Botswana | Lesotho | Namibia | South Africa

The Orange-Senqu River Commission (ORASECOM)

Sharing the Water Resources of the Orange-Senqu River Basin

Contract No.: P-Z1-EAZ-048/CS/01

Preparation of Climate Resilient Water Resources Investment Strategy & Plan and Lesotho-Botswana Water Transfer Multipurpose Transboundary Project

CLIMATE CHANGE REPORT

Component I

August 2021

FINAL REPORT

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PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT I

CLIMATE CHANGE

Prepared for

Orange-Senqu River Commission (ORASECOM)

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PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT I

CLIMATE CHANGE

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Inception Report Components III and IV	ORASECOM 011/2018
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Core Scenario Update Report Component I	ORASECOM 003/2019
Core Scenario Supporting Report: Water Requirements and Return flows **Component I**	ORASECOM 004/2019
Core Scenario Supporting Report: Water Conservation, Water Demand management and Re-use Report **Component I**	ORASECOM 005/2019
Core Scenario Supporting Report: Ground Water Report **Component I**	ORASECOM 006/2019
Climate Change Report **Component I**	ORASECOM 007/2019
Review and assessment of existing policies, institutional arrangements and structures Component I	ORASECOM 008/2019
Optimized IWRMP Core Scenario economic approach Report Component **I**	ORASECOM 009/2019
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Roadmap supporting Report: Strategic actions and TORs (Appendix A to Roadmap Report)	ORASECOM 013/2019
Lesotho-Botswana water transfer multipurpose transboundary project Component III Pre-feasibility Phase	
Pre-feasibility report Phase 1 Report Component **III**	ORASECOM 014/2019
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Report A Phase 2: Dam on the Makhaleng River	ORASECOM 015A/2019

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Report B Phase2: Water Conveyance System	ORASECOM 015B/2019
Report C Phase 2: Environmental and Social Assessment	ORASECOM 015C/2019
Report D Makhaleng River Ecological Water Requirements	ORASECOM 015D/2019
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Geotechnical Investigation Report for the Dam on the Makhaleng River. Annexure A to Volume I – Main Report	ORASECOM 017A/2019
Survey Report Annexure B to Volume I – Main Report	ORASECOM 017B2019

EXECUTIVE SUMMARY

The impact of climate change on the Orange-Senqu Basin was determined by using six global climate change models. The climate change models where downscaled and bias corrected to obtain acceptable regional metrological trends, correlating with historic data within the accepted Southern African Hydrology.

A study area was selected encompassing the Senqu, Makhaleng, Caledon, Upper Orange and Modder catchments, up to the Vanderkloof and Krugersdrift Dam in the Modder Catchment. This area was selected as it produces the majority of the Orange-Senqu Basin runoff which can have far-reaching repercussions on the available yield.

The bias corrected climate change rainfall and evaporation data were used to determine their impacts on the natural runoff. This was done for two scenarios, including bias-corrected climate change rainfall for scenario 1 and bias-corrected rainfall and evaporation for scenario 2. The pitman model was programmatically re-run for the 11 sub-systems containing 119 runoff units for the 6 climate change models and two scenarios. The natural runoff, rainfall and evaporation datasets were compiled as inputs for the Water Resources Yield Model (WRYM). The WRYM was used to determine the yields for the four separate sub-system, consisting of the Lesotho Highlands Water Project (LHWP), Greater Bloemfontein Water Supply Scheme (GBWSS), Makhaleng Dam and the Orange River Project (ORP). A constant development level of 2030 was used for the analysis. The changes in yield for the six climate change models and two scenarios were then compared to the firm yield determined for each of the four systems.

It was found that the average yield for scenario 1 for the entire system decreased by 1% and decreased by 5% for scenario 2. In addition, it was determined that the irrigation requirements increased on average by up to 7% and one of the six models indicated an average decrease of 8%. For the study area, which consists five subsystems, Caledon, Modder, Senqu, Makhaleng and Upper Orange catchments. The Modder Catchment is supported by the Knellpoort and the Welbedacht dams which are located in the Caledon Catchment.

This report indicates that the stochastic analysis is able to encapsulate impacts of climate change on water resources especially for the low flow sequences, it is shown in this report that the stochastic analysis produces runoff which is significantly lower than the projected climate change runoff. If the hydrology is updated on a regular basis to account for new critical periods and their recovery. The general consensus is that the rainfall will decrease towards the north west and the evaporation will increase, however over the eastern parts of the catchment there is no general consensus over the magnitude and direction of change.

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LIST OF ACRONYMS

AGRP	Average Groundwater Resource Potential
AMD	Acid mine drainage
CCM	Climate Change Model
DWA	Department of Water Affairs (RSA)
DWAF	Department of Water Affairs and Forestry (RSA)
DWS	Department Water and Sanitation
EC	Electrical conductivity
EFR	Environmental flow requirements
EWR	Environmental Water Requirement
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GEP	Groundwater Exploitation Potential
GRA II	Groundwater Resources Assessment Phase II
GRP	Groundwater Resource Potential
IAPP	International Association for Public Participation
IGRAC	International Groundwater Resources Assessment Centre

IPCC	International Panel for Climate Change
IVRS	Integrated Vaal River System
IWRM	Integrated Water Resources Management
L-BWT	Lesotho Botswana Water Transfer
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
l/s	Litre per second
MAFS	Ministry of Agriculture and Food Security (Lesotho)
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MAWF	Ministry of Agriculture, Water and Forestry (Namibia)
MC	Management Centre (Botswana)
MEWR	Minerals, Energy and Water Resources (Botswana)
mm/a	Millimetres per annum
m^3/s	Cubic Meters per second
m^3/a	Cubic Meters per annum
MW	Megawatts
NWA	National Water Act
NAP	National Action Programme
NGO	Non-governmental Organisation
ORASECOM	Orange Senqu River Commission
ORP	Orange River Project (Gariep and Vanderkloof dams and supply area)
PES	Present Ecological State
PF	Potability Factor
PGEP	Potable Groundwater Exploitation Potential
PWC	Permanent Water Commission
RSA	Republic of South Africa
SADC	Southern African Development Community
SADC-GIO	Southern African Development Community Groundwater Information Portal

SAP	Strategic Action Programme
SC	Sub-Catchments
TDA	Transboundary Diagnostic Analysis
TDS	Total dissolved solids
TTT	Technical Task Team
TOR	Terms of Reference
UGEP	Utilisable Groundwater Exploitation Potential
UNDP	United Nations Development Programme
VRS	Vaal River System
WARMS	Water Authorisation and Registration Management System
WASCO	Water and Sanitation Company
WC	Water Conservation
WDM	Water Demand Management
WMA	Water Management Area
WRYM	Water Resources Yield Model
WRPM	Water Resources Planning Model
WUC	Water Utilities Company

1 INTRODUCTION

1.1 Background to the Study Area

The Orange-Senqu River Basin is one of the largest river basins south of the Zambezi with a catchment area of approximately 1 million km^2. It encompasses all of Lesotho, a significant portion of South Africa, Botswana and Namibia. The Orange-Senqu River originates in the Highlands of Lesotho and flows in a westerly direction, approximately 2,200 km to the west coast of South Africa and Namibia, where the river discharges into the Atlantic Ocean. See **Figure 1-1.**

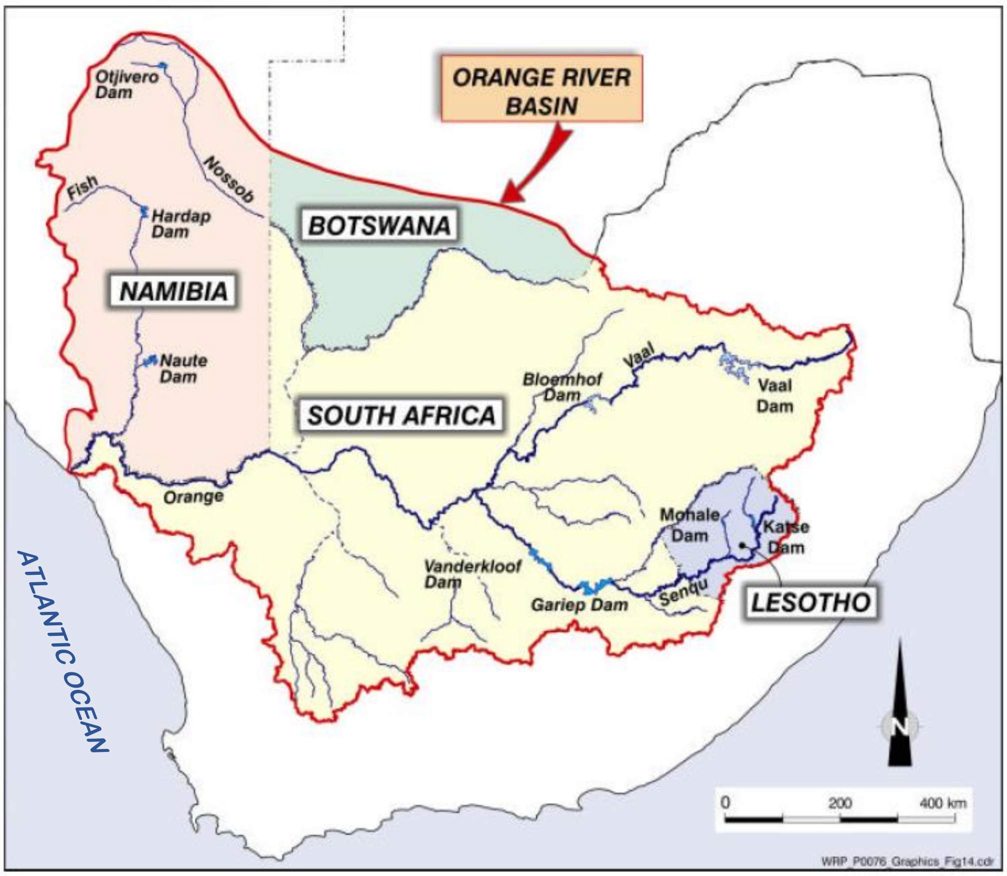

Figure 1-1: Orange-Senqu River Basin

On the part of Lesotho, there are three distinct hydrologically homogenous river basins, where each river basin has its clear source where it originates. These river basins, namely: Senqu, Mohokare and Makhaleng River Basins all flows in the westerly direction and join together outside the border of Lesotho with the Orange River to form one large basin known as the Orange-Senqu River Basin.

It has been estimated that the natural runoff of the Orange-Senqu River Basin is in the order of 11,300 million m^3/a, of which approximately 4,000 million m^3/a originates in the Senqu River Basin in the highlands of Lesotho, 6,500 million m^3/a from the Vaal and Upper Orange River, with approximately 800 million m^3/a from the Lower Orange and Fish River in Namibia. The basin also includes a portion in Botswana and Namibia (north of Fish River) feeding the Nossob and Molopo Rivers.

Southern Africa has fifteen (15) transboundary watercourse systems of which thirteen (13) exclusively stretch over the Southern African Development Community (SADC) Member States. The Orange–Senqu is one of these thirteen (13) transboundary water course systems. SADC member states embrace the ideals of utilizing the water resources of these transboundary watercourses for the regional economic integration and for the mutual benefit of the riparian states. The region has demonstrated a great deal of goodwill and commitment towards collaboration on water issues. Thus, SADC has adopted the principle of basin–wide management of the water resources for sustainable and integrated water resources development.

To enhance the objectives of integrated water resources development and management in the region, the Orange–Senqu River Basin Commission (ORASECOM) was established in November 2000.

ORASECOM was established by the Governments of four States, namely, South Africa, Lesotho, Botswana and Namibia, for managing the transboundary water resources of the Orange-Senqu River Basin and promoting its beneficial development for the socio-economic wellbeing and safeguarding the basin environment. This led to the development of a basin level Integrated Water Resources Management (IWRM) Plan adopted in February 2015 by the ORASECOM Member States. The IWRM Plan provides a strategic transboundary water resources management framework and action areas and serves as a guiding and planning tool for achieving the long-term development goals in the basin. A key aspect of the transformative approach for strengthening cooperation has been identified as the need for joint project implementation that provides a mutually inclusive transboundary benefit.

The IWRM Plan recommends strategies and measures for promoting sustainable management of the water resources of the basin and defines strategic actions that will ensure and enhance water security, considering the long term socio-economic and environmental demands on the water resources of the basin. The Lesotho to Botswana Water Transfer Scheme, a major component under this study, was not included in the 2015 IWRM Plan as one of the strategic actions, but has lately been identified as a priority project.

The Orange-Senqu River basin is a highly complex and integrated water resource system, characterized by a high degree of regulation and major inter-basin transfers to manage the resource availability between the location of relatively abundant precipitation and the location of greatest water requirements. The infrastructure involves water storage and transmission infrastructure, transmitting water to demand centres that are in some cases located outside of the basin through intra and inter basin transfers. Most of the existing infrastructure are those under the Lesotho Highlands Water Project (LHWP) which transfers water to South Africa and also those for inter basin transfer to the Vaal Basin.

Figure 1.2 provides approximate values of the natural run-off in the Orange-Senqu River Basin. These figures highlight the variable and uneven distribution of runoff from east to west in the basin. The figures refer to the natural runoff which would have occurred had there been no developments or impoundments in the catchment. The actual runoff reaching the river mouth is considerably less than the natural values and are estimated to be in the order of half the natural values.

The difference is due mainly to the extensive water utilisation in the Vaal River Basin, most of which is for domestic and industrial purposes. Several major transfer systems are used to bring water into the Upper Vaal River catchment to support the high-water requirements, in particular those within the Gauteng area as well as for several Power Stations.

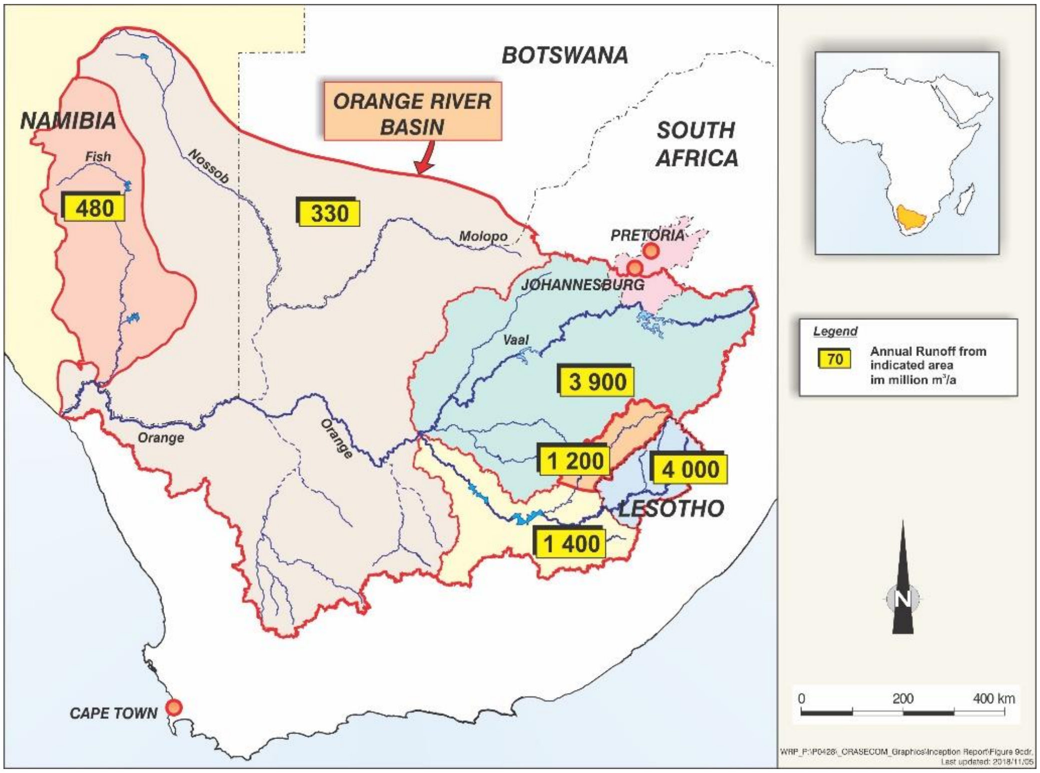

Figure 1-2: Approximate Natural Run-off in the Basin

Large volumes of water are also used to support extensive irrigation and some mining demands along the Orange River downstream of the Orange-Vaal confluence, as well as significant irrigation developments in the Eastern Cape in South Africa, supplied through the Orange-Fish Tunnel. In addition to the water demands, evaporation losses from the Orange River and the associated riparian vegetation that depend on the river account for 500 to 1,000 Million m^3/a.

As already indicated, there are locations of relatively abundant precipitation and water availability and the locations of greatest water requirements. Water scarcity in locations of greatest need is the main challenge in the basin, and this requires a coordinated joint development, management and conservation of the water resources system. The climate in the basin varies from relatively temperate in the eastern source areas, to hyper-arid in the western areas. As shown in **Figure 1.3**, average annual precipitation decreases from more than 1,000 mm/a in the source areas of the basin to less than 50 mm/a at the river mouth. This varies considerably from year to year. Much of the rainfall occurs as intense storms, which can be highly localised. The temporal and spatial distribution of precipitation within any particular year can be considerable.

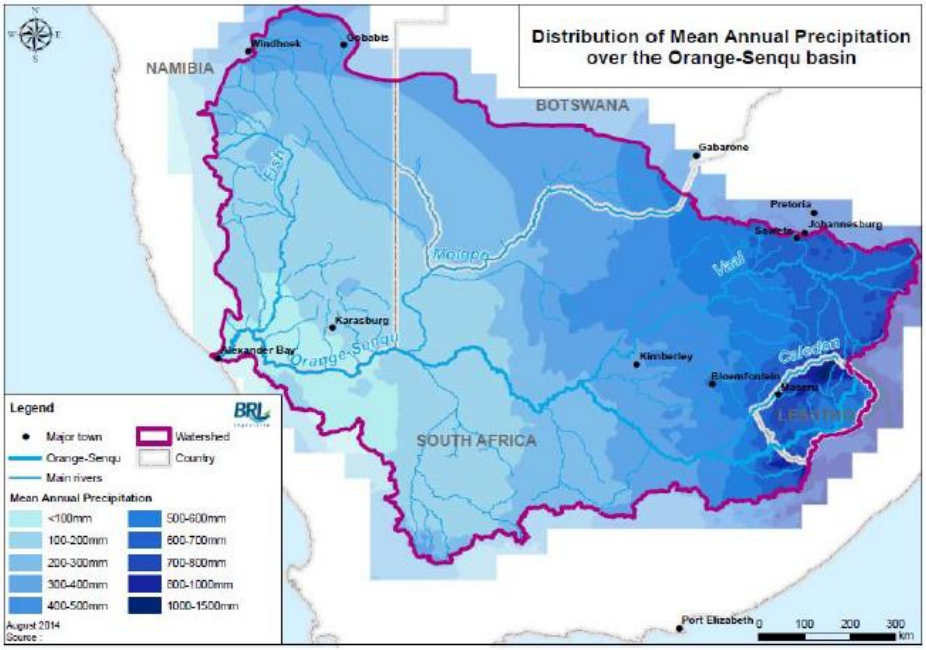

Figure 1-3: Distribution of Mean Annual Precipitation

In **Figure 1.4** it is evident that evaporation increases from south-east to north-west reaching a maximum of more than 1,650 mm/a in the west. Even in the cooler and wetter parts of the basin, evaporation in most cases exceeds precipitation. Temperature and evaporation follow a similar distribution with the coolest temperatures in the Lesotho Highlands and the hottest in the western Kalahari.

It is generally accepted that Southern Africa will be highly impacted by climate change. Consequently, there are concerns around the changes in precipitation and temperature due to climate variability and climate change. This study therefore aims to enhance investment in transboundary water security and to build resilience to climate change into the implementation of the strategic projects and actions described in the IWRM Plan.

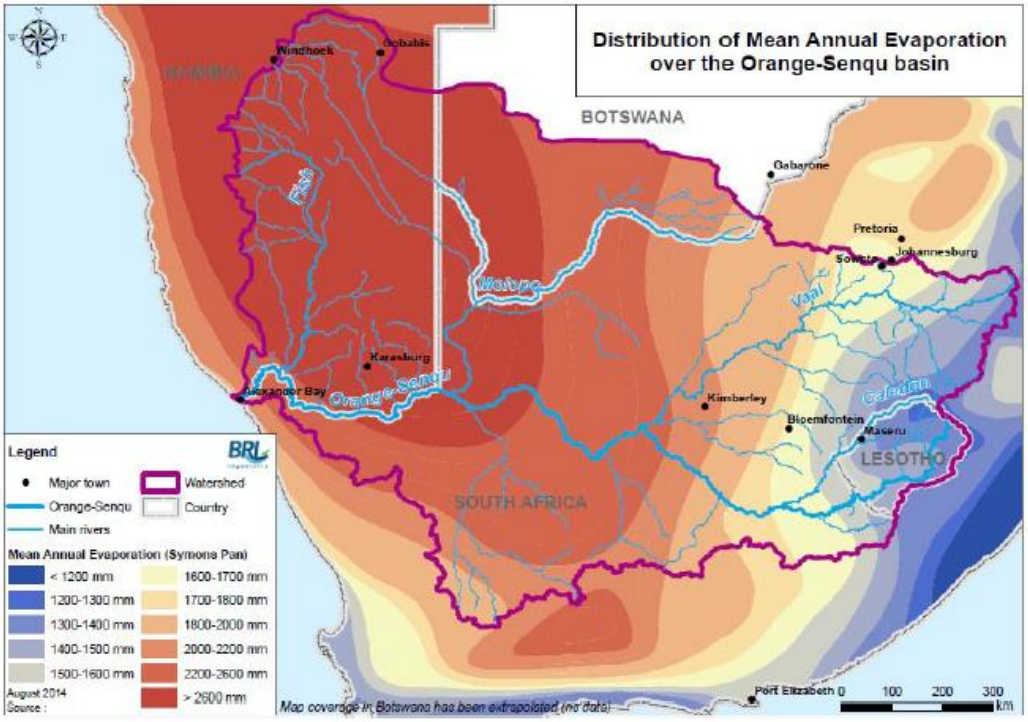

Figure 1-4: Distribution of Mean Annual Evaporation

The Republic of Botswana is an arid country faced with serious water constraints which will worsen with the expected effects of climate change. Botswana will experience chronic water shortages by about 2025, unless major new water sources are developed. Already Gaborone was critically hit by the 2015-2016 drought.

As a consequence, the Governments of Botswana, Lesotho and South Africa, signed a Memorandum of Agreement to undertake a reconnaissance study on the Lesotho to Botswana Water Transfer scheme (L-BWT), which aimed at developing water infrastructure in Lesotho and through South Africa, to convey water to Botswana, at the same time supplying various users in Lesotho and South Africa. This reconnaissance study led to the selection of a technical option which included a new dam on the Makhaleng River in Lesotho and a water conveyance (pipeline) system to Botswana. It was envisaged that eventually 150 million m^3/a will be pumped to Botswana with additional supplies for consumers along the route in Lesotho and South Africa.

1.2 Objective of the Assignment

The objective of the study is to update the IWRM Plan endorsed in 2015 and propose an updated Core Scenario which should include the L-BWT Project, studying at pre-feasibility level the L-BWT Project including the feasibility of the dam, and to assist ORASECOM and the riparian countries in operationalizing the updated IWRM Plan. The objective will therefore be met through three outputs:

- A Climate Resilient Investment Plan for the Orange-Senqu River Basin based on the updated Core Scenario;
- Operationalization Plan for ten (10) priority actions selected from the updated IWRM Plan; and
- Pre-feasibility level report for the L-BWT Project, and the feasibility level report for a new dam, on Makhaleng River in Lesotho.

