.g. vines), but not for others (e.g. deciduous fruit because of their root structure) and
  - it does have disadvantages in that it cannot be used as a cooling agent (as can sprinkler irrigation), nor can it be used effectively on sandy soils.

- **Application of local and crop specific irrigation scheduling** should be practised to avoid excessive losses from irrigated fields of phosphates via surface runoff and nitrates through deep percolation.

- **Use of mulching/crop residue** can save up to 20% of irrigation water requirements.

6.4.9 Rangeland and Livestock

NOTE: With many traditionally crop based agricultural operations now shifting to mixed farming, i.e. including livestock in their production mix, this (and the following) section may become important for the study sites.

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

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

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

- Changes in veld composition: Veld cover and composition are likely to change in future climatic regimes, and farmers will need to adapt their livestock (and game) densities to changing grassveld carrying capacities.
- Losses of herbage yields due to overgrazing will need to be minimised as an adaptation strategy, as will losses due to increased erosion through more surface runoff, where that is projected, both with significant economic and sustainability consequences if not curbed.
- Alien invasive grass species, which are largely unpalatable and which tend to respond more favourably to elevated CO_2 availability than indigenous species, will need to be kept to a minimum as they are likely to become a major threat to indigenous species, with huge potential (and partially unavoidable) losses in biodiversity with climate change.
- Weed infestations in grasslands will need to be minimised as an adaptation strategy because severe weed infestations, being mostly pioneer species, tend to degrade ecosystems and adapt more rapidly to environmental changes than indigenous flora.
- Fodder storage: In areas of projected decreases rainfall and hence herbage yields, the need will increase to store fodder for livestock or to use alternatives such as maize stalks.
- Supplemental feed and water provision is a further adaptation option to livestock
- Shifting of livestock to land with higher carrying capacity.
- Dependence on river flows for water can become an important issue in adapting to future conditions, as domestic animals (and wildlife) become stressed or even die if they depend on river flows and these are low or with insufficient water
- Animal health: adaptation will need to factor in animal health, as changes in rainfall and temperature will impact on the distribution, competence and abundance of vectors and parasites.

6.4.10 Livestock production

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

6.4.11 Small scale / Subsistence Farming

- Overcoming Farmers' Constraints: The main constraints to farmer's low farm incomes may be attributed to three main causes, each of which will need to be addressed regarding adaptation to projected future climatic conditions, viz.

  - poor commercialisation, i.e. farmers' lack of knowledge on markets and their inability to make the most of the domestic and international markets;
  - poor infrastructure, i.e. farmers' limited access to resources such as credit, thereby inhibiting them to investment in on-farm infrastructure, and the system in operation not being equipped to support these small-scale farmers transition to commercial production and with technical advice; and
  - low farm productivity, often the result of a reduction in productivity of land, labour resources and crops, which result from the poor or lack of land and water management, skilled labour availability and management thereof, and farming techniques.
- These factors largely result in a poverty trap that adaptation strategies will aim to reduce or eliminate, by addressing vulnerabilities to the of climate risks faced by those farmers with their limited opportunities to access vulnerability reducing resources such as fertiliser, transport and alternative income opportunities.

These causes and their effe7cts were clearly visible in the small scale farming areas around Dingleydale, where study sites were established.

6.5 Innovative, appropriate and sustainable interventions including (a) internal management measures; and (b) External policy measures

Innovative **internal management measures** other than those listed above (section 6.3) are by definition, novel, and thus need to be determined through an intensive search of NGOs, agricultural entrepreneurs, and engineering scientists. So far the project has engaged with Institute for Poverty, Land and Agrarian Studies (PLAAS) (see box 1), Departments of Agriculture, Department of Water Affairs., the Agricultural Research Council (ARC) amongst others and many of the suggestions incorporated in Section 6.4 emanate from these stakeholders.

BOX 1: Resilience and response-ability: Towards just water service provision in the context of climate change

Pereira T, Wilson J (2010)

Abstract:

Climate change will impact on water service provision, yet it is not integrated into water sector policies and plans. This paper unpacks some of the reasons for this disjuncture: the complex and overwhelming challenge of universal water provision even in the absence of climate change; and the real threat that climate change poses to predictable water availability. Current climate change response policies and practices fall short of what is necessary and also threaten to deepen social inequity. Without considered intervention, climate change impacts on water provision will exacerbate social stratification and inequality, making the lives of poor people harsher and even more marginalised by further limiting access to quality water and sanitation services that are necessary to support a safe, healthy and dignified life. The paper argues that shifts need to happen at both personal and structural levels to build effective resilience, and suggests interventions that could facilitate these shifts.

http://tinyurl.com/b3vnms5

This process will continue and where possible the success (or otherwise) of any these will be documented.

External policy measures infer:

- a lack of suitable policies within the agricultural sector,
- non-execution of existing policies, or
- a need for existing policies to be reviewed and amended.

Climate change policy that recognises climate change as a threat to agriculture includes some national strategies and responses. Specific legislation, such as the Water Act, Conservation of Agricultural Resources Act (including soil conservation) and The Biodiversity Act are aimed at general conservation of agricultural and other resources.

Specific agricultural-relevant policies are contained in the National Climate Change Response Strategy and the Climate Change Sector Plan for Agriculture, Forestry and Fisheries. These are summarised below.

6.5.1 The National Climate Change Response Strategy (NCCRS)

The National Climate Change Response Strategy and White Paper, developed using country study reports compiled on sectoral basis together with information from the IPCC Third Assessment report, recognises that climate change is a cross cutting issue that has ramifications for diverse activities in other government departments and thus requires the joint action of government departments in a coordinated manner, to ensure that response measures are acceptable to all and synergistic towards a clear national focus. The strategy recognises the limited general awareness on the likely impacts of climate change and readiness for such impacts and thus emphasises building capacity within government by efficiently harnessing available skills and competencies.

The Strategy and White Paper calls for the formulation of policies that will adequately address climate change adaptation and mitigation in all sectors. With a number of key interventions on various adaptation and possible mitigation options proposed, the strategy also calls for the development of detailed action plans with defined time scales.

General mandates from the NCCRS that apply to the agriculture sector

- Agriculture urgently has to strengthen its resilience to climate change impacts and has to develop and implement policies, measures, mechanisms and infrastructure that protect its various components (commercial, emerging, rainfed, irrigated, crops, livestock, plantation forestry, etc.).
- Develop and implement education, training and public awareness programmes on climate change within the broader agriculture sector and its highlighting its effects in order to promote and facilitate scientific, technical and managerial skills as well as public access to information, public awareness of and participation in addressing climate change.

Agriculture specific issues from the NCCRS

- Climate resilience needs to address issues of strategic national importance, in this context, for example, to food security and its links to water, health (human, livestock and plant) and land reform.
- Being the largest consumer of water in South Africa (mainly through irrigation), agriculture is vulnerable to changes in water availability as well as increased chemical water pollution and soil erosion from more projected increases in intense rainfall events and increased evapotranspiration.
- Under-resourced, small-scale and subsistence farmers are particularly vulnerable to the impacts of climate change.
- Commercial agriculture is a significant contributor to GDP and to employment. With its full contribution, including multipliers, agriculture contributes up to 12% of South Africa’s GDP and 30% of its national employment. Crop failures can therefore have a significant impact on the nation’s economy.
- The following should be considered, explicitly or implicitly, in light of projected CC:

- A climate-resilient agricultural response depends on the recognition that agriculture should provide not only food, but also a range of other environmental and socio-economic benefits.
- Important as input-intensive commercial agriculture is, it can sometimes have negative environmental, social and economic externalities, which may be exacerbated by climate change.
- The appropriate use of small-scale labour-intensive agriculture techniques and its various overall benefits (e.g. job creation, empowerment, food security, contribution to biodiversity) should also be considered from a climate change perspective.
- Modelling of climate change scenarios is vital to informing land use planning decisions in agriculture in as much as they that determine the mix of livestock and crop cultivation, as well as the types of crops that are likely to be commercially viable under projected future climate scenarios.
- Impacts of alien invasive plant species, which reduce streamflow and may consequently compromise already scarce water resources as well as reducing biodiversity, need to be evaluated through a CC lens.
- The potential for sustainable biofuel production under conditions of climate change, and its possible impacts on food security, needs to be evaluated.
- Issues surrounding grassland degradation through injudicious grazing and burning regimes, as well as the reversal of those negative effects through veld rehabilitation, need to be addressed from a CC perspective.

6.5.2 The Climate Change Sector Plan for Agriculture, Forestry and Fisheries

This was developed by Dept of Agriculture Forestry and Fisheries (DAFF) in line with the National Disaster Management Framework of 2005 and in fulfilment of the requirements of the National Climate Change Response Strategy.

It was considered desirable to put into place a climate change-related plan of action to increase climate intelligence namely awareness and knowledge of, and to plan actions related to, anthropogenic activities impacting the future of all. The basic approach of the sector plan is climate smart agriculture, which entails the integration of land suitability, land use planning, agriculture, forestry and fisheries to ensure that synergies are properly captured and that these synergies will enhance resilience, adaptive capacity and mitigation potential.

6.5.3 Other initiatives within the agriculture and forestry sector

The Working Group on Climate Change (WGCC) convened, coordinated and chaired by the Directorate Climate Change and Disaster Management (DCCDM) developed the climate change discussion document: "Climate Change and the agricultural sector in South Africa", seeking to synthesise the sector and create awareness on the current perceptions and follow-up actions necessary to address the risks and challenges relating to the impacts of climate change on agriculture.

The Department of Agriculture in the Western Cape has embarked on a Western Cape Agricultural Research Forum research and development plan that accounts for the risks associated with climate change. Three of the four strategic drivers that relate to climate change are shown below in Table 53.

Table 53: Strategic Drivers for Agriculture

STRATEGIC DRIVER 1	**ACTION TO BE TAKEN**
Optimise crop and soil interface	Soil Survey & analysis of field crop production area in the WC (fly-over project) – also attention to alternative and new crops Identify areas not suitable for agricultural production
STRATEGIC DRIVER 3	**ACTION TO BE TAKEN**
Optimal cropping/livestock matching (alternative crops, including value adding to current crops)	Aerial Survey of current production area (fly-over project) Identification of land available for production or not suitable for production
	Synchronise with soil/climate survey
	Identify alternative and new crops suitable to the region
	Climate change influence on market access vulnerability study Consumer trends, future scenario
STRATEGIC DRIVER 4	**ACTION TO BE TAKEN**
Agro-processing	Determine the existing research capacity available
	Small scale processing – identify opportunities
	Enhance the integration of processed products up and down in the value chain

CHAPTER 7 : BEYOND THE FARM GATE: LINKAGES BETWEEN FARM-LEVEL VULNERABILITY AND ADAPTATION TO CLIMATE VARIABILITY/CHANGE AND ITS IMPLICATIONS ON THE FOOD VALUE CHAIN

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In this phase of the final report we focus on the impacts of the adaptation strategies that have been adopted at the farm-level and how this would impact the entire food value chain of the selected crops in each of the study areas. The first phase of this report had identified the point at which these crops were vulnerable to climate variability/change, and it had attempted to identify some adaptation strategies adopted at the farm level.

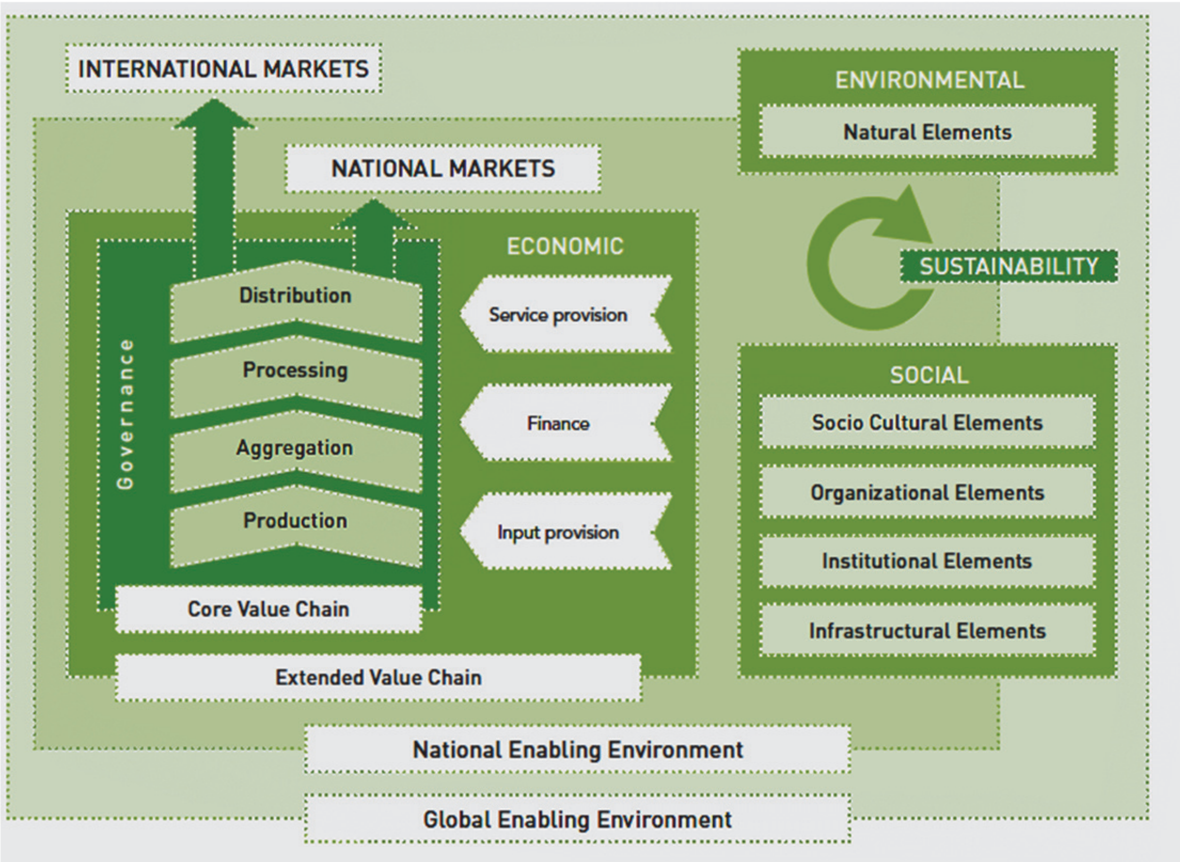


Figure 42: A sustainable and inclusive food value chain framework (Source FAO, 2013)

In this phase we adopt the sustainable and inclusive food value chain framework of the Food and Agricultural Organization (FAO) to facilitate a basic explanation of what a food value chain represents. This is to ensure that all the aspects of the food value chain that are relevant to our study are taken into consideration during our analysis.

FAO (2013) defines a sustainable and inclusive food value chain as "the full range of farms and firms and their successive coordinated value-adding activities that transform raw agriculture materials into food products that are sold to final consumers and disposed after use, in a manner that is profitable throughout the chain, has broad-based benefits for society and does not permanently deplete natural resources".

The four main stages of a food value chain comprise production (farming), aggregation (post-harvest handling and food storage), processing and distribution (wholesale and retail). In this study we are more concerned with what happens beyond the farm gate (i.e. beyond the production phase), and whether there are linkages within vulnerability (and adaptation) at the farm level, and vulnerability (and adaptation) within the specific food value chain. Therefore, we focus of the aggregation (i.e. post-harvest handling and food storage), processing and distributions for each of the crops under the scope of this study.

In analysing a food value chain, it is important to understand that value can be added and it can also be subtracted. For instance, value is added during when a particular product undergoes processing or packaging. Meanwhile, value can be subtracted whenever there are post-harvest losses especially during storage and packaging (due to heat waves or other extreme events). We investigate post-harvest losses during storage as a result of extreme events, and how this impact on the entire food value chain.

The value chain actors operate within a global and national environment, and these comprise of the social elements or socio-cultural elements (e.g. customs, beliefs and values), organizational (e.g. partnerships, cooperatives, associations), institutional (e.g. laws, regulations, policies) and infrastructural (e.g. roads, rail lines, electrical grids, telecommunications).

Therefore, a sustainable food value chain could be said to comprise of three scopes:

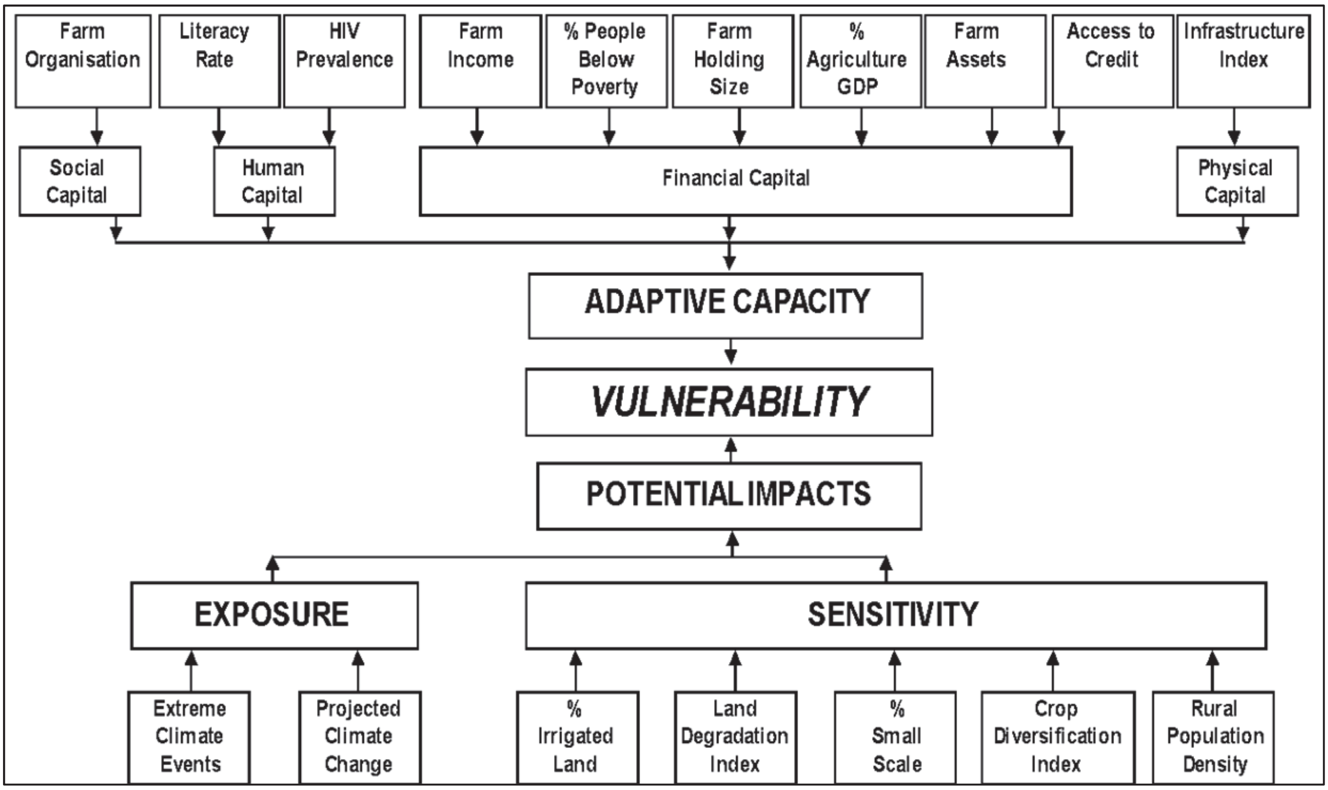
1. *Economic scope* – this comprises of the fiscal and commercial sustainability of any practices within the food value chain.
2. *Social scope* – this involves the social and cultural aspect, it basically revolves around how the society views, responds and understands the food value chain and its nuances.
3. *Environmental scope* – this comprises of efficient and sustainable use of resources within the food value chain. It describes the impact of the natural and extreme events on the food value chain.

Understanding what goes on within any food value chain with respect to climate variability and change requires a balanced knowledge of what vulnerability entails. We investigate the economic vulnerability, social vulnerability and the environmental vulnerability of each crop within specific food value chain by asking the following questions:

- What is vulnerable?
- Who are the vulnerable?

- What are they vulnerable to?

In this study we consider parts of the vulnerability framework presented by Gbetibouo and Ringer (2009) in Figure 43. The figure shows the linkages between vulnerability and adaptation to climate variability/change. We investigate relevant variables within each food value chain with a view to understanding the adaptive capacity (at the farm level and beyond) of each crop within specific food value chain.



Source: Mapping South African Farming Sector Vulnerability to Climate Change and Variability; after from Gbetibouo and Ringler, 2009

Figure 43: A framework for the linkages between vulnerability and adaptation within a food value chain

From the chapter on climate impacts, the following was stated:

- If climate change impacts on the cost of production, it will obviously have a positive or negative impact on production costs and the value at which farmers are prepared to sell their product; either at a higher or lower value. This assumes that farmers are price setters, which is NOT the case for wheat and maize farmers who negotiate a price with silos and cooperatives, based on the ruling prices.
- It is also important to take a holistic view on production regions, especially with export products. Some regions (of the world) will gain (positive impact of climate change for specific region) and others will lose (negative impact). The impact of climate change on the value chains of specific products from specific countries will therefore not be the same. In countries or regions where climate change will have a positive impact on

production (e.g. decrease in input costs, increase in yield) it will in general result in a positive feedback in the value chain and vice versa.

- In general, the predictions for South Africa are that climate change will result in more droughts and more floods (more extremes). It can therefore be expected that this variability in climate will also result in larger variability of supplies and therefore more volatility in world markets for agricultural products (increase in price variability).

We present the linkages and implications on the food value chain for the following crops:

1. Wheat
2. Table grapes
3. Maize
4. Mangoes/Citrus

The study areas for the crops wheat and table grapes were both in the Western Cape, a region expected to become warmer by up to 2 degrees C by 2100 and with rainfall expected to decrease in autumn and perhaps increase around the mountains, combined with the effect of increasing water demand, will be one of heat stress and water shortages (Midgley et. al, 2005).

7.1 Wheat

The major product of the baking industry is bread. 70 to 80 percent of all flour milled is used for bread baking. After maize meal, the bread industry is the second most important supplier of kilojoules in the national diet. Annual consumer expenditure on bread is, however, higher than on maize products. The wheat value chain is thus dominated by products made from flour, such as bread and associated products, biscuits or pasta (durum wheat). Other uses include animal feed (bran and wheat germ), alcohol manufacture, starch and straw (using mostly waste).

Input suppliers provide seeds, fertilizer, pesticides fuel, etc. to wheat farmers. The wheat is harvested and stored in silos, together with imported wheat. This is then delivered to milling companies where the wheat is ground into wheat flour, meal and bran. The wheat flour is then sold to the manufacturing industry to produce perishable products such as bread, rolls, buns, cakes and other products such as frozen dough. Wheat based products such as biscuits, pasta, crackers and breakfast cereals form a smaller, but valuable component to the industry. The animal feed manufacturing industry uses meal and bran in the manufacture of farm feeds and pet foods. (DAFF, 2012d)

Wheat farming provides jobs for about 28 000 people, on a permanent or semi-permanent basis. Harvesting is highly mechanised (DAFF, 2012d).

Wheat production is decreasing slightly in SA on the whole, but imports are increasing to maintain total domestic requirements (see Figure 44).

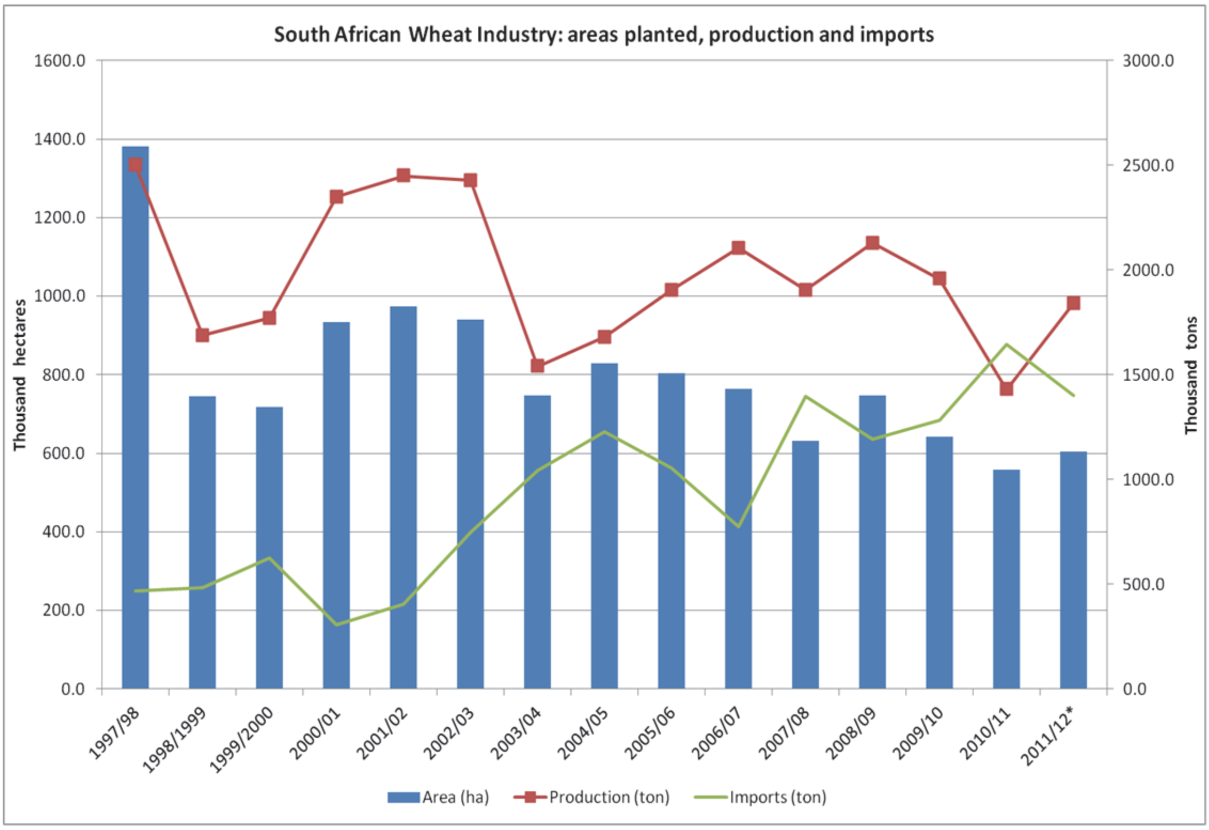


Figure 44. Wheat Planting, Production and Imports (Wallace 2013)

The climate projections for this region reflect:

- a possible decrease in rainfall over the autumn and winter periods
- increased variability of rainfall
- delayed/later start to the rain season

From Oosthuizen's report, the following impacts were identified:

- The modelling results indicate that intermediate climate scenarios from five different Global Circulation Models (GCM's) posed a marginal threat to wheat production in the Moorreesburg area.
- The modelling results project a marginal decrease in yield.
- A decrease in the production volume can lead to a price increase in wheat products. The production of wheat in Moorreesburg can however not be looked at in isolation, because wheat price in South Africa is derived from import parity price. Production in other parts of the country and internationally impacts on price as a result of free trade and the supply and demand principle.
- Adaptation strategies to mitigate the possible negative impact of climate change include:
    - Cropping systems
    - Production practices
- The successful application of adaptation strategies will largely eliminate the negative effects of climate change on the food value chain of wheat for the Moorreesburg area.

Other literature, including Wallace (2013) suggest that increasing CO_2 may increase yields due to fertilisation effects but it is thought that at a certain point increasing temperatures will outweigh these benefits.

7.1.1 Actors in the wheat value chain and their exposure to CC impacts (refer Figure 45):

1. Producers
   - High input cost/land value ratio as a result of sharp increases in variable costs of production resulting in greater production risks.
   - Slow and inadequate input/product price adjustment to external factors, e.g. sluggish input price downward adjustment to exchange rate strength.
   - Expensive crop insurance and limited insurance capacity.
2. Traders
   - High dependency on transport infrastructure – delays and exposure to elements may cause losses
   - Storage risks – risks of quality losses
3. Millers
   - Competition from cheaper/subsidised imports where CC impacts are less
4. Bakers
   - High dependence on quality, which may be affected, and increase prices
   - Competition from cheaper/subsidised imports where CC impacts are less
5. External input providers (non-wheat raw material, transport, packaging, etc.)
   - Risks to power supply (and knock on risk to transport), due to increased temperature and more intense rainfall in electricity production areas
   - Access and availability of water (for small % of irrigated wheat production, and for manufacturing) leading to price increases
   - Increased temperatures and moisture increase demand for pesticides and thus costs
6. Wholesalers/Retailers
   - Distribution risks due to transport cost and threats, and increased risk of spoilage due to increased temperatures and variable, possibly more intense, rainfall
   - Increased costs of raw materials leads to higher selling prices, opening up competition to cheaper imported goods.
7. Socio-economic issues
   - Any risks carried through to retailers will be reflected in the price and supply of bread, biscuits and pasta. Since bread is increasingly becoming a staple food, any increases in price pose a serious threat to food security.

In general, the most significant linkage between the impacts of climate change at the farm level to the rest of the value chain is reflected in the variable price of the raw material, i.e. wheat flour. When climate change causes loss of yield and/or quality in the production of wheat, this will affect the price of the wheat, which in turn will impact on the activities of all the other actors in the value chain. While inputs costs promise to increase making it more difficult to farm wheat, and leading to smaller areas being planted (though increasing yields are evident) the number of individual farms is decreasing, leading to a reduction in employment numbers. This will have a knock-on effect for food security.

Quality is an aspect which can be carried through many of the components of the value chain as increased temperature leads to a higher risk of spoilage, which can be mitigated against by increased air-conditioning and shorter transport periods.

The indirect linkages of climate risk, which can be ascribed to the impacts of increased temperature and more variable rainfall, are reflected in increased costs of non-wheat inputs such as electricity and transport.

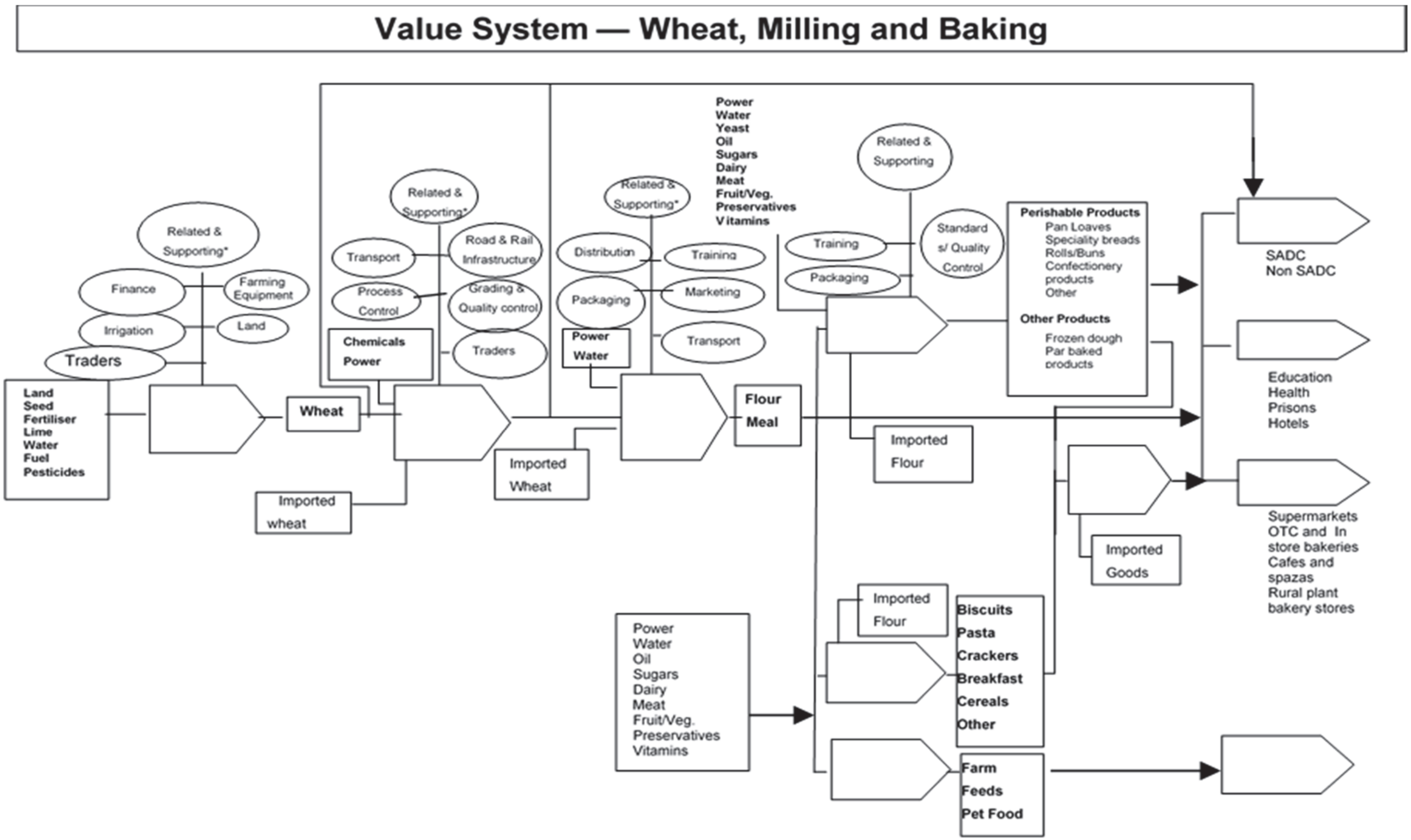


Figure 45: The Wheat Value matrix diagram (after Moloisane, 2003)

7.2 Table Grapes

Areas with hot dry summers, but sufficient irrigation sources, are the leading areas for commercial table grape production in South Africa. For this reason, the Olifants River West region is one of the major sources of table grapes in South Africa.

Heat is important for stimulating early season growth and early ripening. The hotter the climate, the earlier the harvest and this can lead to, in many cases, a higher market price. Though table grapes depend almost entirely on irrigation, increased temperatures and reduced surety of supply of water threaten to impact the grape industry.

Grapes require approximately 60 mm of water per hectare per week. Depending on soil type, table grapes should never go longer than two weeks without irrigation. The allocations of water in South Africa are a cause for conflict and concern, but it is the potential reduction in run-off that offers the largest threat to demand for irrigation (Sheridan, 2005).

Projections show that increases of minimum and maximum temperature increases of up to 3 degrees are likely by 2050. These increases will affect the degree day values of growing localities. Whereas in most parts of the world the lower limit of degree days has been the historical limitation for cultivation, it is the upper limit that is becoming pertinent for South Africa's traditional grape growing regions. Hot weather favours sugar formation and results in sweeter grapes, which though favouring some varieties will lead to detrimental effects on the quality of others (Johnston, 2009).

Interviews with farmers produced some interesting observations and comments:

- Seasons seem to be getting later – shifting harvesting dates and market arrival
- May monthly rainfall seems to be decreasing while June seems the same
- Cold units are sufficient but decreasing and affect the dormancy period – pruning and bud-burst
- Rain in summer is a big problem as it relates to insect infestations and spraying programmes
- A cold spell in spring with rain can have a direct impact on yield in the summer
- Snowfalls in the mountains do not seem to have been affected, though faster melting may pose a threat to dams
- Winds are changing, both in strength and direction, in some localities.
- Some varieties have been shifted to different slopes and locations to take better advantage of local conditions to combat warming, while some varieties are being planted to replace others
- Increased temperatures will have an effect; drip irrigation will help but does not allow sprinkling for cooling for heat waves or 'flooding' opportunities (i.e. more water led than normal)

- Sunburn and windburn, leading to discoloration of grapes, lowers the quality and value. Shade nets are becoming more and more common.
- In a scenario of water scarcity, the response would be to reduce plantings – rather have less crop of good quality than same of worse quality.
- Water costs are minimal in the annual budget and even a doubling of tariffs would not have significant impact (nor lead to reduction in use)

Table grapes are not processed as such, but are carefully picked, selected, graded and packaged before being transported to wholesalers and retailers, for export or domestic use. Table grapes are intended for fresh consumption while grapes grown for wine production, juice production, or for drying into raisins, can be processed and stored. Table grapes contain more water and usually have lower sugar content than wine grapes.

Full-time labourers are employed on table grape farms for specialist tasks such as pruning and training of trees, as well as thinning during flowering or during the first four weeks of fruit growth. Other tasks include harvesting supervision, operational duties in the pack house, irrigation management, checking for insects and diseases on seasonal basis, tractor or forklift driving and grafting.

During the harvest, Seasonal labour is employed on a contractual basis for a fixed period for picking and packing. Table 54 shows the distribution of jobs in the industry.

Table 54: Number of farm workers in the table grape industry, 2009 to 2011 (source DAFF, 2012b)

	2009		2010		2011	
Region	**Seasonal**	**Permanent**	**Seasonal**	**Permanent**	**Seasonal**	**Permanent**
Berg River	13 503	2 491	13 639	2 616	13 445	2 470
Hex River	6 000	12 000	8 783	5 337	8 642	4 740
Northern Provinces	4 478	2 173	3 500	980	2 843	804
Olifants River	2 534	536	2 115	511	2 773	671
Orange River	19 918	3 452	13 750	3 350	14 802	1 943
Total	**46 433**	**20 652**	**41 787**	**12 794**	**42 505**	**10 628**

The implication of the investigations into climate change risk is that the practice of table grape growing is likely to become riskier and more expensive. The most likely effects will be shifts in management practices to accommodate an increasingly limited water supply. The changes that increased temperature and CO2 might have on quality are uncertain but the impacts on chill units and the threat of heat stress should not be overlooked. As the temperature changes do not exceed the range given by Gladstones (1992) for ideal conditions, it may be tempting to assume that quality will not be greatly affected by temperature in the next 50 years.

Responses by farmers to chill unit decreases are usually limited to dormancy breaking chemical application, which increases the costs of production. Sunburn on grapes can threaten quality and price, and the traditional response has been to introduce shade netting but the reduction of light can be detrimental.

The flow diagram (Figure 46) summarises the risk and possible responses facing growers.

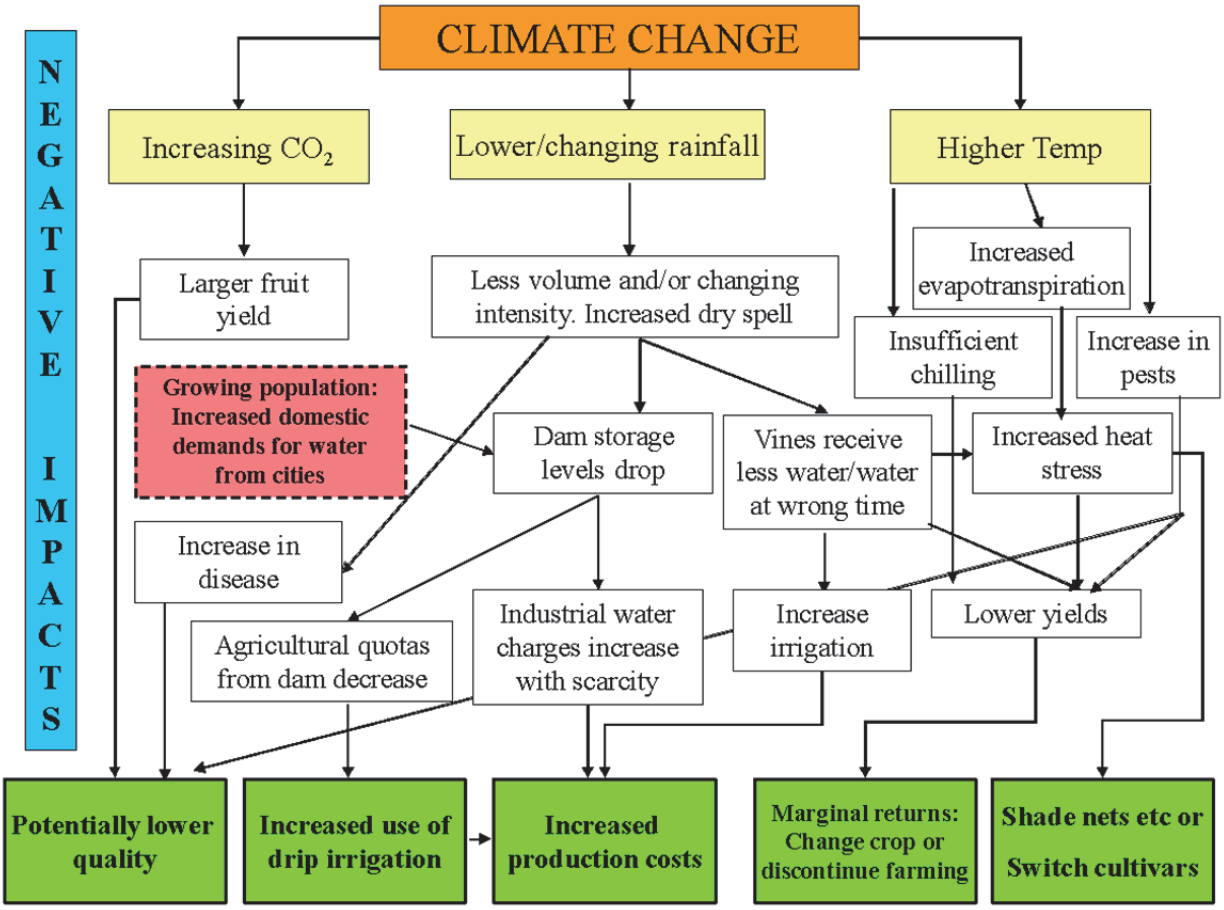


Figure 46: The impacts and responses of climate change on grape production (adapted from Carter, 2006)

The implication of lower rainfall is not, per se, the biggest threat to grape growing, as the need for water is highest in the spring and summer months when the vineyards are irrigated. The supply of irrigation water is however dependent on the rainfall during the previous rainy season, often supplemented by melting snowpack. For this reason, irrigation networks have been constructed, specifically in the case of this research, in the Olifants West region, where the Clanwilliam dam and the canal system supply controlled allocations to farmers. Farmers also build holding dams where surplus allocated irrigation water can be stored.

Increased temperatures are the biggest threat to irrigation supplies. Not only is the chance of regular snowfall reduced, but even if rainfall totals do not change significantly, increased temperatures, through evaporation, reduce the amount of water available and evapotranspiration increases the water demands of the crops. Reducing evaporation from dams and irrigation canals cannot be achieved through any cost effective means, but farmers are employing different irrigation methods to avoid evaporation during watering and to provide precise amounts of water according to the plants' demands.

Figures 46 and 47 reveal how climate change can lead to increased production costs on the farm and thence to the processing and retail chain.

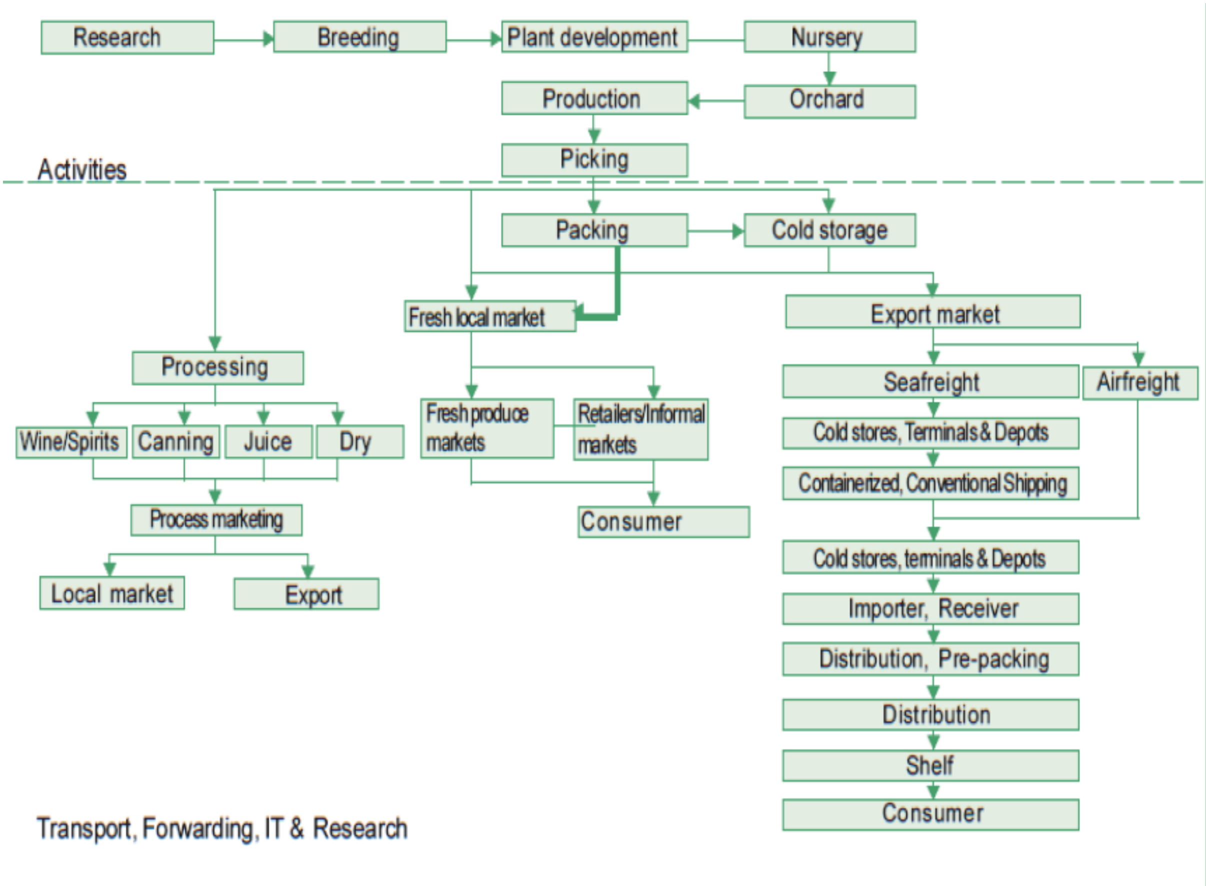


Figure 47: The table grape supply chain (source OABS, 2006)

In most deciduous fruit growing, there is a requirement of a specific number of chill units[3]. Most Grapes need about 150 chill units, compared to over 800 for apples. For this reason, grapes can still thrive in very hot regions, provided the requirement is met.

