Managing climate risk for agriculture and water resources development in South Africa: Quantifying the costs, benefits and risks associated with planning and management alternatives

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- Irrigation representatives in the various regions for providing information on the areal extent of irrigation, crops grown, methods of irrigation and sources of water used

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EXECUTIVE SUMMARY

The Western Cape is an extremely important region to the economic development of South Africa. It is one of South Africa’s most valuable agricultural producing regions and makes a substantial contribution to the country’s balance of payments. Almost all the land that is farmed with high value export crops in this region is under irrigation. Increasing competition for water has resulted in the construction of a number of smaller water storage reservoirs in the last twenty years. The Berg River Dam with a storage capacity of around 130,000 cubic metres was completed in 2007 and more reservoirs are on the drawing boards, but the number of suitable dam sites left for development is quite small, as is their total storage capacity.

The latest release of the Western Cape Water Supply System (WCWSS) Reconciliation Strategy covers the period October 2010 to March 2011. According to the study only a few surface water development options are available for augmenting water supply to the City of Cape Town and surrounding towns. Against this backdrop of rapid water demand growth and increasing competition between agricultural and urban water users, are the issues of local climate variability and climate change.

Clearly an integrated approach encompassing climate, water, the economy and local development agendas is required to ensure the long-term sustainability of all parties and practises. This project addressed two significant problems related to adaptation to climate change in the water resources sector.

1. The first is that relevant and important information from climate change forecasts is not being disseminated to water resource managers, nor is it being integrated into water resources policy, planning and management in a systematic way for agricultural and human use in Africa.

2. The second, related problem is that there is currently a shortage of integrated approaches for evaluating and making adaptation decisions related to water resources in Africa.

Taken together, the lack of awareness and capacity to adapt gives rise to the following priorities:

- To develop and demonstrate the quantitative and qualitative tools and methods to conduct integrated assessments of adaptation decisions vis-à-vis climate change and climate variability,
- To develop the capacity within Africa to use these tools, and
- To develop a much broader understanding of how using these tools will benefit Africa.

During 2007, the University of the Free State (UVS) in collaboration with the University of Cape Town (UCT), the University of Kwazulu-Natal, School of Bioresources Engineering & Environmental Hydrology, the International Research Institute for Climate and Society, Columbia University (IRI) and the UNEP-RISØ Collaborating Centre (URC) at the Technical University of Denmark managed to
secure donor funding from the International Development Research Centre (IDRC). CCAA is a joint program established by the International Development Research Centre (IDRC), Canada, and the Department for International Development (DFID) in April 2006 to improve the capacity of African countries to adapt to climate change.

The description of the Berg and Breede River catchments in Chapter 2 highlighted the complexity of the water management issues in these regions. The description of the water supply and requirements of the irrigation regions provide a background of the dimensions of the study region to be modelled. These dimensions can be summarised as follows:

- During the winter (rainy season) there is ample water but in the summer (dry season) there is severe pressure on the resource due to both a high irrigation and urban demand.
- Few dam sites (and other water supply augmentations) remain for which additional storage capacity can be developed without very high cost (financial and environmental).
- During the summer months the evaporation losses are very high due to high temperatures.
- High-value export crops are being produced in both the Berg and Breede River water catchments. This renders these regions as strategic pillars of the economy of the Western Cape province because of its multiplier effects. According to Eckert et al (1997), approximately 65% of all secondary industries are dependent on agriculture.
- Although water demand strategies have been implemented to curb the growth in urban water use, these strategies can only alleviate the problem; they cannot solve it.
- There is mounting pressure to reallocate water from agricultural use to urban use.

A detailed discussion of the modelling framework follows in Chapter 3. The discussion focuses on the three key modules. They are:

- The regional climate change module – downscaling Global Climate Models.
- A hydrological module. Using the ACRU model to estimate incremental runoff at specific locations within the study region.
- A dynamic programming module with three components:
  - Regional typical farm models (21 farms) to simulate the demand for agricultural water under different climate regimes (scenarios).
  - An intertemporal 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 makes provision for external inputs such as:

- Policies, plans and technology options for increasing water supplies
- Reducing water demand through water demand management options.

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 key climate change scenarios and downscaling results are discussed as well as the impact on the hydrology of the region. The hydrological impacts of climate change are more evident in the distant future (2046-2065) than the near future (2011-2030) as the effects of global warming gain momentum. This is seen in the differences between the High and Low scenarios of the distant future (in terms of rainfall and runoff) when compared to the near future. It is also seen in changes in potential evaporation (driven by increasing temperatures) where no change is projected in the near future, but changes of up to 10% are projected for the distant future.

When comparing the differences between the High and Low scenarios for the different periods (near and distant future), it should be remembered that the scenarios are driven by different processes in the two periods, i.e. in the near future the High and Low scenarios are represented by percentile outputs of the same model and incorporate decadal variability as well as climate change signals, while the High and Low scenarios in the distant future are represented by different models and focus only on climate change. In addition, different emissions scenarios were assumed for the two periods, i.e. A1B for the near future and A2 for the distant future.

In general, the results show that where means of rainfall (and runoff) increase, the variability decreases. This implies that under wetter conditions, rainfall becomes less erratic. This observation is supported by the changes noted in the 10th percentile of annual dam inflows (representative of very dry years), where large increases were projected for the IRI High (near future) and UCT High (distant future) scenarios compared to the corresponding Low scenarios for which both increases and decreases (of relatively small magnitudes) were projected.

The pattern of change in rainfall for the future will not necessarily be consistent throughout the 21st century. An analysis of far distant future (2081-2100) annual rainfall revealed that the direction of change according to the “High” scenario GCM changes from an increasing (distant future) to a decreasing (far distant future) pattern while the pattern for the “Low” scenario GCM remains largely unchanged. It is also in the latter half of the century when there is greater divergence in the emissions scenarios, and thus by implication in the projected climate, adding further uncertainty to this period.

The divergence in runoff results between High and Low scenarios for the distant future implies greater uncertainty which must be incorporated in planning decisions. In contrast, there is much greater certainty regarding the changes expected for temperature and potential evaporation. This implies that decisions related to changes in temperature and potential evaporation can be made with greater confidence, although for many decisions there is a co-dependence with water availability which needs to be considered. A shortcoming of the research is that more GCMs were not considered in the hydrological and economic simulations (this limitation was due to time and computing constraints), as this may have given an indication as to whether there is a greater tendency towards either the High or Low scenarios in terms of water availability. In this context it follows that ‘no’ or ‘low regret’ adaptation options are the most pragmatic.

The results of the integrated modelling exercise are discussed in Chapter 4. The objective of the modelling exercise was to demonstrate that it is possible to develop an integrated modelling framework for evaluating and making adaptation decisions related to water resources in the Western Cape. It should be possible to duplicate the
integrated framework elsewhere in Africa once the methodology has been streamlined.

More than 125 model runs were executed to demonstrate the integrated modelling framework (excluding the model runs for validation) for the purpose of this project which was presented on 22\textsuperscript{nd} of September 2011 at a regional workshop in Paarl, South Africa. However, for the sake of brevity only two sets of results are presented in this report. These are:

- **Set 1**: Comparing the base analysis for all the climate change scenarios which were discussed earlier in this report.
- **Set 2**: Illustrating an increase in farm dam capacity of 20\% as an adaptation strategy to climate change. The relative changes compared to the base analysis are presented and discussed.

The Set 1 analysis which is described in Chapter 4 gives a clear indication that the integrated modelling framework can be used to simulate various climate change scenarios and that the results corresponds with what can be expected from the impact on runoff, the farming systems, and urban water use.

The Set 2 analysis clearly illustrated that the development of 20\% additional farm dam capacities is not a good adaptation strategy for the Low flow scenarios. If the farm dams don’t fill up, it may even worsen the situation of farmers since the high capital cost and resulting high unit cost of farm dam water will increase their financial vulnerability. A more effective adaptation strategy in the Low flow scenario would be to increase overall irrigation efficiency and to make structural changes (increase the ratio of short-term to long-term crops).

A key objective of this project was to develop the capacity within Africa to use the integrated analysis tools and to develop a much broader understanding of how using these tools will benefit Africa. In this regard several actions were executed which are discussed in Chapter 5.

It is very difficult to make a quantitative assessment of what the impact was of this project since projects of this nature is often of too short duration to really estimate if there was a real impact on change in behavior. However, Chapter 6 discusses some of the observations. These are:

- The project made a contribution towards raising awareness on climate change and adaptation at all levels of society – the general public, farmers, water managers, local, provincial and national government and in the research fraternity.
- The project contributed towards capacity building in climate change and the analysis tools to assess vulnerability and adaptation strategies by training and short courses to several students.
- Finally, the integrated modelling framework which was developed is unique. It has not been done anywhere in Africa and very few other places in the world. The project therefore also contributed towards the improvement of the methodologies to study the impact of climate change, climate vulnerability and evaluation methodology of adaptation strategies.

The report is concluded with Chapter 7 with key conclusions and recommendations. The key conclusions are:
• Responding to climate change impacts through appropriate adaptation and mitigation mechanisms requires practical resilient solutions in the form of technological, social and economic aspects. These can be developed through systematic research on climate change and associated impacts. In many African countries there is limited research on climate change and related impacts on livelihood, natural resources. This is partly attributed to limited funding for research on climate change impacts, adaptation and mitigation; limited focus and prioritization by researchers to study climate change; inadequate facilities for collection of weather information on climate change by region. Overall this has an implication of limited knowledge and information on appropriate options to support climate change adaptation and mitigation thereby increasing vulnerability to climate change impacts at all levels.

• South Africa is blessed by the fact that there are researchers and adequate facilities to conduct research that will improve knowledge on how the technical, social and economic elements of climate change can be integrated to provide a holistic solution to adaptation to climate change.

• Finally the authors believe that the models / methodology can never be regarded as final since they have to be developed continuously as new technology and knowledge becomes available. It should therefore be obvious that there is a need for follow up research.

The following recommendations are made for future research:

• The generation of decadal climate projections for the distant future and calculation of appropriate percentiles to represent High, Medium and Low scenarios to assess the influence of decadal climate variability for this period (2046-2065), and to translate these into runoff impacts;

• The incorporation of a more sophisticated climate change signal into the decadal projections accounting for the variation in the IPCC global projections rather than simply assuming the multi-model mean;

• Include other emissions scenarios in near and distant future projections to assess the full range of possible climate and runoff outcomes;

• For the distant future, where regional projections are developed by downscaling individual GCM projections, to include downscalings of multiple GCMs in runoff simulations, rather than only a High and a Low scenario where there is no indication if other available models tend more towards the High or Low GCM (regarding the degree of model consensus).

• It was pointed out that there is a need for more research to increase the sensitivity of the farm models to climate change variables (temperature and water availability).

• Finally, it is also recommended to continue discussion with the Western Cape System Analysis team to incorporate the models in the tools to evaluate water management options and to contribute towards improved policies and strategies to adapt to climate change.
Contents
ACKNOWLEDGEMENTS ........................................................................................................i
EXECUTIVE SUMMARY ....................................................................................................ii
LIST OF TABLES ..................................................................................................................1
LIST OF FIGURES ................................................................................................................1
1. INTRODUCTION .............................................................................................................3
  1.1 INTRODUCTION .........................................................................................................3
  1.2 OBJECTIVES OF THE STUDY .......................................................................................5
  1.3 CHAPTER OUTLINE .....................................................................................................6
2 DESCRIPTION OF THE STUDY REGION ...........................................................................7
  2.1 INTRODUCTION .........................................................................................................7
  2.2 THE BERG RIVER .........................................................................................................7
  2.3 THE BREEDE RIVER .....................................................................................................9
  2.4 DEMARCATION OF THE TOTAL STUDY AREA ..............................................................12
  2.5 URBAN WATER SECTOR .............................................................................................13
  2.6 SUMMARY ..................................................................................................................14
3 INTEGRATED ASSESSMENT OF ADAPTATION DECISIONS ..............................................15
  3.1 INTRODUCTION .........................................................................................................15
  3.2 CLIMATE CHANGE MODELS AND DOWNSCALING (University of Cape Town) 17
    3.2.1 Background ...........................................................................................................17
    3.2.2 Methodology .........................................................................................................17
    3.2.3 CAM3 forecast verification .....................................................................................17
    3.2.4 Downscaling results for the Berg and Breede River catchments .......................21
  3.3 HYDROLOGICAL MODELING .......................................................................................23
    3.3.1 Methodology .........................................................................................................23
    3.3.2 Hydrological modeling results ..............................................................................31
  3.4 INTERTEMPORAL SPATIAL EQUILIBRIUM MODEL .....................................................47
  3.5 KEY CHARACTERISTICS OF THE AGRICULTURAL AND URBAN WATER DEMAND AND THE MODELING APPROACH ...............................................................55
    3.5.1 Agricultural water ....................................................................................................55
    3.5.2 Urban water ............................................................................................................58
  3.6 Summary .....................................................................................................................62
4 INTEGRATED MODEL RESULTS .......................................................................................64
  4.1 INTRODUCTION .........................................................................................................64
  4.2 COMPARISON OF BASE CLIMATE CHANGE SCENARIOS .........................................65
  4.3 ADAPTATION SCENARIO – 20% INCREASE IN FARM DAM CAPACITY71
  4.4 SUMMARY ..................................................................................................................78
5 CAPACITY BUILDING AND AWARENESS RAISING ............................................ 79
5.1 INTRODUCTION ........................................................................................................... 79
5.2 Appointment of a Steering Committee (SC) ................................................................. 79
5.3 Training of students ...................................................................................................... 80
5.4 Awareness raising ........................................................................................................ 81
  5.4.1 Electronic and printed media .................................................................................. 81
  5.4.2 Workshops and contributions at information days ................................................. 82
  5.4.3 Individual and group discussions with stakeholders ................................................ 83
5.5 SUMMARY ....................................................................................................................... 88
6 QUALITATIVE ASSESSMENT OF THE IMPACT OF THE PROJECT .................. 89
  6.1 INTRODUCTION ........................................................................................................... 89
  6.2 ASSESSMENT OF VULNERABILITY TO IMPACTS OF CLIMATE VARIABILITY AND
CHANGE ................................................................................................................................. 89
  6.3 THE PROJECT HAS DEVELOPED OPTIONS FOR ENHANCING ADAPTIVE CAPACITY ......................................................................................................................... 89
  6.4 TRANSFERRING EXPERTISE INTO NEW PROJECTS, COMMUNITIES AND
SCIENTIFIC INITIATIVES ...................................................................................................... 90
  6.5 FACILITATING KNOWLEDGE SHARING PROCESSES AMONGST VULNERABLE
GROUPS, CIVIL SOCIETY, POLICY MAKERS AND RESEARCHERS ........................................ 91
  6.6 PARTICIPATING IN KNOWLEDGE SHARING NETWORKING ..................................... 91
  6.7 INVOLVEMENT OF STAKEHOLDERS IN ADAPTATION RESEARCH THAT
RESPONS TO THEIR NEEDS .................................................................................................. 92
  6.8 RESEARCH FINDINGS CONTRIBUTE TO THE DEVELOPMENT OF ADAPTATION
POLICIES AND PLANS ....................................................................................................... 92
  6.9 SUMMARY ....................................................................................................................... 92
7 CONCLUSIONS AND RECOMMENDATIONS .................................................... 94
  7.1 CONCLUSIONS ............................................................................................................ 94
  7.2 RECOMMENDATIONS .................................................................................................. 95
REFERENCES ....................................................................................................................... 96
Appendix 1: Slopes of area: volume for dams ................................................................. 98
Appendix 2: Training material ........................................................................................... 100
Appendix 3: Project profile ............................................................................................... 101
Appendix 4: Regional workshop agenda + notes .............................................................. 102
Appendix 5: Scenario results ............................................................................................. 105
Appendix 6: OM framework ............................................................................................. 106
LIST OF TABLES

Table 3.1: Main storage dams in the study area ................................................................. 24
Table 3.2: Sources of information used to develop inputs to the ACRU model .................. 27
Table 3.3: Summary of climate projections applied in hydrological modelling ................ 29
Table 3.4: Percentage changes in mean summer, winter and annual accumulated runoff for each river basin according to the IRI High, IRI Medium and IRI Low scenarios ........ 35
Table 3.5: Percentage changes in mean summer, winter and annual accumulated runoff for each river basin for the UCT High and UCT Low scenarios ........................................... 42
Table 3.6: Bulk storage capacity of the WCWS 2007-2011 .............................................. 59

LIST OF FIGURES

Figure 2.1: Description of the Berg River basin and inter basin transfers from the Breede .... 8
Figure 2.2: Estimated irrigated land use in the Berg River basin ........................................ 9
Figure 2.3: Estimate rain fed land use in the Berg River Basin ........................................... 9
Figure 2.4: The Breede Water Management Area (WMA) .................................................. 11
Figure 2.5: Aggregated agricultural land use in the Breede part of the study region .......... 12
Figure 2.6: Demarcation of the total study regions ............................................................ 13
Figure 3.1: Schematic diagram of the Berg River Dynamic Spatial Equilibrium Model (BRDSEM) .................................................................................................................. 16
Figure 3.2: Mean rainfall over southern Africa from CMAP (top panel), CAM3 (middle panel) and mean error (lower panel) for summer (left panel) and winter (right panel) .... 18
Figure 3.3: ROC scores, defined as the area under the ROC curve, for the total rainfall is tested for 26 year forecasts and only significant values are shown ......................... 19
Figure 3.4: Brier Score (a) and Brier Skill Score (b) from DJF (left panel) and JJA (right panel) rainfall forecast over southern Africa for the total rainfall is tested for 26 year forecasts .............. 19
Figure 3.5: Winter (JJA) rainfall anomaly projections (2046-2065) for SA ......................... 21
Figure 3.6: Summer (DJF) rainfall anomaly projections (2046-2065) for SA ...................... 21
Figure 3.7: Projected changes in rainfall pattern and magnitude; Monthly Total anomalies, Downscaling to a 0.1º precipitation grid ......................................................... 22
Figure 3.8: Projected temperature anomalies (a) DJF (b) MAM (c) JJA and (d) SON .......... 23
Figure 3.9: Layout of the study area ................................................................................. 24
Figure 3.10: Representative farms identified in the study area ......................................... 25
Figure 3.11: Subcatchments delineated in the study area .................................................. 26
Figure 3.12: Schematic of major processes represented in the ACRU model (after Schulze, 1995) ....................................................................................................................... 26
Figure 3.13: Comparison of monthly totals and accumulated monthly totals of daily simulated and observed streamflows for the Koekedou and Upper Breé WMUs in the Upper Breede Catchment ........................................................................................................... 26
Figure 3.14: Ratios of near future to present mean annual rainfall, potential evaporation and runoff for the IRI High, IRI Medium and IRI Low scenarios ................. 33
Figure 3.15: Ratios of near future to present standard deviation of annual rainfall, potential evaporation and runoff for the IRI High, IRI Medium and IRI Low scenarios .......... 34
Figure 3.16: Ratios of near future to present statistics of monthly accumulated winter inflows to major dams for the IRI High scenario ................................................. 36
Figure 3.17: Ratios of near future to present statistics of monthly accumulated winter inflows to major dams for the IRI Low scenario ....................................................... 37
Figure 3.18: Ratios of near future to present statistics of annual accumulated inflows to major dams for the IRI High scenario ................................................................. 39
Figure 3.19: Ratios of near future to present statistics of annual accumulated inflows to major dams for the IRI Low scenario ................................................................. 39
Figure 3.20: Ratios of distant future to present mean annual precipitation, potential evaporation and runoff for the UCT High and UCT Low scenarios ................................................................. 40
Figure 3.21: Ratios of distant future to present standard deviation of annual precipitation, potential evaporation and runoff for the UCT High and UCT Low scenarios .................................................................................................................. 41
Figure 3.22: Ratios of distant future to present statistics of monthly accumulated winter inflows to major dams for the UCT High scenario .................................................................................................................. 43
Figure 3.23: Ratios of distant future to present statistics of monthly accumulated winter inflows to major dams for the UCT Low scenario .................................................................................................................. 44
Figure 3.24: Ratios of distant future to present statistics of annual accumulated inflows to major dams for the UCT High scenario .................................................................................................................. 45
Figure 3.25: Ratios of distant future to present statistics of annual accumulated inflows to major dams for the UCT Low scenario .................................................................................................................. 45
Figure 3.26: Area east of the Theewaterskloof dam .................................................................................................................. 49
Figure 3.27: The area South West of the Theewaterskloof dam .................................................................................................................. 50
Figure 3.28: Connections for inter basin transfers between the Breede River and the Berg River catchment .................................................................................................................. 51
Figure 3.29: Upper Berg River Basin .................................................................................................................. 52
Figure 3.30: Lower Berg River .................................................................................................................. 53
Figure 3.31: Tulbach, 24-Rivers and Voëlvlei to Berg .................................................................................................................. 54
Figure 3.32: Conceptual modelling framework .................................................................................................................. 56
Figure 3.33: The process of identifying representative farm boundaries and water sources in the study area .................................................................................................................. 57
Figure 3.34: Representative farms in the study area .................................................................................................................. 57
Figure 3.35: Conceptualization of water flows within and between representative farms .................................................................................................................. 58
Figure 3.36: Water demand per urban water use sector (CCT, 2006) .................................................................................................................. 60
Figure 3.37: Estimated population for Cape Town (2001-2021) .................................................................................................................. 60
Figure 3.38: Estimated water demand for the CTC .................................................................................................................. 61
Figure 4.1: Average annual incremental runoff .................................................................................................................. 65
Figure 4.2: Base comparison – irrigation intensities .................................................................................................................. 66
Figure 4.3: Base comparison - crop combination .................................................................................................................. 66
Figure 4.4: Total average agricultural water use per annum .................................................................................................................. 67
Figure 4.5: Average annual crop water use per ha .................................................................................................................. 67
Figure 4.6: Average annual urban water demand .................................................................................................................. 67
Figure 4.7: Average monthly main dam storage .................................................................................................................. 68
Figure 4.8: Total income and costs for the urban water sector .................................................................................................................. 68
Figure 4.9: Total cost of agricultural water .................................................................................................................. 69
Figure 4.10: Net Disposable Farm Income – total over 20-years .................................................................................................................. 69
Figure 4.11: Total welfare – objective function value .................................................................................................................. 70
Figure 4.12: Average capitalised marginal value of agricultural water .................................................................................................................. 70
Figure 4.13: Irrigation intensity ...................................................................................................................................................... 71
Figure 4.14: Crop combinations ...................................................................................................................................................... 72
Figure 4.15: Agricultural water use ...................................................................................................................................................... 73
Figure 4.16: Urban water demand ...................................................................................................................................................... 73
Figure 4.17: Average monthly urban demand ...................................................................................................................................................... 74
Figure 4.18: Average monthly main dam storage ...................................................................................................................................................... 75
Figure 4.19: Total urban water costs and income from urban water sales ...................................................................................................................................................... 76
Figure 4.20: Costs of agricultural water ...................................................................................................................................................... 76
Figure 4.21: Net Disposable Farm Income over 20-years ...................................................................................................................................................... 76
Figure 4.22: Total welfare – objective function value ...................................................................................................................................................... 77
Figure 4.23: Capitalised marginal value of agricultural water ...................................................................................................................................................... 77
Figure 4.24: Average annual incremental runoff ...................................................................................................................................................... 78
Figure 1: Schematic representation of the project and the boundary partner ...................................................................................................................................................... 108
1. INTRODUCTION