The study is divided into two distinct parts:

1) Preparation of a Climate Resilient Investment Plan, based on the updated Water Resources Yield and Planning Model and the updated Core Scenario defined in the IWRM Plan of 2015, as Components I & II of the study; and
2) The pre-feasibility study of Lesotho-Botswana Water Transfer Project, including the feasibility study of a new dam on Makhaleng River in Lesotho as Components III & IV of the study.

The four components of the study referred to above are:

- Component I: Climate Resilient Water Resources Investment Plan;
- Component II: Operationalisation of the Integrated Water Resources Management Plan;
- Component III: Pre-feasibility study of the Lesotho to Botswana Water Transfer Project;
- Component IV: Feasibility Study of the Dam on Makhaleng River in Lesotho.

1.2.1 Climate Resilient Investment Plan (Components I and II)

The high level of variability in precipitation due to climate variability and change, defines the need to optimize and implement efficient water resources development and management in the basin. The development of new infrastructure to meet increasing water demands, even if technically and environmentally feasible, is both expensive and complex. Economic considerations of water use have been identified as a key part in the planning and optimum use of what will become an increasingly scarce and expensive resource. Projections of future water demand and associated infrastructure development must be based on balanced considerations of economic, social, and environmental factors. The integration of water resources yield analysis, water resources development planning and economic optimization will ensure the development of short, medium- and long-term solutions to address basin water resources needs and development challenges.

The study includes water resource studies in Botswana, Lesotho, Namibian and South Africa. This will include updating of inputs from the Reconciliation Strategy Studies, updating of inputs with more recent results from the Reconciliation Strategy Maintenance Studies as well as other recent water resource related studies conducted in the basin countries. The study will establish comprehensive basin wide analyses which will be integrated with economic analyses to determine the optimized and most efficient development options, as part of setting the long-term development investment strategy and plan for the basin.

Components I & II will thus address the water resources investment plan and the operationalization of the updated IWRM Plan with the following outputs:

- Updated Core Scenario of the IWRM Plan, which would include the Lesotho-Botswana Water Transfer Scheme and any other new projects identified;
- Estimate of the Climate Change Effects on the updated Core Scenario;
- Optimised IWRM Plan Core Scenario through an economic approach;
- Financial Strategy for the Core Scenario;
- Updated Basin Wide Investment Plan approved by ORASECOM, which would include new projects that takes into consideration climate change effects;
- A comprehensive assessment of existing policies, legal and institutional arrangements and structures;
- Selected 10 strategic actions, Terms of Reference and cost estimates for each strategic action; and
- A road map for operationalization of the ten (10) strategic actions contained in the updated Integrated Water Resource Management Plan.

1.2.2 Lesotho-Botswana Water Transfer (L-BWT) Project (Components III and IV)

The south eastern urban complex of Botswana centred around the capital city, Gaborone, has experienced rapidly increasing growth over the last few decades, and is expected to continue doing so. Its water demands have long outstripped local bulk water resources, which are already supplemented by sources in the north-east of the country. The country has experienced several severe drought spells that have, in the recent past, led to water restrictions. Despite several concerted efforts to alleviate the water shortage challenges, indications are that the water sources will not be adequate to meet the growing demand as early as 2025.

The solution for addressing the water security challenges lies in the need for increasing the efficient use of existing water resources, developing additional water resources and improving the management systems based on availability and usage.

A Reconnaissance Study to identify possible water resources was completed in October 2015, which outlined various options of water sources and conveyance routes to supply water from Lesotho to Botswana. The various sources covered by the study include the Lesotho Highlands Water Project, the Makhaleng River and the Orange-Senqu in the south of Lesotho. The preferred supply scheme recommended in the Reconnaissance Study was a dam on the Makhaleng River, and a conveyance system to bring the water from Lesotho, across South Africa to Botswana.

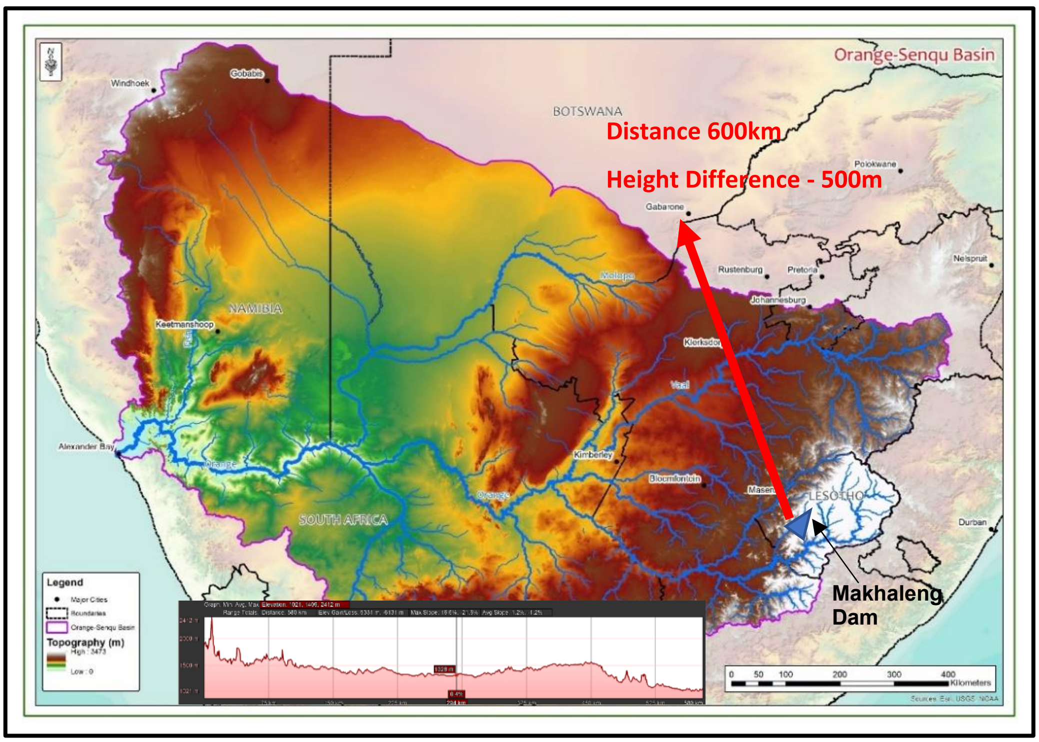

Figure 1.5: Orange Senqu basin topographical map showing the possible Lesotho Botswana Water Transfer Project

A Pre-feasibility Study is required to determine water demands up to 2050 for specified areas in Botswana, Lesotho and South Africa, from available relevant information in all countries, and further investigate suitable dam site(s) by analysing the Makhaleng catchment hydrology, determining the size of the dam(s) on the basis of topography, geology, yield, sedimentation, hydropower generation and water demands for the specific areas in Botswana, Lesotho and South Africa. For the conveyance system, the study is only required to investigate pipeline options along the shortest route, to either Gaborone or Lobatse in Botswana, preferably along existing road servitudes.

Depending on the results and recommendations from the Pre-feasibility Study, a Feasibility Study for a new dam on the Makhaleng River will follow, but this depends on a final decision by the State Parties to the project. **Figure 1.5,** is the topographic map of the catchment, showing the Lesotho to Botswana water transfer project stretch and the major topographic features of the two end points of the water transfer scheme.

Components III & IV of the study focus on the Lesotho-Botswana Water Transfer Multipurpose Trans-boundary (L-BWT) Project and address:

<u>Component III - Phase 1</u>

- Validation of the water requirements for irrigation in Lesotho, the water demand in South Africa along the pipeline route, and the water demand in Botswana;
- Assessment of the water resource, in the Makhaleng catchment;
- Dam site selection; and
- Conveyance route selection.

<u>Component III - Phase 2</u>

- Pre-feasibility study of a dam on the Makhaleng River;
- Prefeasibility study of the water conveyance pipeline from Makhaleng to Gaborone/Lobatse;
- Assessment of environmental and social impacts;
- Economic assessment of the dam and the Lesotho-Botswana water conveyance pipeline; and
- Multi-Criteria Analysis (MCA) of the options.

<u>Component IV - Feasibility of the Makhaleng Dam (Depending on the outcomes from the Pre-Feasibility Study):</u>

- Hydrological analysis, including climate change effects;
- Feasibility Study of the Makhaleng Dam:
- Economic, Social and Financial analysis update; and

- Preparation of project implementation plan.

1.3 Purpose and Structure of this Report

The purpose of this report is to describe the climate change modelling methodology, results and conclusions. Six climate change models were downscaled and disseminated into quaternary catchments. Both rainfall and evaporation data were changed in the rainfall runoff Water Resources Simulation Model 2000 (WRSM 2000) in which the natural runoff was obtained to assess the changes in yield with the Water Resources Yield Model (WRYM). The simulation was conducted in two separate scenarios by only changing the rainfall and secondly by changing the rainfall and runoff.

The structure of the report is following:

- **Chapter 1**: INTRODUCTION;
- **Chapter 2**: METHODOLOGY;
- **Chapter 3**: RESULTS;
- **Chapter 4:** DISCUSSION AND CONCLUSION; and
- **Chapter 5:** RECOMMENDATIONS.

2 METHODOLOGY

2.1 Introduction to Methodology

This section describes the workflow used to obtain the changes in yield for selected dams for changes in rainfall only, as well as rainfall and evaporation. These changes are indicated for the downscaled 6 climate change models.

2.1.1 Water Resources Simulation Software

Figure 2-1 presents a schematic diagram of the primary analysis components and data flow of the water resource modelling. Both the historical and climate change data flow elements are presented, also indicating rainfall and evaporation data were adjusted to simulate the future climate scenarios.

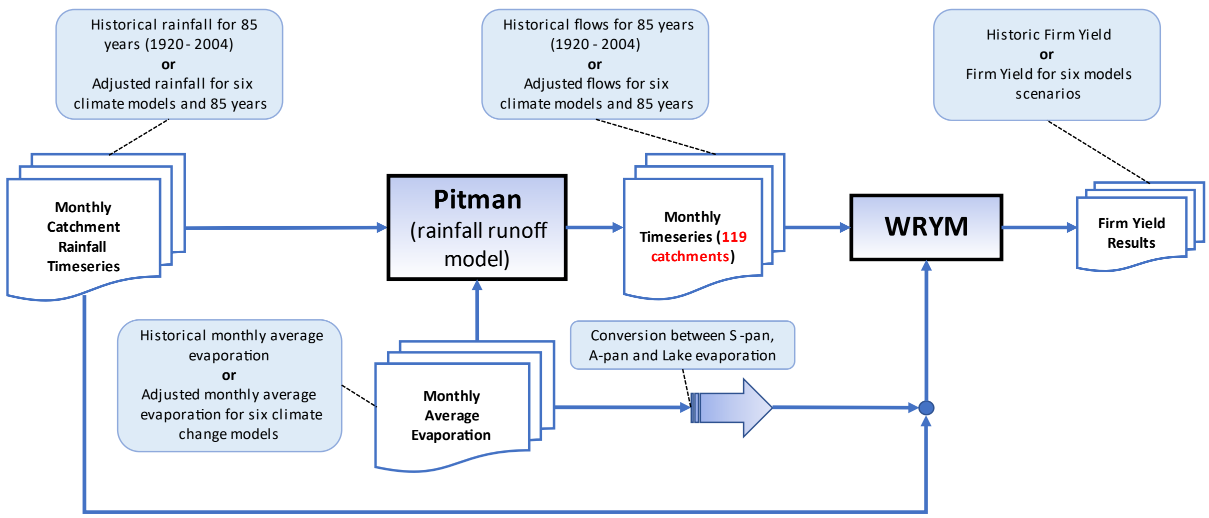

Figure 2-1: Primary water resource modelling components & data flow

The method of deriving the adjusted climate model rainfall and evaporation data were formulated based on the results of the comparative statistical evaluations and are presented in **Section 3.4**.

2.1.2 Climate Change Scenarios

The High-resolution regional projections of future climate change over Africa generated at the Council for Scientific and Industrial Research (CSIR) as a contribution to the Coordinated Regional Climate Downscaling Experiment (CORDEX), and their subsequent downscaling to 8 km resolution, is discussed in this section of the report.

The first step in the downscaling process involved six GCM simulations of the Coupled Model Inter-comparison Project Phase Five (CMIP5) and Assessment Report Five (AR5) of the Intergovernmental Panel on Climate Change (IPCC), obtained for the emission scenarios described by Representative Concentration Pathways 4.5 and 8.5 (RCP4.5 and 8.5), being downscaled to 50 km resolution globally (referred to as the CSIR CORDEX simulations). The simulations span the period 1960-2099. In this study the simulations for the RCP 8.5 scenario was applied.

The 6 climate models were selected among others on the basis that they simulate a realistic ENSO (EL-Nino-Southern Oscillation) signal (Bellenger et al. 2014). This variable exhibits a strong association between South African climate variability.

The six Global Climate Models that were downscaled are:

- Australian Community Climate and Earth System Simulator (ACCESS1-0), hereafter referred to as ACC.
- Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3), hereafter referred to as GFD.
- National Centre for Meteorological Research Coupled Global Climate Model, version 5 (CNRM-CM5), hereafter referred to as CNR.
- Max Planck Institute Coupled Earth System Model (MPI-ESM-LR), hereafter referred to as MPI.
- Norwegian Earth System Model (NorESM1-M), hereafter referred to as NOR.
- Community Climate System Model (CCSM4), hereafter referred to as CCS.

Catchment rainfall and evaporation were derived for the 13 sub-catchments, which comprise of 119 quaternary catchments, by averaging the respective intersecting 8km grids' data from the six climate model simulations respectively.

The method applied by the CSIR to derive the evaporation for the six climate models entailed the following (email correspondence with Trevor Lumsden):

- Select multiple grid points representative of each sub-catchment.
- Estimate evaporation using the Penman-Monteith equation for each of the selected grid points. Inputs to this equation include maximum temperature (tmax), minimum temperature (tmin), maximum relative humidity (RHmax), minimum relative humidity (RHmin), solar radiation and wind speed. Temperature and relative humidity are an output form the climate models. Solar radiation is derived from temperature, altitude and latitude. Default values were assumed for wind speed.

- Convert Penman-Monteith evaporation to A-pan values using local coefficients.
- Convert A-pan evaporation to open water evaporation using local coefficients.
- If multiple grid points were used to represent a catchment, the evaporation values would be averaged at this point.
- Apply bias corrections to the evaporation values which entailed calculating monthly mean totals in the observed (period 1961 to 1999) and modelled climate time series, and then determine the ratio of these means. The ratios are then applied to the modelled monthly time series (period 1961 to 2098).
- Finally, the corrected data is manipulated into the required format.

2.1.3 Comparative Statistical Evaluation

Given that direct year-by-year or month-by-month comparisons of the historical rainfall data with the simulation results of the climate models is not appropriate for validation, comparative statistical analyses were carried to evaluate and compare pertinent characteristics exhibited by the simulated timeseries.

The analysis entailed deriving the following metric from the respective rainfall timeseries for the Validation Period 1961 to 1999:

- Annual and monthly means for each month of the year.
- Annual and monthly standard deviation for each month of the year.
- Annual minimum and maximum.
- Box a whisker plots of annual rainfall – indicating the probability distribution.
- Cross correlation of annual rainfall for within the four sub-catchments.
- Minimum run sum statistics – presenting the cumulative rainfall over most critical dry periods.
- Significance of linear slope.
- Statistical test to determine if the annual rainfall is normally distributed.
- Difference analysis of selected statistics between periods of the simulated timeseries.

The analyses were carried out in Excel using the RealStatistics add-in and bespoke user defined functions developed in Visual Basic for Applications (VBA).

2.2 Adjustment method and statistics

The adjustment method entailed calculating a multiplication factor based on the average monthly rainfall (for each month of the year) for a future period: (a) 2000 to 2050, and for the verification period (b), 1961 to 1999. The factor was calculated as (a)/(b). A factor < 1 indicates that a reduction in the rainfall average occurred in the future climate and a factor > 1 indicate an increase. Sets of 12 factors were determined for each of the 13 sub-catchments and six climate model simulations.

The sets of factors were then applied to the historical rainfall timeseries of 85 years in length to obtain the adjusted catchment rainfall timeseries.

Note that the adjustment method was selected to preserve the historical observed drought periods when considering future scenarios. See **Section 3.2.2** and preceding sections describing the statistical analysis over the validation period.

2.3 Statistics of adjusted rainfall, evaporation and runoff

Two scenarios of adjusted runoff were derived, **Scenario 1** comprises of applying the adjusted catchment rainfall to generate the monthly runoff and **Scenario 2** both the adjusted rainfall and evaporation were applied. All runoff timeseries covered a period on 85 years corresponding to the historical dataset of monthly data ranging from 1920 to 2004.

2.4 Comparison with stochastic generated runoff

The stochastic flow generator applied in the system analysis risk projections inherently account for variations in runoff that are higher and lower than the historical dataset.

A comparison of the minimum runoff of the historical, six climate model datasets and the stochastic generated runoff (applying the historical dataset for parameter estimation of the stochastic model). The result of the comparison is presented in **Section 3.5**.

2.5 Yield analysis scenarios

Yield analysis were carried out with the WRYM as configured for various dams in the Orange-Senqu Catchment. The hydrology for the six models entailed the adjusted runoff, rainfall and evaporation for **Scenario 2** and only runoff and rainfall for **Scenario 1**.

The Firm Yield (maximum abstraction without a supply failure over the 85-year simulation period) were determined for the six models and two scenarios.

3 RESULTS

3.1 Introduction to Results

The results obtained for the climate change study are summarised in this section. Firstly, the downscaled climate change results are discussed in **Section 3.2**. Followed by the statistical analysis of the CCM input data, which is compared to the observed historic data in **Section 3.3**. The statistical characteristics of the future adjusted rainfall, evaporation and runoff data is discussed in **Section 3.4**

A comparison between the future adjusted runoff and the simulated CCM runoff is done in **Section 3.5**, additionally some dam storage trajectory plots are shown to further explain the findings.

A water demand comparison for selected irrigation areas is shown in **Section 3.6**, as it is expected that a change in rainfall and evaporation will have a direct impact on the irrigation requirements.

The results are concluded with the resulting change in yield for the four sub-systems LHWP, GBWSS, Modder, Makhaleng and the ORP, in **Section 3.7**.

3.2 Climate change scenario results

The following results were obtained from the climate change study. **Figure 3-1** shows the simulated change in mean annual rainfall for 3 periods in the 21st century (2025-2049, 2050-2074 and 2075-2099) compared to the mean simulated for the baseline (1985-2005) period based on bias-corrected Sea Surface Temperatures and Sea-Ice Concentrations of 6 GCMs described earlier. These simulations were forced by atmospheric CO_2 concentrations as per RCP8.5.

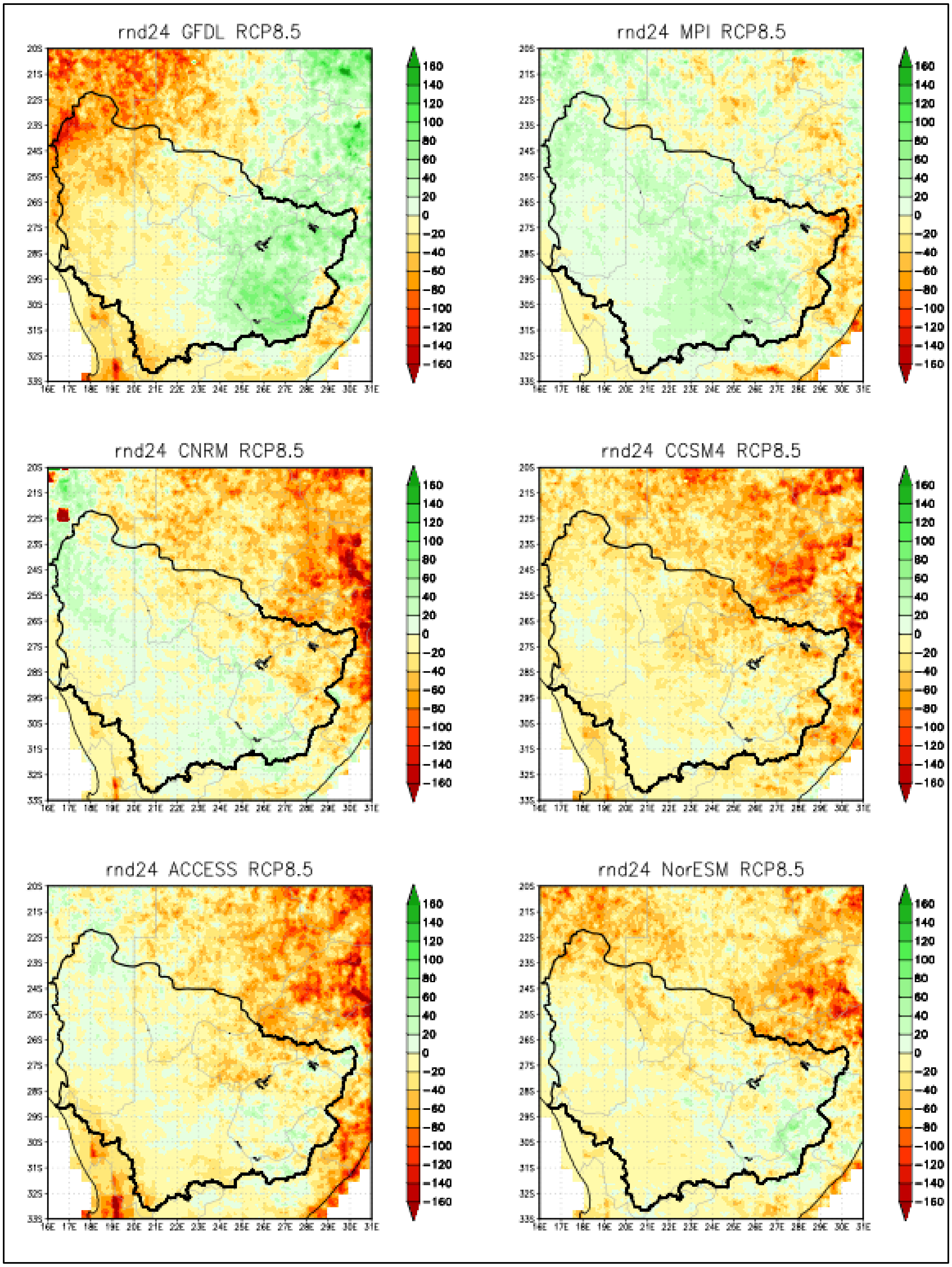

Figure 3-1: CCAM-simulated change in mean annual rainfall (mm) for the period 2025 – 2049 compared to the mean for the period 1986-2005 according to RCP8.5. The Orange-Senqu basin is indicated. Downscaling was performed based on GCMs as indicated.