Rest-breaking agents (e.g. hydrogen cyanamide) can partially mitigate the effects of insufficient chill units and can substitute for up to 300 chill units, but excessive spraying and any timing errors may damage the buds (Southwick et. al, 2003).

[3] A chill unit is defined as the minimum period of cold weather after which a fruit-bearing tree will blossom. A full chill unit is assigned only to temperatures lower than 9°C per hour. Temperatures higher than 16°C have negative weights: they reduce the number of accumulated chill units.

Of greater concern was the requirement revealed by farmers in Vredendal that the differential between the daily maximum and minimum temperature needed to be above 10°C to avoid a reduction of quality and quantity. The history of increased temperatures in the region has shown that minimum temperatures are rising faster than maxima, thus reducing the differential. Other than cooling the vine temperatures through spraying, no other adaptations have shown to be effective against this.

7.2.1 Actors in the grape value chain and their exposure to CC impacts:

1. Producers
   - High input cost/land value ratio as a result of increases in variable costs of production resulting in greater production risks.
   - Increased costs of mitigating impacts of high temperatures, such as shadecloth, and drip irrigation
2. Processors
   - Increased risks during packaging and transport due to increased temperatures.
   - Higher costs of air condition and cold chain maintenance
   - Market supply remains a weather/climate related variable. If the timing of the grape ripening period is altered, then the profitability of the grapes reaching the market can be affected.
3. External input providers (non-grape raw material, transport, packaging, etc.)
   - Risks to power supply (and knock on risk to transport), due to increased temperature and more intense rainfall in electricity production areas
   - Access and availability of water leading to price increases
   - Increased temperatures and moisture increase demand for pesticides and thus costs
4. Wholesalers/Retailers
   - Distribution risks due to transport cost and threats, and increased risk of spoilage due to increased temperatures and variable, possibly more intense, rainfall
   - Increased costs of raw materials leads to higher selling prices, opening up competition to export markets by other countries.
5. Socio-economic issues
   - The major risk in decreasing production is the consequent reduction in seasonal and permanent labour, as table grape farming is highly labour intensive.
   - Any risks carried through to retailers will be reflected in the price and supply of fruit. As it is not a staple food, the risks are relatively small.

Thus, the most significant linkage between the impacts of climate change at the farm level to the rest of the value chain is reflected in the variable price of the raw material, i.e. grapes. When climate change causes loss of yield and/or quality in the production of table grapes, this will affect the profitability of the industry. While inputs costs promise to increase making it more expensive to farm grapes, and leading to smaller areas being planted (though increasing yields are evident) the number of individual farms is decreasing, leading to a reduction in employment numbers. This will have a knock-on effect for food security.

Quality is also an aspect which can be carried through the value chain as increased temperature leads to a higher risk of spoilage, which can be mitigated against by increased air-conditioning and shorter transport periods.

Once again, the indirect linkages of climate risk, which can be ascribed to the impacts of increased temperature and more variable rainfall, are reflected in increased costs of non-grape inputs such as electricity and transport.

7.3 Maize

The importance of maize as a crop in South Africa can be summarised by quoting from the DAFF report, Maize Market Value Chain Profile (2012):

Maize is the most important grain crop in South Africa, being both the major feed grain and the staple food for the majority of the South African population. About 60% of maize produced in South Africa is white and the other 40% is yellow maize. Yellow maize is mostly used for animal feed production while the white maize is primarily for human consumption. Maize is the second large crop produced in South Africa after sugar cane. The maize industry is important to the economy both as an employer and earner of foreign currency because of its multiplier effects. This is because maize also serves as a raw material for manufactured products such as paper, paint, textiles, medicine and food. (p3)

Some yellow maize is also used for the production of snack and cereal products as well as animal feeds.

Maize kernels are usually milled after harvest into products such as samp, maize grits and maize rice, unsifted, sifted, coarse, super and special maize meal. Wet milling is a process carried out in water after which the kernel can be separated into its components, the husk, starch, gluten and the germ. These are used in animal feed production. The starch pastes from maize are also used to manufacture starch-based puddings and salad creams. The starch paste is also used industrially for paper coating and sizing, textile sizing, the manufacture of corrugated boards and adhesives (DAFF, 2012c).

The germ and the gluten are used in the manufacture of maize oil and animal feed supplements. The maize oil can be used in cooking, where its high smoke point makes it valuable for frying food. Maize oil is also used as one source of bio-diesel. Other industrial uses for maize oil include soap, salve, paint, rust proofing for metal surfaces, inks, textiles, insecticides, and even as a carrier for drug molecules in pharmaceutical preparations. (DAFF 2012)

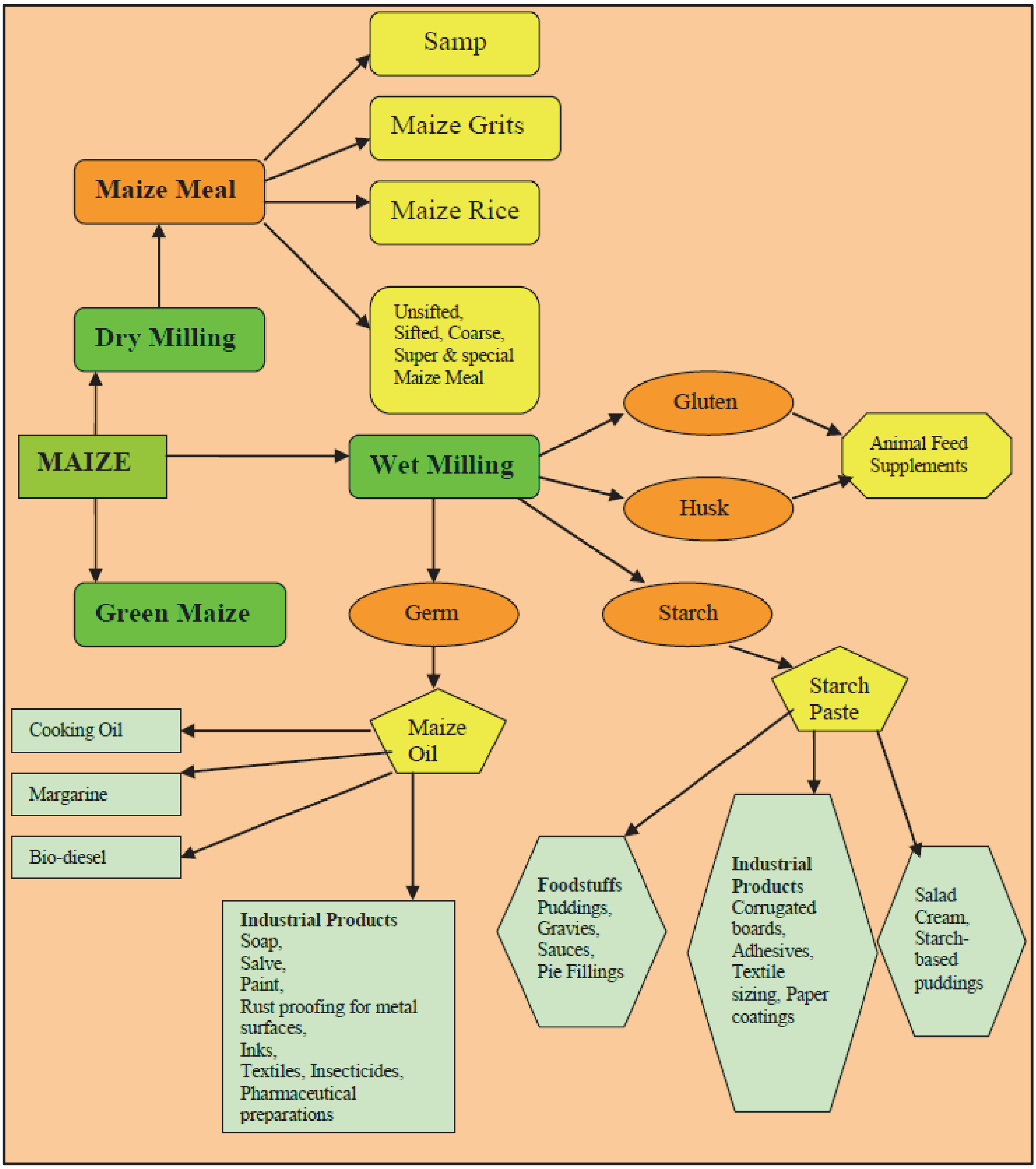


Figure 48: The Maize Product Chain. (Source DAFF 2012)

Though the area planted to maize has been decreasing slightly, the yield has generally increased to maintain, and even increase the total production (see Figure 48). The industry is divided into commercial and developing agriculture. Commercial maize farmers are estimated at 9000 providing direct employment for an estimated workforce of 128 000, but the number of developing small scale maize farmers is unknown. Commercial agriculture produces about 98% of maize in South Africa, while the remaining 2% is produced by small scale farmers. The value of maize production in South Africa varies according to production (between 8-12 million tons per annum) and is averaged at R1.5 billion (DAFF 2012c). Maize is the staple diet of a large proportion of people of South Africa and is therefore produced by emerging farmers to provide basic household requirements. Excess production is sold as green mealies or grain to supplement the household income.

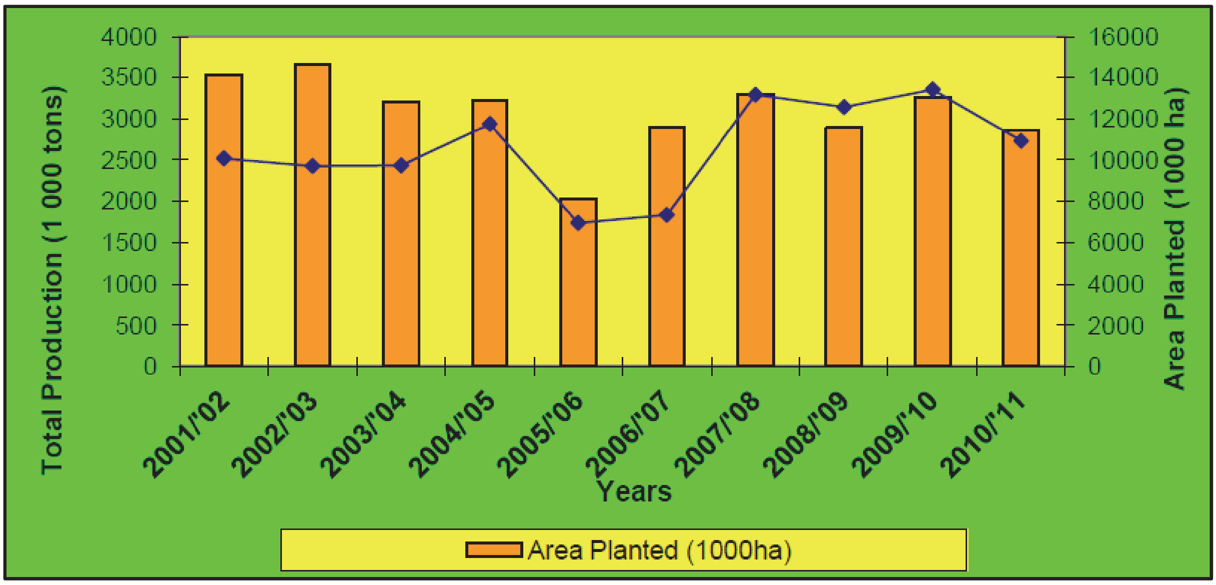


Figure 49: Maize production and area planted 2001-2011. (Source: DAFF 2012)

The amount of maize produced is directly proportional to the weather conditions experienced before, during and (to a smaller degree) after harvest. The study on maize was conducted in Carolina situated in Mpumalanga province which is the second largest maize-producing province in South Africa. In Oosthuizen (2014) it is reported that the modelling results of intermediate climate scenarios from five different General Circulation Models (GCMs) pose little or no threat to maize production in the Carolina area. The modelling results project an increase in yield for maize production. However, the report further states that maize production in the area could not be assessed in isolation due to the fact that there are other factors that must be taken into consideration.

This report extends Oosthuizen's research beyond the farm level, as it seeks to clarify the impact of other factors that could affect the maize value chain in the study area with a view to understanding the linkages with other forms of vulnerability such as; social, economic and environmental vulnerabilities. It seeks to investigate whether the impacts of climate change, including the effect of an increase in the yield of maize production in Carolina farms, may have other impacts and/or could actually be sustained beyond the farm gate as production enters the value chain.

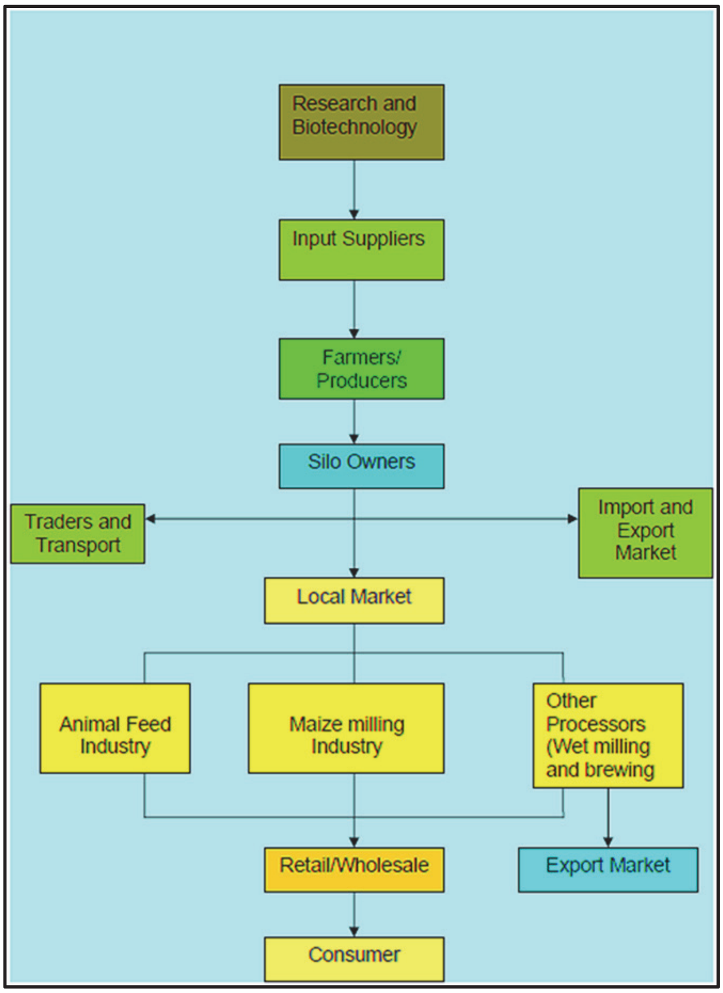


Figure 50: The maize market value chain (Source: Maize Tariff working Group, 2005)

As illustrated by Figure 50, a sustainable food value chain framework is employed to clarify the actors within the South African maize value chain, since Carolina farms could not be taken in isolation. Table 55 describes the South African maize market value chain and profiles its actors.

7.3.1 Actors in the South African maize value chain and their exposure to CC impacts

According to DAFF's 2010-2011 profile of the South African maize market value chain (DAFF 2012c), the maize market value chain can be classified into different levels: producers of maize (farmers), silo owners (those who store maize on their own account and on behalf of others); traders in maize (buy and sell maize); millers of maize (those who convert it to usable form); and end users. These actors can be broadly classified into primary sector, secondary sector and tertiary sector. Table 55 summarises the actors, their functions and vulnerabilities.

Table 55. South African maize value chain actors, their functions and vulnerabilities

		Vulnerabilities		
		Social	**Economic**	**Environmental**
Primary	Input suppliers, producers and silo owners/storage facilities owners	Membership of association, access to information, etc.	Access to subsidy, credit facilities, government policies, etc.	Exposure to extreme events, i.e. flooding, drought. Heat waves affecting stored grains.
Secondary	Millers, animal feed manufacturers, and processors	Norms, values and belief system	Licensing/labelling, disease outbreak in livestock, etc.	Impacts on the immediate environment.
Tertiary	Traders (export and import markets), retailers and transporters	Barriers to entry, road/rail network, telecommunication, other social amenities, etc.	Export/import parity.	Global environmental change from trading countries

While modelling results indicate that climate change poses no threat to maize production in Carolina farms, storage and handling may be hampered by extreme events both in the short and long run. It is therefore important to consider the possible effect of extreme events on the storage of maize in Carolina. The following are the possible linkages between vulnerability and adaptation of maize yield to climate change/variability in Carolina farms:

1. Maize farmers
   - While yields are projected to increase, there are still climate risks associated with increasing temperatures and erratic rains especially in marginal areas. The decrease in area planted to improve economies of scale will impact on the labour force, with or without increased yields.
   - The costs of conservation agriculture approaches may require more capital outlays, but are expected to be more than compensated by increased returns through increased soil moisture and fertility, and reduction in pests.
2. Silo Owners (often include millers)
   - Storage and handling: Beyond the farm gate, extreme events associated with climate change and variability may affect maize in the form of increased temperatures and heat waves, resulting in a higher post-harvest risk of disease and losses.
   - Increased input costs borne by farmers and by silo-owners will drive prices higher and possibly increase the risk of competition from imports.
3. Traders
   - Traders are actors that can influence prices by hedging and adopting longer term positions in the financial markets. The perception of changing climate risk can be enough to influence prices and have forward and backward knock-on effects.
4. Millers and processors

- Maize products are used in a multitude of different products outside of the food chain, and thus offer some resilience to consumer demands for food. Thus price increases are not always directly borne by consumers of maize products as such but by those who purchase goods using relatively small amounts of maize products in their manufacture.

5. Wholesalers/Retailers
   - Distribution risks due to transport cost and threats, and increased risk of spoilage due to increased temperatures and variable, possibly more intense, rainfall
   - Increased costs of raw materials leads to higher selling prices, opening up competition to imports from other countries.
6. Socio-economic issues
   - Any risks carried through to retailers will be reflected in the price and supply of maize meal. Since this is a staple food for many, any increases in price pose a serious threat to food security.

In general, once again the most significant linkage between the impacts of climate change at the farm level to the rest of the value chain is reflected in the variable price of the raw material, i.e. milled maize flour. When climate change causes changes in yield and/or quality in the production of maize, this will affect the price of the maize (admittedly subject to world prices and risks), which in turn will impact on the activities of all the other actors in the value chain. While inputs costs promise to increase, making it more difficult to farm maize, and leading to smaller areas being planted (though increasing yields are evident), the number of individual farms may decrease, leading to a reduction in employment numbers. This will have a knock-on effect for food security.

Quality is an aspect which can be carried through many of the components of the value chain as increased temperature leads to a higher risk of spoilage, which can be mitigated against by increased air-conditioning and shorter transport periods.

The indirect linkages of climate risk, which can be ascribed to the impacts of increased temperature and more variable rainfall, are reflected in increased costs of non-maize inputs such as electricity and transport.

7.4 Mangoes

Mangoes are an important economic crop to South African economy. Although, South Africa is a small exporter of mangoes, its domestic market is significant in the processing market for bottled juice and canned drinks, and it is often consumed fresh by a significant segment of the population. The total volumes of production for mangos during the past ten years has decreased over the last 10 years, though the total production value has stayed relatively constant at between R150 and 200 m over the same period.

DAFF (2012a) describes the industry:

A total volume of 50 592 tons of mangos was produced in South Africa during the 2010/11 production season. This represented a 2% increase from the 2009/10 volume of 51 702 tons. The highest volume produced during the last decade was 89 464 tons in the 2004/05 season. Considering data for the past decade, the 2001/02, 2004/05 and 2007/08 seasons experienced bumper crops. There was a 40% drop in quantities produced between 2001/02 and 2010/11 production seasons. The decline in production over the years is an indication that the area under mango production has not been increasing during the period under review. (p4)

Approximately 84% of the total crop is planted under micro, drip, sprinkler or flood irrigation. It is estimated that approximately 20% of the producers produce 80% of the total annual crop (DAFF, 2012a).

Direct and indirect employment is substantial in the mango production, processing and support industries in the areas where mangos are grown. During 2011 this was estimated at 2 900 with approximately 17 400 dependents (DAFF, 2012a).

The annual mango crop is processed into dried mangos, achar (spicy mango chutney) and juice and sold fresh through the fresh produce markets. A relatively small and decreasing amount of fresh fruit is exported, namely 1449 tons, of a total of 13,055 tons in 2011 (DAFF 2012a).

As a large proportion of the fruit remains unprocessed (fresh fruit) or semi processed (dried), the question of quality is important. The appearance and taste of the fruit is paramount in its acceptance and consumption by the market, as well as the price. The food value chain may be affected as a result of lower production volumes, leading to higher prices, but on the other hand, lower quality would result in decreased prices.

Figure 51 describes the nature of South African Mango value chain.

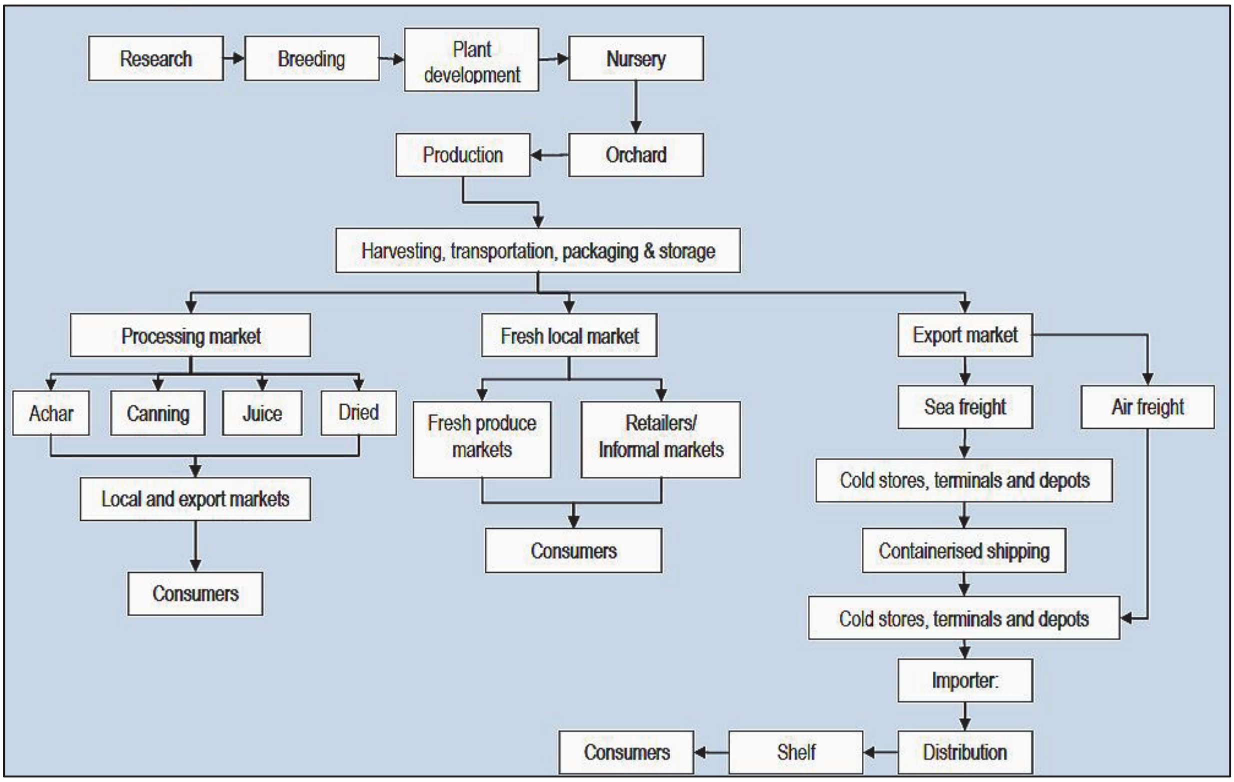


Figure 51: The mango value chain (Source: DAFF, 2012)

According to DAFF (2012a), “Climatic phenomena like El Niño and La Niña create periods of under or oversupply of mangos on the markets, due to their influence on production, i.e. rain (storm), drought damage and hot or cold temperatures during flowering” (p38). Studies have shown that processing of mango locally into juice and other locally made products have received significant attention as opposed to the export market for mango (NAMC, 2013). This has significant implication on the entire mango value chain market. The reduction in export market for mango is partly due to the nature of risks involved in the handling and storage of mango for export market.

DAFF (2012a) also states that:

“due to the cyclical drought/rain periods (5 to 10 years), mangos planted in different localities do not produce the same quality results. In dry cycles the wet areas close to the escarpment have good quality with low disease pressure and good yields. During wet cycles, areas further from the escarpment, dry areas experience less disease pressure. Higher rainfall causes higher disease levels of Anthracnose and Soft Brown Rot. Low lying areas with extended periods of night time temperatures below 8C are unfavourable for fruit set with most cultivars. Wind plays an important role on the spreading of diseases like Bacterial Black Spot. The ideal planting would therefore be in a windless, low rainfall area, with night time temperatures of 10-15C and daytime temperatures of 20-35C, with sufficient underground or canal water supply systems for irrigation.” (p38)

The Blyde river irrigation area, where this study was focused lies thus in an ideal position to grow mangoes, but climate change impacts will threaten this.

The results of the climate scenarios from the five GCM indicate that climate variability and change may pose a threat to mango (and citrus) production in the Olifants East area.

A decrease in yield and quality of mango (and citrus) was projected by the modelling results. The projected decrease may impact the entire mango food value chain.

Adaptations by farmers currently involve the introduction of shade nets, but future options may be in irrigation management changes (Pavel et al., 2004).

7.4.1 Actors in the South African mango value chain and their exposure to CC impacts

1. Producers
    - High input cost/land value ratio as a result of increases in variable costs of production resulting in greater production risks.
    - Increased costs of mitigating impacts of high temperatures, such as shade cloth, and irrigation technique enhancements.
2. Processors
    - Increased risks during packaging and transport due to increased temperatures.
    - Higher costs of air conditioning and cold chain maintenance
    - Market supply remains a weather/climate related variable. If the timing of the mango ripening period is altered, then the profitability of the mangoes reaching the market can be affected. It has been determined that the Christmas/New Year holiday period has the highest demand for mangoes. Missing this period would have serious effects for the producers/processors.
3. External input providers (non-mango raw material, transport, packaging, etc.)
    - Risks to power supply (and knock on risk to transport), due to increased temperature and more intense rainfall in electricity production areas
    - Access and availability of water leading to price increases
    - Increased temperatures and moisture increase demand for pesticides and thus costs
4. Wholesalers/Retailers
    - Distribution risks due to transport cost and threats, and increased risk of spoilage due to increased temperatures and variable, possibly more intense, rainfall. See also market timing as for producers/processors
    - Increased costs of raw materials leads to higher selling prices, opening up competition to export markets by other countries.
5. Socio-economic issues

- The major risk in decreasing production is the consequent reduction in seasonal and permanent labour, as mango farming and processing is highly labour intensive.
- Any risks carried through to retailers will be reflected in the price and supply of fruit. As it is not a staple food, the risks are relatively small.

The current tendency for farmers to concentrate more on local market could translate to a more profitable venture locally, but reduced foreign exchange nationally for mango supply chain. A lower yield of mango due to climate change/variability at the Oliphant East farms may necessarily not result into low income for the actors within mango value chain, and further study would confirm this.

Hence, beyond the farm gate, there are two possibilities for the mango value chain with respect to the linkages between vulnerability and adaptation:

Reduced yield due to vulnerability at the farm level may not necessarily translate to reduced incomes for the actors within the mango value chain, if they can utilise processing and immediate distribution for the local market, as opposed to storage for export market. Therefore, when farmers see themselves as part of the longer chain beyond the farm gate they could mitigate their loss resulting from reduced yield.

Adaptation to climate change/variability for mango producers at the Olifants East area could be in the form of strong social networks with other actors within the mango value chain. Access to quality information could also be explored. Crop diversification could also serve as a means of adaptation, such that when there is a reduced yield in mango production, citrus and other fruits in that category could be explored as alternatives.

CHAPTER 8 : THE DEVELOPMENT OF INNOVATIVE ADAPTATION STRATEGIES

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8.1 Introduction

The purpose of this chapter is to identify and discuss adaptation strategies for the different case study areas.

Extensive literature review was undertaken to establish possible adaptation strategies for the different case study areas. These strategies were discussed and debated during workshops with experts to get to practical strategies that can be implemented.

Two main types of adaptation are autonomous and planned adaptation. In this study the focus will be on autonomous adaptation, in other words, adaptation strategies which can be applied at farm level without support from other levels, e.g. policies, etc. The success of adaptation strategies will be evaluated by comparing financial vulnerability criteria of different climate and management scenarios.

From the literature research it became clear that a gap exists in the integrated economic modelling at farm level, which this study is attempting to address. The adaptation strategies that were identified as practical solutions by the expert panels will be discussed in the following sections.

8.2 Adaptation strategies – Olifants West (LORWUA)

For the grape producing area of Olifants West the adaptation strategies that were identified to be included in the integrated model are:

- **Shift in wine grape cultivars** towards cultivars that are more tolerant towards projected climate change
- **Increase raisin and table grape production**
- The installation of **shade nets** over table grapes production areas.

Shift in wine grape cultivars

The world is experiencing a warming trend. Warming may bring benefits to cool viticultural regions, but is likely to create problems in areas that are already close to the upper temperature limits for the cultivars and wine styles concerned. In these cases, relocation, or replacement with varieties that are better adapted to the higher temperatures will be necessary if it is not possible to ameliorate the effects of climate change through management practices (Woolridge, 2007).

We need to understand regional and wine cultivar difference as cultivars have fairly narrow optimal ranges within which they can produce wines of a certain style. As the climate changes, certain regions may move out of these optimal temperature ranges resulting in altered wine style or even altered optimal cultivars that should be planted (Bonnardot et al., 2011).

It is important to state that one must take mesoclimatic differences into account. Within a larger area, local climates that are determined by slope aspect, altitude and distance from the sea, can result in average growing season temperatures that are very different (Carey V, 2001, cited by Bonnardot, 2011).

Certain wine cultivars may however be more tolerant to increased temperatures than others and a shift to more heat tolerant cultivars in wine production can also be an adaptation strategy.

The expert panel indicated that within the case study region, white wine grape cultivars that will be more tolerant towards climate change include Chenin Blanc and Colombard. White wine grape cultivars that will be most vulnerable towards climate change include Sauvignon Blanc and Chardonnay.

Red wine grape cultivars that will be more tolerant towards climate change include Cabernet Sauvignon, Pinotage and Ruby. Red wine grape cultivars that will be most vulnerable towards climate change are Shiraz and Merlot.

Increase raisin and table grape production

Raisin and table grapes cultivars in general are more resilient towards climate change projections (Bonnardot, V., Carey, V. and Rowswell, D. 2011). The expert panel agreed that a shift from wine grape production to raisin and table grape production can be an adaptation strategy which will reduce the negative impact of climate change on wine grape production.

Shade nets

Shade netting is used in agriculture to protect crops from either excessive solar radiation (i.e. shading), or environmental hazards (e.g. hail, strong winds, sand storms), or as fully enclosed nets for flying pests (birds, fruit-bats, insects) (Shahak et al., 2004).

The production of table grapes under shade nets has already started to take place in the Olifants West area, but to a limited extent. In other areas, e.g. Marble Hall and Groblersdal it is common practice to produce table grapes under shade nets, although the initial main driver was the risk of hail damage.

The expert panel agreed that shade nets over table grapes can eliminate most problems associated with projected climate change and will have the following advantages:

- More efficient water use
- More consistent yield and quality
- Increase in quality (less wind damage, less quality loss due to birds)
- Lower input cost (lower labour cost due to increased quality)

Other adaptation strategies (not included in the model)

The following are a list of adaptation strategies debated but not included in the integrated climate change model:

- Irrigate at night to save water
- Plastic or mulch cover to conserve moist
- Soil preparation and site selection are important for future plantings to ensure optimum production – rather scale down and eliminate marginal blocks.

8.3 Adaptation strategies – Olifants East (Blyde River WUA)

An increase in average temperatures and seasonal shifts are the biggest threats that the Hoedspruit area faces. The following are problems associated with increased temperatures:

- Quality losses as a result of wind and sunburn (citrus & mangoes)
- Reduction in fruit set (citrus) as a result of sunburn
- Seedless cultivars are less tolerant to increased temperatures than seeded cultivars – the demand however is for seedless cultivars (citrus)

The only adaptation strategy that was identified to eliminate the threats associated with climate change and to be included in the integrated model is:

- The installation of **shade nets** over citrus and mango production areas

Shade nets

While water efficiency is a key concept to solve water-shortage problems in semiarid areas, shading nets structures in semiarid and arid environments can be considered as an intermediate solution for increasing water use efficiency and reducing plant water stress. It offer many advantages and environmental benefits, this is why an increasing area of crops, including citrus, is being grown under shading materials of various types. It was found that the use of the shading net reduces wind speed within the foliage and helped to decrease fruit dropping. The shade provided by the net does not affect yield and internal fruit quality (ratio of sugar to acid) but may increase fruit average weight and diameter (Abouatallah et al., 2012).

The Panel of experts agreed that shade nets on citrus and mangoes can eliminate most threats associated with projected climate change and will have the following advantages:

- Improvement in fruit quality (citrus & mangoes) [less hail, wind and sun damage]
- Less stress on tree (citrus & mangoes) [more consistent yields]
- More effective use of irrigation water (citrus & mangoes) [less evapotranspiration]

Other adaptation strategies (not included in the model)

The following are a list of adaptation strategies debated but not included in the integrated climate change model:

- Mulching cover to conserve moisture
- More effective management of irrigation systems
- Focus on cultivar development to increase natural heat resistance.

8.4 Adaptation strategies – Moorreesburg

Adaptation options for the Moorreesburg area can be divided in two categories, namely changes in:

- Cropping systems
- Production practices

Cropping systems (crop rotation)

The benefit of crop rotation in reducing production risk involves three distinct influences that were described by Helmers et al. (2001). Firstly, rotations, as opposed to monoculture cropping, may result in overall higher crop yields as well as reduced production costs. Secondly, rotation cropping is generally thought to reduce yield variability compared with monoculture practices. Thirdly, crop rotation involves diversification, with the theoretical advantage that low returns in a specific year for one crop is combined with a relatively high return for a different crop. Drought however, is usually detrimental to all crops, often preventing this advantage from occurring. An obvious benefit of diversification is the reduction of risk through the inclusion of alternative crops with relatively low risk (Nel & Loubser, 2004).

Higher yields associated with rotated crops will increase the per hectare cost of activities such as harvesting. On the other hand, weed and often pest control costs are less on rotated than monoculture crops, which will increase the net return. It is also known that nitrogen fertilization of grain crops can be reduced when grown in rotation with oil and protein rich crops without affecting the yield. The savings on inputs most probably outweigh the extra costs of harvesting higher yields, which suggests that the net returns and risk for the rotation systems are conservative estimates (Nel & Loubser, 2004).

Current cropping system for the case study is wheat-medics-wheat-medics combined with mutton production. Other alternative cropping systems adapted for the region to be included in the model are:

- Wheat-medics-wheat-medics (with soutbos)
- Wheat-medics-medics-wheat
- Wheat-wheat-wheat-wheat (mono cropping system) [with no sheep]
- Wheat-lupin-wheat-canola (no sheep)

Production practices

In the past 15 years, successful adoption of conservation agriculture (CA) took place among grain and sugar farmers in Kwa-Zulu Natal, as well as among grain farmers in the Western Cape and Free State, but has remained rather slow in other production areas of South Africa. Their main reasons for adopting CA relate to the improved water conservation properties and the ability to substantially lower production costs (Du Toit, 2007).

In 2004 it was reported that 45% of the total land cultivated in Brazil, is now estimated to be managed with no-till. In the case of land cropped by smallholder farmers (<50 ha), this figure is even reported to exceed 80% (Du Toit, 2012). Worldwide, a total of approximately 95 million hectares (ha) are currently being cultivated according to the principles of CA (Derpsch, 2005). The United Nations Food and Agriculture Organization, who have promoted the concept for the past ten years, state that CA has great potential in Africa, being the only truly sustainable production system for the continent (Food and Agriculture Organization, 2006).

It is thus evident that South Africa lack behind in adapting to long term sustainable production practices.

Conservation agriculture is an integrated system built on the following basic principles (Nel, 2010; du Toit, 2012):

- Minimum soil disturbance – Conventional tillage methods are replaced by reduced or no-tillage and crops being planted by adapted planting equipment.
- Establishment and maintenance of an organic soil cover in the form of a mulch.
- Implementation of crop diversification and rotations, as opposed to mono-cropping.

The BFAP study (Du Toit, 2007) extensively researched conservation agriculture and concluded that it can definitely serve as an adaptation strategy. The study indicated significant economic and biological benefits, in the form of increased crop yields and net farm income, since starting with CA.

Adaptations options include:

- Conservation agricultural production practices versus conventional production practices

8.5 Adaptation strategies – Carolina

Adaptation options for the Carolina area can be divided in two categories, namely changes in:

- Cropping systems
- Production practices

Cropping systems (crop rotation)

For a detailed discussion on cropping systems the reader is referred to section 8.4 (Cropping systems).

Current cropping systems are maize-soybeans-maize-soybeans and maize-sugar beans-maize-sugar beans combined with beef and mutton production. An alternative cropping system adapted for the region to be included the integrated model is:

- Maize-maize-maize-maize (mono system)

Production practices

For a detailed discussion on cropping systems the reader is referred to section 8.4 (Production practices).

Adaptations options include:

- Conservation agricultural production practices versus conventional production practices

Other adaptation strategies (not included in the model)

The following are a list of adaptation strategies debated in the reference group, but not included in the integrated climate change model:

- Narrower row width (for better moisture conservation)
- More short growers (access to genetics is a problem)
- Moist management is very important
- Grain sorghum and sunflower production can be an alternative (to be researched)

8.6 Olifants East/Inkomati (small scale/subsistence)

Findings from the research from Bushbuckridge support the argument that farmers live and work in a multi-stressor environment, where vulnerability is location specific. The research reflects the need to strengthen small-scale farmers' capacity to deal with challenges in their current environment, while at the same time preparing for future climatic change. Future climate change projections indicate that current thresholds, points beyond which farming objectives, under current practices and adaptation mechanisms, are no longer maintained, are at risk of being more commonly exceeded in the future. Climate change projections should therefore be incorporated into agricultural development that encourages a long-term perspective while at the same time dealing with current problems.

When considering how small-scale farmers can best improve their current conditions, and further improve their ability to deal with climatic change, it is important to keep in mind that people are "active agents rather than passive victims of circumstances" (Eriksen et al., 2005, p.302). This research proposes that a participatory community process is necessary at the ground level, a process that builds on local capacity and knowledge, and which can identify locally appropriate and suitable adaptations. This should be a participatory process that is aware of and sensitive to local considerations of culture, ethics, knowledge and risk. Local actors, such as extension officers, who have a continuous presence in farming communities, should ideally run such initiatives. This does not mean that external knowledge from scientists and practitioners is not required. As was highlighted by Maddison (2006), some of the possible limits to adaptation include both the lack of knowledge about adaptations and the lack of weather and climatic information. It is also important to remember that climate change projections indicate future conditions and extremes that are potentially beyond what farmers have experienced in their lifetime, and a participatory community process may therefore require scientific and professional input.

Such efforts as those involved in creating the participatory community processes outlined above come with a number of challenges. Firstly, creating the time necessary might pose a challenge both to farmers and to extension officers. Farming is a time consuming occupation, and many rural households also face daily and immediate issues and tasks, such as acquiring water for domestic use. It might therefore be difficult for small-scale farmers to find, or to prioritise, the time necessary for such a process. As for extension officers, they would have to add the process to their current work tasks.

At policy level, focus and prioritising is required, as resources should be brought towards training extension officers and providing them with the necessary resources. Accordingly, projects in NGOs and academic institutions should focus on partnering and knowledge sharing with local extension officers. This might be challenging, both in relation to making the necessary financial resources and skills available, and in relation to partnerships, as the willingness of stakeholders such as scientists, NGO workers and government officials to cooperate might be limited.

As the research from Bushbuckridge has illustrated, more research is required in order to further uncover and understand the inter-related nature of stressors and responses in the small-scale farming sector. Research should also focus further attention on the thresholds that reflect the point beyond which current practices and adaptation strategies are no longer able to sustain farming objectives, thereby guiding the adaptation process towards the areas where further adaptation action is needed. The limited scope of the research from Bushbuckridge also reflects the need for similar, though larger, community scale research that can work to strengthen the findings from this research.

In conclusion this research has shown that using a vulnerability framework helps to uncover context and location specific dynamics. The research has highlighted the need to focus on the current challenges facing small-scale farmers, while also preparing for future change. It is clear that adaptation initiatives need to include partnerships that are based on understanding local context and needs, and that further ensure continuity through which adaptation can be treated as a process rather than an end point.

This chapter summarised the different adaptation strategies that were identified through literature review and discussions with experts and expert panels within each of the case study regions. These adaptation strategies will be included into the integrated model as alternative options to current farming practices. The impact of the different adaptation strategies on the financial vulnerability of the different farming systems in the case study areas will be evaluated.

CHAPTER 9 : INTEGRATED MODELLING TO DETERMINE FINANCIAL VULNERABILITY

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9.1 Introduction

In this chapter the model is developed to predict the impact of climate change on the financial vulnerability of different farming systems. The modelling framework includes 4 modules that will be discussed in more detail below.

9.2 Layman's description of the model

Figure 52 is a diagrammatical illustration of the modelling framework which consists of 4 modules:

- Climate change impact modelling:
  - Modelling of physical climate data (daily minimum and maximum temperatures and daily rainfall from different downscaled GCMs) that impact on crop yield and quality.
  - Changing crop irrigation requirements (as a result of climate change).
  - Hydrological modelling – impact of climate change on the availability of irrigation water (for the Blyde WUA).
- DLP model.
- Modelling interphases.
- Financial Vulnerability Assessment model.

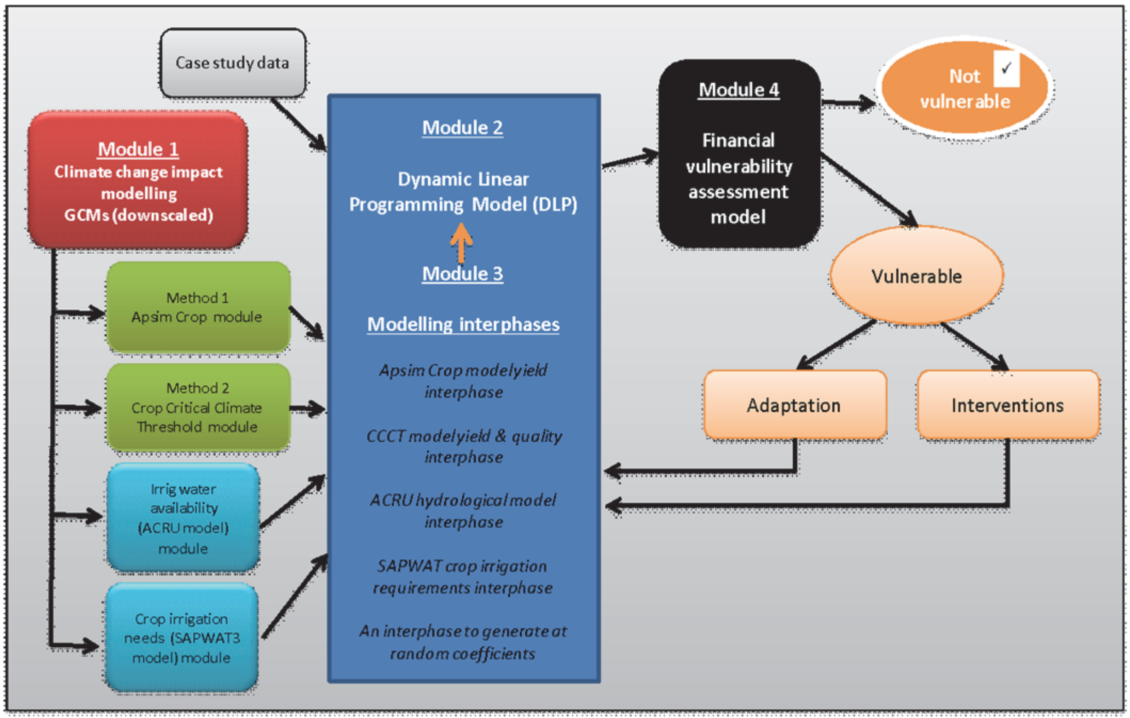


Figure 52: Diagrammatic illustration of the modelling framework

In the next four sections these modules are discussed in more detail.

9.2.1 Climate change impact modelling

The impact of climate change on the financial vulnerability of the case study farms is modelled by using downscaled climate information from different GCMs to determine the impact of climate change on:

- Yield and quality of agricultural produce in the case study areas
- Crop irrigation requirements (for irrigation case studies LORWUA and the Blyde River WUA)
- Availability of irrigation water (for the Blyde River WUA case study).

The subsections of climate change impact modelling are discussed in more detail below.

<u>9.2.1.1 Downscaled GCMs</u>

<u>GCMs</u>

The interactions between the many processes that govern the Earth's climate are so complex and extensive that quantitative predictions of the impacts of increasing concentrations of greenhouse gases on climate cannot be made through simple intuitive reasoning (Shaka, 2008). For this reason, computer models, i.e. Global Climate Models (GCMs), have been developed, which are mathematical representations of the Earth's system, and in which physical and biogeochemical processes are described numerically to simulate the climate system as realistically as possible (Jacob and van den Hurk, 2009).