1.1 INTRODUCTION
The Western Cape is an extremely important region to the economic development of South Africa. It is one of South Africa’s most valuable agricultural producing regions and makes a substantial contribution to the country’s balance of payments. Almost all the land that is farmed with high value export crops in this region is under irrigation. In recent years, the economy of the region has received an added stimulus from tourism, with visits to Cape Town from Europe, Asia, and North America growing at an annual rate of over 10 per cent. Growth in the tourism industry has created a boom in the local building industry and this growth has been supplemented by equally rapid growth in the construction of vacation and retirement housing. Not surprisingly, the population in Metropolitan Cape Town and a number of smaller cities in the region is also growing rapidly, swelled by the demand for jobs in the construction and services industries related to tourism.

As this has happened, the demand for water in Metropolitan Cape Town has increased around 4 per cent per year over the last decade, more than tripling since the late 1970s (Louw & Van Schalkwyk, 2001). Increasing competition for water has resulted in the construction of a number of smaller water storage reservoirs in the last twenty years. The Berg River Dam with a storage capacity of around 130,000 cubic metres was completed in 2007 and more reservoirs are on the drawing boards, but the number of suitable dam sites left for development is quite small, as is their total storage capacity.

The latest release of the Western Cape Water Supply System (WCWSS) Reconciliation Strategy covers the period October 2010 to March 2011. According to the study only a few surface water development options are available for augmenting water supply to the City of Cape Town and surrounding towns. However the Department is leading efforts to explore alternatives to ensure sufficient water is available for future use. Water conservation is however a major component of the strategy to secure sufficient water.

Population growth and the subsequent growth in the economy have been identified as major factors that are placing exponential strain on the water available for users of the Western Cape Water Supply System (WCWSS). These users include the City of Cape Town, as well as the municipalities of Stellenbosch, Drakenstein, Swartland and Saldanha as well as agricultural users.

At present the system can safely provide 556 million m$^3$ (cubic meters) per year. The 2010 water requirement on the system was already 511 million m$^3$ (cubic meters) of which 32% was used by the irrigation farmers and 68% by the urban dwellers supplied by the system. According to projections, the remaining 45 million m$^3$ will be fully utilised anywhere between 2017 and 2019 - depending on the growth in the area and the City’s and its residents further successful implementation of its water conservation and water demand management programme.

Against this backdrop of rapid water demand growth and increasing competition between agricultural and urban water users, are the issues of local climate variability and climate change. The climate of the Western Cape can be characterised as a Mediterranean climate, with most of the rainfall occurring during the winter months. It is one of the few regions to
demonstrate consistent projections of climate change. These scenarios suggest a future reduction in available rainfall, which will exacerbate an already water-stressed region. On top of this, the region has experienced a series of unusual droughts in the last decade, the most recent of which during 2004-2005, left the region critically short of water, resulting in a roughly thirty per cent decline in irrigated agricultural production in the Berg River basin and forcing Cape Town and the local municipalities in the region to ration water. At present it is unclear whether these droughts are a consequence of climate change or multi-decadal variability. Though they are projected to occur more frequently in scenarios of future climate change, they potentially result from the combination of variability on both multi-decadal and longer timescales. Early in the 20th century drought periods of up to 6 years occurred, stimulating the search for new sources and demonstrating that persistent drought conditions have occurred before. If climate change leads to an increased frequency of drought years, the statistical possibility of a crippling drought of 3 years or longer, will increase.

The regional picture is further complicated due to the socio-economic realities and priorities at the municipal, provincial and governmental levels. As previously indicated, the Western Cape is currently undergoing rapid population growth. Much of this is due to high rates of immigration, largely of relatively poor peoples who arrive in search of jobs and opportunities, and who settle in the poorest townships. The resulting increased competition for water is the result of a two-edged sword, as the agricultural and urban services sectors provide livelihoods for the rural population as well as contributing to the local economy.

Also, since 1994, after the election of a democratic government, a new strategy of land reform was initiated with the objective to transfer at least 30% of the available agricultural land and water in the country to previously disadvantaged individuals (PDI’s). Although the process has been slow, most of the successful land reform projects in the Western Cape have been in the fruit and wine industry. According to most climate change estimates, the fruit sector will be the most vulnerable due to increases in winter temperature. It is therefore of paramount importance to develop adaptation strategies for these new, mainly resource poor farmers (probably the most vulnerable).

Clearly an integrated approach encompassing climate, water, the economy and local development agendas is required to ensure the long-term sustainability of all parties and practises. This project addressed two significant problems related to adaptation to climate change in the water resources sector.

1. The first is that relevant and important information from climate change forecasts is not being disseminated to water resource managers, nor is it being integrated into water resources policy, planning and management in a systematic way for agricultural and human use in Africa.

In this regard the problem statement evolved from a broad statement to a more specific one to target the Catchment Management Agencies (CMA’s) of the Berg and the Breede River. It should be obvious that it will not be possible to implement adaptation and mitigation strategies without institutional support. South Africa is blessed with a water act that makes provision for strong institutional governance developed at the river catchment level to manage water resources. All efforts are directed towards integrating climate change into water resources policy and planning at the catchment level (the primary decision making unit).

2. The second, related problem is that there is currently a shortage of integrated approaches for evaluating and making adaptation decisions related to water resources in Africa. Taken together, the lack of awareness and capacity to adapt gives rise to the following priorities:
To develop and demonstrate the quantitative and qualitative tools and methods to conduct integrated assessments of adaptation decisions vis-à-vis climate change and climate variability,

- To develop the capacity within Africa to use these tools, and
- To develop a much broader understanding of how using these tools will benefit Africa.

This problem also evolved from a broad problem statement towards a more specific one. The primary planning tool for water resources management in the Western Cape is the Western Cape Systems Analysis which is being used mainly for water supply and water demand management. However, a major shortcoming in the analysis tools is the economic impact of various water supply and demand management options as well as the impact of climate change and variability. It is therefore of paramount importance to work in close collaboration with the scientists and engineers who are responsible for the Western Cape Systems Analysis to ensure that the integrated set of analysis tools that are being developed in this study are accepted as part of the "tool kit" of the Western Cape Systems Analysis.

During 2007, the University of the Free State (UVS) in collaboration with the University of Cape Town (UCT), the University of Kwazulu-Natal, School of Bio resources Engineering & Environmental Hydrology, the International Research Institute for Climate and Society, Columbia University (IRI) and the UNEP-RISØ Collaborating Centre (URC) at the Technical University of Denmark managed to secure donor funding from the International Development Research Centre (IDRC) within The Climate Change Adaptation in Africa Research and Capacity Development Programme (CCAA) on the topic:

"Managing climate risk for agriculture and water resources development in South Africa: Quantifying the costs, benefits and risks associated with planning and management alternatives."

CCAA is a joint program established by the International Development Research Centre (IDRC), Canada, and the Department for International Development (DFID) in April 2006 to improve the capacity of African countries to adapt to climate change.

1.2 OBJECTIVES OF THE STUDY

The project addressed two significant problems related to adaptation to climate change in the water resources sector. The first is that relevant and important information from climate change forecasts is not being disseminated to water resource managers, nor is it being integrated into water resources policy, planning and management in a systematic way for agricultural and human use. The second, related problem is that there is currently a shortage of integrated approaches for evaluating and making adaptation decisions related to water resources in Africa. Taken together, the lack of awareness and capacity to adapt gives rise to the following priorities:

- To develop and demonstrate the quantitative and qualitative tools and methods to conduct integrated assessments of adaptation decisions vis-à-vis climate change and climate variability,
- To develop the capacity within Africa to use these tools, and
- To develop a much broader understanding of how using these tools will benefit Africa.

The execution of the study consisted of six key tasks. These were:

- Task 1: Capacity building: Establishment of a representative steering committee, transfer models and methods to stakeholders (workshops) and training of researchers.
1.3 CHAPTER OUTLINE

The study is primarily concerned with “Managing climate risk for agriculture and water resources development in South Africa: Quantifying the costs, benefits and risks associated with planning and management alternatives”.

The present chapter is followed by a comprehensive description of the Berg and Breede River basin. This is followed by a description of the methodologies which were used to develop an integrated analytical model to quantify the costs, benefits of climate change adaptation strategies in Chapter 3.

In Chapter 4, several climate change base scenarios are analysed to demonstrate the impact of climate change without adaptation followed by a demonstration of how the model can be used to evaluate the impact of a adaptation strategy (20% increase in farm dam capacity). Chapter 5 gives an overview of the awareness raising and capacity building activities which were part of this project. Chapter 6 deals with a qualitative assessment of the potential impact of this project.

The final chapter consists of conclusions and recommendations.
2 DESCRIPTION OF THE STUDY REGION

2.1 INTRODUCTION

The Western Cape Water Supply System (WCWSS) serves the City of Cape Town (CCT), surrounding urban centres and irrigators. It consists of infrastructure components owned and operated by both the CCT and the Department of Water Affairs (DWA). The initial proposal for this study only included the Berg River basin. However, since there is inter basin transfers between the Breede and the Berg River basin, it was decided to also include water supply sources of the Breede River basin (only parts of it, specifically the Sonderend, Palmiet and Steenbras Rivers) where basin transfers occur which is relevant to this study. The following two sections give a condensed summary of the Berg River basin and parts of the Breede River basin.

2.2 THE BERG RIVER

The upper region of the Berg River Basin is surrounded by high mountain ranges (RL 1500 m) to the south, east and west. The river basin is fairly narrow (10-15 km) between the sources (Groot Drakenstein) and Wellington. Northwards of Wellington, the Limietberg continues to bound the valley to the west. In the east, the basin levels out and the river valley widens to approximately 25 km (DWAF, 1993e). Figure 2.1 is a graphical presentation of the study region.

The climate which prevails in the Berg River Basin is typical of the Western Cape Region. This region is classified as a humid zone and experiences winter rainfall together with high summer evaporation. Precipitation is from cold fronts approaching the area from the north-west. As a result of the topographical influence of the mountains, a large spatial variability is experienced in the mean annual precipitation (MAP). In the high lying areas of the Groot Drakenstein, the MAP is around 2 600 mm, while further northwards, where the Berg River Basin levels out, the MAP drops to below 500 mm (DWAF, 1993e).

The area is characterised by a significant seasonal variation in monthly evaporation, which is typically 40 to 50 mm in winter, and 230 to 250 mm in the summer months. The mean annual evaporation throughout the basin show less spatial variability than the mean annual precipitation. The high rainfall/low evaporation during winter and low rainfall/high evaporation during summer is an important climatic feature of the Western Cape Region (DWAF, 1993e).

Land in the Upper Berg River area is primarily used for viticulture and to a lesser extent, for fruit farming. A portion of the land is irrigated with water either collected in farm dams or abstracted directly from the river and its tributaries. Lucerne, vegetables and other crops are also grown, but only in small amounts. Forestry is found throughout the Berg River Basin, but predominates in the high altitude and rainfall areas.

The Berg River is an important water supply source to the agricultural as well as the urban water use sectors. The Berg River basin is an interesting case study because of its complex nature, the fact that it supplies amongst others water to the Cape Metropolis and also because of its strategic importance for high valued summer crops in the winter rainfall region of the Western Cape.
In the Lower Berg River areas, towards the north, land utilisation changes from wine farming to dryland grain farming. Apart from crops and forestry, indigenous "fynbos" vegetation is found in most areas. This growth varies from dense concentrations in gulleys to sparse coverings on rocky mountain slopes (DWAF, 1993e).

It is clear from Figure 2.2 that approximately 27% of the irrigated land is used for white wine production, 26% for red wine and 16% for table grapes. The remainder of the area (about 31%) is utilised for the production of citrus, olives, stone fruit, other fruits and vegetables and a small area under wheat, proteas and oats.
In the Berg River area below Wellington, the typical farming pattern includes rain fed agriculture. The majority of rain fed crops includes wheat (38%), white wine (21%), Lucerne (12%) and several other crops of less significance (see Figure 2.3).

**Figure 2.3: Estimate rain fed land use in the Berg River Basin**

### 2.3 THE BREEDE RIVER

The Breede River, situated in the Western Cape, is the largest river in the province with a total catchment area of 12 600 km2 (Figure 2.4) comprising 7 drainage basins (DWAF, 2007). The river lies on the east coast of the Western Cape, approximately 250 km from Cape Town, and extends from Cape Infanta up into the Hex River Mountains. Originating in
the Ceres Valley, it drains in a south-easterly direction meeting the Indian Ocean at Witsand/Cape Infanta (Sebastian Bay) and flows through a key agricultural region in the Western Cape (DWAF, 2007).

Being a winter rainfall region, roughly 80% of precipitation falls within the months of April to September, brought by mid-latitude cyclones, which are dominant over the region in these months. As is the case with many mountainous areas, there is a considerable spatial variation in rainfall. In the Western mountain areas rainfall can be as high as 2 300 mm/a whereas in the middle reaches rainfall decreases to as low as 400 mm/a (DWAF, 2007). There is intensive irrigation in the Breede and Riviersonderend River valleys (Breede component of the Water Management Area) as well as in the extreme west of the Western Overberg, notably in the Palmiet River catchment.

Operation of the Breede River is such that water is collected during the winter period in municipal storage dams, such as Brandvlei and Theewaterskloof, for subsequent dispersal during summer. A unique feature in the operation of the Theewaterskloof Dam is the transference of water into the dam from the Berg River water management area for seasonal storage, as the Berg River does not have sufficient storage capacity of its own in the form of dams and reservoirs. During the dry season, the water is then transferred back into the Berg River together with a large quantity of additional water from the Breede River in order to meet the demands for water from the Berg River (DWAF, 2007).

A major inter-basin transfer takes place between the Breede and Berg Water Management Area’s (WMA’s) via the Riviersonderend-Berg-Eerste River Government Water Scheme (Theewaterskloof Dam), which also supplies water for irrigators in the Riviersonderend sub-area and to the Overberg Water Board schemes in the Overberg.

Of the total scheme yield of 234 million m$^3$/a, an average annual net transfer of 161 million m$^3$/a takes place into the Berg WMA, within which the largest beneficiary in the Berg WMA is the City of Cape Town (CCT). Irrigators in the Berg and Eerste River catchments also have an allocation out of this scheme. Four other small transfer schemes totalling approximately 12 million m$^3$/a also transfer water out of the Breede River.

An inter-basin transfer also takes place out of the Palmiet River (Overberg West) into the Upper Steenbras Dam (Berg WMA), via the Palmiet Pumped Storage Scheme. The average annual volume transferred is 22.5 million m$^3$/a and this is utilised by the CCT. The Overberg Water Board operates the Ruensveld West and Ruensveld East Schemes, which abstract water from the Riviersonderend River. The water is treated and distributed to rural users and for stock watering. Collectively, the transfers from the two Ruensveld Schemes total about 4 million m$^3$/a.

Stettynskloof Dam (Worcester) and De Bos Dam near Hermanus are the only dams of significant size that are owned by local authorities, and for which the primary purpose is urban water supply. The remaining larger dams supply water primarily for irrigation. Farm dams collectively provide about 83 million m$^3$ of storage.
It was mentioned earlier that only the sub-catchments within the Breede River basin where there is a link (inter-basin transfer) to the Berg River were included in the study region for the purpose of this project. These include:

- The Villiersdorp / Grabouw region
- The Riviersonderend
- The Palmiet River.

The agricultural land use in these regions (aggregated to the total) is estimated in Figure 2.5. The major crops are apples (44%), lucerne (13%), pears (10%). The remainder of the area (33%) is used for a large variety of other crops including citrus, wine, olives, stonefruit, vegetables and several others.

However, it is important to note that there are significant differences between the Riviersonderend area and the other two areas (Villiersdorp/Grabouw and the Palmiet River). In these two areas, apples and pears and stone fruit are the most significant crops.
Figure 2.5: Aggregated agricultural land use in the Breede part of the study region

There is only significant rain fed production in the Riviersonderend region where the farm structure is comparable to that of the Berg River basin below Wellington. Most farms consist of a combination of irrigation and rain fed agriculture. The majority of the rain fed crops is small grains (wheat, oats and barley).

2.4 DEMARCATION OF THE TOTAL STUDY AREA

Figure 2.6 is a map of the total study area. It shows all the the regions of the Berg and the Breede River which were included in the integrated model. The area includes about 56 000 ha of irrigation land and 28 000 ha of rain fed agriculture. It is important for the reader to note that the irrigation areas do not correspond to most of the statistics available since they are not based on magisterial district.

The boundaries are hydrological. It was therefore extremely difficult to make a accurate estimate of the contribution of individual crops (area) to the total cultivated area in all of those regions since cross references / statistics is not available which are based on the hydrological borders.

The relative contribution of crops which were used for modeling the present situation (the base analysis) were therefore calculated from the farm survey information which is probably the most accurate estimate available.
2.5 URBAN WATER SECTOR

The Water Service Authority (WSA) referred to in this study is the City of Cape Town Water and Sanitation Department which is responsible for the provision of bulk water services. The CMC utilises water from various dams within the Cape Metropolitan Area (CMA) and also from dams outside the Cape Metropolitan Area (CMA).

Some of the dams are operated and controlled by the CMC, whilst the other dams are operated and controlled by the Department of Water Affairs (DWA). The CMC obtains approximately 70 to 75 percent of its raw water requirements from DWA and the remainder from its own sources. Approximately 15 percent of the raw water requirements are obtained from sources within the CMA.

The Western Cape Water Supply System (WCWSS) is a complex water supply system in the Western Cape region of South Africa comprising an inter-linked system of six dams, pipelines, tunnels and distribution networks. Some elements of the system are owned and operated by the Department (Ministry) of Water Affairs and some by the City of Cape Town. The principal dams are all located in the Cape Fold Mountains to the east of Cape Town. They are:

- Theewaterskloof Dam
- Wemmershoek Dam
- Steenbras Dams (Upper and lower)
- Voëlvlei Dam
- Berg River Dam
In 2009, 63% of the water in the system was being used for domestic and industrial purposes in the city of Cape Town, 5% in smaller towns and 32% in agriculture.

The largest component of the WCWSS is the Rivieronderend Government Water Scheme, which is a large inter-basin water transfer scheme that regulates the flow of the Sonderend River flowing South towards the Indian Ocean, the Berg River flowing North towards the Atlantic Ocean and Eerste River that flows into False Bay.