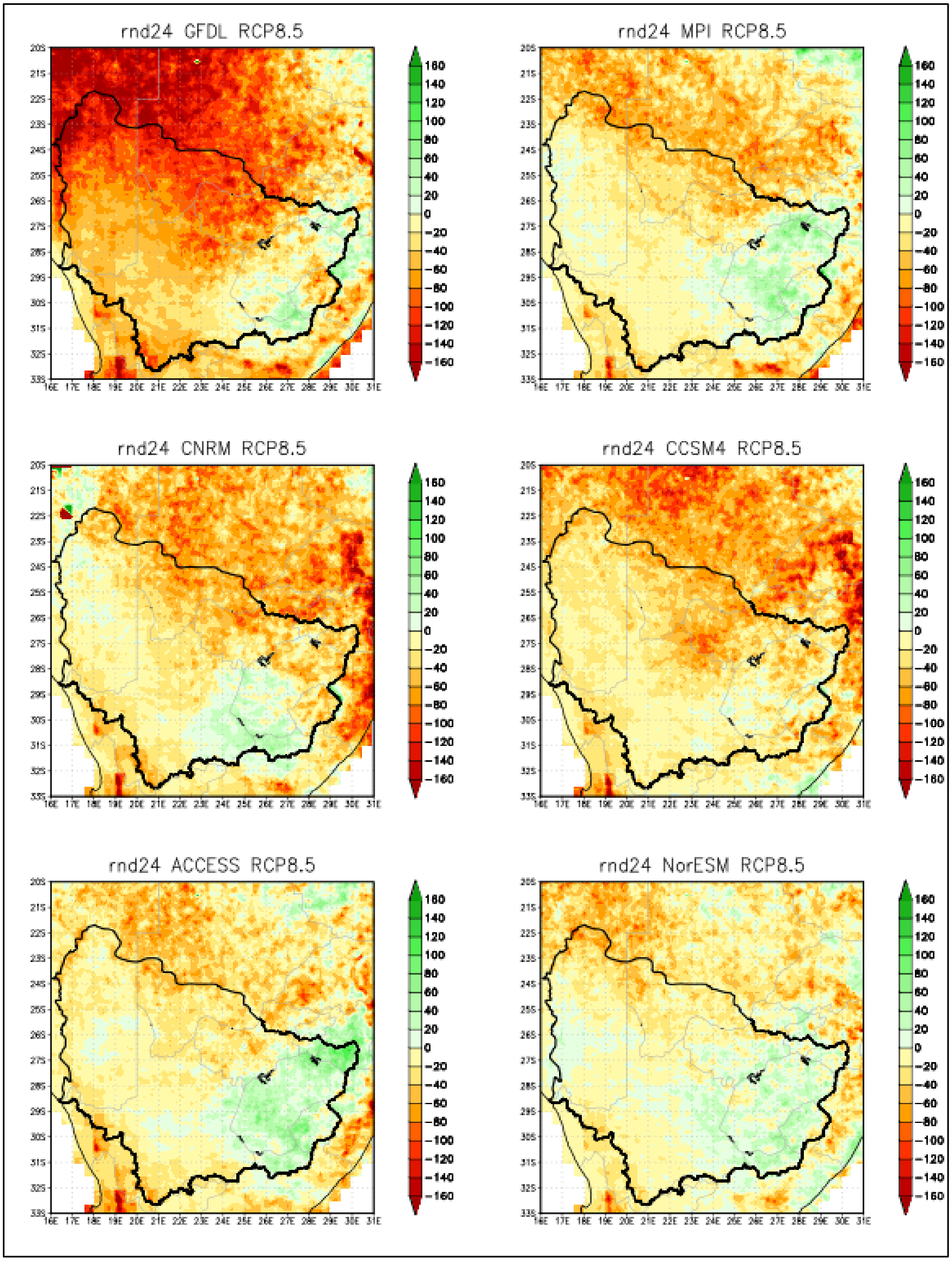

Figure 3-2: Simulated change in mean annual rainfall (mm) for the period 2050 – 2074 compared to the mean for the period 1986-2005 according to RCP8.5. The Orange-Senqu basin is indicated. Downscaling was performed based on GCMs as indicated.

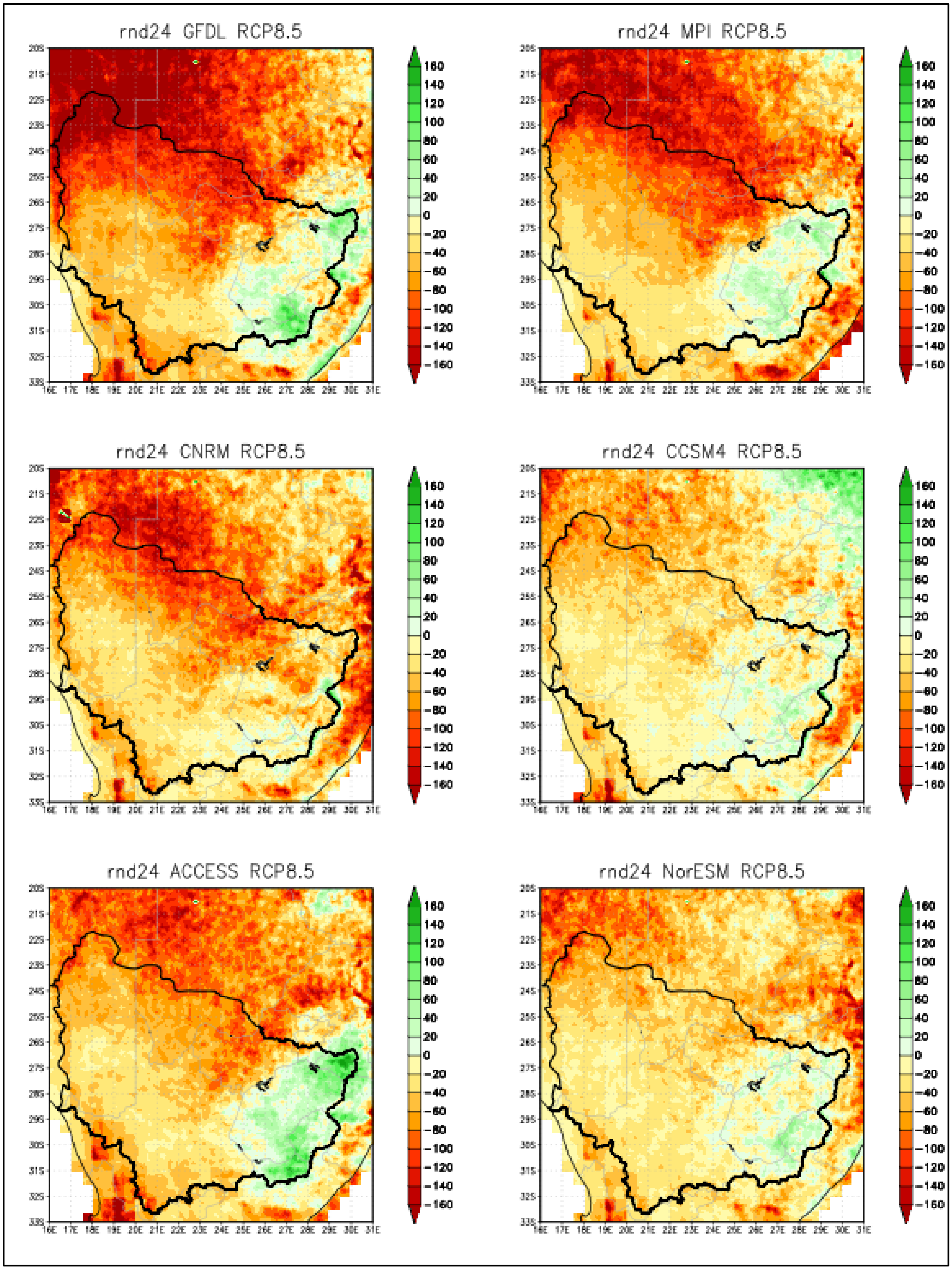

Figure 3-3: Simulated change in mean annual rainfall (mm) for the period 2075 – 2099 compared to the mean for the period 1986-2005 according to RCP8.5. The Orange-Senqu basin is indicated. Downscaling was performed based on GCMs as indicated.

The simulated rainfall trends (**Figure 3-1, Figure 3-2** and **Figure 3-3**) through the 21st century indicate strong downward tendencies particularly towards the north and west in the region of the basin. Towards the southeast, including much of Lesotho, simulated changes are less clear, with several simulations indicating positive trend. The stronger downward simulated trend in rainfall over the north-eastern parts of the area together with the weaker or positive trend towards the southeast and south is in broad agreement with earlier findings regarding long-term trends through the 20th century in these areas respectively (Kruger, 2013).

Figure 3-4, Figure 3-5 and **Figure 3-6** shows the simulated change in mean annual maximum temperature for 3 periods in the 21st century (2025-2049, 2050-2074 and 2075-2099) compared to the mean simulated for the baseline (1985-2005) period. These simulations are also as per RCP8.5.

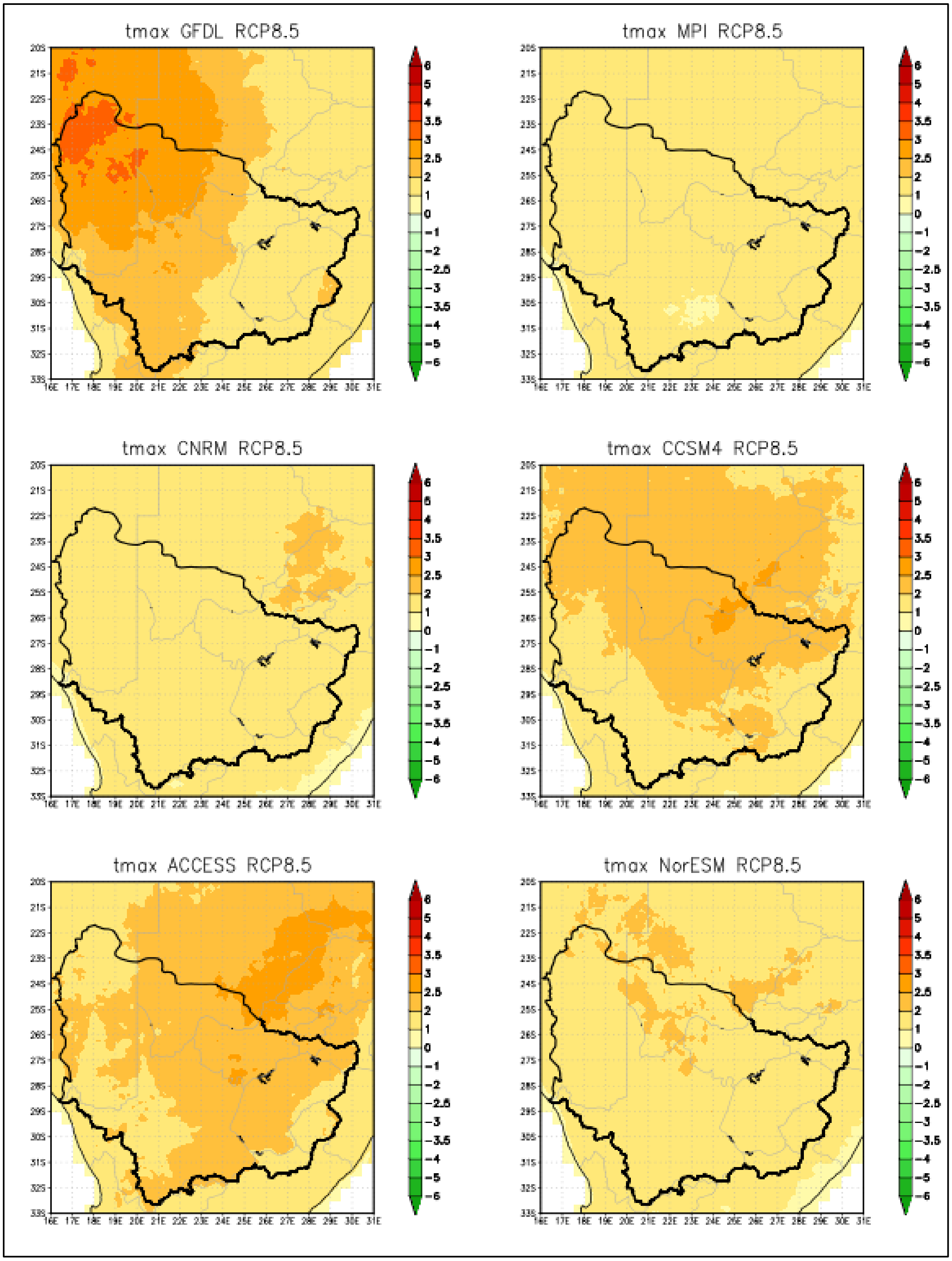

Figure 3-4: CCAM-simulated change in mean annual maximum temperature (°C) for the period 2025 – 2049 compared to the mean for the period 1986-2005 according to RCP8.5.

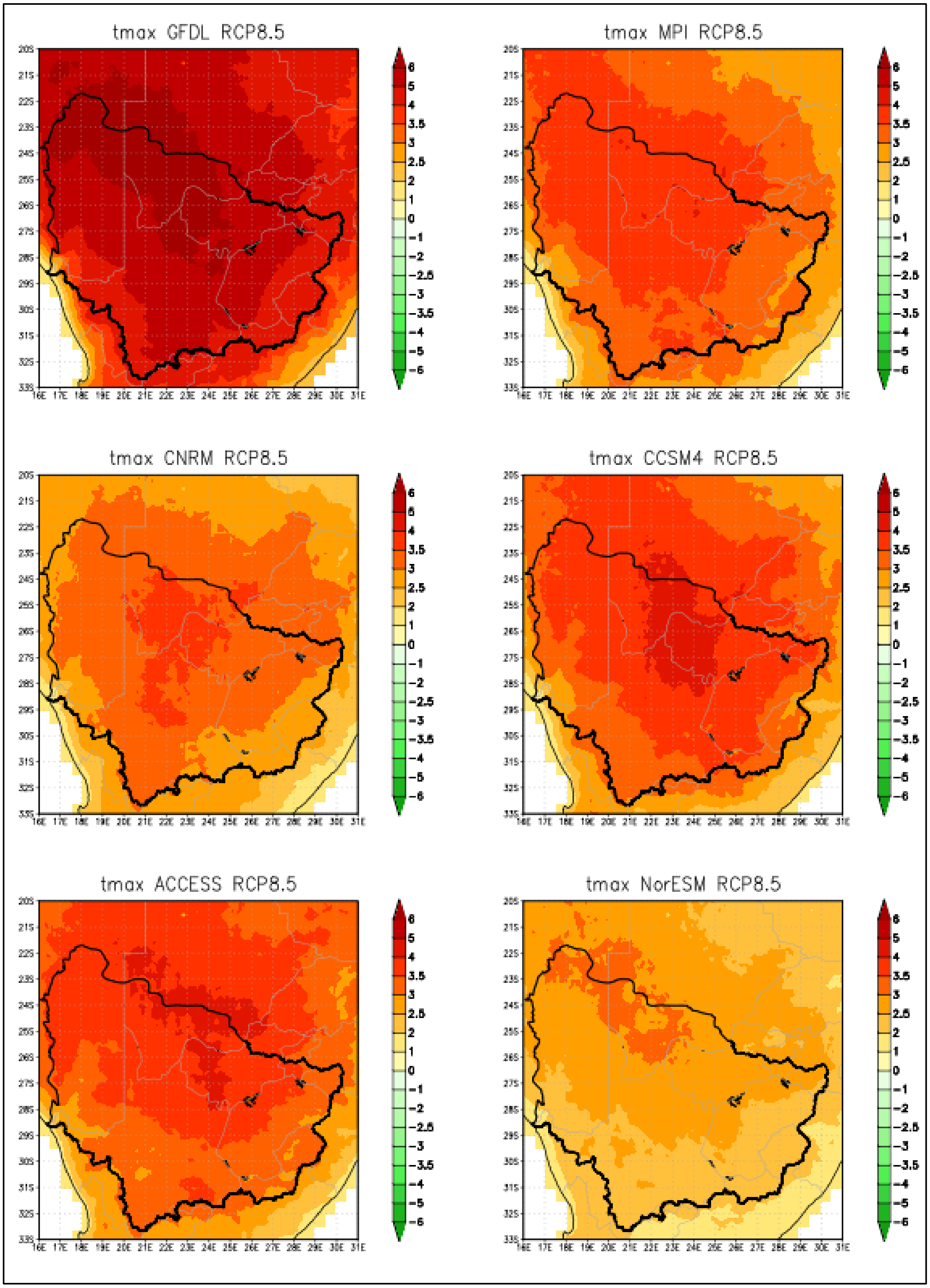

Figure 3-5: CCAM-simulated change in mean annual maximum temperature (°C) for the period 2050 – 2074 compared to the mean for the period 1986-2005 according to RCP8.5.

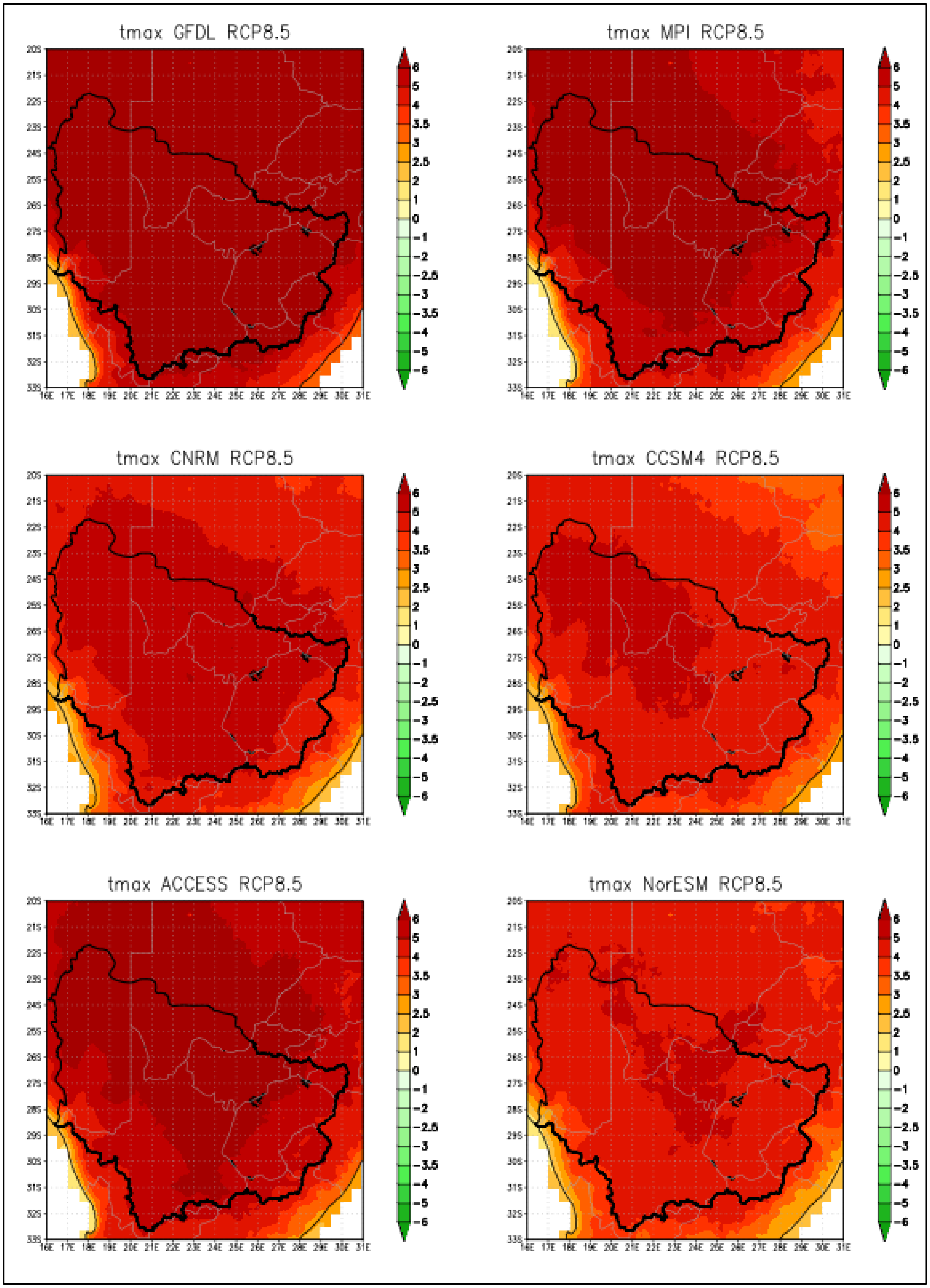

Figure 3-6: CCAM-simulated change in mean annual maximum temperature (°C) for the period 2075 – 2099 compared to the mean for the period 1986-2005 according to RCP8.5.

Simulated anomalies of +1 - +2°C relative to maximum temperatures in 1986-2005 by 2025-2049 gradually increases to a range of +3.5 - +7 by late century. Spatially, the largest increases are simulated towards the Kalahari, and generally increases towards the north. Relatively smaller increases are simulated over the escarpment towards the south and east in the basin.

For the 2 focus-areas shown in **Figure 3-7**, **Figure 3-8** and **Figure 3-9** show simulated future trends in the spatial average annual precipitation and maximum temperature with respect to the observed (1986-2005) baseline climate.

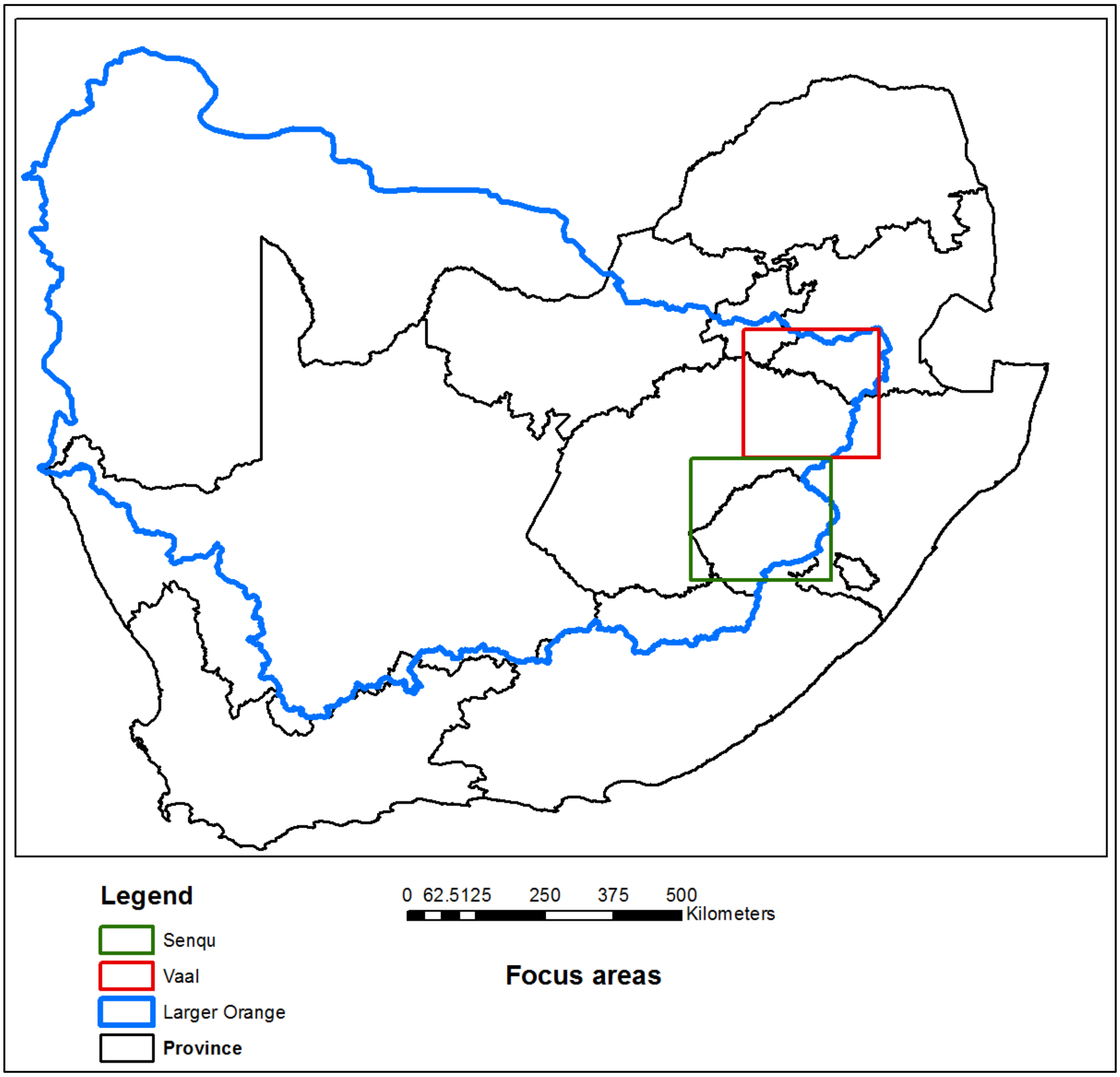

Figure 3-7: The Orange-Senqu River Basin, with 2 focus areas (Senqu and upper-Vaal as indicated) for which spatial average annual rainfall and maximum temperatures were extracted.