GCMs are founded on assumptions about the evolution of drivers of climate change, for example the distributions of aerosols and greenhouse gases, and their respective concentrations, in the atmosphere (Jacob and van den Hurk, 2009). These depend directly on natural and anthropogenic emissions, which are estimated through emission scenarios developed by using so-called “storylines” (Nakićenović et al., 2000) that describe possible developments in global population growth and other aspects of the socio-economic system (Cox and Stephenson, 2007; Jacob and van den Hurk, 2009). These emission scenarios are used to drive atmospheric chemistry and carbon cycle models that simulate changes in the concentration of greenhouse gases and aerosols (Cox and Stephenson, 2007). The resulting concentration scenarios are then input into GCMs, which generate climate change scenarios that in turn drive models of the impacts on human and natural systems (Cox and Stephenson, 2007).

Uncertainties inherent to GCMs

Uncertainties inherent in GCMs have been well documented (UKCIP, 2003; Cox and Stephenson, 2007; Giorgi et al., 2008; Jacob van den Hurk, 2009; Schulze, 2009). In addition to the limitations resulting from uncertainties, GCMs are less capable of simulating second order atmospheric processes such as precipitation, compared to those related to first order atmospheric processes such as surface heat and vapour fluxes (Hardy, 2003). These limitations include (Schulze et al., 2011):

- Failure to simulate individual convective rainfall events, owing to the coarse spatial resolutions of GCMs, and the smaller spatial and temporal nature of convective rainfall, which poses problems in many parts of the world, including most of southern Africa, where convective rainfall is a dominant form of precipitation.
- Difficulty in simulating the intensity, frequency and distribution of extreme rainfall (IPCC, 2007).
- Tending to simulate too many light rainfall events and generally too few heavy rainfall events, whilst maintaining a fairly realistic mean precipitation (IPCC, 2007).
- Poorly representing major drivers of climate variability, such as the El Niño – Southern Oscillation phenomenon (Hulme et al., 2001), which is associated with a broad band of variability throughout southern Africa (Tyson, 1996).
- Poorly accounting for climatological variables that represent other atmospheric conditions that lead to high magnitude precipitation and flood-producing events.

These factors tend to reduce the accuracy of precipitation output from GCMs. Additionally, global mean temperatures can be quite unrepresentative at the local scale (Jacob and van den Hurk, 2009) and so can any subsequent estimations of potential evaporation. Therefore, questions remain in regard to the usability of direct GCM output in detailed hydrological studies, where precipitation, temperature and potential evaporation at the local scale are primary inputs into hydrological models (Schulze et al., 2011).

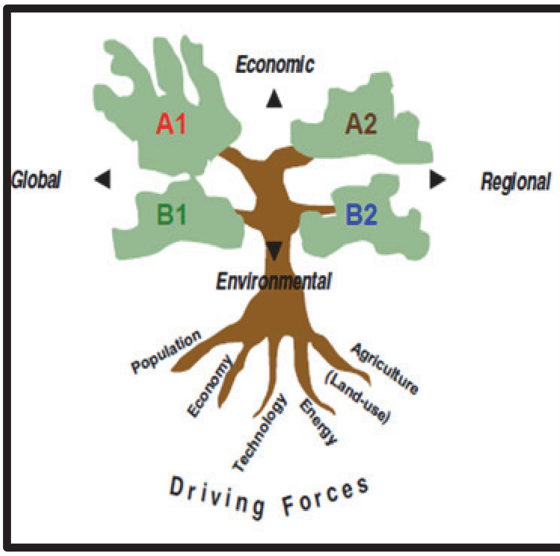
Nevertheless, output from GCMs forms the basis for climate change impact assessments. A significant discontinuity, however, exists between the output from GCMs (spatial scales of 10^4-10^5 km^2) and the catchment scale (10^1-10^2 km^2) at which local decisions are sought and local adaptation options need to be considered (Schulze, 2009). It is due to this discontinuity that GCM output needs to be translated from the coarse to more local scales by the process of regional climate downscaling (Giorgi et al., 2008, cited by Schulze, 2011).

Statistically downscaled GCMs

Statistical downscaling involves developing a quantitative relationship between local-scale variables and large-scale atmospheric variables, which is subsequently applied to the GCM output to obtain local and regional climate change signals (Jacob and van den Hurk, 2009). An advantage of this technique is that GCM output can be downscaled to a point, which is useful for obtaining projections for, say, rainfall at a particular site, which can then be input into a hydrological or crop yield model. A major disadvantage of this approach is the implicit assumption that these statistical relationships will remain stationary under a future climate (UKCIP, 2003; Jacob and van den Hurk, 2009).

The resolving scale of GCMs has improved significantly in the past ten years with many state of the art GCMs able to resolve at a scale of around 100 km. Downscaled climate data (daily rainfall and temperature) were obtained from CSAG.

The climate change scenarios developed by CSAG for application in this project were derived from global scenarios produced by five GCMs, all of which were applied in the IPCC's (2007) Fourth Assessment Report [AR4] (Schulze et al., 2011). Details of the five GCMs used in this study are provided in Table 56. All of the future global climate scenarios that were downscaled by CSAG to point scale for use in this study were based on the A2 emissions scenario (Figure 53) defined by the IPCC SRES (Nakićenović et al., 2000).



A1:	A world of rapid economic growth and rapid introductions of new and more efficient technologies
A2:	A very heterogeneous world with an emphasis on family values and local traditions
B1:	A world of dematerialization and introduction of clean technologies
B2	A world of emphasis on local solutions to economic and environmental sustainability

Source: After Nakićenović et al.*, 2000; graphic illustration from IPCC-TGICA (2007)*

Figure 53: SRES scenario storylines considered by the IPCC

Table 56 gives a condensed description of the information on GCMs, the global climate change scenarios of which were statistically downscaled by CSAG to point scale for application in this project. Five GCMs were used from various respected international organisations.

Table 56: GCMs description

Institute	GCM
Canadian Center for Climate Modelling and Analysis (CCCma), Canada ***Abbreviation: CCC***	**Name:** CGCM3.1(T47) **First published:** 2005 Website: http://www.cccma.bc.ec.gc.ca/models/cgcm3.shtml
Meteo-France / Centre National de Meteorologiques (CNRM), France ***Abbreviation: CRM***	**Name:** CNRM-CM3 **First published:** 2004 Website: http://www.cnrm.meteo.fr/scenario2004/indexenglish.html
Max Planck Institute for Meteorology Germany ***Abbreviation: ECH***	**Name:** ECHAM5/MPI-OM **First published:** 2005 Website: http://www.mpimet.mpg.de/en/wissenschaft/modelle.html
NASA / Goddard Institute for Space (GISS), USA ***Abbreviation: GISS***	**Name:** GISS-ER **First published:** 2004 Website: http://www.giss.nasa.gov/tools/modelE
Institut Pierre Simon Laplace (IPSL), France ***Abbreviation: IPS***	**Name:** IPSL-CM4 **First published:** 2005 Website: http://mc2.ipsl.jussieu.fr/simules.html

The statistically downscaled climate data from the various GCMs include daily minimum and maximum temperatures and rainfall. The climate change scenarios were developed for the “present” (1971-1990) and “intermediate future” (2046-2065).

These statistically downscaled GCMs values were used in various modelling phases including determining:

- Climate change impacts on yield and quality of crops
- Climate change impacts on crop irrigation requirements
- Climate change impacts on irrigation water availability.

A note of caution on the GCMs used in this study

Overall changes in future scenarios of climate depend strongly on (Schulze et al., 2011):

- which GCMs were used, and
- how many GCMs were in the ensemble used.

The five GCMs which were available for use in this study, viz. CGCM3.1(T47), CNRM-CM3, ECHAM5/MPI-OM, GISS-ER and IPSL-CM4 are considered by climatologists to produce rainfall output possibly on the wetter side of the spectrum (Hewitson, 2010. Personal communication with Prof Schulze), and this has to be borne in mind in interpreting any impacts in which rainfall is an input variable. Furthermore, an error in GISS GCM's rainfall values for parts of South Africa was reported during the course of the project and all statistics from multiple GCMs involving rainfall had to be re-calculated in order to eliminate the known error from that GCM (Schulze et al., 2011).

However, the reader should note that the main contribution of this study is to develop the methodology to analyse the financial vulnerability of farmers on a micro level. The accuracy of the selected GCMs and the error which was discovered in one of the GCMs is therefore irrelevant for the purpose of this study. The methodology developed in this study can use the data/information generated by any existing/future GCM. However, at this point in time the GCMs remain the only credible tools we have for climate change impact studies (Schulze, 2014).

The following sections will focus on the methodologies applied to quantify the impact of climate change on the financial vulnerability of farming systems.

9.2.1.2 Climate change impact on yield and quality of crops

Two different methodologies were used to determine the impact of projected future climates on yield and quality (only for CCCT scenarios) of crops in the different case study areas. In both these methodologies the statistically downscaled climate values were used as input to determine present and projected future yield and quality. The methodologies used to determine the impact of climate change are:

- APSIM model for impact on yield.
- CCCT model for impact on yield and quality.

The methodologies will be discussed in the following sections.

APSIM modelling – impact on yield

The APSIM software is a modular modelling framework that has been developed by the APSIM Initiative and its predecessor, the Agricultural Production Systems Research Unit (APSRU) in Australia (McCown, 1995).

APSIM was developed to simulate biophysical processes in agricultural systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk.

It is structured around plant, soil and management modules. These modules include a diverse range of crops, pastures and trees, soil processes including water balance, N and P transformations, soil pH, erosion and a full range of management controls. APSIM resulted from a need for tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factors while addressing the long-term resource management issues (Keating et al., 2003).

The APSIM modelling framework is made up of the following components (Keating et al., 2003):

- A set of biophysical modules that simulate biological and physical processes in farming systems.
- A set of management modules that allow the user to specify the intended management rules that characterise the scenario being simulated and that control the simulation.
- Various modules to facilitate data input and output to and from the simulation.
- A simulation engine that drives the simulation process and facilitates communication between the independent modules.

APSIM has been used in a broad range of applications, including support for on-farm decision making, farming systems design for production or resource management objectives, assessment of the value of seasonal climate forecasting, analysis of supply chain issues in agribusiness activities, development of waste management guidelines, risk assessment for government policy making and as a guide to research and education activity (Keating et al., 2003).

APSIM was used to determine probable yield changes that could materialise with different downscaled GCMs data from present to intermediate future climate scenarios. APSIM calibration and simulation for this study were performed by CSAG relying on project data made available and summarised in the WRC (2012) report.

Crop yields were simulated under climate change scenarios for the following:

- Wheat (Moorreesburg)
- Maize (Carolina)
- Grape vineyards (LORWUA) – *[prototype model]*

The APSIM crop model for vineyard is a prototype model and does not distinguish between wine grapes, table grapes and raisins. Hence, results for future wine grape simulations should be interpreted carefully.

Fruit tree models are uncommon, and no mango model was found to respond to the process-based, future climate driven, including management options, requirements of the study. APSIM does not currently have a model for citrus or mangoes and could therefore not contribute to the modelling of the impact of climate change on yield and/or quality of mango or citrus crops. Like most numerical models, the APSIM model strength relies on quantitative information, while qualitative information is difficult to extract.

The results of the APSIM crop modelling (crop yield for different crops) will be discussed with the different case study analyses. The projected yields are integrated into the DLP model via an interphase namely APSIM crop model interphase.

In the absence of crop models to model the impact of climate change on yield and/or quality of certain crops, a new methodology was developed namely the CCCT modelling technique, which will be discussed in the section below.

CCCT modelling – impact on yield and quality.

The Crop Critical Climate Threshold (CCCT) modelling technique is based on the following pillars:

- Statistically downscaled daily climate values (rainfall, minimum and maximum temperatures).
- Physical/biological critical climate thresholds for different crops.
- Expert group discussions (for guidance on crop critical climate thresholds and also the impact on yield and/or quality should a threshold be exceeded).

The use of expert group discussions, as a research method is suitable, firstly, for gathering information in a meaningful manner and, secondly, to stimulate individual creativity by presenting alternative perspectives provided by various participating experts (Hoffmann, 2010). However, due to the various uncertainties in the models, when analysing CCCT modelling results the emphasis should be on trends in projected yield and quality, rather than absolute values.

The CCCT modelling consists of the following steps:

- The crop critical climate thresholds for different crops were determined during workshops with farmers and experts. This includes the impact on yield and/or quality of the crop if the threshold is breached.
- These thresholds are then applied to different climate scenarios (present and intermediate) of the downscaled GCMs to determine the number of breaches per threshold for the different climate scenarios.
- The effects of critical climate threshold breaches (which can be positive or negative) are then calculated to determine the impact on yield and/or quality of crops.

The results of the crop critical threshold modelling are integrated into the DLP model through an interphase (critical crop climate threshold interphase).

9.2.1.3 Climate change impacts on crop irrigation requirements

The term crop water requirement is defined as the "amount of water required to compensate the evapotranspiration loss from the cropped field" (Allen et al., 1998). The ICID (2000) describes it as the "total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield". "Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration" (Allen et al., 1998).

Crop irrigation requirements are a function of various climate variables and therefore will vary under different climate scenarios. In order to provide for changing crop irrigation requirements in the integrated model, the SAPWAT3 program was used to calculate crop irrigation requirements under different climate scenarios. The following section will briefly describe the SAPWAT3 program.

SAPWAT3

SAPWAT3 is essentially an enhanced and improved version of SAPWAT (South African Plant WATer), a program that is extensively applied in South Africa and was developed to establish a decision-making procedure for the estimation of crop irrigation requirements by irrigation engineers, planners and agriculturalists. Subsequent to the development of the initial SAPWAT programme, the FAO published the Irrigation and Drainage Report No. 56, Crop Evapotranspiration – Guidelines for computing crop water requirements (Allen et al., 1998) – hereafter referred to as FAO 56. This comprehensive document is highly acclaimed and has become accepted internationally. As the calculation of crop evapotranspiration is the first and essential element of any routine for estimating crop irrigation requirement, the decision was taken to reprogram the initial model and SAPWAT3 has at its core the computer procedures contained in FAO 56 and all recommendations have been applied to the letter (Van Heerden et al., 2009).

The irrigation requirement of crops is dominated by weather, particularly in the yearly and seasonal variation in the evaporative demand of the atmosphere as well as precipitation. SAPWAT3 has included in its installed database comprehensive weather data that is immediately available to the user (Van Heerden et al., 2009):

- Firstly, it includes the complete FAO Climwat climate data base encompassing not only South Africa, but many other countries in the world where there is irrigation development. Climwat comprises 3 262 weather stations from 144 countries, including South Africa, and contains long-term monthly average data for calculating Penman-Monteith ET_0 values as well as rainfall. While Climwat climate data output is monthly averages, SAPWAT3 calculations are based on daily values, thus requiring interpolation. This has been facilitated in SAPWAT3 by statistically fitting a curve to the monthly ET_0 values.
- The second installed set of weather data in SAPWAT3 consists of data derived from weather stations and is only applicable to South Africa. This database was developed from the "South African Atlas of Climatology and Agro hydrology" by the team from the School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-

Natal (Schulze, 2008). The data were generated from actual weather stations and then interpolated to locations at the centroids of the polygons that represent each of the 1 946 Quaternary Catchments (drainage regions) covering the country, thereby provide not only comprehensive spatial coverage, but also 50 years of historical (1950 to 1999) daily climate data for each Quaternary Catchment on a calendar basis (Schulze, 2008). This capability has major implications when it comes to planning and strategy development. It is possible to select any day during this period and access the maximum and minimum temperatures, humidity, rainfall, solar radiation and ET_0.

SAPWAT3 provides facilities for importing data from additional weather stations. If the weather station database consists of average monthly values, similar to Climwat, then manual importation is recommended, but if the data are more detailed there are facilities for formatting and importing the data files as a package (Van Heerden et al., 2009).

SAPWAT3 can be applied for estimating the irrigation requirements for a single crop, for a field with multiple cropping, for a single farm, for a group of farms (e.g. WUA), for a group of WUAs or even a river basin. Output is provided, where appropriate, in millimetres and cubic metres. Provision is made for printing comprehensive output tables and/or saving to file and/or exporting for further processing by spread sheet applications (Van Heerden et al., 2009).

SAPWAT3 utilises the four stage crop development curve procedure based on relating crop evapotranspiration in each stage to the short grass (Penman-Monteith) reference evapotranspiration by applying a crop coefficient. Typical values of expected average crop coefficients under a mild, standard climatic condition are published in FAO 56 and are applied in SAPWAT3 (Van Heerden et al., 2009).

SAPWAT3 incorporates the internationally recognised Köppen-Geiger climatic system. The system is based on temperature-rainfall combinations so that the climate of the weather station can be classified by using the temperature and rainfall data of a weather station record (Van Heerden et al., 2009).

SAPWAT3 makes use of the FAO 56 procedure that separates soil water evaporation from plant transpiration and, therefore, conforms to the FAO 56 defaults that determine soil water characteristics and evaporation parameters. Fortunately, FAO 56 specifies soils according to the familiar sand, silt and clay criteria into nine texture classes. The profile water balance during irrigation is also calculated and tabulated strictly in accordance with FAO 56 methodology (Van Heerden et al., 2009).

The methodology for estimating crop evapotranspiration under so-called “standard” conditions has been well researched and due allowance can be made for non-standard conditions arising from unusual circumstances and the realities of practical management (Van Heerden et al., 2009).

The SAPWAT3 program was applied to determine changing crop irrigation requirements under present and future climate scenarios using downscaled climate data of the various GCMs used in this study. The changing crop irrigation requirements will be discussed with the different case study analyses.

The crop irrigation requirements data is introduced to the DLP model via the crop irrigation requirements interphase which will be elaborated upon in later sections.

9.2.1.4 Climate change impacts on the availability of irrigation water

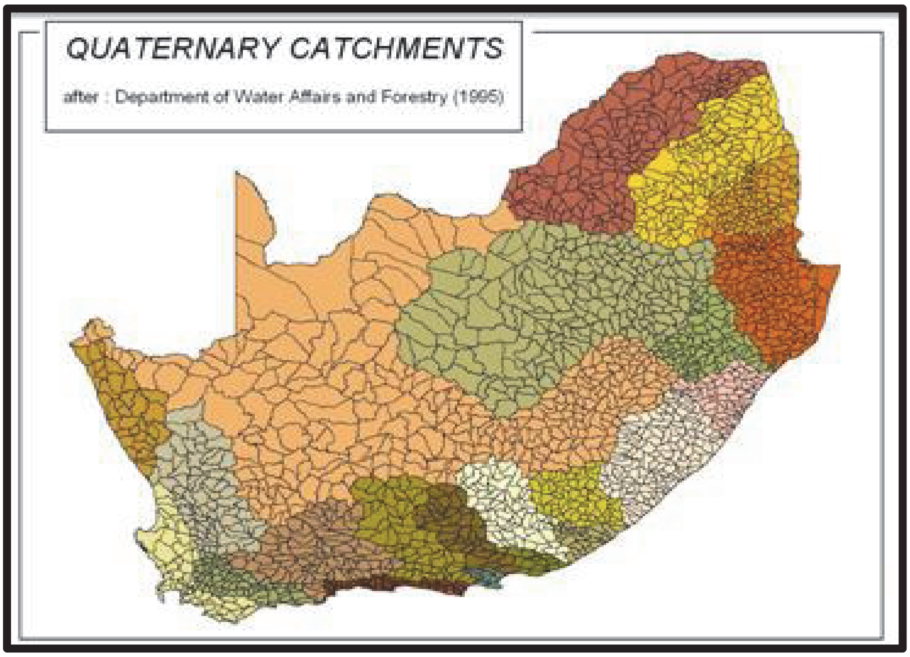
The availability of irrigation water is dependent on dam levels that are a function of, amongst others, rainfall patterns and catchment responses to rainfall. To determine the impact of climate change on the financial vulnerability of irrigation farming systems, the availability of irrigation water should be investigated (subject to data availability).

The projected future dam levels for the Blydepoort Dam were computed by the Centre of Water Resources Research in the School of Agricultural, Earth and Environmental Science, University of KwaZulu-Natal (UKZN). The daily present and intermediate climate values from downscaled GCMs were used in the ACRU model to project future changes in dam levels. The following sections give a brief description of the background and methodology followed to arrive at the projected dam levels.

For this study the projected dam level information for LORWUA was not available and the availability of irrigation water could thus not be factored into the integrated model. The proposed enlargement of the Clanwilliam Dam is another uncertainty which contributed to the decision to rather treat the availability of irrigation water in the Olifants-Doring system as a constant and focus on the projected impact of climate change on yield and quality of crops in that catchment.

The concept of quinary catchments

The erstwhile South African Department of Water Affairs and Forestry (DWAF; later DWA – the Department of Water Affairs and as of June 2014 DWS – the Department of Water and Sanitation) delineated the RSA, together with Swaziland and Lesotho, into 22 primary catchments, which in turn were disaggregated into secondary, then tertiary and finally, into 1 946 interlinked and hydrologically cascading quaternary catchments (QCs), as shown in Figure 54. This “fourth level” of discretisation has, to date, constituted the most detailed spatial level of operational catchment in the DWA (now DWS) for general planning purposes (Schulze et al., 2011).

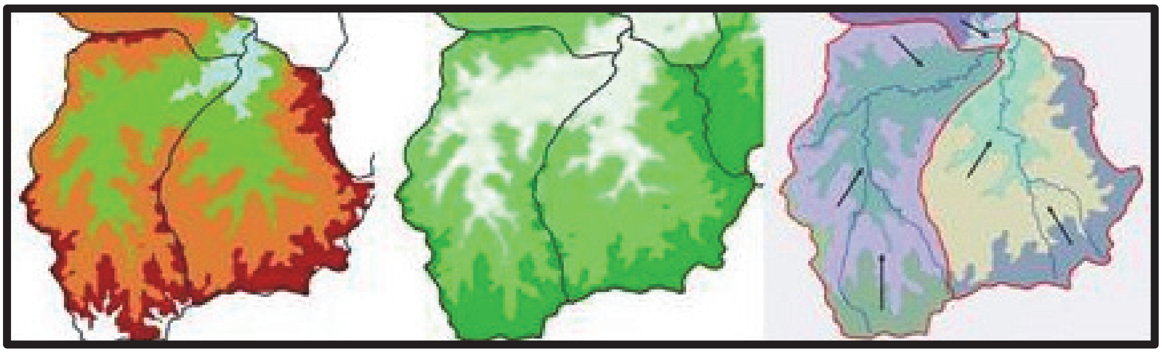


Source: After Midgley et al. (1994)

Figure 54: Primary catchments (in colours) and quaternary catchments covering the RSA, Lesotho and Swaziland

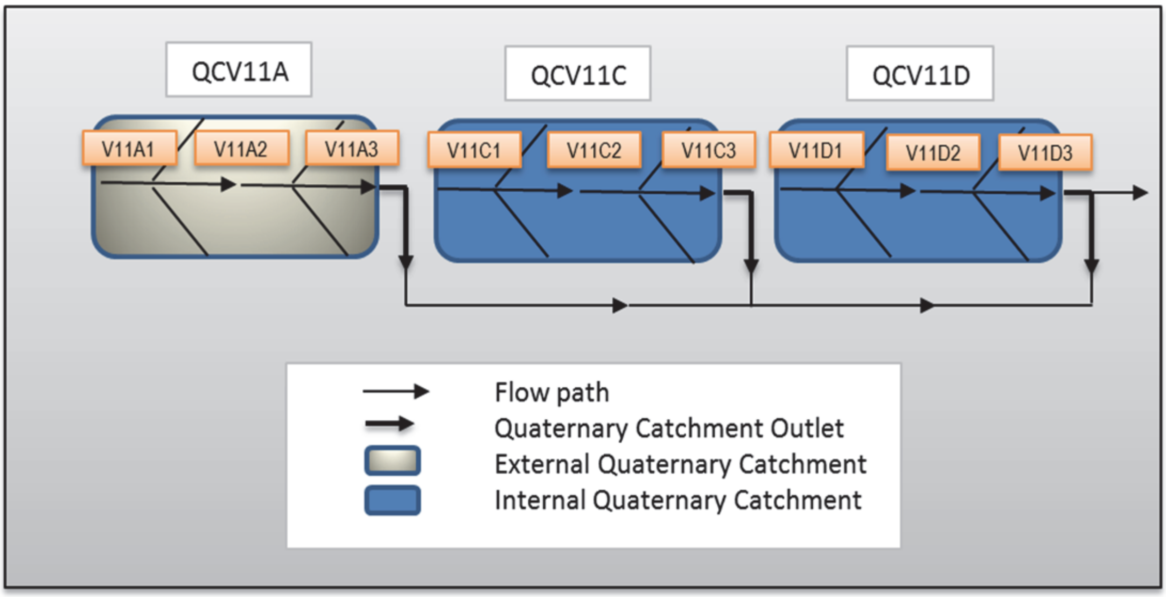
Schulze and Horan (2007; 2010) have shown that many fourth level quaternary catchments in southern Africa are physiographically too diverse for hydrological responses from them to be considered relatively homogeneous. By applying Jenks' optimisation procedures available within the ArcGIS software suite, a three-fold altitude break based sub-delineation of QCs into fifth level quinary catchments (the Upper, middle and lower quinaries of a QC) has been carried out (Figure 55). These quinary catchments were then configured within the QC configuration, such that the outflow of the upper quinary enters the middle, which in turn flows into the lower quinary. However, the lower quinary outflow of a QC does not enter the upper quinary of the next downstream quaternary catchment, because that QC's upper quinary may be at a higher altitude than the lower quinary of the immediate upstream quaternary. Therefore, the outflow of the lower quinary has been configured to rather enter the downstream Quaternary at its exit (Schulze and Horan, 2010). A schematic of the flowpath configuration between quinaries and quaternaries, taken from the Upper Thukela Catchment, is given in Figure 56.

The sub-delineation of quaternary into quinary catchments has resulted in 5838 hydrologically interlinked and cascading quinaries (Figure 57) covering the RSA, Lesotho and Swaziland. These have been demonstrated to be physiographically considerably more homogeneous than the quaternaries (Schulze and Horan, 2007; 2010) and on a national and smaller scale are considered to be relatively homogeneous hydrological (as well as agricultural) response zones.



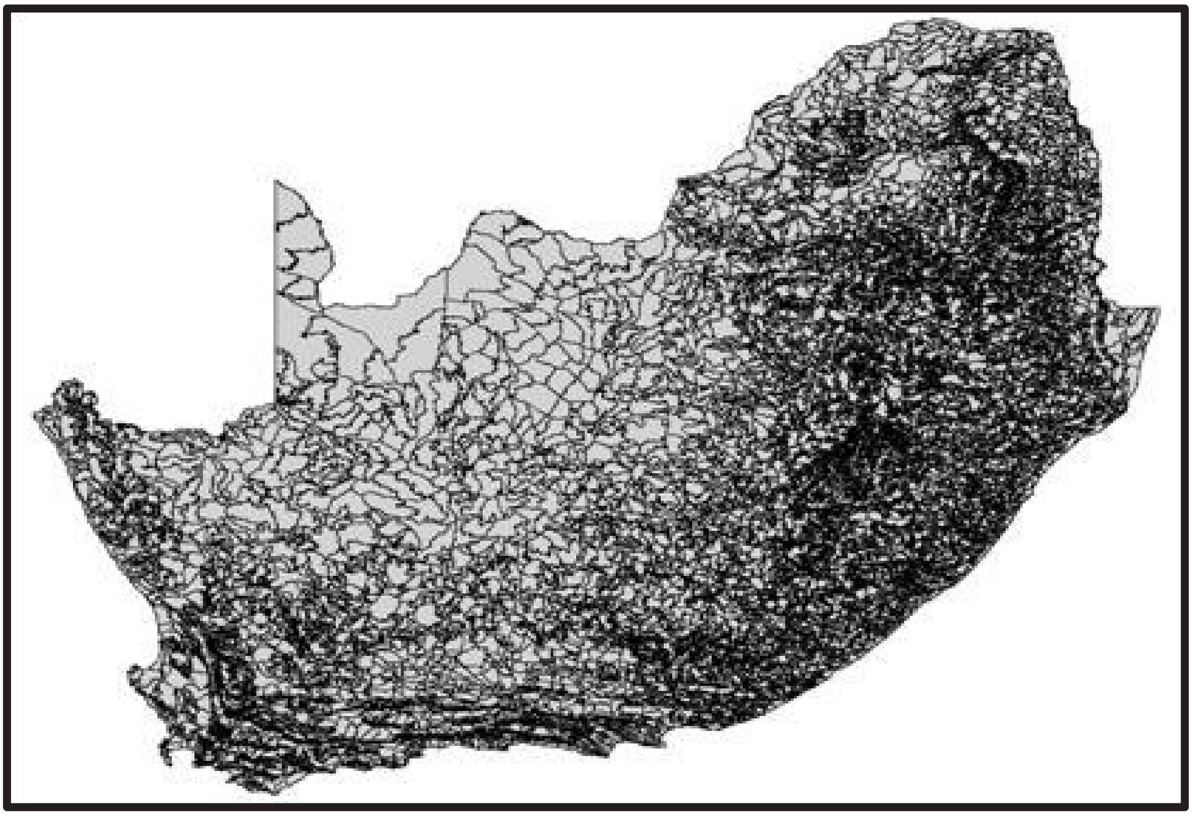
Source: Schulze and Horan (2010)

Figure 55: Sub-delineation of quaternary catchments from altitude (left) into three quinaries by natural breaks (middle) with flow paths (right) of water



Source: Schulze and Horan (2010)

Figure 56: Flowpaths between quinary and quaternary catchments, with the example taken from the Upper Thukela catchment



Source: Schulze and Horan (2010)

Figure 57: Delineation of the RSA, Lesotho and Swaziland into 5 838 hydrologically interlinked and cascading quinary catchments

From a quaternary to quinary catchments database

Following the delineation of the southern African countries of the RSA, Lesotho and Swaziland into hydrologically interlinked quinary catchments, the formerly used Quaternary Catchments Database (QCB) (Schulze et al., 2005) needed to be expanded to form a new database, viz. the Southern African Quinary Catchments Database, QnCDB (Schulze et al., 2011). The expansion of the QCD to the newly created QnCDB was achieved in collaboration with researchers from another climate change impact study (Schulze et al., 2010a).

The key climatic and catchment input into the QnCDB include (Schulze et al., 2011):

- Daily rainfall input per quinary catchment:
  - Estimations of daily rainfall values for simulations under baseline historical climatic conditions.
  - Estimations of daily rainfall values for simulations with GCM derived present and future climate scenarios.

  Rainfall is generally considered to be the most important input into any hydrological model.
- Daily temperature input per quinary catchment:
  - Estimations of daily values of maximum and minimum temperatures for simulations under baseline historical climatic conditions.

- Estimations of daily values of maximum and minimum temperatures for simulations with GCM derived present and future climate scenarios.

Daily maximum and minimum temperature values, derived from procedures described in detail by Schulze and Maharaj (2004), facilitate estimations to be made, either implicitly or explicitly, of solar radiation, vapour pressure deficit and potential evaporation (Schulze, 2008). Using these variables in addition to rainfall, as input into hydrological models such as ACRU, the generation of soil moisture content, runoff and/or irrigation demand becomes possible (Schulze et al., 2010b).

- Estimations of daily values of reference crop evapotranspiration per quinary catchment:
  - Estimations of daily values of reference crop evapotranspiration for simulations under baseline historical climatic conditions.
  - Estimations of daily values of reference crop evapotranspiration for simulations with GCM derived present and future climate scenarios.

Methods of estimating potential evapotranspiration (Ep) range from complex physically based equations to relatively simple surrogates based on single variables such as temperature. The various methods all yield different estimates under different climatic conditions, and a reference potential evaporation (Er) therefore has to be selected as that evaporation against which other methods must be adjusted appropriately. In simulating the hydrological landscape with a vegetative cover and/or under irrigation, the physically based FAO (1992) version of the Penman-Monteith equation (Penman, 1948; Monteith, 1981) has now become the *de facto* international standard of what is termed reference crop evapotranspiration, replacing the A-Pan and other techniques (Schulze et al., 2010b).

- Soils information

The ACRU model (Schulze, 1995 and updates) revolves around multi-layer soil water budgeting and therefore requires soils information as input. Being a threshold based model, ACRU needs input values on the following soils variables (Schulze et al., 2010b):

- thickness (m) of the topsoil and the subsoil
- soil water contents (m/m) at:
  - saturation (porosity)
  - drained upper limit (also commonly referred to as field capacity)
  - permanent wilting point (i.e. the lower limit of soil water availability to plants)
- rates of saturated drainage from topsoil horizon into the subsoil, and from the subsoil horizon into the intermediate groundwater zone
- erodibility of the soil (Schulze et al., 2010b).

Values of these variables have been derived by Schulze and Horan (2008) using the AUTOSOILS decision support tool (Pike and Schulze, 1995 and updates) applied to the soils database from the Institute for Soil, Climate and Water (SIRI, 1987 and updates) for each of the soil mapping units, called Land Types, which cover South Africa, on the basis that the hydrological properties of all the soil series making up an individual land type were area-weighted. For each quinary catchment the values of the hydrological soils variables required by the ACRU model were derived from the land types identified in that quinary, again on an area-proportioned basis (Schulze et al., 2010b).

- Baseline land cover information

It is reported in Schulze et al. (2010b) that in order to assess impacts of land use or of climate change on hydrological responses, a baseline land cover is required as a reference against which to evaluate the impacts. For the RSA, Lesotho and Swaziland the 70 veld types delineated by Acocks (1988) have become the recognised baseline (i.e. reference) land cover for application in hydrological impact studies (Schulze, 2004).

Based on a set of working rules, month-by-month hydrological attributes, developed by and given in Schulze (2004), were assigned to each of the 70 Acocks veld types and were incorporated into the QCD. These attributes are (Schulze et al., 2010b):

- the water use coefficient (Kcm)
- interception loss per rain day (Il)
- fraction of roots in the topsoil (RA)
- a coefficient of infiltrability (c) dependent on rainfall intensity estimates
- soil surface cover by litter (Cs%), an index of suppression of soil water evaporation by a litter / mulch layer.

For each of the 5 838 quinaries in the database the spatially most dominant veld type was then selected as the representative baseline land cover (Schulze et al., 2010b).

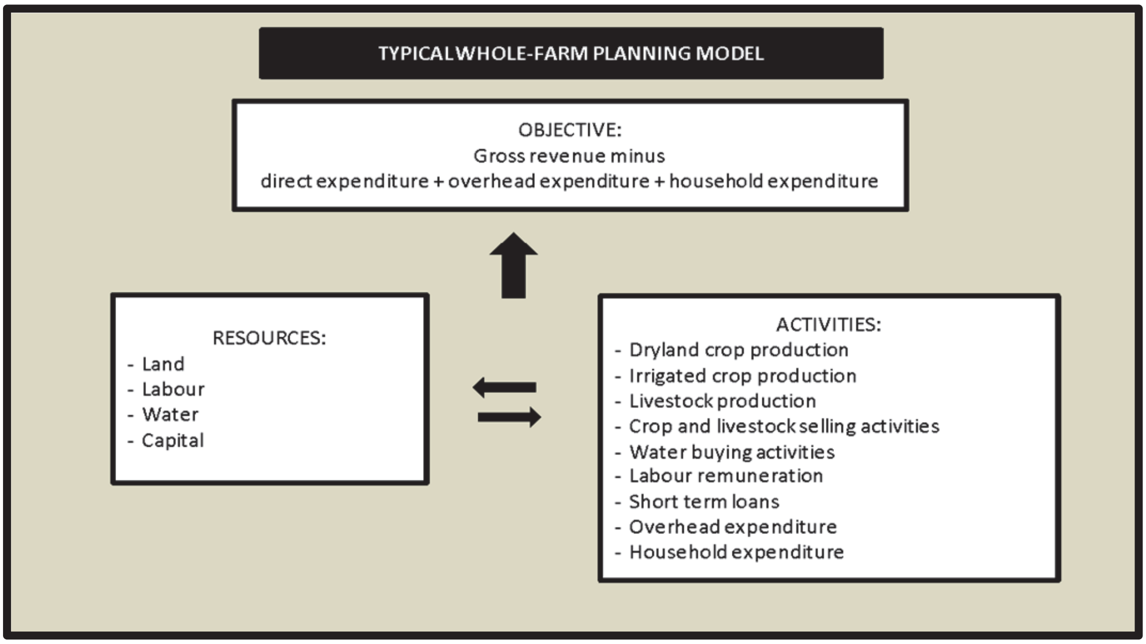
From all of the above daily runoff could be computed using the climate input from the GCMs used and dam levels generated. The projected dam levels of the Blydepoort Dam for the GCMs used in this study (present and future climate scenarios) are introduced to the DLP model as constraints through the irrigation water availability interphase.

9.2.2 Whole-farm dynamic linear programming approach

The main objective of the mathematical modelling exercise is to simulate the selected farming systems (case studies) with the best available information. Climate change scenario data are then imported into the models to study the impact on economic and financial vulnerability with no adaptation. In the second round of analysis adaptation strategies are tested to analyse their efficiency in reducing vulnerability. Linear programming (LP) is one of the most practical agricultural economic tools to simulate farming systems and has been used by various South African researchers, e.g. Hancke and Groenewald, 1972; Van Rooyen, 1979; Brotherton and Groenewald, 1982. Later researchers used dynamic linear programming (DLP) (Backeberg, 1984; Oosthuizen, 1994; Maré, 1995; Louw, 1996; Louw and Van Schalkwyk, 1997; Haile et al., 2003). DLP is a mathematical technique that can be employed by management to determine the optimal utilisation of limited resources. It comprises the formulation of a model, which is solved mathematically to provide an optimal answer (Redelinghuis et al., 1985). In order to analyse a problem using DLP, it must be moulded into a particular structure that must at least contain the following components:

- Objective – to obtain the best or optimal solution, i.e. maximizing profit.
- Activities or decision variables which define what to do.
- Constraints or restrictions that limit the availability of a resource.

Therefore, it is important that any attempt to simulate the farm system should include the objectives of the farm unit, the resources available to reach these objectives as well as the alternative activities to reach them. These elements are presented in the following conceptual framework below (see Figure 58).



Source: Louw and Jooste (2006)

Figure 58: Conceptual dynamic linear programming modelling framework

The structure of a whole-farm planning model with the capability to simulate the impact of climate change should contain at least the following elements:

- A description of producers' economic behaviour (the objective function).
- A description of production functions, and technology sets.
- The relationship between climate (temperature and rainfall) and crop yield/quality.
- The relationship between climate and the availability of irrigation water.
- A specification of the market environment in which the producer operates.
- A specification of the policy environment of the sector.

The primary objective with economic planning is to establish the best choice between alternative uses of limited resources in order to maximise return on capital. Independent of the scale of farming, five objectives must be reached:

- Establish which plan reflects the best use of land, water, capital and human resources.
- Establish the financial implications of the plan based on the expected future cash flow.
- Establish the capital required and the time when needed from own and borrowed sources.
- Analyse the complexity of marketing, financial and production management and the demands it will put on management capability.
- Analyse the financial incentive to put the plan into operation.

With this information it is possible to put forward the implications of alternative choices. The aim is to maximise return on capital. The plan put forward is not a guarantee for success but it is undoubtedly of help for better decision making. In farm planning the human element is the starting point: What are the objectives of the farmer, can the farm comply with these objectives and what are the financial consequences? Technology determines what is possible, economic analysis shows what is feasible and financial analysis shows how much money is needed and when. Analysis and planning, therefore evaluate current performance as well as potential changes to this performance (Louw, 1996).

Evaluating the profitability and financial feasibility of farms within the context of climate change requires a high level of specialisation. The task is challenging and requires the analyst to integrate information regarding climate change, hydrology, crop irrigation requirements, crop yield and quality response to changing water and temperature, infrastructural constraints, credit availability and input and output prices into the modelling framework in order to conduct a thorough feasibility analysis. The analyses are furthermore complicated by the stochastic (risky) and dynamic environment in which decisions are made. Mathematical programming techniques are pre-eminently suited for conducting this study of the financial vulnerability of farming systems without and with climate change adaptations. Modern programming languages such as GAMS (General Algebraic Modelling System) allow the modeller to realistically represent the link between crop production (yield and quality) and projected climate change.

For the purpose of this study two generic types of DLP models were programmed in GAMS and then adapted for each of the regions. These are:

- Irrigation model (applicable to LORWUA and Blyde River WUA case studies).
- Dryland model with livestock (applicable to Moorreesburg and Carolina case studies).

The sections below are brief descriptions of the models (not in mathematical terms).

9.2.2.1 Irrigation DLP

Description of the objective of households in mathematical terms

The objective of households is to make a living out of farming. In quantitative terms this means that the farmer must at least be able to pay for:

- operational expenditure
- overhead expenditure
- household expenditure.

If there is any surplus left this can be invested to make provision for expansions and/or provision for risk.

The objective functions of the LORWUA and Blyde River WUA case studies are calculated in two steps (b = region, tu = case study, ph = year):

- **Equation NDICALC(b,tu,ph)** calculates the net disposable income per farm (b,tu) and per year (ph)

  Plus gross income from product sales

  Plus non-farm income (if applicable)

Minus direct allocated production costs
Minus overhead cost
Minus household cost
Minus water tariffs
Minus pumping costs
Plus loans (cash inflow)
Minus payback of loans (cash outflow)
Plus surplus (if any from the previous year) + interest on surplus
Plus terminal values
= EndB(b,tu,ph)

- **Objective function Z** (quantified in mathematical terms)
  Z = **Maximise sum (EndB(b,tu,ph))**

Although two case studies (per region) are included in one model, all the calculations are done per case study. By including the two case studies in one model enables the user to use one climate data set to impose on both the farms and thereby save time to run scenarios.

Activities/variables

The variables include both short and long-term crop activities but no livestock activities. The variables included in the models are:

- Z (total cumulative net cash balance per case study)
- Area of crop production per year
- Total crop area per LT crop per growth stage per farm per year
- Total LT irrigation crop area for all regions
- Total ST irrigation crop area for all region
- Sum of total production volume per crop per farm
- Irrigation crops total monthly water use in any specific year
- Overhead expenditure per case study farm
- Household expenditure per case study farm
- Own capital in the first year per case study farm
- Short term production loans per case study farm per year
- Investment of surplus funds in per year
- End balance at end of planning horizon
- Terminal value of LT crops at the end of the planning horizon.

Resource constraints

Resource constraints included in the models are:

- Irrigation land (area).

- Water delivery capacity (canal delivery constraint by month) – linked to monthly water availability depending on climate change. Also linked to the crop irrigation requirements (a function of climate scenarios).
- Total water allocation (by year) – linked to climate scenarios.
- Operational capital requirements (linked to the annual surplus available plus the maximum loans available if there is inadequate funds available from own sources).
- Maximum loans.
- Overhead costs – forced into the model and currently based on the existing overhead costs.
- Household costs – forced into the model.
- Non-farm income.
- Minimum and maximum temperature thresholds.
- Rainfall and temperature thresholds linked to yield.
- Rainfall and temperature thresholds linked to both yield and quality.
- Calibration constraints to trim the model in order to simulate the current farm structure – these are released when calculating the farming system's adaptive capacity.

9.2.2.2 Dryland with livestock DLP model

The dryland model is similar to the irrigation model in many aspects. Unique features are highlighted in the sections below.

Description of the objective of households in mathematical terms

The objectives in mathematical terms are exactly the same as for the irrigation model; however, the objective also includes maximizing livestock production within the limitation of natural veld carrying capacity, crop residue and own feed production.

Activities/Variables

The following variables are unique to the dryland and livestock model:

Livestock variables

- Present livestock numbers
- Sell livestock products per annum
- Reproduction of livestock
- Total number in specific year
- Calculates maximum weight of livestock sales in kg
- Calculates wool production in kg
- Sums terminal values for livestock

Feed transfer variables

- Initial stock of feed

- Feed bank transfer to period j+1
- Purchase feed
- Use of natural veld
- Transfer of feed production to feed use
- Total animal feed mix
- Total stock plus production

Resource constraints

The resource constraints unique to the dryland livestock model are:

- Minimum feed requirements in terms of dry matter, crude protein and energy per livestock unit
- Dry matter production of feed and fodder crop per ha
- Nutrient production (protein and energy) per tonne of dry matter
- Transfer of dry matter (where possible) from one year to the next year

9.2.3 Modelling interphases

9.2.3.1 Introduction

The development of interphases between the downscaled climate data sets which were applied in the CCCT, ACRU and SAPWAT3 models and the DLP model is of paramount importance. Not only do they enable a better understanding of the relative changes in the observed and projected climate, but they also make a substantial contribution towards the interpretation and the dissemination of the results. For the purpose of this project, four interphases were developed. They are:

- The APSIM crop model – DLP model interphase
- The CCCT yield and quality model – DLP model interphase
- The ACRU hydrological model – DLP model interphase
- The SAPWAT3 crop irrigation requirement – DLP model interphase
- An interphase to generate at random variation coefficients to be imposed on all the crops in the model where APSIM/CCCT models are not available.

In the sections below each of the interphases is briefly discussed.

9.2.3.2 APSIM crop model interphase

The APSIM crop model was used to simulate crop yields for different climate scenarios. These crops include: grapes (LORWUA) [only a generalised prototype model available], wheat (Moorreesburg) and maize (Carolina). Where crops could not be modelled, the research team had to rely on expert knowledge to attempt to simulate the impact of climate change on these crops by applying crop critical climate thresholds to different climate scenarios.

Figure 59 illustrates the APSIM crop model interphase in GAMS file format.