Its centerpiece is the Theewaterskloof Dam on the Sonderend River, the largest dam in the system with a storage capacity of 480 million cubic metres. It is linked to the Berg River via a tunnel system through the Franschhoek Mountains. During winter, when water requirements are lower, this tunnel system conveys surplus flows from the Berg River Dam and the tributaries of the Berg River to the Theewaterskloof Dam, where the water is stored. In summer, when water requirements are high, water can be released back via the tunnel system into the catchments of the Berg and Eerste River.

Other storage dams of the WCWSS are the Voëlvlei Dam (159 million cubic meters), the Wemmershoek Dam (59 million cubic meter) in the Berg River basin, the Upper and Lower Steenbras Dams on the Steenbras River as well as the Palmiet Pumped Storage Scheme dams on the Palmiet River, from which water can be transferred to the Steenbras dams.

In 2009 storage capacity in the system was increased by 17% from 768 to 898 million cubic meters through the completion of the Berg River Dam.

2.6 SUMMARY

The description of the Berg and Breede River catchments highlighted the complexity of the water management issues in these regions. The description of the water supply and requirements of the irrigation regions provide a background of the dimensions of the study region to be modelled. These dimensions can be summarised as follows:

- During the winter (the rainy season) there is ample water but in the summer (dry season) there is severe pressure on the resource due to both a high irrigation and urban demand.
- Few dam sites (and other water supply augmentations) remain for which additional storage capacity can be developed without very high cost (financial and environmental).
- During the summer months the evaporation losses are very high due to high temperatures.
- High-value export crops are being produced in both the Berg and Breede River water catchments. This renders these regions as strategic pillars of the economy of the Western Cape province because of its multiplier effects. According to Eckert et al (1997), approximately 65% of all secondary industries are dependent on agriculture.
- Although water demand strategies have been implemented to curb the growth in urban water use, these strategies can only alleviate the problem; they cannot solve it.
- There is mounting pressure to reallocate water from agricultural use to urban use.
3 INTEGRATED ASSESSMENT OF ADAPTATION DECISIONS

3.1 INTRODUCTION

The previous chapter gave a broad overview of the characteristics of the study region. In this chapter the methodology of an integrated approach to analyse the impact of climate change and adaptation strategies are discussed.

During 2005 a case study within the Assessment of Impacts and Adaptations to Climate Change programme (AIACC) was devoted to developing an integrated climate-hydrology-economic model the Berg River Dynamic Spatial Equilibrium Model (BRDSEM). The Berg River Basin is located northeast of Metropolitan Cape Town and is the water supply source for a large share of South Africa’s agricultural exports (mainly irrigated deciduous fruits) and for the bulk of the population in metropolitan and suburban Cape Town. BRDSEM was developed specifically for this region to help water policy-makers and planners to examine the physical and economic impacts of rapid population growth and climate change; to assess the physical and economic benefits and costs of structural and non-structural measures for coping with both these problems; and to estimate the economic value of the physical damages that could be avoided by these options.

The modelling framework (see Figure 3.1) consists of three modules. These are:

- The regional climate change module – downscaling Global Climate Models.
- A hydrological module. Using the ACRU model to estimate incremental runoff at specific locations with the study region.
- A dynamic programming module with three components:
  - Regional typical farm models (21 farms) to simulate the demand for agricultural water under different climate regimes (scenarios).
  - An intertemporal 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 makes provision for external inputs such as:

- Policies, plans and technology options for increasing water supplies
- Reducing water demand through water demand management options.

The output of the model consisted 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.
BRDSEM is an optimisation model that maximises the economic value of the net returns to water from urban and agricultural water users on a monthly basis over a thirty-year (or longer) time horizon. Runoff nodes, storage and farm reservoirs and water diversions are linked together by spatially differentiated flows consistent with basin hydrology. The model also maintains dynamic storage balances in all reservoirs. Urban water demand is characterised by monthly demand functions. Seven regional farm linear programming (LP) models were developed to simulate the demand for irrigation water. Monthly runoff, reservoir evaporation and crop water use adjustments in the optimisation model were linked directly to a spatially-differentiated water balance model that is, in turn, linked to a model that downscales climate data from Global Climate Model (GCM) scenarios to the regional level.

The use of the model was illustrated using three deterministic climate scenarios to examine the incremental net economic benefits of adjusting to population growth and then to climate change by increasing the maximum storage capacity in the Berg River Dam and/or implementing a system of efficient water markets. A mixed strategy that involved adjusting to population growth by changing to water markets and then adapting to climate change by adding a water storage reservoir to the new water allocation system proved to be the most economically efficient approach to adjust to both population growth and climate change.

The basic features of the BRDSM were used to expand and improve the modeling framework for the CCAA project. Amongst others these included:

- Improvement in the downscaling methodology
- The extension of the geographical area to include the entire Berg River catchments and parts of the Breede River (where inter basin transfers exist).
- Improvement of the farm models
- Development of a methodology to match representative farm model regions with the hydrological regions.
- Improvement of the urban demand module
• Improvement in the interfaces between the downscaled climate models, the hydrological models and the intertemporal spatial equilibrium model.

The next chapter is a description of the Global Climate Models (GCM's) and the methodology to downscale GCM models to the regional level. The section that follows gives a description of the methodology used to convert climate data into hydrological impacts and an analysis of the resulting impacts. This is followed by a section on the modeling of the bulk infrastructure and the agricultural and urban demand modules to simulate the demand for agricultural and urban water. The chapter is concluded with a summary of the key findings / experience gained.

3.2 CLIMATE CHANGE MODELS AND DOWNSCALING (University of Cape Town)

3.2.1 Background

The resolving scale of GCMs has improved significantly in the last 10 years with many state of the art GCMs able to resolve at a scale of around 100km. However, most of the GCMs used for seasonal forecasting are of the order of 200km, with the skill of the model at this resolution typically low due to the GCM’s simplified topography and representation of regional processes. GCM skill is much higher when aggregated up to large scales such 500km to 1000km.

The problem is that these scales are far too coarse for most users who are dealing with regional issues such as water management and agriculture. Society and ecosystems typically operate at much finer scales. Downscaling is the 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. There are two main types of downscaling, dynamical and empirical. Dynamical downscaling utilises a higher resolution, limited domain, dynamical model that follows the same principles as a GCM but because of the limited domain is able to be run at much higher spatial resolutions with moderate computation costs. Dynamical downscaling offers a physically based regional response to the large scale forcing. However dynamical modelling is complicated by similar problems to those of GCMs, namely bias and errors due to parameterisations and scale.

3.2.2 Methodology

Tests with the implementation of the statistical downscaling revealed that the projected changes in rainfall using climate change models are particularly sensitive to the inclusion of specific humidity as a predictor. Given this sensitivity and that changes in specific humidity are potentially less important for simulating change in the current climate (and that the training data comes from an older version of the reanalysis), the statistical downscaling of the seasonal forecasts did not use specific humidity as a predictor (relative humidity was still used to provide information on moisture content of the atmosphere). We repeated the procedure for calculating skill scores using the hindcast data (I.e. perfect skill in predicting SSTs), as well as using a different version of the downscaling (removing specific humidity as a predictor). The simulated skill scores are similar to previously attained ones.

3.2.3 CAM3 forecast verification

This was part of the preliminary results from a study that investigated and compared the skills of the seasonal forecasts produced from CAM3 over Southern Africa and discussed the forecast skill of the model for seasonal rainfall over Southern Africa. The focus of this study was a statistical analysis of the performance of CAM3 in predicting probabilities of rainfall events during summer and winter over southern Africa. The correlation between the ensemble mean rainfall and CMAP observed rainfall is 0.68 for DJF and 0.52 for JJA for the
26 year (1980-2005/2006) period. Figure 1 explains the 26 years mean forecasts and their mean errors for the seasonal mean from DJF and JJA. Mean rainfall is relatively high over southern Africa during summer (DJF) and relatively low in winter (JJA). The rainfall generally increases towards the equator in both seasons; low rainfall is observed over south west of the region in DJF. Maximum rainfall is observed in the middle east of the region.

CAM3 simulated a very different pattern of the mean rainfall for DJF. However, it simulates the rainfall in the middle east region as observed but fails to simulate the low rainfall over western cape rains. CAM3 shows errors ranging from 1-5 for DJF at most part of the region. During JJA, the model reproduces rainfall well except that it shows more rainfall at the northwest of the study region and could not capture the Western Cape rains during that season. For JJA, the model shows some errors at the northwest of southern Africa. In Figure 3.2 and Figure 3.3, the skill of the forecasts is shown for DJF and JJA. The ROC scores, defined as the area under the ROC curve, for the total rainfall is tested for 26 year forecasts. The p-values are masked out so only the fields that are significant are plotted. The DJF forecast show some skill at the northeast (over Congo, Angola and Rwanda) and at southwest (over Zambia, Zimbabwe and some part of South Africa). The JJA forecast is skilful in most part of the southern continent.

Figure 3.2: Mean rainfall over southern Africa from CMAP (top panel), CAM3 (middle panel) and mean error (lower panel) for summer (left panel) and winter (right panel)
Figure 3.3: ROC scores, defined as the area under the ROC curve, for the total rainfall is tested for 26 year forecasts and only significant values are shown

A Brier score of 0.2 to 0.3 is shown over most part of Southern Africa in both seasons (Figure 3.4a and Figure 3.4b below). The score is the mean squared error of the probability forecasts for rainfall. The DJF has between 0.3 to 0.4 errors near the equator and also over Cape Town. The forecast shows some skills at the shaded areas (skill is set from 0 to 0.3). These show good skills from the forecast.

Figure 3.4: Brier Score (a) and Brier Skill Score (b) from DJF (left panel) and JJA (right panel) rainfall forecast over southern Africa for the total rainfall is tested for 26 year forecasts.

However, taking the climatological forecast into consideration as the reference forecast, the improvement of the probabilistic forecast relative to that is measured in the BSS. The BSS is shown in Figure 3.4b, where most part of the region show no or negative skill for whether or not it rained with a probability above the mean threshold. It means the forecast has the same skill as climatology. Zero to positive scores (shaded parts) representing some skills is shown only small parts of the region in both seasons.

The model forecast shows a lot of bias estimates from the observed frequencies associated with the different forecast probability values. Various measures used show that the forecast is not able to discriminate in advance between situations under which the events occur with lower or higher climatological frequency values. The forecast has low resolution and only some skills over Southern Africa in both seasons.

Statistical downscaling utilises statistical methods to approximate the regional scale response to the large scale forcing. Various methods have been developed, including the SOMD (Self Organising Map based Downscaling) developed at the University of Cape Town which is used in this report. Details of the method can be found in Hewitson and Crane.
The method recognises that the regional response is both stochastic as well as a function of the large scale synoptics. As such it generates a statistical distribution of observed responses to past large scale observed daily synoptic states. These distributions are then sampled based on the GCM generated daily synoptic states in order to produce a time series of GCM downscaled daily values for the observed variables on which it is trained (typically temperature and rainfall). An advantage of this method is that the relatively poorly resolved grid scale GCM precipitation and surface temperature are not used by the downscaling, but the relatively better simulated large scale circulation (pressure, wind and humidity) fields are used.

In summary, the empirical downscaling technique involved the following steps:

- For each day of the observations, classify the daily synoptic state using a SOM of 10m u and v winds, 700 hPa u and v winds, 500-850 hPa lapse rate, 2m surface temperature, relative humidity and specific humidity taken from the NCEP reanalysis;
- Create a cumulative distribution function (CDF) of the observed variable for each synoptic type;
- Map the GCM daily synoptic states to the SOM using the same variables as above;
- Randomly sample from CDF of each synoptic state that the GCM states map to.

This then allows a stochastic sampling of the local observed variable, conditioned on the large-scale synoptic state.

The work in developing the seasonal forecasts (next 3 months) and climate change scenarios (for the 2046-2065 period) for the project has revolved around 3 focal areas:

- Installing and running a new high resolution GCM to be used as the basis for the seasonal forecasts;
- Downscaling the output of the seasonal and climate change forecasts to a spatial resolution that can be used for assessing change over the Berg river catchment;
- Making the climate forecasts available for hydrologic and crop modelling, both of which need realistic daily estimates of rainfall and temperature.

The new GCM used for the seasonal forecasts is the HadAM3P model from the UK Meteorological Office. This model had been installed on the CSAG cluster and runs at 1.875°x1.25° resolution, which is double the resolution of the previous model (3.75°x2.5°). This increase in resolution allows a better representation of the topography of the Western Cape which is expected to enable better distinction between forecasts of high and coastal areas.

Statistical downscaling has been implemented on the seasonal forecasts, as well as 10 GCMs from the CMIP3 archive (the archive used by the IPCC to make their assessments of climate change in the IPCC 4th Assessment Report). The downscaling relies on access to weather station (point) observations of rainfall and temperature in the Berg river catchment. There is generally reasonable coverage over the Berg river catchment, with more rainfall stations than temperature stations, and a tendency to not have observations over the higher mountainous regions. The outputs from the downscaled climate simulations have been made available for the hydrological and crop modelling activities via an FTP site. Most of these activities have used the downscaled climate change projections for simulating crop and hydrological changes as these were available for the project sooner than the downscaled seasonal forecasts.

Future application of these techniques to the rest of Africa is dependent on the availability of observed data with which to train the downscaling. This data can be sparse in many regions,
but there is the possibility of extending the observed data into other regions using satellite-based observations. Before making such a system operational it would be necessary to assess how biases in the satellite data affect the forecasts using these data.

### 3.2.4 Downscaling results for the Berg and Breede River catchments

From the model downscaling the map for winter and summer and shown below in Figure 3.5 and Figure 3.6 respectively.

![Winter rainfall anomaly projections](image1)

*Figure 3.5: Winter (JJA) rainfall anomaly projections (2046-2065) for SA*

![Summer rainfall anomaly projections](image2)

*Figure 3.6: Summer (DJF) rainfall anomaly projections (2046-2065) for SA*

These seasonal results were further analysed to produce monthly figures for the rainfall anomalies for the Western Cape region. The 6 downscaled outputs for the winter rainfall season can be seen in Figure 3.7. These were sorted into “dry” or Low Scenario, and “wetter” or High Scenario for use in the hydrological models.
A glance at the results shows that there is some variation in the model output over the study area. While many models show a drying, there are more than a few that display a slight wetting. The distinction of High and Low scenarios therefore gives the hydrological model a range of possible rainfall outcomes.

It must be understood that the temperature projections (which were not downscaled for the GCM) and are shown in Figure 3.8, display a general increase in temperatures of the entire study region. The result of this general increase would be higher evaporation possibly resulting in lower runoff.
Figure 3.8: Projected temperature anomalies (a) DJF (b) MAM (c) JJA and (d) SON

3.3 HYDROLOGICAL MODELING

3.3.1 Methodology

3.3.1.1 Background

The study area considered in the hydrological analyses extended beyond the Berg River (in accordance with the project objectives) to include catchments in both the Berg and Breede Water Management Areas (WMAs). There are significant transfers of water between the two WMAs and the region’s water resources are managed conjunctively as an integrated system. The layout of the study area is shown in Figure 3.9. There are five main river basins in the study area, these being the Berg, Eerste/Kuils, Palmiet, Steenbras and Rivieronderend basins. Although the Palmiet and Steenbras Rivers have separate basins they are mapped collectively in Figure 3.9 owing to the relatively small area of the Steenbras Basin. Also shown in Figure 3.9 are the main storage dams in the study area. In the economic modelling conducted in the project, some of the smaller dams were aggregated, as shown in Table 3.1 Significant transfers of water occur via the:

- Rivieronderend / Berg / Jonkershoek tunnel systems (linking the Theewaterskloof, Berg and Kleinplaas Dams)
- Berg Supplement Scheme (diverting water from below the Banhoek / Berg River confluence to the Berg Dam)
- 24 Rivers and Klein Berg canal systems (diverting water from the 24 Rivers / Leeuw and Klein Berg Rivers to the Voëlvlei Dam)

Sites where water is diverted (referred to as exchange sites) are shown in Figure 3.9.

![Layout of Study Area](image)

Figure 3.9: Layout of the study area

Table 3.1: Main storage dams in the study area

<table>
<thead>
<tr>
<th>Aggregate Dams</th>
<th>Component Dams</th>
<th>Capacity (10^6 m^3)</th>
<th>River Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berg</td>
<td>Berg</td>
<td>126.37</td>
<td>Berg</td>
</tr>
<tr>
<td>Wemmershoek</td>
<td>Wemmershoek</td>
<td>58.78</td>
<td>Berg</td>
</tr>
<tr>
<td>Voëlvlei</td>
<td>Voëlvlei</td>
<td>172.17</td>
<td>Berg</td>
</tr>
<tr>
<td>Misverstand</td>
<td>Misverstand</td>
<td>5.77</td>
<td>Berg</td>
</tr>
<tr>
<td>Elandskloof</td>
<td>Elandskloof</td>
<td>11.35</td>
<td>Riviersonderend</td>
</tr>
<tr>
<td>Theewaterskloof</td>
<td>Theewaterskloof</td>
<td>480.19</td>
<td>Riviersonderend</td>
</tr>
<tr>
<td>Steenbras</td>
<td>Upper Steenbras</td>
<td>31.77</td>
<td>Steenbras</td>
</tr>
<tr>
<td></td>
<td>Lower Steenbras</td>
<td>33.73</td>
<td>Steenbras</td>
</tr>
<tr>
<td>Upper Palmiet</td>
<td>Nuweberg</td>
<td>3.88</td>
<td>Palmiet</td>
</tr>
<tr>
<td></td>
<td>Eikenhof</td>
<td>29.75</td>
<td>Palmiet</td>
</tr>
<tr>
<td>Lower Palmiet</td>
<td>Applethewaite</td>
<td>3.48</td>
<td>Palmiet</td>
</tr>
<tr>
<td></td>
<td>Kogelberg</td>
<td>17.28</td>
<td>Palmiet</td>
</tr>
<tr>
<td></td>
<td>Arieskraal</td>
<td>4.46</td>
<td>Palmiet</td>
</tr>
<tr>
<td></td>
<td>Grootvlei</td>
<td>1.65</td>
<td>Palmiet</td>
</tr>
</tbody>
</table>

3.3.1.2 Identification of Representative Farms

The economic modelling in the project required the identification of representative farms in the study area, where these farms represent relatively homogenous areas in terms of agricultural production and water sources used (for irrigation purposes). The boundaries of the farms were defined by using GIS information, including information derived from aerial photos and satellite imagery (e.g. from the National Land Cover study of 2001). Interviews were also conducted with irrigation representatives in the different areas to assist with this
process. This resulted in the identification of 21 representative farms in the study area. These farms are shown in Figure 3.10.

![Representative Farms](image)

**Figure 3.10: Representative farms identified in the study area**

### 3.3.1.3 Delineation of Subcatchments

It was necessary to delineate subcatchments within the study area in order to provide runoff estimates at sites of interest in the economic modelling. These sites of interest included the 9 large storage dams (Table 3.1), 21 representative farms and 7 exchange sites (Figure 3.10). Other sites of interest, not related to economic modelling, included gauging weirs (required for verification of the hydrological model) and major river confluences. The Department of Water Affairs' Quaternary Catchments formed the starting point of the subcatchment delineation process. The subcatchment boundaries were defined with the aid of a Digital Elevation Model (DEM) and Geographic Information System (GIS). The area was divided into a total of 218 subcatchments (Figure 3.11).

### 3.3.1.4 Selection of a Hydrological Model

The ACRU hydrological model (Schulze, 1995; Smithers and Schulze, 2004) was selected to be applied in the project to assess the impact of climate change on hydrological variables (runoff and evaporation) and to supply the required inputs for the economic modelling. ACRU was developed in South Africa and has been widely applied both locally and internationally. It is a daily time step and conceptual-physical model. The major multi-layer soil water budgeting processes in the model are illustrated schematically in Figure 3.12.
The model satisfies many of the requirements of a model (in terms of process representation and structure) for application in assessing the hydrological impacts of climate change, including, for example (Schulze, 2011):
• capturing the sensitivity of hydrological responses (e.g. runoff, evaporation, transpiration) to climate
• operating at a time step appropriate (daily) for relevant processes likely to be affected by climate change (e.g. evaporation, transpiration)
• being conceptual-physical in nature, where processes are adequately represented and physical boundary conditions exist, thus enabling the model to be extrapolated to new contexts (e.g. climate change)

3.3.1.5 Configuration of ACRU

Required inputs to the model relate to, inter alia, daily climate, soils and land cover.. The sources of information utilized for this study are summarized in Table 3.2.

Table 3.2: Sources of information used to develop inputs to the ACRU model

<table>
<thead>
<tr>
<th>Model Input</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate (observed)</td>
<td>SBEEH Quinary Catchments Database (originally derived from SAWS, ARC-ISCW &amp; other observation networks)</td>
</tr>
<tr>
<td>Land cover</td>
<td>CSIR/ARC National Land Cover Database 2000 (satellite derived)</td>
</tr>
<tr>
<td>Soils</td>
<td>ARC-ISCW Land Type Database</td>
</tr>
<tr>
<td>Topography</td>
<td>20 m digital elevation model</td>
</tr>
</tbody>
</table>

The various land cover types present in each of the 218 subcatchments of the study area were represented in the model setup. Dominant land covers included natural vegetation (typically, different species of fynbos) and irrigated agriculture (wine and table grapes, deciduous fruits). Forest land covers (and associated water demands) were also represented in the model setup. The water resources infrastructure (i.e. dams, transfer tunnels/canals etc.) and urban and agricultural abstractions were not represented in the hydrological model setup (except in the process of delineating subcatchments) as these were handled elsewhere in the modelling scheme of the project. Hence, the hydrological model simulated the runoff that would occur if no infrastructure or abstractions were present.