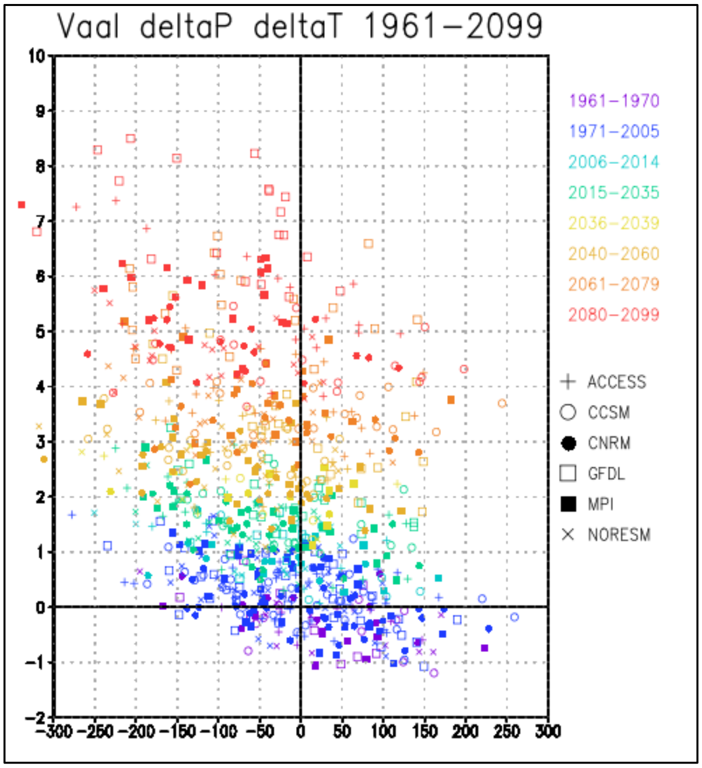

Figure 3-8: Model simulated trends in average annual temperature anomalies (y-axis) and annual rainfall anomalies (x-axis) for the Upper-Vaal for the historical period 1961-2000 (bias-corrected using observations) and projected trends until 2099 (RCP8.5 emission scenario).

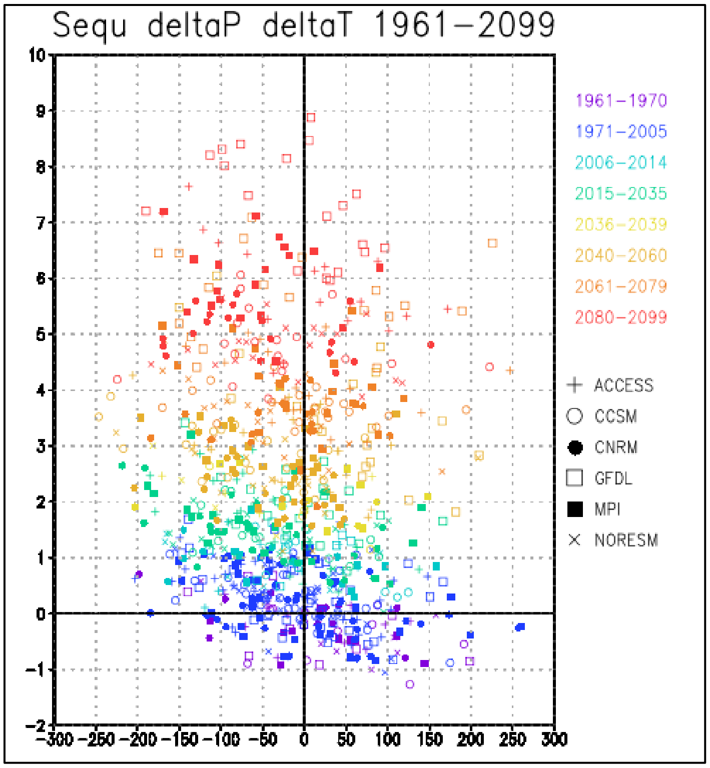

Figure 3-9: Model simulated trends in average annual temperature anomalies (y-axis) and annual rainfall anomalies (x-axis) for the Senqu for the historical period 1961-2000 (bias-corrected using observations) and projected trends until 2099 (RCP8.5 emission scenario).

For both important areas (Upper-Vaal and Senqu), climate simulations indicate a general trend towards warmer and drier conditions. The trend in the Senqu catchment however is weaker in terms of the rainfall signal, with only a slight reduction according to most GCM ensemble members. It is also clear that certain models indicate a larger change (e.g. GFDL) than the rest. Towards late century, the change in annual mean rainfall Senqu (Vaal) Catchment is expected to be between -200 mm and +150mm (-250 and + 100). Mean annual temperature, according to the spread of driving GCMs for the Senqu (Vaal) is between 4 and 8°C (**Figure 3-8** and **Figure 3-9**).

3.2.1 CSIR simulations in context

To provide a broad idea of the position of the simulations performed relative to the larger suite of CMIP5 ensemble members, shows the spread of annual rainfall within the entire suite of CMIP5 members, for the period 2025 – 2099, relative to 1986-2005, for the Vaal and Senqu catchments respectively. GCMs used to drive the CCAM simulations in this report are indicated in colour.

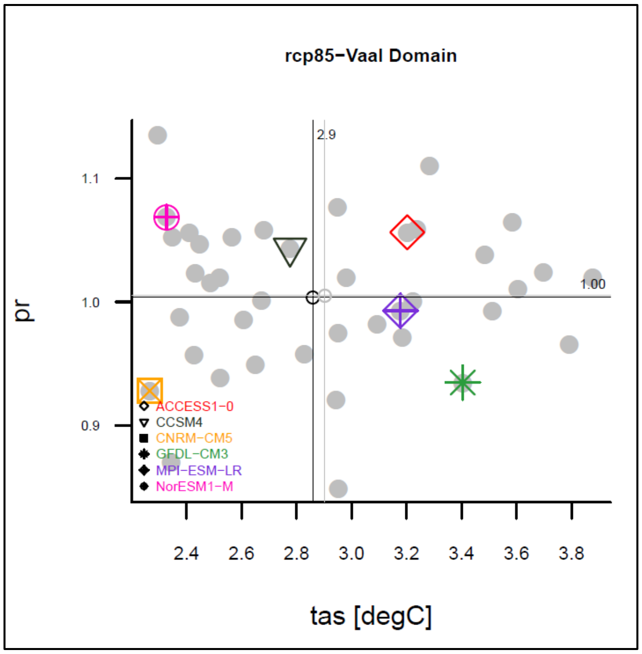

Figure 3-10: Average change in annual mean rainfall (fraction of baseline) and temperature (°C) through the 21st century according to RCP8.5 in the Vaal Catchment. CMIP ensemble members are shown (grey circles) with models used to drive CCAM highlighted. Vertical and horizontal lines show the mean values for temperature and rainfall respectively for the entire ensemble (light grey) and for the 6 downscaled models (dark grey). Source: CRIDF

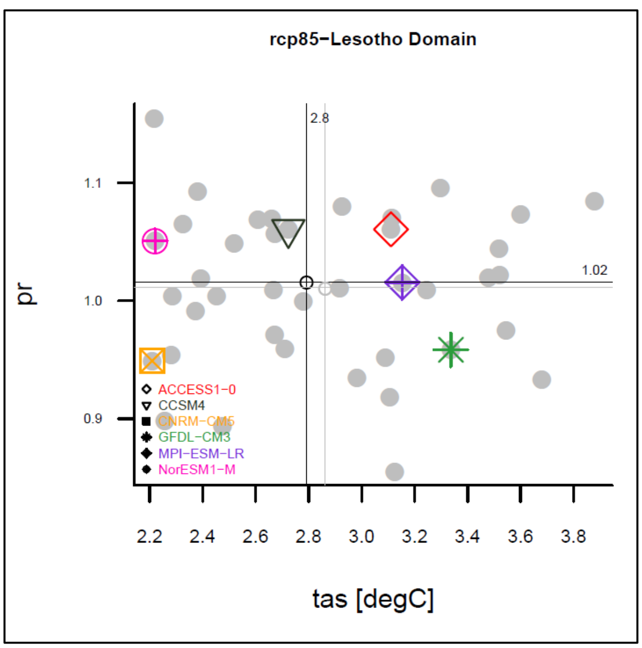

Figure 3-11: Average change in annual mean rainfall (fraction of baseline) and temperature (°C) through the 21st century according to RCP8.5 in the Senqu Catchment. CMIP ensemble

members are shown (grey circles) with models used to drive CCAM highlighted. Vertical and horizontal lines show the mean values for temperature and rainfall respectively for the entire ensemble (light grey) and for the 6 downscaled models (dark grey). Source: CRIDF

The CMIP5 GCMs downscaled by CCAM represent a relatively good spread of the models within the entire ensemble, even though these models were specifically chosen for their realistic simulation of the ENSO signal. What is also clear, from both **Figure 3-8**, **Figure 3-9**, **Figure 3-10** and **Figure 3-11**, is that the GFDL GCM represents somewhat of an outlier compared to the rest of the members.

3.2.2 Projected trends according to other studies

Several studies have given an overview of projected changes in rainfall and temperature over the Orange-Senqu basin. Some of these were reviewed. The following is a list of such studies:

A) CRIDF Rapid Advisory Service (RAS05): Assessment of the climate change projections applied in the Orange-Senqu River Basin from existing climate change studies

1) Knoesen et al 2009: Impacts of Climate Change on Water Resources in the Orange-Sengu River Basin

2) S. Crerar, J. Volkholz and J. Lutz; 2011: Projection of Impacts under Plausible Scenarios and Guidelines on Climate Change Adaptation Strategies – ORASECOM Document 008/2011 – February 2011.

3) F. Gerstengarbe, J. Lutz and J. Volkholz; 2010: Downscaling Methodology and On-Going Climate Modelling Initiatives - ORASECOM Document 007/2010 – February 2010.

4) F. Gerstengarbe, J. Lutz and J. Volkholz; 2011: GCC Downscaling for the Orange-Senqu River Basin – ORASECOM Document 009/2011 – April 2011.

5) World Bank. 2016. “Lesotho Water Security and Climate Change Assessment.” World Bank, Washington, DC. License: Creative Commons Attribution CC BY 3.0 IGO

B) Masike S 2018: Preparation of vulnerability assessment and adaptation to the effect of climate change for Botswana Third National Communication-Water Sector. Prepared for Department of Meteorological Services, Ministry of Environment, Natural Resources Conservation and Tourism.

The findings from these studies, related to temperature and rainfall, are shown in the table below

Study	Models	Scenario	Period	Element	Trend		
					Lesotho	**Botswana**	**Orange - Vaal**
R.E. Schulze, 2011. A 2011 Perspective on Climate Change and the South African Water Sector	CGCM3.1 CNRM-CM3 ECHAM5/MPI-OM GISS-ER IPSL-CM4	RCP3 -3.2	1971-1990 2046-2065 2081-2100	Temperature (°C) Rainfall (mm)			-18 +4
F. Gerstengarbe, J. Lutz and J. Volkholz; 2011: GCC Downscaling for the Orange - Senqu River Basin – ORASECOM Document 009/2011 – April 2011.	STAR (Statistical downscaling)	A1B	2031-2060 vs. 1971-2000	Temperature (°C)	+1.5	+2	+1.8
	CCLM (Dynamic downscaling)	A1B	2031-2060 vs. 1971-2000	Temperature (°C)	+2	+2.3	+2
	STAR (Statistical downscaling)	A1B	2051-2060 vs. 1971-2000	Rainfall (mm)	-60 - 40 - 40 + 40 - 40 + 80	-120 - 40 -60 - 80 -20 - 80	-100 - 60 -40 + 20 -20 + 40
World Bank: 2016: Lesotho Water Security and Climate Change Assessment	CMIP3	A2, A1b, RCP4.5, RCP8.5	2031-2050 vs. 19712000	Temperature (°C)	+0.8 - +2.1		
				Rainfall (mm)	-140 - +140		
	CMIP5 (BCSD)			Temperature (°C)	1.1 - 2.5		
				Rainfall (mm)	-120 - +160		
	CMIP5 (CSAG)			Temperature (°C)	1.1 - 2.5		
				Rainfall (mm)	-80 - +80		
Preparation of vulnerability assessment and adaptation to the effect of climate change for Botswana Third National Communication Water Sector (2018)	CMIP5 ensemble	RCP4.5	2050 vs. Base-line	Temperature		1.4 - 1.9	
				Rainfall		-24 - + 6	
		RCP8.5	2050 v. base-line	Temperature		1.9 - 2.7	
				Rainfall		-33 - + 9	

The results from previous studies support the recent findings with regard to the relative strength of projected temperature and rainfall trends as simulated by CCAM. Weaker signals are evident towards the Senqu catchment, while, towards the north of the larger Orange-Senqu basin, stronger indications of warmer, drier futures exist.

3.3 Comparative statistical evaluation

The analyses were carried out for the verification period 1961 to 1999 as described in the subsequent sections.

3.3.1 Comparisons for the Validation Period (1961 – 1999)

The statistics and graphs presented in this section were derived for the Modder Sub-catchment (SC) combined over the period 1961 to 1999 (water years) unless otherwise stated. This period is also referred to as the Validation Period in subsequent sections. There are five SCs which were selected for the climate change modelling. These are; Modder, Senqu, Makhaleng, Upper Orange and Caledon, as shown in **Figure 3-12**. Per metric discussed one example of the analysed data is shown, and the trends for the remaining catchments are discussed.

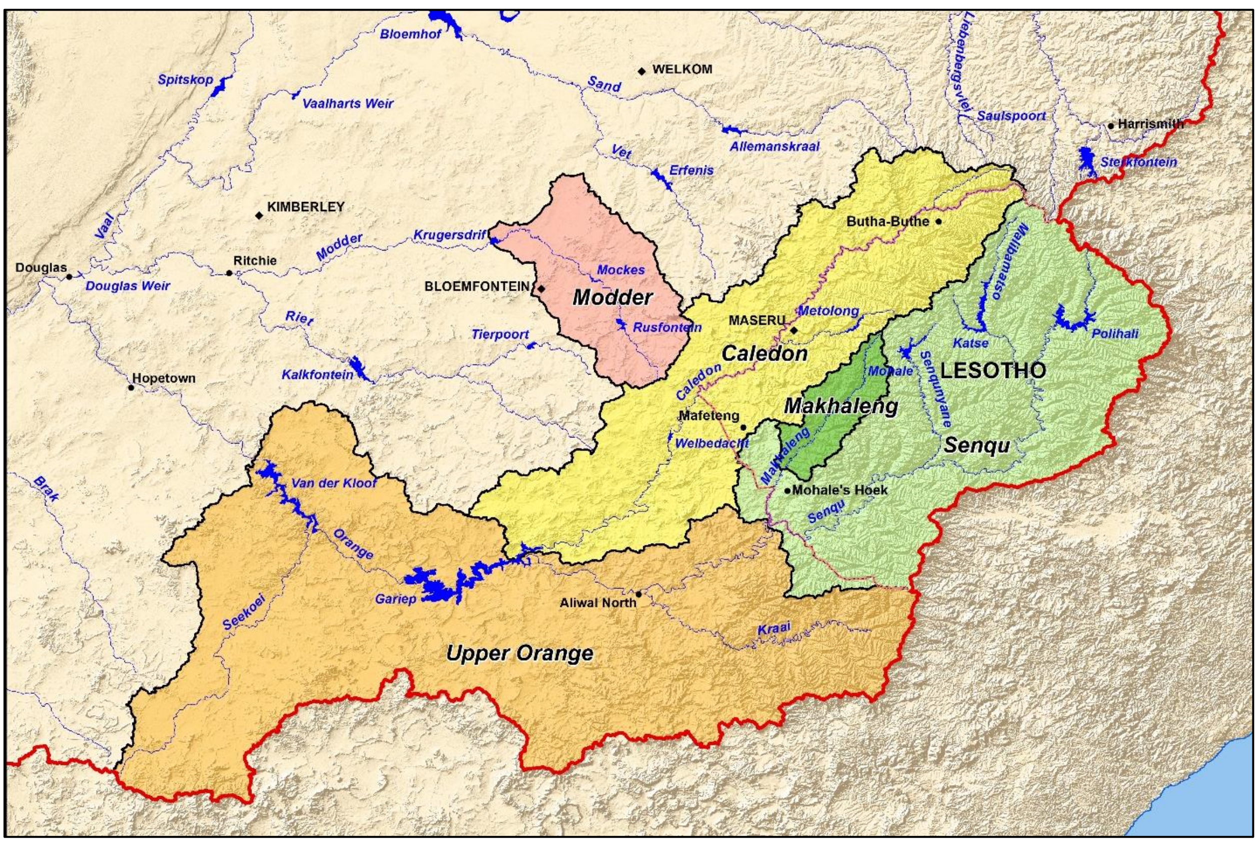

Figure 3-12: Study Area Overview Map

Table 3-1 presents the annual statistics for the historical and six future climate scenarios, indicating that the mean annual precipitation of the simulated datasets is similar compared to the historical (as a result of bias correction – described in Chapter 2). The other metrics, such as the annual standard deviation, coefficient of variance, as well as the minimum and maximum rainfall, reflect differences in excess of 20%. This shows the inability of the climate models to replicate the observed variance, and in particular to the generate minimum rainfall events which are mostly 5% greater than the observed rainfall records. Both the standard deviation and coefficient of variance are lower than the observed historical data by more than 20% compared to the historical. The same trends were observed for the other 4 SCs of which Upper Orange indicated the most significant statistical differences of on average 34% greater minimum annual rainfall and decrease in standard deviation of 50%. The remainder of areas annual statistics are collated in **Appendix A**.

Table 3-1: Annual statistics of the average rainfall for the Modder SC

Dataset	Mean Annual Precipitation[1]	Minimum Annual Precipitation[2]	Maximum Annual Precipitation[3]	Standard Deviation of Annual Totals[4]	Coefficient of Variance[5]
Historical	571.0	372.2	885.3	126.4	0.22
ACC	568.3	367.8	827.2	91.3	0.16
CCS	573.0	402.0	809.0	94.1	0.16
CNR	571.3	377.3	894.1	99.5	0.17
GFD	571.2	339.4	799.2	103.4	0.18
MPI	570.7	378.7	832.5	96.8	0.17
NOR	572.4	394.9	794.4	100.8	0.18
Percentage difference compared to historical statistic					
ACC	-0.5%	-1.2%	-6.6%	-27.8%	-27.3%
CCS	0.4%	8.0%	-8.6%	-25.6%	-27.3%
CNR	0.1%	1.4%	1.0%	-21.3%	-22.7%
GFD	0.0%	-8.8%	-9.7%	-18.2%	-18.2%
MPI	-0.1%	1.7%	-6.0%	-23.4%	-22.7%
NOR	0.2%	6.1%	-10.3%	-20.3%	-18.2%

Notes: 1.) average precipitation occurring over the hydrological year, from October to September, over the assigned record period
2.) minimum precipitation occurring over the hydrological year
3.) maximum precipitation occurring over the hydrological year
4.) indicates the deviation or difference to the average annual precipitation
5.) ratio of the standard deviation to the average annual precipitation

The inability of the models to replicate the observe low rainfall are further illustrated by the annual distribution graphs presented in **Figure 3-13** and **Figure 3-14** where it is shown that the historical low rainfall years are below the simulated over the exceedance probability range 85% to 100%. The same phenomenon can be observed for the other SCs.

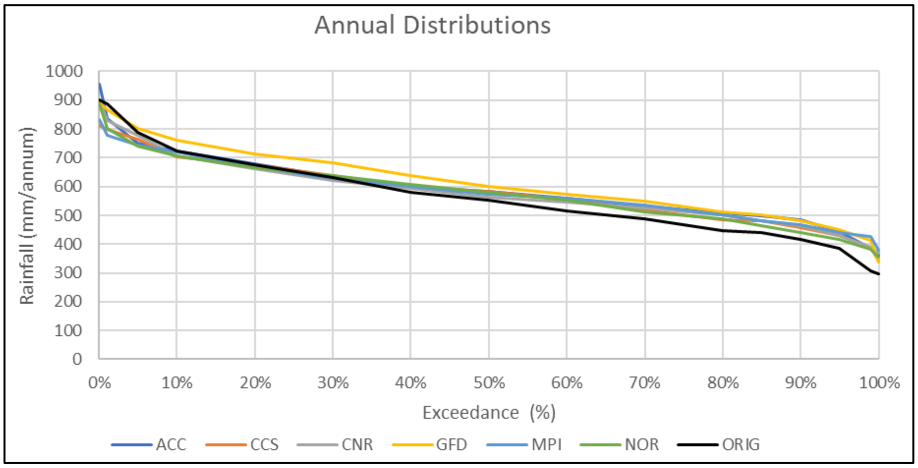

Figure 3-13: Distribution of annual totals, historical (ORIG) and six models

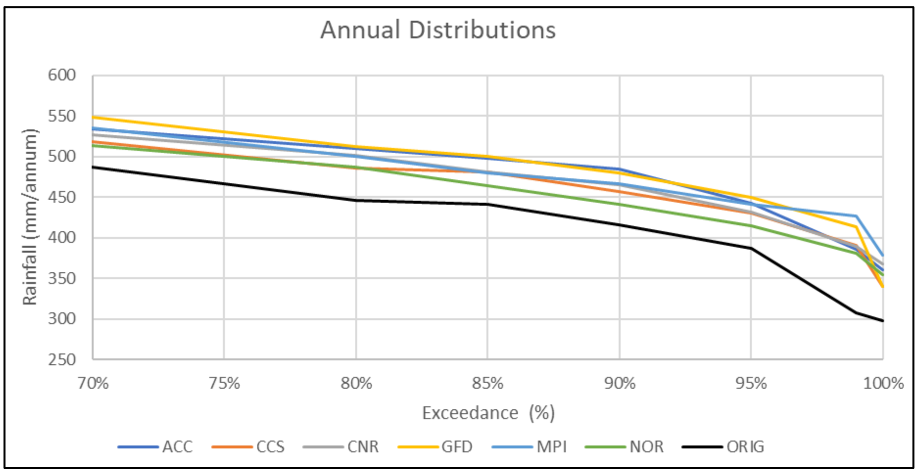

Figure 3-14: Zoomed distribution of annual totals, historical (ORIG) and six models

Table 3-2 shows the linear slope with significance test as well as the significance test to determine if the annual rainfall is normally distributed for the indicated data sets, showing the following observations:

- The observed annual rainfall slope for the Modder SC is slightly positive, however not significant. None of the slopes appear to be significant over the validation period. All the distributions are normally distributed (outside of the 95% confidence interval).
- The Makhaleng, Senqu and Caledon SCs indicated no significant slopes and are all normally distributed for the observed period as well as the six CCMs.

- The Upper Orange SC indicated an observed annual rainfall slope which is slightly negative (-0.43, not significant), and the Norwegian Earth System Model (**NOR**) exhibited a significant negative slope. The observed data is not normally distributed, 0.03 which exceeds the 95% confidence interval, meaning that the SC, specifically quaternary catchment C52D, has to be flagged and its hydrology should be reviewed in future studies.
- The Modder, Makhaleng and Senqu SC have positive observed slopes, and the Upper Orange and Caledon SC have slightly negative observed slopes, both are however insignificant. Positive slope meaning that the rainfall is increasing over time.