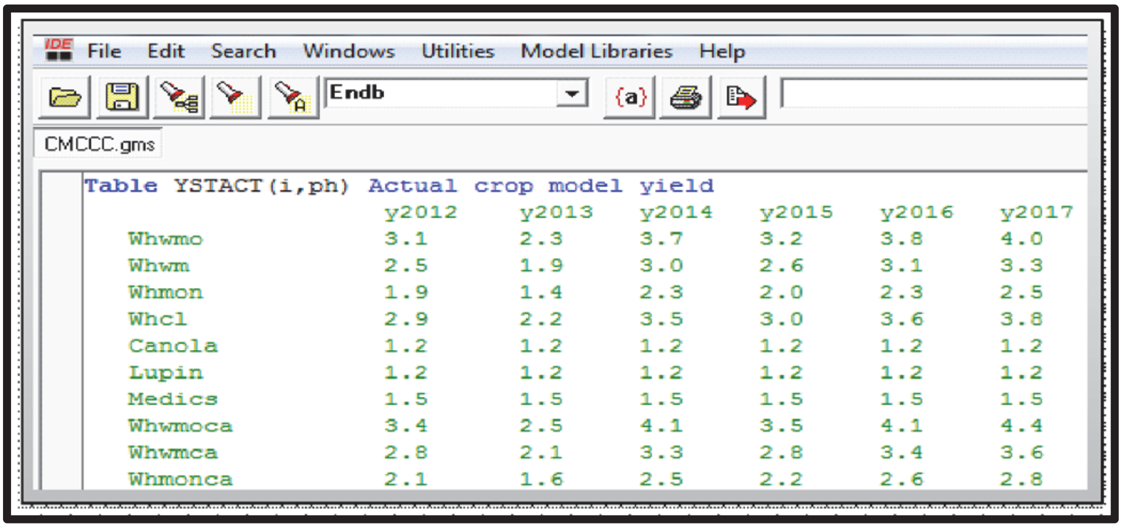


Table YSTACT(i,ph) Actual crop model yield

	y2012	y2013	y2014	y2015	y2016	y2017
Whwmo	3.1	2.3	3.7	3.2	3.8	4.0
Whwm	2.5	1.9	3.0	2.6	3.1	3.3
Whmon	1.9	1.4	2.3	2.0	2.3	2.5
Whcl	2.9	2.2	3.5	3.0	3.6	3.8
Canola	1.2	1.2	1.2	1.2	1.2	1.2
Lupin	1.2	1.2	1.2	1.2	1.2	1.2
Medics	1.5	1.5	1.5	1.5	1.5	1.5
Whwmoca	3.4	2.5	4.1	3.5	4.1	4.4
Whwmca	2.8	2.1	3.3	2.8	3.4	3.6
Whmonca	2.1	1.6	2.5	2.2	2.6	2.8

Figure 59: APSIM crop model interphase – GAMS file format

After normalization of the APSIM crop model results, the annual projected crop yields are imported into the DLP model through a link to the GAMS file which contains the crop yield information. Table YSTACT (i,ph) in Figure 59 above is the projected crop yield per annum derived from APSIM crop model results.

9.2.3.3 The CCCT yield and quality model interphase

Crop models for annual crops are fairly common and well used (Crespo (2012); Midgley (2012)). However, there is a considerable gap in the knowledge and the technology to simulate the response of perennial crops to climate change. The need for an alternative simulation method ultimately resulted in the development of the CCCT modelling technique, which proved to be a reliable tool for the purpose of this study. The output of the technique depends heavily on the quality of the input. For this reason, the input that went into the modelling was obtained from expert group discussions in the various case study areas.

The downscaled climate data sets for the various GCMs feed into the CCCT model. The basic output of the CCCT model is projected yield and quality (annually and per crop cycle) over the planning horizon for each GCM data set in this project specifically in respect of-

- the present (observed) – 1971 to 1990, and
- the intermediate future – 2046 to 2065.

The output of the CCCT model (projected annual yield and quality) feeds into the DLP model.

The following section gives an overview of the different elements in the modelling process.

Similar to Hoffmann's (2010) approach, the minimum and maximum climate thresholds (temperature and rainfall) for all the important crops were identified during a validation workshop and through expert group discussions.

These climate thresholds are used as input to the CCCT model, which is then run with different climate data sets. The model calculates the number of times that each critical threshold is breached. A factor (positive or negative) is assigned to each critical threshold, which implies that the crop yield/quality will be adjusted each time a threshold is breached.

Table 57 reflects the crop critical climate thresholds for citrus (grapefruit) in the Blyde River WUA area as well as the expected impact on yield and/or quality.

Table 57: Example of Blyde River WUA citrus (grapefruit) critical climate thresholds

Critical climate thresholds	Yield penalty factor	Quality penalty factor
Tmxd > 40 °C and RH < 30% for 2 days Sept	-0.40	0.00
Tmxd >35 °C and RH < 30% for 2 days Sept	-0.40	0.00
Tmxd > 35 °C and RH < 20% for 2 days Sept	-0.40	0.00
Fruit drop (Nov/Dec) >7 days of Tmxd > 36 °C and RH < 40%	-0.30	-0.10
2 °C warmer in May - colour deteriorates	0.00	-0.04
During picking temp > 36 °C - increase rind problems	0.00	-0.01
>14 days continuous rain during picking (autumn) causes leaf wetness and overripe fruit	0.00	-0.10

The following procedures are then executed:

Step 1

The daily temperature and rainfall for each climate change scenario per planning horizon (present [1971-1990] and intermediate future [2046-2065]) as received from the climatologists are converted to a pivot table in Excel. This includes daily data for five downscaled climate models (GCMs). The data are then processed through a procedure where the threshold breaches for temperature and rainfall are identified.

The threshold breach results for a specific crop are summarised into one table (see Table 57 and Table 59). The yield/quality is then penalised with a certain percentage according to the breaches of each threshold. In this specific model all the threshold breaches have a negative effect on the yield/quality. Owing to a lack of positive factors, a dummy scaling factor is used to normalise the data, without disturbing the trends. The combined effect of all the threshold breaches that occurred in that specific year is then calculated.

For yield calculation, the DLP model provides for 19 levels of impact ranging from -50% to plus 50% at intervals of 5% to 10% (which can easily be changed). During the procedure any number from 1 to 19 is allocated in the event that the climate condition exceeds the threshold. These are converted into tables for each crop (it can be any number) that is compatible with the GAMS program.

Similar to the yield calculation, the impact of climate change on quality is calculated. The DLP model provides for 10 levels of impact ranging from minus 40% to plus 50% of the base quality (price). The results are summarised in a table to be fed into the DLP model.

For illustration purposes, quality scaling as a result of climate change will be illustrated in the rest of this section. Table 58 presents the process to arrive at a quality scaling code due to temperature and rainfall threshold breaches. For each year under consideration the quality deviation from the base quality (realistic price) is incorporated in the respective row, e.g. for 2047 there is a 25% negative impact and a 5% positive impact (scaling dummy). The net effect is therefore -20% which results in a quality scaling Code 3 which GAMS will read as 80% x base quality. See Step 2.

Table 58: Allocation of quality deviation per code derived from Step 1

Climate impact quality scaling	Tmxd > 40 °C and RH < 30% for 2 days Sept	Tmxd >35 °C and RH < 30% for 2 days Sept	Tmxd > 35 °C and RH < 20% for 2 days Sept	Fruit drop (Nov/Dec) ≥7 days of Tmxd > 36 C and RH < 40%	2 °C warmer in May - colour deteriorates	During picking temp > 36 °C - increase rind problems	>14 days continuous rain during picking (autumn)	Scaling dummy	Temp Quality Scaling factor	Rainfal Quality Scaling factor	Temp & Rain Quality Scaling factor	Climate model Quality scaling code
2046					-0.04	-0.1875		0.05	**-0.1775**		**-0.1775**	**3**
2047					-0.04	-0.21		0.05	**-0.2**		**-0.2**	**3**
2048					-0.04	-0.1425		0.05	**-0.1325**		**-0.1325**	**4**
2049					-0.04	-0.1875		0.05	**-0.1775**		**-0.1775**	**3**
2050						-0.15		0.05	**-0.1**		**-0.1**	**4**
2051					-0.04	-0.1725		0.05	**-0.1625**		**-0.1625**	**3**
2052						-0.12		0.05	**-0.07**		**-0.07**	**4**
2053					-0.04	-0.21		0.05	**-0.2**		**-0.2**	**3**
2054					-0.04	-0.1725		0.05	**-0.1625**		**-0.1625**	**3**
2055					-0.04	-0.1875		0.05	**-0.1775**		**-0.1775**	**3**
2056					-0.04	-0.15		0.05	**-0.14**		**-0.14**	**4**
2057						-0.18		0.05	**-0.13**		**-0.13**	**4**
2058					-0.04	-0.165		0.05	**-0.155**		**-0.155**	**3**
2059					-0.04	-0.18		0.05	**-0.17**		**-0.17**	**3**
2060					-0.04	-0.1875		0.05	**-0.1775**		**-0.1775**	**3**
2061					-0.04	-0.21		0.05	**-0.2**		**-0.2**	**3**
2062					-0.04	-0.15		0.05	**-0.14**		**-0.14**	**4**
2063						-0.1425		0.05	**-0.0925**		**-0.0925**	**4**
2064					-0.04	-0.18		0.05	**-0.17**		**-0.17**	**3**
2065					-0.04	-0.165		0.05	**-0.155**		**-0.155**	**3**

The GAMS program now uses the scaling code number in Table 58 and applies the adjustment factor in Table 59 to determine with how much the model must increase/decrease the base quality (price). It should be clear that by following this procedure it is possible to trace back the specific reason why the experts were of the opinion that the quality will decrease in a specific year.

Step 2

In this step a scaling percentage is attached to the quality scaling codes which were calculated in Step 1. The quality code is adjusted by allocating a model code of 1 to 9 to the event (where 5 means no change and the others are four factors negative and four factors positive).

Table 59: Allocating a code to scale quality (price) of crops

Scaling code	1	2	3	4	5	6	7	8	9	10
ManTA	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
ManKent	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
ManSens	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
ManKeitt	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
CitPom	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
CitVal	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
CitLem	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
ManA	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
CitA	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5

For example, if a Code 5 is allocated the GAMS model will establish that there is zero change in quality/price. Figure 60 illustrates the CCCT quality model interphase with the DLP model in GAMS file format. A Code 4 will result in the model changing the quality of, for example, crop CitPom (Citrus Grapefruit) to 80% of base quality (price).

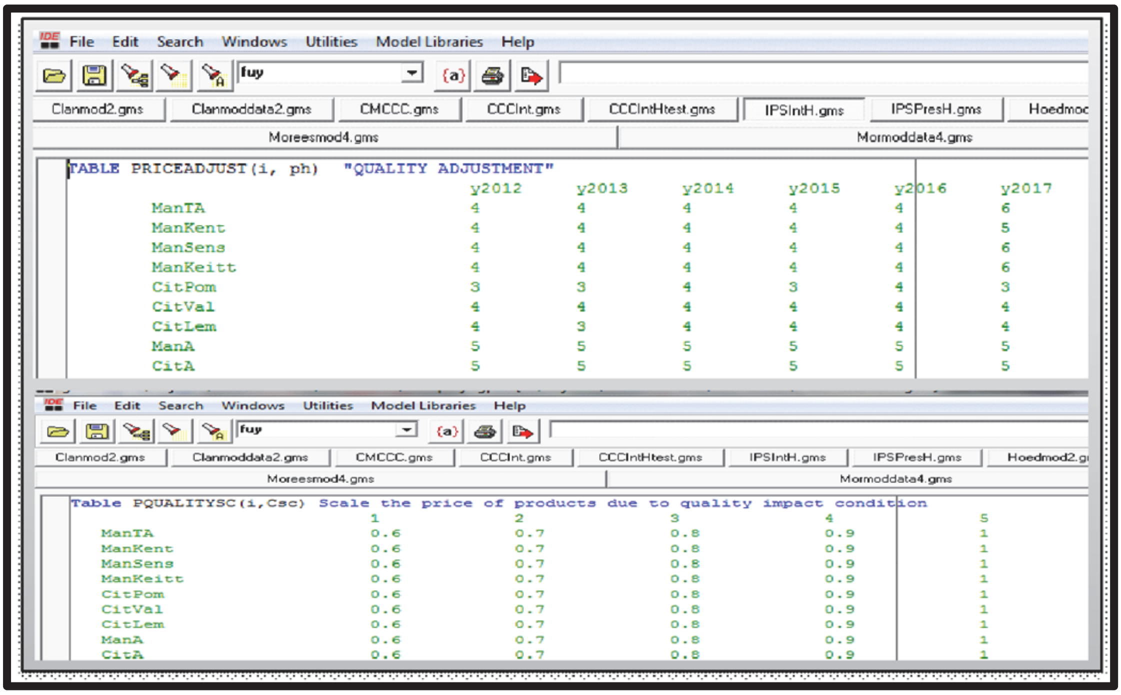


Figure 60: CCCT quality model interphase – GAMS file format

Figure 61 illustrates the CCCT yield model interphase with the DLP model in GAMS file format. A Code 4 will result in the model changing the quality of, for example, crop CitPom (Citrus Grapefruit) to 70% of base yield.

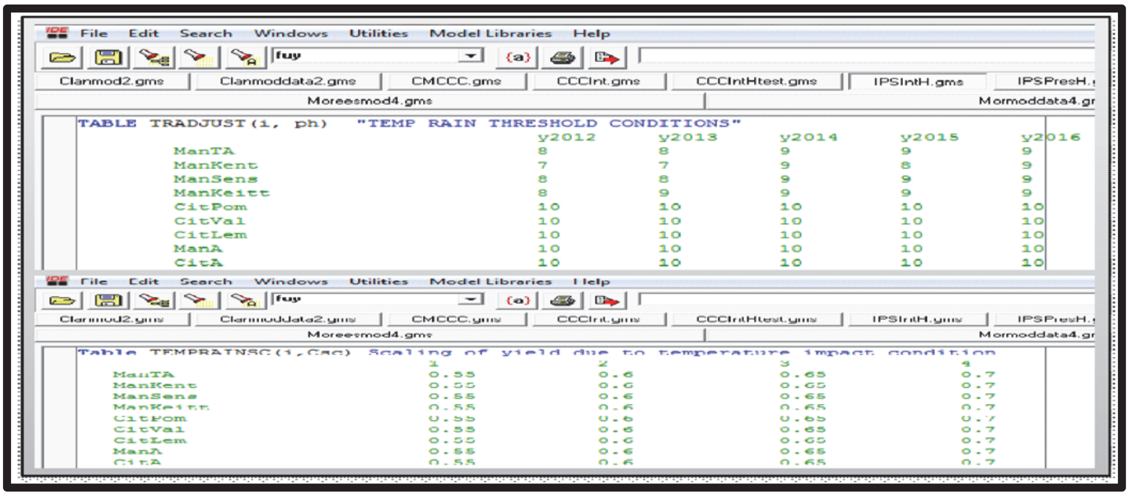


Figure 61: CCCT yield model interphase – GAMS file format

The procedure described here is a practical solution to estimate yield and quality variation based on critical climate thresholds for crops. It can be very useful where crop models either do not exist, or where there is doubt about the reliability of the crop models or where crop models do not account for the quality of produce.

<u>The ACRU hydrological model interphase</u>

The present and intermediate daily climate values from downscaled GCMs were used in the ACRU model to project future dam levels, which form the base to calculate the annual allocation of irrigation water quotas to farmers. The projected total annual irrigation water quota (m^3) allocated to a farming system and monthly canal capacity is included in the DLP model as a resource constraint.

The ACRU hydrological model interphase and canal capacity restraint in GAMS code file format are illustrated in Figure 62.

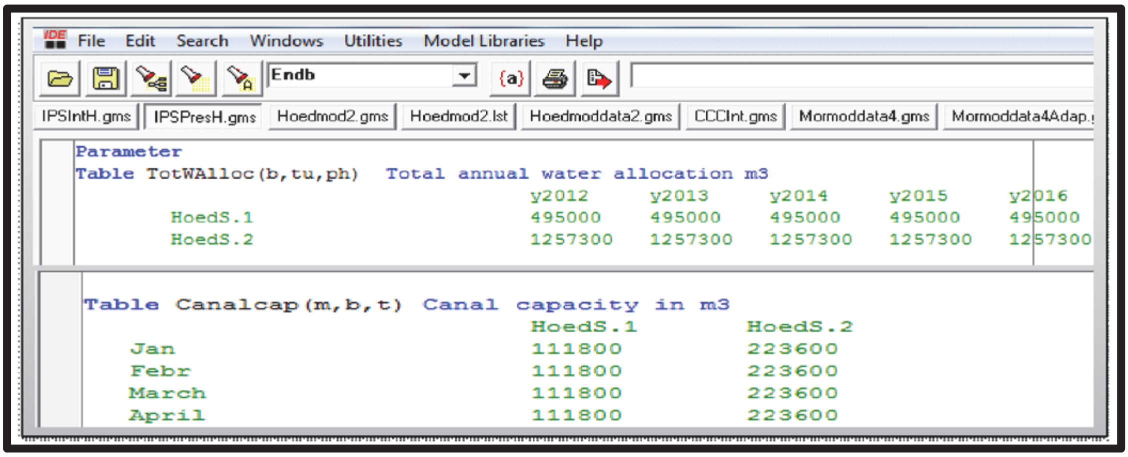
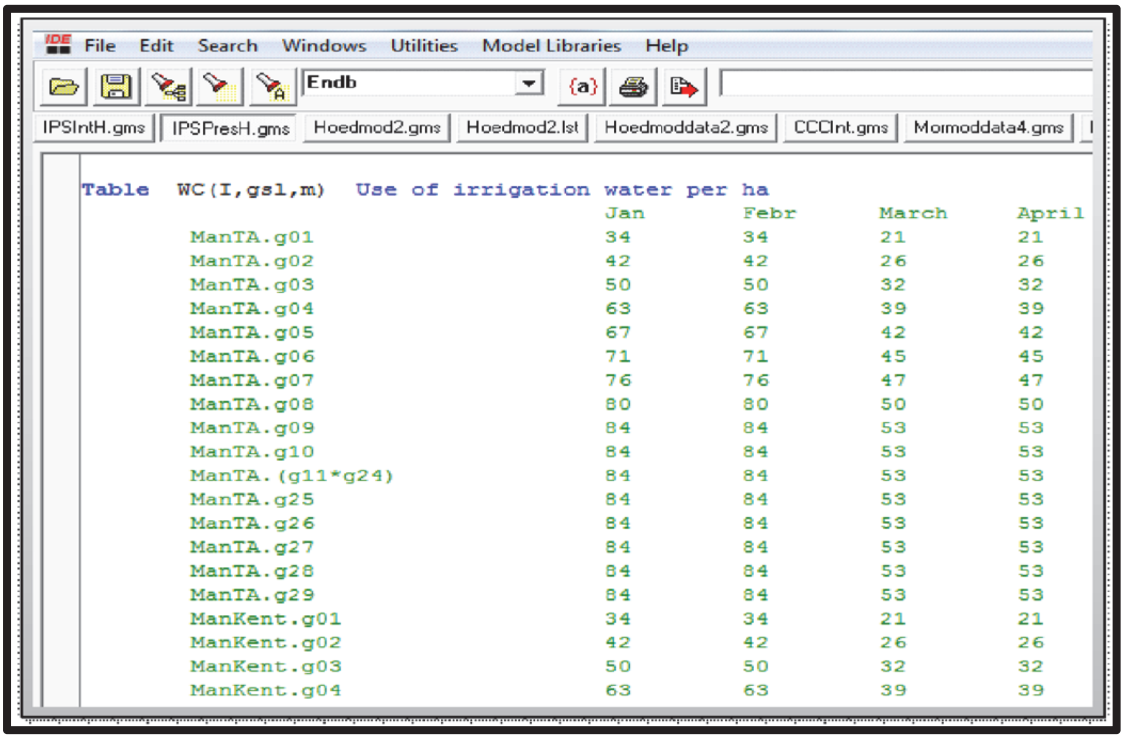


Figure 62: Annual irrigation quota allocation and monthly canal constraint – Blyde River WUA example (GAMS code)

<u>The SAPWAT3 crop irrigation requirements interphase</u>

The SAPWAT 3 program was used to determine changing crop irrigation requirements under present and future climate scenarios using downscaled climate data of the various GCMs used in this study.

The monthly irrigation water requirements per crop per growth stage are included in the DLP model (see Figure 63 – crop irrigation requirements interphase in GAMS code file format).




```
Table  WC(I,gsl,m)  Use of irrigation water per ha
                                       Jan        Febr       March      April
        ManTA.g01                      34         34         21         21
        ManTA.g02                      42         42         26         26
        ManTA.g03                      50         50         32         32
        ManTA.g04                      63         63         39         39
        ManTA.g05                      67         67         42         42
        ManTA.g06                      71         71         45         45
        ManTA.g07                      76         76         47         47
        ManTA.g08                      80         80         50         50
        ManTA.g09                      84         84         53         53
        ManTA.g10                      84         84         53         53
        ManTA.(g11*g24)                84         84         53         53
        ManTA.g25                      84         84         53         53
        ManTA.g26                      84         84         53         53
        ManTA.g27                      84         84         53         53
        ManTA.g28                      84         84         53         53
        ManTA.g29                      84         84         53         53
        ManKent.g01                    34         34         21         21
        ManKent.g02                    42         42         26         26
        ManKent.g03                    50         50         32         32
        ManKent.g04                    63         63         39         39
```

Figure 63: Monthly crop irrigation requirements – Blyde River WUA example (GAMS code)

<u>An interphase to generate at random variation coefficients</u>

There are several smaller crops where very little information on the thresholds is available. However, it is possible to impose decreases or increases in variation in GAMS through a very simple but useful function in the program. This function can be incorporated to generate at random variation in yield from a base yield. The upper and lower variation can be changed to increase or decrease variation based on estimates from the climate data. For example, if a climate change scenario indicates that the standard deviation from the base is increasing (for both temperature and rainfall or for a combination thereof), it can be interpreted as an increase in climate variability and also possibly an increase in yield variability.

Figure 64 illustrates a random variation in yield over a twenty-year projected period with -10% and 10% as the lower and upper boundaries.

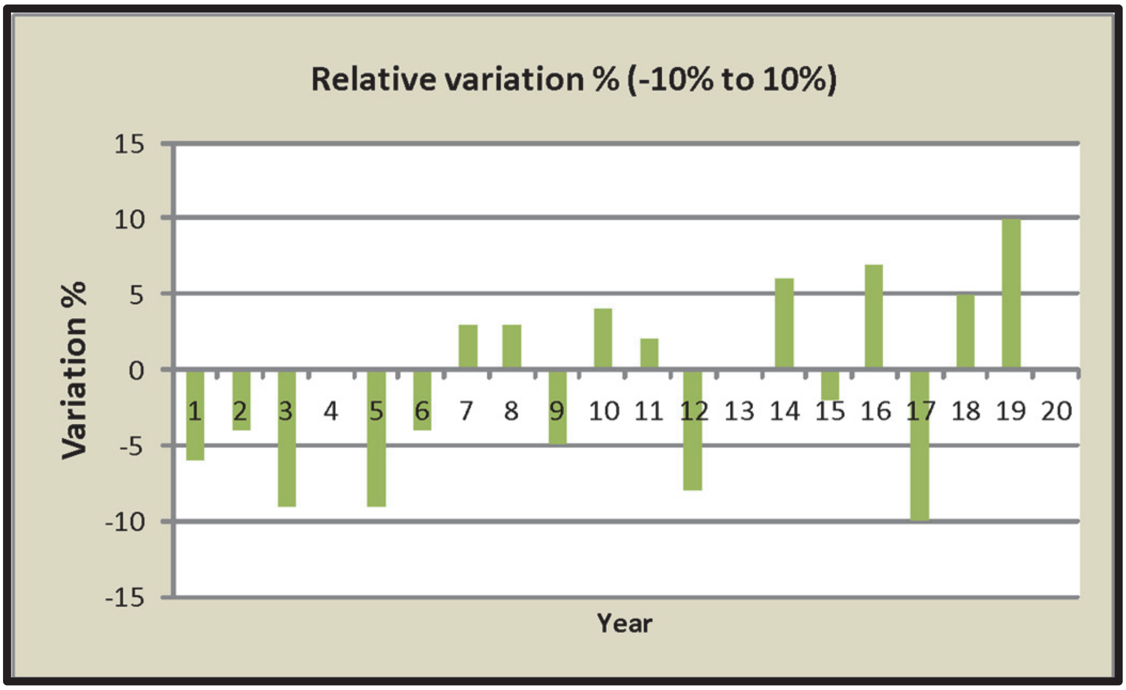


Figure 64: Relative variation in yield (-10% to 10%)

Variation can simply be increased by increasing the upper and lower boundary. Also, if the resilience of a farming system needs to be tested it is possible to increase the pessimistic boundary to establish whether or not the farm will still be economically viable.

This tool is extremely useful in studying the impact of climate variability on farming systems in a realistic way considering the many uncertainties surrounding climate change predictions.

9.2.4 Financial Vulnerability Assessment model

The output of the DLP whole-farm model feeds into an excel-based financial assessment model. In order to determine the financial vulnerability of the farming system, a set of criteria provided for in the financial model are applied.

These criteria are:

- IRR (Internal Rate of Return)
- NPV (Net Present Value)
- Cash flow ratio
- Highest debt ratio
- Highest debt

The definitions for these criteria are expounded below.

Internal rate of return (IRR)

The internal rate of return (IRR) is probably the most widely used sophisticated capital budgeting technique. The IRR is the compound annual rate of return that the firm will earn if it invests in the project and receives the given cash inflows (Gitman, 2009).

Net present value (NPV)

Because net present value (NPV) gives explicit consideration to the time value of money, it is considered a sophisticated capital budgeting technique (Gitman, 2009). NPV can be described as the "difference amount" between the sums of discounted cash inflows and cash outflows. It compares the present value of money today to the present value of money in the future, taking inflation, risk and opportunity cost of capital into account.

Cash flow ratio

A measure of how well cash flow out is covered by the cash flow in. The cash flow ratio can gauge a company's liquidity in the short term. Using cash flow as opposed to income is sometimes a better indication of liquidity simply because cash is how bills are normally paid (Oosthuizen, 2014 & Pienaar and Louw, 2002).

Debt ratio

The debt position of a firm indicates the amount of other people's money (debt) being used to generate profits (Gitman, 2009). It is the total liabilities divided by total assets. If the ratio is less than 0.5, most of the company's assets are financed through equity. If the ratio is greater than 0.5, most of the company's assets are financed through debt.

Highest debt

Within the context of this study it is simply the highest debt in any specific year over the 20-year planning horizon.

The financial vulnerability assessment in respect of each case study includes individual assessment runs for present and intermediate climate scenarios for each of the five GCMs included in the study. The results for each case study will be discussed in Chapter 10.

9.3 Modelling summary

In Chapter 9 the development of the integrated climate change model was discussed. It comprises a layman's description of the integrated model and the four modules that form the pillars of the integrated climate model. These four modules are: (a) climate change impact modelling, (b) DLP model, (c) modelling interphases, and (d) the Financial Vulnerability Assessment model.

Climate change impact modelling comprises the modelling of statistically downscaled data climate data which impacts on crop yield and quality, changing crop irrigation requirements as a result of climate change and hydrological modelling to determine the availability of irrigation water due to changing weather patterns.

Chapter 9 outlines the role of GCMs, statistical downscaling, the APSIM crop modelling and the newly developed CCCT modelling technique. The contribution of the ACRU hydrological model and the

SAPWAT3 model, as well as where the respective modelling outputs fit into the integrated climate model are also described.

The objective, purpose and reasons for using the DLP modelling technique in the study are discussed in detail. The primary objective with the economic planning for a farming system is to establish the best choice between the alternative uses of limited resources to maximise return on capital invested. Independent of the scale of farming, five objectives must be reached:

- Establish which plan reflects the best use of land, water, capital and human resources.
- Establish the financial implications of the plan based on the expected future cash flow.
- Establish the capital required and the time when needed from own and borrowed sources.
- Analyse the complexity of marketing, financial and production management and the demands it will put on management capability.
- Analyse the financial incentive to put the plan into operation.

Mathematical programming techniques are pre-eminently suited to conducting the study of the financial vulnerability of farming systems without and with climate change adaptations.

The modelling interphases that link the output from the climate change modelling, hydrological modelling, crop irrigation requirements modelling and an interphase that generate at random variation coefficients, are discussed and graphically illustrated.

The Financial Vulnerability Assessment model comprises a set of criteria namely: IRR, NPV, cash flow ratio, debt ratio and highest debt.

CHAPTER 10 : INTEGRATED CLIMATE CHANGE MODELLING RESULTS

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10.1 Introduction

In Chapter 10 the integrated modelling results, impact of future projected climates on financial vulnerability and possible adaptation strategies will be discussed.

The modelling results for each of the case study areas will be discussed under the following headings (where applicable):

- Climate change impact on quality and yield of crops
  - APSIM (for selected crops – depending on availability)
  - CCCT modelling.
- Climate change impact on crop irrigation requirements (for irrigation crops only – SAPWAT3 modelling).
- Climate change impact on the availability of irrigation water requirements (only in respect of Blyde River WUA – ACRU modelling).
- Available adaptation strategies. In the context of this study vulnerability focused on the inability of individual commercial farmers to respond to, or cope with, climate change effects on crop yields from a financial vulnerability point of view. In order to determine the impact of climate change, the case study farming systems were measured against a set of financial vulnerability assessment criteria, viz. IRR, NPV, cash flow ratio, highest debt ratio and highest debt.
- Financial vulnerability assessment results.

10.2 LORWUA

10.2.1 Climate change impact on quality and yield of crops modelling results

10.2.1.1 APSIM crop modelling results

It needs to be reiterated that the APSIM model for grapes is currently still a prototype and therefore the outcome needs to be interpreted with caution.

Figure 65 shows the projected yield for grapes for the intermediate future (2046-2065) in the LORWUA area, derived from APSIM calculations. The figures are expressed as percentage of the yield used in the base analysis.

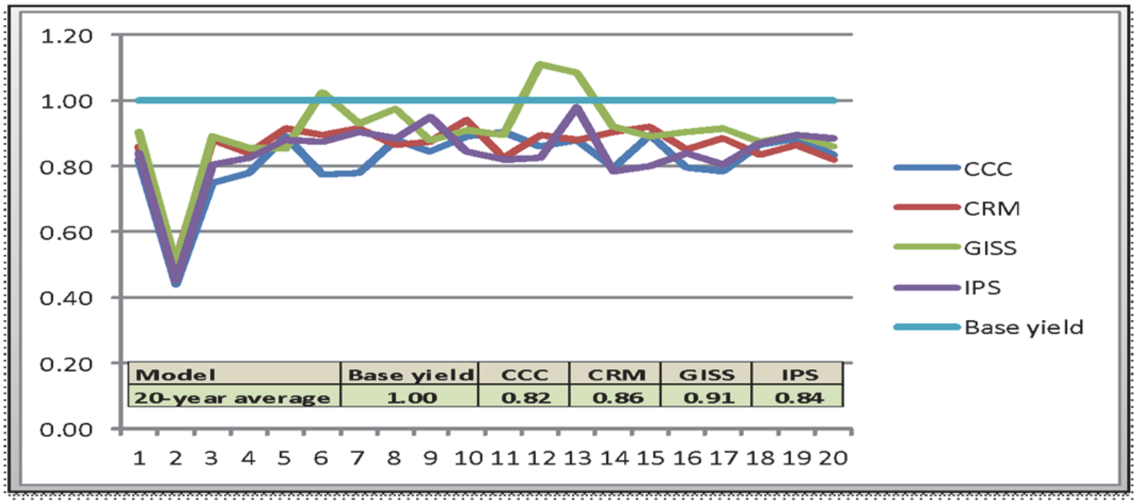

Figure 65: Projected yield (%) [2046-2065] for grapes in the LORWUA area based on APSIM calculations

Climate data from four GCMs were applied in the APSIM modelling. All the GCMs project a 20-year average decrease in yield, varying from 9% to 18%.

10.2.1.2 CCCT modelling results

The critical crop climate thresholds for different crops were collected during a workshop that was attended by various role-players, including amongst others, industry experts and farmers.

Table 60 summarises the critical crop climate thresholds for wine grapes, raisins and table grapes. These threshold values were used in the CCCT modelling to determine the impact of climate change on yield and quality.

Table 60: Critical climate thresholds for wine grapes, raisins and table grapes

Critical climate thresholds	Impact
Wine grapes	
Tmxd > 38 °C for 5 days	Negative
Tmxd> 45 °C in Nov	Negative
Tmxd> 42 °C Nov - Dec	Negative
Difference Tmax and Tmnd > 20 °C in Dec	Negative
Tmnd <9 °C and Tmxd < 20 °C May - Jun	Positive
Average temperature < 22 °C in summer	Positive
5 days above 40 °C	Negative
> 33 °C for > 5 days with high Tmnd	Negative
5-10 mm rain Dec - Jan	Negative
> 5 mm rain for 3 days Dec - Jan	Negative
Any Rain from Dec to Apr = bursting/rotting	Negative
Raisins	
Tmxd > 38 °C for 5 days	Negative
Tmxd > 45 °C in Nov	Negative
Tmxd > 42 °C Nov - Dec	Negative
Difference Tmax and Tmnd > 20 °C in Dec	Negative
Tmnd < 9 °C and Tmxd < 20 °C May - Jun	Positive
Average temperature < 22 °C in summer	Positive
5 days above 40 °C	Negative
> 33 °C for > 5 days with high Tmnd	Negative
5 - 10 mm rain Dec - Jan	Negative
> 5 mm for 3 days Dec - Jan	Negative
Any Rain from Dec to Apr = bursting/rotting	Negative
Table grapes	
Tmxd > 38 °C for 5 days	Negative
Tmxd > 45 °C in Nov	Negative
Tmxd > 42 °C Nov - Dec	Negative
Difference Tmax and Tmnd > 20 °C in Dec	Negative
Tmnd < 9 °C and Tmxd < 20 °C May - Jun	Positive
Average temperature < 22 °C in summer	Positive
Difference Tmxd and Tmnd < 10 °C Oct - Nov	Negative
> 33 °C for > 5 days with high Tmnd	Negative
5 - 10 mm rain Dec - Jan	Negative
> 5 mm for 3 days Dec - Jan	Negative

Source: LORWUA workshop and expert group discussions (2012)

Refer to Table 60 and the Appendix for threshold penalty weights for yield and quality. The critical thresholds for **wine grapes** can be interpreted as follows:

- Tmxd > 38°C for 5 days during flowering – maximum daily temperature in excess of 38°C for more than 5 consecutive days have a negative impact of -5% on yield.
- Tmxd > 45°C in Nov – maximum daily temperature in excess of 45°C in November have a negative impact of -5% on yield.
- Tmxd > 42°C in Nov-Dec – maximum daily temperature in excess of 42°C in November to December have a negative impact of -5% on yield.

- Difference Tmax and Tmnd > 20°C in Dec – a difference between daily minimum and daily maximum temperature in excess of 20°C during the month of December has a -5% impact on yield.
- Tmnd < 9°C and Tmxd < 20°C May-Jun – low temperatures during May and June positively impacts on yield (+10%).
- Average temperature < 22°C in summer – average temperature below 22°C during summer months positively impacts on yield (+10%).
- 5 days above 40°C – daily maximum temperature in excess of 40°C for 5 days or more impact negatively on yield (-5%).
- > 33°C for > 5 days with high Tmnd – daily maximum temperature in excess of 33°C with high daily minimum temperatures impact negatively on quality (-5%).
- 5-10 mm rain Dec-Jan – 5-10 mm rain (or more) per day during the months of December and January impacts negatively on quality (-5%).
- > 5 mm rain for 3 days Dec-Jan – more than 5 mm rain per day for three consecutive days during the months of December and January impacts negatively on quality (-5%).
- Any rain from Dec-Apr = bursting/rotting – any rain from December to April cause bursting/rotting, which impacts negatively on quality (-5%).

Refer to Table 60 and the Appendix for threshold penalty weights for yield and quality. The critical thresholds for **table grapes** can be interpreted as follows:

- Tmxd > 38°C for 5 days during flowering – maximum daily temperature in excess of 38°C for more than 5 consecutive days have a negative impact of -5% on quality.
- Tmxd > 45°C in Nov – maximum daily temperature in excess of 45°C in November have a negative impact of -10% on yield and -5% on quality.
- Tmxd > 42°C in Nov-Dec – maximum daily temperature in excess of 42°C in November to December have a negative impact of -10% on yield and -5% on quality.
- Difference Tmax and Tmnd > 20°C in Dec – a difference between daily minimum and daily maximum temperature in excess of 20°C during the month of December have a -10% impact on yield and -5% impact on quality.
- Tmnd < 9°C and Tmxd < 20°C May-Jun – low temperatures during May and June positively impacts on yield (+10%) and quality (+10%).
- Average temperature < 22°C in summer – average temperature below 22°C during summer months positively impacts on yield (+10%) and quality (+10%).
- Difference Tmxd and Tmnd < 10°C Oct-Nov – average of less than 10°C in difference between maximum and minimum daily temperatures has negative impact (-5%) on quality.
- > 33°C for > 5 days with high Tmnd – daily maximum temperature in excess of 33°C with high daily min temperatures impact negatively on quality (-5%).
- 5-10 mm rain Dec-Jan – 5-10 mm rain (or more) per day during the months of December and January impacts negatively on quality (-5%).

- > 5 mm rain for 3 days Dec-Jan – more than 5 mm rain per day for three consecutive days during the months of December and January impacts negatively on quality (-5%).

Refer to Table 60 and the Appendix for threshold penalty weights for yield and quality. The critical thresholds for **raisins** can be interpreted as follows:

- Tmxd > 38°C for 5 days during flowering – maximum daily temperature in excess of 38°C for more than 5 consecutive days have a negative impact of -5% on yield.
- Tmxd > 45°C in Nov – maximum daily temperature in excess of 45°C in November has a negative impact of -10% on yield.
- Tmxd > 42°C in Nov-Dec – maximum daily temperature in excess of 42°C in November to December have a negative impact of -5% on yield.
- Difference Tmax and Tmnd > 20°C in Dec – a difference between daily minimum and daily maximum temperature in excess of 20°C during the month of December has a -5% impact on yield.
- Tmnd < 9°C and Tmxd < 20°C May-Jun – low temperatures during May and June positively impacts on yield (+10%).
- Average temperature < 22°C in summer – average temperature below 22°C during summer months positively impacts on yield (+10%).
- 5 days above 40°C – daily maximum temperature in excess of 40°C for 5 days or more impact negatively on yield (-10%).
- > 33°C for > 5 days with high Tmnd – daily maximum temperatures in excess of 33°C with high daily minimum temperatures impact negatively on quality (-5%).
- 5-10 mm rain Dec-Jan – 5-10 mm rain (or more) per day during the months of December and January impacts negatively on quality (-5%).
- > 5 mm rain for 3 days Dec-Jan – more than 5 mm rain per day for three consecutive days during the months of December and January impacts negatively on quality (-5%).
- Any rain from Dec-Apr = bursting/rotting – any rain from December to April cause bursting/rotting, which impacts negatively on quality (-5%).

Table 61 shows the CCCT modelling results for the different GCMs for the present and intermediate future (2046-2065). The values are 20-year average values for the different models. All the GCMs project a decrease in yield for wine grapes, table grapes and raisins and a decrease in quality for table grapes, e.g. average yield for raisins decreases from code 11 to code 10, implying a 5% decrease in projected yield. Average projected quality for table grapes decreases from code 5 to code 4, equalling 10% decrease in projected quality.

Table 61: CCCT modelling yield and quality projections for wine grapes, table grapes and raisins in the LORWUA area

Model	Wine grapes		Table grapes		Raisins	
	Yield	Quality	Yield	Quality	Yield	Quality
CCC Pres	12	4	12	5	12	4
CCC Int	10	4	9	4	10	4
CRM Pres	12	4	12	5	12	4
CRM Int	10	4	9	4	10	4
ECH Pres	12	4	12	5	12	4
ECH Int	10	4	10	5	10	4
GISS Pres	11	4	11	5	11	4
GISS Int	10	4	10	5	10	4
IPS Pres	11	4	11	5	11	4
IPS Int	10	4	10	4	10	4
AVE Pres	**11**	**4**	**11**	**5**	**11**	**4**
AVE Int	**10**	**4**	**10**	**4**	**10**	**4**

Legend: Yield (% of base yield)			*Legend: Quality (% of base quality)*		
8	=	*90%*	*3*	=	*80%*
9	=	*95%*	*4*	=	*90%*
10	=	*100%*	*5*	=	*100%*
11	=	*105%*	*6*	=	*110%*
12	=	*110%*	*7*	=	*120%*

10.2.2 Climate change impact on crop irrigation requirements results

Table 62 to Table 64 display the simulated irrigation requirements for table grapes, wine grapes and raisins for the current and intermediate future projected climates.

A 10% average annual increase in irrigation requirements is projected for table grapes for intermediate future climates in order to obtain the same yield as with present climates (Table 62).

Table 62: SAPWAT3 simulated irrigation requirements for table grapes for the present and intermediate future projected climates

Table grapes - present														
Case study region	Irri01	Irri02	Irri03	Irri04	Irri05	Irri06	Irri07	Irri08	Irri09	Irri10	Irri11	Irri12	Total	
Vredendal_CCC_PR3	146	137	115	61	9	0	0	0	0	12	113	153	**746**	
Vredendal_ECH_PR3	159	126	98	55	7	0	0	0	0	9	124	155	**733**	
Vredendal_GISS_PR3	175	151	126	74	28	0	0	0	0	25	142	186	**907**	
Vredendal_IPS_PR3	159	135	128	61	14	0	0	0	0	21	132	162	**812**	
Average	**160**	**137**	**117**	**63**	**15**	**0**	**0**	**0**	**0**	**17**	**128**	**164**	**800**	
Table grapes - intermediate future														
Case study region	Irri01	Irri02	Irri03	Irri04	Irri05	Irri06	Irri07	Irri08	Irri09	Irri10	Irri11	Irri12	Total	% change
Vredendal_CCC_INT	180	139	126	60	16	0	0	0	0	21	132	172	**846**	13%
Vredendal_ECH_INT	160	142	110	57	12	0	0	0	0	12	128	180	**801**	9%
Vredendal_GISS_INT	185	164	144	77	29	0	0	0	0	36	150	199	**984**	8%
Vredendal_IPS_INT	170	145	130	71	17	0	0	0	0	22	143	180	**878**	8%
Average	**174**	**148**	**128**	**66**	**19**	**0**	**0**	**0**	**0**	**23**	**138**	**183**	**877**	**10%**

For wine grapes, an average annual increase of 11% in irrigation requirements is projected for intermediate future climates in order to obtain the same yield as with present climates (Table 63).

Table 63: SAPWAT3 simulated irrigation requirements for wine grapes for the present and intermediate future projected climates

Wine grapes - present														
Case study region	Irri01	Irri02	Irri03	Irri04	Irri05	Irri06	Irri07	Irri08	Irri09	Irri10	Irri11	Irri12	Total	
Vredendal_CCC_PR3	119	109	86	50	11	0	0	0	0	5	90	124	**594**	
Vredendal_ECH_PR3	132	100	81	38	7	0	0	0	0	4	94	131	**587**	
Vredendal_GISS_PR3	147	129	96	66	28	0	0	0	0	12	125	150	**753**	
Vredendal_IPS_PR3	133	112	92	54	9	0	0	0	0	13	104	138	**655**	
Average	**133**	**113**	**89**	**52**	**14**	**0**	**0**	**0**	**0**	**9**	**103**	**136**	**647**	
Wine grapes - intermediate future														
Case study region	Irri01	Irri02	Irri03	Irri04	Irri05	Irri06	Irri07	Irri08	Irri09	Irri10	Irri11	Irri12	Total	% change
Vredendal_CCC_INT	147	116	94	54	14	0	0	0	0	10	106	149	**690**	16%
Vredendal_ECH_INT	139	109	84	47	8	0	0	0	0	7	101	143	**638**	9%
Vredendal_GISS_INT	154	140	119	68	24	0	0	0	0	20	130	158	**813**	8%
Vredendal_IPS_INT	142	120	102	61	20	0	0	0	0	8	126	150	**729**	11%
Average	**146**	**121**	**100**	**58**	**17**	**0**	**0**	**0**	**0**	**11**	**116**	**150**	**718**	**11%**

An 11% average annual increase in irrigation requirements is projected for raisins for intermediate future climates in order to obtain the same yield as with present climates (Table 64).

Table 64: SAPWAT3 simulated irrigation requirements for raisins for the present and intermediate future projected climates

Raisins - present														
Case study region	Irri01	Irri02	Irri03	Irri04	Irri05	Irri06	Irri07	Irri08	Irri09	Irri10	Irri11	Irri12	Total	
Vredendal_CCC_PR3	119	109	86	50	11	0	0	0	0	5	90	124	**594**	
Vredendal_ECH_PR3	132	100	81	38	7	0	0	0	0	4	94	131	**587**	
Vredendal_GISS_PR3	147	129	96	66	28	0	0	0	0	12	125	150	**753**	
Vredendal_IPS_PR3	133	112	92	54	9	0	0	0	0	13	104	138	**655**	
Average	**133**	**113**	**89**	**52**	**14**	**0**	**0**	**0**	**0**	**9**	**103**	**136**	**647**	
Raisins - intermediate future														
Case study region	Irri01	Irri02	Irri03	Irri04	Irri05	Irri06	Irri07	Irri08	Irri09	Irri10	Irri11	Irri12	Total	% change
Vredendal_CCC_INT	147	116	94	54	14	0	0	0	0	10	106	149	**690**	16%
Vredendal_ECH_INT	139	109	84	47	8	0	0	0	0	7	101	143	**638**	9%
Vredendal_GISS_INT	154	140	119	68	24	0	0	0	0	20	130	158	**813**	8%
Vredendal_IPS_INT	142	120	102	61	20	0	0	0	0	8	126	150	**729**	11%
Average	**146**	**121**	**100**	**58**	**17**	**0**	**0**	**0**	**0**	**11**	**116**	**150**	**718**	**11%**

10.2.3 Climate change impact on the availability of irrigation water requirements

The projected dam level data for Clanwilliam Dam (ACRU calculation), which determine the availability of irrigation water, was not available at the time and is not included as a constraint in the calculations for the LORWUA case studies. Another reason for not including projected dam levels and availability of irrigation water for the Clanwilliam Dam is the uncertainty associated with the expansion of the dam, of which construction is due to start by the end of 2014. The final distribution of additional water between different sectors of the economy also still needs to be finalised.