The IRI climate projections applied in hydrological modelling (cf. Section 3.3.1.7) were generated using a stochastic climate model based in part on observed climate records in the study area. The observed climate records provided for this purpose were those selected to represent the Quinary Catchments in the area, as described in Schulze et al. (2010). Schulze et al. (2010) selected a daily rainfall station from which quality controlled data were used to represent daily rainfall for each Quinary Catchment and they also generated a daily maximum and minimum temperature data set for the period 1950-1999. For modelling at the scale of Quinary Catchments (e.g. in Schulze et al., 2010), a unique set of adjustment factors was applied to the rainfall station data of each Quinary to make it more representative of the rainfall across the Quinary. The temperature data generated for a Quinary Catchment was specific and unique to that Quinary. The rainfall data provided for the development of the IRI climate projections in this project constituted the unadjusted rainfall station data. Once the IRI climate projections were developed (on a per Quinary Catchment basis) the following procedure was adopted when applying them to the 218 subcatchments delineated in this study. Firstly, the Quinary Catchment that best represents each of the 218 subcatchments was identified. This was done on the basis of the largest overlap in area. The climate records of the representative Quinaries were then assumed to represent climate in the respective 218 subcatchments. A set of rainfall adjustment factors specific to each of the 218 subcatchments was then calculated. This step was required since the rainfall stations are generally in the valley bottoms and do not adequately represent rainfall throughout the subcatchments, especially in mountainous areas. The Quinary temperature records were not adjusted to represent the 218 subcatchments as temperature is not as spatially variable as rainfall and the records were considered to be an adequate
representation of temperature in the newly delineated subcatchments. The abovementioned rainfall adjustment factors were calculated using Median Monthly Precipitation (MMP) values according to a methodology given in Smithers and Schulze (2004):

adjustment factor = catchment MMP / rainfall station MMP

An adjustment factor was calculated for each month of the year using the respective MMP statistics. The catchment MMP values were derived by isolating and averaging the relevant pixels from the 1’ x 1’ resolution national grids of MMP developed by Dent et al. (1989).

The UCT climate projections developed for application in hydrological modelling (cf. Section 3.3.1.7) were produced at the scale of climate stations. These projections had previously been associated with Quinary Catchments, as described in Lumsden et al. (2010). The procedure to associate the projections with the 218 subcatchments delineated in this study followed the same process as for the IRI projections. In most cases UCT climate projections were produced at the same stations as those used to represent observed climate in the Quinary Catchments. The same rainfall adjustment factors developed for observed records and for the IRI projections (for the 218 subcatchments) were thus also applied to the UCT projections. The Quinary level UCT temperature projections described in Lumsden et al. (2010) were not adjusted for the 218 subcatchments for the same reasons outlined above for IRI projections.

3.3.1.6 Verification of ACRU Simulations Based on Observed Historical Climate

A verification study has previously been carried out to ascertain the ability of the ACRU model to simulate historical observed streamflows in the region (Warburton et al., 2010). It is important to verify the ability of the model for an historical period (where observed streamflow data are available) so that it can be applied with confidence for future periods (where observations are not available).

The verification study was not carried out directly in the study area, but in the neighbouring Breede River Catchment, of which the Riviersonderend River is a tributary. The climate, topography, soils and vegetation are thus similar to most parts of the study area (with the exception of the dry lower Berg River region). The verification sites comprised two Water Management Units (WMUs) in the Upper Breede River in the vicinity of the town of Ceres. These two WMUs are known as the Koekedou and Upper Breë WMUs.

The verification study focused on the period 1987 to 1998 for which good quality observed streamflow data were available. The goodness-of-fit statistics for the Koekedou WMU were found to be highly acceptable and the total accumulated flows were well simulated, with the simulated pattern closely matching that of the observed (Figure 3.13). A comparison of the flow duration curves of daily simulated and observed streamflows indicated an oversimulation of the baseflows and a slight undersimulation of the high flows. The oversimulation of baseflows and undersimulation of high flows was also found for the Upper Breë WMU. The total accumulated flows in the Upper Breë WMU were oversimulated (Figure 3.13), however, the statistics of performance for the Upper Breë WMU were still within the acceptable limits defined for the verification study (Warburton et al., 2010). The verification study concluded that ACRU performed well in the Koekedou WMU and satisfactorily in the Upper Breë WMU and thus could be applied with reasonable confidence for future periods.
Figure 3.13: Comparison of monthly totals and accumulated monthly totals of daily simulated and observed streamflows for the Koekedou and Upper Breë WMUs in the Upper Breede Catchment

Source: Warburton et al. (2010)

3.3.1.7 Climate Projections and Emissions Scenarios

The climate projections and associated emissions scenarios that were developed in the project (described in previous chapters) and applied in hydrological modelling are given in Table 3.3. The projections were available at daily level for rainfall as well as for maximum and minimum temperature.

Table 3.3: Summary of climate projections applied in hydrological modelling

<table>
<thead>
<tr>
<th>Period</th>
<th>IRI</th>
<th>UCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near future (2011 - 2030)</td>
<td>20th % (“Low”) 50th % (“Medium”) 80th % (“High”) (percentiles of stochastic decadal climate simulations)</td>
<td>A1B emissions scenario</td>
</tr>
<tr>
<td>Distant future (2046 - 2065)</td>
<td>IPSL-CM4 (“Low”) ECHAM5/MPI-OM (“High”)</td>
<td>A2 emissions scenario</td>
</tr>
</tbody>
</table>

The University of Cape Town (UCT) climate projections developed in the project were regional downscalings of global projections derived from five IPCC coupled General Circulation Models (GCMs), namely, CGCM3.1(T47), CNRM-CM3, ECHAM5/MPI-OM, GISS-ER and IPSL-CM4 (the GISS-ER projections were later excluded owing to errors in the source GCM data). The climate projections applied in hydrological modelling were limited to a “High” (ECHAM5/MPI-OM) and “Low” (IPSL-CM4) GCM (based on projected changes in annual rainfall) to limit the number of hydrological and economic simulations to a
manageable level. The present period selected for hydrological and economic modelling was shortened to 20 years (from the number of years available in the climate projections) to ensure that the present and near/distant future periods were of the same length (for comparison purposes).

The IRI stochastic simulations developed for the project were designed specifically to investigate the potential for natural, internal climate variability on decadal time scales to augment (or possibly attenuate) regional climate changes of anthropogenic origin. These simulations combined climate change trends from the IPCC AR4 models with estimates of regional annual-to-decadal climate variability derived from quinary-catchment-level observational records. Three simulations were provided, each covering all of the catchments in the study area. These were a "low," a “neutral” and a “high” scenario, representing the 20th, 50th and 80th percentiles, respectively, for 20-year mean rainfall deviations from the A1B scenario mean precipitation trend for the Western Cape area. The simulations were downscaled to daily time resolution for use in the ACRU model.

3.3.1.8 Post-Processing of ACRU Output for Application in Economic Modelling

The hydrological outputs required as input to the economic modelling included:

- monthly time series of incremental runoff (m³ x 10⁶) generated at dam, farm and exchange sites
- monthly time series of dam evaporation “coefficients” (m³ / ha) for major storage dams and representative farm dams
- monthly time series of crop water use change factors (CWUC) for representative farms

To prepare the incremental runoff inputs for the economic modelling, the runoff output from ACRU was first accumulated from daily to monthly for each subcatchment in the study area. Then, the subcatchments contributing to each site were identified, and the runoff from those subcatchments accumulated to provide the incremental runoff to each site (since incremental runoff was required, only runoff generated since the site immediately upstream was accumulated in this process). The dam evaporation “coefficients” were defined as the depth of water evaporated from an open water surface, expressed in units of m³ / ha. The ACRU model uses the A-pan as its reference potential evaporation and is estimated from temperature based equations (in this case from the equation by Hargreaves and Samani, 1985).

To convert evaporation from a small water body (A-pan) to that of a large water body (such as a dam), the A-pan values are multiplied by regionally determined monthly factors published in the ACRU documentation (Schulze, 1995; Schulze and Smithers, 2004). To obtain the amount of evaporation at any dam volume (and associated dam surface area), the following equation was applied.

\[ \text{evap. (m}^3\text{)} = \text{evap. coefficient (m}^3/\text{ha}) \times \text{slope (ha/m}^3\text{)} \times \text{dam volume (m}^3\text{)} \]

The slope term in the above equation was estimated as follows: For large storage dams known relationships of surface area vs volume are available. These relationships are nonlinear in nature, but for this context were simplified to a straight line relationship in accordance with the requirements of the economic modelling. For representative farm dams (an accumulation of actual farm dams within a representative farm), the slope was estimated by the best linear fit through a plot of cumulative areas and volumes of the ranked (by volume) component farm dams. The capacity of individual component farm dams was estimated from their area (determined from the digitised 1:50000 topographic map series of
South Africa) using a robust empirical relationship. The capacities of individual farm dams were then accumulated within a representative farm to determine the representative farm dam capacity. The slopes of the area : volume relationships for the representative farm dams and large storage dams are given in Appendix 1, along with the areas and volumes of the dams at full supply capacity.

The crop water use change factors were calculated as follows:

\[
\text{CWUC (month, year)} = \frac{E_p (\text{month, year})}{\bar{E}_p (\text{month})}
\]

where CWUC = crop water use change factor
\[E_p (\text{month, year}) = \text{reference potential evaporation for future month and year}\]
\[\bar{E}_p (\text{month}) = \text{mean reference potential evaporation for month in present period}\]

The crop water use change factors are, in effect, a scaling factor (based on reference potential evaporation), which is applied to current crop water demand estimates (estimated elsewhere) to scale them to a future condition. The assumption is that crop water demand will change in proportion to changes in reference potential evaporation. As mentioned previously, ACRU uses the A-pan as its reference potential evaporation, which is estimated from temperature based equations. Since future daily temperatures were included in the climate projections developed in the project, the estimation of future reference potential evaporation was sensitive to changes in temperature.

3.3.2 Hydrological modeling results

3.3.2.1 Background

The monthly time series of incremental runoff (for dams, representative farms and exchanges), dam evaporation coefficients and farm crop water use change factors were first prepared from the daily output of the ACRU model for the different climate projections and then made available for the economic modelling (reported in other chapters).

In this chapter, the projected impacts of climate change (on rainfall, potential evaporation and runoff) are assessed at subcatchment level. In addition, the impacts on accumulated dam inflows and accumulated flows at river basin scale are also assessed. These impacts are reported in separate sections for the near future (2011-2030) and distant future (2046-2065) periods. As alluded to previously, these simulations exclude the influence of dam storages, transfers and abstractions. In most cases, changes in magnitude of the variables (resulting from climate change) are expressed as ratios of future to present values, where a ratio of greater than one indicates an increase in the magnitude of the variable over time, while a value less than one represents a decrease.

3.3.2.2 Hydrological Impacts of Climate Change in the Near Future

Figure 3.14 shows the projected impact of climate change in the near future (2011-2030) on mean annual rainfall, reference potential evaporation and runoff at subcatchment level for the IRI High, IRI Medium and IRI Low scenarios. Ratios of change greater than one are shaded in blue (increasing pattern) while ratios less than one are shaded in red (decreasing pattern). Ratios between 1.03 and 0.97 are deemed to signify no marked change and are shaded in green. The maps show that for rainfall the differences between High, Medium and Low scenarios are small. For potential evaporation the three scenarios are almost entirely green (indicating no marked change). For runoff the differences between the scenarios are still relatively small, although there are more areas with extreme ratios of change (i.e. greater than 2 and less than 0.7) compared to rainfall, indicating the non-linear nature of runoff responses to rainfall. The middle and lower sections of the Berg River appear to generate more runoff in the Medium scenario than for the High scenario.
Figure 3.15 shows the projected impact of climate change in the near future on the standard deviation of annual rainfall, reference potential evaporation and runoff at subcatchment level for the IRI High, IRI Medium and IRI Low scenarios. Rainfall and runoff show patterns of decreasing variability for the High scenario, while for the Medium and Low scenarios the patterns are similar and mixed in their response to changes in climate. For potential evaporation, variability increases for the High and Low scenarios but displays a mixed pattern for the Medium scenario. Since potential evaporation was estimated using a temperature based equation, these patterns are likely to be reflected in temperature as well. The increased variability for the High and Low scenarios could be a function of the decadal
Figure 3.14: Ratios of near future to present mean annual rainfall, potential evaporation and runoff for the IRI High, IRI Medium and IRI Low scenarios
Figure 3.15: Ratios of near future to present standard deviation of annual rainfall, potential evaporation and runoff for the IRI High, IRI Medium and IRI Low scenarios
variability incorporated in the IRI climate projections rather than the climate change signal *per se*.

The projected impact of climate change on accumulated runoff was assessed for the five river basins in the study area for the various IRI scenarios (*Table 3.4*). Impacts were expressed as percentage changes in mean accumulated runoff for the summer half-year (October to March), winter half-year (April to September) and on an annual basis. *Table 3.4* shows that the High scenario projects increases in accumulated runoff for all river basins and seasonal/annual periods (with the exception of the Riviersonderend basin in summer). The Medium scenario projects increases annually and in winter and decreases in summer for all river basins except the Riviersonderend, where decreases are consistently projected across all seasonal/annual periods. The Low scenario projects a mixed pattern for the various basins, except for the Riviersonderend basin which again shows consistent reductions in flow for all periods.

Since large dams are a crucial element of water resources management, the projected impact of climate change on inflows to the major dams was assessed. These inflows represent the accumulated runoff at the dam sites. As with all runoff simulated with the *ACRU* model in this project, these inflows do not reflect the influence of upstream dam storages, water transfers or abstractions.

The projected impact of climate change on inflows to major dams is shown in *Figure 3.16* and *Figure 3.17* for the IRI High and IRI Low scenarios, respectively. The graphs in these figures show the impact on a monthly basis for the winter half-year months in terms of means and standard deviations of flow. The dry summer (half-year) months were omitted from the graphs as they sometimes produced very large ratios of change (over 4 in some cases) even though the absolute changes were very small (small changes in small flow values can produce a large ratio of change).

The axes of the graphs were limited to ratios of change between 0.6 and 1.8 so that smaller (but noteworthy) changes (e.g. 10% increase or decrease) were still discernible on the graphs. The Misverstand Dam (in the lower section of the Berg River) was omitted from the analyses as the Berg River is highly regulated at this point, making it less meaningful to consider the climate impact on *ACRU* simulated flows (which are assumed to be on unregulated rivers). Figure 3.16 shows that for the IRI High scenario the impacts on means are greatest for the Wemmershoek, Voëlvlei and Upper Palmiet Dams (although impacts are relatively low for the wettest months of June and July).

---

**Table 3.4: Percentage changes in mean summer, winter and annual accumulated runoff for each river basin according to the IRI High, IRI Medium and IRI Low scenarios**

<table>
<thead>
<tr>
<th>River Basin</th>
<th>Period</th>
<th>IRI High</th>
<th>IRI Medium</th>
<th>IRI Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berg</td>
<td>summer</td>
<td>+11.6</td>
<td>-1.9</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>+7.7</td>
<td>+16.0</td>
<td>+2.3</td>
</tr>
<tr>
<td></td>
<td>annual</td>
<td>+8.7</td>
<td>+11.6</td>
<td>+1.7</td>
</tr>
<tr>
<td>Eerste / Kuils</td>
<td>summer</td>
<td>+11.5</td>
<td>-4.0</td>
<td>+6.5</td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>+4.6</td>
<td>+5.2</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>annual</td>
<td>+6.2</td>
<td>+3.1</td>
<td>+1.0</td>
</tr>
<tr>
<td>Palmiet / Steenbras</td>
<td>summer</td>
<td>+4.5</td>
<td>-4.9</td>
<td>-7.1</td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>+5.8</td>
<td>+6.1</td>
<td>+8.9</td>
</tr>
<tr>
<td></td>
<td>annual</td>
<td>+5.5</td>
<td>+3.7</td>
<td>+5.4</td>
</tr>
<tr>
<td>Riviersonderend</td>
<td>summer</td>
<td>-0.1</td>
<td>-12.9</td>
<td>-14.8</td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>+4.0</td>
<td>-0.3</td>
<td>-1.6</td>
</tr>
<tr>
<td></td>
<td>annual</td>
<td>+2.9</td>
<td>-3.5</td>
<td>-5.0</td>
</tr>
</tbody>
</table>
Figure 3.16: Ratios of near future to present statistics of monthly accumulated winter inflows to major dams for the IRI High scenario
Figure 3.17: Ratios of near future to present statistics of monthly accumulated winter inflows to major dams for the IRI Low scenario
Most changes in monthly means represent increases in flow (except for Steenbras Dam which mainly experiences decreases). Changes in monthly standard deviations of flow appear to be random with both increases and decreases in variability evident for all dams. Wemmershoek Dam exhibits the largest range in monthly variability changes (0.6 to > 1.8 of present period variability). Figure 3.17 reveals that for the IRI Low scenario there are more cases where monthly means decrease in the near future (relative to the IRI High scenario). Changes in monthly flow variability also appear to be random for the IRI Low scenario with both increases and decreases in variability evident for most dams. The Upper and Lower Palmiet Dams are the exception to this with a pattern of variability increases that reduce as winter progresses.

The projected impact of climate change on annual accumulated inflows to major dams was assessed in Figure 3.18 and Figure 3.19 for the IRI High and IRI Low scenarios, respectively. The statistics of annual flows that were considered included means, standard deviations and the 10th (driest year in 10), 50th (median) and 90th (wettest year in 10) percentiles. These figures reveal that for both IRI High and IRI Low scenarios the impact on mean annual dam inflows displays a neutral to increasing pattern. The variability of annual inflows decreased for the different dams, although to a lesser degree for the Low scenario. In terms of the impact on annual percentiles, the largest difference between the High and Low scenarios was for the 10th percentile where increases were generally much greater for the High scenario. The impacts on the median and 90th percentiles for the different dams were generally very similar for the High scenario.

3.3.2.3 Hydrological Impacts of Climate Change in the Distant Future

Figure 3.20 shows the projected impact of climate change in the distant future (2046 - 2065) on mean annual rainfall, reference potential evaporation and runoff at subcatchment level for the UCT High and UCT Low scenarios. The maps show that for rainfall the differences between the High and Low scenarios are relatively small. For potential evaporation both scenarios indicate an increase of 3 to 10%. For runoff the differences between the scenarios are more noticeable compared to those for rainfall. For the High scenario, increases in mean annual runoff are projected throughout study area, while for the Low scenario decreases are projected for the Eerste / Kuils basin and for much of the Berg River basin.

Figure 3.21 shows the projected impact of climate change in the distant future on the standard deviation of annual rainfall, reference potential evaporation and runoff at subcatchment level for the UCT High and UCT Low scenarios. Analysis of Figure 3.21 reveals widespread reductions in annual variability of rainfall, potential evaporation and runoff for the High scenario. For the Low scenario, a neutral to increasing pattern in variability is mostly evident, except for the upper and mid sections of the Berg River basin which shows decreases in rainfall and runoff variability.

In Table 3.5 the projected impact of climate change on accumulated runoff was assessed for the five river basins in the study area for the UCT High and UCT Low scenarios. Impacts were expressed as percentage changes in mean accumulated runoff for the summer half-year (October to March: dry season), winter half-year (April to September: wet season) and on an annual basis. For the High scenario, large increases in winter and annual accumulated runoff were projected for all river basins while for summer a mixed pattern was projected.
Figure 3.18: Ratios of near future to present statistics of annual accumulated inflows to major dams for the IRI High scenario

Figure 3.19: Ratios of near future to present statistics of annual accumulated inflows to major dams for the IRI Low scenario
Figure 3.20: Ratios of distant future to present mean annual precipitation, potential evaporation and runoff for the UCT High and UCT Low scenarios
Figure 3.21: Ratios of distant future to present standard deviation of annual precipitation, potential evaporation and runoff for the UCT High and UCT Low scenarios
Table 3.5: Percentage changes in mean summer, winter and annual accumulated runoff for each river basin for the UCT High and UCT Low scenarios

<table>
<thead>
<tr>
<th>River Basin</th>
<th>Period</th>
<th>UCT High</th>
<th>UCT Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>summer</td>
<td>+0.6</td>
<td>+5.8</td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>+29.9</td>
<td>-5.7</td>
</tr>
<tr>
<td></td>
<td>annual</td>
<td>+20.8</td>
<td>-2.3</td>
</tr>
<tr>
<td>Berg</td>
<td>summer</td>
<td>-0.2</td>
<td>-11.5</td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>+28.9</td>
<td>-14.0</td>
</tr>
<tr>
<td></td>
<td>annual</td>
<td>+20.4</td>
<td>-13.3</td>
</tr>
<tr>
<td>Eerste / Kuils</td>
<td>summer</td>
<td>-2.7</td>
<td>+21.4</td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>+16.9</td>
<td>-3.8</td>
</tr>
<tr>
<td></td>
<td>annual</td>
<td>+11.5</td>
<td>+2.1</td>
</tr>
<tr>
<td>Palmiet / Steenbras</td>
<td>summer</td>
<td>-1.9</td>
<td>+20.4</td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>+20.9</td>
<td>+5.2</td>
</tr>
<tr>
<td></td>
<td>annual</td>
<td>+13.8</td>
<td>+9.5</td>
</tr>
<tr>
<td>Riviersonderend</td>
<td>summer</td>
<td>-2.7</td>
<td>+21.4</td>
</tr>
</tbody>
</table>

The opposite pattern was projected for the Low scenario in the Palmiet / Steenbras and Riviersonderend basins (large increases in summer, mixed patterns annually and in winter) while consistent reductions in flow were projected for the Eerste / Kuils basin for the different seasonal/annual periods. A mixed pattern of weak changes was projected for the Berg River basin.