Table 3-2: Trend analysis, significance of linear slope and Normality Test of annual rainfall for the Modder SC

Dataset	Slope[1] (mm/annum)	Significance of slope[2]	Significance Test for Normal Distribution[3]
Historical	0.17	0.920	0.217
ACC	-2.05	0.115	0.509
CCS	1.35	0.321	0.338
CNR	1.16	0.421	0.170
GFD	-0.66	0.658	0.627
MPI	-0.08	0.957	0.649
NOR	-2.19	0.128	0.402

Notes: 1.) slope is a measure of the direction and steepness of changes in precipitation occurring over the assigned record period, e.g. positive slope indicates an average increase over time
2.) significance test is used to confirm if the slope conforms to a continuous trend, therefore the 95% confidence interval, e.g. if the metric is greater or equal to 0.95 then the slope is deemed significant
3.) test for normality indicates if the datasets conforms to the normal distribution characteristics with a specified confidence level e.g. if value is less than 0.05 then the dataset does not conform to the normal distribution

A comparison of the cross correlation (annual rainfall) for the historical (**Table 3-3**) and the Max Planck Institute Coupled Earth System Model (**MPI**) - **Table 3-4**, between the pair of 13 selected Quaternary Catchments in the Upper Orange SC, shows the cross correlation for the simulated dataset is mostly 20% or more lower than the historical catchment rainfall dataset as indicated in

Table 3-5. Note that the differences are similar for the other five models and SCs.

Table 3-3: Cross correlation of annual historical rainfall (Upper Orange SC)

	D31D	D32D	D12D	D13B	D13G	D34B	D35F	D31B	D13M	D32G	D35B	D32J	D34G
D31D	1.00	0.95	0.87	0.87	0.87	1.00	0.93	1.00	0.87	0.95	0.93	0.95	1.00
D32D		1.00	0.85	0.87	0.87	0.95	0.91	0.95	0.85	1.00	0.91	1.00	0.95
D12D			1.00	0.95	0.95	0.87	0.95	0.87	1.00	0.85	0.95	0.85	0.87
D13B				1.00	1.00	0.87	0.91	0.87	0.95	0.87	0.91	0.87	0.87
D13G					1.00	0.87	0.91	0.87	0.95	0.87	0.91	0.87	0.87

D34B						1.00	0.93	1.00	0.87	0.95	0.93	0.95	1.00
D35F							1.00	0.93	0.95	0.91	1.00	0.91	0.93
D31B								1.00	0.87	0.95	0.93	0.95	1.00
D13M									1.00	0.85	0.95	0.85	0.87
D32G										1.00	0.91	1.00	0.95
D35B											1.00	0.91	0.93
D32J												1.00	0.95
D34G													1.00

Table 3-4: Cross correlation of annual rainfall for the MPI climate model (Upper Orange SC)

	D31D	D32D	D12D	D13B	D13G	D34B	D35F	D31B	D13M	D32G	D35B	D32J	D34G
D31D	1.00	0.65	0.58	0.46	0.51	0.68	0.63	0.86	0.64	0.76	0.59	0.83	0.81
D32D		1.00	0.42	0.56	0.62	0.72	0.45	0.74	0.60	0.76	0.59	0.70	0.74
D12D			1.00	0.44	0.50	0.47	0.64	0.56	0.61	0.48	0.70	0.56	0.67
D13B				1.00	0.74	0.58	0.50	0.53	0.57	0.60	0.56	0.56	0.58
D13G					1.00	0.69	0.53	0.67	0.73	0.74	0.74	0.66	0.76
D34B						1.00	0.54	0.79	0.53	0.91	0.52	0.82	0.79
D35F							1.00	0.60	0.62	0.58	0.70	0.63	0.76
D31B								1.00	0.67	0.89	0.69	0.92	0.85
D13M									1.00	0.64	0.78	0.55	0.74
D32G										1.00	0.64	0.87	0.86
D35B											1.00	0.64	0.79
D32J												1.00	0.83
D34G													1.00

Table 3-5: Percentage difference of annual cross correlation, historical and MPI datasets

	D31D	D32D	D12D	D13B	D13G	D34B	D35F	D31B	D13M	D32G	D35B	D32J	D34G
D31D	0%	-31%	-33%	-47%	-41%	-32%	-32%	-14%	-27%	-21%	-37%	-13%	-19%
D32D		0%	-51%	-36%	-29%	-24%	-51%	-22%	-29%	-24%	-36%	-30%	-22%
D12D			0%	-53%	-47%	-46%	-32%	-36%	-39%	-43%	-26%	-34%	-23%
D13B				0%	-26%	-33%	-45%	-39%	-40%	-31%	-39%	-36%	-33%
D13G					0%	-20%	-42%	-24%	-23%	-14%	-19%	-24%	-13%
D34B						0%	-42%	-21%	-39%	-4%	-44%	-14%	-21%
D35F							0%	-35%	-35%	-37%	-30%	-31%	-19%
D31B								0%	-23%	-7%	-26%	-4%	-15%
D13M									0%	-25%	-18%	-36%	-15%
D32G										0%	-30%	-13%	-10%
D35B											0%	-30%	-16%
D32J												0%	-13%
D34G													0%

The Modder SC indicated a low correlation of the observed historic rainfall data of the quaternary catchment C52D with its surrounding catchments of 20%. These observations are flagged and need to be investigated in a follow up study. The six models did not replicate the low correlation of the historic data.

Figure 3-15 and **Figure 3-16** respectively presents the monthly average and standard deviation for the indicated datasets. While the monthly average of all seven datasets are similar (as a result of bias correction – described in **Section 2.2** the standard deviations of the simulated datasets mostly exhibit lower values compared to the historical data.

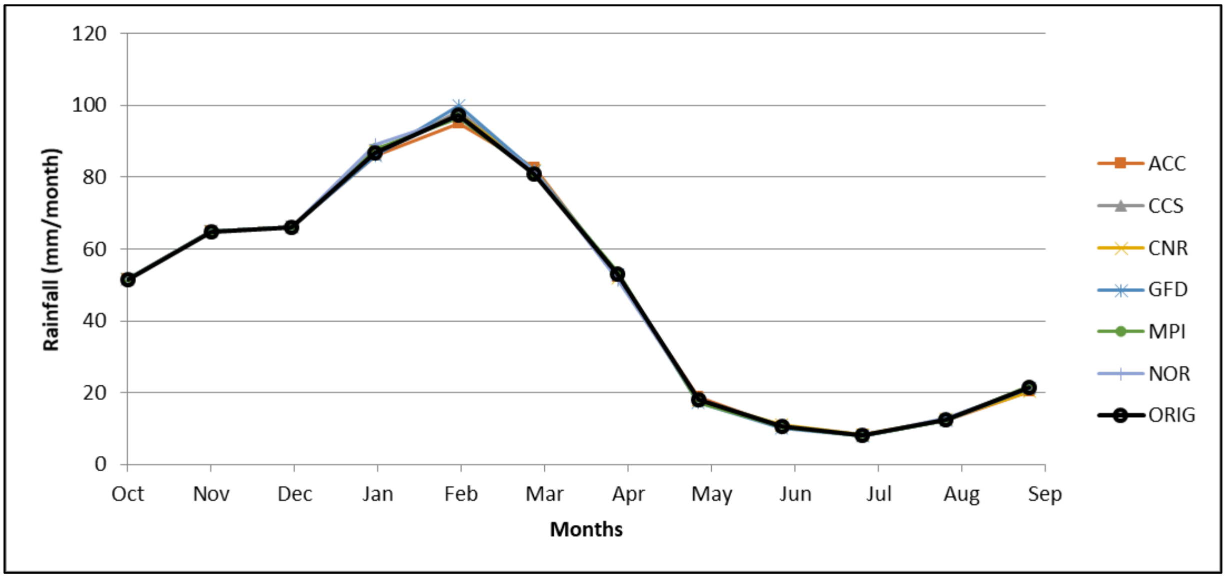

Figure 3-15: Monthly average rainfall for the six models and historical datasets (Modder SC)

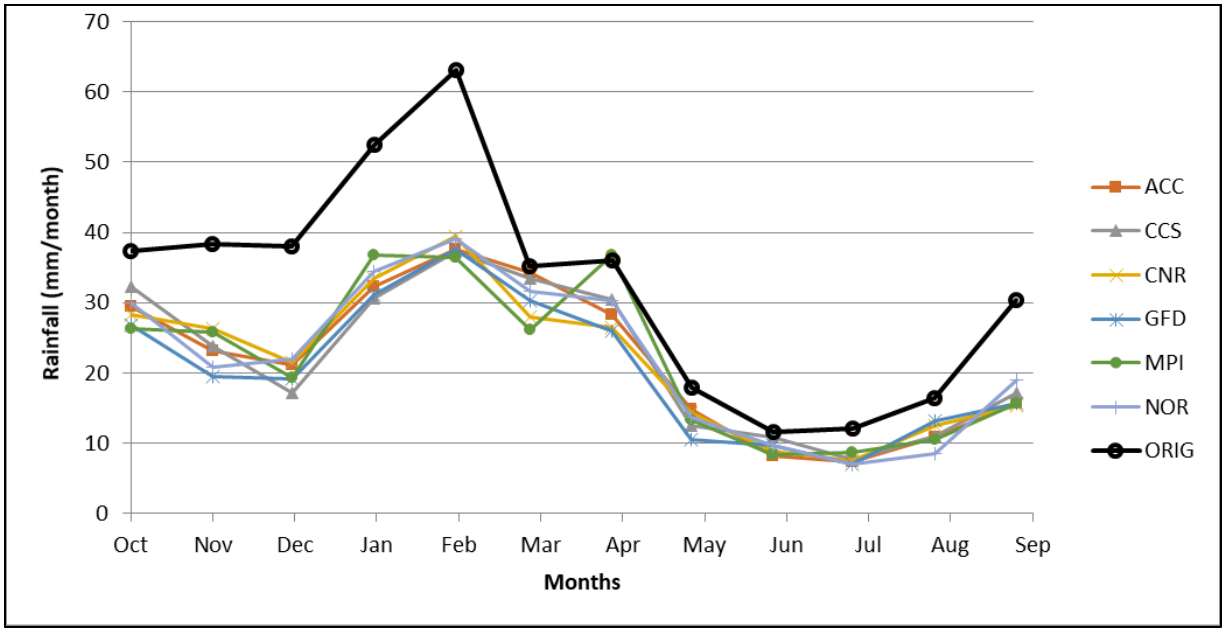

Figure 3-16: Standard deviation of monthly rainfall for the six models and historical datasets (Modder SC)

In order to compare the rainfall during dry periods longer than a year, minimum cumulative rainfall analysis for duration ranging from 6 to 60 months are tabulated in **Table 3-6** and graphically displayed in **Figure 3-17**. It can be observed that the historical dataset is the below the simulations or second lowest for the 12 to 60-month duration cases.

Table 3-6: Minimum cumulative total rainfall (Modder SC)

Scenario	Minimum cumulative rainfall (mm) for indicated number of months duration						
	6	12	18	24	36	48	60
His	**22.1**	**290.8**	**412.3**	**774.2**	**1188.2**	**1674.1**	**2302.6**
ACC	25.3	343.6	487.0	770.2	1326.4	1833.4	2296.9
CCS	33.1	389.0	512.0	872.2	1392.1	1873.5	2369.7
CNR	35.7	327.3	476.0	793.1	1286.2	1785.0	2261.9
GFD	36.0	339.4	474.6	834.3	1313.1	1788.0	2244.3
MPI	40.1	344.6	474.7	790.7	1184.6	1692.0	2240.9
NOR	50.1	357.2	465.8	814.2	1384.0	1858.8	2429.8

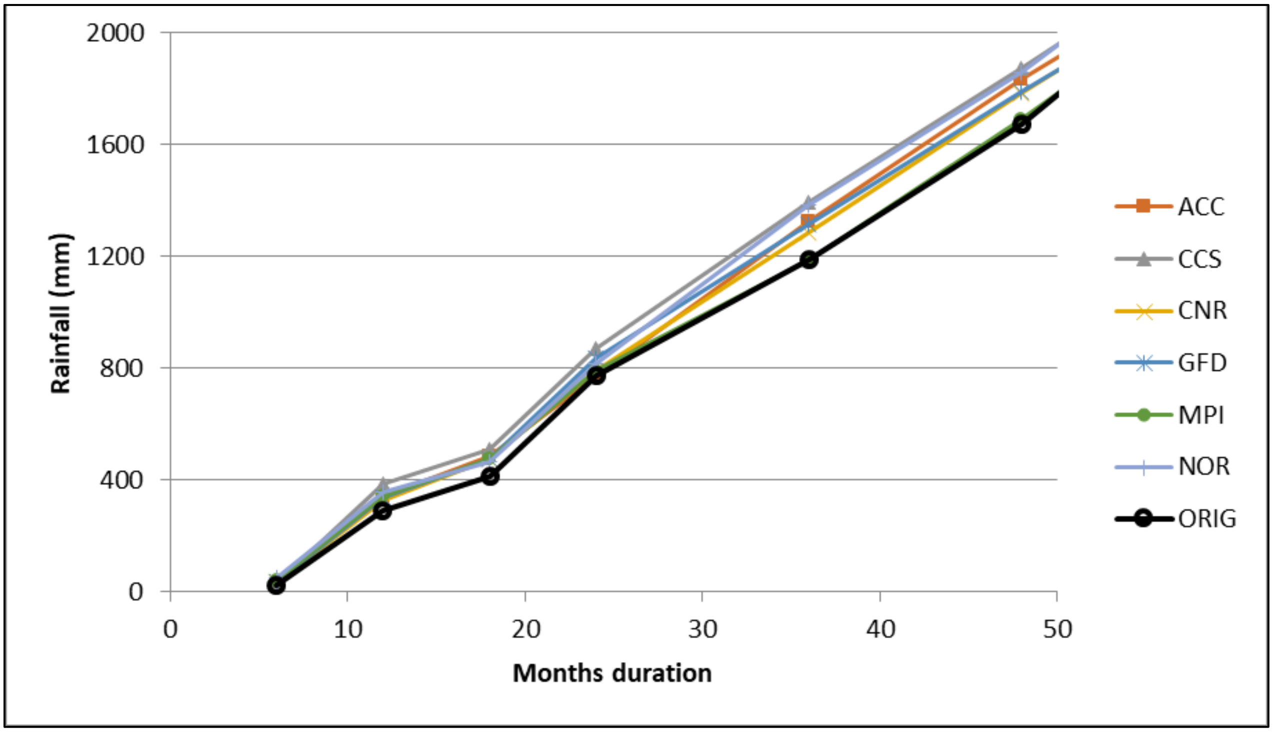

Figure 3-17: Minimum cumulative total rainfall (Modder SC)

A graphical comparison of the annual rainfall for the Modder SC is provided in **Figure 3-19** as box and whisker plots for the indicated periods and datasets. **Figure 3-18** presents a definition of a box and whisker plot.

The following can be observed from **Figure 3-19**:

- The variance (spread) of the historical data is wider than the simulated datasets for the Validation Period.
- The historical lowest value is not replicated by any of the models over the indicated simulation periods, except for GFD over the validation period (1961 - 1999) and NOR over the factored period (2000 - 2050)
- The historical highest values are exceeded only by the ACC dataset in the simulation period 2051 – 2098.

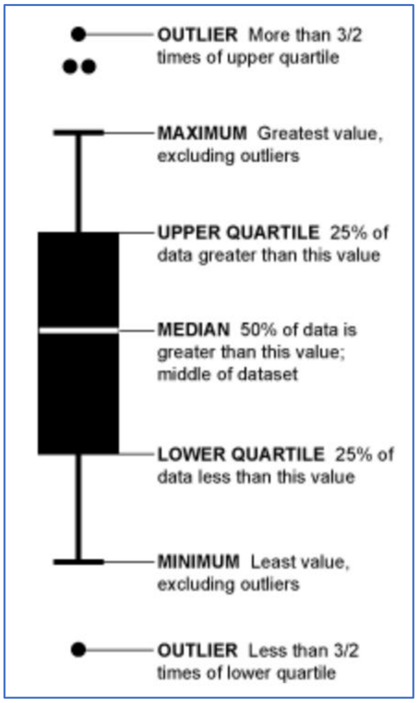

Figure 3-18: Box and whisker plot definition

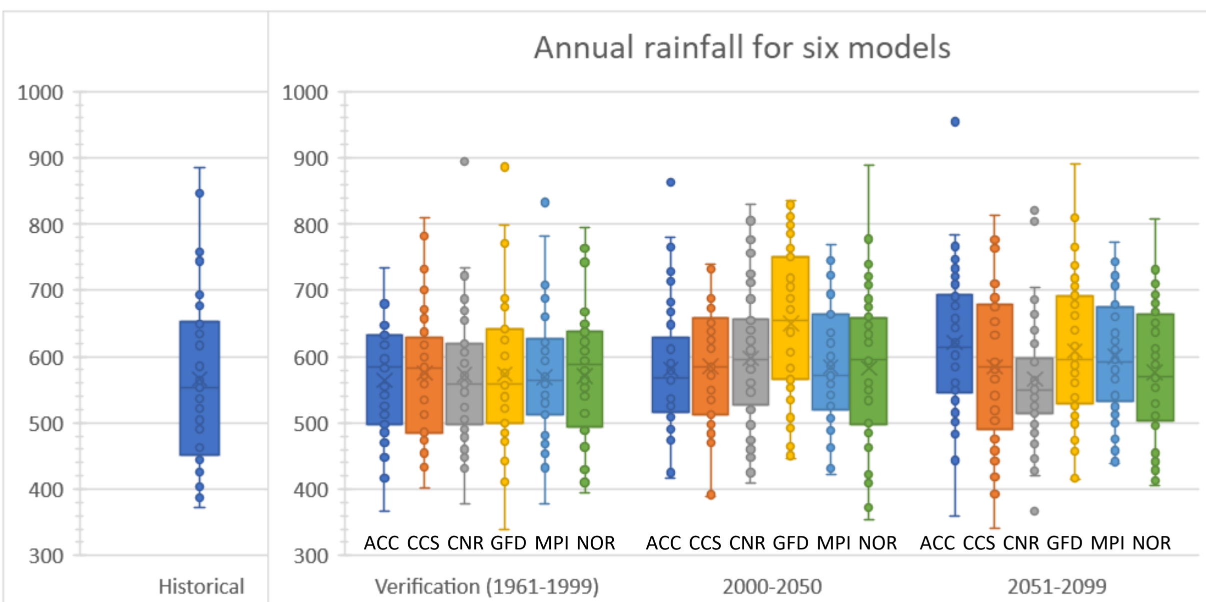

Figure 3-19: Box and whiskers plot of annual rainfall, indicated periods – Modder SC (Historical 1961-1999)

In **Figure 3-20** the historical data for the period 1920 to 2004 are presented. The density of the annual data points (dots) on the whiskers increased as a result of the longer period.

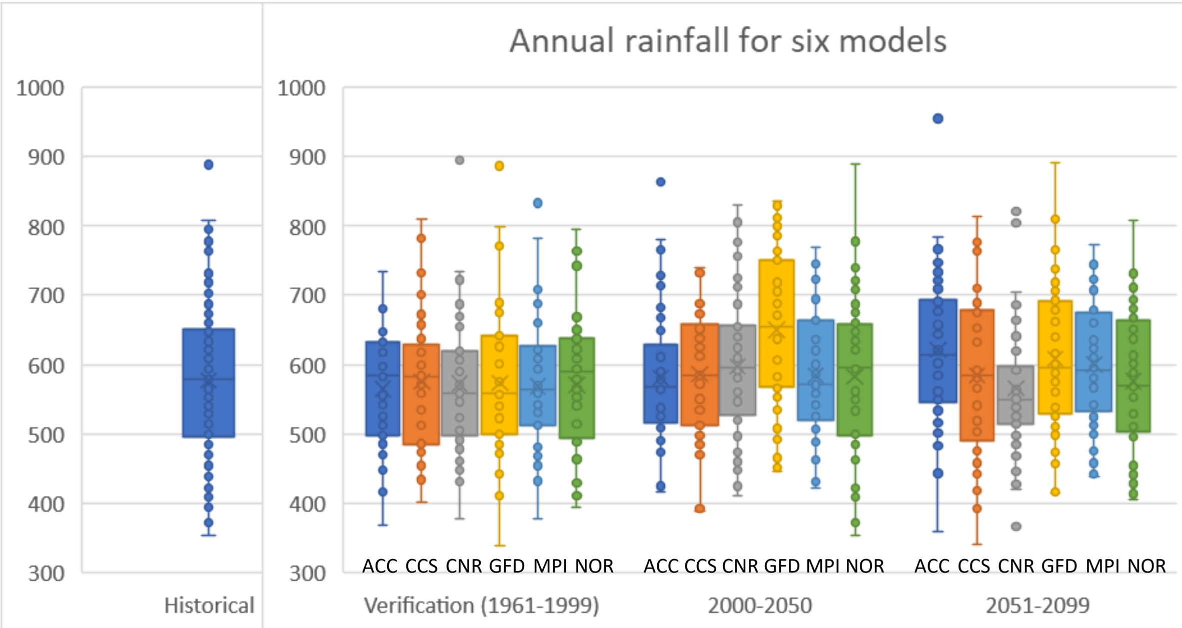

Figure 3-20: Box and whiskers plot of annual rainfall, indicated periods – Modder SC (Historical 1920-2004)

3.3.2 Discussion of evaluation

The evaluation and comparison of the timeseries presented above indicate the climate models do not replicate the low (critical periods) observed in the historical data. This is also reflected by the modelled datasets not able to replicate the standard deviation of the historical data. Since the focus of the yield assessment is on the dry or critical periods, a method was devised where the historical timeseries was adjusted to account for future climate while retaining the structure of the dry periods. This was achieved by deriving the average monthly flows over the adjustment (factored 2000 – 2050) period, which was used to multiply the historic dataset. The adjustment method and the resulting timeseries statistics are described in **Section 3.4**.

3.4 Statistical comparative results adjusted rainfall, evaporation and runoff

3.4.1 Rainfall

The adjusted statistical rainfall metrics are presented in **Table 3-7** for the Modder SC, by bias correction to the mean. The CV and minimum annual rainfall statistics are very different compared to the historical data. Comparative results can be observed for the remainder of the SCs in **Appendix B**.

Table 3-7: Annual rainfall averages for Modder SC

Scenario	Annual Rainfall Statistics (in mm except for CV)				
	Mean	Minimum	Maximum	St dev	CV
Historical	571.0	372.2	885.3	126.4	0.221
ACC	583.0	417.1	863.5	97.1	0.167
CCS	587.6	389.1	740.3	86.3	0.147
CNR	600.4	410.3	830.7	100.4	0.167
GFD	654.4	446.9	886.0	112.7	0.172
MPI	585.3	423.1	768.4	90.4	0.154
NOR	582.9	354.3	888.2	103.4	0.177
	Percentage difference compared to the historical record:				
ACC	2.1%	12.1%	-2.5%	-23.1%	-24.7%
CCS	2.9%	4.6%	-16.4%	-31.7%	-33.7%
CNR	5.1%	10.2%	-6.2%	-20.6%	-24.4%
GFD	14.6%	20.1%	0.1%	-10.8%	-22.2%
MPI	2.5%	13.7%	-13.2%	-28.5%	-30.2%
NOR	2.1%	-4.8%	0.3%	-18.2%	-19.8%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

The adjusted monthly statistical rainfall metrics are presented in **Table 3-8** for the Modder SC.