10.2.4 Adaptation strategies available

For the grape producing area of LORWUA the adaptation strategies that were identified to be included in the integrated model are:

- Shift wine grape cultivars towards cultivars that are more tolerant towards projected climate change.
- Increase raisin and table grape production.
- Install shade nets over table grapes production areas.

10.2.4.1 Shift in wine grape cultivars

The world is experiencing a warming trend. Warming may bring benefits to cool viticultural regions, but is likely to create problems in areas that are already close to the upper temperature limits for the cultivars and wine styles concerned. In these cases, relocation, or replacement with varieties that are better adapted to the higher temperatures will be necessary if it is not possible to ameliorate the effects of climate change through management practices (Wooldridge, 2007). Problems that could occur due to climate change include: (a) delayed or uneven bud break, (b) change in phonological stages, (c) yield reduction, (d) change in harvest date, and (e) change in wine type and style (Vink et al., 2012).

Bonnardot et al. (2011) emphasise the importance of understanding regional and wine cultivar differences as cultivars have fairly narrow optimal ranges within which they can produce wines of a certain style. As the climate changes, certain regions may move out of these optimal temperature ranges resulting in altered wine style or even altered optimal cultivars that should be planted.

It is important to state that one must take mesoclimatic differences into account. Within a larger area, local climates that are determined by slope aspect, altitude and distance from the sea, can result in average growing season temperatures that are very different (Carey, 2001, cited by Bonnardot et al., 2011).

Certain wine cultivars may, however, be more tolerant to increased temperatures than others and a shift to more heat tolerant cultivars in wine production can also be an adaptation strategy. Vink et al. (2012) highlighted the fact that South Africa's wine grape growing regions are characterised by diversity (in climate, topography, soil type, etc.) and, for most farmers, diversity is the key to managing the effects of climate change, mainly in terms of increasing wine complexity brought by blending wines from different terroir units/regions.

The expert panel indicated that within the case study region, white wine grape cultivars that will be more tolerant towards climate change include Chenin Blanc and Colombard. White wine grape cultivars that will be most vulnerable towards climate change include Sauvignon Blanc and Chardonnay.

Red wine grape cultivars that will be more tolerant towards climate change include Cabernet Sauvignon, Pinotage and Ruby. Red wine grape cultivars that will be most vulnerable towards climate change are Shiraz and Merlot.

<u>10.2.4.2 Increase raisin and table grape production</u>

Raisin and table grapes cultivars in general are more resilient to climate change projections (Bonnardot et al., 2011). The expert panel agreed that a shift from wine grape production to raisin and table grape production can be an adaptation strategy which will reduce the negative impact of climate change on wine grape production.

<u>10.2.4.3 Shade nets</u>

Netting is used in agriculture to protect crops from either excessive solar radiation, i.e. shading, or environmental hazards, e.g. hail, strong winds, sand storms, or flying pests such as birds, fruit-bats, insects (Shahak et al., 2004).

The production of table grapes under shade nets has already started to take place in the LORWUA area, but to a limited extent. In other areas, e.g. Marble Hall and Groblersdal it is common practice to produce table grapes under shade nets, although the initial main driver was the risk of hail damage.

The expert panel agreed that shade nets over table grapes can eliminate most problems associated with projected climate change and will have the following advantages:

- More efficient water use
- More consistent yield and quality
- Increase in quality (less wind damage, less quality loss due to birds)
- Lower input cost (lower labour cost due to increased quality)

<u>10.2.4.4 Other adaptation strategies (not included in the model)</u>

The following are a list of adaptation strategies debated but not included in the integrated climate change model:

- Irrigate at night to save water
- Plastic or mulch cover to conserve moist
- Soil preparation and site selection are important for future plantings to ensure optimum production – rather scale down and eliminate marginal blocks.

10.2.5 Financial vulnerability assessment results

<u>10.2.5.1 Financial vulnerability assessment methodology</u>

To determine the financial vulnerability of a farming system, the financial model provides a set of criteria, viz. IRR, NPV, cash flow ratio, highest debt ratio and highest debt.

The financial vulnerability assessment for each case study includes individual assessment runs for present and intermediate climate scenarios for each of the five GCMs included in the study.

The modelling scenarios can be divided into four broad categories namely:

- Base run use current average yields and prices to project over a 20-year period – 15% variability in yield and price.
- Present climate scenario – static production system
    - Crop Critical Climate Threshold (CCCT modelling technique) – use crop critical climate thresholds and present climate scenarios data to determine potential yield and grading of crop produce as input to the model.
- Intermediate climate scenario – static production system
    - CCCT modelling technique – use crop critical climate thresholds and intermediate future climate scenarios data to determine potential yield and grading of crop produce as input to the model – model is restrained to simulate current production structures.
    - Use APSIM crop model results for the intermediate future climate scenarios as input (yield) to the model – model is restrained to simulate current production structures.
- Intermediate climate scenario – including adaptation strategy options
    - CCCT modelling technique – use crop critical climate thresholds and intermediate future climate scenarios data to determine potential yield and grading of crop produce as input to the model – adaptation strategy options are included.
    - Use APSIM crop model results for the intermediate future climate scenarios as input to the model – adaptation strategy options are included.

The first runs can be described as static runs, where the production structure is not altered and only climate change is imposed on the farming system. During the second round, the adaptation strategy options are included in the modelling in order to quantify the potential reduction in vulnerability by including adaptation strategy options.

10.2.5.2 Financial vulnerability assessment results – LORWUA case studies

Case Study 1

Table 65 summarises the financial ratios of the different climate scenarios that were modelled. The model assumes a 20% start-up debt ratio.

Table 65: Financial assessment results for LORWUA Case Study 1

Model	IRR	NPV	Cash flow ratio	Highest debt ratio	Highest debt
Base run	8%	13,661,925	126%	34%	(6,133,936)
CCC Present (1971 - 1990)	8%	12,761,558	124%	38%	(7,110,334)
CRM Present (1971 - 1990)	8%	11,501,920	123%	36%	(6,648,816)
ECH Present (1971 - 1990)	8%	11,009,134	123%	36%	(6,410,320)
GISS Present (1971 - 1990)	7%	9,369,220	121%	33%	(5,892,668)
IPS Present (1971 - 1990)	7%	7,285,521	120%	37%	(6,578,781)
CCC Intermediate (2046 - 2065)	-1%	(10,978,058)	77%	182%	(30,392,710)
CRM Intermediate (2046 - 2065)	2%	(3,588,125)	107%	38%	(6,862,694)
ECH Intermediate (2046 - 2065)	4%	(363,189)	110%	37%	(6,651,443)
GISS Intermediate (2046 - 2065)	4%	176,284	112%	40%	(7,066,932)
IPS Intermediate (2046 - 2065)	3%	(2,448,110)	108%	38%	(6,721,745)
CM CCC Intermediate (2046 - 2065)	-1%	(11,719,450)	73%	223%	(35,560,588)
CM CRM Intermediate (2046 - 2065)	0%	(9,068,582)	86%	123%	(22,928,438)
CM GISS Intermediate (2046 - 2065)	3%	(2,982,295)	108%	47%	(8,290,861)
CM IPS Intermediate (2046 - 2065)	0%	(8,879,978)	85%	125%	(23,705,675)
CCC Intermediate (2046 - 2065) Adaptations	4%	230,363	95%	119%	(31,512,108)
CRM Intermediate (2046 - 2065) Adaptations	5%	2,538,502	101%	87%	(23,509,123)
ECH Intermediate (2046 - 2065) Adaptations	6%	6,689,431	105%	69%	(18,791,899)
GISS Intermediate (2046 - 2065) Adaptations	6%	6,074,350	104%	75%	(20,546,507)
IPS Intermediate (2046 - 2065) Adaptations	5%	4,467,748	103%	82%	(22,200,220)
CM CCC Intermediate (2046 - 2065) Adaptations	-2%	(12,011,770)	67%	398%	(51,850,648)
CM CRM Intermediate (2046 - 2065) Adaptations	2%	(4,189,793)	105%	56%	(10,389,262)
CM GISS Intermediate (2046 - 2065) Adaptations	5%	2,788,969	117%	52%	(9,954,975)
CM IPS Intermediate (2046 - 2065) Adaptations	2%	(5,743,530)	98%	70%	(12,998,011)
Colour code legend:					
Base run					
CCCT technique for different GCM's - Present climate - static runs					
CCCT technique for different GCM's - Intermediate climate - static runs					
Apsim technique for different GCM's - Intermediate climate - static runs					
CCCT technique for different GCM's - Intermediate climate - adaptation options included					
Apsim technique for different GCM's - Intermediate climate - adaptation options included					

The modelling results for Case Study 1 (20% start-up debt ratio) can be interpreted as follows:

- An average internal rate of return (IRR) of 8% is projected under the present climate scenario. When intermediate climate scenarios are imposed on the model, the IRR decreases to respectively 2% for the CCCT model and 0% for the APSIM crop model (ACM). The inclusion of adaptation strategies tends to have a positive effect on profitability with the IRR increasing to 5% (CCCT) and 2% (ACM). Intermediate climate projections will ultimately impact negatively on profitability and return on investment.
- An average net present value (NPV) of R10.3 million is projected under present climate conditions. For intermediate climate conditions a negative NPV is projected for both the CCCT (-R3.4 million) and ACM models (-R8.2 million). Both these projections are positively influenced by the inclusion of adaptation strategies in the model. A NPV of R4 million is projected for the CCCT model and a NPV of (-R4.8 million) for the ACM model. Intermediate climate projections will ultimately impact negatively on profitability and return on investment.

- A cash flow ratio of 122% is projected under present climate conditions. This ratio, however, declines to 103% (CCCT model) and 88% (ACM) when intermediate climate scenarios are imposed on the model. Both models show an improvement in cash flow ratio when adaptation strategies are included in the model (CCCT model = 102%, ACM model = 97%). The intermediate climate projections will strain cash flow and repayment ability and may put the farming business in a financial position that falls outside the generally accepted financing norms. A cash flow ratio of less than 110% for a farming business is not attractive to any financier.
- A highest debt ratio of 36% is projected under present climate scenarios. When intermediate climate scenarios are imposed on the model, the highest debt ratio increases to 67% (CCCT model) and 130% (ACM model). The inclusion of adaptation strategies negatively influences the highest debt ratio to 86% and 144% for the CCCT model and the ACM model respectively. This is however due to expensive capital outlay forced into the model over a very short period of time. In order to be attractive to outside financiers, the highest debt ratio should not exceed 50%. It seems that without adaptation, intermediate climate projections will push the farming business outside this norm.
- A highest debt level of R6.5 million is projected under present climate conditions. This level increased to R11.5 million (CCCT model) and R22.6 million (ACM model) when intermediate climate scenarios are imposed on the model. With the inclusion of adaptation strategies in the model, the highest debt levels of R23.3 million (CCCT model) and R21.3 million (ACM model) are projected. It is clear that intermediate climate projections will ultimately increase debt levels.

Case Study 2

Table 66 summarises the financial ratios of the different climate scenarios that were modelled. The model assumes a 20% start-up debt ratio.

Table 66: Financial assessment results for LORWUA Case Study 2

	IRR	NPV	Cash flow ratio	Highest debt ratio	Highest debt
Base run	7%	2,799,405	125%	33%	(1,640,398)
CCC Present (1971 - 1990)	8%	3,291,840	126%	29%	(1,445,470)
CRM Present (1971 - 1990)	7%	2,916,788	125%	35%	(1,771,662)
ECH Present (1971 - 1990)	7%	2,374,958	123%	38%	(1,881,231)
GISS Present (1971 - 1990)	6%	1,909,257	122%	33%	(1,664,205)
IPS Present (1971 - 1990)	5%	1,020,348	119%	43%	(2,143,920)
CCC Intermediate (2046 - 2065)	1%	(2,228,002)	87%	120%	(4,757,187)
CRM Intermediate (2046 - 2065)	1%	(1,792,781)	94%	75%	(3,377,952)
ECH Intermediate (2046 - 2065)	2%	(1,389,240)	100%	55%	(2,621,659)
GISS Intermediate (2046 - 2065)	2%	(1,279,782)	100%	55%	(2,770,071)
IPS Intermediate (2046 - 2065)	1%	(1,628,370)	100%	55%	(2,590,152)
CM CCC Intermediate (2046 - 2065)	1%	(2,378,007)	79%	169%	(6,687,537)
CM CRM Intermediate (2046 - 2065)	1%	(2,245,535)	84%	138%	(5,582,665)
CM GISS Intermediate (2046 - 2065)	2%	(1,485,437)	93%	81%	(4,116,514)
CM IPS Intermediate (2046 - 2065)	1%	(2,284,209)	84%	142%	(5,650,910)
CCC Intermediate (2046 - 2065) Adaptations	9%	6,095,140	106%	96%	(5,810,083)
CRM Intermediate (2046 - 2065) Adaptations	10%	8,487,143	110%	93%	(5,813,761)
ECH Intermediate (2046 - 2065) Adaptations	11%	9,146,352	112%	83%	(5,403,461)
GISS Intermediate (2046 - 2065) Adaptations	11%	9,399,558	112%	88%	(5,518,351)
IPS Intermediate (2046 - 2065) Adaptations	11%	9,675,078	112%	88%	(5,689,920)
CM CCC Intermediate (2046 - 2065) Adaptations	1%	(2,266,151)	67%	331%	(13,480,037)
CM CRM Intermediate (2046 - 2065) Adaptations	2%	(1,448,736)	91%	99%	(4,951,281)
CM GISS Intermediate (2046 - 2065) Adaptations	4%	(329,267)	110%	80%	(4,170,584)
CM IPS Intermediate (2046 - 2065) Adaptations	1%	(2,058,579)	82%	154%	(6,562,455)
Colour code legend:					
Base run					
CCCT technique for different GCM's - Present climate - static runs					
CCCT technique for different GCM's - Intermediate climate - static runs					
Apsim technique for different GCM's - Intermediate climate - static runs					
CCCT technique for different GCM's - Intermediate climate - adaptation options included					
Apsim technique for different GCM's - Intermediate climate - adaptation options included					

The modelling results for Case Study 2 (20% start-up debt ratio) can be interpreted as follows:

- An average internal rate of return (IRR) of 7% is projected under the present climate scenario. When intermediate climate scenarios are imposed on the model, the IRR decreases to respectively 1% for the CCCT model and 1% for the APSIM crop model (ACM). The inclusion of adaptation strategies tends to have a positive effect on profitability with the IRR increasing to 10% (CCCT) and 2% (ACM). Intermediate climate projections will ultimately impact negatively on profitability and return on investment.
- A net present value (NPV) of R2.3 million is projected under present climate conditions. For intermediate climate conditions a negative NPV is projected for both the CCCT model (-R1.7 million) and ACM model (-R2.1 million). Both these projections are positively influenced by the inclusion of adaptation strategies in the model. A NPV of R8.5 million is projected for the CCCT model and a NPV of -R1.5 million for the ACM model.

- A cash flow ratio of 123% is projected under present climate conditions. This ratio, however, declines to 96% (CCCT model) and 85% (ACM) when intermediate climate scenarios are imposed on the model. Both models show an improvement in cash flow ratio when adaptation strategies are included in the model (CCCT model = 110%, ACM model = 88%). The intermediate climate projections will strain cash flow and repayment ability and may put the farming business in a financial position that falls outside the generally accepted financing norms. A cash flow ratio of less than 110% for a farming business is not attractive to any financier.
- A highest debt ratio of 36% is projected under present climate scenarios. When intermediate climate scenarios are imposed on the model, the highest debt ratio increases to 72% (CCCT model) and 133% (ACM model). The inclusion of adaptation strategies negatively influences the highest debt ratio to 90% and 166% for the CCCT model and the ACM model respectively. This is, however, due to expensive capital outlay forced into the model over a very short period of time. In order to be attractive to outside financiers, the highest debt ratio should not exceed 50%. It seems that without adaptation, intermediate climate projections will push the farming business outside this norm.
- A highest debt level of R1.7 million is projected under present climate conditions. This level increased to R3.2 million (CCCT model) and R5.5 million (CM model) when intermediate climate scenarios are imposed on the model. With the inclusion of adaptation strategies in the model, the highest debt level of R5.6 million (CCCT model) and R7.2 million (ACM model) is projected. It is clear that intermediate climate projections will ultimately increase debt levels.
- It is also significant to note that there is a strong correlation between the CCCT (expert opinions) and the APSIM model (crop model) approach. The results indicate that the CCCT methodology can be used with confidence.

10.3 Blyde River WUA

The following sections show a summary of the financial modelling results for the Blyde River WUA area.

10.3.1 Climate change impact on quality and yield of crops modelling results

There are no APSIM crop models (or any other crop model) for citrus and mangoes. For the Blyde River WUA area, the CCCT modelling technique developed by Oosthuizen (2014), was the only tool available to model the impact of projected climate change on the yield and quality of citrus and mangoes. The positive correlation between APSIM crop modelling results and CCCT modelling results in other areas increases confidence in the accuracy of the modelling outcome for the Blyde River WUA area.

10.3.1.1 CCCT modelling results

When breaching a critical climate threshold, the impact on yield and/or quality can be either positive or negative. The critical crop climate thresholds for different crops were collected during a workshop which was attended by various role-players, including amongst others, industry experts and farmers.

Table 67 shows the critical climate thresholds for different citrus types namely oranges (Valencia), lemons and grapefruit.

Table 67: Critical climate thresholds for citrus

Critical climate thresholds	Impact
Citrus - Valencia	
Tmxd > 40 °C and RH < 30% for 2 days Sept	Negative
Tmxd >35 °C and RH < 30% for 2 days Sept	Negative
Tmxd > 35 °C and RH < 20% for 2 days Sept	Negative
Fruit drop (Nov/Dec) >7 days of Tmxd > 36 °C and RH < 40%	Negative
During picking temp > 36 °C - increase rind problems	Negative
> 14 days continuous rain during picking (autumn) causes leaf wetness and overripe fruit	Negative
Citrus - Lemons	
Tmxd > 40 °C and RH < 30% for 2 days Sept	Negative
Tmxd >35 °C and RH < 30% for 2 days Sept	Negative
Tmxd > 35 °C and RH < 20% for 2 days Sept	Negative
Fruit drop (Nov/Dec) >7 days of Tmxd > 36 °C and RH < 40%	Negative
During picking temp > 36 °C - increase rind problems	Negative
>14 days continuous rain during picking (autumn) causes leaf wetness and overripe fruit	Negative
Citrus - Grapefruit	
Tmxd > 40 °C and RH < 30% for 2 days Sept	Negative
Tmxd >35 °C and RH < 30% for 2 days Sept	Negative
Tmxd > 35 °C and RH < 20% for 2 days Sept	Negative
Fruit drop (Nov/Dec) >7 days of Tmxd > 36 °C and RH < 40%	Negative
2 °C warmer in May - colour deteriorates	Negative
During picking temp > 36 °C - increase rind problems	Negative
>14 days continuous rain during picking (autumn) causes leaf wetness and overripe fruit	Negative

Source: Blyde River WUA workshop and expert group discussions (2012)

Refer to Table 67 and the Appendix for threshold penalty weights for yield and quality. The critical thresholds for citrus can be interpreted as follows:

Valencia

- Tmxd > 40°C and RH < 30% for 2 days Sept – daily maximum temperature in excess of 40°C and relative humidity less than 30% for 2 days or more during the month of September have a negative impact of -25% on yield.
- Tmxd >35°C and RH < 30% for 2 days Sept – daily maximum temperature in excess of 35°C and relative humidity less than 30% for 2 days or more during the month of September have a negative impact of -15% on yield.
- Tmxd >35°C and RH < 20% for 2 days Sept – daily maximum temperature in excess of 35°C and relative humidity less than 30% for 2 days or more during the month of September have a negative impact of -15% on yield.
- Fruit drop (Nov/Dec) > 7 days of Tmxd > 36°C and RH < 40% – daily maximum temperatures in excess of 36°C and relative humidity less than 40% for 7 days and more during November and December cause fruit drop and have a negative impact on yield (-40%).
- During picking temp > 36°C – increase rind problems – maximum daily temperatures in excess of 36°C increase rind problems and have a negative effect on quality (-1%).
- >14 days' continuous rain during picking (autumn) causes leaf wetness and overripe fruit – negative impact of -8% on quality.

Lemons

- Tmxd > 40°C and RH < 30% for 2 days Sept – daily maximum temperature in excess of 40°C and relative humidity less than 30% for 2 days or more during the month of September have a negative impact of -25% on yield.
- Tmxd >35°C and RH < 30% for 2 days Sept – daily maximum temperature in excess of 35°C and relative humidity less than 30% for 2 days or more during the month of September have a negative impact of -15% on yield.
- Tmxd >35°C and RH < 20% for 2 days Sept – daily maximum temperature in excess of 35°C and relative humidity less than 30% for 2 days or more during the month of September have a negative impact of -15% on yield.
- Fruit drop (Nov/Dec) > 7 days of Tmxd > 36°C and RH < 40% – daily maximum temperatures in excess of 36°C and relative humidity less than 40% for 7 days and more during November and December cause fruit drop and have a negative impact on yield (-40%).
- During picking temp > 36°C – increase rind problems – maximum daily temperatures in excess of 36°C increase rind problems and have a negative effect on quality (-1%).
- >14 days' continuous rain during picking (autumn) causes leaf wetness and overripe fruit – negative impact of -15% on quality.

Grapefruit

- Tmxd > 40°C and RH < 30% for 2 days Sept – daily maximum temperature in excess of 40°C and relative humidity less than 30% for 2 days or more during the month of September have a negative impact of -40% on yield.
- Tmxd >35°C and RH < 30% for 2 days Sept – daily maximum temperature in excess of 35°C and relative humidity less than 30% for 2 days or more during the month of September have a negative impact of -40% on yield.
- Tmxd >35°C and RH < 20% for 2 days Sept – daily maximum temperature in excess of 35°C and relative humidity less than 30% for 2 days or more during the month of September have a negative impact of -40% on yield.
- Fruit drop (Nov-Dec) > 7 days of Tmxd > 36°C and RH < 40% – daily maximum temperatures in excess of 36°C and relative humidity less than 40% for 7 days and more during November and December cause fruit drop and have a negative impact on yield (-30%) and quality (-10%).
- 2°C warmer temperatures in May cause colour to deteriorate – impact negatively on quality (-4%).
- During picking temp > 36°C – increase rind problems – maximum daily temperatures in excess of 36°C increase rind problems and have a negative effect on quality (-1%).
- >14 days' continuous rain during picking (autumn) causes leaf wetness and overripe fruit and has a negative impact of -10% on quality.

Table 68 shows the critical climate thresholds for different mango cultivars namely Keitt, Kent and Tommy Atkins.

Table 68: Critical climate thresholds for mangoes

Critical Climate Thresholds	Impact
Mango - Keitt	
Average May Tmnd 3 °C warmer	Negative
Tmnd < 2 °C Jul - Aug	Negative
Sept - Dec (HU requirement 350 hours > 17.9 °C) cool temps averaging < 17.9 °C cause late maturation and market delivery delay	Negative
Tmxd > 38 °C Dec - Jan	Negative
Mango - Kent	
Average May Tmnd 3 °C warmer	Negative
Tmnd < 2 °C Jul - Aug	Negative
Tmxd > 38 °C Sept	Negative
Sept - Dec (HU requirement 350 hours > 17.9 °C) cool temps averaging < 17.9 °C cause late maturation and market delivery delay	Negative
Tmxd > 38 °C Dec - Jan	Negative
Mango - Tommy Atkins	
Average May Tmnd 3 °C warmer	Negative
Tmnd < 2 °C Jul - Aug	Negative
Sept - Dec (HU requirement 350 hours > 17.9 °C) cool temps averaging < 17.9 °C cause late maturation and market delivery delay	Negative
Tmxd > 38 °C Dec - Jan	Negative

Source: Blyde River WUA workshop and expert group discussions (2012)

Refer to Table 68 and the Appendix for threshold penalty weights for yield and quality. The critical thresholds for mangoes can be interpreted as follows:

Keitt

- Average May Tmnd 3°C warmer – an increase of 3% in average minimum temperatures for the month of May will impact negatively on yield (-4%).
- Tmnd < 2°C Jul-Aug – minimum daily temperatures less than 2°C have a negative impact on yield (-4%).
- Sept-Dec (HU requirement 350 hours > 17.9°C) cool temps averaging < 17.9°C cause late maturation and market delivery delay – less than the required 350 hours heat units > 17.9°C during September to December has a negative impact on quality (-10%).
- Tmxd > 38°C Dec-Jan – maximum daily temperature in excess of 38°C during the months of December to January have a negative impact on yield (-1%) and quality (-1%).

Kent

- Average May Tmnd 3°C warmer – an increase of 3% in average minimum temperatures for the month of May will impact negatively on yield (-8%).
- Tmnd < 2°C Jul-Aug – minimum daily temperatures less than 2°C have a negative impact on yield (-8%).
- Tmxd > 38°C Sept – maximum daily temperatures in excess of 38°C during the month of September impact negative on yield (-1%) and quality (-1%).
- Sept-Dec (HU requirement 350 hours > 17.9°C) cool temps averaging < 17.9°C cause late maturation and market delivery delay – less than the required 350 hours heat units > 17.9°C during September to December have a negative impact on quality (-10%).
- Tmxd > 38°C Dec-Jan – Maximum daily temperature in excess of 38°C during the months of December to January has negative impact on yield (-1%) and quality (-1%).

Tommy Atkins

- Average May Tmnd 3°C warmer – an increase of 3% in average minimum temperatures for the month of May will impact negatively on yield (-6%).
- Tmnd < 2°C Jul-Aug – Minimum daily temperatures less than 2°C have a negative impact on yield (-6%).
- Sept-Dec (HU requirement 350 hours > 17.9°C) cool temps averaging < 17.9°C cause late maturation and market delivery delay – less than the required 350 hours heat units > 17.9°C during September to December has a negative impact on quality (-20%).
- Tmxd > 38°C Dec-Jan – Maximum daily temperature in excess of 38°C during the months of December to January have a negative impact on yield (-1%) and quality (-1%).

Table 69 shows the CCCT modelling results for the different GCMs for the present and intermediate future (2046-2065). The values are 20-year average values for the different models. Although only one out of five GCMs projects a decrease in yield for citrus, all models project a negative impact on quality. For mangoes the models project a negative impact on both yield and quality.

Table 69: CCCT modelling yield and quality projections for citrus and mangoes in the Blyde River WUA area

	Citrus						Mangoes					
	Grapefruit		Lemons		Valencia		Keitt		Kent		Tommy Atkins	
	Yield	Quality	Yield	Quality	Yield	Quality	Yield	Quality	Yield	Quality	Yield	Quality
CCC Pres	10	6	10	6	10	6	10	5	10	5	10	5
CCC Int	10	4	10	4	10	4	9	4	8	4	8	4
CRM Pres	10	5	10	5	10	6	10	5	10	5	10	5
CRM Int	10	3	10	3	10	4	8	4	7	4	8	4
ECH Pres	10	5	10	5	10	6	10	5	8	5	9	5
ECH Int	10	3	10	4	10	4	8	4	7	4	8	4
GISS Pres	10	6	10	6	10	6	11	6	10	5	10	6
GISS Int	8	4	9	4	9	4	9	4	8	4	8	4
IPS Pres	10	5	10	5	10	5	10	5	9	5	10	5
IPS Int	10	3	10	4	10	4	9	4	8	4	8	4
AVE Pres	**10**	**5**	**10**	**5**	**10**	**6**	**10**	**5**	**9**	**5**	**10**	**5**
AVE Int	**10**	**4**	**10**	**4**	**10**	**4**	**8**	**4**	**7**	**4**	**8**	**4**

Legend: Yield (% of base yield)

8 = 90%
9 = 95%
10 = 100%
11 = 105%
12 = 110%

Legend: Quality (% of base quality)

3 = 80%
4 = 90%
5 = 100%
6 = 110%
7 = 120%

10.3.2 Climate change impact on crop irrigation requirements results

Table 70 and Table 71 display the simulated irrigation requirements for citrus and mangoes for the current and intermediate future projected climates.

An 8% average annual increase in irrigation requirements is projected for citrus for intermediate future climates in order to obtain the same yield as with present climates (Table 70).

Table 70: SAPWAT3 simulated irrigation requirements for citrus for the present and intermediate future projected climates

Citrus - present														
Case study region	**Irri01**	**Irri02**	**Irri03**	**Irri04**	**Irri05**	**Irri06**	**Irri07**	**Irri08**	**Irri09**	**Irri10**	**Irri11**	**Irri12**	**Total**	
Hoedspruit_CCC_PR3	105	90	105	100	82	54	97	99	110	114	96	110	**1,162**	
Hoedspruit_CRM_PR3	64	44	64	84	88	62	105	111	111	98	70	74	**975**	
Hoedspruit_ECH_PR3	100	78	83	75	85	58	96	103	109	112	102	74	**1,075**	
Hoedspruit_GISS_PR3	101	92	99	86	82	49	89	95	94	83	90	88	**1,048**	
Hoedspruit_IPS_PR3	89	84	92	90	79	58	108	105	107	107	99	84	**1,102**	
Average	**92**	**78**	**89**	**87**	**83**	**56**	**99**	**103**	**106**	**103**	**91**	**86**	**1,072**	
Citrus - intermediate future														
Case study region	**Irri01**	**Irri02**	**Irri03**	**Irri04**	**Irri05**	**Irri06**	**Irri07**	**Irri08**	**Irri09**	**Irri10**	**Irri11**	**Irri12**	**Total**	**% change**
Hoedspruit_CCC_INT	105	100	114	100	96	63	102	98	127	122	104	108	**1,239**	7%
Hoedspruit_CRM_INT	80	54	67	73	91	71	108	120	131	108	72	86	**1,061**	9%
Hoedspruit_ECH_INT	102	85	81	75	91	70	105	114	122	113	98	113	**1,169**	9%
Hoedspruit_GISS_INT	107	91	108	99	94	60	104	101	99	100	98	109	**1,170**	12%
Hoedspruit_IPS_INT	83	83	102	90	90	63	96	111	103	121	103	90	**1,135**	3%
Average	**95**	**83**	**94**	**87**	**92**	**65**	**103**	**109**	**116**	**113**	**95**	**101**	**1,155**	**8%**

An 8% average annual increase in irrigation requirements is projected for mangoes for intermediate future climates in order to obtain the same yield as with present climates (Table 71).

Table 71: SAPWAT3 simulated irrigation requirements for mangoes for the present and intermediate future projected climates

Mangoes - present														
Case study region	Irri01	Irri02	Irri03	Irri04	Irri05	Irri06	Irri07	Irri08	Irri09	Irri10	Irri11	Irri12	Total	
Hoedspruit_CCC_PR3	122	112	116	89	65	99	99	105	128	128	107	122	1,292	
Hoedspruit_CRM_PR3	76	50	76	80	69	105	107	121	125	118	77	96	1,100	
Hoedspruit_ECH_PR3	112	86	99	73	67	96	101	116	122	133	110	95	1,210	
Hoedspruit_GISS_PR3	114	106	113	85	67	94	91	104	107	102	109	106	1,198	
Hoedspruit_IPS_PR3	99	103	100	85	64	107	104	119	121	121	115	98	1,236	
Average	105	91	101	82	66	100	100	113	121	120	104	103	1,207	
Mangoes - intermediate future														
Case study region	Irri01	Irri02	Irri03	Irri04	Irri05	Irri06	Irri07	Irri08	Irri09	Irri10	Irri11	Irri12	Total	% change
Hoedspruit_CCC_INT	120	116	129	98	75	108	101	117	134	141	121	125	1,385	7%
Hoedspruit_CRM_INT	96	70	79	69	77	115	121	135	139	118	88	105	1,212	10%
Hoedspruit_ECH_INT	116	114	93	74	74	118	119	120	130	130	116	120	1,324	9%
Hoedspruit_GISS_INT	130	106	126	90	75	108	97	110	117	116	113	119	1,307	9%
Hoedspruit_IPS_INT	99	98	120	83	75	105	103	115	112	141	119	106	1,276	3%
Average	112	101	109	83	75	111	108	119	126	129	111	115	1,301	8%

10.3.3 Climate change impact on the availability of irrigation water requirements

The Blyde River WUA is an irrigation area and dependent on irrigation water for production. The present and intermediate climate data for downscaled GCMs were used in the ACRU model to project future dam levels, which forms the base for calculating the annual allocation of irrigation water quotas to farmers. The projected total annual irrigation water quota (m^3) allocated to a farming system and monthly canal capacities are included in the DLP model as resource constraints.

The projection of the Blydepoort Dam level was done by UKZN, using the ACRU model. Figure 66 illustrates the historical and projected dam level of the Blydepoort Dam.

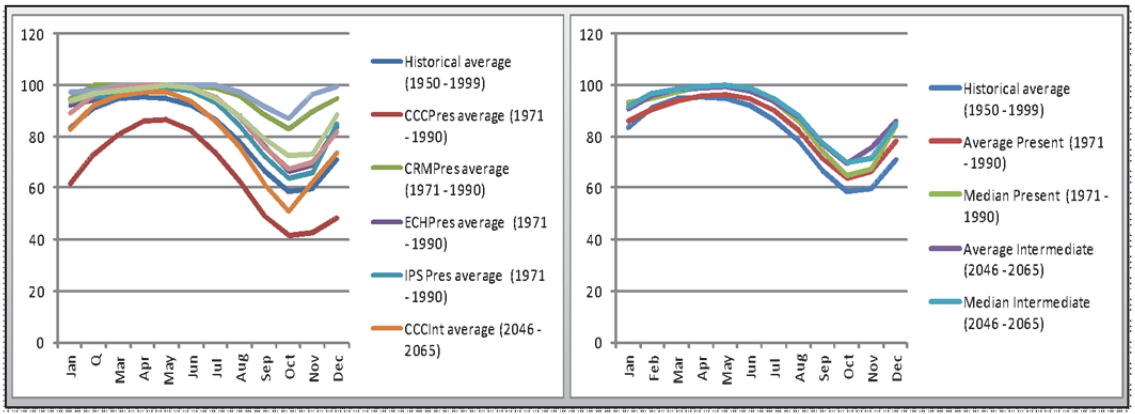

Figure 66: Historical and projected dam level for Blydepoort Dam

All indications are that the availability of irrigation water for the Blyde area irrigators (in terms of quota consistency) will not be negatively affected by the projected climate scenarios.

10.3.4 Adaptation strategies available

Increases in average temperatures and seasonal shifts are the biggest threats that the Blyde River WUA area faces. The following are problems associated with increased temperatures:

- Quality losses as a result of wind and sunburn (citrus and mangoes)
- Reduction in fruit set (citrus) as a result of sunburn
- Seedless cultivars are less tolerant to increased temperatures than seeded cultivars; the demand, however, is for seedless cultivars (citrus).

The only adaptation strategy that was identified to eliminate the threats associated with climate change to be included in the integrated model is the installation of shade nets over citrus and mango production areas.

10.3.4.1 Shade nets

While water efficiency is a key concept to solve water-shortage problems in semiarid areas, shading nets structures in semiarid and arid environments can be considered as an intermediate solution for increasing water use efficiency and reducing plant water stress. It offer many advantages and environmental benefits, which is why an increasing area of crops, including citrus, is being grown under shading materials of various types. It was found that the use of the shading net reduces wind speed within the foliage and helps to decrease fruit dropping. The shade provided by the net does not affect yield and internal fruit quality (ratio of sugar to acid) but may increase fruit average weight and diameter (Abouatallah et al., 2012).

The panel of experts agreed that shade nets on citrus and mangoes can eliminate most threats associated with projected climate change and will have the following advantages:

- Improvement in fruit quality (less hail, wind and sun damage)
- Less stress on tree (more consistent yields)
- More effective use of irrigation water (less evapotranspiration).

10.3.4.2 Other adaptation strategies (not included in the model)

The following are a list of adaptation strategies debated but not included in the integrated climate change model:

- Mulching cover to conserve moisture
- More effective management of irrigation systems
- Cultivar development to increase natural heat resistance.

10.3.5 Financial vulnerability assessment results – Blyde River WUA case studies

10.3.5.1 Case Study 1

Table 72 summarises the financial ratios of the different climate scenarios that were modelled. The model assumes a 20% start-up debt ratio.

Table 72: Financial assessment results for Blyde River WUA Case Study 1

	IRR	NPV	Cash flow ratio	Highest debt ratio	Highest debt
Base run	14%	12,258,800	129%	43%	(3,419,599)
CCC Present (1971 - 1990)	18%	15,324,906	131%	56%	(4,439,923)
CRM Present (1971 - 1990)	19%	15,135,705	125%	35%	(2,759,573)
ECH Present (1971 - 1990)	13%	9,520,929	122%	46%	(3,638,295)
GISS Present (1971 - 1990)	19%	18,387,418	138%	42%	(3,342,224)
IPS Present (1971 - 1990)	13%	11,213,918	128%	56%	(4,446,420)
CCC Intermediate (2046 - 2065)	3%	(1,779,436)	97%	112%	(8,858,550)
CRM Intermediate (2046 - 2065)	-1%	(5,563,182)	79%	295%	(23,441,992)
ECH Intermediate (2046 - 2065)	0%	(4,800,209)	83%	235%	(18,687,659)
GISS Intermediate (2046 - 2065)	2%	(2,374,432)	94%	84%	(6,675,536)
IPS Intermediate (2046 - 2065)	3%	(1,426,069)	100%	76%	(5,958,340)
CCC Intermediate (2046 - 2065) Adaptions	7%	10,616,893	115%	177%	(28,995,741)
CRM Intermediate (2046 - 2065) Adaptations	7%	10,616,893	115%	177%	(28,995,741)
ECH Intermediate (2046 - 2065) Adaptations	7%	10,616,893	115%	177%	(28,995,741)
GISS Intermediate (2046 - 2065) Adaptations	7%	10,311,704	114%	175%	(28,350,214)
IPS Intermediate (2046 - 2065) Adaptations	7%	10,616,893	115%	177%	(28,995,741)
Colour code legend:					
Base run					
CCCT technique for different GCM's - Present climate - static runs					
CCCT technique for different GCM's - Intermediate climate - static runs					
CCCT technique for different GCM's - Intermediate climate - adaptation options included					

The modelling results for Case Study 1 can be interpreted as follows:

- An IRR of 16% is projected under the present climate scenario. When intermediate climate scenarios are imposed on the model, the IRR decreases to 1%. The inclusion of adaptation strategies tends to have a positive effect on profitability with the IRR increasing to 7%. Intermediate climate projections will ultimately impacts negatively on profitability and return on investment.
- A NPV of R13.3 million is projected under present climate scenarios. For intermediate climate scenarios a negative NPV (-R3.7 million) is projected. The inclusion of adaptation strategies in the modelling has a positive impact on profitability, to the extent that a NPV of R10.5 million is projected if adaptation strategies are included in the model.
- A cash flow ratio of 126% is projected under present climate conditions. This ratio however declines to 89% when intermediate climate scenarios are imposed on the model. The model shows an improvement in cash flow ratio when adaptation strategies are included in the model (cash flow ratio = 115%). The intermediate climate projections will strain cash flow and repayment ability and may put the farming business in a financial position that falls outside the general accepted financing norms. A cash flow ratio of less than 110% for a farming business is not attractive to any financier.
- A highest debt ratio of 47% is projected under present climate scenarios. When intermediate climate scenarios are imposed on the model, the highest debt ratio increases to 176%. To be attractive to outside financiers, the highest debt ratio should not exceed 50%. It seems that,

without adaptation, intermediate climate projections will push the farming business outside this norm.

- A highest debt level of R3.7 million is projected under present climate conditions. This level increased to R14 million when intermediate climate scenarios are imposed on the model. It is clear that intermediate climate projections will ultimately increase debt levels.

10.3.5.2 Case Study 2

Table 73 summarises the financial ratios of the different climate scenarios that were modelled. The model assumes a 20% start-up debt ratio.

Table 73: Financial assessment results for Blyde River WUA Case Study 2

	IRR	NPV	Cash flow ratio	Highest debt ratio	Highest debt
Base run	18%	28,534,499	121%	31%	(5,490,201)
CCC Present Static (1971 - 1990)	27%	45,642,841	130%	45%	(7,854,056)
CRM Present Static (1971 - 1990)	23%	37,444,867	125%	22%	(3,946,723)
ECH Present Static (1971 - 1990)	20%	31,694,562	124%	24%	(4,270,149)
GISS Present Static (1971 - 1990)	30%	49,489,167	133%	24%	(4,161,145)
IPS Present Static (1971 - 1990)	17%	26,358,453	119%	24%	(4,237,474)
CCC Intermediate Static (2046 - 2065)	6%	4,868,599	106%	43%	(7,482,152)
CRM Intermediate Static (2046 - 2065)	2%	(5,044,555)	97%	55%	(9,772,454)
ECH Intermediate Static (2046 - 2065)	2%	(3,320,299)	102%	46%	(7,967,866)
GISS Intermediate Static (2046 - 2065)	4%	(467,839)	99%	40%	(6,955,239)
IPS Intermediate Static (2046 - 2065)	3%	(1,782,510)	104%	49%	(8,523,710)
CCC Intermediate(2046 - 2065) Adaptations	7%	17,291,478	104%	193%	(64,441,051)
CRM Intermediate (2046 - 2065) Adaptations	7%	17,291,478	104%	193%	(64,441,051)
ECH Intermediate (2046 - 2065) Adaptations	7%	17,291,478	104%	193%	(64,441,051)
GISS Intermediate (2046 - 2065) Adaptaions	7%	17,595,057	106%	186%	(60,869,250)
IPS Intermediate (2046 - 2065) Adaptations	7%	17,291,478	104%	193%	(64,441,051)
Colour code legend:					
Base run					
CCCT technique for different GCM's - Present climate - static runs					
CCCT technique for different GCM's - Intermediate climate - static runs					
CCCT technique for different GCM's - Intermediate climate - adaptation options included					

The modelling results for Case Study 2 (20% start-up debt ratio) can be interpreted as follows:

- An average IRR of 21% is projected under the present climate scenario. When intermediate climate scenarios are imposed on the model, the IRR turns negative. The inclusion of adaptation strategies tends to have a positive effect on profitability with the IRR increasing to 7%. Intermediate climate projections will ultimately impact negatively on profitability and return on investment.
- A NPV of R30.4 million is projected under present climate scenarios. For intermediate climate scenarios a negative NPV (-R8.8 million) is projected. The inclusion of adaptation strategies in the modelling has a positive impact on profitability, to the extent that a NPV of R17.2 million is projected if adaptation strategies are included in the model.
- A cash flow ratio of 119% is projected under present climate conditions. This ratio, however, declines to 81% when intermediate climate scenarios are imposed on the model. The model

shows an improvement in cash flow ratio when adaptation strategies are included in the model (cash flow ratio = 97%). The intermediate climate projections will strain cash flow and repayment ability and may put the farming business in a financial position which falls outside the general accepted financing norms. A cash flow ratio of less than 110% for a farming business is not attractive to any financier.

- A highest debt ratio of 45% is projected under present climate scenarios. When intermediate climate scenarios are imposed on the model, the highest debt ratio increases to 246%. To be attractive to outside financiers, the highest debt ratio should not exceed 50%. It seems that without adaptation, intermediate climate projections will push the farming business outside this norm.
- A highest debt level of R7.9 million is projected under present climate conditions. This level increased to R43.4 million when intermediate climate scenarios are imposed on the model. It is clear that intermediate climate projections will ultimately increase debt levels.

10.4 Moorreesburg case study

10.4.1 Climate change impact on quality and yield of crops modelling results

10.4.1.1 APSIM crop modelling results

Figure 67 shows the projected yield for wheat for the intermediate future (2046-2065) in the Moorreesburg area, derived from APSIM calculations. The figures are expressed as percentage of the yield used in the base analysis.

Climate data from four GCMs were applied in the APSIM modelling to project intermediate future yield for wheat. The different GCM projections (20-year average) vary from a decrease of 4% to an increase of 4% compared to present yield. The overall average yield between the four models equals the average present yield.

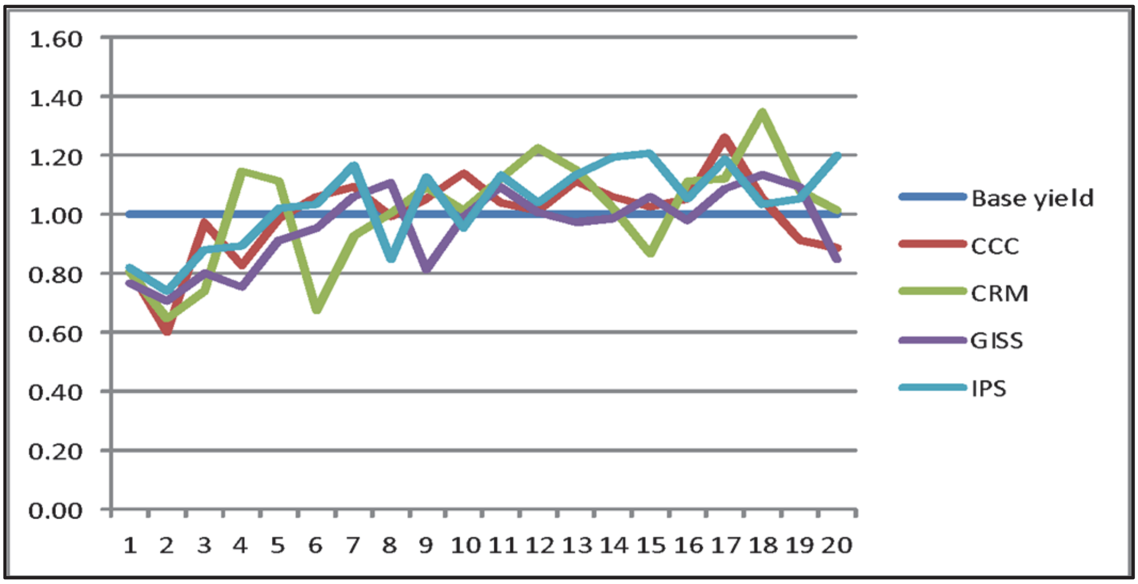

Figure 67: Projected yield (% of base yield) [2046-2065] for wheat in Moorreesburg area based on APSIM calculations

10.4.1.2 CCCT modelling results

When breaching a critical climate threshold, the impact on yield and/or quality can be either positive or negative. The critical crop climate thresholds for different crops were collected during a workshop that was attended by various role-players, including amongst others, industry experts and the case study farmer.