The impact of climate change on major dams in the distant future was assessed in a similar manner to the near future, i.e. in terms of accumulated inflows on a monthly basis during the winter months for each dam for the UCT High (Figure 3.22) and UCT Low (Figure 3.23) scenarios.

For the UCT High scenario (Figure 3.22), there is a general pattern of increases in flow means during the course of the wet season in winter, with increases peaking in July. Increases in July are projected to be 80% or more for 6 out 8 dams (the exceptions being the Berg and Steenbras Dams). Decreases in September mean flows are projected for all dams. Changes in monthly flow variability appear to follow the same pattern as changes in means (usually variability changes are less than for means), particularly for the months of June to September (the exception is Voëlvlei Dam).

For the UCT Low scenario (Figure 3.23), mean flows are generally projected to decrease or to remain unchanged. Flow variability is projected to increase for all months except for August and September.

The projected impact of climate change on annual accumulated dam inflows is shown in Figure 3.24 and Figure 3.25 for the UCT High and Low scenarios, respectively. The impacts on mean inflows for the High scenario are in the form of increases of 10 to 20 %, while for the Low scenario a neutral to decreasing pattern (of up to 10%) is evident. The UCT High scenario projects large decreases in flow variability while the UCT Low scenario projects both increases and decreases (of lesser magnitude) depending on the dam. The UCT High scenario projects neutral to increasing patterns for changes in the annual percentiles of flow, while for the UCT Low scenario both increases and decreases are projected depending on the dam. The UCT High scenario projects large increases in the 10th percentile flows. For a particular dam and scenario (High or Low), the difference in the impact on the 50th and 90th percentiles is generally small compared to the 10th percentile.
Figure 3.22: Ratios of distant future to present statistics of monthly accumulated winter inflows to major dams for the UCT High scenario
Figure 3.23: Ratios of distant future to present statistics of monthly accumulated winter inflows to major dams for the UCT Low scenario
Figure 3.24: Ratios of distant future to present statistics of annual accumulated inflows to major dams for the UCT High scenario

Figure 3.25: Ratios of distant future to present statistics of annual accumulated inflows to major dams for the UCT Low scenario
3.3.2.4 Discussion and Conclusions

The IRI Medium scenario represents the climate change signal for the near future, as derived from the mean response of the IPCC AR4 GCMs (multi-model mean). The IRI High and Low scenarios represent deviations from this owing to decadal variability which can serve to enhance or offset the impact of climate change. The outlook according to the IRI Medium scenario at river basin scale (Table 3.4) is mostly one of increases in runoff, except for the Rivieronderend basin where flows are projected to decrease. The influence of decadal variability can be inferred by comparing the IRI High and IRI Low scenarios where the High scenario continues to suggest increases in runoff across the study area, but the Low scenario transitions to a mixed pattern.

The decreases in runoff in the Rivieronderend basin (referred to above) occur below the Theewaterskloof Dam as the impact on the dam inflows for the IRI Low scenario is projected to be a neutral to slightly increasing pattern. This highlights the need to consider the location of a dam (in the delineation of subcatchments and aggregation of runoff outputs) when evaluating impacts on the dam, rather than just assuming the overall basin response, especially in basins with a high rainfall gradient such as the Rivieronderend.

The near future (IRI) downscaling methodology does not result in changes across the study area that are entirely consistent with the sequence of the High, Medium and Low scenarios. For example, the middle and lower sections of the Berg River appear to generate more runoff in the Medium scenario than for the High scenario and the Palmiet / Steenbras basin produces more runoff in the Low scenario than the Medium scenario (Figure 3.14, Table 3.4).

The impacts of climate change are more evident in the distant future as the effects of global warming gain momentum. This is seen in the differences between the High and Low scenarios of the distant future (in terms of rainfall and runoff) when compared to the near future. It is also seen in changes in potential evaporation (driven by increasing temperatures) where no change is projected in the near future, but changes of up to 10% are projected for the distant future.

When comparing the differences between the High and Low scenarios for the different periods (near and distant future), it should be remembered that the scenarios are driven by different processes in the two periods, i.e. in the near future the High and Low scenarios are represented by percentile outputs of the same model and incorporate decadal variability as well as climate change signals, while the High and Low scenarios in the distant future are represented by different models and focus only on climate change. In addition, different emissions scenarios were assumed for the two periods, i.e. A1B for the near future and A2 for the distant future.

In general the results show that where means of rainfall (and runoff) increase, the variability decreases. This implies that under wetter conditions, rainfall becomes less erratic. This observation is supported by the changes noted in the 10th percentile of annual dam inflows (representative of very dry years), where large increases were projected for the IRI High (near future) and UCT High (distant future) scenarios compared to the corresponding Low scenarios for which both increases and decreases (of relatively small magnitudes) were projected.
The divergence in runoff results between High and Low scenarios for the distant future implies greater uncertainty which must be incorporated in planning decisions. In contrast, there is much greater certainty regarding the changes expected for temperature and potential evaporation. This implies that decisions related to changes in temperature and potential evaporation can be made with greater confidence, although for many decisions there is a co-dependence with water availability which needs to be considered. A shortcoming of the research is that more GCMs were not considered in the hydrological and economic simulations (this limitation was due to time and computing constraints), as this may have given an indication as to whether there is a greater tendency towards either the High or Low scenarios in terms of water availability. In this context it follows that ‘no’ or ‘low regret’ adaptation options are the most pragmatic.

3.3.2.5 Comparison of Results with Previous Studies

Schulze et al. (2005) reported potential reductions in annual runoff across the entire Western Cape of up to 25% for the period 2070-2100 (relative to a present period of 1975-2005). These runoff simulations were based on climate projections by the CCAM model assuming the A2 emissions scenario.

Hellmuth and Sparks (2005) reported potential reductions in annual runoff of up to 11% for the period 2010-2039 and up to 23% for 2070-2099 (relative to 1961-1990) for a small subcatchment of the Berg River. These changes were considered representative of the upper Berg and Riviersonderend catchments. They were based on two GCMs (CSIRO and HadCM3) and two emissions scenarios (A2 and B2).

The results generated in this study thus signify a shift from widespread reductions in runoff (seen in previous research) to a more mixed pattern.

3.3.2.6 Recommendations for Future Research

The following recommendations are made for future research:

- The generation of decadal climate projections for the distant future to assess the influence of decadal climate variability for this period (2046-2065), and to translate these into runoff impacts;
- The incorporation of a more sophisticated climate change signal into the decadal projections accounting for the variation in IPCC global projections rather than simply assuming the multi-model mean;
- The inclusion of other emissions scenarios in the near and distant future projections to assess the full range of possible climate and runoff outcomes; and
- For the distant future, where regional projections are developed by downscaling individual GCM projections, to include downscalings of multiple GCMs in runoff simulations rather than only a High and a Low scenario where there is no indication if other available models tend more towards the High or Low GCM.

3.4 INTERTEMPORAL SPATIAL EQUILIBRIUM MODEL

Information on the bulk water resources infrastructure of the study area has been obtained from reports and meetings with DWAF and its consultants. This infrastructure includes reservoirs, transfer systems (pipes, canals, tunnels), offtakes and water treatment works. This information was all taken into account in defining nodes of interest
for runoff estimation. Schematic layouts indicating the infrastructure, rivers and representative farms were produced for the study area. For practical reasons, a degree of simplification in these schematics was necessary for the purposes of modeling. There are 6 schematics to describe the modelling of the bulk infrastructure.

These are:

- Figure 3.26: The area east of the Theewaterskloof dam (the Villiersdorp, Riviersonderend, Houtveldt-Vyeboom areas).
- Figure 3.27: The area South West of the Theewaterskloof dam (the Upper and Lower Palmiet areas).
- Figure 3.28: The connections for inter basin transfers between the Breede River and the Berg River catchment.
- Figure 3.29: Upper Berg region
- Figure 3.30: Lower Berg region
- Figure 3.31: The 24-Rivers, Tulbach and Voëlklei dam region and connection to the Berg River

These figures were transposed into GAMS code (mathematical code) to simulate the bulk infrastructure in the study region. The models were then rigorously tested to verify the flow of water.
Figure 3.26: Area east of the Theewaterskloof dam
Figure 3.27: The area South West of the Theewaterskloof dam
Figure 3.28: Connections for inter basin transfers between the Breede River and the Berg River catchment
Figure 3.29: Upper Berg River Basin

<table>
<thead>
<tr>
<th>Site</th>
<th>Total Supply</th>
<th>Outflow</th>
<th>Field</th>
<th>Inc.</th>
<th>Runoff</th>
<th>Inc.</th>
<th>Runoff</th>
<th>Total Supply</th>
<th>Outflow</th>
<th>Field</th>
<th>Inc.</th>
<th>Runoff</th>
<th>Inc.</th>
<th>Runoff</th>
<th>TO LOWER BERG</th>
</tr>
</thead>
<tbody>
<tr>
<td>BERG1</td>
<td></td>
<td></td>
<td></td>
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<td>BERG2</td>
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<td></td>
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<tr>
<td>BERG3</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>BERG EAST</td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SPRUIT RIVER</td>
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<td></td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>KLEIN-DRAKENSTEIN</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>TO LOWER BERG</td>
<td></td>
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</table>

Note: This diagram illustrates the flow of water from various sites to the Upper Berg River Basin, including contributions from different sources and their respective outflows and field dam losses.
Figure 3.30: Lower Berg River
The following sections describe the key characteristics of the agricultural and urban water demand and the modelling approach to simulate the demand.
3.5 KEY CHARACTERISTICS OF THE AGRICULTURAL AND URBAN WATER DEMAND AND THE MODELING APPROACH

3.5.1 Agricultural water

Farmers are not direct users of water. The utility of irrigation water is indirect, as an input to production of other goods demanded by consumers. Willingness to pay for water would, therefore, depend upon the increased value of the output over and above the cost of producing that extra output. This concept is referred to as producer surplus. As product prices decrease, the derived demand for water tends to become more elastic. The long-run value of water is estimated as the residual after returns to long-run production factors are subtracted from the short-run value estimates. Kulshreshta & Tewari found that only under high product price scenarios is there a long-run return to water, that is, greater than zero. For low-price scenarios, they found negative return to water, indicating that costs of fixed factors of production were not fully recovered.

Approximately 400 farmers were surveyed during July to September 2008 through a personal survey. The data were processed and typical farms were constructed which were discussed during a road show in September 2009. Farmers, researchers and other stakeholders were invited. The objective was to give them feedback on the survey, and a opportunity to make an input in terms of what they perceive what the impact of climate change is in their region and proposals on how to adapt.

Dynamic linear programming (DLP) typical farm models were developed to simulate the demand for irrigation water. These models also provide for the inclusion of crop-water relationships and different irrigation technologies (e.g. drip, micro, sprinkle) to simulate the impact of changes in water availability. The demand for agricultural water is a derived demand from the demand for agricultural products. For each of the typical farms there is a possibility of two water supply sources. One from a farm dam and one for direct diversion from the river. However in reality there will for example be more than one farm dam, if so, the farm dams are all aggregated to represent one water abstraction.

The main objective of any mathematical modelling exercise is to simulate the real world situation with the best available information. Linear programming (LP) is one of the most practical agricultural economic tools to simulate farming system. LP is a mathematical technique, which 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., 1985:193).

In order to analyse a problem using LP, it must be moulded into a particular structure that must at least contain the following components:

- Objective – to obtain the best or optimal solution
- Activities or decision variables which defines what to do
- Constraints or restrictions which limits on the availability of a resource

The structure of the model contains the following elements (Louw, 2008):

- A description of producers’ economic behaviour
- A description of production functions, technology sets
• A definition of the resource endowments
• A specification of the market environment in which the producer operates
• A specification of the policy environment of the sector

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 and could be presented as follows (see Figure 3.32).

Figure 3.32: Conceptual modelling framework

The whole farm planning models were constructed in such a way as to capture all the basic elements of the irrigation regions. These include the present water supply infrastructure, farm dams and individual farm models embedded in the spatial equilibrium model for each of the irrigation sub-regions to simulate the demand for agricultural water.

In the process of developing farm models, both for areas considered in previous studies (Berg River) and for the new extended areas (Cape Winelands), it was necessary to refine/define boundaries of the representative farms and their respective water sources. The boundaries of the farms and their water sources were defined by using GIS information, including information derived from aerial photos and satellite imagery. Interviews were also conducted with irrigation representatives in the different areas to assist with this process. Figure 3.33 shows the process of identifying representative farm boundaries where the area under irrigation according to satellite imagery is shaded in light green and the identified farms are in other colours. The quaternary catchment boundaries are shown as black lines. Figure 3.34 shows all of the identified
representative farms for the study area, with the exception of the Ceres farm (in the upper Breede River catchment), which does not appear on the map. Only the upper part of the Breede River Catchment is being considered in the study area at this stage.

Figure 3.33: The process of identifying representative farm boundaries and water sources in the study area

Figure 3.34: Representative farms in the study area
For the purposes of economic modelling, the flows of water within and between representative farms were conceptualized as follows (Figure 3.35). The total water available to a representative farm comprised of runoff generated within the catchments containing the farm (incremental runoff), as well as the runoff available from upstream catchments. The incremental runoff is split into a portion that enters the farm’s idealized dam (an aggregation of all actual farm dams) as natural runoff, and a portion that remains in the river.

**Figure 3.35: Conceptualization of water flows within and between representative farms**

The water in the river (including upstream contributions) can then be pumped into the farm dam, pumped direct to the field or allowed to flow down to the next representative farm. Water in the farm dam can then be applied to the field. Return flows from the field to the river are then also accounted for.

### 3.5.2 Urban water

Cape Town, its neighbouring municipalities and the agricultural sector in the region are supplied with water from the Western Cape Water Supply System (WCWSS), a system of dams and pipelines owned and operated by the City and the Department of Water Affairs (DWA).

According to long term rainfall records, the City’s main catchment dams are not yet reflecting any change in long term rainfall trends, however, the potential impact of climate change has been factored into strategic water resource planning (CCT, 2011). The CMA has a structurally diverse economy, with key sectors being manufacturing, tourism, services and trade. The key growth sectors include financial services, construction, service and industrial niches such as food processing and high technology. Major factors affecting the economic development in the CTC have been the growth in the tourism industry and strong foreign investment interest. The CTC is the primary economic centre of the Western Cape Province, with a 75 percent share in the provincial gross domestic product (GDP) and more than a 10 percent share in the national gross domestic product. The GDP of the CMA is approximately R83 billion.
Cape Town is a growing city, with a burgeoning economy and population. Due to the implementation of a long term Water Conservation and Demand Management (WC&DM) strategy, Cape Town’s water demand is now 27% less than what it would have been if demand had grown at an unconstrained rate from 2000 onwards.

The key focus is to reduce per capita demand in order to ensure that existing resources and infrastructure are used as cost-effectively as possible. With Cape Town's current demand growth, it is anticipated that the current Western Cape Water Supply System (WCWSS) supply will be sufficient until between 2017 and 2019, after which a new resource or supply scheme will be required. While six to eight years is a fairly tight timeframe for the implementation of a large water supply scheme, the groundwork is being laid now to ensure that this can be achieved when needed. Table 3.6 presents the bulk storage capacity for the main storage dams of the CTC and the storage levels from 2007-2011. It is clear that in three of the five years the dams did not fill up to their maximum capacities. There is a large probability that increasing temperatures and reduced runoff will aggravate this situation in future.

**Table 3.6: Bulk storage capacity of the WCWS 2007-2011**

<table>
<thead>
<tr>
<th>DAM</th>
<th>BULK STORAGE CAPACITY Ml</th>
<th>% 2007</th>
<th>% 2008</th>
<th>% 2009</th>
<th>% 2010</th>
<th>% 2011</th>
<th>Previous week</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEMMERSHOEK</td>
<td>58,644</td>
<td>87.7</td>
<td>95.2</td>
<td>99.6</td>
<td>92</td>
<td>79.4</td>
<td>79.6</td>
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<tr>
<td>STEENBRAS LOWER</td>
<td>33,517</td>
<td>89.1</td>
<td>98.3</td>
<td>98</td>
<td>64.9</td>
<td>81.7</td>
<td>83.3</td>
</tr>
<tr>
<td>STEENBRAS UPPER</td>
<td>31,767</td>
<td>102.1</td>
<td>100</td>
<td>98.5</td>
<td>99.6</td>
<td>98.2</td>
<td>98.2</td>
</tr>
<tr>
<td>VOËLVLEI</td>
<td>164,122</td>
<td>100</td>
<td>98.8</td>
<td>97</td>
<td>97.2</td>
<td>85.7</td>
<td>87.2</td>
</tr>
<tr>
<td>THEEWATERSKLOOF</td>
<td>480,250</td>
<td>99.5</td>
<td>103.3</td>
<td>102.5</td>
<td>90.3</td>
<td>81.9</td>
<td>82.7</td>
</tr>
<tr>
<td>BERG RIVER</td>
<td>130,000</td>
<td></td>
<td>100.7</td>
<td>100.1</td>
<td>99.3</td>
<td>94.9</td>
<td>94.9</td>
</tr>
<tr>
<td>TOTAL STORED</td>
<td>898,300</td>
<td>98.3</td>
<td>101.3</td>
<td>100.7</td>
<td>92.4</td>
<td>84.9</td>
<td>85.7</td>
</tr>
</tbody>
</table>

**Source:** CCT (2011)

As can be seen in Figure 3.36, domestic consumption accounts for two thirds of the City of Cape Town’s demand. Any demand-side management strategy should initially focus on this sector (Mukheibir and Ziervogel, 2006). Based on the potential economic growth and population growth, it is estimated that the unconstrained water demand growth in the City will vary between 2.7% and 3.7% per annum (City of Cape Town, 2006a).

Based on the middle migration rate the population in Cape Town is expected to grow by nearly 17% over the 20-year projection period. In 2006 the population is growing at 1.61% per annum due to a natural increase rate (excess of births over death) of 0.86% pa and a migration rate of 0.75% pa. At the end of the projection period (2021) the population growth rate will have fallen to 0.62% pa as determined by a natural increase rate of 0.09% pa and a migration rate of 0.53% pa. The most recent estimate of the population for Cape Town is 3,367,235 from the September 2007 Labour Force Survey. This is in line with the high migration rate projection (see Figure 3.37).
Figure 3.36: Water demand per urban water use sector (CCT, 2006)

Figure 3.37: Estimated population for Cape Town (2001-2021)
Source: Ogutu (2007)

Figure 3.38 shows the estimated water demand for the CTC. Package 1 options included; pressure management, user education, elimination of automatic flushing urinals, leakage repair and metering and credit control. Package 2 options, which were to be promoted through the user education program included; promotion of private boreholes, introduction of water efficient fittings and promotion of grey water use (Ogutu, 2007). It is clear from Figure 3.38 that the water demand has outstripped water supply since 1999. Even after the construction of the Berg River dam, there is still a shortage in supply. The only way that the CTC is coping with this situation is by a very sufficient water demand management strategy which suppresses actual demand by between 20-30%.
The urban demand water sector is based on two previous studies of the Berg River by Callaway et al. (2008, 2009). In these papers, the urban water demand sector was represented by demand functions for industrial, commercial, council, gardens and sports fields, lower-income and middle to high-income households. At the time, there were no estimates of the price elasticity of demand for water in the urban sector in the Cape Metropolis. An average figure from various studies (Palmer Development Group, 2000) was assumed for the non-household urban demand functions. The demand elasticity estimates of household water for Alberton and Thokoza (Veck and Bill, 1999) were used to characterize Cape Town. The Cape Water Undertaking (CWU) supplies more than 90 percent of all the urban water to the Cape Metropolis, Stellenbosch, Paarl and Wellington. All the present water supply sources are incorporated in the model.