Table 3-8: Monthly and annual average rainfall for the Modder SC

Scenario	Monthly and annual average rainfall (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	52	65	66	87	97	81	53	18	11	8	12	21	571
ACC	53	68	80	94	96	80	46	16	12	7	13	18	583
CCS	45	71	68	89	109	76	60	18	11	9	12	20	588
CNR	56	76	68	94	116	76	54	16	11	7	11	16	600
GFD	62	79	77	105	125	89	54	14	12	7	9	21	654
MPI	45	74	72	96	94	83	58	20	10	9	9	15	585
NOR	65	61	66	86	95	83	59	18	9	8	13	19	583
	Percentage difference compared to the historical record:												
ACC	2%	5%	21%	8%	-1%	-1%	-12%	-9%	11%	-20%	9%	-17%	2%
CCS	-12%	10%	3%	3%	12%	-6%	13%	-1%	4%	10%	-6%	-9%	3%
CNR	8%	17%	3%	8%	19%	-6%	2%	-11%	0%	-18%	-10%	-27%	5%
GFD	20%	22%	17%	22%	28%	10%	2%	-21%	12%	-9%	-27%	-4%	15%
MPI	-13%	14%	9%	11%	-3%	3%	10%	11%	-8%	8%	-28%	-28%	3%
NOR	26%	-6%	0%	0%	-2%	3%	11%	1%	-13%	-5%	5%	-12%	2%

The tables are further summarised as geographical maps for the main study area as shown in **Figure 3-21** for the observed MAP and **Figure 3-22** for the percentage change in MAP for the six climate change models. The GFD CCM produces the greatest increase in runoff compared to the

MPI and ACC CCMs which produce the lowest rainfall prognosis. Larger format maps can be seen in the **Appendix F**.

It is important to note the current historic observed MAP in relation to the percentage change. As for example a small base MAP in the Modder and the Upper Orange catchments, and its associated projected change has a minor impact on the overall runoff, whereas small changes in the Upper Caledon and the Upper Senqu will have drastic impacts on simulated runoff.

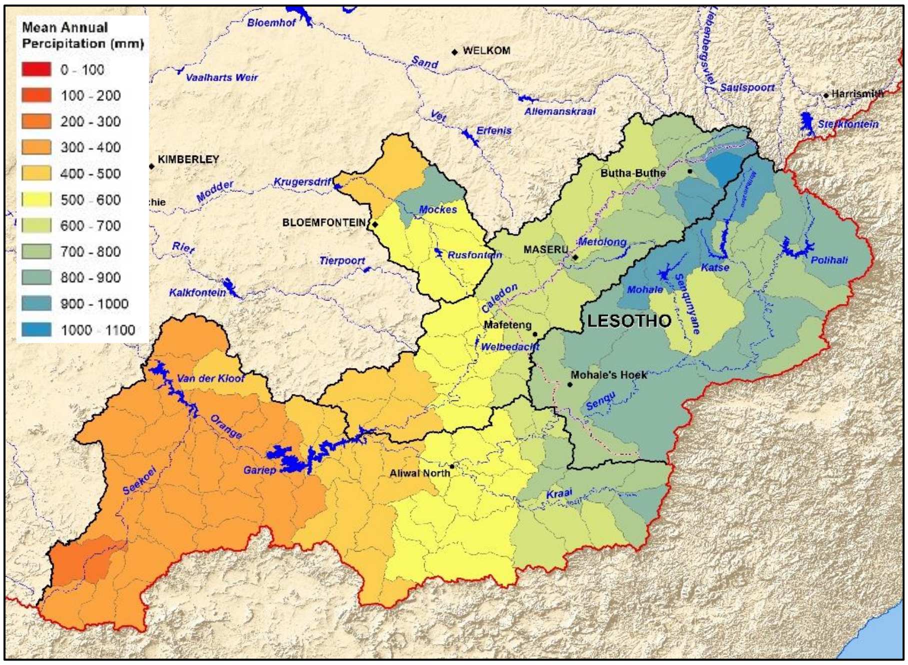

Figure 3-21: Historic Observed Mean Annual Precipitation (mm)

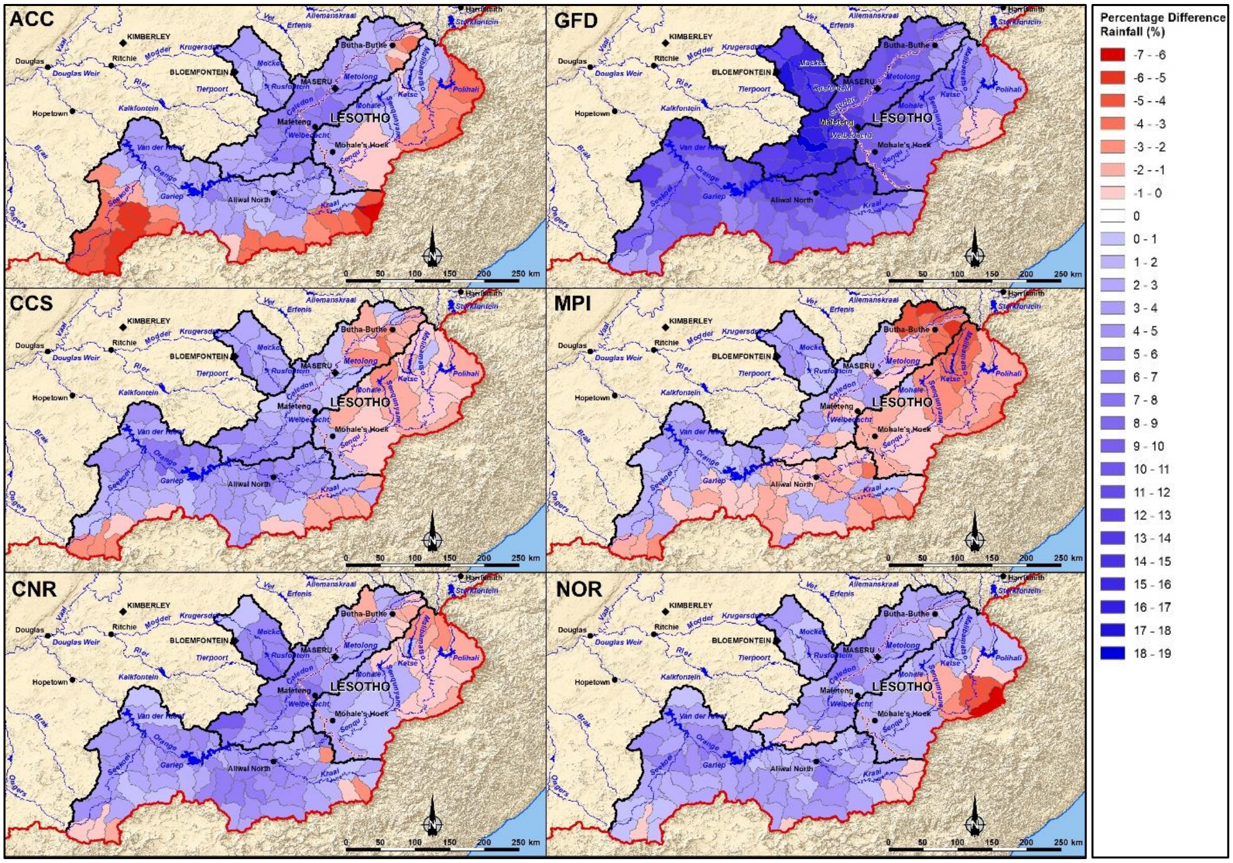

Figure 3-22: Percentage difference in MAP for the six CCMs

The changes in MAP for the entire Orange-Senqu Catchment are shown in **Figure 3-23**, it can be observed that the rainfall according to all six CCMs are projected to decrease over the next 30 years towards the north west. The study area, which for some models indicate and increase and others a decrease, is discernible with a lime green boundary.

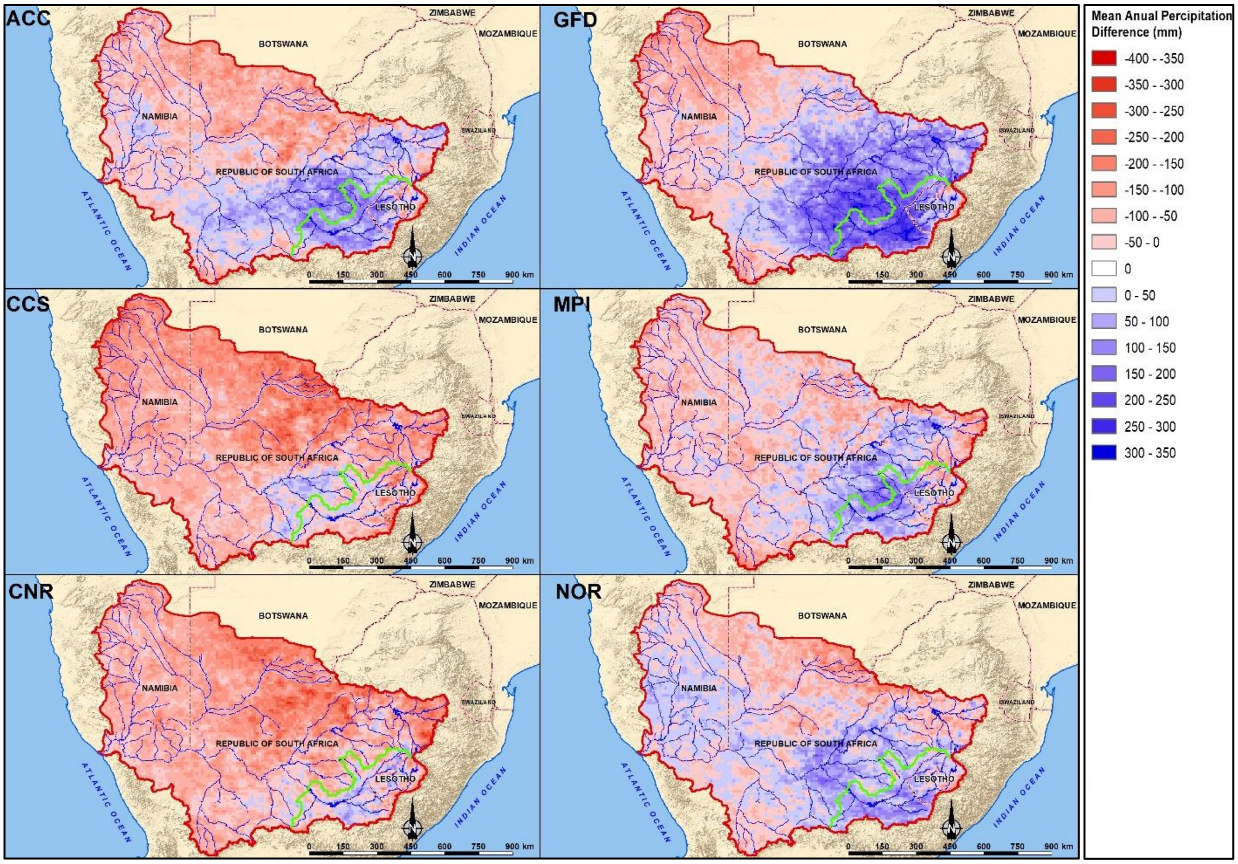

Figure 3-23: MAP changes from 2000 to 2050 according to the CCMs without bias correction

3.4.2 Evaporation

Evaporation is simulated as monthly averages in both the WRSM2000 rainfall runoff and WRYM models. The historical Simons Pan Evaporation (S-pan) for the detailed study area are presented in **Table 3-9** with the annual total in the last row.

Table 3-9: Historical monthly and annual average Simons Pan Evaporation (7 sub-catchments)

Sub-system	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Modder	173	196	224	219	165	143	96	71	51	61	89	134	1624
Makhaleng	157	170	195	184	143	124	86	67	51	59	87	126	1449
Senqu	145	157	181	170	132	115	79	62	47	55	80	117	1340
Upper Orange	181	207	237	228	173	149	104	77	60	69	100	139	1723
Caledon	157	174	199	189	145	126	87	66	51	59	87	124	1463

Note: 1 Catchment reference names. (All values in millimeters)

Table 3-10 shows the Modder Catchment average evaporation for the historical dataset and six climate models as well as the percentage difference compared to the historical data. Comparative results can be observed for the remainder of the SCs in **Appendix C**. The Caledon Catchment indicates higher rainfall and runoff similar to the Modder Catchment, whereas the Makhaleng, Senqu and Upper Orange have some models which exhibit a lower rainfall and runoff compared to the historical observed sequences.

Table 3-10: Monthly and annual average Simons Pan Evaporation for Modder SC

Scenario	Monthly and annual average S-Pan Evaporation (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	173	196	224	219	165	143	96	71	51	61	89	134	1624
ACC	212	214	207	208	160	143	102	74	51	68	104	171	1713
CCS	204	209	229	224	163	145	99	73	54	65	98	153	1714
CNR	184	181	238	222	159	143	96	70	50	66	106	160	1675
GFD	171	184	212	200	149	135	96	70	49	60	97	149	1572
MPI	214	207	222	216	159	145	98	70	52	64	106	169	1721
NOR	173	208	231	215	172	148	99	74	52	61	108	152	1693
Percentage difference compared to the historical data													
ACC	22%	9%	-8%	-5%	-3%	0%	6%	4%	0%	11%	16%	27%	5%
CCS	17%	7%	2%	2%	-1%	1%	2%	2%	5%	7%	9%	14%	6%
CNR	6%	-7%	6%	1%	-4%	0%	-1%	-1%	-3%	9%	18%	19%	3%
GFD	-1%	-6%	-6%	-9%	-10%	-5%	0%	-2%	-5%	-2%	9%	11%	-3%
MPI	23%	6%	-1%	-2%	-4%	1%	2%	-2%	1%	4%	19%	26%	6%
NOR	0%	6%	3%	-2%	4%	4%	3%	4%	0%	0%	21%	13%	4%

Notes: The monthly averages for the six climate models were derived from the 2000 to 2050 simulated.

The tables are further summarised as geographical maps for the main study area as shown in **Figure 3-24** for the observed S-pan MAE and **Figure 3-25** for the percentage change in MAE for the six climate change models. It can be seen that the GFD CCM produces a decreased in in future evaporation for over parts of the Modder, Caledon, and Upper Orange Catchment, compared to remaining five CCMs which indicate an increase in evaporation over the entire study area. Larger format maps are added in **Appendix G**.

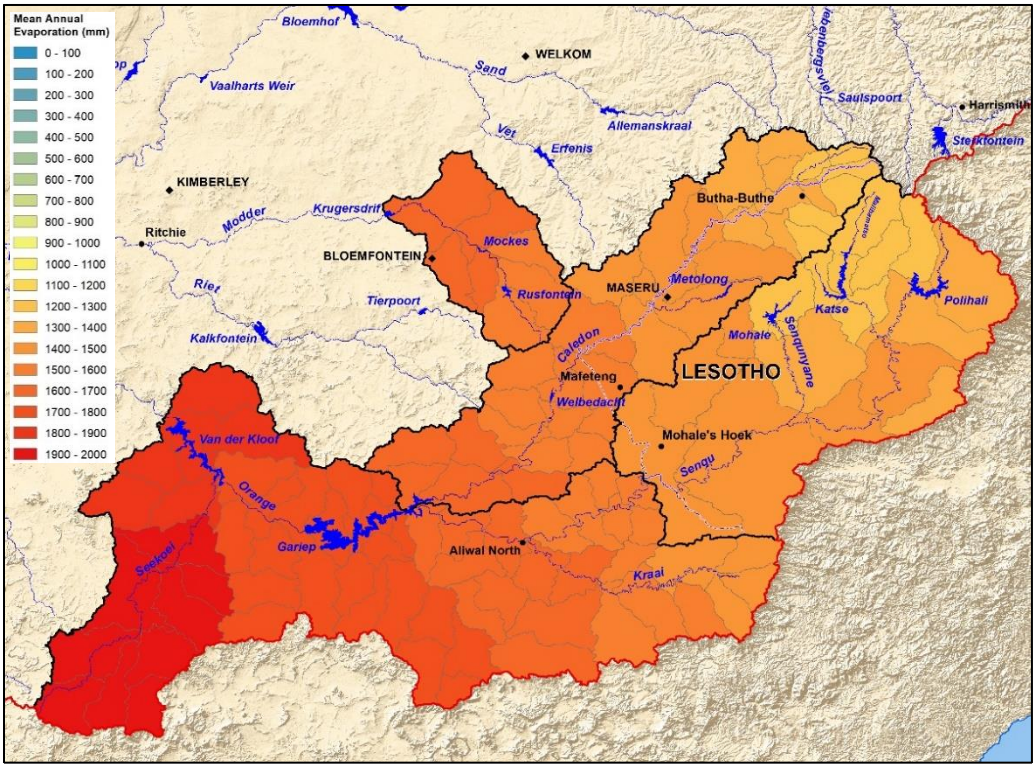

Figure 3-24: Historic Observed Mean Annual S-pan Evaporation (mm)

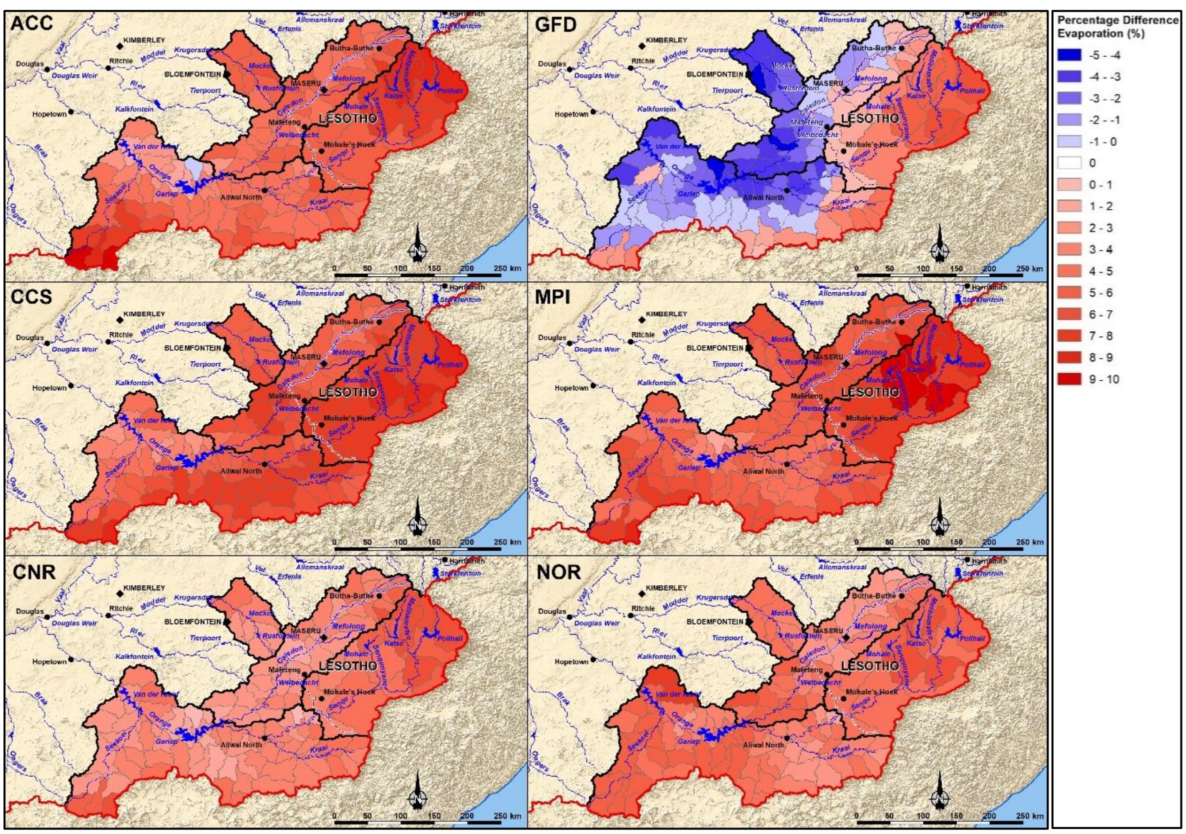

Figure 3-25: Percentage difference in S-pan MAE for the six CCMs

The changes in MAE for the entire Orange-Senqu Catchment are shown in **Figure 3-26**, it can be observed that the evaporation towards the north east of all six CCMs are projected to increase significantly over the next 30 years. The detailed study area, for which extensive rainfall/runoff and yield modelling was undertaken, is discernible with a lime green boundary towards the south east. The Orange-Senqu wide evaporation maps were not bias corrected, meaning that over the validation period (1960 to 2000) they were not adjusted to match the historic evaporation dataset.

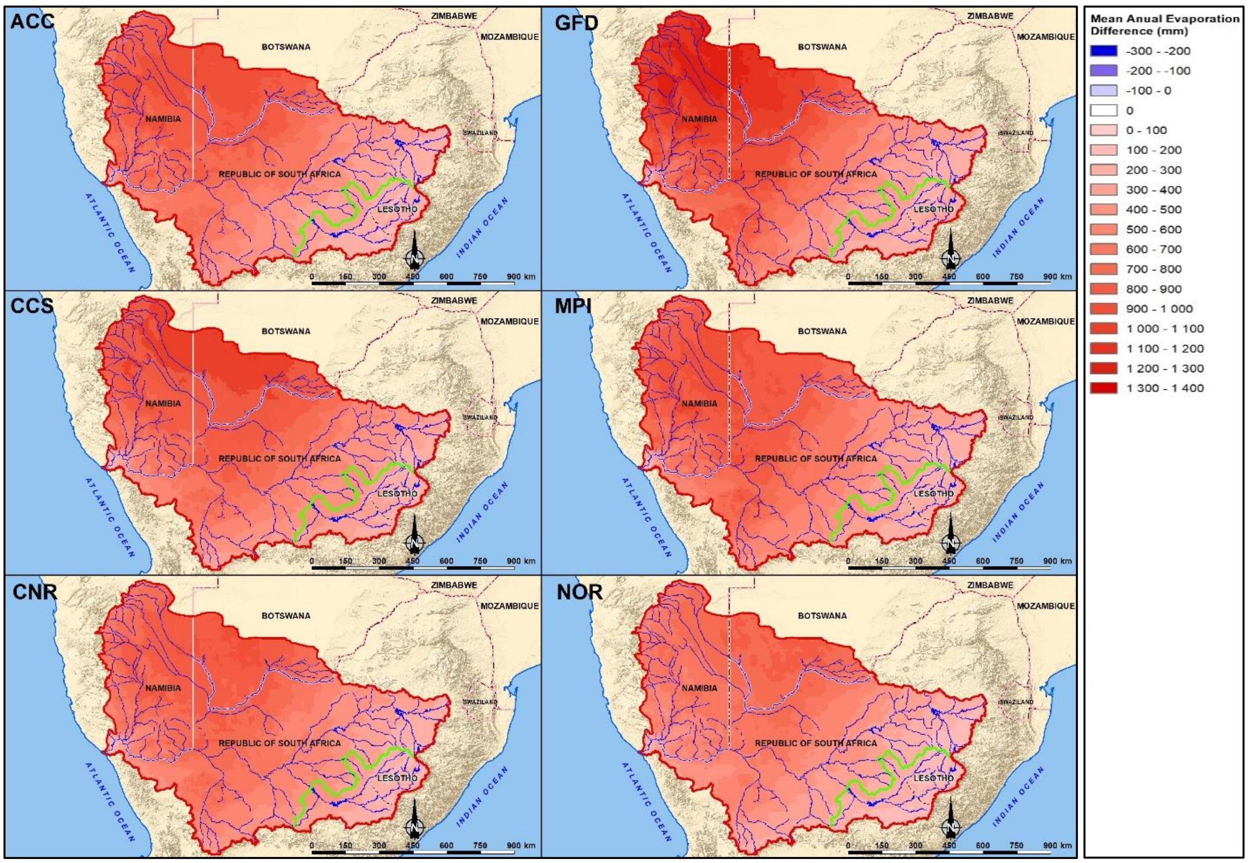

Figure 3-26: MAE changes from 2000 to 2050 according to the CCMs without bias correction

3.4.3 Runoff

Two scenarios of adjusted runoff were derived, **Scenario 1** comprises of applying the adjusted catchment rainfall to generate the monthly runoff and **Scenario 2** both the adjusted rainfall and evaporation were applied. All runoff timeseries covered a period on 85 years corresponding to the historical dataset of monthly data ranging from 1920 to 2004. Comparative runoff results for scenario 1 and scenario 2 for the remainder of the SCs can be observed in **Appendix D** and **Appendix E** respectively.