Table 74 shows the critical climate thresholds for wheat.

Table 74: Critical climate thresholds for wheat

Critical climate thresholds	Impact
Mid May - Aug Tmxd > 20 °C	Negative
Tmxd > 25 °C in Sept	Negative
Rainfal May - less than 50 mm	Negative
Rainfal May - Sept < 200 mm	Negative
Rainfal May - Sept > 400 mm	Positive
Rainfal May - Sept > 10 mm/week	Positive
Rainfal Sept weeks 1 and 2 > 10 mm	Positive
Rainfal Sept weeks 3 and 4 > 10 mm	Positive
May-Jun no rain	Negative
Jun - Jul < 70 mm	Negative
Jul - Aug < 70 mm	Negative
Sept < 15 mm	Negative
Sept < 5 mm	Negative

Source: Moorreesburg workshop and expert group discussions (2012)

Refer to Table 74 and the Appendix for threshold penalty weights for yield and quality. The critical thresholds for wheat can be interpreted as follows:

- Mid May-Aug Tmxd > 20°C – maximum daily temperatures in excess of 20°C from mid-May to August have a negative impact of -10% on yield.
- Tmxd > 25°C in Sept – maximum daily temperatures in excess of 25°C in September have a negative impact of -10% on yield.
- Rainfall May – less than 50 mm – less than 50 mm of rain in the month of May impacts negatively on yield (-10%).
- Rainfall May-Sept < 200 mm – less than 200 mm of rainfall for the period from May to September has a -30% negative impact on yield.
- Rainfall May-Sept > 400 mm – more than 400 mm of rainfall from May to September has a positive impact on yield (+20%).
- Rainfall May-Sept > 10 mm/week – weekly rainfall of 10 mm or more from May to September positively impact on yield (33%).
- Rainfall Sept weeks 1 and 2 > 10 mm – rainfall of 10 mm or more during week 1 and week 2 of September impacts positively on yield (+10%).
- Rainfall Sept weeks 3 and 4 > 10 mm – rainfall of 10 mm or more during week 3 and week 4 of September has a positive impact on yield (+10%).
- May-Jun no rain – no rain during May and June results in -10% impact on yield.
- Jun-Jul < 70 mm – less than 70 mm of rain from June to July has a negative impact on yield (-10%).
- Jul-Aug < 70 mm – less than 70 mm of rain from July to August has a negative impact on yield (-10%).
- Sept < 15 mm – less than 15 mm of rainfall in September impacts negatively on yield (-10%).
- Sept < 5 mm – less than 5 mm of rain during the month of September has a negative impact on yield (-10%).

Table 75 shows the CCCT modelling results for five different GCMs for the present and intermediate future (2046-2065). The values are 20-year average values for the different models. Despite relative small variances between the different GCM projections, no major changes in yield, from the present to the intermediate future, are projected. This result correlates with the APSIM crop modelling results, which increases confidence in the CCCT modelling technique.

Table 75: CCCT modelling yield projections for wheat in the Moorreesburg area

CCC Pres	CCC Int	CRM Pres	CRM Int	ECH Pres	ECH Int	GISS Pres	GISS Int	IPS Pres	IPS Int	AVE Pres	AVE Int
11	10	9	10	11	11	10	10	11	7	**10**	**10**

Legend: Yield (% of base yield)

8	=	*90%*
9	=	*95%*
10	=	*100%*
11	=	*105%*
12	=	*110%*

10.4.2 Adaptation strategies available

Adaptation options for the Moorreesburg area can be divided in two categories, namely changes in:

- Cropping systems
- Production practices

10.4.2.1 Cropping systems (crop rotation)

The benefit of crop rotation in reducing production risk involves three distinct influences that were described by Helmers et al. (2001). Firstly, rotations, as opposed to monoculture cropping, may result in overall higher crop yields as well as reduced production costs. Secondly, rotation cropping is generally thought to reduce yield variability compared with monoculture practices. Thirdly, crop rotation involves diversification, with the theoretical advantage that low returns in a specific year for one crop are combined with a relatively high return for a different crop. Drought, however, is usually detrimental to all crops, often preventing this advantage from occurring. An obvious benefit of diversification is the reduction of risk through the inclusion of alternative crops with relatively low risk (Nel and Loubser, 2004).

Higher yields associated with rotated crops will increase the per hectare cost of activities such as harvesting. On the other hand, weed and often pest control costs are less on rotated than monoculture crops, which will increase the net return. It is also known that nitrogen fertilization of grain crops can be reduced when grown in rotation with oil and protein rich crops without affecting the yield. The savings on inputs most probably outweigh the extra costs of harvesting higher yields, which suggests that the net returns and risk for the rotation systems are conservative estimates (Nel and Loubser, 2004).

The current cropping system for the case study is wheat-medics-wheat-medics combined with mutton and wool production. Other alternative cropping systems adapted for the region to be included in the model are:

- Wheat-medics-wheat-medics (with old man saltbush)
- Wheat-medics-medics-wheat
- Wheat-wheat-wheat-wheat (mono cropping system with no sheep)
- Wheat-lupin-wheat-canola (no sheep).

10.4.2.2 Production practices

In the past 15 years, successful adoption of conservation agriculture (CA) took place among grain and sugar farmers in Kwa-Zulu Natal, as well as among grain farmers in the Western Cape and Free State, but has remained rather slow in other production areas of South Africa. The main reasons for adopting CA relate to the improved water conservation properties and the ability to substantially lower production costs (Du Toit, 2007).

In 2004 it was reported that 45% of the total land cultivated in Brazil is estimated to be managed with no-till. In the case of land cropped by smallholder farmers (<50 ha), this figure is even reported to exceed 80% (Du Toit, 2012). Worldwide, a total of approximately 95 million hectares (ha) are currently being cultivated according to the principles of CA (Derpsch, 2005). The United Nations Food and Agriculture Organization, who has promoted the concept for the past ten years, states that CA has great potential in Africa, being the only truly sustainable production system for the continent (FAO, 2006).

Conservation agriculture (CA) is an integrated system built on the following basic principles (Nel, 2010; Du Toit, 2012):

- Minimum soil disturbance – conventional tillage methods are replaced by reduced or no-tillage and crops being planted by adapted planting equipment.
- Establishment and maintenance of an organic soil cover in the form of a mulch.
- Implementation of crop diversification and rotations, as opposed to mono-cropping.

The BFAP study (Du Toit, 2007) extensively researched conservation agriculture and concluded that it can definitely serve as an adaptation strategy. The study indicated significant economic and biological benefits, in the form of increased crop yields and net farm income, since starting with CA.

Adaptations options in terms of production practices for the Moorreesburg area include:

- Conservation agricultural production practices versus conventional production practices.

10.4.3 Financial vulnerability assessment results – Moorreesburg case study

Table 76 summarises the financial ratios of the different climate scenarios that were modelled. The model assumes a 20% start-up debt ratio.

Table 76: Financial assessment results for Moorreesburg case study

	IRR	NPV	Cash flow ratio	Highest debt ratio	Highest debt
Base run	5%	2,340,998	127%	17%	(3,871,160)
CCC Present (1971 - 1990)	6%	5,425,457	133%	17%	(3,871,160)
CRM Present (1971 - 1990)	5%	2,492,260	126%	14%	(3,871,160)
ECH Present (1971 - 1990)	6%	4,149,426	128%	14%	(3,871,160)
GISS Present (1971 - 1990)	5%	1,942,384	126%	10%	(3,871,160)
IPS Present (1971 - 1990)	7%	5,727,930	133%	7%	(3,871,160)
CCC Intermediate (2046 - 2065)	5%	2,197,053	126%	17%	(3,871,160)
CRM Intermediate (2046 - 2065)	5%	2,552,802	127%	12%	(3,871,160)
ECH Intermediate (2046 - 2065)	7%	5,499,782	133%	17%	(3,871,160)
GISS Intermediate (2046 - 2065)	5%	1,460,138	124%	22%	(4,281,636)
IPS Intermediate (2046 - 2065)	2%	(4,187,047)	112%	10%	(3,871,160)
CM CCC Intermediate (2046 - 2065)	5%	3,324,716	129%	23%	(4,417,363)
CM CRM Intermediate (2046 - 2065)	5%	3,418,428	129%	24%	(4,573,033)
CM GISS Intermediate (2046 - 2065)	4%	1,081,604	123%	23%	(4,401,884)
CM IPS Intermediate (2046 - 2065)	6%	4,204,177	131%	21%	(3,976,255)
CCC Intermediate (2046 - 2065) Adaptations	14%	24,560,173	159%	8%	(3,871,160)
CRM Intermediate (2046 - 2065) Adaptations	17%	24,332,290	158%	0%	(3,871,160)
ECH Intermediate (2046 - 2065) Adaptations	18%	28,973,417	167%	8%	(3,871,160)
GISS Intermediate (2046 - 2065) Adaptations	14%	23,437,682	156%	17%	(3,871,160)
IPS Intermediate (2046 - 2065) Adaptations	11%	14,254,306	139%	0%	(3,871,160)
CM CCC Intermediate (2046 - 2065) Adaptations	13%	22,798,326	158%	14%	(3,871,160)
CM CRM Intermediate (2046 - 2065) Adaptations	13%	23,072,360	159%	14%	(3,871,160)
CM GISS Intermediate (2046 - 2065) Adaptations	11%	19,347,228	153%	15%	(3,871,160)
CM IPS Intermediate (2046 - 2065) Adaptations	14%	24,985,717	161%	14%	(3,871,160)
Colour code legend:					
Base run					
CCCT technique for different GCM's - Present climate - static runs					
CCCT technique for different GCM's - Intermediate climate - static runs					
Apsim technique for different GCM's - Intermediate climate - static runs					
CCCT technique for different GCM's - Intermediate climate - adaptation options included					
Apsim technique for different GCM's - Intermediate climate - adaptation options included					

The modelling results for Moorreesburg case study (20% start-up debt ratio) can be interpreted as follows:

- An average IRR of 6% is projected under the present climate scenario. When intermediate climate scenarios are imposed on the model, the IRR decreases to respectively 5% for the CCCT model and 5% for the ACM. The inclusion of adaptation strategies tends to have a positive effect on profitability with the IRR increasing to 15% (CCCT) and 13% (ACM).
- A NPV of R3.9 million is projected under present climate conditions. For intermediate climate scenarios a NPV of R1.5 million for the CCCT model and R3 million for the ACM model are projected. Both these projections are positively influenced by the inclusion of adaptation strategies in the model. A NPV of R23 million is projected for the CCCT model and a NPV of R22 million for the ACM model. The impact of intermediate climate projections tends to be marginally negative on profitability and return on investment. The inclusion of adaptation

strategies can ultimately put the farming system in a better position than the current conventional system under present climate scenarios.

- A cash flow ratio of 129% is projected under present climate conditions. This ratio, however, declines marginally to 124% (CCCT model) and 128% (ACM) when intermediate climate scenarios are imposed on the model. Both models show an improvement in cash flow ratio when adaptation strategies are included in the model (CCCT model = 155%, ACM model = 158%). The adoption of conservation agriculture principles seems to counter the negative effect of climate change completely in the Moorreesburg area.
- A highest debt ratio of 12% is projected under present climate scenarios. When intermediate climate scenarios are imposed on the model, the highest debt ratio increases to 16% (CCCT model) and 22% (ACM model). The inclusion of adaptation strategies positively influences the highest debt ratio to 7% and 14% for the CCCT model and the ACM model respectively. All these ratios are well within acceptable financing norms.
- A highest debt level of R3.8 million is projected under present climate conditions. This level increased to R4 million (CCCT model) and R4.3 million (ACM model) when intermediate climate scenarios are imposed on the model. With the inclusion of adaptation strategies in the model, the highest debt level of R3.9 million (CCCT model) and R3.9 million (ACM model) is projected. It is clear that neither the intermediate climate projections nor the inclusion of adaptation strategies will cause a significant increase in debt levels.
- The case study farm is already on a profitable crop rotation system (wheat-medics-wheat). With optimisation of the farming system there was no significant deviation in the crop rotation, except the inclusion of old man saltbush. Old man saltbush is commonly known as a drought strategy for small livestock farming in South Africa. The results clearly indicate that changing to conservation agriculture is an efficient adaptation strategy for climate change in the Moorreesburg region.

10.5 Carolina case study

10.5.1 Climate change impact on quality and yield of crops modelling results

10.5.1.1 APSIM crop modelling results

Figure 68 shows the projected yield for maize for the intermediate future (2046-2065) in the Carolina area, derived from APSIM calculations. The figures are expressed as percentages of the yield used in the base analysis.

Climate data from four GCMs were applied in the APSIM modelling to project intermediate future yield for wheat. One model projects an average decrease of 25% while three models project an increase in average yield of approximately 10%.

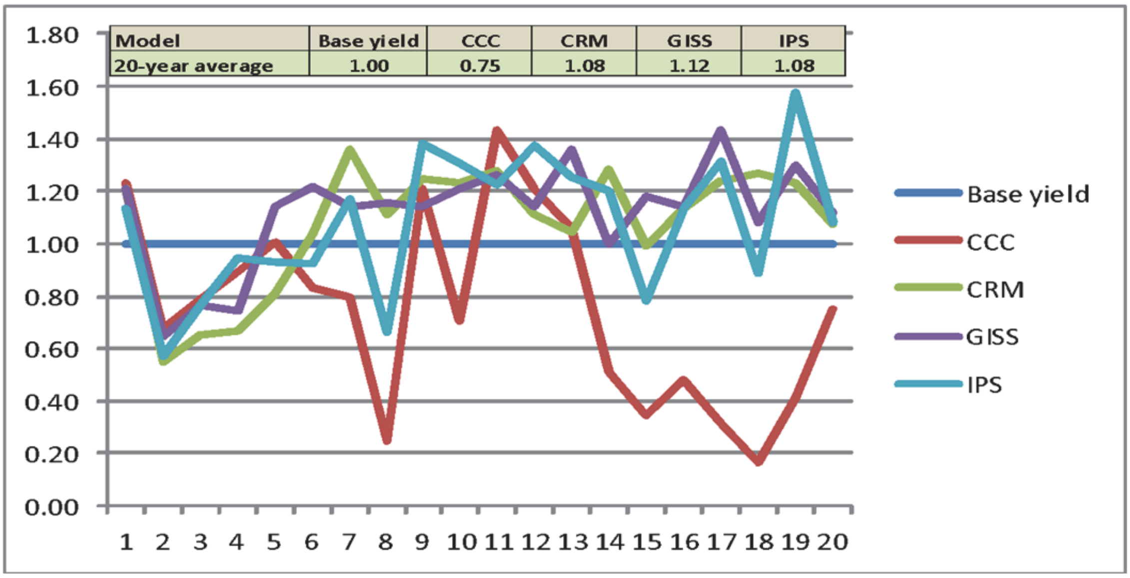

Figure 68: Projected yield (% of base yield) [2046-2065] for maize in Carolina area based on APSIM calculations

10.5.1.2 CCCT modelling results

When breaching a critical climate threshold, the impact on yield and/or quality can be either positive or negative. The critical crop climate thresholds for different crops were collected during a workshop which was attended by various role-players, including amongst others, industry experts and the case study farmer.

Table 77 shows the critical climate thresholds for maize, soybeans and sugar beans.

Table 77: Critical climate thresholds for maize, soybeans and sugar beans

Critical Climate Thresholds	Impact
Maize	
Tmnx < -5 °C in Dec	Negative
Tmxd > 35 °C for 3+ days Jan - Feb	Negative
Tmnd < 12 °C in Nov	Negative
Rainfall < 40 mm in Oct	Negative
Rainfall < 60 mm in Nov	Negative
Rainfall < 80 mm in Dec	Negative
Rainfall < 100 mm in Jan	Negative
Rainfall < 60 mm in Feb	Negative
Rainfall > 80 mm in Feb	Positive
Rainfall > 80 mm in Mar	Positive
Rainfall > 160 mm in Feb - Mar	Positive
Soybeans	
Tmnd < -5 °C Oct - Jan	Negative
Tmxd > 28 °C for 3+ days in mid Jan - Feb	Negative
Average temperature > 25 °C in Nov	Negative
Tmxd > 35 °C Jan	Negative
Tmxd > 30 °C with low RH in Jan	Negative
Rainfall < 50 mm in Nov	Negative
Rainfall < 80 mm in Dec	Negative
Rainfall < 100 mm in Jan	Negative
Rainfall < 60 mm in Feb	Negative
Rainfall < 40 mm Jan	Negative
Rainfall > 60 mm and < 150 mm in Feb	Positive
Rainfall > 60 mm and < 150 mm in Mar	Positive
Rainfall > 120 mm and < 300 mm in Feb - Mar	Positive
Sugar beans	
Tmnd < -5 °C Oct - Jan	Negative
Tmxd > 26 °C for 3+ days in mid Jan - Feb	Negative
Tmxd > 30 °C with high RH in Jan	Negative
Tmxd > 30 °C during Jan	Negative
Rainfall < 50 mm in Nov	Negative
Rainfall < 80 mm in Dec	Negative
Rainfall < 100 mm in Jan	Negative
Rainfall < 60 mm in Feb	Negative
Rainfall > 140 mm in Jan	Positive
Rainfall > 60 mm en < 100 mm in Feb	Positive
Rainfall > 60 mm en < 100 mm in Mar	Positive
Rainfall > 120 mm en < 200 mm in Feb - Mar	Positive

Source: Carolina workshop and expert group discussions (2012)

Refer to Table 77 and the Appendix for threshold penalty weights for yield and quality. The critical thresholds for wheat can be interpreted as follows:

Maize

- Tmnx < -5°C in Dec – daily minimum temperature of less than -5°C results in a -5% reduction in yield.
- Tmxd > 35°C for 3+ days Jan-Feb – maximum daily temperatures of 35°C for 3 days or more during January and February have a negative impact on yield (-5%).
- Tmnd < 12°C in Nov – minimum daily temperatures of less than 12°C negatively impact on yield (-1%).
- Rainfall < 40 mm in Oct – less than 40 mm of rain during the month of October has a negative impact on yield (-5%).
- Rainfall < 60 mm in Nov – less than 60 mm of rain during the month of November has a negative impact on yield (-5%).
- Rainfall < 80 mm in Dec – less than 80 mm of rain during the month of December has a negative impact on yield (-5%).
- Rainfall < 100 mm in Jan – less than 100 mm of rain during the month of January has a negative impact on yield (-15%).
- Rainfall < 60 mm in Feb – less than 60 mm of rain during the month of February has a negative impact on yield (-5%).
- Rainfall > 80 mm in Feb – more than 80 mm of rain during the month of February has a positive impact on yield (+10%).
- Rainfall > 80 mm in Mar – more than 80 mm of rain during the month of March has a positive impact on yield (+10%).
- Rainfall > 160 mm in Feb-Mar – more than 160 mm of rain during February and March has a positive impact on yield (+10%).

Soybeans

- Tmnd < -5°C Oct-Jan – daily minimum temperatures less than -5°C during October to January impact negatively on yield (-50%).
- Tmxd > 28°C for 3+ days in mid Jan-Feb – maximum daily temperatures in excess of 28°C for 3 days or more from mid-January to end of February have a negative impact on yield (-5%).
- Average temperature > 25°C in Nov – average temperature in excess of 25°C impacts negatively on yield (-10%).
- Tmxd > 35°C Jan – maximum daily temperatures in excess of 35°C during the month of January have a negative impact on yield (-10%).
- Tmxd > 30°C with low RH in Jan – maximum daily temperatures in excess of 30°C with low relative humidity during the month of January have a negative impact on yield (-10%).
- Rainfall < 50 mm in Nov – less than 50 mm of rain during the month of November has a negative impact on yield (-10%).
- Rainfall < 80 mm in Nov – less than 80 mm of rain during the month of December has a negative impact on yield (-10%).

- Rainfall < 100 mm in Jan – less than 100 mm of rain during the month of January has a negative impact on yield (-10%).
- Rainfall < 60 mm in Feb – less than 60 mm of rain during the month of February has a negative impact on yield (-10%).
- Rainfall < 40 mm in Jan – less than 40 mm of rain during the month of January has a negative impact on yield (-10%).
- Rainfall > 60 mm and < 150 mm in Feb – total rainfall of more than 60 mm but less than 150 mm during the month of February has a positive impact on yield (+5%).
- Rainfall > 60 mm and < 150 mm in Mar – total rainfall of more than 60 mm but less than 150 mm during the month of March has a positive impact on yield (+5%).
- Rainfall > 120 mm and < 300 mm in Feb-Mar – total rainfall of more than 120 mm but less than 300 mm during February and March has a positive impact on yield (+5%).

Sugar beans

- Tmnd < -5°C Oct-Jan – daily minimum temperatures less than -5°C during October to January impact negatively on yield (-50%).
- Tmxd > 26°C for 3+ days in mid Jan-Feb – maximum daily temperatures in excess of 26°C for 3 days or more from mid-January to end of February have a negative impact on yield (-10%).
- Tmxd > 30°C with low RH in Jan – maximum daily temperatures in excess of 30°C with low relative humidity during the month of January have a negative impact on yield (-10%).
- Tmxd > 30°C Jan – maximum daily temperatures in excess of 30°C during the month of January have a negative impact on yield (-10%).
- Rainfall < 50 mm in Nov – less than 50 mm of rain during the month of November has a negative impact on yield (-10%).
- Rainfall < 80 mm in Nov – less than 80 mm of rain during the month of December has a negative impact on yield (-10%).
- Rainfall < 100 mm in Jan – less than 100 mm of rain during the month of January has a negative impact on yield (-10%).
- Rainfall < 60 mm in Feb – less than 60 mm of rain during the month of February has a negative impact on yield (-5%).
- Rainfall > 140 mm Jan – total rainfall of more than 140 mm during the month of January has a positive impact on yield (+5%).
- Rainfall > 60 mm and < 100 mm in Feb – total rainfall of more than 60 mm but less than 100 mm during the month of February has a positive impact on yield (+5%).
- Rainfall > 60 mm and < 100 mm in Mar – total rainfall of more than 60 mm but less than 150 mm during the month of March has a positive impact on yield (+5%).

Table 78 shows the CCCT modelling results for five different GCMs for the present and intermediate future (2046-2065). The values are 20-year average values for the different models. All five models project an average increase in yield of approximately 10%. This result correlates to a large extent with the APSIM crop modelling results where three out of four models projected similar increases in average yield.

Table 78: CCCT modelling yield projections for maize in the Carolina area

CCC Pres	CCC Int	CRM Pres	CRM Int	ECH Pres	ECH Int	GISS Pres	GISS Int	IPS Pres	IPS Int	AVE Pres	AVE Int
10	12	9	12	10	12	10	12	10	12	**10**	**12**

Legend: Yield (% of base yield)

8	=	*90%*
9	=	*95%*
10	=	*100%*
11	=	*105%*
12	=	*110%*

10.5.2 Adaptation strategies available

Adaptation options for the Carolina area can be divided in two categories, namely changes in:

- Cropping systems
- Production practices

10.5.2.1 Cropping systems (crop rotation)

Current cropping systems are maize-soybeans-maize-soybeans and maize-sugar beans-maize-sugar beans combined with beef and mutton production. An alternative cropping system adapted for the region to be included in the integrated model is maize-maize-maize-maize (mono system).

10.5.2.2 Production practices

Adaptations options include conservation agricultural production practices versus conventional production practices.

10.5.2.3 Other adaptation strategies (not included in the model)

The following are a list of adaptation strategies debated in the group discussions, but not included in the integrated climate change model:

- Narrower row width (for better moist conservation)
- More short growers (access to genetics is a problem)
- Moisture management is very important
- Grain sorghum and sunflower production as alternatives (to be researched).

10.5.3 Financial vulnerability assessment results

Table 79 summarises the financial ratios of the different climate scenarios that were modelled.

Table 79: Financial assessment results for Carolina case study

	IRR	NPV	Cash flow ratio	Highest debt ratio	Highest debt
Base run	5%	8,810,019	134%	16%	(17,600,000)
CCC Present (1971 - 1990)	5%	9,642,378	134%	14%	(17,600,000)
CRM Present (1971 - 1990)	4%	2,951,799	130%	15%	(17,600,000)
ECH Present (1971 - 1990)	5%	10,191,475	135%	16%	(17,600,000)
GISS Present (1971 - 1990)	5%	9,164,137	134%	16%	(17,600,000)
IPS Present (1971 - 1990)	5%	6,971,932	133%	14%	(17,600,000)
CCC Intermediate (2046 - 2065)	6%	19,911,856	142%	14%	(17,600,000)
CRM Intermediate (2046 - 2065)	6%	25,137,859	146%	15%	(17,600,000)
ECH Intermediate (2046 - 2065)	6%	19,456,349	141%	14%	(17,600,000)
GISS Intermediate (2046 - 2065)	6%	22,965,632	144%	14%	(17,600,000)
IPS Intermediate (2046 - 2065)	6%	21,677,866	144%	14%	(17,600,000)
CM CCC Intermediate (2046 - 2065)	4%	(2,984,864)	123%	11%	(17,600,000)
CM CRM Intermediate (2046 - 2065)	7%	38,604,274	158%	12%	(17,600,000)
CM GISS Intermediate (2046 - 2065)	8%	44,826,148	162%	12%	(17,600,000)
CM IPS Intermediate (2046 - 2065)	7%	38,858,886	158%	12%	(17,600,000)
CCC Intermediate (2046 - 2065) Adaptations	9%	51,182,114	160%	12%	(17,600,000)
CRM Intermediate (2046 - 2065) Adaptations	9%	56,165,104	165%	13%	(17,600,000)
ECH Intermediate (2046 - 2065) Adaptations	9%	50,892,980	160%	11%	(17,600,000)
GISS Intermediate (2046 - 2065) Adaptations	9%	52,960,065	164%	12%	(17,600,000)
IPS Intermediate (2046 - 2065) Adaptations	9%	52,083,487	164%	12%	(17,600,000)
CM CCC Intermediate (2046 - 2065) Adaptations	9%	46,472,120	157%	5%	(17,600,000)
CM CRM Intermediate (2046 - 2065) Adaptations	13%	104,039,509	194%	5%	(17,600,000)
CM GISS Intermediate (2046 - 2065) Adaptations	14%	113,484,946	198%	5%	(17,600,000)
CM IPS Intermediate (2046 - 2065) Adaptations	13%	103,346,315	193%	7%	(17,600,000)
Colour code legend:					
Base run					
CCCT technique for different GCM's - Present climate - static runs					
CCCT technique for different GCM's - Intermediate climate - static runs					
Apsim technique for different GCM's - Intermediate climate - static runs					
CCCT technique for different GCM's - Intermediate climate - adaptation options included					
Apsim technique for different GCM's - Intermediate climate - adaptation options included					

The modelling results for Carolina case study (20% start-up debt ratio) can be interpreted as follows:

- An IRR of 5% is projected under the present climate scenario. When intermediate climate scenarios are imposed on the model, the IRR increases to respectively 6% for the CCCT model and 7% for the ACM model. The inclusion of adaptation strategies tends to have a positive effect on profitability with the IRR increasing to 9% (CCCT) and 12% (ACM).
- A NPV of R7.8 million is projected under present climate conditions. For intermediate climate scenarios a NPV of R21.8 million for the CCCT model and R29.8 million for the ACM model are projected. Both these projections are positively influenced by the inclusion of adaptation strategies in the model. A NPV of R52 million is projected for the CCCT model and a NPV of R91 million for the ACM model. The impact of intermediate climate projections tends not to have a negative impact on profitability and return on investment. The inclusion of adaptation

strategies can ultimately put the farming system in a better position than the current conventional system under present climate scenarios.

- A cash flow ratio of 133% is projected under present climate conditions. This ratio, however, declines marginally to 143% (CCCT model) and 150% (ACM) when intermediate climate scenarios are imposed on the model. Both models show an improvement in cash flow ratio when adaptation strategies are included in the model (CCCT model = 163%, ACM model = 186%). The adoption of conservation agriculture principles seems to contribute to profitability in the Carolina area.
- A highest debt ratio of 15% is projected under present climate scenarios. When intermediate climate scenarios are imposed on the model, the highest debt ratio increases to 14% (CCCT model) and 12% (ACM model). The inclusion of adaptation strategies positively influences the highest debt ratio to 12% and 5% for the CCCT model and the ACM model respectively. All these ratios are well within acceptable financing norms.
- A highest debt level of R17.6 million is projected under present climate conditions. This is the starting debt level for all scenarios and also the highest for the 20-year projection period.
- Similar to the Moorreesburg case study, the Carolina case study farm already converted to the more sustainable cropping system. The best adaptation strategy for the region is also to convert to conservation agriculture.

CHAPTER 11 : LESSONS LEARNT FROM THE CASE STUDY AREAS ON ACHIEVING EFFECTIVE KNOWLEDGE DISSEMINATION

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11.1 Lessons learnt from information sessions

11.1.1 Moorreesburg Farming Area

This meeting was held on 20/04/2015 and was attended by members of the farming community, WC Department of Agriculture, Agri-business and an NGO.

The focus of the research for this region was wheat and the results of the research were presented. For the Moorreesburg area, the results show that from a financial point of view, a slight decrease in profitability can be expected, although farming operations will still be profitable. Farmers with high debt levels ratios will be more financially vulnerable than those with low debt levels.

Adaptations mentioned and approved by the audience were:

- **Diversification** –alternative crops/livestock – using Medics spp as cover crop, keeping sheep to graze and as a hedge during dry years. Also some evidence of using any available water for high value crops (in terms of net rand value, such as vineyard root stocks, OR in terms of soil improvement value, such as Fava beans and other legumes)
- Applying **conservation agriculture** principles – minimal/no till planting, not burning or overgrazing residue.

Lessons that emerged:

- Farmers who do not diversify run a higher risk during dry years, but there is evidence that larger farms that practice exclusive wheat production can make enough profit during good years to see them through the poorer years.
- It was felt that for wheat farmers to survive in the future would require them to employ conservation agriculture principles especially minimum till, and that although the capital cost of machinery was considerable, adaptations to existing equipment could be made resulting in considerable saving.
- It was clear that the farmers appreciated the efforts of the team and were grateful for the information provided.
- Although not many farmers were present at the meetings, it was expressed that word amongst the farmers travelled fast and that the efforts of the provincial department

facilitated the spread of adaptation principles and uptake of conservation agriculture especially.

11.1.2 Vredendal (Lower Oliphant's River Water Users Association)

This meeting was held on 21/04/2015 and was attended by members of the farming community, WC Department of Agriculture, Agri-business, LORWUA and Department of Water and Sanitation.

The focus of the research for this region was grapes, including table, wine and dried, and the results of the research were presented. For the Lower Oliphant's River region, the results show that from a financial point of view a decrease in profitability can be expected. Farmers with high debt levels ratios will be more financially vulnerable than those with low debt levels.

- Climate data from four GCMs was applied in the APSIM modelling. All the GCMs project a 20-year average decrease in yield, varying from 9% to 18%.
- Data from five GCMs was applied in the CCCT model. All five models project a decrease in yield for wine grapes, table grapes and raisins and a decrease in quality for table grapes.
- A 10% average annual increase in irrigation requirements is projected for table grapes for intermediate future climates in order to obtain the same yield as with present climates. For wine grapes and raisins, an 11% average increase in irrigation requirements is projected.
- Both climate change financial modelling techniques (APSIM crop modelling and CCCT modelling technique) indicate that intermediate climate scenarios from five different GCMs pose a threat to the financial vulnerability of farming systems in the LORWUA grape producing area.

Several **adaptation strategies** to counter the impact of climate change on financial vulnerability were used by farmers. These strategies include:

- Shift wine grape cultivars towards cultivars that are more tolerant towards projected climate change
- Increase raisin and table grape production
- Install **shade nets** over table grapes production areas.

The above adaptation strategies all seem to lessen the impact of climate change on financial vulnerability to a certain extent and seem worth further investigation.

Adaptation strategies not included in the model we used, but suggested to the farming group, included:

- Irrigation at night to save water
- Plastic or mulch cover to conserve moisture
- Soil preparation and site selection for future plantings in order to ensure optimum production – rather scale down and eliminate marginal blocks.

Lessons that emerged:

- Climate information *per se* was only helpful if it presented farmers with the specific detail they required. For example, with grapes, the maximum temperatures were not as limiting as the actual diurnal range experienced, in this case anything less than 10 degrees between maxima and minima on a daily basis, compromised quality.
- The availability of irrigation water is critical to this industry and the projections of flow into and from the Clanwilliam dam and canal system are of paramount importance. The impact of the pending raising of the dam wall is being eagerly anticipated but is slightly offset by the deterioration of the canal system
- Shade nets are a big capital expense and farmers felt that (as with crop insurance) the expense was not always justified.

11.1.3 Hoedspruit (Blyde River Irrigation Scheme/Water Users Association)

This meeting was held on 29/4/2015 and was attended by farmers and a representative from SubTrop, the marketing company representing subtropical fruit and nuts.

The focus of the research for this region was mangoes and citrus and the results of the research were presented. For the Blyde River irrigation area, the results show that from a financial point of view a slight decrease in profitability can be expected, although farming operations will still be profitable. Farmers with high debt levels ratios will be more financially vulnerable than those with low debt levels.

- Empirically downscaled climate values of five GCMs were applied in the CCCT model. Although, only one out of five GCMs projects a decrease in yield for citrus, all models project a negative impact on quality. For mangoes the models project a negative impact on both yield and quality.
- An 8% average annual increase in irrigation requirements is projected for both citrus and mangoes for intermediate future climates in order to obtain the same yield as with present climates.
- The projection of the Blydepoort Dam level was done by UKZN, using the ACRU model. All indications are that the availability of irrigation water for the Blyde River WUA area irrigators (in terms of quota consistency) will not be negatively affected by the projected climate scenarios.
- The CCCT modelling results indicate that intermediate climate scenarios from different GCMs pose a threat to the financial vulnerability of farming systems in the Blyde River mango and citrus producing area.

An **adaptation strategy** to counter the impact of climate change on financial vulnerability is to install **shade nets** over mango and citrus production areas. The installation of shade nets proves to lessen the impact of climate change on financial vulnerability to a certain extent and seems worthwhile to investigate further.

Adaptation strategies not included in the model, but suggested to farmers, include:

- Mulching cover to conserve moisture
- More effective management of irrigation systems
- Cultivar development to increase natural heat resistance

Lessons that emerged:

- Hail storms have increased in frequency in the area and just prior to our meeting a severe, but small storm had devastated a mango orchard, which had, ironically, been covered by shade netting. The presence of the netting had reduced the damage, but the farmer concerned was undecided whether to replace the netting due to the capital expense. The question to the team was whether climate change was likely to result in a greater likelihood of hail. This was not in our models and needs to be considered in the future.
- The availability of irrigation water is critical to this industry and the projections of flow into and from the Blyde dam and pipe system are of paramount importance. The demand lower downstream has already impacted on the river flow, but the BRWUA community were assured that their supply from the dam would be maintained. The reality is that regardless of rainfall, they are dependent on irrigation and anything that threatens that source is a risk.

11.1.4 Carolina Farming Area

This meeting was held on 30/4/2015 at the Local department of Agriculture offices in Carolina. Though none of the original case study farmers (who were invited) chose to attend, the meeting was crowded with around 50 small scale farmers invited in collaboration with the department and a former development agent from Grain SA.

The focus of the research for this region was maize and soya beans, and the results of the research were presented. For the Carolina-Middelburg area, the results show that from a financial point of view no change or possibly an increase in profitability can be expected. Farmers with high debt levels ratios will be more financially vulnerable than those with low debt levels.

- Climate data from four GCMs was applied in the APSIM modelling to project intermediate future yield for maize. One model projects an average decrease of 25% while three models project an increase in average yield of approximately 10%.
- Data from five GCMs was used in CCCT modelling. All five models project an average increase in yield of approximately 10%. This result correlates to a large extent with the APSIM crop modelling results where three out of four models projected similar increases in average yield.
- Both climate change financial modelling techniques (APSIM crop modelling and the CCCT modelling technique) indicate that intermediate climate scenarios from five different GCMs pose no threat to the financial vulnerability of farming systems in the Carolina summer rainfall dryland area. Please note that abnormal climate events like storms, hail, etc. were not included in the climate modelling.

Adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:

- Cropping systems (crop rotation maize-soybeans-maize)
- Production practices (conservation agriculture).

The above adaptation strategies seem to not only counter the impact of climate change, but to positively impact on profitability.

Lessons that emerged:

- There is a major difference between capacity, technical know-how and resource availability between the commercial farmers and the small scale farmers. In dealing with both groups it became clear that their risk exposure is much more than climate, in both cases, but that the small scale farmers need much more support in terms of advice regarding crop and cultivar choice, weather information and drought warnings. The commercial farmers were already practising precision agriculture, whereas the small scale famers who barely understood English or Afrikaans were seriously disadvantaged when it came to communication dissemination.
- There seems to be very little collaboration between the two groups, which hinders development and cross fertilisation of ideas and adaptation options.
- Coal mining and land redistribution are seen as important threats to successful agriculture in this area, particularly with its very high soil fertility and yield potential, and thus a threat to food security.
- Soya is seen as a very viable alternative to maize when the latter's price decreases. Farmers see the soya price as more profitable, generally.

11.2 Scientific communication

11.2.1 Conference papers and posters

- Dr Oosthuizen presented a paper at SANCID 2012 Symposium South African National Committee on Irrigation and Drainage "Modelling the Financial Vulnerability of Farming Systems to Climate Change" 20-23 Nov 2012 Alpine Heath Drakensberg
- International Conference on Regional Climate – CORDEX 2013 was held 4-7 November 2013 in Brussels, Belgium, Dr Peter Johnston presented "Using downscaled climate change scenarios to model the impact on farming systems from a financial vulnerability point of view", which was enthusiastically received by the audience.
- Dr Oosthuizen delivered a paper at the International Water Association conference in Mexico.: Oosthuizen, H.J., Louw, D.B., Schulze, R.E., Johnston, P.J., Lombard, J.P. and Backeberg, G.R. Modelling the impact of climate on the financial vulnerability of farms – a Hoedspruit irrigation farm case study. Paper presented at IWA Water Energy and Climate Conference 21 -23 May 2014, Mexico.

- Dr Oosthuizen is due to present a poster at The International Crop Modelling Symposium, iCROPM2016 in Berlin in April 2016: Crop Critical Climate Threshold (CCCT) modelling as an alternative modelling technique to determine the financial impact of climate change on crop yield and quality – a South African case-study" in Session III – Crop modelling for risk/impact assessment.

11.2.2 Scientific Articles

- Submitted to Agrekon for publication: Oosthuizen et al.: Modelling the impact of climate on the financial vulnerability of farms – a Moorreesburg dry land case study.
- In preparation, revision: Johnston and Kloppers: Climate risk, wheat yield variation and ocean-climate teleconnections: Options for adaptation – a Swartland case study.
- It is expected to produce at least one more paper on the use of thresholds as an adjunct for crop modelling.

11.2.3 Popular Articles

- An article on the project published in Nov/Dec 2015 issue of Water Wheel.
- Project website: www.csag.uct.ac.za/wrc/a4a.

11.2.4 Farmer Workshops

Workshops with stakeholders, including farmers and other stakeholders were held on 12 occasions during the project (3 per case study area). At each workshop the project aims, progress and results were presented according to the project's progress. Climate change impacts, vulnerabilities and adaptations were presented and discussed.

A further 6 meetings were held with crop and irrigation experts and this were designed to feed into site selections and the modelling aspects of the project.

Through the presentations and ensuing discussions a very valuable exchange of information was attained. As an additional consequence further presentations were given by invitation to government departments, such as Agriculture and Water, both provincial and national.

In this way, the message of climate change, the impacts and responses has been, and continues to be, disseminated.

CHAPTER 12 : CONCLUSIONS AND RECOMMENDATIONS

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12.1 Key findings

The modelling results were analysed in terms of climate change impact on:

- Quality and yield of crops (APSIM and CCCT modelling results).
- Crop irrigation requirements (for irrigation crops only – SAPWAT3 modelling results).
- The availability of irrigation water requirements (only for Blyde River WUA – ACRU modelling results).
- Financial vulnerability assessment results (for current and intermediate future climates).

12.1.1 LOWER OLIFANTS IRRIGATION SCHEME (LORWUA)

The modelling results for the LORWUA case studies can be summarised as follows:

- Climate data from four GCMs was applied in the APSIM modelling. All the GCMs project a 20-year average **decrease in yield**, varying from 9% to 18%.
- Data from five GCMs was applied in the CCCT model. All five models project a **decrease in yield for wine grapes, table grapes and raisins and a decrease in quality for table grapes**.
- A 10% average annual **increase in irrigation requirements** is projected for table grapes for intermediate future climates in order to obtain the same yield as with present climates. For wine grapes and raisins, an 11% average increase in irrigation requirements is projected.
- The ACRU was not included in the integrated climate change modelling for LORWUA due to various reasons.
- Both climate change financial modelling techniques (APSIM crop modelling and CCCT modelling technique) indicate that intermediate climate scenarios from five different GCMs pose **a threat to the financial vulnerability of farming systems** in the LORWUA grape producing area.
- Several adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:
  - Shift wine grape cultivars towards cultivars that are **more tolerant** towards projected climate change
  - **Increase raisin and table grape** production
  - Install **shade nets** over table grapes production areas.

- The above adaptation strategies all seem to lessen the impact of climate change on financial vulnerability to a certain extent and seem worth further investigation.
- Adaptation strategies not included in the model, but worth investigation, include:
  - Irrigation at night to save water
  - Plastic or mulch cover to conserve moisture
  - Soil preparation and site selection for future plantings in order to ensure optimum production – rather scale down and eliminate marginal blocks.

12.1.2 BLYDE RIVER

The modelling results for Blyde River WUA case studies can be summarised as follows:

- Statistically downscaled climate values of five GCMs were applied in the CCCT model. Although, only one out of five GCMs projects a decrease in yield **for citrus, all models project a negative impact on quality**. For **mangoes the models project a negative impact on both yield and quality**.
- An 8% average annual **increase in irrigation requirements** is projected for both citrus and mangoes for intermediate future climates in order to obtain the same yield as with present climates.
- The projection of the Blydepoort Dam level was done by UKZN, using the ACRU model. All indications are that the availability of **irrigation water** for the Blyde River WUA area irrigators (in terms of quota consistency) **will not be negatively affected** by the projected climate scenarios.
- The CCCT modelling results indicate that intermediate climate scenarios from different GCMs pose **a threat to the financial vulnerability of farming systems** in the Blyde River mango and citrus producing area.
- The impact of intermediate climate scenarios on financial vulnerability will be more severe on farming systems that are highly geared (high debt levels).
- An adaptation strategy to counter the impact of climate change on financial vulnerability is to install **shade nets** over mango and citrus production areas. The installation of shade nets proves to lessen the impact of climate change on financial vulnerability to a certain extent and seems worthwhile to investigate further.
- Adaptation strategies not included in the model, but worth investigation, include:
  - Mulching cover to conserve moisture
  - More effective management of irrigation systems
  - Cultivar development to increase natural heat resistance

12.1.3 MOORREESBURG

The modelling results for the Moorreesburg case study can be summarised as follows:

- Climate data from four GCMs were applied in the APSIM modelling to project intermediate future yield for wheat. The different GCM projections (20-year average) vary from a decrease of 4% to an increase of 4% compared to present yield. The **overall average yield between the four models equals the average present yield**.

- Data from five GCMs was used in CCCT modelling. Despite relatively small variances between the different GCM projections, **no major changes in yield**, from the present to the intermediate future, are projected. This result correlates with the APSIM crop modelling results, which increases confidence in the CCCT modelling technique.
- Both climate change financial modelling techniques (APSIM crop modelling and CCCT modelling technique) indicate that intermediate climate scenarios from different GCMs pose a very **marginal threat to the financial vulnerability** of farming systems in the Moorreesburg dryland wheat producing area.
- The impact of intermediate climate scenarios on financial vulnerability will be more severe on farming systems that are highly geared (high debt levels).
- Adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:
  - **Cropping systems**
  - **Production practices.**
- The above adaptation strategies seem not only to counter the impact of climate change, but to positively impact on profitability.

12.1.4 CAROLINA

The modelling results for the Carolina case study can be summarised as follows:

- Climate data from four GCMs was applied in the APSIM modelling to project intermediate future yield for maize. One model projects an average decrease of 25% while three models project an increase in average yield of approximately 10%.
- Data from five GCMs was used in CCCT modelling. All five models project an **average increase in yield of approximately 10%.** This result correlates to a large extent with the APSIM crop modelling results where three out of four models projected similar increases in average yield.
- Both climate change financial modelling techniques (APSIM crop modelling and the CCCT modelling technique) indicate that intermediate climate scenarios from five different GCMs pose **no threat to the financial vulnerability** of farming systems in the Carolina summer rainfall dryland area. Please note that abnormal climate events like storms, hail, etc. are not included in the climate modelling.
- Adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:
  - **Cropping systems**
  - **Production practices**.
- The above adaptation strategies seem to not only counter the impact of climate change, but to positively impact on profitability.