Information about the price elasticity of demand for water for the non-household water using sectors in Cape Town has not improved since these studies. However, there is a more recent study on the price elasticities of water demand in Cape Town (Jansen and Schulz, 2006), which was used in this study. These elasticity estimates were higher than those developed by Veck and Bill (1999).

Because of the lack of reliable elasticity information for the other sectors, a different strategy was adopted in this study. Specifically, the linear water demand functions used by Callaway et al. (2008 and 2009) for the non-household sectors were aggregated and then blended together with the household demand functions using the newer elasticity estimated. This procedure resulted in a single, monthly, aggregate demand for Cape Town and other municipalities in the region. The relative elasticities for the non-
household sectors were preserved in these aggregate demand functions, using the Jansen and Schulz estimates as the reference for normalization. This approach does not provide detailed estimates of water use for all sectors: However, given the lack of information, these estimates were probably not very accurate anyway and the aggregate demand approach was seen as more reliable and tractable, computationally.

As in the previous study on the Berg River, the monthly aggregate water demand functions for Cape Town and the other municipalities in the regions were linear, with just two parameters to calculate, an intercept and a slope term. This was done using three pieces of information: water tariffs and consumption for the years 2006-2009 provided by the Cape Town municipal water utility and the consumption weighted price elasticities of demand for all water consuming sectors. The methodology is detailed in Callaway et al. (2005). Shifts in these water demand functions were systematically related to expected population growth in Cape Town, an approach which made it possible to examine changes in water demand due to different scenarios for future population growth.

These demand functions play an important role in determining the net economic returns to water for two reasons. First, monthly water consumption and the shadow prices of urban water consumption (the price paid by water customers + the scarcity price) are calculated endogenously in the inter-temporal spatial equilibrium model. Second the integral of these demand functions appear in the objective function of the model and are the basis for calculating consumer’s willingness to pay for water and consumer surplus.

Except for the new water supply sources that has been identified through the Western Cape System Analysis (mostly new dams, canal schemes and underground sources), there are also other sources that are more expensive but in the long-run probably more sustainable. Seawater is part of the solution to the global water problem, and there are some simple methods to harness sea water for human progress. What is needed is political will to provide water and to bring about sustainable development. Political will still seems to be lacking because many of these do-it-yourself methods do not need the capital intensive, high technology which is often favoured by governments (Ryan, 1995).

According to the CMC (2000) approximately 40 percent of the total demand of water for urban use in the larger Cape Town area is purified to meet minimum standards to be released into rivers and the sea.

At present the demand is estimated to be approximately 400 million m$^3$, the maximum potential volume of water available for recycling will therefore be 160 million m$^3$. This is more than the allocation of water from the Theewaterskloof Dam. Although it will be impossible (for financial and practical reasons) to recycle this volume, it is clear that there is a large potential.

The model also provides for alternative water augmentation schemes, in particular the desalination of seawater and recycling.

3.6 Summary
This Chapter describes the methodologies used for downscaling climate change scenarios, the methodology used for the hydrological modeling, the methodology to simulate the bulk infrastructure and spatial balances and finally the methodology to simulate agricultural and urban water demand.

The following Chapter discusses the scenarios which were analyzed for this study and the modeling results of the integrated framework.
4 INTEGRATED MODEL RESULTS

4.1 INTRODUCTION

The previous Chapter gave a description of the methodologies which were used to construct the integrated modelling framework. This chapter discusses the scenarios which were analysed and the results. The objective of the modelling exercise was to demonstrate that it is possible to develop an integrated modelling framework for evaluating and making adaptation decisions related to water resources in the Western Cape. It should be possible to duplicate the integrated framework elsewhere in Africa once the methodology has been streamlined.

More than 125 model runs were executed to demonstrate the integrated modelling framework (excluding the model runs for validation) for the purpose of this project which was presented on 22nd of September 2011 at a regional workshop in Paarl, South Africa. However, for the sake of brevity only two sets of results are presented in this report. These are:

- Set 1: comparing the base analysis for all the climate change scenarios which were discussed earlier in this report.
- Set 2: Illustrating an increase in farm dam capacity of 20% as an adaptation strategy to climate change. The relative changes compared to the base analysis are presented and discussed.

The next section gives a description of the base scenarios (Set 1) which were analysed and the key results:

- UCT Base Low
- UCT Base Low Future (same as UCT Base Low except for runoff and crop water use)
- UCT Base High
- UCT Base High Future (same as UCT Base Low except for runoff and crop water use)
- IRI Base
- IRI Base Low Near Future
- IRI Base Low Distant Future
- IRI Base High Near Future
- IRI Base High Distant Future

This is followed by a section which illustrates the application of the integrated model to analyse the impact of an adaptation scenario (20% increase in farm dam capacity) compared to the base (Set 2).

All the results are described in the following sequence:

- Irrigation intensities (optimal, supplemental, deficit irrigation and dry land)
- Crop combinations
• Agricultural water demand
• Average urban water demand per annum
• Main dam water storage per month
• Income from water sales to the urban sector and water supply cost to the sector.
• Total cost of agricultural water
• Total Net Disposable Farm Income
• Capitalised marginal value of irrigation water
• Average annual Incremental Runoff
• Average annual agricultural and urban water demand and the average annual main dam storage.

Finally the chapter is concluded with a summary of the key conclusions.

4.2 COMPARISON OF BASE CLIMATE CHANGE SCENARIOS

Figure 4.1 shows the average annual incremental runoff (at all sites) for the different climate scenarios. It is clear that there is no significant difference between the UCT Base Low and the UCT Base Future Low Scenarios. However, the runoff is significantly higher in the UCT Base High and even higher in the UCT Base Future High scenarios. All the IRI base scenarios shows a significantly higher runoff compared to the UCT Low scenarios albeit lower compared to the UCT High scenarios. It is important to take note of this since it explains most of the results which are discussed.

![Average annual Incremental Runoff](image)

**Figure 4.1: Average annual incremental runoff**

Figure 4.2 presents the area under different irrigation intensities for the base scenarios. It is clear that there are not significant differences. However, the general trend is that in the "wetter" scenarios there is a larger area under optimal irrigation compared to the "drier" scenario’s (UCT Base Low and UCT Base Future Low). The results also indicate that there is mainly a substitution from supplemental irrigation to optimal irrigation.
Figure 4.2: Base comparison – irrigation intensities

Figure 4.3 shows the change in crop combinations for the base scenarios. The key trend is that in the “drier” base scenarios (UCT Low), there is a larger area under other crops (which is mainly dry land) and a smaller area under high value crops such as fruit. In the “wetter” scenarios, there is a slight decrease in the “other” crops and an increase in the area of fruit (mainly deciduous fruit). One of the shortcomings of the model is that crop-water and crop-temperature relationships were not modeled in detail since the model became too large to accommodate the level of detail which is required to adequately simulate these relationships. The authors are of the opinion that the farm models will become much more sensitive to climate change if these relationships are refined in future development of the model.

Figure 4.3: Base comparison - crop combination

The total average agricultural water use responds to the availability of water over the 20-year planning horizon. It is therefore obvious that if there is more water available, agriculture will respond by irrigating more optimal irrigation intensities (and more profitable) which will result in an overall increase in the demand for water (see Figure 4.4). In the UCT Base High future scenario (wet), there is an increase in the average annual water use of almost 100 million m$^3$. 
Figure 4.4: Total average agricultural water use per annum

The average annual water use per ha is shown in Figure 4.5. The trend is almost identical to the total annual water use for agriculture in Figure 4.4.

Figure 4.5: Average annual crop water use per ha

The average annual urban water demand also responds to the availability of water since the value of the water is based on the scarcity value of the water. Since water is in general more scarce in the UCT Low water scenarios, the urban water demand is in general significantly lower compared to the “wetter” scenarios since urban users will respond to the higher value of the water by using less water (see Figure 4.6).

Figure 4.6: Average annual urban water demand
It was pointed out earlier in Chapter 4 that runoff will have a significant impact on the storage level of the main dams. Figure 4.7 shows the average aggregated water storage for all the main dams in a particular month. It is clear that with the UCT Low scenarios the average monthly storage is significantly lower compared to the UCT High and the IRI scenarios. The UCT Base Low Future scenario also indicates that the major dam water storage levels will be lower compared to the UCT Base Low with the exception of the month of May where a slightly higher average storage level is indicated.

Figure 4.7: Average monthly main dam storage

Figure 4.8 shows the total income from urban water sales as well as the total cost to deliver the water. It is clear that there is a direct correlation between the income and costs. When the income is higher it signifies an increase in water demand which is accompanied by an increase of delivery costs.

Figure 4.8: Total income and costs for the urban water sector
Similar to the urban water costs, the cost of water to the agricultural sector is also determined by the scarcity value, especially the value of water in farm dams since they are directly linked to the storage levels in the farm dams. If the farm dams do not fill up due to reduced runoff, the unit cost of farm dam water increases significantly due to the high fixed cost of the infrastructure. Figure 4.9 shows that for both the UCT Low scenarios and the IRI Base Low Distant Future scenarios, the total cost of agricultural water is significantly higher compared to the other base scenarios which are in general the “wetter” scenarios where the farm dams are more likely to fill up.

![Figure 4.9: Total cost of agricultural water](image)

**Figure 4.9: Total cost of agricultural water**

Although not the only explanation, there seems to be a direct link between the total cost of agricultural water and the total Net Disposable Income for agriculture. However, the fact that higher value crops are produced when in the “wetter” scenarios also contributes to a higher Net Disposable Farm income for these scenarios (see Figure 4.10 and Figure 4.3).

![Figure 4.10: Net Disposable Farm Income – total over 20-years](image)

**Figure 4.10: Net Disposable Farm Income – total over 20-years**
Figure 4.11 shows the total welfare (or objective function value) for all sectors. In general, the “dry” climate scenarios (UCT Base Low and UCT Base Future Low) results in a lower overall welfare compared to the “wetter” scenarios where more water is available and where agriculture can produce higher value crops (both through more optimal irrigation and a change in crop structure) and where there is more water available for the urban sector.

Figure 4.11: Total welfare – objective function value

The average capitalised marginal value of water gives an indication of the scarcity value of the water. In the UCT Base Low and the UCT Base Future Low scenarios the marginal value reflects that water is scarcer compared to the UCT Base High, the UCT Base Future High and the IRI scenarios (compare Figure 4.12 with Figure 4.1).

Figure 4.12: Average capitalised marginal value of agricultural water

The analyses which were described in this section gives a clear indication that the integrated modelling framework can be used to simulate various climate change
scenarios and that the results corresponds with what can be expected from the impact on runoff, the farming systems, and urban water use.

4.3 ADAPTATION SCENARIO – 20% INCREASE IN FARM DAM CAPACITY

The objective of the research was also to demonstrate how adaptation scenarios can be evaluated on their costs and benefits and the impact that they will have on dam storage levels, on agricultural and urban water use and on the value of water. For this purpose several scenarios were analysed where the farm dam capacity was increased by 10%, 20% and 30% (see Appendix 5 for all the results). For the purpose of this report only the results of a 20% increase in farm dam capacity is reported. Figure 4.13 shows the relative change in the area under different irrigation intensities when there is a 20% increase in farm dam storage capacity. In the IRI scenarios (which is in general wetter), there is slight increase in the total cultivated area accompanied by an increase in optimal, deficit and supplemental irrigation. In the UCT High Distant scenario (wetter), the area under deficit and optimal irrigation decreases and the area under optimal irrigation increases since there is more water available and irrigation scheduling / management can improve with an increase in farm dam capacity. In the UCT Low Distant scenario, the area under optimal irrigation and deficit irrigation decreases and there is an increase in supplemental irrigation even if there is a 20% increase in farm dam capacity.

The explanation for this is that in the UCT Low Distant scenario the farm dams, not even the existing farm dams, do not fill up (as was pointed out in Section 4.3). Adding more farm dam capacity in this scenario only contributes to even higher agricultural water costs since the cost per unit of water stored in farm dams increases significantly. However, it is clear that when farm dam capacity is increased in the UCT High Distant scenario the farm dams will up and this results in a change towards more optimal irrigation. The same results from the IRI scenarios which is in general “wetter” than the UCT scenarios with the exception of the IRI Low Distant Future (which is slightly “wetter that the UCT Low Distant but “drier” than the other IRI scenarios) where is very small changes compared to the base.

Figure 4.13: Irrigation intensity
The UCT Low Distant scenario results in a reduction in the area under fruit production (most of the fruit must be irrigated optimally for the fruit export market). The UCT High Distant Future as well as the IRI scenarios all indicate that increasing farm dam capacities by 20% will have a positive impact on fruit production in the region since more water will be available for optimal irrigation. It is also significant to note that in the UCT High Distant scenario there is a significant increase in Citrus production. Although not shown in this report, the runoff in the Piketberg / 24-Rivieren region (main Citrus region in the study area) actually increases, which results in more water storage in farm dams and therefore a potential to increase citrus production.

Increasing farm dam capacities in the UCT Low Distant Future scenario also result in an increase in table grape production and other short-term irrigation crops which can be irrigated with supplemental irrigation.

Figure 4.14 shows the relative impact on an increase in farm dam capacity on the total agricultural water use. The model indicates that the total agricultural water use in the low distant scenario increases slightly but not to the same extent as the UCT High Distant scenario since the farm dam storage levels are lower. It is also important to note that in the IRI scenarios, an increase in farm dam capacity only results in marginally higher total agricultural water use (due to increased water availability). However, the model indicates that the water use per ha irrigated in the UCT Low Distant scenario significantly increases mainly because of structural changes and higher temperatures which results in an increase in the crop water use requirements.
With the exception of the UCT High Distant scenario (significant increase in runoff), the model indicates that increases in farm dam capacities will not result in significant changes in the urban water demand (see Figure 4.16). The increased demand in the UCT High Distant scenario can be explained by the higher on-farm storage capacity and availability of farm dam water and therefore a reduced dependence on the main storage dams and therefore a higher availability of water supplies to the urban water use sector.

The average monthly urban water demand is shown in Figure 4.17. The results are in line with those in Figure 4.16. They show that the monthly urban water demand for the UCT High Distant scenario will increase significantly with an increase in farm dam capacity. Although not significant, the UCT Low Distant and IRI High Near Future also indicates that increasing farm dam capacities will result in more water available for the urban sector.
Figure 4.17: Average monthly urban demand

Figure 4.18 indicates that the average storage level for the major dams will increase in all the “wetter” scenarios when there is an increase in farm dam capacities since it will result in a reduced dependence on water to be released from the main dam storage for irrigation purposes. However, the results for the UCT Low Distant and the IRI Low Near Future scenarios indicates that increasing farm dam capacities will not result in a positive impact on main dam storage levels for most months. This impact can be explained by the farm dams that don’t fill up even with an increase in storage capacity and an increase dependency on irrigation from main storage dams.
It was pointed out earlier in Section 4.1 that there is a direct correlation between the income derived from water sales to the urban sector and the water supply cost. However, the water supply cost is also determined by the scarcity value of the water. In the “wetter” scenarios the scarcity value is high which results in an increase in the water supply cost to the urban sector. It is clear from Figure 4.19 that the water supply cost relative increase for the UCT Low Distant scenarios and the UCT High Distant scenario is higher compared to the relative increase in income from water sales to the urban sector. However, the explanation for this is not the same in both scenarios. In the UCT High Distant Scenario there is a significant increase in both the Urban and Agricultural water demand which results in a relative scarcity even if there is more water available.

Most of the IRI scenarios show that increasing farm dam capacities will result in a lower relative water cost to the urban sector due to a reduction in the scarcity value of the water and a slight reduction in the urban demand.
Figure 4.19: Total urban water costs and income from urban water sales

Figure 4.20 shows the relative change in the total cost of agricultural water with an increase in farm dam capacities. It is significant to note that the highest relative change is for the UCT Low Distant scenario due to the high unit cost for farm dam water if they don’t fill up their capacity frequently. The results for the UCT High Distant scenario shows that increasing farm dams will not result in higher agricultural costs since the farm dams will frequently fill up resulting in a lower unit cost for farm dam water. The results in Figure 4.20 also indicate that the farm dams do not fill up frequently in the IRI Low Distant Future and the IRI High Distant future scenarios.

Figure 4.20: Costs of agricultural water

Although there are not significant relative changes in the overall Net Disposable Farm Income, all the scenarios with the exception of the UCT Low Distant and the UCT High Distant scenarios indicate a slightly positive impact on Net Disposable Farm Income. The slightly negative impact on the UCT Low Distant scenario can be explained by the higher water cost (see Figure 4.21).

Figure 4.21: Net Disposable Farm Income over 20-years
Figure 4.22 shows the relative change in total welfare due to an increase in farm dam capacity. These results show why it is so important for an integrated and multi-sectoral approach in the evaluation of adaptation strategies. The results indicate that with the exception of the UCT Low Distant scenario, an increase in farm dam capacity will be beneficial for all the other climate change scenarios since both the agricultural and the urban sector will benefit.

**Figure 4.22: Total welfare – objective function value**

The relative change in the average capitalised marginal values for agricultural water is shown in Figure 4.23. Figure 4.24 shows the relative change in incremental runoff for each of the scenarios. It is clear that there is a strong correlation between the scarcity (in this case derived from runoff) value and the total runoff. In the UCT Low Distant scenario, the marginal values slightly increase even with a slight increase in the average annual runoff (although insignificant). The result indicates that building farm dams that don't fill up may even contribute to water scarcity? For all the other scenarios the marginal values correspond directly with the relative change in runoff.

**Figure 4.23: Capitalised marginal value of agricultural water**
4.4 SUMMARY

The comparison of the base analysis demonstrated that it is possible to compare the impact of several downscaled climate change scenarios in the study region. The basic structure of the model makes it possible to change the input coefficients with little effort to simulate the impact of several downscaled climate change scenarios as they become available (as GCM and the technology to downscale and to simulate the hydrological impact improve).

It was also demonstrated how this integrated modeling framework can be used to evaluate proposed adaptation strategies such as an increase in farm dam storage capacities (which were identified as one of the key obstacles towards adaptation to climate change).
5 CAPACITY BUILDING AND AWARENESS RAISING

5.1 INTRODUCTION
A key objective of this project was to develop the capacity within Africa to use the integrated analysis tools and to develop a much broader understanding of how using these tools will benefit Africa. In this regard several actions were executed which are discussed in the following section.

5.2 Appointment of a Steering Committee (SC)
A SC comprising of members from various stakeholder groups was established and enabled to determine their needs, upon which the research was based, and which guided the project. The first SC meeting was held on 12 August 2008. The SC was representative of all stakeholders including:

- Department of Water Affairs – Bertrand van Zyl / Wilna Kloppers
- City of Cape Town – Arn Singels, D Klopper
- Household water – J Cartwright
- Industrial water - J Bouwer
- Agriculture
  - Deciduous Fruit Development Chamber (small fruit farmers) - Kevin Maart
  - Emerging commercial farmer - A Thops
  - National African Farmers Union (NAFU) – David Seale
  - Dept.Agric of the Western Cape – Andre Roux
  - Commercial farmers - Johan Conradie
  - Agri-West Cape - Carl Opperman
- Environment - Dean Impson / Deon Rossouw
- Cape Nature – Dana Grobler
- Gender – Women on Farms (Fatima Shadodien)
- Exporters – David Farrel, Steward Symington
- Water Research Commission – Gerhard Backeberg
- Research – Jo Barnes / Dudley Rosewell (ARC)
- Department of Agriculture: Western Cape – Andre Roux
- Provincial Government – Mr. Peterson

Most of these individuals made invaluable contributions towards the study. Mr. Bertrand van Zyl attended two of the CCAA workshops (in Addis Ababa and Nairobi) where he made valuable contribution especially on policy issues. Mr. van Zyl also ensured that the message of climate change was conveyed into many discussions on policy within the Department of Water Affairs.

Mr. Kevin Maart resigned as the manager of the Deciduous Fruit Development Chamber early in the project. However, at least two of the DFDC members, Mr. Andre Thops and Mr. Raymond Koopstad participated actively in the project. Mr. Koopstad attended the COP in Bali and Mr. Thops a CCAA workshop in Nairobi. Both these gentleman introduced water efficient technology in their farming operations and is an example for other farmers.
Prof. Louw and Peter Johnston have been invited to present papers at numerous farmers days, to the fruit exporters (Fruit Vision), water users associations, Department of Agriculture (Extension officers conference), and to the Western Cape Reconciliation Study (Western Cape Systems Analysis). This is indicative that the members of the steering committee did convey the message to their members.

5.3 Training of students

A lot of time and effort went into the training of the two PhD students (Mr. Trevor Lumsden on the hydrology and Mr. Abiodun Ogundej on the economics modeling). Dr. Mac Callaway and Prof. Daan Louw spend several weeks since 2009 to train Mr. Ogundej in the basics of the economic modelling. After the training he is able to run the farm model sub-module on his own. His primary contribution for his PhD is to develop small scale and commercial farm models that is more adaptive to climate change in the Ceres region of the Breede River catchment. He will be submitting his PhD thesis in January 2012.