For scenario 1, which is shown in **Table 3-11** for the annual statistics and **Table 3-12** for the monthly means, the average historical runoff is lower compared to the six CCMs., similarly the standard deviation of the CCMs are significantly higher than the observed historic rainfall. Meaning that the spread of the rainfall events, high and low occurrences, is wider for the adjusted CCMs compared to the observed historic rainfall sequence. The mean runoff for the Modder Catchment increased compared to the historic simulated sequence. This is also the case for the Caledon Catchment, however the Senqu, Makhaleng and Upper Orange catchments indicate a decrease in runoff for some of the CCMs.

Table 3-11: Annual average runoff for Modder catchment - undeveloped (Scenario 1)

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	St dev	CV	Minimum	Maximum
Historical	149	163	1.10	8	1203
ACC	170	170	1.00	9	1155
CCS	175	197	1.12	9	1473
CNR	192	209	1.09	11	1525
GFD	259	255	0.99	18	1752
MPI	177	182	1.03	9	1239
NOR	166	175	1.05	9	1256
	Percentage difference compared to the historical record:				
ACC	15%	4%	4%	12%	-4%
CCS	18%	21%	21%	25%	22%
CNR	29%	28%	28%	50%	27%
GFD	74%	57%	57%	143%	46%
MPI	19%	12%	12%	16%	3%
NOR	11%	7%	7%	22%	4%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

Table 3-12: Monthly and annual average runoff: Modder catchment – undeveloped (Scenario 1)

Scenario	Monthly and annual Runoff (million m3/a)												
	Oct	No v	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	5	13	15	25	36	31	17	5	1	0	0	2	149
ACC	5	15	27	36	38	31	13	3	0	0	1	1	170
CCS	3	16	18	27	47	33	21	7	1	0	0	1	175
CNR	6	21	19	32	57	35	16	5	0	0	0	1	192
GFD	9	26	27	47	71	51	21	4	0	0	0	1	259
MPI	3	18	20	35	38	32	21	7	1	0	0	0	177

NOR	10	13	14	25	35	35	24	7	1	0	1	1	166
Percentage difference compared to the historical data													
ACC	1%	18%	82%	45%	6%	1%	-21%	-44%	-42%	-39%	47%	-41%	15%
CCS	-39%	28%	21%	10%	32%	5%	25%	47%	6%	57%	-17%	-30%	18%
CNR	17%	66%	29%	30%	58%	13%	-5%	-6%	-42%	-54%	-33%	-67%	29%
GFD	85%	99%	82%	90%	98%	65%	28%	-9%	-61%	-13%	-75%	-18%	74%
MPI	-47%	43%	38%	41%	7%	2%	26%	56%	81%	34%	-76%	-73%	19%
NOR	117%	1%	-7%	2%	-2%	11%	42%	51%	16%	-22%	25%	-34%	11%

Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

For scenario 2, which is shown in **Table 3-13** for the annual statistics and **Table 3-14** for the monthly means of the Modder Catchment, the average historical observed rainfall is lower than the six CCMs, the standard deviation trend is similar to scenario 1. The other SCs indicate a decrease in runoff, with a few CCMs indicating an increase in runoff.

Table 3-13: Annual average runoff for the Modder catchment - undeveloped (Scenario 2)

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	**St dev**	**CV**	**Minimum**	**Maximum**
Historical	149	163	1.10	8	1203
ACC	171	170	1.00	9	1153
CCS	174	195	1.12	9	1463
CNR	193	210	1.09	11	1531
GFD	265	265	1.00	18	1800
MPI	177	182	1.03	9	1237
NOR	164	172	1.05	9	1237
	Percentage difference compared to the historical record:				
ACC	15%	4%	-9%	12%	-4%
CCS	17%	20%	2%	25%	22%
CNR	30%	29%	-1%	50%	27%
GFD	78%	63%	-9%	143%	50%
MPI	19%	12%	-6%	16%	3%
NOR	10%	5%	-5%	22%	3%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.
Period length 85 years. Historical record period 1920 to 2004

Table 3-14: Monthly and annual average runoff: Caledon catchment – undeveloped (Scenario 2)

Scenario	Monthly and annual Runoff (million m3/a)												
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Total**
Historical	5	13	15	25	36	31	17	5	1	0	0	2	149
ACC	5	15	27	36	38	32	13	3	0	0	1	1	171

CCS	3	16	18	27	48	32	21	7	1	0	0	1	174
CNR	6	21	19	32	57	35	16	5	0	0	0	1	193
GFD	9	26	27	47	74	54	23	5	0	0	0	1	265
MPI	3	18	20	35	39	32	21	7	1	0	0	0	177
NOR	10	13	14	25	35	34	23	7	1	0	0	1	164
Percentage difference compared to the historical data													
ACC	1%	18%	82%	45%	6%	2%	-22%	-48%	-46%	-39%	35%	-42%	15%
CCS	-39%	28%	21%	10%	32%	5%	23%	42%	-3%	56%	-22%	-30%	17%
CNR	17%	67%	29%	30%	59%	14%	-3%	-4%	-40%	-54%	-33%	-67%	30%
GFD	85%	100%	82%	90%	105%	73%	35%	-3%	-59%	-13%	-75%	-18%	78%
MPI	-47%	43%	38%	41%	7%	2%	25%	54%	82%	34%	-76%	-73%	19%
NOR	116%	1%	-7%	2%	-3%	10%	38%	43%	3%	-24%	14%	-35%	10%

Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

The tables are further summarised as geographical maps for the main study area as shown in for the simulated unit MAR and **Figure 3-25** for the percentage change in MAR for the six climate change models. It can be seen that the GFD CCM produces a decreased in in future evaporation for over parts of the Modder, Caledon, and Upper Orange Catchment, compared to remaining five CCMs which indicate an increase in evaporation over the entire study area. Larger format maps are added in **Appendix G**.

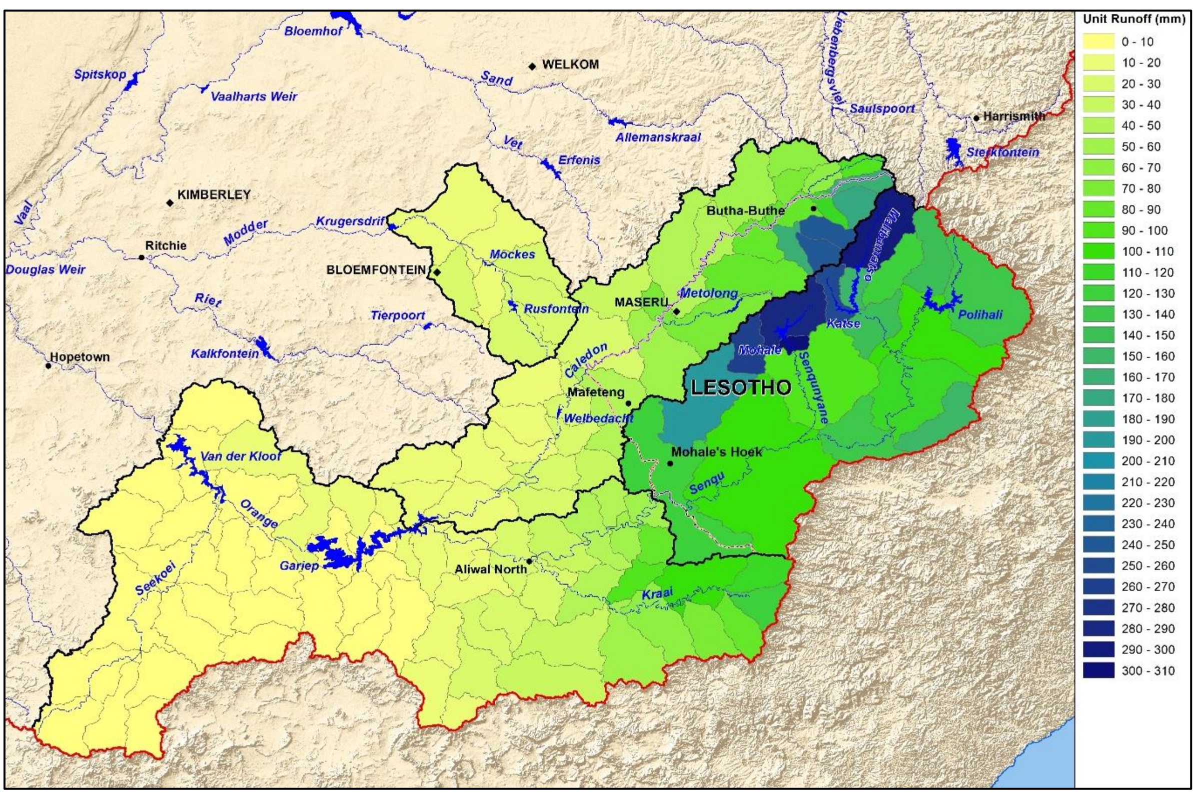

Figure 3-27: Mean Annual Unit Runoff (mm)

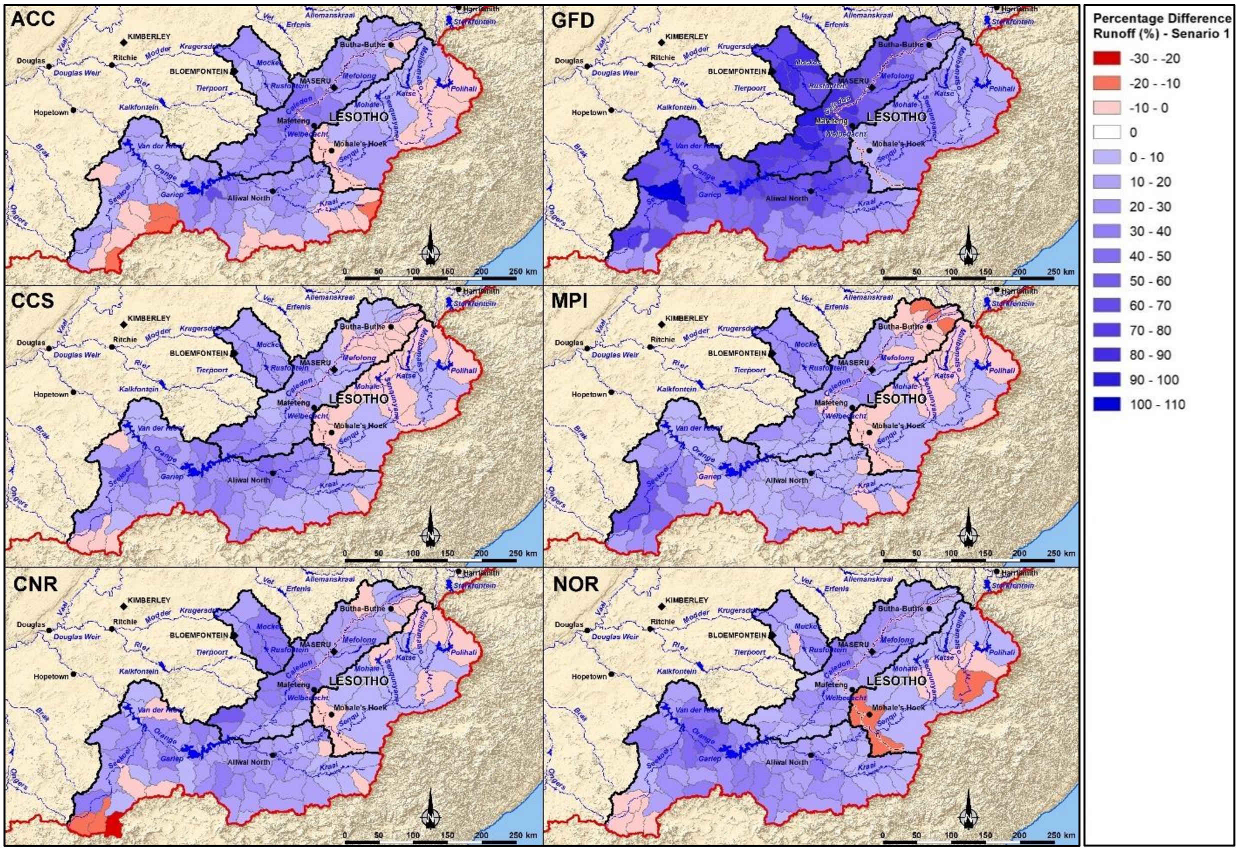

Figure 3-28: Percentage difference in Runoff for Scenario 1 the six CCMs

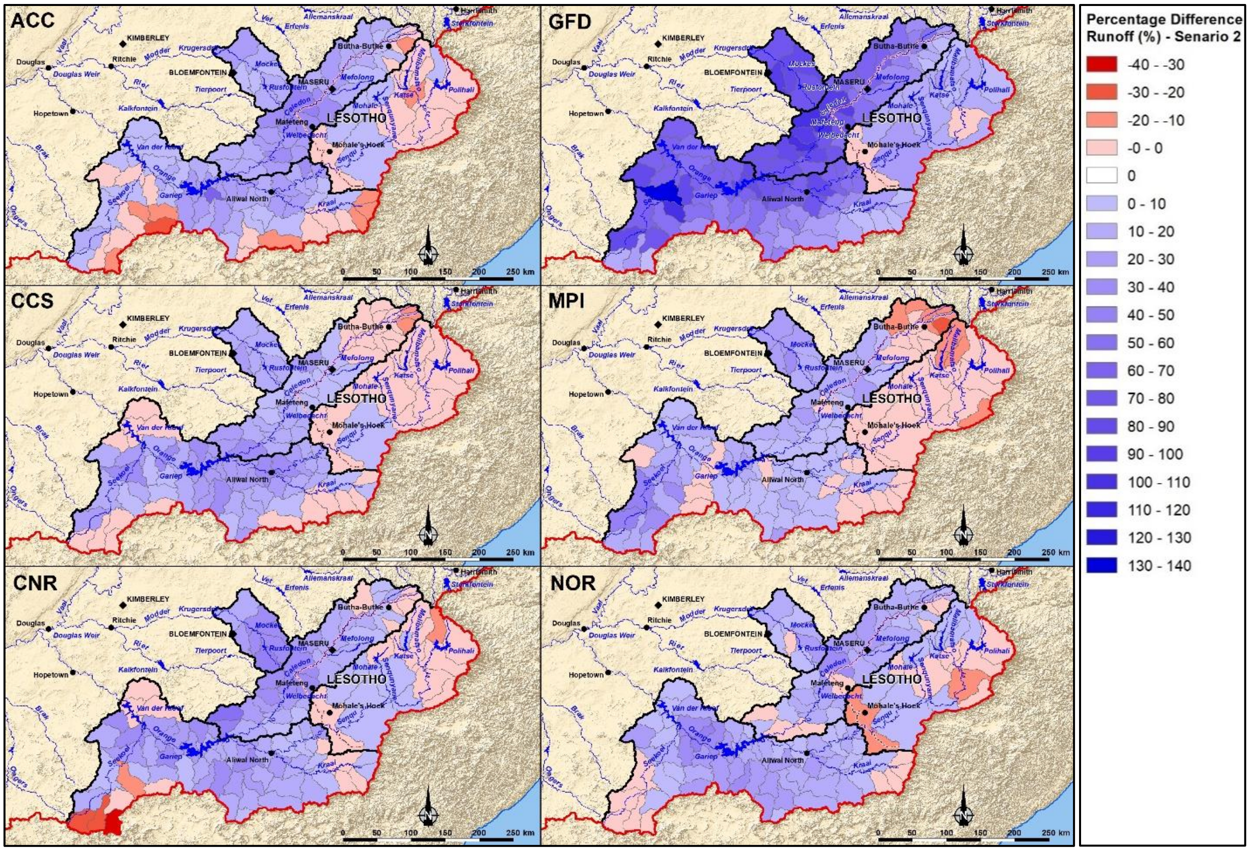

Figure 3-29: Percentage difference in Runoff for Scenario 2 the six CCMs

The study area contains 119 individual runoff units which had to be adjusted for rainfall and evaporation for the six CCMs. A total of 1428 natural runoff units were simulated and grouped for use in the 29 natural flow files to be used in the WRYM. This is an indication of the level of detail which was used to determine the impact of the various CCMs on the yield, demands and natural runoff.

3.5 Comparison with stochastic generated runoff and yield analysis

This section of the report contains comparative test results between the historic yield, natural runoff and dam trajectories, with the six CCMs and a stochastic analysis based on the historic simulated dataset. The comparison was conducted for scenario 2 only where both a change in rainfall and evaporation were analysed.

The lowest moving average annual runoff sequence, up to six years is shown in **Figure 3-30** for the Modder SC. There are three main components in the chart, which are the stochastically generated 1000 sequences, shown as box plots, the simulated historic runoff sequence as black line and blue squares and the six CCMs as triangles with different colours. All the CCMs fall within the stochastic band except for GFD, which is outside of the box plot only for the two and three year duration plot. In addition, all the CCM models appear to generate a net increase in runoff for the SC compared to the historic sequence.

The remainder SCs N-month Run Sums are summarised in **APPENDIX I**. The Makhaleng SC exhibits a similar trend to the Modder SC, whereas the Senqu, Upper Orange and Caledon contain some CCMs which produce lower runoffs. GFD consistently produces the highest moving average low sequence compared to all the other CCMs and the historic simulated sequence. It is therefore important to note that the stochastic analysis encapsulates the low flow sequences which are presented by the climate change models.

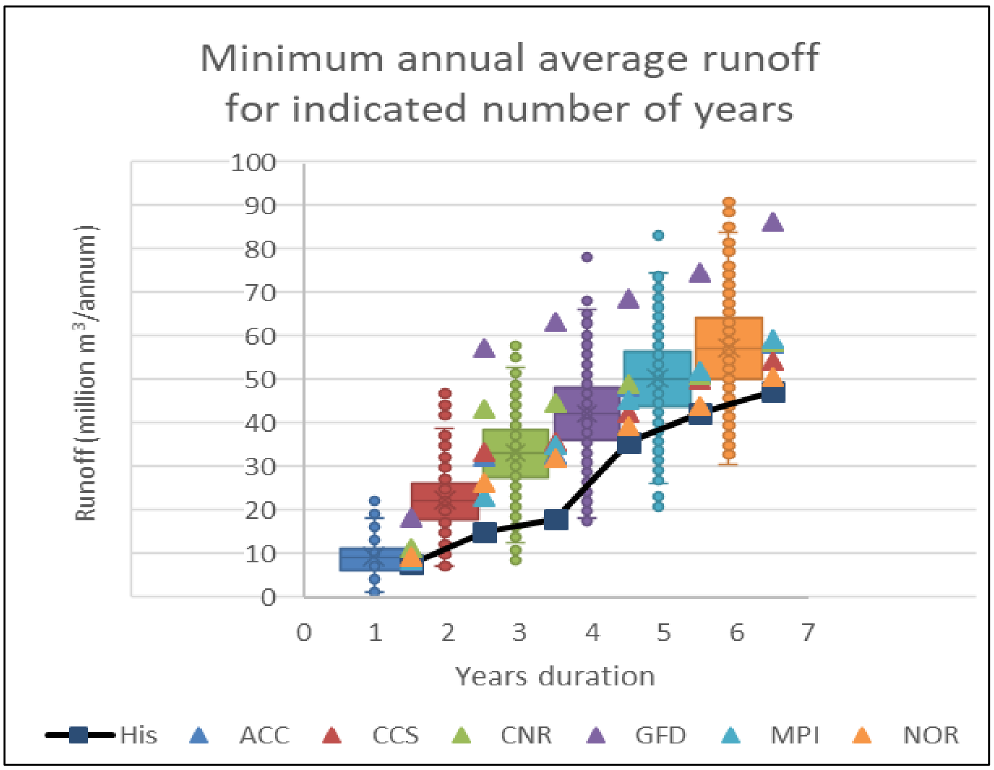

Figure 3-30: N-month run sums for the Modder SC

In addition to the lowest moving average annual runoff sequences, the dam trajectories for selected dams such as the Mohale Dam in **Figure 3-31** and the Gariep Dam in **Figure 3-33** are presented for the period from 1920 to 1970. This period was chosen as it contains the critical period in 1933 and a 50 year record period is shown as a longer period would make the graph too congested. Additional comparative dam trajectories are shown in **Appendix J** for Katse, Polihali and Rustfontein dams.

The dam trajectories again contain three distinct components, being the box plots, which are the blue blocks in the background, the historic trajectory, as red line, and the six CCMs as different markers. It is interesting to note that the results of the six CCMs are contained within the range of the stochastic results. The resulting comparative plots indicates the importance of conducting stochastic analysis, as a wider band of possible storages and their associated probabilities are analysed. The upper and lower limits in the graph are attributed to the operating rule of Mohale Dam which tends to support Katse Dam, the storage is preferably kept at the highest dam to be utilised only if necessary, as transfer to Katse.

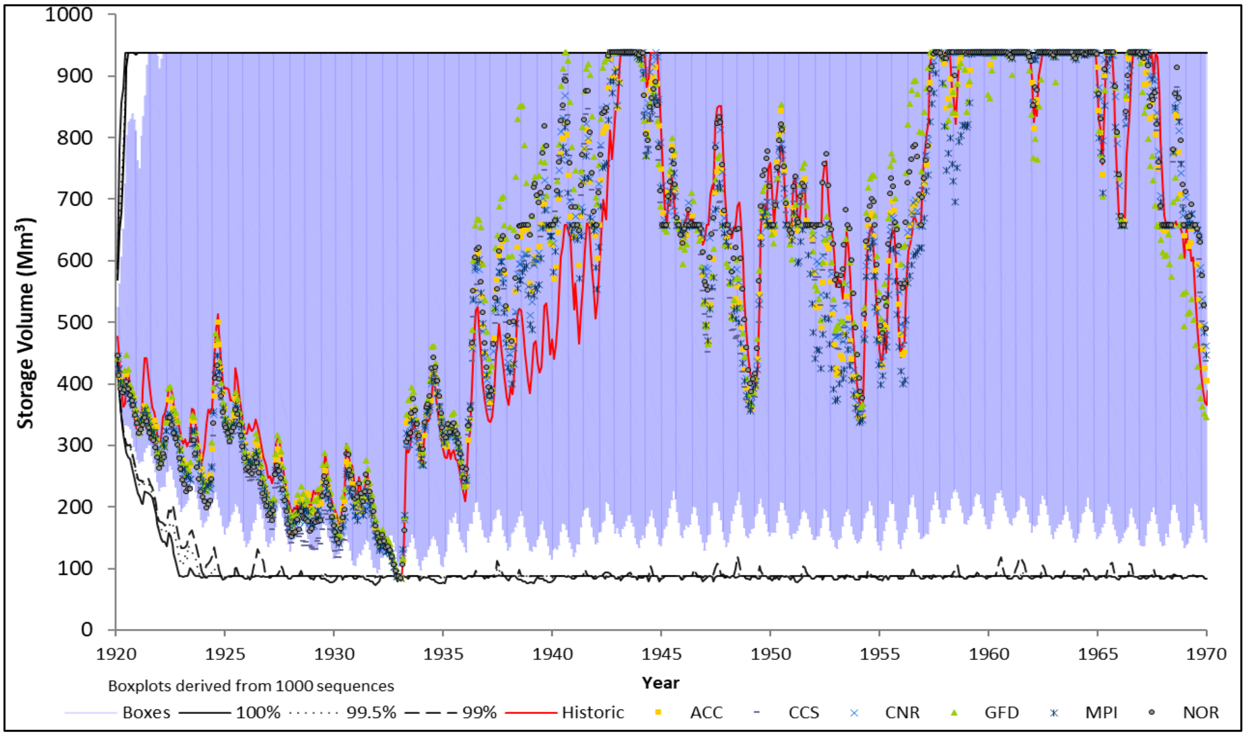

Figure 3-31: Mohale Dam Trajectory

A closeup graph for the period from 1940 to 1945 is shown for Mohale Dam **Figure 3-32**. Indicating the historic simulated storage falls within the box potion of the plot and the GFD CCM is produces the greatest storage. The observations made on the figure can are directly comparable to the changes in yields and demands, where most models indicate a decrease in yield and increase demands except for GFD.