Figure 69 illustrates the mapping of selective case studies included in the study, viz. LORWUA, Blyde River WUA, Moorreesburg and Carolina. The map shows the location of the case studies and the financial vulnerability towards projected future climates. The colour coding legend indicates the degree of vulnerability to climate change, i.e. pink – marginally vulnerable, red – vulnerable, light green – marginally less vulnerable than present scenario, and green – less vulnerable than present scenario.

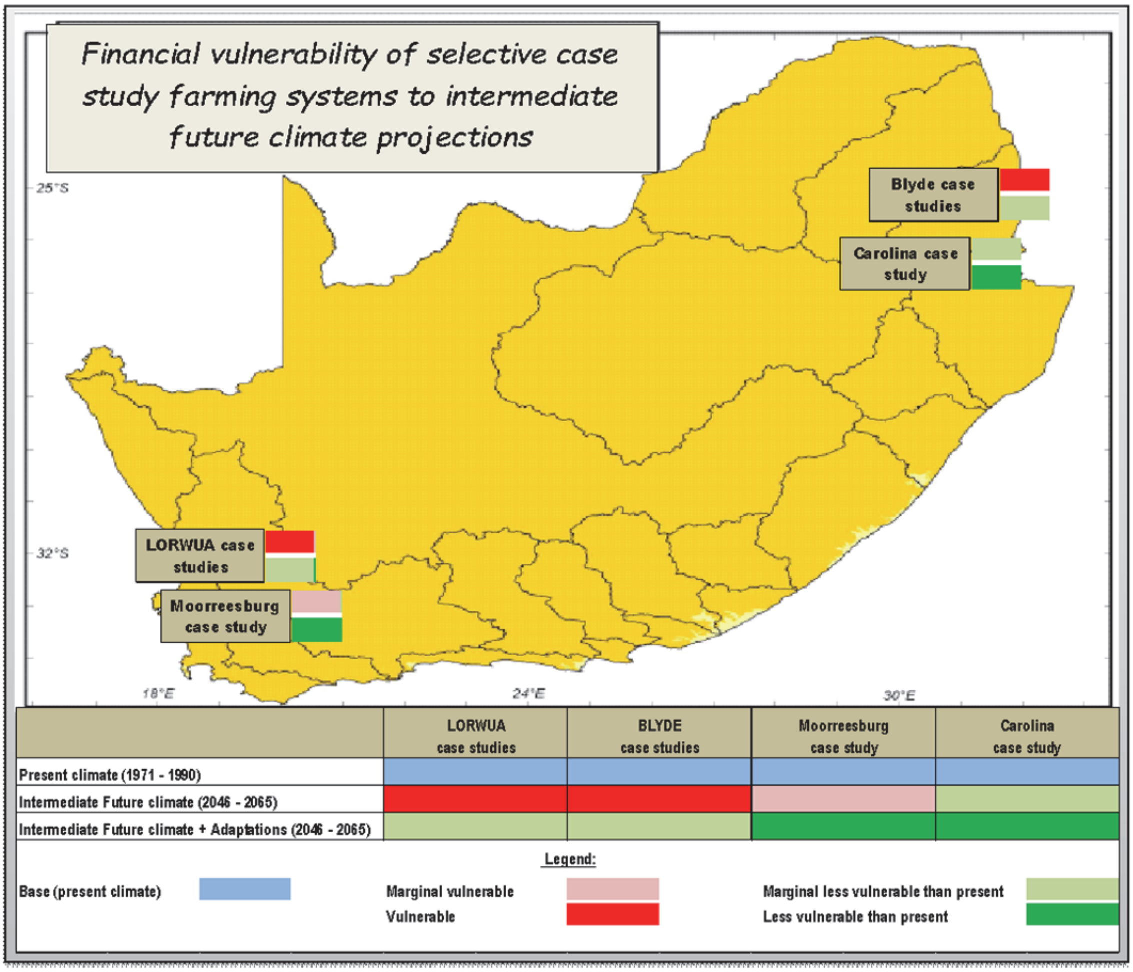

Figure 69: Mapping of selective case studies and their financial vulnerability to projected future climates

The LORWUA and Blyde River WUA are more vulnerable to climate change than Moorreesburg and Carolina areas.

12.2 Conclusions

This study sets out to develop an integrated climate change model to determine the financial vulnerability of different farming systems to climate change. The approach in this study successfully links a series of models, viz. empirically downscaled GCMs, whole-farm DLP model, APSIM and CCCT crop modelling techniques, ACRU hydrological model, SAPWAT3 crop irrigation requirements model and a Financial Vulnerability Assessment model.

Empirically downscaled climate data from five GCMs, all of which were applied in the IPCC's (2007) Fourth Assessment Report [AR4], served as basis for the APSIM, CCCT, ACRU and SAPWAT3 models. The modelling output from these models feed into the DLP model through a series of interphases. These modelling interphases are unique and for the first time successfully link the APSIM, CCCT, ACRU and SAPWAT3 model outputs to the DLP model at micro/farm level. The interphase that links the DLP model output to the financial assessment model is also a new contribution.

The newly developed CCCT modelling technique proves to be a useful tool to determine the impact of projected climates on crop yield and quality. The APSIM crop modelling results and CCCT modelling results demonstrate similar trends for the two dryland case study areas, i.e. Moorreesburg and Carolina and also for the prototype APSIM model for grapes in LORWUA area. The similar trends in the results prove that, where APSIM crop models are not available, the CCCT modelling technique is suitable to quantify the impact of climate change on crop yield and quality. When interpreting crop modelling results the emphasis should be on changing trends in yield and quality projections rather than on absolute values.

No APSIM crop models exist for citrus and mangoes in the Blyde River WUA producing area and only the CCCT modelling technique could be applied to model the impact of projected climates on crop yield and quality. The crop modelling results and expected impact of projected climates on crop yield and quality were validated by expert opinions. A unique feature of the CCCT modelling technique is its ability to model the impact of projected climate change on both crop yield and quality as oppose to APSIM and other crop models that only model impact on yield. The value of this feature is underlined in the Blyde River WUA area for citrus where the projected impact of climate change will be more severe on quality than on yield.

The Financial Vulnerability Assessment model quantifies the economic and financial impact of changes in crop yield and quality as a result of changing climates. The model criteria provide for economic viability criteria (IRR and NPV) as well as for financial feasibility criteria, i.e. cash flow ratio and debt ratio, over a twenty year planning horizon. Not only does the model provide an accurate tool to quantify the financial impact of changing climates on farm level, but is also very useful to determine the economic viability and financial feasibility of adaptive strategies.

The empirically downscaled climate data from five GCMs applied in this study underline the correctness of those early predictions in the 1980s, that the world would become warmer. Increases in temperature for the intermediate future are projected for all four case study areas, varying from 1°C to 2.5°C with the highest projected increases (1.5°C to 2.5°C) in respect of the Carolina area.

This study clearly indicates the importance of biophysical factors and the capacity to adapt to climate change. The Moorreesburg as well as the Carolina case study results indicated that changing to conservation agriculture (more resilient cropping system) improves the adaptive capacity of the farming systems. In the Blyde River WUA case study, shade netting improves the biophysical adaptive capacity of mangoes and citrus (in terms of yield and quality). The LORWUA case study showed similar results for table grapes under shade nets.

For the Carolina case study, all five CCCT models project an average increase in maize yield of approximately 10%. This result correlates to a large extent with the APSIM crop modelling results where three out of four models projected similar increases in average yield and the findings of Du Toit et al. (2002). The study results show that, similar to Nelson et al. (2009), some regions will gain due to the impact of climate change and some will lose, e.g. Blyde River WUA area (mangoes and citrus). The results of the study echoed those of Andersson et al. (2009), indicating that impacts of a changing climate could be considerable. Different regions of the country will likely be affected in many different ways. For this reason alone local scale analyses are needed to assess potential impacts (showing the importance of a micro scale integrated climate change modelling approach).

As already been pointed out by various studies, this study also clearly illustrates that, without the capacity to implement adaptation strategies such as conservation agriculture (Moorreesburg and Carolina), shade netting (LORWUA and Blyde River WUA) and structural changes to land use patterns (LORWUA), the farming systems of the selected case studies will financially be extremely vulnerable to climate change (as indicated by reduction in IRR and NPV, higher debt ratios and decreasing cash flow ratios).

The high capital cost of certain adaptive strategies, e.g. shade nets would not be affordable to all farmers, especially on smaller operations and those that are highly geared. Systematic and timely implementation over a longer period of time can reduce the pressure on cash flow. This once again highlights the importance of strategic and long term planning, in which Government also could have a role to play. Timely research efforts should be implemented to determine the most appropriate adaptation strategies and communicate research findings on an ongoing basis to all role-players. For the sake of food security, regional socio-economic welfare, protection of much needed export earnings and to preserve land resources for generations to come, it may be worthwhile to investigate subsidies or green box grants in some instances to assist farmers to timeously adapt to projected climate change. The Scottish Government, for instance, has developed a policy initiative, “Farming for a better climate (FFBC)”, with the specific aim of mitigating climate change in agriculture. The FFBC has a communication programme that encourages farmers to adopt efficiency measures that reduce emissions, while at the same time having an overall positive impact on business performance. The purpose of such a body could not only be to identify and research the best practices, etc. but also to serve as communication channel to inform and keep role-players up to date with latest research, developments, etc.

This study shows the importance of research for cultivar development, e.g. short grower cultivars (e.g. maize) for the summer rainfall area and more heat resistant cultivars for the Blyde River WUA area (citrus and mangoes). It also points out the importance of locality for future plantings and the projected switch to cultivars that are more tolerant to increasing temperatures (e.g. wine grape cultivars in the LORWUA area). The different results in terms of yield and quality projections for the four case study areas emphasise the importance of locality specific climate change research. In the summer rainfall area, for example, an increase in yield is projected for maize (Carolina case study) compared to a projected decrease in yield and quality for citrus and mangoes (Blyde River WUA area). The impact of projected climate change on yield and quality also differs in the winter rainfall area; the LORWUA grape producing area seems more vulnerable than the dryland wheat producing area of Moorreesburg.

In terms of vulnerability, the sensitivity in Moorreesburg is relatively low compared to, e.g. the Blyde River WUA farming systems where adaptation strategies (shade nets) are more costly than adaptation strategies in Moorreesburg (converting to conservation agriculture and alternative cropping systems). The return on investment for implementing adaptation strategies is also more rapid for Moorreesburg compared to the Blyde River WUA area.

This study points out that citrus and mangoes in the Blyde River WUA area are extremely vulnerable to increasing temperatures. This is because prices of perishable produce depend to a large extent on quality grading and market requirements. The Moorreesburg and Carolina dryland mixed crop and livestock farming systems are less vulnerable.

This study achieved its primary and secondary objectives by filling the identified gap in climate change research, i.e. integrated economic modelling at micro or farm level and thereby making a contribution to integrated climate change modelling.

12.3 Gaps in Knowledge and Recommendations

During this project extensive validation of climate models have been undertaken and while GCMs generally capture present climatic conditions adequately there are differences between the outputs of the various GCMs and especially individual events and extreme conditions are not captured as well as one would like. It is for this reason that ratio changes between future climatic conditions and present climatic conditions are made, rather than evaluating absolute outputs from the climate models. Uncertainty and the way in which to express it remain a challenge in climate change impact studies. At the time this project commenced the GCMs were the only credible tools that were available for climate change impact studies. Subsequently various downscaling attempts have been made, but the validation of these were not available for input in this project (Schulze, 2014; Johnston, 2014). Future research should take updated models into account.

Recommendations from the experiences of the project team and the stakeholders include:

- A limiting factor was the availability of suitable CC data (a sense that the models used were not fully representative of the spread)
- Would the situation have been different with another (set of) model(s)?
- Crops in different regions may have shown different results.

- Other crops need to be investigated, as well as livestock and pasture.
- Farmers were eager to be involved and made valuable contributions.
- Agro-business and other value chain actors need to be actively drawn into the engagement.

A number of recommendations for further research are presented as outcomes of the interaction with users:

- In terms of the CCCT modelling technique the critical climate thresholds for crops need to be further researched and refined. It could be worthwhile for future research to merge existing climate and existing yield data sets and deriving a variance-covariance matrix to test the assumption of independence and capture the interdependence of climate effects.
- The financial vulnerability assessment of farming systems to climate change should be executed throughout all production regions in South Africa. This will provide policy makers, industry leaders, input suppliers and researchers with valuable information for future strategizing.
- Adaptation options identified in this study need to be further researched and validated. Research should focus on a number of items, viz. cropping patterns, production practices, cultivar development, optimal irrigation equipment and practices, moisture conservation techniques and shade nets. Within the scope of this project it was not possible to do long term trials.
- The development of crop models should be a high priority on the research agenda. Models that cover more crops and more accurate models will make a significant contribution to the integrated climate change impact modelling framework that was developed through this study.
- Role players stressed the important role that Government could play in research and communication with regard to climate change research, adaptation treatments and implementation of adaptive interventions.

Impacts further along the value chains are inevitable and need to be addressed. It is also important that climate change impacts are not just focused on the production side and are carefully considered and studied. The communication of the impacts will need to consider all the role players in the value chain and as in the case of the existing project not just focused on the case study areas.

REFERENCES

ABOUATALLAH, A., SALGHI, R., FADL, A., HAMMOUTI, B., ZARROUK, A., ATRAOUI, A. and GHNIZAR, Y. 2012. Shading Nets Usefulness for Water Saving on Citrus Orchards under Different Irrigation Doses. *Current World Environ, Vol. 7 (1).*

ADGER, W.N. 1996. *Approaches to vulnerability to climate change*. Centre for Social and Economic Research on the Global Environment Working Paper GEC 96-05. University of East Anglia, Norwich, UK.

ADGER, W.N., 2003. Social aspects of adaptive capacity. In: Smith, J.B., Klein, R.J.T., Huq, S. (Eds.), Climate Change, Adaptive Capacity and Development. Imperial College Press, London.

ADGER, M. and KELLY, N. 1999. Social Vulnerability to Climate Change and the Architecture of Entitlements. *Mitigation and adaptation strategies for global change, Vol. 4 (3-5).*

AJETOMOBIA, J., ABIODUNB, A. and HASSAN, R.M. 2011. Impacts of Climate Change on Rice Agriculture in Nigeria. *Tropical and Subtropical Agroecosystems, Vol. 14 (2)*.

ALLEN, R.G., PEREIRA, L.S., RAES, D. and SMITH, M. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements – FAO Irrigation and drainage paper 56, FAO, Rome.

ANDERSSON, L., WILK, J., GRAHAM, P. and WARBURTON, M. 2009. Local Assessment of Vulnerability to Climate Change Impacts on Water Resources and Suggestions of Adaptation Strategies in the Mhlwazini/Bergville Area (Upper Thukela River basin, South Africa). Swedish Meteorological and Hydrological Institute, Norrköping, Sweden.

ARRHENIUS, S. 1896. On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground. *Philosophical Magazine and Journal of Science Series 5, Vol. 41*.

BACHELT, D., LENIHAN, J.M., DALY, C. and NEILSON, R.P. 2000. Interaction between Fire, Grazing and Climate Change at Wind Cave National Park, SD. *Ecological Modelling*, 134: 229-244.

BACKEBERG, G.R. 1984. Besproeiingsontwikkeling in die Groot-Visriviervallei. Ongepubliseerde MSc (Agric)-verhandeling. Universiteit van Pretoria, Pretoria.

BASHER, R. and BRICENO, S. 2005. Global warming and African climate change: a reassessment. *Climate Change and Africa*. Low, P.S. (ed). Cambridge University Press: Cambridge.

BELETSE Y.G., W. DURAND, C. NHEMACHENA, O. CRESPO, W.A. TESFUHUNEY, M.R. JONES, M.Y. TEWELDEMEDHIN, S.M. GAMEDZE, P.M. BONOLO, S. JONAS, S. WALKER, P. GWIMBI, T.N. MPUISANG, D. CAMMARANO, R.O. VALDIVIA. 2015, Projected Impacts of Climate Change Scenarios on the Production of Maize in Southern Africa: An Integrated Assessment Case Study of the Bethlehem District, Central Free State, South Africa. Part 2, Section I, Chapter 4, in : Daniel Hillel & Cynthia Rosenzweig (Editors). Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project Integrated Crop and Economic Assessments.

BENHIN, J.K.A. 2008. South African crop farming and climate change: An economic assessment of impacts. *Global Environmental Change, Vol. 18.*

BEUKES, D., DE VILLIERS, M., MKHIZE, S., SALLY, H. and VAN RENSBURG, L., 2003. The Bloemfontein Declaration on Water and Nutrient Conservation Technologies. *Proceedings, Symposium and Workshop on Water Conservation Technologies for Sustainable Dryland Agriculture in sub-Saharan Africa*. Bloemfontein, RSA.

BHARWANI, S., BITCHELL, M., DOWING, T.E., NEW, M., WASHINGTON, R. and ZIERVOGEL, G. 2005. Multi-agent modelling of climate change outlooks and food security on a community garden scheme in Limpopo, South Africa. *Philosophical Transactions of the Royal Society*, 360, 2183-2194.

BLAIKIE, P., CANNON, T., DAVIS, I. and WISNER, B. 1994. At Risk: Natural Hazards, People's Vulnerability and Disasters. London: Routledge.

BLIGNAUT, J., UECKERMANN, L. and ARONSON, J. 2009. Agriculture production's sensitivity to changes in climate in South Africa. *South African Journal of Science, Vol. 105 (1-2).*

BOHLE, H.G. 2001. Vulnerability and Criticality: Perspectives from social geography. *IHDP Update, Newsletter of the International Human Dimension Programme on Global Environmental Change* (IHDP) 2, 1-4.

BOHLE, H.G., Downing, T.E. and Watts, M.J.1994. Climate change and social vulnerability: Toward a sociology and geography of food insecurity. *Global Environmental Change* 4(1), 37-48.

BOKO, M., NIANG, I., NYONG, A., VOGEL, C., GITHEKO, A., MEDANY, M., OSMAN-ELASHA, B. TABO, R. and YANDA, P. 2007. Africa in Climate Change 2007. Impacts, Adaptation and Vulnerability. *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds.). Cambridge University Press, Cambridge UK.

BOLIN, B., DÖÖS, B.R., WARRICK, R.A. and JÄGER, J. 1986. *The Greenhouse Effect: Climate Change and Ecosystems*. SCOPE Publication, No. 29. pp 541.

BONNARDOT, V., CAREY, V. and ROWSWELL, D. 2011. Observed climatic trends in Stellenbosch: Update and brief overview. *Wynboer, Vol. 263*.

BOSELLO, F., EBOLI, F. and PIERFEDERICI, R. 2012. Assessing the Economic Impacts of Climate Change. An Updated CGE Point of View. *Fondazione Eni Enrico Mattei (FEEM): Climate Change and Sustainable Development CCSD Report 2.2012*.

BROECKER, W.S. 1975. Climatic Change: Are We on the Brink of a Pronounced Global Warming? *American Association for the Advancement of Science. New Series, Vol. 189 (4201).*

BROOKS, N. 2003. *Vulnerability, risk and adaptation: A conceptual framework*. Working paper 38. Tydall Centre for Climate Change Research, University of East Anglia, Norwich, UK.

BROOKE, A., KENDRICK, D., MEERAUS, A. and RAMAN, R. 1998. GAMS users guide. *Gams development corporation*, Washington, DC.

BROTHERTON, I.A. and GROENEWALD, J.A. 1982. Optimale organisasie op ontwikkelde besproeiingsplase in die Malelane-Komatipoortstreek. *Agrekon, Vol. 21 (2).*

BRYAN, E., DEGRESSA, T., GBETIBOUO, G. and RINGLER, C. 2007. Determinants of Adaptation to Climate Change in Ethiopia and South Africa. International Food Policy Research Institute (IFPRI), Washington DC, USA and Centre for Environmental Economics and Policy (CEEPA), University of Pretoria, Pretoria, RSA.

BUNCE, J.A. and ZISKA, L.H. 2000. Crop Ecosystem Responses to Climatic Change: Crop/Weed Interactions. *In:* Reddy, K.R. and Hodges, H.F. (Eds) *Climate Change and Global Crop Productivity.* CABI Publishing, Wallingford, UK.. 333-348.

CALLENDAR, G.S. 1937. The artificial production of carbon dioxide and its influence on temperature. *Quarterly Journal of the Royal Meteorological Society, Vol. 64 (275).*

CAREY, V.A. 2001. Spatial characterization of terrain units in the Bottelaryberg/Simonsberg/Helderberg winegrowing area. MSc Thesis, Department of Viticulture, University of Stellenbosch, South Africa.

CARTER, S. 2006. The Projected Influence of Climate Change on the South African Wine Industry Interim Report IR-06-043, International Institute for Applied Systems Analysis, Austria

CHAMBERS, R. 1989. Editorial introduction: Vulnerability, coping and policy. *IDS Bulletin* 20 (2), 7.

CHRISTENSEN, J., HEWITSON, B.C., BUSUIOC, A., CHEN, A., GAO, X., JONES, R., KWON, W.T., LAPRISE, R., MAGANA, V., MEARNS, L., MENENEDEZ, C., RAISAENEN, J., RINKE, A., KOLLI, R. K. and SARR, A. 2007. Regional Climate Projections. *IPCC Fourth Assessment Report "Climate Change 2007: The Scientific Basis",* Cambridge University Press.

COX, P. and STEPHENSON, D. 2007. A changing climate for prediction. *Science, Vol. 317 (5835),*

CRESPO, O. 2012. Crop modeller for Climate Systems Analysis Group, University of Cape Town. Personal interview.

CSIR-NRE (CENTRE FOR SCIENTIFIC AND INDUSTRIAL RESEARCH – NATURAL RESOURCES AND ENVIRONMENT). 2009. Climate Change: Key Issues for Farmers in Southern Africa, Opportunities and Possible Responses. SACAU Discussion Paper No.3 September 2009.

DAFF 2012a. A Profile of South African Mango Market Value Chain. Department of Agriculture, Forestry and Fisheries, Pretoria

DAFF 2012b. A profile of the South African table grape market value chain, Department of Agriculture, Forests and Fisheries, Pretoria

DAFF 2012c. Maize market value chain profile Department of Agriculture, Forestry and Fisheries, Pretoria

DAFF 2012d. Wheat market value chain profile Department of Agriculture, Forestry and Fisheries, Pretoria

DAFF (Department Agriculture, Forestry and Fisheries), 2014. Trends in the Agricultural Sector 2013

DARWIN, R., TSIGAS, M., LEWANDROSKI, J. and RANESES, A. 1995. World Agriculture and Climate Change. *Agricultural Economic Report no. 703 (June).* Washington: US Department of Agriculture, Economic Research Service.

DAVIS, C.L. 2011. Climate risk and vulnerability: A handbook for Southern Africa. Council for Scientific and Industrial Research, Pretoria, South Africa.

DEAT 2004. *South African National Climate Change Response Strategy Report.* Department of Environmental Affairs and Tourism, Pretoria, RSA.

DEJENE, A., MIDGLEY, S., MARAKE, M.V. and RAMASAMY, S. 2011. Strengthening Capacity for Climate Change Adaptation in Agriculture: Experience and Lessons from Lesotho. Food and Agriculture Organization of the United Nations Rome.

DEPARTMENT OF AGRICULTURE. 2007. Discussion document: Climate Change and the Agricultural Sector in South Africa. Department of Agriculture, Pretoria, RSA.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, SOUTH AFRICA. 2009. Water Management Plan for the Olifants-Doorn Water Management Area. Prepared by De Wet, J.S. of S J de Wet Consulting Services as part of the Feasibility Study for the Raising of Clanwilliam Dam. DWAF Report No. P WMA 17/E10/00/1209.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, SOUTH AFRICA. 2009. Report on the Department of Water Affairs' Integrated Water Resources Management IWRM Programme funded Irrigation and Food Security Projects in the Lower Olifants River Water User Association (LORWUA) region of the Olifants-Doorn Water Management Area. Prepared by Nik Wullschleger / Informage IWRM Coordination Western Cape. http://www.iwrm.co.za/resource%20doc/od_diverse_docs/november2009/ 2009 0831_ dwa_iwrm-od-s3projectreport_v1.4.pdf (accessed 11 February 2012).

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, SOUTH AFRICA. 2010. Development of operating rules for the integration of the Blyde and Olifants river systems. Prepared by Seago, C.J., van Rooyen, P.G. and Hattingh, L. of WRP Consulting Engineers. DWAF Report No. P WMA 04/B60/00/8510.

DERESSA, T., HASSAN, R. and POONYTH, D. 2005. Measuring the economic impact of climate change on South Africa's sugarcane growing regions. *Agrekon, Vol. 44 (4).*

DERESSA, T., HASSAN, R.M. and RINGLER, C. 2007. Measuring Ethiopian Farmers' Vulnerability to Climate Change Across Regional States. IFPRI Discussion Paper 00806.

DERPSCH, R. 2005: The Extent of Conservation Agriculture Adoption Worldwide: Implications and Impacts, Paper presented at the third World Congress on Conservation Agriculture, October 2005, Nairobi, Kenya. Food and Agriculture Organization, 2006.

D'HAESE, M., VAN ROOYEN, J., VAN HUYLENBROECK, G. and D'HEASE, L. 1998. Problem-solving strategies for small-scale emerging commercial mango farmers in Venda. *Development Southern Africa*, 15, 471-489.

Downing, T.E., Aerts, J., Soussan, J., Barthelemy, O., Bharwani, S., Ionescu, C., Hinkel, J., Klein, R.J.T., Mata, L.J., Martin, N., Moss, S., Purkey, D. and Ziervogel, G. 2006. Integrating social vulnerability into water management. SEI Working Paper and NeWater Working Paper No. 4. Stockholm Environment Institute, Stockholm, Sweden.

DU PREEZ, J. 2012. Representative of Bavaria Estates and Citrus Growers Association. Personal interview.

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

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

DU TOIT, G. 2007. Promoting conservation agriculture in South Africa: a case study among commercial grain producers in the North West province. Pretoria: Bureau of Food and Agricultural Policy. BFAP report, 04 April 2007.

DU TOIT, P. 2012. A look at conservation agriculture and the developing grain farmer. ARC – Grain crops institute. http://www.grainsa.co.za/a-look-at-conservation-agricul-ture-and-the-developing-grain-farmer (accessed 22 October 2014).

EASTERLING, W.E. 1996. Adapting North American Agriculture to Climate Change in review. *Agricultural and Forest Meteorology, USA, Vol. 80 (1).*

EASTERLING, D., EVANS, J., GROISMAN, P., KARL, T., KUNKEL, K. and AMBENJE, P. 2000. Observed variability and trends in extreme climate events: a brief review. *Bulletin of the American Meteorological Society, Vol. 81 (3).*

EASTERLING, W.E., AGGARWAL, P.K., BATIMA, P., BRANDER, K.M., ERDA, L., HOWDEN, S.M., KIRILENKO, A., MORTON, J., SOUSSANA, J.F., SCHMIDHUBER, J. and TUBIELLO, F.N. 2007. Food, Fibre and Forest Products. Climate Change 2007 Impacts, Adaptation and Vulnerability. *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds.). Cambridge University Press, Cambridge, UK.

EICHBERGER, J. and GUERDJIKOVA, A. 2012. Technology Adoption and Adaptation to Climate Change – A Case-Based Approach.

ENGELBRECHT, F.A. 2013. Principle Researcher, Council for Scientific and Industrial Research. Personal interview.

ENVIRONMENTAL ALERT. 2010. Climate Change in Uganda: Insights for Long term adaptation and Building Community Resilience. *Environmental Alert c2010.*

ERASMUS, B., VAN JAARSVELD, A., VAN ZYL, J. and VINK, N. 2000. The Effects of Climate Change on the Farm Sector in the Western Cape. *Agrekon, Vol. 39 (4).*

ESTES, L. D., BEUKES, H., BRADLEY, B. A., DEBATS, S. R., OPPENHEIMER, M. G., RUANE, A. C., SCHULZE, R., TADROSS, M. A. (2013), Projected climate impacts to South African maize and wheat production in 2055: A comparison of empirical and mechanistic modeling approaches. Global Change Biology. doi: 10.1111/gcb.12325

EYKHOFF, P. 1974. System identification: parameter and state estimation. *Wiley-Interscience: New York, 1974*.

FAO. FOOD and AGRICULTURAL ORGANISATION OF THE UNITES NATIONS. 1999. The State of Food Insecurity in the World. The Food and Agriculture Organization of the United Nations (FAO) Viale delle Terme di Caracalla, 00100 Rome, Italy.

FAO. 2003. Responding to Agricultural and Food Insecurity Challenges Mobilising Africa to Implement Nepad Programes. Conference of ministers of agriculture of the African Union, Maputo, Mozambique.

FAO. 2005. "Impact of Climate Change, Pests and Diseases on Food Security and Poverty Reduction." Special event background document for the 31st Session of the Committee on World Food Security. Rome.

FAO. 2006. What is Conservation Agriculture? (Adapted from: http://www.fao.org/ag/ca/1c. html (Accessed 21 August 2006)).

FAO INTERDEPARTMENTAL WORKING GROUP ON CLIMATE CHANGE. 2007. Climate Change and Food Security: A Framework for Action. Food and Agriculture Organization of the United Nations Rome.

FAO INTERDEPARTMENTAL WORKING GROUP ON CLIMATE CHANGE. 2007. Adaptation to climate change in agriculture, forestry and fisheries: Perspective, framework and priorities. Food and Agriculture Organization of the United Nations Rome, 2007.

FAO. 2007b. Modernizing irrigation management – the MASSCOTE approach. FAO Irrigation and Drainage Paper 63. Food and Agriculture Organization of the United Nations Rome.

FAO. 2009a. Declaration of the World Summit on Food Security. World Summit on Food Security, 16-18 November 2009, Food and Agriculture Organization of the United Nations Rome.

FAO. 2009b. Lesotho: Strengthening capacity for climate change adaptation in the agriculture sector; TCP/LES/3203 (D), Food and Agriculture Organization of the United Nations, Rome.

FAO. 2010. The state of Food Insecurity in the World, Food and Agriculture Organization of the United Nations Rome.

FAO, 2013. Principles of sustainable food value chain development with a meta guide to value development resource materials. Food and Agricultural Organisation, Rome

FOFANA, I. 2011. Simulating the Impact of Climate Change and Adaptation Strategies on Farm Productivity and Income – A Bio-economic Analysis. International food policy research institute (IFPRI).

FRANKLIN, S. 2004. Towards a narrative theory of climate change vulnerability. Stockholm Environment Institute, Stockholm, Sweden.

FÜSSEL, H.M. and KLEIN, R.J.T. 2006. Climate change vulnerability assessments: An evolution of conceptual thinking. *Climatic Change* 75 (3). 301-329.

GBETIBOUO, G.A. and HASSAN, R.M. 2004. Economic impact of climate change on major South African field crops: A Ricardian approach, MSc Agricultural Economics, Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa.

GBETIBOUO, G.A. and HASSAN, R.M. 2005. Measuring the economic impact of climate change on major South African field crops: a Ricardian approach. Centre for Environmental Economics and Policy in Africa (CEEPA), Department of Agricultural Economics, University of Pretoria, South Africa.

GBETIBOUO, G.A. and RINGLER, C. 2009 Mapping South African Farming Sector Vulnerability to Climate Change and Variability. International Food Policy Research Institute, Nairobi, Kenya, *IFPRI Discussion Paper 00885*. pp 30.

GBETIBOUO, G.A., HASSAN, R.M. and RINGLER, C. 2010. Modelling Farmers' Adaptation Strategies for Climate Change and Variability: The case of the Limpopo Basin, South Africa. *Agrekon, Vol. 49 (2).*

GBETIBOUO, G.A., HASSAN, R.M. and RINGLER, C. 2010a. Vulnerability of the South African farming sector to climate change and variability: An indicator approach. *Natural Resources Forum 34.*

GIORGI, F., DIFFENBAUGH, N.S., GAO, X.J., COPPOLA, E., DASH, S.K., FRUMENTO, O., RAUSCHER, S.A., REMEDIO, A., SEIDOU SANDA, I., STEINER, A., SYLLA, B. and ZAKEY, A.S. 2008. The regional climate change hyper-matrix framework. *EOS, Vol. 89 (45).*

GITMAN, L.J. 2009. Principles of managerial finance. 12th edition. Boston Pearson Addison Wesley.

GREGORY, P.J., INGRAM, J.S.I. and BRKLACICH, M. 2005. Climate change and food security. *Philosophical Transactions of the Royal Society B, Vol. 360 (1463).*

HAILE, B.O., GROVÉ, B. and OOSTHUIZEN, L.K. 2003. Impact of capital on the growth process of a sugarcane farm in Mpumalanga. 41st Annual Conference of the Agricultural Economics Association of South Africa, Agribusiness, Profits and Ethics: Pretoria, South Africa.

HANCKE, H.P. and GROENEWALD, J.A. 1972. Die effek van bronbeskikbaarheid op optimum organisasie in besproeiingsboerdery. *Agrekon, Vol. 11 (3).*

HARDY, J.T. 2003. Climate Change: Causes, Effects, and Solutions. John Wiley and Sons Ltd, West Sussex, England.

HASSAN, R.M., NHEMACHENA, C. and KURUKULASURIYA, P. 2010. Measuring the Economic Impact of Climate Change on African Agricultural Production Systems. *Climate Change Economics, Vol. 1 (1)*.

HAVERKORT, A.J., FRANKE, A.C., ENGELBRECHT, F.A. and STEYN, J.M. 2013. Climate Change and Potato Production in Contrasting South African Agro-ecosystems. Effects on Land and Water Use Efficiencies. European Association for potato research (EAPR).

HELMERS, G.A., YAMOAH, C.F. and VARVEL, G.E., 2001. Separating the impacts of crop diversification and rotations on risk. *Agronomy Journal, Vol. 93 (6).*

HELTBERG, R., JORGENSEN, S.L. and SIEGEL, P.B. 2008. Climate Change, Human Vulnerability, and Social Risk Management. Social Development, The World Bank, Washington.

HEWITSON, B.C. 2010. University of Cape Town, personal communication with R.E. Schulze.

HOFFMANN, W.H. 2010. Farm Modelling for Interactive Multidisciplinary Planning of Small Grain Production Systems in South Africa. PhD thesis – University of Stellenbosch.

HOUGH, E. and COETZEE, T. 2012. Moorreesburgse Koringboere (Edms) Beperk (MKB) representatives. Personal interviews.

HULME, M., DOHERTY, R., NGARA, T., NEW, M. and LISTER, D. 2001. African Climate Change: 1900-2001. *Climate Research, Vol. 17 (2).*

IAASTD, 2009. Sub-Saharan Africa: Agriculture at a crossroads. McIntyre, B.D., Herren, H.R., Wakhungu, J. and Watson, R.T. (eds.). 2009. *International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). Vol. V*. Island Press, Washington DC.

ICID-CIID. 2000. Multilingual Technical Dictionary on Irrigation and Drainage – CD Version September 2000, International Commission on Irrigation and Drainage, New Delhi.

ICLEI – Local Governments For Sustainability. 2012. http://www.iclei.org/index.php?id=13107, (accessed 19/2/13)

IISD. 1997. Agriculture and climate change: A Prairie Perspective. Prepared by the International Institute for Sustainable Development and the Environmental Adaptation Research Group, Institute for Environmental Studies University of Toronto.

IGBP. INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAM. 2009. Climate Change in a Nutshell. *Global Change, Vol. 74*.

IFPRI. INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE. 2009. Building Climate Resilience in the Agriculture Sector of Asia and the Pacific. Asian Development Bank, Mandaluyong: Philippines. http://www.adb.org/Documents/Books/Building-Climate-Resilience-Agriculture-Sector/Building-Climate-Resilience-Agriculture-Sec-tor.pdf.

IONESCU, C., KLEIN, R.J.T, HINKEL, J., KAVI KUMAR, K.S. and KLEIN, R. 2005. Towards a Formal Framework of Vulnerability to Climate Change. NeWater Working Paper 1, Potsdam Institute for Climate Impacts Research, Potsdam, Germany.

IPCC. INTERGOVERMENTAL PANEL ON CLIMATE CHANGE. 2000a. Presentation of Robert T Watson, Chair, IPCC, at the Sixth Conference of the Parties to the United Nations Framework Convention on Climate Change, The Hague.

IPCC. TAR. 2001a. Climate Change 2001. Impacts, Adaptation and Vulnerability. IPCC Third Assessment Report, Cambridge University Press.

IPCC. 2007. Summary for Policymakers. In: Climate Change 2007. Impacts, Adaptation and Vulnerability. *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds.). Cambridge University Press, Cambridge, UK.

IPCC. 2007. Climate Change 2007: The Physical Science Basis. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S., Quin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.). Cambridge University Press, Cambridge, UK.

IPCC-TGICA. 2007. General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version 2. Prepared by T.R. Carter on behalf of the Intergovernmental Panel on Climate Change, Task Group on Data and Scenario Support for Impact and Climate Assessment.

IPCC. 2012. Summary for Policymakers. Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. and Ebi, M.D. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*.

JACOB, D. and VAN DEN HURK, B. 2009. Climate Change Scenarios at the Global and Local Scales. Ludwig, F., Kabat, P., van Schaik, H. and van der Valk, M. (eds.). *Climate Change Adaptation in the Water Sector*. Climate Change Adaptation in the Water Sector. Earthscan, London, UK.

JOHNSTON, P.A. 2009. Climate change risk model for table grape growers. Unpublished report for Fynbos Foundation.

JOHNSTON, P.A. 2014. Personal communication. Climate Systems Analysis Group, University of Cape Town (UCT).

JONES, R. and WILSON, S. 2002. PRECIS: Providing Regional Climates for Impact Studies. A presentation to the Tyndall Centre AIACC training workshop.

JOUBERT, J. and VAN WYK, G. 2012. VINPRO representatives. Personal interviews.

KAISER, H.M. and DRENNEN, T.E. 1993. Agricultural Dimensions of Global Climate Change. St. Lucie Press, Delray Beach, Florida.

KEATING, B.A., CARBERRY, P.S., HAMMER, G.L., PROBERT, M.E., ROBERTSON, M.J., HOLZWORTH, D., HUTH, N.I., HARGREAVES, J.N.G., MEINKE, H., HOCHMAN, Z., MCLEAN, G., VERBURG, K., SNOW, V., DIMES, J.P., SILBURN, M., WANG, E., BROWN, S., BRISTOW, K.L., ASSENG, S., CHAPMAN, S., MCCOWNA, R.L., FREEBAIRN, D.M. and SMITH, C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy, Vol. 18 (3-4).*

KELLY, P.M. and ADGER, W.N. 2000: Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change, Vol. 47 (4*).

KNOX, J.W., HESS, T.M., DACCACHE, A. and ORTOLA, M.P. 2011. What are the projected impacts of climate change on food crop productivity in Africa and South Asia? Department of International Development (DFID), United Kingdom. Systematic Review Final Report.

KURUKULASURIYA, P., MENDELSOHN, R., HASSAN, R.M., BENHIN, J., DERESSA, T., DIOP, M., EID, H.M., FOSU, K.Y., GBETIBOUO, G., JAIN, S., MAHAMADOU, A., MANO, R., KABUBO-MARIARA, J., EL-MARSAFAWY, S., MOLUA, E., OUDA, S., OUEDRAOGO, M., SE´NE, I., MADDISON, D., SEO, S.N. and DINAR, A. 2006. Will African Agriculture Survive Climate Change? The World Bank Economic Review Advance Access published August 23, 2006.

LANDBOU-ONTWIKKELINGSPROGRAM (LOP). 1991. Landbouontwikkelingsinstituut vir die winterreëngebied, Elsenburg.

LANDTYPE SURVEY STAFF. 1972-2002. 1:250 000 SCALE LAND TYPE SURVEY. ARC-Institute for Soil, Climate and Water, Pretoria.

LEICHENKO, R.M. and O'BRIEN, K.L. 2002. The dynamics of rural vulnerability to global change: the case of Southern Africa. *Mitigation and Adaptation Strategies for Global Change*, 7, 1-18.

LE TREUT, H., SOMERVILLE, R., CUBASCH, U., DING, Y., MAURITZEN, C., MOKSSIT, A., PETERSON, T. and PRATHER, M. 2007. Historical Overview of Climate Change. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

LEVINA, E and TIRPAK, D. 2006. Adaptation to climate change: key terms. OECD/IEA, Paris, France.

LIVERMAN, D.M. 1990. Vulnerability to global environmental change. *In*: Kasperson, R.E., Dow, K., Golding, D. and Kasperson, J.X. (Eds) *Understanding global environmental change: The contributions of risk analysis and management*. Clark University. Worcester, MA.

LOBELL, D.B., BURKE, M.B., TEBALDI, C., MASTRANDREA, M.D., FALCON, W.P. and NAYLOR, R.L. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science, Vol. 319 (5863).*

LOUW, A. and PIENAAR, J.S. 2002. ABSA commercial bank Agribusiness financial model. Personal discussions with the model developers.

LOUW, D.B. 1996. Die ontwikkeling van 'n geheelboerderybeplanningsmodel met behulp van dinamiese lineêre programmering vir die vee-kleingraanweidingsgebiede van die Suid-kaap. MSc verhandeling, Universiteit Stellenbosch, Suid-Afrika.

LOUW, D.B. and VAN SCHALKWYK, H.D. 1997. The true value of irrigation water in the Olifants River Basin: Western Cape. *Agrekon, Vol. 36 (4).*

LOUW, D.B. 2001. Modelling the potential impact of a water market in the Berg River Basin. PhD thesis, University of the Free State, South Africa.

LOUW, D.B. and JOOSTE, A. 2006. Feasibility study into food security programmes in the Kgalagadi district municipality (KDM). Unpublished consulting report prepared for the Kgalagadi District Municipality.

LOUW, D.B., CALLAWAY, J.M., JOHNSTON, P. and LUMSDEN, T. 2012. Managing climate risk for agriculture and water resources development in South Africa: Quantifying the costs, benefits and risks associated with planning and management alternatives. Paper Prepared for the International Conference on: Water Management Issues in Africa 29-31 March 2012 – Port Louis, Mauritius.

LOWER OLIFANTS RIVER WATER USERS ASSOCIATION (LORWUA). 2007. Survey to determine land use patterns.

LOWER OLIFANTS RIVER WATER USERS ASSOCIATION (LORWUA). 2011. Personal interview with Mr Johan Matthee, LORWUA manager.

LYNCH, S.D. 2004. Development of a Raster Database of Annual, Monthly and Daily Rainfall for Southern Africa. Water Research Commission, Pretoria, RSA, WRC Report 1156/1/04.

MAIZE TARIFF WORKING GROUP 2005. www.grainmilling.org.za/_document/Maize%20TARIFF%20Sec%20A.doc accessed 25/2/14

MANGO GROWERS ASSOCIATION. 2012. Personal interview with Mr J Fivaz.

MARÉ, H.G. 1995. Marico-Bosveld Staatswaterskema: Stogastiese waterbronontledings gekoppel aan ekonomiese evaluasies. BKS Ing. Verslag P5425/95/1. Departement van Landbou, Direktoraat Besproeiingsingenieurswese, Pretoria.

MASIKATI P, CRESPO O, DESCHEEMAEKER K, WALKER S, HOMANN KEE TUI S, CLAESSENS L, FAMBA S, VAN ROOYEN A, GAMA A, LENNARD C. 2013.. Crop-Livestock Intensification in the Face of Climate Change: Exploring Opportunities to Reduce Risk and Increase Resilience in Southern Africa by Using an Integrated Multi-modelling Approach. Part 2, Section I, Chapter 5, in : Daniel Hillel & Cynthia Rosenzweig (Editors). Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project Integrated Crop and Economic Assessments.

MASTRANDREA, M.D., MACH, K.J., PLATTNER, G.-K., ALLEN, S.K., TIGNOR, M. and MIDGLEY, P.M. (eds.). A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

MCCARTHY, J.J., CANZIANI, O.F., LEARY, N.A., DOKKEN, D.J. and WHITE, K.S. (Eds) 2001. *Climate change 2001: Impacts, adaptation and vulnerability.* Cambridge University Press, Cambridge, UK.

McCLEAN, C.J., LOVETT, J.C., KÜPER, W., HANNAH, L., SOMMER, J.H., BARTHLOTT, W., TERMANSEN, M., SMITH, G.F., TOKUMINE, S. and TAPLIN, J.R.D. 2005. African Plant Diversity and Climate Change. *Annals of the Missouri Botanical Garden, Vol. 92 (2).*

MCCOWN, R.L., HAMMER, G.L., HARGREAVES, J.N.G., HOLZWORTH, D. and HUTH, N. I. 1995. APSIM – an agricultural production system simulation-model for operational-research. *Mathematics and Computers in Simulation, Vol. 39 (305).*

MEADOWS, M.E. 2006. Global change and southern Africa. *Geographical Research, Vol. 44 (2).*

MENDELSOHN, R. and DINAR, A. 1999. Climate Change, Agriculture, and Developing Countries: Does Adaptation Matter? *World Bank Research Observer, Vol. 14 (2).*

MIDGLEY, S. 2012. Personal communication. Department of Horticulture, University of Stellenbosch, Stellenbosch.

MIDGLEY, G.F., CHAPMAN, R.A., HEWITSON, B., JOHNSTON, P., DE WIT, M., ZIERVOGEL, G., MUKHEIBIR, P., VAN NIEKERK, L., TADROSS, M., VAN WILGEN, B.W., KGOPE, B., MORANT, P.D., THERON, A., SCHOLES, R.J., FORSYTH, G.G.2005. A Status Quo, Vulnerability and Adaptation Assessment of the Physical and Socio-economic Effects of Climate Change in the Western Cape. Report to the Western Cape Government, Cape Town, South Africa. CSIR Report No. ENV-S-C 2005-073, Stellenbosch.

MIDGLEY, D.C., PITMAN, W.V. and MIDDLETON, B.J. 1994. Surface Water Resources of South Africa 1990, User's Manual. Water Resources 1990 Joint Venture. Water Research Commission, Pretoria, RSA, WRC Report 298/1/94.