A ‘Training of Trainers’ workshop on climate change and water resources was held at UKZN from 26 - 30 January 2009. The workshop was held under the auspices of WaterNet and Cap-Net and was aimed at capacity building of water professionals in the SADC region.

PhD student: Mr T Lumsden was involved in the hydrological modeling component of the project. The topic of his study is ‘Assessing the impact of climate on water at various time scales in the Berg and Mgeni Catchments’

Intern students: A student from Wageningen University in The Netherlands, Mr M Dorlandt, and a student from the Swiss Federal Institute of Technology in Switzerland, Mr M Reinhard, spent approximately 4 months working on the project to obtain work experience as part of their Masters’ degrees. Their contributions were mainly in the field of data collection, GIS and modeling.

Climate change data is disseminated via the website http://data.csag.uct.ac.za. Seasonal forecast data is disseminated via the website http://www.gfcsa.net.

Climate change data has been provided for and training has been given to another IDRC funded project: “Managing Risk, Reducing Vulnerability and Enhancing Agricultural Productivity under a Changing Climate”

Mark Tadross supervised a PhD student Mike Wallace whose thesis will evaluate the impact of climate change on agriculture in the Berg river. Another PhD student, Sepo Hachigonta, also assisted in running crop models for the region.

To transfer the tools and methods developed for this project to stake-holder groups and provide training in their application the following actions are reported:

- The project team had several meetings with Mr. Anton Sparks, responsible for modeling in the Western Cape Systems Analysis (WCSA), and with Mr. Bertrand van Zyl of the Department of Water Affairs (DWA). The result of this is that the data that being used is being coordinated with the data used by the WCSA and the operating rules being used by the DWAF is exactly the same in the models.
This is of paramount importance if to accomplish the objective to introduce the models developed in this study to the “analytical tool kit” of the WCSA.

- In addition a three day training course in the use of the integrated models were presented to three individuals during 8-10 April 2011:
  - Mr. Hamman Oosthuizen (PhD student)
  - Mr. Ferdi Botha (PhD student)
  - Mrs. S Louw (OABS)
- Mr. Ferdi Botha resigned his post in September 2011 but training to Mr. Hamman Oosthuizen and Mrs S Louw continued in October and from the 28th of November to the 8th of December they received intensive training by Dr. Mac Callaway and Prof. Daan Louw. They both now have a good understanding of all the components (modules) of the models and can run scenarios with the integrated model with no or very little assistance. They also received training on the interpretation of the results. See Appendix 2 for course material.

Finally, it was stated previously that the duration of the project (after obtained real results were obtained) was too short to really evaluate this. However, the project team (specifically Prof. Daan Louw, Prof. Roland Schultze, Dr. Peter Johnston and Mr. Hamman Oosthuizen – PhD candidate) has been appointed by the Water Research Commision on a project:

“ON ADAPTIVE INTERVENTIONS IN AGRICULTURE TO REDUCE VULNERABILITY OF DIFFERENT FARMING SYSTEMS TO CLIMATE CHANGE IN SOUTH AFRICA (PROJECT NUMBER 80/1566/01)”

The models which will be used in this project is to a large extent based on those that were developed within the CCAA project which means that the methodology will be used and improved outside the borders of the Western Cape. Thus, the CCAA project made a very valuable contribution towards capacity building in the methodology to “Managing climate risk for agriculture and water resources development in South Africa: Quantifying the costs, benefits and risks associated with planning and management alternatives” since it laid the foundation for several other follow up studies and therefore more capacity building.

5.4 Awareness raising

5.4.1 Electronic and printed media

Several actions were taken to raise awareness and to empower stakeholders with knowledge about climate change and possible adaptation strategies. These are:

- Developed in collaboration with IDRC staff and a local magazine editor a project profile for our project which was presented at the COP in Bali. Please find the profile in Appendix 3.
- Developed a website www.bergriver.co.za for our project
- Three TV programmes was made for Agri-TV (national TV) during April to March 2009. This is an important media to raise awareness in South Africa on the results of the research. The team received positive feedback from Agri-TV.
• A paper was presented at the CLIMATE CHANGE Global risks, challenges and decisions conference in Copenhagen, Denmark from 10-12 March 2009.

5.4.2 Workshops and contributions at information days

During the project numerous information sessions were held

• A regional workshop in Paarl at the Nelsons Creek Wine Estate on the 13th of February 2008. More than 60 people attended with representatives from almost all the stakeholders from our main boundary partner, the “Berg River Catchment Management Agency”. On this occasion a steering committee was appointed for our project. Please find notes on this meeting in Appendix 4.
• Peter Johnston presented a talk to educators at the “Climate Change Education and Awareness Programme Teacher Training Workshop” in December 2008, where over 100 teachers were present. This was followed up by 3 visits to schools.
• Difficult Dialogues, Cape Town: 25/2/09: Climate Change and food security in SA
• Swedish Met Institute, Walvis Bay – Training course 11/5/09: Climate change vulnerability and modelling/regional downscaling with focus on agriculture in southern Africa
• Womens Farmer Association, Durbanville 12/5/09: Climate Change, - some implications for SA and agriculture
• Norwegian Dep of Foreign Affairs, Seminar, Cape Town 13/5/09 Climate change vulnerability and modelling/regional downscaling with focus on southern Africa
• WC Dept of Agric, 17/6/09 Somerset West: Climate Change, - some implications for SA and agriculture
• SASEV Cape Town 30/07/09. Climate Change and the grape industry in the Western Cape
• Hex River Table Grape Farmers Association – 17/11/2008 – Climate change. What can we expect?
• Paarl Agricultural Society – 11 June 2009 – Adaptation to climate change in the Western Cape.
• Orange River Renewable Energy Information Day (10 November 2009)
• Bien Don Farmers Day (6 November, 2009)
• Wesgro Information session (29 September 2009)
• Boegeoeberg Renewable Energy Information Day (24 July 2009)
• Dept Agriculture – workshop on climate information for farmers- Pretoria (16 Oct 2009)
• Agri-business forum – Nedbank, Jefferies Bay (19 Nov 2009)
• CSIRO Adelaide Australia – trans boundary water and SE modelling seminar (12 Dec 09).
• A presentation was made at the M&E workshop in May 2009 in Mombasa, Kenya.
• A paper was presented at the IDRC Roundtable event in Cape Town on 11 November 2009.
• Climate change adaptation and mitigation strategies in agriculture: threats and opportunities, 4 May 2010 – Extension Association annual conference, Langebaan, Western Cape
• Economic impact of climate change on woolgrowers in the Western Cape, 10 March 2010 – National Woolgrowers Association, Eisenburg, Western Cape
The project also actively participated in at least four knowledge sharing networks or communities of practice

- We adapt – online forum
- National Water Forum Northern Cape with the Minister of Water Affairs
- Potato SA – Water Work Group
- Water Research Commission project on the Socio Aspects of climate change - WRC proj1843

5.4.3 Individual and group discussions with stakeholders

Approximately 400 farmers were surveyed during July to September 2009 through a personal survey. This effort by itself had a huge impact on raising awareness since basic information was transferred about climate change. The survey also included questions to farmers on how they intend to adapt to climate change. Follow up workshops were held in September 2009 where these farmers, researchers and other stakeholders were invited. The objective was to give them feedback on the survey, and for them to make an input in terms of what they perceive to be the impact of climate change in their region and to make proposals on adaptation strategies. The following workshops were held:

- September 14th – Robertson
- September 14th – Worcester
- September 15th – Paarl
- September 15th – Worcester
- September 16th – Piketberg
- September 16th – Ceres
The survey and workshops contributed indirectly to changing water use behavior in that farmer and water users associations now consider climate change in water management decisions. For example, the Project leader was recently approached by the Berg River Irrigation board to point out that the 1:50 flood line is shifting due to climate change which threatens the quality of water in the Berg River due to a planned potential land fill site of which a portion is just below the 1:50 flood line. The argument of climate change will be used to appeal to government to reject the proposal (January 2012).

In addition, one of the farmers which were on the SC (Mr. Johan Conradie) implemented new hydroponic technology on his table grapes in the 24-Rivers (Berg River) region. He claims that it resulted in a 30% water saving and improved yield and quality.

Mr. EC Malan (Chair of the Berg River Irrigation Board), implemented cellphone technology on his farm to improve his irrigation efficiency. In this way he can now switch his irrigation cycle on or off depending on the rainfall and the moisture contents of the soil, even when he is not on the farm. He claims that this resulted in significant water savings.

There is also indications that farmers in the Hex River valley (after severe floods and at least two presentations on climate change in the region) are now reconsidering the establishment of table grapes on the banks of the Hex River (which is close to the flood line) since they realize that the frequency of extreme events will increase.

This is only a few examples where it is believed that the project made a direct contribution towards changing water management behavior and farming practices.

Amongst others, stakeholders observed the following in terms of climate change:

5.4.3.1 Ceres

Special situation
- Very large variation in altitude
- Hot dry summers
- Heavy rainfalls in winter
- Lack of storage capacity

Climate changes experienced
- Same annual rainfall but less rainy days and rain more intense
- Winter is coming later – May is drier, September wetter
- Heavier snow but less frequent, not necessarily good for recharge
- More extremes, cold + hot
- Some say changes maybe due to natural cycles

What kind of adaptations?
- Changing cultivars
- Sensible planting
- Drip irrigation cannot be applied to all circumstances – most important is more efficient irrigation and scheduling
- Exclude marginal land from cultivation

5.4.3.2 Piketberg

Special situation
• On the edge of the “Rooi Karoo” – edge of marginal crop cultivation
• Vary vulnerable to even a small reduction in rainfall
• No alternatives unless access to irrigation land
• Necessity for expert knowledge all over the region
• Night temperature in winter is approximately 5 degrees lower than the rest of the Breede Valley
• Storage of winter water is a prerequisite for irrigation farming
• They experience the presence of birds in the region that were not there before – hadidas and crows.
• Warmer May temperatures

**Climate changes experienced**
• Winter rain intensity increased and hail storms not experienced before
• Less soft penetrating rain
• It is getting warmer in winter
• New diseases on both livestock and crops not experienced before

**What kind of adaptations?**
• Need for earlier cultivars
• Need to use bud break agents because of fewer cold units
• Stone fruit is more prone to hail, therefore a need for earlier fruit
• Need to consider the observed changes in planning new plantings
• No till cultivation had become essential

**5.4.3.3 Grabouw**

**Special situation**
• Cold units are marginal – ideal is 1000 to 1200, they are only getting 800
• Lower cold units means higher input costs to reduce the impact
• Their soils have a high clay contents – high water holding capability but prone to drowning of crops
• They are fortunate to be in the Palmiet catchment with a high security of water supply
• 2-5 degrees cooler compared to Stellenbosch
• Intensity of the South Easter wind is less
• The Eastern side of Grabouw has a substantial lower rainfall (600mm) compared to the Western side (1200).

**Climate changes experienced**
• Snow line had become lower and snow comes later and sometimes twice per year
• Winter comes later – fewer fronts and lower intensity
• Increased hot spells – higher frequency of sunburn on crops
• They experience a seasonal shift of approximately two months – May/June is warmer
• Cooler spring
• Reduced frost and increase in pests
• North Western winds in January/February strengthens
• Less hail, more veldt fires
• However, some years more hail and more storms
• Villiersdorp dams fills quickly

**What kind of adaptations**
Need for the use of rest breaks and more spraying – increase in input costs
Need to change the orientation of rows in new planting to reduce sunburn
Mulching has become very important
Shorter and more frequent irrigation cycles essential to adapt
Improve drip and micro jet irrigation technology
In general a need for more sustainable farming methods to adapt.

5.4.3.4 Paarl

Special situation
- All users in the region depends on the same source – need for equity
- Irrigators are using advanced technology
- The Berg River is the main water transport. The interaction with humans has a severe impact on the water quality
- Intense winter rain – polluted inflows from urban areas – water quality problems
- Shallow soils
- Contamination of ground water
- The uniqueness of the area is being destroyed by farm land that is being developed
- Small farms become unsustainable
- In general most farms are extremely vulnerable to water cuts since they are already using efficient irrigation systems
- Salinity in the West Coast area is a major problem
- Limited water-reuse potential
- Poor quality of irrigation water is a major threat for fruit exports
- Alien vegetation in the area is also a threat to reduced irrigation water availability

Climate changes experienced
- More frequent hail and storms
- South Eastern wind is less
- Rainfall is more intense and leads to land slides
- Increase in veld fires
- Later onset of winter and rainfall also shifting to later
- Later rain and weak South Easter – later harvest of wheat
- Intense storms
- Temp is 1-2 degrees higher
- The mist belt is moving outward
- Increased UV radiation
- In the positive, scattered early summer rainfall on the West coast leads to re-growth of wheat which can be used for live-stock and or for harvesting
- The intensity of the rain changed – fewer long penetrating rains – impact on recharge
- Evaporation increased – higher irrigation demands

What kind of adaptations
- Plant modification to overcome water stress conditions to achieve maximum fertility
- Make more use of biological resources to adapt to pests
- Relook at plant requirements – soil equilibrium
- Deciduous fruit industry to develop cultivars with a lower chill unit requirements
• Research into market implications (impact on competitors)
• Time factor has become critical – integrated planning is required
• Constant awareness campaign required
• More research necessary on crop water requirements
• Need for integrated water planning required to adapt to climate change
• Mulching to save water
• No tillage for rain fed agriculture
• Align crops to changing climate conditions

5.4.3.5 Worcester

Special situation
• Subject to extreme weather – floods and droughts, wind
• Hailstorms at night
• Mainly long-term crops – vulnerable to water shortages/cuts
• Winter rain adequate but not enough storage capacity
• They also depend on groundwater sources
• They are concerned about rain in summer – they don’t want rain when harvesting table grapes
• The micro climate in the Hex River is favourable for table grape production. However, irrigation water is very expensive and labour requirements are high.
• In the Rawsonville area – rivers dries up and they depend on boreholes

Climate changes experienced
• Rivers running dry both because of climate change and higher water demands
• Flooding is worse and occurs in more months
• Rain is more intense
• Less snow and snow melts faster
• More heat waves
• More droughts
• Warmer minimum temperatures
• Less frost
• Pests more resistant
• Algae blooms in storage dams

What kind of adaptations
• Change to more efficient drip irrigation – although more efficient also more expensive technology
• Look at market projections – opportunities and new markets
• Gene research on more drought resistance crops
• Clear alien vegetation – need to engage with policy makers/partners
• Plastic covers on grapes
• Shade clothing – prevents frost damage
• Increase the use of cover crops

5.4.3.6 Robertson

Special situation
• All crop production in the region is from irrigation
• Very little groundwater resources
• Same as for Worcester

Climate changes experienced
- More summer rainfall
- Reduction in chill units
- Budbreak dates earlier AND later
- More flooding
- More damages
- Growth of aliens out of control

**What kind of adaptations**
- Clear alien vegetation
- Desalinate saline water
- Government support to keep agriculture profitable
- Clean up municipal effluent
- More crops under drip and underground irrigation

### 5.5 SUMMARY

The authors are convinced that the project made a contribution towards capacity building amongst water managers, students and the general public in terms of a better understanding of climate change, climate variability, vulnerability and possible adaptation strategies. At the same time, the research team was capacitated in terms of a better understanding of what the problems are that water manager's face and their perceptions of climate change and how to adapt.

Due to the complexity of the methodology which resulted in the final results to be available only during the last three months of the study, the impact that the project had on capacity building and technology transfers were not as high as envisaged when the project started. However, the authors believe that the project will leave a legacy behind for other research projects to build on (for example, the WRC project which was mentioned).
6  QUALITATIVE ASSESSMENT OF THE IMPACT OF THE PROJECT

6.1  INTRODUCTION
It is very difficult to make a quantitative assessment of what the impact of this project was since projects of this nature are often of too short duration to really estimate if there was a tangible impact on change in behavior. However, the following sections discuss some of the observations.

6.2  ASSESSMENT OF VULNERABILITY TO IMPACTS OF CLIMATE VARIABILITY AND CHANGE
All major stakeholders attended the regional and local workshops, including farmers, researchers and water managers. The following key questions were normally discussed:

- What is your unique/special situation in this area?
  - Weather/climate
  - Inputs/problems
- What climate changes have you seen/experience?
- What kind of adaptations have you made or do you expect to make?

The key observations of stakeholders were discussed in Section 5.4.3 in Chapter 5.

6.3  THE PROJECT HAS DEVELOPED OPTIONS FOR ENHANCING ADAPTIVE CAPACITY
Since a large effort went into data capturing and model development it was possible to assess and develop adaptation scenarios close to the end of the project (March 2011). The model output was discussed in Chapter 3. The results of several climate change scenarios and the impact of some adaptation options were disseminated at several workshop / information sessions. The adaptation options which were analyzed included (see Appendix 5 for the detail):

- Increasing agricultural water use efficiency by 10, 20, and 30 percent.
- Increasing farm dam capacities by 10, 20 and 30 percent.
- Increasing agricultural water tariffs by 25, 50, 75 percent (currently at a very low base) and urban tariffs with 10, 20 and 30 percent.

The following lessons were learned:

- Increasing water use efficiency is a no-regret climate change adaptation option and can potentially make a huge contribution towards increasing water supply in the study region. Both the agricultural and the urban sector will benefit. There is a significant drive from farmers to increase soil health which will contribute towards water use efficiency. During that last three months of the study, a number of farmers started to use vermosoil compost tea in combination with compost to contribute to healthier soils and increasing water holding capacity of the soils (Mr.
Dave Rennie, Mr. Gerhard de Kock, Chingford and others). A new business has evolved directly through the input of Prof. Louw. It is called Vermisoil Africa (see Vermisoil.co.za). Although this entity is still in its infant stage, it is believed that it will make a huge contribution to promote the improvement of soil health as an adaptation to climate change.

- Increasing farm dam capacity is clearly a possible regret option. The analysis clearly indicated that due to the capital intensive nature of this adaptation, it will only benefit the community in the “wet” scenarios where the farm dams frequently fill up. In the “dry” scenarios this adaptation can result in a negative outcome for the farming community since it will increase their water costs considerably. A much more sensible adaptation will be to increase water use efficiency through more efficient irrigation technology and practices such as mulching, cover crops, compost and compost tea to improve soil fertility and water holding capacity.

- The model results indicate that increasing water tariffs as an adaptation strategy to curb the water demand is less effective in the agricultural sector and can even result in a negative impact since farmers are forced to grow higher value crops which often use even more water compared to the lower tariff scenarios. The results indicate that water total irrigation water demand will increase with about 7-8% in the UCT Low Distant future scenarios and by about 4-5% in the UCT High distant future if irrigation water tariffs are increased with 50%, albeit from a relatively low base tariff. Also, the demand elasticity for agricultural water is very inelastic since they cannot simply stop irrigating or irrigate suboptimal if they produce fruit and other crops for the export market. A more efficient adaptation measure to be promoted by the water supply utilities will be to promote water demand management (WDM) measures as an adaptation (e.g. irrigating at night, using tension meters, more efficient irrigation systems, fixing water leakages). However, increasing water tariffs in the urban sector seems to be a very efficient water demand management tool. The model indicates that an increase of 20% in the urban water tariffs will, for example, result in a reduction in demand of between 10-15% depending on the climate change scenario. The total net output (welfare) of the region will however, decrease with about 7-9% as a result of the increased water tariffs.

6.4 TRANSFERRING EXPERTISE INTO NEW PROJECTS, COMMUNITIES AND SCIENTIFIC INITIATIVES

Some of the methodologies developed in this project will also be used in a Water Research Commission project with the title:

“ADAPTIVE INTERVENTIONS IN AGRICULTURE TO REDUCE VULNERABILITY OF DIFFERENT FARMING SYSTEMS TO CLIMATE CHANGE IN SOUTH AFRICA”

The project commenced in March 2010 and will be conducted over a five year period. The communities that will benefit are in the Olifants River catchment, the Swartland (Berg River), the Hoedspruit region (Mpumalanga) and the Levubu catchment (Limpopo). We are of the opinion that the groundbreaking work of the current IDRC/DFID CCAA project in the Western Cape will make a significant contribution towards this scientific initiative. Mr. Hamman Oosthuizen (one of the capacity building candidates) already submitted his research proposal for a PhD on this project.
Mr. Abiodun Ogundeji will be submitting his PhD on the IDRC project during January 2012.

**Lessons learned**

It is important to constantly be on the lookout for other potential initiatives to broaden the capacity of adaptation research and for opportunities to benefit other communities in Africa beyond the scope of the existing project.

**6.5 FACILITATING KNOWLEDGE SHARING PROCESSES AMONGST VULNERABLE GROUPS, CIVIL SOCIETY, POLICY MAKERS AND RESEARCHERS**

Approximately 14 groups of emerging farmers, totaling about 32 resource poor farmers will directly benefit from the project. They were actively engaged in knowledge sharing through participating in the farm survey and at workshops to discuss the results. Two farmers, Mr. Raymond Ackerman and Andre Thops also had the opportunity to attend workshops of the IDRC (one in Bali at the COP and the other in Nairobi).

Civil society is involved through the steering committee which was discussed in Chapter 4. Many of these members attended presentations and a road show of the project team. Members of the project team (Daan Louw, Peter Johnston and Roland Shultze) also made several presentations for individual civil society stakeholder groups on invitation.

The project team constantly communicated with Mr. Anton Sparks, responsible for modeling in the Western Cape Systems Analysis (WCSA), and with Mr. Bertrand van Zyl of the Department of Water Affairs and Forestry (DWAF). The result of this is that the data that were used is being coordinated with the data used by the WCSA and the operating rules being used by the DWAF is exactly the same in our models. This is of paramount importance if to accomplish the objective to introduce the models developed in this study to the “analytical tool kit” of the WCSA.

**Lessons learned**

Since the inception of the project, the general observation is that more and more people are hungry for knowledge sharing on climate change, adaptation and mitigation. We expect that once we have results from the modeling exercise their will also be a stimulus on the stakeholder side to share this information.

**6.6 PARTICIPATING IN KNOWLEDGE SHARING NETWORKING**

The project participated in at least three knowledge sharing networks:

- We adapt – online forum
- National Water Forum Northern Cape with the Minister of Water Affairs
- Potato SA – Water Work Group
6.7 INVOLVEMENT OF STAKEHOLDERS IN ADAPTATION RESEARCH THAT RESPONDS TO THEIR NEEDS

Prof Roland Schulze has on several occasions been consulted by the National Department of Agriculture and Forestry to make an input on climate change and adaptation. The IDRC project has made a significant contribution to the knowledge and understanding of integrating climate, hydrological and economic models and this knowledge is currently being shared with the DAFF.

The WRC has consulted Prof. Daan Louw to review at least two research projects on climate change:

- “Water-efficient production methods in relation to soils, crops and technology in rain-fed and irrigated agriculture”
- Impact assessment and environmental management of agricultural production

In both of these studies the WRC (one of our stakeholders) requested Prof. Louw to evaluate the proposals based on the experience gained from the CCAA program.

Deciduous Fruit Industry – Prof. Daan Louw made a presentation at the Fruit Route strategic session in 2010 to provide guidelines on the external environmental aspect (including climate change adaptation) that will impact on the fruit industry in the next century and that will guide research on new cultivars. Hortgro SA is an important stakeholder in the Western Cape since 75% of the total crop is produced in this province.

6.8 RESEARCH FINDINGS CONTRIBUTE TO THE DEVELOPMENT OF ADAPTATION POLICIES AND PLANS

The authors believe that the project has already contributed through awareness rising to the development of adaptation strategies and strategic plans of commodity organizations and local government. Prof. Daan Louw and Dr. Peter Johnston met with the WESTERN CAPE RECONCILIATION STRATEGY (WCRS): STRATEGY STEERING COMMITTEE on the 15th of November 2011 to discuss the possible uptake of the model as part of the tools of the so-called “Western Cape System Analysis (WCSA)”. The presentation made was received positively and laid the foundation for follow up talks to integrate the integrated modelling framework with the existing tools of the WCSA. The WCRS basically guides the work of the WCSA. If model integration can be achieved, it will make a useful contribution to the development of adaptation policies and plans in the Western Cape.

6.9 SUMMARY

It was mentioned earlier that it very difficult to quantify the impact of a research project of this nature. However, the casual observations are:

- The project made a contribution towards raising awareness on climate change and adaptation at all levels of society – the general public, farmers, water managers, local, provincial and national government and in the research fraternity.
• The project contributed towards capacity building in climate change and the analysis tools to assess vulnerability and adaptation strategies by training and short courses to several students.
• Finally, the integrated modelling framework which was developed is unique. It has not been done anywhere in Africa and very few other places in the world. The project therefore also contributed towards the improvement of the methodologies to study the impact of climate change, climate vulnerability and evaluation methodology of adaptation strategies.
7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Responding to climate change impacts through appropriate adaptation and mitigation mechanisms requires practical resilient solutions in the form of technological, social and economic aspects. These can be developed through systematic research on climate change and associated impacts. In many African countries there is limited research on climate change and related impacts on livelihood, natural resources. This is partly attributed to limited funding for research on climate change impacts, adaptation and mitigation; limited focus and prioritization by researchers to study climate change; inadequate facilities for collection of weather information on climate change by region. Overall this has an implication of limited knowledge and information on appropriate options to support climate change adaptation and mitigation thereby increasing vulnerability to climate change impacts at all levels.

South Africa is blessed by the fact that there are researchers and adequate facilities to conduct research that will improve the knowledge on how the technical, social and economic elements of climate change can be integrated to provide a holistic solution to adaptation to climate change.

The project contributed in at least three ways towards reducing vulnerability to climate change in the Western Cape. These are:

- Raising awareness about climate change and the need to adapt.
- Building capacity within the research, agricultural and water management fraternity in South Africa and especially in the Western Cape.
- Development of an analytical framework to calculate the costs and benefits of various climate change adaptation strategies and to demonstrate to water managers how the models can be used to provide holistic answers to adaptation issues.

Since climate change is a multi-dimensional challenge it was necessary to use the participating action research (PAR) approach for this project. The Berg River Catchment Management Agency was selected as the key boundary partner since all stakeholders in the broader society are represented on the agency. This approach enabled the research team to engage actively with all stakeholders to share knowledge and to integrate local knowledge with science. The authors are of the opinion that this approach contributed significantly towards the achievement of the objectives of the project.

An Outcome Mapping framework (see Appendix 6) was developed early in the project to monitor and evaluate the project. Although the approach seems to be useful, the framework was abandoned when the Minister of Water Affairs decided to merge the Berg River Catchment Management agency with the Olifants River Catchment agency towards the second half of the project. This event made it difficult since many new
stakeholders from a different catchment were incorporated with different issues. The approach was therefore abandoned. It is also important to note that the project team did not incorporate this approach in their project proposal and it would have had budget implications.

Finally the authors believe that the models / methodology can never be regarded as final since they have to be developed continuously as new technology and knowledge becomes available. It should therefore be obvious that there is a need for follow up research. In this regard the project team is fortunate that all the key members is involved in a WRC commission project (which was mentioned earlier in this report) where the research will continue on the strong foundation which was laid by the CCAA program (grant funding well spend). The authors believe that this project will contribute towards the sustainable use and improvement of the methodology which was developed in this project.

7.2 RECOMMENDATIONS

The following recommendations are made for future research:

- The generation of decadal climate projections for the distant future to assess the influence of decadal climate variability for this period (2046-2065), and to translate these into runoff impacts;
- The incorporation of a more sophisticated climate change signal into the decadal projections accounting for the variation in IPCC global projections rather than simply assuming the multi-model mean;
- Include other emissions scenarios in near and distant future projections to assess the full range of possible climate and runoff outcomes; and
- For the distant future, where regional projections are developed by downscaling individual GCM projections, to include downscalings of multiple GCMs in runoff simulations, rather than only a High and a Low scenario where there is no indication if other available models tend more towards the High or Low GCM.
- It was pointed out that there is a need for more research to increase the sensitivity of the farm models to climate change variables (temperature and water availability).
- It is recommended that the PAR approach as well as the OM framework approach for monitoring and evaluation be incorporated in the final terms of reference for all the IDRC / DFID project proposals. However, researchers should be sensitised about this so that they can make provision for this approach in their project budgets.
- Finally, it is also recommended to continue discussion with the WCSA to incorporate the models in the tools to evaluate water management options and to contribute towards improved policies and strategies to adapt to climate change.
REFERENCES


CAPE METROPOLITAN COUNCIL (CMC). (2000). Private communication with Mr. A. Singels, City Engineer, Cape Town.


Appendix 1: Slopes of area: volume for dams

Slopes of Area to Volume Relationships of Representative Farm Dams and Major Storage Dams

**Representative Farm Dams**

<table>
<thead>
<tr>
<th>Farm Dam</th>
<th>Area at Full Supply Capacity (ha)</th>
<th>Full Supply Capacity (m³)</th>
<th>Slope (ha/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berg1</td>
<td>189</td>
<td>3 354 113</td>
<td>0.0000660550</td>
</tr>
<tr>
<td>Suid Agter Paarl</td>
<td>75</td>
<td>1 291 887</td>
<td>0.0000707795</td>
</tr>
<tr>
<td>Nooord Agter Paarl</td>
<td>111</td>
<td>2 334 221</td>
<td>0.0000707746</td>
</tr>
<tr>
<td>Berg2</td>
<td>90</td>
<td>2 514 489</td>
<td>0.0000414648</td>
</tr>
<tr>
<td>Perdeberg</td>
<td>232</td>
<td>4 069 942</td>
<td>0.0000667263</td>
</tr>
<tr>
<td>Berg3</td>
<td>36</td>
<td>596 463</td>
<td>0.0000682354</td>
</tr>
<tr>
<td>Riebeck Kasteel</td>
<td>142</td>
<td>2 252 919</td>
<td>0.0000725859</td>
</tr>
<tr>
<td>Berg4</td>
<td>2</td>
<td>30 026</td>
<td>0.0000857863</td>
</tr>
<tr>
<td>Berg5</td>
<td>13</td>
<td>224 859</td>
<td>0.0000655459</td>
</tr>
<tr>
<td>Berg6</td>
<td>3</td>
<td>20 434</td>
<td>0.0001419352</td>
</tr>
<tr>
<td>Berg East</td>
<td>485</td>
<td>9 497 487</td>
<td>0.0000722636</td>
</tr>
<tr>
<td>24 Rivieren</td>
<td>181</td>
<td>3 955 838</td>
<td>0.0000546231</td>
</tr>
<tr>
<td>Tulbagh</td>
<td>407</td>
<td>7 090 635</td>
<td>0.0000748547</td>
</tr>
<tr>
<td>Franschhoek</td>
<td>71</td>
<td>868 636</td>
<td>0.0000932854</td>
</tr>
<tr>
<td>Stellenbosch</td>
<td>818</td>
<td>13 397 507</td>
<td>0.0000765653</td>
</tr>
<tr>
<td>Banhoek</td>
<td>7</td>
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<tr>
<td>Villiersdorp</td>
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<td>0.0000901835</td>
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<tr>
<td>Houtveld</td>
<td>299</td>
<td>6 422 730</td>
<td>0.0000610315</td>
</tr>
<tr>
<td>Rivieronderend</td>
<td>256</td>
<td>4 109 442</td>
<td>0.0000785891</td>
</tr>
<tr>
<td>Palmiet (Upper)</td>
<td>128</td>
<td>2 485 476</td>
<td>0.0000666260</td>
</tr>
<tr>
<td>Palmiet (Lower)</td>
<td>483</td>
<td>8 779 237</td>
<td>0.0000666260</td>
</tr>
</tbody>
</table>

**Major Storage Dams**

<table>
<thead>
<tr>
<th>Storage Dam</th>
<th>Area at Full Supply Capacity¹ (ha)</th>
<th>Full Supply Capacity¹ (m³)</th>
<th>Slope (ha/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Misverstand</td>
<td>249</td>
<td>5 770 000</td>
<td>0.000036710</td>
</tr>
<tr>
<td>Voëlvlei</td>
<td>1573</td>
<td>172 170 000</td>
<td>0.000011523</td>
</tr>
<tr>
<td>Theewaterskloof</td>
<td>5082</td>
<td>480 190 000</td>
<td>0.000012150</td>
</tr>
<tr>
<td>Wemmersonderend</td>
<td>296</td>
<td>58 780 000</td>
<td>0.00006101</td>
</tr>
<tr>
<td>Bergz</td>
<td>525</td>
<td>126 370 000</td>
<td>0.00004154</td>
</tr>
<tr>
<td>Elandskloofz</td>
<td>61</td>
<td>11 350 000</td>
<td>0.00005374</td>
</tr>
<tr>
<td>Upper Palmietz</td>
<td>291</td>
<td>33 630 000</td>
<td>0.00008653</td>
</tr>
<tr>
<td>Lower Palmietz</td>
<td>636</td>
<td>26 870 000</td>
<td>0.000023670</td>
</tr>
<tr>
<td>Steenbras</td>
<td>663</td>
<td>65 500 000</td>
<td>0.000011181</td>
</tr>
<tr>
<td>-----------</td>
<td>-----</td>
<td>------------</td>
<td>--------------</td>
</tr>
</tbody>
</table>

1 Sourced from Sparks (2008) and DWAF (2008)
2 Slopes estimated by dividing area by volume at full supply capacity (detailed area : volume relationships not readily available)

References

Sparks, A, 2008. Personal communication. Aurecon, Aurecon Centre, Century City Drive, Waterford Precinct, Century City, South Africa
Department of Water Affairs and Forestry (Western Cape Region), 2008. *Western Cape System Assessment of the Need for Water Restrictions from 1st December 2008: First Draft* by A Sparks.
Appendix 2: Training material

See PDF attachment: Training material
Appendix 3: Project profile

See PDF file: Appendix 3 – Project profile
Appendix 4: Regional workshop agenda + notes

Managing climate risk for agriculture and water resources development in South Africa – A IDRC project

STAKEHOLDER MEETING – 14 FEBRUARY 2008
NELSON’S CREEK WINE ESTATE

AGENDA

10.00 Welcome and team introduction Peter Johnston

10.15 Project Background
    - Climate scenarios Peter Johnston
    - Project description Daan Louw
    - Project outcomes Daan Louw

11.15 TEA

11.35 Methodology and Progress Daan Louw/Peter Johnston

12.00 Project Monitoring Donna Podems

12.10 Feedback and discussion Team and Participants

12.50 Steering Committee Discussion Daan Louw

13.00 Closing and LUNCH

Notes / comments from participants
- It was very interactive and informative - Anonymous

- How are communication channels going to be developed - Anonymous

Gustav Haumann

- Nothing really new, but still very interesting. I would be interested in the first 5-10 graphs on Climate Change.

- Very good presentation.
- No action plans.
- Very bad farmers representation.
- Water, power, environmental regulations to be politicized and implemented through BEE ‘credits’ reality?
- How will this group influence this process?

Mike Shand

- Suggest you meet with DWAF and their hydrological modellers at some stage
- Obtain DWAF reports
  - WC Recon Study
  - WAAS study
  - West Coast Study
- Keep data collection as simple as possible i.e. easily repeated in future. Identify institutions who keep data and can be custodians/sources of data.
- Model output must be easily understood by laymen.
- Identify those who will act as future custodians of model. e.g. DWAF National Water Resources Planning

- Very useful information
- Think your approach is correct.
- I would urge you to lobby for funding for education regarding this (…) aimed at local communities. I know the above is not part of the scope now.

Arthur Chapman

- Great project idea
- Good luck – it’s really complex.

Hannel Ham

- Keep us posted, please would like regular feedback.
- Information made available today that can feed back to deciduous fruit breeding programmes.
Jessica Wilson

- More detail on scenarios and their value
- Questions of equity being dealt with – how does equity fit into that
- More detail on urban demand

City of Cape Town

- Very informative, eye – opener. Eager to be involved
Appendix 5: Scenario results
Appendix 6: OM framework

Outcome Mapping Framework:

Managing climate risk for agriculture and water resources development in South Africa: Quantifying the costs, benefits and risks associated with planning and management alternatives.

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Peter Johnston (UCT) Tel: +27(0)21 650 2884 Fax: +27(0)21 650 5773 E-mail: Johnston@egs.uct.ac.za
VISION STATEMENT

Within water management areas in South Africa, there is a general and open access to climate change information, which facilitates the enhancement of capacity among Africans to be resilient to climate change impacts and challenges.

All local water management authorities in the SW Cape use and apply CC scenarios and model output in their long term planning in order to provide sufficient quality water for all users.

Local communities and authorities gain adaptive capacities in agriculture and associated activities to mitigate CC impacts and increase food security through development and integration of marginalised agricultural producers in the broader economy.

Centres of excellence exist within Southern Africa that create and support a wide network of climate scientists.

**Mission Statement:**

In support of the vision, the project will develop downscaled CC scenarios for the SW Cape to raise awareness about CC by inserting CC on the agendas of boundary partner meetings. The project in collaboration with CMA stakeholders will develop an integrated modelling framework to quantify the costs, benefits and risks associated with CC scenarios. The model output will be used to raise awareness among stakeholders, influence policy makers and to develop adaptation strategies to reduce vulnerability through an integrated approach by applying the scientific output towards socio-economic challenges induced by CC.

The project will work with CMA structures to communicate and disseminate CC forecast information to water managers, policy makers and vulnerable groups. Participatory Action Research (PAR), in collaboration with the CMAs, through data collection, interpretation and assistance in the development of adaptation strategies will guide the project. The focus will also be on access to information, capacity-building and involvement of women stakeholders (organisations such as women on farms – within the CMA structures) to provide alternative gender specific viewpoints through directed communication strategies.

**Boundary Partners:**

The boundary partners to be influenced by the project output will mainly consist of the Catchment Management Authority/Agency (CMA) (executive committee) which is representative of all
relevant stakeholders such as provincial government, local government, parastatals, water-users associations, NGOs, CBOs and business.

**Outcome challenges**

1) CMA recognises the importance of Global Climate Change and the project and establishes appropriate structures

2) The project intends to see a strong and viable CMA that will be able to use the model and model output data effectively to develop adaptive strategies to:
   i) Influence policy makers
   ii) Disseminate information to stakeholders

The CMA will also serve as a facilitator for the implementation of adaptation strategies among various diverse stakeholder groups. CMA members will attend capacity development workshops to strengthen their understanding of the implications of modelling results and to bridge communication gaps amongst the different groups.

**Figure 25: Schematic representation of the project and the boundary partner**

**Progress Markers**

**EXPECT TO SEE:**

1) The incorporation of climate change adaptation on the agenda of the CMA and issues are discussed.
2) The appointment of an official within the CMA that will be responsible for the facilitation of climate change related actions and/or issues.

3) The CMA to be seen to be actively involved in raising public awareness of climate change and adaptation through open meetings and media campaigns.

4) The CMA to support the project team by setting up specialist sectoral stakeholder sub-groups to validate the model output.

5) The CMA to appoint selected representatives to attend capacity building workshops on adaptation strategies.

6) Stakeholder sub-group participate in the formulation and prioritisation of adaptation strategies.

LIKE TO SEE:

1) The CMA taking on a coordinating role in water resource related climate change adaptation within the catchment area

2) The CMA, through CMA structures, develops a plan to implement selected prioritised strategies.

3) Collaboration between CMAs, through common CMA structures, such as DWAF, on climate change related issues and activities.

4) The CMA to assist the project team with communications on data collection to various stakeholders and to facilitate actions to verify data.

5) The CMA identify and request new opportunities for training and extension on climate change and adaptation.

LOVE TO SEE:

1) CMA support initiatives to secure funding for climate change research.

2) CMA take ownership of integrated modelling framework by initiating and funding periodic updates of database information.

3) More efficient water use by stakeholders as a result of the implemented strategies.

4) CMA sharing experiences and resources on a National level making an input to cabinet.

5) BR CMA initiates discussion around the formation of Provincial and National Climate change catchment reference groups.

6) CMA submit input to research advisory committees.

7) CMA making a input on national level.
**Strategy Maps**

**Outcome Challenge:**

The project intends to see the CMA as a facilitator for

a) data collection and verification of data with stakeholders
b) verification of model output and output recommendations
c) the development and dissemination of adaptation strategies based on modelling results to influence policy makers.

The CMA will also serve to facilitate the implementation of adaptation strategies among various diverse stakeholder groups. CMA members will attend capacity development workshops to strengthen their understanding of the implications of modelling results and to bridge communication gaps amongst the different groups.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>I-1 Causal - Immediate output</th>
<th>I-2 Persuasive – capacity building</th>
<th>I-3 Supportive - guidance, mentoring</th>
</tr>
</thead>
</table>
| Strategies and Activities Aimed at a Specific Individual or Group | • Use current contacts and structures within CMA to negotiate CC agenda items  
• Use sectoral groups to coordinate data collection | • Propose creation of CC portfolio and appointment of existing or new officer to handle it.  
• Compile and give project information and awareness presentation to key role players.  
• Compile and give data verification and model output presentation to sectoral groups for | • Offer to train and monitor the portfolio holder.  
• Set up sectoral stakeholder groups within CMA  
• Hold workshop with sectoral groups to discuss and formulate adaptation strategies |
<table>
<thead>
<tr>
<th>Strategy</th>
<th>E-1 Causal – change physical/policy environment</th>
<th>E-2 Persuasive – media or publications</th>
<th>E-3 Supportive – utilising networks, relationships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategies and Activities Aimed at Individual or Group’s Environment</td>
<td>Use current contacts and structures within CMA to negotiate CC agenda items</td>
<td>Compile and present media and information broadsheets to CMA structure for dissemination</td>
<td>Present adaptation options to CMA at a dedicated workshop for discussion, adoption and implementation</td>
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<td></td>
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<td>• Propose creation of CC portfolio and appointment of existing or new officer to handle it.</td>
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