MIDGLEY, G.F., THUILLER, W. and HIGGINS, S.I. 2007. Plant species migration as a key uncertainty in predicting future impacts of climate change on ecosystems: Progress and challenges, Terrestrial Ecosystems in a Changing World, Springer-Verlag. Canadell, J., Pataki, D.E. and Pitelka, L.F. (eds.).

MOLOISANE P.J. 2003. Strategy document for the South African wheat to bread value chain, The Wheat Steering Committee, Nov 2003.

MOLOPE, B.M. 2006. Adaptation to negative effects of climate change in the agricultural sector. *Proceedings, Agricultural Sector Workshop on Climate Change.* Department of Agriculture, Pretoria, RSA. 46-48.

MONTEITH, J.L. 1981. Evaporation and surface temperature. *Quarterly Journal of the Royal Meteorological Society, Vol. 107 (451).*

MORTIMORE, M.J. and ADAMS, W.M. 2001. Farmer adaptation, change and 'crisis' in the Sahel. *Global Environmental Change,* 11, 49-57.

MUKHEIBIR, P. and SPARKS, D. 2003. Climate variability, climate change and water resource strategies for small municipalities. Water resource management strategies in response to climate change in South Africa, drawing on the analysis of coping strategies adopted by vulnerable communities in the Northern Cape province of South Africa in times of climate variability. University of Cape Town for the Water Research commission.

NAKIĆENOVIĆ, N., ALCAMO, J., DAVIS, G., DE VRIES, B., FENHANN, J., GAFFIN, S., GREGORY, K., GRÜBLER, A., JUNG, T.Y., KRAM, T., LA ROVERE, E.L., MICHAELIS, L., MORI, S., MORITA, T., PEPPER, W., PITCHER, H., PRICE, L., RAIHI, K., ROEHRL, A., ROGNER, H.-H., SANKOVSKI, A., SCHLESINGER, M., SHUKLA, P., SMITH, S., SWART, R., VAN ROOIJEN, S., VICTOR, N. and DADI, Z. 2000. Emissions Scenarios. *A Special Report of Working Group III of the Intergovernmental Panel on Climate Change.* Nakicenovic, N. and Swart, R. (eds.). Cambridge University Press, UK and New York, NY, USA.

NAMC 2013. National Agricultural Marketing Council, South African Fruits Trade Flow; Market and Economic Research Centre. http://www.namc.co.za/upload/Fruit-Trade-Flow--June-2013-Issue-No-10.pdf

NEL, A.A. and LOUBSER, H.L. 2004. The impact of crop rotation on profitability and production risk in the eastern and north western Free State. *Agrekon, Vol. 43 (1*).

NEL, A.A. 2010. Bevorder grondkwaliteit. LNR – Instituut vir graangewasse.

NELSON, G.C., ROSEGRANT, M.W., KOO, J., ROBERTSON, R., SULSER, T., ZHU, T., RINGLER, C., MSANGI, S., PALAZZO, A., BATKA, M., MAGALHAES, M., VALMONTE-SANTOS, R., EWING, M., and LEE, D. 2009. Climate change impact on agriculture and cost of adaptation. International Food Policy Research Institute (IFPRI).

NEPAD, AU. 2007. Comprehensive African Agriculture Development Programme (CAADP). Pillar III Draft Framework for African Food Security.

NHEMACHENA, C. and HASSAN, R.M. 2007. Micro-level analysis of farmers' adaptation to climate change in southern Africa. International Food Policy Research Institute (IFPRI), Washington DC, USA and Centre For Environmental Economics and Policy (CEEPA), University of Pretoria, Pretoria, RSA.

NZUMA, J. M., WAITHAKA, M., MULWA, R. M., KYOTALIMYE, M. and NELSON, G. 2010. Strategies for Adapting to Climate Change in Rural Sub-Saharan Africa. A Review of Data Sources, Poverty Reduction Strategy Programs (PRSPs) and National Adaptation Plans for Agriculture (NAPAs) in ASARECA Member Countries. Environment and Production Technology Division, IFPRI Discussion paper 01013.

OABS 2006 Report: The Future Strategy of the Fruit Industry in South Africa.

O'BRIEN, K.L., ERIKSEN, S., SCHJOLDEN, A. and NYGAARD, L. 2004. *What's in a word? Conflicting interpretations of vulnerability in climate change research.* CICERO Working Paper 2004, 04. Oslo, Norway, Centre for International Climate and Environmental Research.

OLMOS, S. 2001. Vulnerability and adaptation to climate change: concepts, issues, assessment methods. Foundation paper for the Climate Change Knowledge Network.

OOSTHUIZEN, H.J. 1994. Ekonomiese aspekte van die privatisering van die Marico-Bosveld-Staatswaterskema. Ongepubliseerde MCom verhandeling. Universiteit van Pretoria, Suid-Afrika.

OOSTHUIZEN, H.J. 1995. Berekening van die impak van die Marico-Bosveld Staatswaterskema op die nasionale ekonomie van Suid-Afrika en finale gevolgtrekkings oor die rehabilitasie van die skema. Departement van Landbou, Direktoraat Landbou-ekonomie, Pretoria.

OOSTHUIZEN, H.J. 2014. Modelling the financial vulnerability of farming systems to climate change in selected case study areas in South Africa. Unpublished PhD Thesis. Stellenbosch University, South Africa.

PARRY, M., EVANS, A., ROSEGRANT, M.W. and WHEELER, T. 2009. Climate change and hunger – Responding to the challenge. Published by the World Food Programme, the International Food Policy Research Institute, the New York University Center on International Cooperation, the Grantham Institute at Imperial College London, and the Walker Institute, University of Reading (United Kingdom).

PAVEL, E.W.; DE VILLIERS, A.J. 2004. Responses of mango trees to reduced irrigation regimes. Acta Horticultural, The Hague, Mendoza, n.646, p.63-68.

PIKE, A. and SCHULZE, R.E. 1995. AUTOSOILS: A Program to Convert ISCW Soils Attributes to Variables Usable in Hydrological Models. Department of Agricultural Engineering, University of Natal, Pietermaritzburg, RSA (Also updates).

REDELINGHUIS, A. and JULYAN, F.W. 1985. Quantitative Methods for Managerial Decision Making. Families History Bound, 1996.

REID, P., MASSEY, R. and VOGEL, C. 2005. Climate and Development: Experiences of Farmers in KwaZulu-Natal, South Africa. *In*: Schulze, R.E. (Ed) *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation.* Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05. Chapter 25, 395-414.

REILLY, J.M. and SCHIMMELPFENNING, D. 1999. Agricultural impact assessment, vulnerability, and the scope for adaptation. *Climatic Change, Vol. 43 (4).*

RINGLER, C., ZHU, T., CAI, X., KOO, J. and WANG, D. 2011. How can African agriculture adapt to climate change? Insights from Ethiopia and South Africa. Climate Change Impacts on Food Security in Sub-Saharan Africa. Insights from Comprehensive Climate Change Modelling. IFPRI Research Brief.

SALINGER, J., SIVAKUMAR, M.V.K. and MOTHA, R. P. (eds.). 2005. Increasing Climate Variability and Change: Reducing the Vulnerability of Agriculture and Forestry. *Climatic Change, Vol. 70 (1-2).*

SAPWAT calculation. 2012. SAPWAT computer program that is used for estimating irrigation water requirements of crops, farms and bigger areas for the planning and management of crop and area irrigation water requirements.

SCHINDLER, D.W. 1999. The Mysterious Missing Sink. *Nature, Vol. 398 (6723).*

SCHULZE, R.E., KIKER, G.A. and KUNZ, R.P. 1993. Global climate change and agricultural productivity in Southern Africa. *Global Environmental Change, Vol. 3 (4), 4 (1).*

SCHULZE, R.E. and MAHARAJ, M. 2004. Development of a database of gridded daily temperatures for Southern Africa. Water Research Commission, Pretoria, RSA, WRC Report 1156/2/04.

SCHULZE, R.E. 2007. Climate Change and the Agriculture Sector in South Africa: An Assessment of Findings in the New Millennium. University of KwaZulu-Natal, Pietermaritzburg, RSA, School of Bioresources Engineering and Environmental Hydrology, *ACRUcons Report*, 55. pp 71.

SCHULZE, R.E. and HORAN, M.J.C. 2007. Hydrological Modelling as a Tool for Ecosystem Services Trading: Case Studies from the Drakensberg Region of South Africa. University of KwaZulu-Natal, School of Bioresources Engineering and Environmental Hydrology, Pietermaritzburg, RSA. *ACRUcons Report, 56*.

SCHULZE, R.E. and HORAN, M.J.C. 2008. Soils: Hydrological Attributes. In Schulze, R.E. (Ed). 2008. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/08, Section 4.2.

SCHULZE, R.E. 2009. IDRC Project Climate Change Roadshow: Farmer Feedback. University of KwaZulu-Natal, School of Bioresources Engineering and Environmental Hydrology, Pietermaritzburg, RSA. pp 3.

SCHULZE, R.E. 2009. Uncertainty in Climate Change Impact Studies in the Water Sector: Some Conceptual and Practical Issues in a Southern African Context. Unpublished document. University of KwaZulu-Natal, School of Bioresources Engineering and Environmental Hydrology, Pietermaritzburg, RSA.

SCHULZE, R.E. and HORAN, M.J.C. 2010. Methods 1: Delineation of South Africa, Lesotho and Swaziland into Quinary Catchments. In: Schulze, R.E., Hewitson, B.C., Barichievy, K.R., Tadross, M.A., Kunz, R.P., Horan, M.J.C. and Lumsden, T.G. 2010a. Methodological Approaches to Assessing Eco-Hydrological Responses to Climate Change in South Africa. Water Research Commission, Pretoria, RSA, WRC Report 1562/1/10.

SCHULZE, R.E., HEWITSON, B.C., BARICHIEVY, K.R., TADROSS, M.A.., KUNZ, R.P., LUMSDEN, T.G. and HORAN, M.J.C. 2010. Methods to Assess Eco-Hydrological Responses to Climate Change over South Africa. Water Research Commission, Pretoria, RSA, WRC Report 1562/1/10.

SCHULZE, R.E., HORAN, M.J.C., KUNZ, R.P., LUMSDEN, T.G. and KNOESEN, D.M. 2010. Methods 2: Development of the Southern African Quinary Catchments Database. In: Schulze, R.E., Hewitson, B.C., Barichievy, K.R., Tadross, M.A.., Kunz, R.P., Lumsden, T.G. and Horan, M.J.C. 2010. Methods to Assess Eco-Hydrological Responses to Climate Change over South Africa. Water Research Commission, Pretoria, RSA, WRC Report 1562/1/10.

SCHULZE, R.E. 2011. Atlas of Climate Change and the South African Agricultural Sector: A 2010 Perspective. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA.

SCHULZE, R.E., KNOESEN, D.M., KUNZ, R.P. and LUMSDEN, T.G. 2011. General Circulation Models and Downscaling for South African Climate Change Impacts Studies: A 2011 Perspective. In: Schulze, R.E. 2011. A 2011 Perspective on Climate Change and the South African Water Sector. Water Research Commission, Pretoria, RSA, WRC Report 1843/2/11.

SCHULZE, R.E., HORAN, M.J.C., KUNZ, R.P., LUMSDEN, T.G. and KNOESEN, D.M. 2011. The South African Quinary Catchments Database. In: Schulze, R.E. 2011. A 2011 Perspective on Climate Change and the South African Water Sector. Water Research Commission, Pretoria, RSA, WRC Report 1843/2/11.

SCHULZE, R.E. 2012. Compilation of soil characteristics. School of Agricultural, Earth and Environmental Sciences, University of Kwazulu-Natal (UKZN).

SCHULZE, R.E. 2013. Adaptation and Mitigation Plan for the South African Agriculture Sector. Draft report for DAFF

SCHULZE, R.E. 2014. Personal communication. School of Agricultural, Earth and Environmental Sciences, University of Kwazulu-Natal (UKZN).

SCHULZE, R.E., SCHÜTTE, S. AND WALLACE, M. 2016. Wheat and Climate Change. In: Schulze, R.E. (ed.) *Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the Agriculture Sector within South Africa*. Section C: Crops and Climate Change, Chapter C2. pp 19.

SEGNESTAM, L. 2004. Poverty and Vulnerability to Environmental Stress: Working with Multiple Dimensions of Poverty. SEI Briefing Note. Stockholm Environment Institute, Stockholm, Sweden. pp 3

SEO, S.N., MENDELSOHN, R., DINAR, A., HASSAN, R.M. and KURUKULASURIYA, P. 2009. A Ricardian Analysis of the Distribution of Climate Change Impacts on Agriculture across Agro-Ecological Zones in Africa. *Environmental Resource & Economies, Vol. 43 (3)*.

SHAHAK, Y., GUSSAKOVSKY, E.E., GAL, E. and GANELEVIN, R. 2004. ColorNets: Crop Protection and Light-Quality Manipulation in One Technology.

SHAKA, A.K. 2008. Assessment of Climate Change Impacts on the Hydrology of Gilgel Abbay Catchment in Lake Tana Basin, Ethiopia. Unpublished MSc Dissertation, International Institute for Geo-Information Science and Earth Observation, Enschede, Netherlands.

SHERIDAN, C. 2005. Perceptions and realities – water, effluent and environmental management systems in the SA wine industry. Wynboer Jan 2005

SMIT, B. (ed.). 1993. Adaptation to climatic variability and change. Report of the Task Force on Climate Adaptation. Prepared for the Canadian Climate Program, Department of Geography Occasional Paper No. 19, University of Guelph, Guelph, Canada.

SMIT, B., BURTON, I., KLEIN, R.J.T. and WANDEL, J. 2000. An anatomy of adaptation to climate change and variability. Kluwer academic publishers, The Netherlands.

SMITH, J.B., RAGLAND, S.F. and PITTS, G.J. 1996. A Process for Evaluating Anticipatory Adaptation Measures for Climate Change. *Water, Air and Soil Pollution, Vol. 92 (1-2).*

SMITH, J.B. and HULME, M. 1998. Climate change scenarios. Feenstra, J., Burton, I., Smith, J.B. and Tol, R.S.J. (eds.). *Handbook on Methods of Climate Change Impacts Assessment and Adaptation Strategies.* UNEP/IES, Version 2.0, October, Amsterdam.

SNC AGRICULTURE, 2009. Vulnerability, Impacts and Adaptation to Climate Change in the Agriculture Sector. Second National Communication to the UNFCCC, Working Group 3, Draft Document. pp 16.

SOUTHWICK, S.; KHAN, Z.; GLOZER, K. 2003. Evaluation of Chill Models from Historical Rest-Breaking Spray Experiments on Bing Sweet Cherry. University of California, Davis. PENMAN, H.L. 1948. Natural evaporation from open water, bare soil, and grass. Proceedings of the Royal Society of London, Vol. 193 (1032).

STAINFORTH, D.A., DOWNING, T.E., WASHINGTON, R., LOPEZ, A. and NEW, M. 2007. Issues in the Interpretation of Climate Model Ensembles to Inform Decisions. *Philosophical Transactions of the Royal Society, Vol. 365 (1857*).

STAKHIV, E. 1993. Evaluation of IPCC strategies. Institute for Water Resources, U.S. Army Corps of Engineers, Fort Belvoir, Virginia.

STATISTICS SA, 2002. *Census of Commercial Agriculture.* Statistics South Africa, Pretoria, RSA, Report No. 11-02-01.

STATISTICS SA, 2016. Gross domestic product First quarter 2016,*Statistical releaseP0441*

TADROSS, M.A., JACK, C., and HEWITSON, B.C. 2005. On RCM-based projections of change in Southern African summer climate. Geophysical Research Letters, 32, L23713.

TADROSS, M.A., HEWITSON, B.C. and Usman, M.T. 2005a. The interannual variability of the onset of the maize growing season over South Africa and Zimbabwe. *Journal of Climate, Vol. 18 (16)*.

TURNER B.L., R.E. KASPERSON, P.A. MATSON, J.J. MCCARTHY, R.W. CORELL, L. CHRISTENSEN, N. ECKLEY, J.X. KASPERSON, A. LUERS, M.L. MARTELLO, C. POLSKY, A. PULSIPHER and A. SCHILLER. 2003. Framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences, USA. PNAS 100: 8074-8079.

TYSON, P.D. 1996. South African Climate Change and Variability. Shackleton, L.Y., Lennon, S.J. and Tosen, G.R. (eds.). *Global Climate Change and South Africa.* Environmental Scientific Association, Cleveland, USA.

UKCIP. 2003. Climate adaptation: Risk, uncertainty and decision-making. In: Willows, R.I. and Conell, R.K. (eds.). UKCIP Technical Report. UKCIP, Oxford, UK.

UKCIP. 2004. Costing the impacts of climate change in the UK. United Kingdom climate impacts programme. Oxford, UK.

UNDP. 2010. Gender, climate change and community-based adaptation. United Nations development programme. New York, USA.

UNFCCC. 1994. Article 1: Definitions. Accessed online available from: http://unfccc.int/essential_background/convention/background/items/2536.php

UNITED NATIONS. 2009. The Millennium Development Goals Report. UN, New York.

UNITED NATIONS (UN). 2014. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352).

VAN DER STOEP, I. and TYLCOAT, C. 2014. South African Irrigation Statistics – An Analysis of the 2014 Water Registration Management System (WARMS) Data, Presentation during the SANCID 2014 Symposium, Glenburne Lodge, Muldersdrift.

VAN HEERDEN, P.S., CROSBY, C.T., GROVÉ, B., BENADÉ, N., THERON, E., SCHULZE, R.E. and TEWOLDE, M.H. 2009. Integrating and Updating of SAPWAT and PLANWAT to Create a Powerful and User-Friendly Irrigation Planning Tool. Program version 1.0. Water Research Commission, Pretoria, RSA, WRC Report TT 391/08.

VAN ROOYEN, C.J. 1979. Waterbeskikbaarheid en Arbeid as Veranderlike Hulpbronne in Beplanning vir Optimale Organisasie in Besproeiingsboerdery. *Agrekon, Vol. 18 (1).*

VINK, N., DELOIRE, A., BONNARDOT, V. and EWERT, J. 2012. Climate change and the future of South Africa's wine industry. American Association of Wine Economists, Working paper No. 105.

VOGEL, C., and O'BRIEN, K. 2004. Vulnerability and global environmental change: Rhetoric and reality. *AVISO Bulletin*, 13, 1-8.

VOGEL, C.H. and REID, P. 2005. Vulnerability, Adaptive Capacity, Coping and Adaptation: A Conceptual Framework. *In*: Schulze, R.E. (Ed) *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation*. Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05. Chapter 21, 351-358.

WALKER, N.J. and SCHULZE, R.E. 2008. Climate change impacts on agro-ecosystem sustainability across three climate regions in the maize belt of South Africa. *Agriculture Ecosystems and Environment, Vol. 124 (1-2*).

WALLACE, M. 2103. Modelling yield impacts on wheat production zones in the Western Cape under future climate change. PhD thesis, University of Cape Town.

WATER RESEARCH COMMISSION (WRC). 2010. Adaptive interventions in agriculture to reduce vulnerability of different farming systems to climate change in South Africa. *Knowledge review 2009/2010, ISBN no. 978-1-431-0004-7.*

WATER RESEARCH COMMISSION (WRC). 2012. Project no. K4: 1882. Adaptive interventions in agriculture to reduce vulnerability of different farming systems to climate change in South Africa. Deliverable No.5 Interim report on the sensitivity assessment and vulnerability analysis.

WATSON, R.T., ZINYOERA, M.C. and MOSS, R.H. 1996. Climate change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis. *Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

WATTS, M.J. and H.G. BOHLE. 1993. The space of vulnerability: the causal structure of hunger and famine. *Progress in Human Geography* 17 (1), 43-67.

WEART, S.R. 2008. The Discovery of Global Warming. Harvard University Press.

WEHBE, M.B., SEILER, R., VINOCUR, M., EAKIN, H., SANTOS, C., and CIVITARESI, H. 2005. Social Methods for Assessing Agricultural Producers' Vulnerability to Climate Variability and Change Based on the Notion of Sustainability. AIACC Working Paper No.19.

WHITE, T.A., CAMPBELL, B.D., KEMP, P.D. and HUNT, C.L. 2001. Impacts of extreme climaticevents on competition during grassland invasions. *Global Change Biology,* 7, 1-13.

WILBY, R., DAWSON, C.W. and BARROW, E.M. 2002. SDSM — a decision support tool for the assessment of regional climate change impacts. *Environmental Modelling and Software, Vol. 17 (2*).

WILBY, R. 2007. Decadal Climate Forecasting Techniques for adaptation and development planning. Report for Department for International Development DFID.

WILLOWS, R. and CONNELL, R. 2003.Climate adaptation: Risk, uncertainty and decision-making. UK Climate Impact Programme (UKCIP).

WILSON C.A., FEATHERSTONE A.M., KASTENS, T.L. and JONES, J.D. 2006. Determining What's Really Important to Lenders: Factors Affecting the Agricultural Loan Decision-Making Process. Staff Paper 06-07 Purdue University, Department of Agricultural Economics.

WISNER, B., BLAIKIE, P., CANNON, T. and DAVIS, I. 2004. *At Risk: Natural Hazards, People's Vulnerabiity and Disasters*. Second Edition, Routledge, London. UK.

WOOLDRIDGE, J. 2007. A perspective on climate change. *Wynboer Technical Yearbook 2007/2008: 15-19*.

WORLD BANK. 2007. World development report 2008. Agriculture for development. The World Bank, Washington DC.

WORLD RESOURCES INSTITUTE (WRI) IN COLLABORATION WITH UNITED NATIONS DEVELOPMENT PROGRAMME, UNITED NATIONS ENVIRONMENT PROGRAMME, AND WORLD BANK. 2005. World Resources 2005. The Wealth of the Poor—Managing Ecosystems to Fight Poverty. Washington, DC: WRI.

ZERAY, L., ROEHRIG, J. and CHEKOL, D.A. 2006. "Prosperity and Poverty in a Globalised World – Challenges for Agricultural Research" Climate Change Impact on Lake Ziway Watershed's Water Availability, Ethiopia. Conference on International Agricultural Research. University of Bonn, Switzerland.

ZIERVOGEL, G. 2008. Adapting to climate change in Africa: What does it mean for household water access and use? *In*: Petermann, T. (Ed) *Towards Climate Change Adaptation – Building Adaptive Capacity in Managing African Transboundary River Basins*. InWent, Zschortau, Germany. 189-202.

ZIERVOGEL, G. and CALDER, R. 2003. Climate variability and rural livelihoods: Assessing the impact of seasonal forecasts. *Area*, 35, 403-417.

ZIERVOGEL, G., BHARWANI, S. and DOWNING, T.E. 2006. Adapting to climate variability: Pumpkins, people and policy. *Natural Resource Forum*, 30, 294-305.

ZIERVOGEL, G. and TAYLOR, A. 2008. Feeling stressed: Integrating climate adaptation with other priorities in South Africa. *Environment*, 50, 32-41.

ZIERVOGEL, G., CARTWRIGHT, A., TAS, A., ADEJUWON, J., ZERMOGLIO, F., SHALE, M. and SMITH, B. 2008. Climate change and adaptation in African agriculture. Prepared for Rockefeller Foundation. By Stockholm Environment Institute.

APPENDICES:

Appendix A: Capacity Building.

Student: Katinka Waagsaether

Title: Preparing for the future: Assessing the vulnerability of small-scale farmers in Bushbuckridge

Degree: MSc

University: University of Cape Town

Abstract:

Farming is a precarious profession, impacted by the social, economic, political, institutional and physical environment, to which climate change projections pose an additional challenge. South Africa has a highly diverse agricultural sector, with agricultural systems ranging from subsistence farming in homesteads to commercial estates with thousands of hectares under cultivation. In order to inform agricultural adaptation strategy and action, this thesis takes a multidisciplinary approach that focuses on preparing for the future by understanding the present. The focal aim of this thesis is to assess whether the current coping and adaptation mechanisms of small-scale farmers in the South African Province of Mpumalanga are sufficient for dealing with projected climate change. This is achieved through assessment of how small-scale farmers are currently coping with and adapting to climate variability and extreme weather events. A theoretical framework for vulnerability assessments, that situates farmers in a multi-stressor environment, is employed in order to get an understanding of the multifaceted setting in which small-scale farmers currently live and work. Farmers' understanding of the current climate is analysed through a comparison of local historical climate data with farmers' perceptions, while analysis of downscaled climate change projections provides a picture of what the future climate might look like. The study combines fieldwork data with historical and projected climate data from local stations in a combination of qualitative and quantitative data analysis, producing a number of findings that contribute to the discourse on adaptation, and further work to inform future policy and adaptation action.

Student: Hamman Oosthuizen

Title: Modelling the financial vulnerability of farming systems to climate change in selected case study areas in South Africa.

Degree: PhD

University: Stellenbosch University

Abstract:

Numerous studies indicate that the agricultural sector is physically and economically vulnerable to climate change. In order to determine possible impacts of projected future climates on the financial vulnerability of selective farming systems in South Africa, a case study methodology was applied. The integrated modelling framework consists of four modules, viz.: climate change impact modelling, dynamic linear programming (DLP) modelling, modelling interphases and financial vulnerability assessment modelling. Empirically downscaled climate data from five global climate models (GCMs) served as base for the integrated modelling. The APSIM crop model was applied to determine the impact of projected climates on crop yield for certain crops in the study. In order to determine the impact of projected climates on crops for which there are no crop models available, a unique modelling technique, Critical Crop Climate Threshold (CCCT) modelling, was developed and applied to model the impact of projected climate change on yield and quality of agricultural produce. Climate change impact modelling also takes into account the projected changes in irrigation water availability (ACRU hydrological model) and crop irrigation requirements (SAPWAT3 model) as a result of projected climate change. The model produces a set of valuable results, viz. projected changes in crop yield and quality, projected changes in availability of irrigation water, projected changes in crop irrigation needs, optimal combination of farming activities to maximise net cash flow, and a set of financial criteria to determine economic viability and financial feasibility of the farming system. A set of financial criteria, i.e. internal rate of return (IRR), net present value (NPV), cash flow ratio, highest debt ratio, and highest debt have been employed to measure the impact of climate change on the financial vulnerability of farming systems. Adaptation strategies to lessen the impact of climate change were identified for each case study through expert group discussions, and included in the integrated modelling as alternative options in the DLP model. This aims at addressing the gap in climate change research, i.e. integrated economic modelling at farm level; thereby making a contribution to integrated climate change modelling.

Student: Steve Arowolo

Title: The Impact of Climate Variability on Food System Activities -–A Case Study of the Maize Value Chain in South Africa

Degree: PhD

University: University of Cape Town

Abstract:

Over a decade ago, during the year 2003/2004, seven out of the South African nine provinces were declared drought risk areas. Maize, the country's major crop produced for domestic and international markets was severely affected, with major shortages, thereby posing serious threat to the livelihoods of farmers, traders and consumers alike. Using a combination of historical climate, socio-economic and maize yield data over a 30 year period, the study investigates the possible impact of historical climate variability on the maize value chain in South Africa. Station climate data was used for precipitation and temperature from 1980 -2013 in the maize growing regions of South Africa. Maize storage, processing, distribution and consumption data were included in the correlation analysis. In order to emphasis the effects of short term variations in the climate, the study focuses on the possible impact of climate variability on the maize value chain variables, using case studies from the extreme climate events of 1991/1992 and 2003/2004 both representing pre and post maize market liberalization periods, respectively corresponding to ENSO years that do not necessarily represent a trend. Preliminary result shows that maize value chain variables were more sensitive to climate variability during the pre-maize market liberalization years.

Appendix B: Publications

Conference papers:

- Dr Oosthuizen presented a paper at SANCID 2012 Symposium South African National Committee on Irrigation and Drainage "Modelling the Financial Vulnerability of Farming Systems to Climate Change" 20-23 Nov 2012 Alpine Heath Drakensberg
- Dr Peter Johnston presented at The International Conference on Regional Climate – CORDEX 2013 held 4-7 November 2013 in Brussels, Belgium, "Using downscaled climate change scenarios to model the impact on farming systems from a financial vulnerability point of view", which was enthusiastically received by the audience.
- Dr Oosthuizen delivered a paper at the International Water Association conference in Mexico.: Oosthuizen, H.J., Louw, D.B., Schulze, R.E., Johnston, P.J., Lombard, J.P. and Backeberg, G.R. Modelling the impact of climate on the financial vulnerability of farms – a Hoedspruit irrigation farm case study. Paper presented at IWA Water Energy and Climate Conference 21-23 May 2014, Mexico.
- Dr Oosthuizen presented a poster at The International Crop Modelling Symposium, iCROPM2016 in Berlin in April 2016: Crop Critical Climate Threshold (CCCT) modelling as an alternative modelling technique to determine the financial impact of climate change on crop yield and quality – a South African case-study" in Session III – Crop modelling for risk/impact assessment.

Scientific Papers:

- Submitted to Agrekon for publication: Oosthuizen et al.: Modelling the impact of climate on the financial vulnerability of farms – a Moorreesburg dry land case study.
- In draft revision: Johnston and Kloppers: Climate risk, wheat yield variation and ocean – climate teleconnections: Options for adaptation – a Swartland case study.
- It is expected to produce at least one more paper on the use of thresholds as an adjunct for crop modelling.

Popular Articles

- An article on the project published in Nov/Dec 2015 issue of Water Wheel.
- An article in *Landbou weekblad* awaits publication
- Project website: www.csag.uct.ac.za/wrc/a4a.

Appendix C: Summary of crop critical climate threshold breaches

Summary of crop threshold breaches – LORWUA case study area

Wine grapes	Threshold Penalty weight - Yield	Threshold Penalty weight - Quality	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
			CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Tmxd > 38 °C for 5 days	-5%	0%	0	0	0	0	0	**0**	**0**	1	1	0	0	0	**2**	**0**
Tmxd> 45 °C in Nov	-5%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd> 42 °C Nov - Dec	-5%	0%	1	0	1	0	2	**4**	**1**	32	14	8	2	7	**63**	**13**
Difference Tmax and Tmnd > 20 °C in Dec	-5%	0%	1	0	1	0	0	**2**	**0**	7	3	2	0	3	**15**	**3**
Tmnd <9 °C and Tmxd < 20 °C May - Jun	10%	0%	16	16	17	25	16	**90**	**18**	3	3	9	2	2	**19**	**4**
Average temperature < 22 °C in summer	10%	0%	3	2	2	0	0	**7**	**1**	0	0	0	0	0	**0**	**0**
5 days above 40 °C	-5%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
> 33 °C for > 5 days with high Tmnd	0%	-5%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
5-10 mm rain Dec - Jan	0%	-5%	12	7	10	6	12	**47**	**9**	8	10	10	4	13	**45**	**9**
> 5 mm rain for 3 days Dec - Jan	0%	-5%	1	0	0	0	0	**1**	**0**	0	0	0	0	0	**0**	**0**
Any Rain from Dec to Apr = bursting/rotting	0%	-5%	20	19	20	17	20	**96**	**19**	20	20	20	17	20	**97**	**19**

Summary of crop threshold breaches – LORWUA case study area

Table grapes	Threshold Penalty weight Yield	Threshold Penalty weight Quality	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
			CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Tmxd > 38 °C for 5 days	0%	-5%	0	0	0	0	0	**0**	**0**	1	1	0	0	0	**2**	**0**
Tmxd > 45 °C in Nov	-10%	-5%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd > 42 °C Nov - Dec	-10%	-5%	1	0	1	0	2	**4**	**1**	32	14	8	2	7	**63**	**13**
Difference Tmax and Tmnd > 20 °C in Dec	-10%	-5%	1	0	1	0	0	**2**	**0**	7	3	2	0	3	**15**	**3**
Tmnd < 9 °C and Tmxd < 20 °C May - Jun	10%	10%	16	16	17	25	16	**90**	**18**	3	3	9	2	2	**19**	**4**
Average temperature < 22 °C in summer	10%	10%	3	2	2	0	0	**7**	**1**	0	0	0	0	0	**0**	**0**
Difference Tmxd and Tmnd < 10 °C Oct - Nov	0%	-5%	75	55	93	25	69	**317**	**63**	62	64	69	35	100	**330**	**66**
>33 °C for > 5 days with high Tmnd	0%	-5%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
5 - 10 mm rain Dec - Jan	0%	-5%	12	7	10	6	12	**47**	**9**	8	10	10	4	13	**45**	**9**
>5 mm for 3 days Dec - Jan	-10%	-5%	1	0	0	0	0	**1**	**0**	0	0	0	0	0	**0**	**0**

Summary of crop threshold breaches – LORWUA case study area

Raisins	Threshold Penalty weight Yield	Threshold Penalty weight Quality	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
			CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Tmxd > 38 °C for 5 days	-5%	0%	0	0	0	0	0	**0**	**0**	1	1	0	0	0	**2**	**0**
Tmxd > 45 °C in Nov	-10%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd > 42 °C Nov - Dec	-5%	0%	1	0	1	0	2	**4**	**1**	32	14	8	2	7	**63**	**13**
Difference Tmax and Tmnd > 20 °C in Dec	-5%	0%	1	0	1	0	0	**2**	**0**	7	3	2	0	3	**15**	**3**
Tmnd < 9 °C and Tmxd < 20 °C May - Jun	10%	0%	16	16	17	25	16	**90**	**18**	3	3	9	2	2	**19**	**4**
Average temperature < 22 °C in summer	10%	0%	3	2	2	0	0	**7**	**1**	0	0	0	0	0	**0**	**0**
5 days above 40 °C	-10%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
> 33 °C for > 5 days with high Tmnd	0%	-5%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
5 - 10 mm rain Dec - Jan	0%	-5%	12	7	10	6	12	**47**	**9**	8	10	10	4	13	**45**	**9**
> 5 mm for 3 days Dec - Jan	0%	-5%	1	0	0	0	0	**1**	**0**	0	0	0	0	0	**0**	**0**
Any Rain from Dec to Apr = bursting/rotting	0%	-5%	20	19	20	17	20	**96**	**19**	20	20	20	17	20	**97**	**19**

Summary of crop threshold breaches – Blyde River WUA case study area

Citrus Grapefruit	Threshold Penalty weight - Yield	Threshold Penalty weight - Quality	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
			CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Tmxd > 40 ^{0}C and RH < 30% for 2 days Sept	-40%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd >35 ^{0}C and RH < 30% for 2 days Sept	-40%	0%	0	0	0	0	1	**1**	**0**	0	0	0	7	1	**8**	**2**
Tmxd > 35 ^{0}C and RH < 20% for 2 days Sept	-40%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Fruit drop (Nov/Dec) >7 days of Tmxd > 36 ^{0}C and RH < 40%	-30%	-10%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
2 ^{0}C warmer in May - colour deteriorates	0%	-4%	0	0	3	0	2	**5**	**1**	18	18	19	10	16	**81**	**16**
During picking temp > 36 ^{0}C - increase rind problems	0%	-1%	89	119	119	58	146	**531**	**106**	332	520	505	232	460	**2 049**	**410**
>14 days continuous rain during picking (autumn) causes leaf wetness and overripe fruit	0%	-10%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**

Citrus Lemons	Threshold Penalty weight - Yield	Threshold Penalty weight - Quality	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
			CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Tmxd > 40 ^{0}C and RH < 30% for 2 days Sept	-25%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd >35 ^{0}C and RH < 30% for 2 days Sept	-15%	0%	0	0	0	0	1	**1**	**0**	0	0	0	7	1	**8**	**2**
Tmxd > 35 ^{0}C and RH < 20% for 2 days Sept	-15%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Fruit drop (Nov/Dec) >7 days of Tmxd > 36 ^{0}C and RH < 40%	-40%	-1%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
During picking temp > 36 ^{0}C - increase rind problems	0%	-1%	89	119	119	58	146	**531**	**106**	332	520	505	232	460	**2 049**	**410**
>14 days continuous rain during picking (autumn) causes leaf wetness and overripe fruit	0%	-15%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**

Citrus Valencia	Threshold Penalty weight - Yield	Threshold Penalty weight - Quality	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
			CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Tmxd > 40 ^{0}C and RH < 30% for 2 days Sept	-25%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd >35 ^{0}C and RH < 30% for 2 days Sept	-15%	0%	0	0	0	0	1	**1**	**0**	0	0	0	7	1	**8**	**2**
Tmxd > 35 ^{0}C and RH < 20% for 2 days Sept	-15%	0%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Fruit drop (Nov/Dec) >7 days of Tmxd > 36 ^{0}C and RH < 40%	-40%	-1%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
During picking temp > 36 ^{0}C - increase rind problems	0%	-1%	89	119	119	58	146	**531**	**106**	332	520	505	232	460	**2 049**	**410**
> 14 days continuous rain during picking (autumn) causes leaf wetness and overripe fruit	0%	-8%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**

Summary of crop threshold breaches – Blyde River WUA case study area

Mango Keitt	Threshold Penalty weight - Yield	Threshold Penalty weight - Quality	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
			CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Average May Tmnd 3 °C warmer	-4%	0%	0	0	2	0	0	**2**	**0**	14	19	14	15	13	**75**	**15**
Tmnd < 2 °C Jul - Aug	-4%	0%	1	4	6	2	2	**15**	**3**	0	0	0	0	0	**0**	**0**
Sept - Dec (HU requirement 350 hours > 17.9 °C) cool temps averaging < 17.9 °C cause late maturation and market delivery delay	0%	-10%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd > 38 °C Dec - Jan	-1%	-1%	5	13	10	0	10	**38**	**8**	24	58	37	0	30	**149**	**30**

Mango Kent	Threshold Penalty weight - Yield	Threshold Penalty weight - Quality	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
			CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Average May Tmnd 3 °C warmer	-8%	0%	0	0	2	0	0	**2**	**0**	14	19	14	15	13	**75**	**15**
Tmnd < 2 °C Jul - Aug	-8%	0%	1	4	6	2	2	**15**	**3**	0	0	0	0	0	**0**	**0**
Tmxd > 38 °C Sept	-1%	-1%	53	20	44	46	63	**226**	**45**	113	151	166	142	145	**717**	**143**
Sept - Dec (HU requirement 350 hours > 17.9 °C) cool temps averaging < 17.9 °C cause late maturation and market delivery delay	0%	-10%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd > 38 °C Dec - Jan	-1%	-1%	5	13	10	0	10	**38**	**8**	24	58	37	0	30	**149**	**30**

Mango Tommy Atkins	Threshold Penalty weight - Yield	Threshold Penalty weight - Quality	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
			CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Average May Tmnd 3 °C warmer	-6%	0%	0	0	2	0	0	**2**	**0**	14	19	14	15	13	**75**	**15**
Tmnd < 2 °C Jul - Aug	-6%	0%	1	4	6	2	2	**15**	**3**	0	0	0	0	0	**0**	**0**
Sept - Dec (HU requirement 350 hours > 17.9 °C) cool temps averaging < 17.9 °C cause late maturation and market delivery delay	0%	-20%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd > 38 °C Dec - Jan	-1%	-1%	5	13	10	0	10	**38**	**8**	24	58	37	0	30	**149**	**30**

Summary of crop threshold breaches – Moorreesburg case study area

Wheat	Threshold	Present dimate (1971 - 1990)							Intermediate future dimate (2046 - 2065)						
	Penalty weight	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Mid May - Aug Tmxd > 20 °C	-10%	0	0	0	0	0	**0**	**0**	14	17	5	10	20	**66**	**13**
Tmxd > 25 °C in Sept	-10%	0	0	0	0	0	**0**	**0**	0	2	1	0	2	**5**	**1**
Rainfal May - less than 50 mm	-10%	6	9	8	10	8	**41**	**8**	5	5	7	8	13	**38**	**8**
Rainfal May - Sept < 200 mm	-30%	1	5	3	4	0	**13**	**3**	1	0	1	2	4	**8**	**2**
Rainfal May - Sept > 400 mm	20%	1	2	2	2	1	**8**	**2**	2	3	3	4	1	**13**	**3**
Rainfal May - Sept > 10 mm/week	33%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Rainfal Sept weeks 1 and 2 > 10 mm	10%	16	12	14	12	13	**67**	**13**	14	15	12	10	11	**62**	**12**
Rainfal Sept weeks 3 and 4 > 10 mm	10%	8	7	7	6	9	**37**	**7**	7	8	8	9	9	**41**	**8**
May-Jun no rain	-10%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Jun - Jul < 70 mm	-10%	1	3	5	2	2	**13**	**3**	1	4	0	1	0	**6**	**1**
Jul - Aug < 70 mm	-10%	4	4	2	2	1	**13**	**3**	1	5	1	2	2	**11**	**2**
Sept < 15 mm	-10%	4	6	2	3	6	**21**	**4**	2	1	3	6	3	**15**	**3**
Sept < 5 mm	-10%	0	0	0	1	1	**2**	**0**	0	1	1	3	2	**7**	**1**

Summary of crop threshold breaches – Carolina case study area

Maize	Threshold Penalty weight	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
		CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Tmnd < -5 °C in Dec	-5%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd > 35 °C for 3+ days Jan - Feb	-5%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmnd < 12 °C in Nov	-1%	211	165	188	160	165	**889**	**178**	82	51	68	72	51	**324**	**65**
Rainfall < 40 mm in Oct	-5%	6	3	5	2	5	**21**	**4**	2	0	1	0	2	**5**	**1**
Rainfall < 60 mm in Nov	-5%	5	5	6	0	4	**20**	**4**	2	0	2	1	5	**10**	**2**
Rainfall < 80 mm in Dec	-5%	3	4	3	4	6	**20**	**4**	3	2	6	4	1	**16**	**3**
Rainfall < 100 mm in Jan	-15%	6	6	3	6	5	**26**	**5**	3	5	3	6	1	**18**	**4**
Rainfall < 60 mm in Feb	-5%	5	5	6	8	5	**29**	**6**	5	3	6	2	5	**21**	**4**
Rainfall > 80 mm in Feb	10%	12	10	10	10	10	**52**	**10**	10	13	9	13	14	**59**	**12**
Rainfall > 80 mm in Mar	10%	10	8	9	10	9	**46**	**9**	10	10	12	12	9	**53**	**11**
Rainfall > 160 mm in Feb - Mar	10%	13	8	10	10	11	**52**	**10**	11	14	14	15	8	**62**	**12**

Summary of crop threshold breaches – Carolina case study area

Soybeans	Threshold Penalty weight	Present dimate (1971 - 1990)							Intermediate future dimate (2046 - 2065)						
		CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Tmnd < -5 °C Oct - Jan	-50%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd > 28 °C for 3+ days in mid Jan - Feb	-5%	18	17	19	20	23	**97**	**19**	107	104	125	110	94	**540**	**108**
Average temperature > 25 °C in Nov	-10%	0	0	0	0	0	**0**	**0**	2	0	0	0	0	**2**	**0**
Tmxd > 35 °C Jan	-10%	0	0	0	0	0	**0**	**0**	0	0	0	0	1	**1**	**0**
Tmxd > 30 °C with low RH in Jan	-10%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Rainfall < 50 mm in Nov	-10%	5	5	6	0	4	**20**	**4**	2	0	2	1	5	**10**	**2**
Rainfall < 80 mm in Dec	-10%	3	4	3	4	6	**20**	**4**	3	2	6	4	1	**16**	**3**
Rainfall < 100 mm in Jan	-10%	6	6	3	6	5	**26**	**5**	3	5	3	6	1	**18**	**4**
Rainfall < 60 mm in Feb	-10%	5	5	6	8	5	**29**	**6**	5	3	6	2	5	**21**	**4**
Rainfall < 40 mm Jan	-10%	1	0	1	0	1	**3**	**1**	1	0	1	2	0	**4**	**1**
Rainfall > 60 mm and < 150 mm in Feb	5%	14	15	12	10	15	**66**	**13**	13	14	12	17	13	**69**	**14**
Rainfall > 60 mm and < 150 mm in Mar	5%	14	11	14	15	13	**67**	**13**	9	14	13	14	9	**59**	**12**
Rainfall > 120 mm and < 300 mm in Feb - M	5%	17	17	16	16	15	**81**	**16**	15	18	16	19	15	**83**	**17**

Summary of crop threshold breaches – Carolina case study area

Sugar beans	Threshold Penalty weight	Present climate (1971 - 1990)							Intermediate future climate (2046 - 2065)						
		CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models	CCC	CRM	ECH	GISS	IPS	Total All models	Avg All models
Tmnd < -5 °C Oct - Jan	-50%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd > 26 °C for 3+ days in mid Jan - Feb	-10%	62	50	53	61	55	**281**	**56**	166	146	157	147	135	**751**	**150**
Tmxd > 30 °C with high RH in Jan	-10%	0	0	0	0	0	**0**	**0**	0	0	0	0	0	**0**	**0**
Tmxd > 30 °C during Jan	-10%	5	5	6	0	4	**20**	**4**	2	0	2	1	5	**10**	**2**
Rainfall < 50 mm in Nov	-10%	3	4	3	4	6	**20**	**4**	3	2	6	4	1	**16**	**3**
Rainfall < 80 mm in Dec	-10%	6	6	3	6	5	**26**	**5**	3	5	3	6	1	**18**	**4**
Rainfall < 100 mm in Jan	-10%	5	5	6	8	5	**29**	**6**	5	3	6	2	5	**21**	**4**
Rainfall < 60 mm in Feb	-5%	9	9	11	9	9	**47**	**9**	12	11	13	10	13	**59**	**12**
Rainfall > 140 mm in Jan	5%	8	7	7	4	9	**35**	**7**	9	8	7	8	5	**37**	**7**
Rainfall > 60 mm en < 100 mm in Feb	5%	10	8	10	9	9	**46**	**9**	5	8	6	6	8	**33**	**7**
Rainfall > 60 mm en < 100 mm in Mar	5%	13	11	10	10	11	**55**	**11**	10	11	7	10	13	**51**	**10**