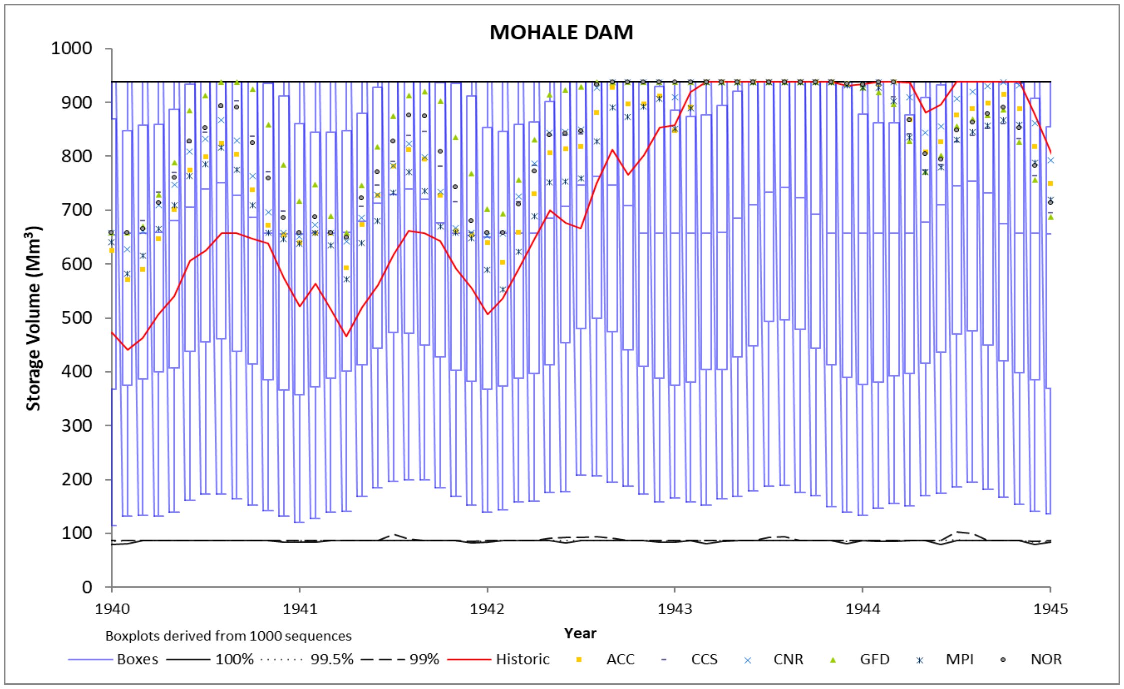

Figure 3-32: Closeup Mohale Dam Trajectory

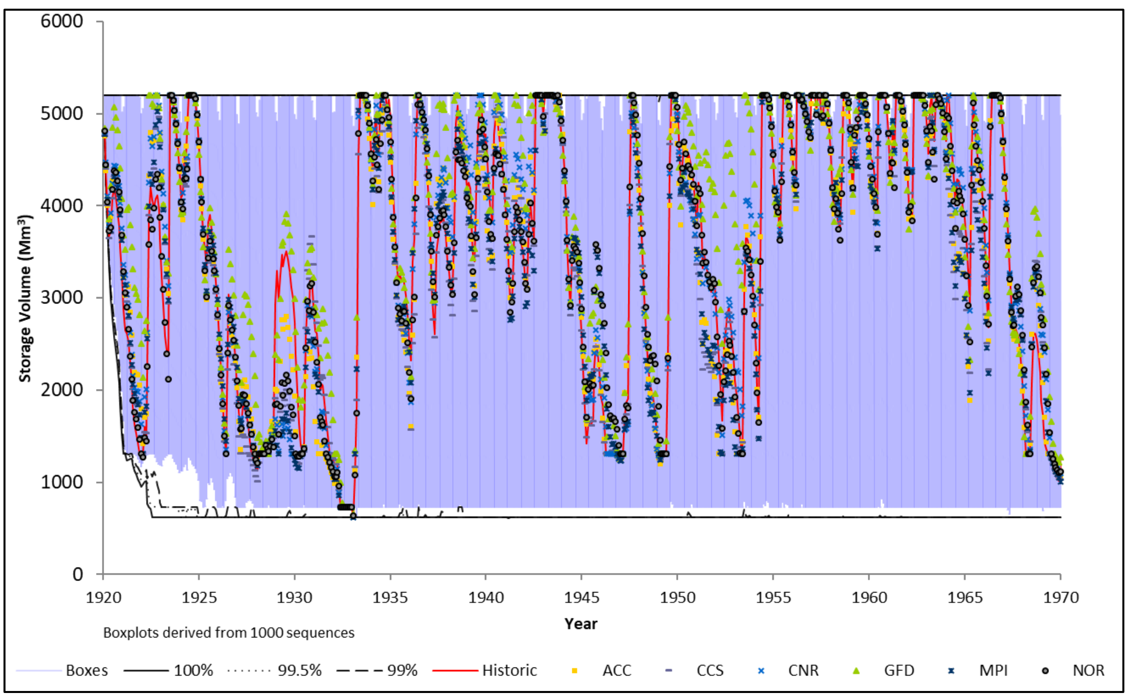

Figure 3-33: Gariep Dam Trajectory

A shorter record period dam trajectory for Gariep Dam is shown in **Figure 3-34**, indicating how the six CCMs track the historic record and that the GFD CCM produces the fullest dam storage plots.

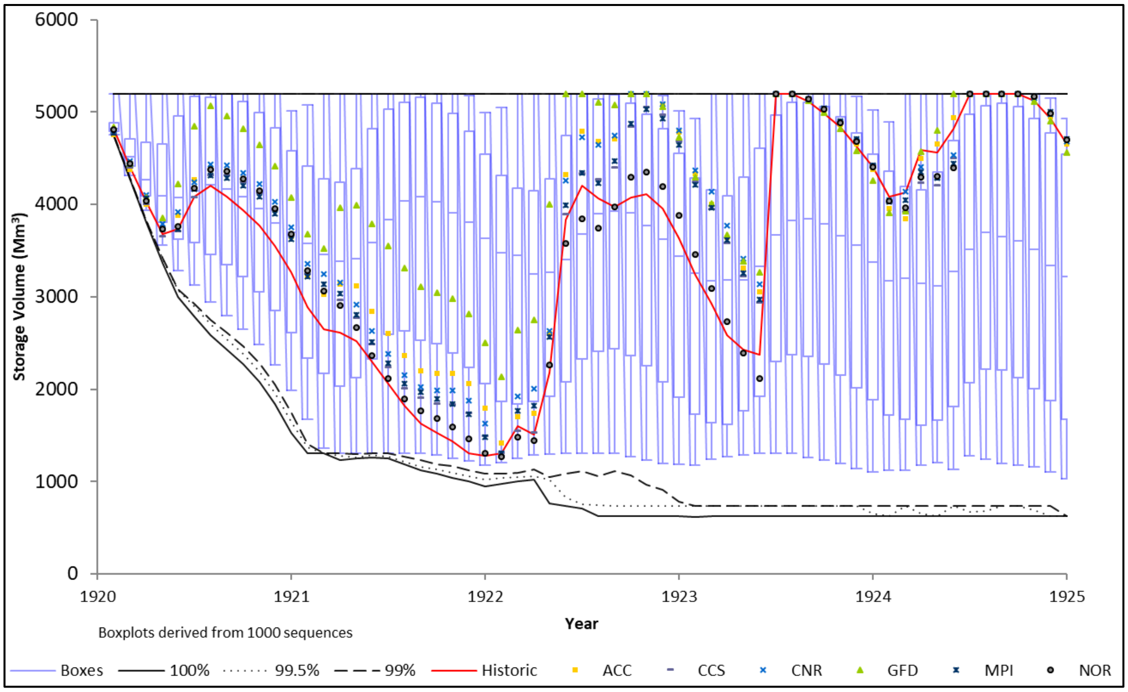

Figure 3-34: Closeup Gariep Dam Trajectory

3.6 Impacts on Demand

Various studies were conducted on the changes in demand due to climate change studies both for urban and irrigation requirements, as well as their impacts on water resources. Kusangaya et. al (2013), indicates that there are no significant changes observed in the rainfall trends in South Africa, however there is an increasing trend in temperature. It is further reported that there is no general consensus yet on the magnitude and direction of potential climate change, similar to the results obtained in this study in terms of streamflow. The Long-term Adaptation Scenarios (LTAS) Project was initiated in 2013, to address the socio-economic risks as a result of climate change, the models derived through the study do not indicate a consistent result regarding precipitation. A gap identified in recent papers, indicated that the impact of climate change on urban and irrigation demand has not yet been addressed (Ziervogel et. al, 2014). Therefore, it was decided to determine the impact of changes in precipitation and evaporation on irrigation requirements, as it is an easily accessible component in the WRYM.

The impact of the CCMs on demands was investigated by determining the change of the irrigation block demands, due to evaporation and rainfall changes. The pre-requisite for the comparison is that there are existing irrigation blocks in the SCs, such as for the Caledon, Modder and Upper Orange SCs. For the remainder of the SCs a different methodology was used to model irrigation demands, which do not take changes in evaporation and rainfall into account. The changes in irrigation demands are indicated in **Table 3-15**.

All the CCMs indicate an increased irrigation demand, except for GFD which indicates a decrease in irrigation demands of 8% throughout the study area. The average increase in demands range from 5% to 9%.

Table 3-15: Changes in irrigation demands

Sub-system	CCMs (%) difference in irrigation demands					
	ACC	CCS	CNR	GFD	NOR	MPI
Caledon	7%	7%	3%	-6%	5%	8%
Modder	10%	9%	3%	-6%	6%	10%
Upper Orange	5%	9%	2%	-10%	4%	9%
Average	**6%**	**8%**	**2%**	**-8%**	**5%**	**9%**

3.7 Comparative yield analysis

Yield analysis were carried out with the WRYM as configured for the ORP using constant development level for all land use activities (irrigation, mining, in-catchment abstractions and small dams) in 2030. The hydrology for the six models entailed the adjusted runoff, rainfall and evaporation for **Scenario 2** and only runoff and rainfall for **Scenario 1**.

The Firm Yield (maximum abstraction without a supply failure over the 85-year simulation period) were determined for the six models and two scenarios. The Historic Firm Yield results are presented in **Table 3-16** and the climate change impacts on the yield are summarised in **Table 3-17** along with the respective percentage difference compared to the Historical Firm yield.

Table 3-16: Firm yield results for Historical

Sub-system	Firm Yield for 85 year simulation period (million m^3/annum)
GBWSS	80
LHWP	1 037
Makhaleng	378
Orange River Project	3 339
Combined Averages	**4 834**

Table 3-17: Firm yield results for Historical and future climate scenarios

Description		Firm Yield for 85year simulation period (million m^3/annum)		Percentage difference of Firm Yield results for the climate change scenarios compared to the Historical Firm Yield	
Sub-system	**CCM**	**Scenario 1 (Adjusted rainfall)**	**Scenario 2: (Adjusted rainfall and evaporation)**	**Scenario 1 vs. Historical Firm Yield**	**Scenario 2 vs. Historical Firm Yield**
GBWSS	ACC	91	88	14%	10%
	CCS	88	83	10%	3%
	CNR	98	97	22%	21%
	GFD	108	110	35%	37%
	MPI	91	85	13%	6%
	NOR	93	91	16%	13%
	Average	**95**	**92**	**19%**	**15%**
LHWP	ACC	1093	1031	5%	-1%
	CCS	1028	973	-1%	-6%
	CNR	1018	987	-2%	-5%
	GFD	1215	1181	17%	14%
	MPI	1011	954	-2%	-8%
	NOR	1084	1036	5%	0%
	Average	**1075**	**1027**	**4%**	**-1%**
Makhaleng	ACC	398	379	5%	0%
	CCS	367	345	-3%	-9%
	CNR	394	388	4%	3%
	GFD	446	448	18%	19%
	MPI	380	358	1%	-5%
	NOR	388	375	3%	-1%
	Average	**396**	**382**	**5%**	**1%**
Orange River Project	ACC	3194	3011	-4%	-10%
	CCS	3116	2927	-7%	-12%
	CNR	3060	2974	-8%	-11%
	GFD	3702	3665	11%	10%
	MPI	3037	2853	-9%	-15%
	NOR	3175	3011	-5%	-10%
	Average	**3214**	**3074**	**-4%**	**-8%**
Combined Averages		**4779**	**4575**	**-1%**	**-5%**

4 DISCUSSION AND CONCLUSION

A repeatable methodology was chosen to simulate the impact of changes in rainfall and evaporation of the six chosen global CCMs on the natural runoff and yield of selected SCs in the Study Area. The base CCMs were unable to replicate the statistical properties of the base datasets, therefore bias correction over the validation period was done to match the means of the historic observed datasets to the CCMs.

The changes in runoff and subsequent changes in yield are relatively small, with five of the six CCMs producing consistent decreases in runoff with an average decrease in yield of 1% for scenario 1 and a 5% decrease in yield for scenario 2.

The importance of using a stochastic simulation method is apparent as they encapsulate the potential impacts of climate change. The lowest stochastically generated sequences are lower than the climate change models. Meaning that if the hydrology is updated and stochastically analysed, consistently after the occurrence and recovery of severe droughts, the results will be able to guide managers to plan for potential shortfalls and to engage restrictions sooner, use more efficient operating rules or to implement interventions timely.

The overarching consensus among the CCMs, except for GFD, was that there is an increase in demand for the irrigation blocks, ranging from 5% to 9%.

From the basin wide rainfall and evaporation maps it can be observed that there is a general decrease towards the north-west, whereas the some CCMs indicate a decrease for the study area and others produce an increase. This highlights the inherent uncertainty regarding the CCMs.

5 RECOMMENDATIONS

It is recommended that CCMs are chosen which are inherently able to replicate the metrics of the historically observed rainfall and evaporation data. Such highly regionalised models do not currently exist, and are therefore identified as major gap. The hydrology should be continuously updated, after recovery of server drought event.

The stochastic analysis is able to encapsulate the potential impacts of climate change, as shown in this study. Currently there are no statistically significant trends rainfall trends over the historic observed rainfall record.

The impacts of climate change on urban water use should be further investigated, as it is expected that a decrease in precipitation and increase in evaporation can lead to longer restrictions if the water supply infrastructure and available yields are not sufficient to cover the increased demands. The impacts of such changes on the Gross Domestic Product (GDP) might be severe. The inherent uncertainty pertaining to the climate change projections needs to be addressed and quantified before further impacts are determined.

It is vital that rainfall and river runoff gauging stations are maintained to be able to observe long-term trends. With advancement and decrease in cost of technology there should be no reasons for closing or decommissioning of stations, which are crucial for gathering accurate localised data. A more transparent open data transfer platform should be developed to allow for researchers and water resources specialists to obtain reliable up-to-date access to metrological and hydrological data.

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APPENDIX A - COMPARISONS FOR THE VALIDATION PERIOD

Annual statistics of the average rainfall for the Makhaleng SC

Dataset	Mean Annual Precipitation	Minimum Annual Precipitation	Maximum Annual Precipitation	Standard Deviation of Annual Totals	Coefficient of Variance
Historical	929.0	540.6	1306.9	167.6	0.18
ACC	926.1	613.2	1192.0	134.7	0.15
CCS	927.9	709.8	1122.1	101.3	0.11
CNR	929.7	643.6	1168.8	114.1	0.12
GFD	927.6	740.6	1168.6	113.7	0.12
MPI	926.9	701.6	1221.3	121.6	0.13
NOR	925.4	695.0	1138.7	113.9	0.12
Percentage difference compared to historical statistic					
ACC	0.3%	-13.4%	8.8%	19.6%	19.4%
CCS	0.1%	-31.3%	14.1%	39.5%	39.5%
CNR	-0.1%	-19.1%	10.6%	31.9%	31.9%
GFD	0.1%	-37.0%	10.6%	32.1%	32.0%
MPI	0.2%	-29.8%	6.5%	27.5%	27.3%
NOR	0.4%	-28.6%	12.9%	32.0%	31.8%

Annual statistics of the average rainfall for the Senqu SC

Dataset	Mean Annual Precipitation	Minimum Annual Precipitation	Maximum Annual Precipitation	Standard Deviation of Annual Totals	Coefficient of Variance
Historical	817.2	592.7	1139.9	132.8	0.16
ACC	814.5	552.0	994.0	88.6	0.11
CCS	816.8	632.5	963.0	74.0	0.09
CNR	818.0	687.3	951.8	68.4	0.08
GFD	815.8	684.0	966.6	76.9	0.09
MPI	815.4	656.7	980.1	77.9	0.10
NOR	815.3	662.0	960.5	76.6	0.09
Percentage difference compared to historical statistic					
ACC	0.3%	6.9%	12.8%	33.3%	33.1%
CCS	0.0%	-6.7%	15.5%	44.3%	44.3%
CNR	-0.1%	-16.0%	16.5%	48.5%	48.6%
GFD	0.2%	-15.4%	15.2%	42.1%	42.0%
MPI	0.2%	-10.8%	14.0%	41.4%	41.2%
NOR	0.2%	-11.7%	15.7%	42.3%	42.2%

Annual statistics of the average rainfall for the Upper Orange SC

Dataset	Mean Annual Precipitation	Minimum Annual Precipitation	Maximum Annual Precipitation	Standard Deviation of Annual Totals	Coefficient of Variance
Historical	471.6	251.4	867.5	132.4	0.28
ACC	472.8	315.0	598.5	62.4	0.13
CCS	474.5	345.4	592.6	62.0	0.13
CNR	475.4	334.2	647.1	68.4	0.14
GFD	472.7	354.2	626.7	68.7	0.15
MPI	471.7	369.1	603.4	67.1	0.14
NOR	473.0	317.3	581.7	62.6	0.13
Percentage difference compared to historical statistic					
ACC	-0.3%	-25.3%	31.0%	52.9%	53.0%
CCS	-0.6%	-37.4%	31.7%	53.2%	53.5%
CNR	-0.8%	-33.0%	25.4%	48.3%	48.7%
GFD	-0.2%	-40.9%	27.8%	48.1%	48.2%
MPI	0.0%	-46.8%	30.4%	49.3%	49.3%
NOR	-0.3%	-26.2%	32.9%	52.7%	52.9%

Annual statistics of the average rainfall for the Caledon SC

Dataset	Mean Annual Precipitation	Minimum Annual Precipitation	Maximum Annual Precipitation	Standard Deviation of Annual Totals	Coefficient of Variance
Historical	680.0	386.4	1007.0	136.4	0.20
ACC	678.4	450.7	851.9	84.8	0.12
CCS	680.4	535.6	805.5	62.5	0.09
CNR	680.3	484.4	861.7	74.3	0.11
GFD	679.0	478.9	853.0	87.4	0.13
MPI	679.0	553.1	839.3	67.8	0.10
NOR	679.3	505.8	815.1	75.5	0.11
Percentage difference compared to historical statistic					
ACC	0.2%	-16.6%	15.4%	37.9%	37.7%
CCS	-0.1%	-38.6%	20.0%	54.2%	54.2%
CNR	0.0%	-25.4%	14.4%	45.5%	45.5%
GFD	0.1%	-23.9%	15.3%	35.9%	35.9%
MPI	0.2%	-43.2%	16.7%	50.3%	50.2%
NOR	0.1%	-30.9%	19.1%	44.7%	44.6%

Annual rainfall averages for Makhaleng SC

Dataset	Slope (mm/annum)	Significance of slope	Significance Test for Normal Distribution
Historical	0.77	0.732	0.997
ACC	-4.28	0.024	0.493
CCS	1.00	0.496	0.504
CNR	0.33	0.840	0.834
GFD	-0.67	0.685	0.416
MPI	-0.90	0.610	0.282
NOR	-2.46	0.131	0.338

Annual rainfall averages for Senqu SC

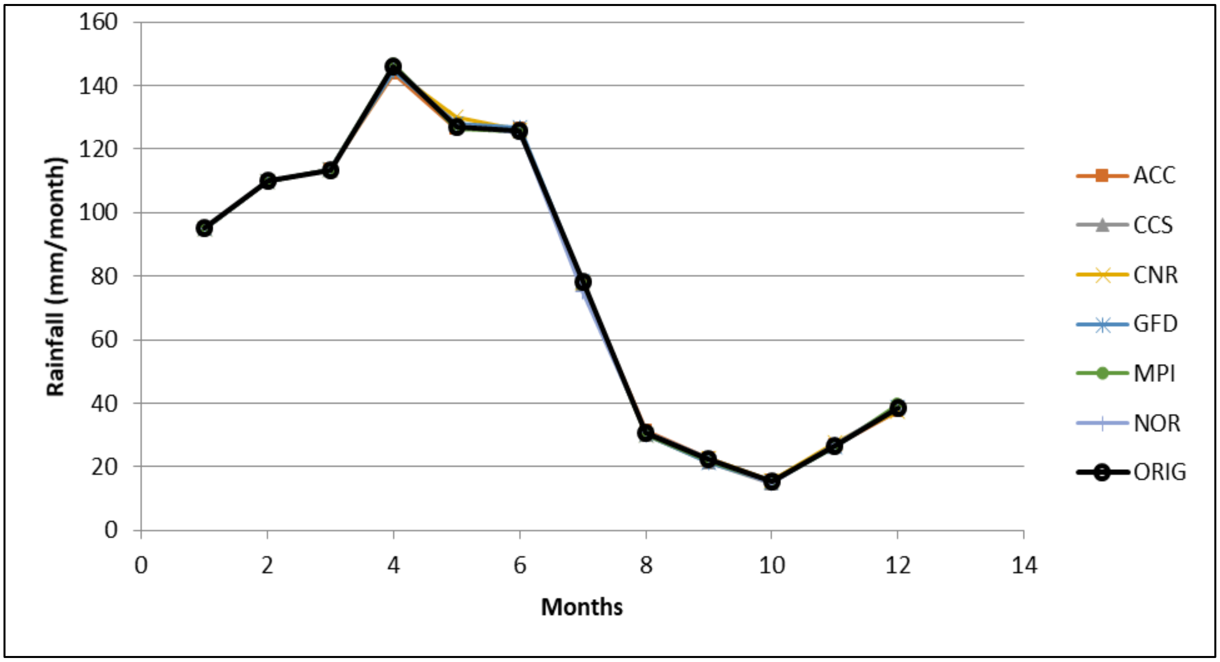
Dataset	Slope (mm/annum)	Significance of slope	Significance Test for Normal Distribution
Historical	0.97	0.585	0.498
ACC	-2.04	0.106	0.198
CCS	0.97	0.362	0.855
CNR	0.86	0.385	0.583
GFD	0.28	0.804	0.239
MPI	-1.18	0.292	0.661
NOR	-0.86	0.440	0.566

Annual rainfall averages for Upper Orange SC

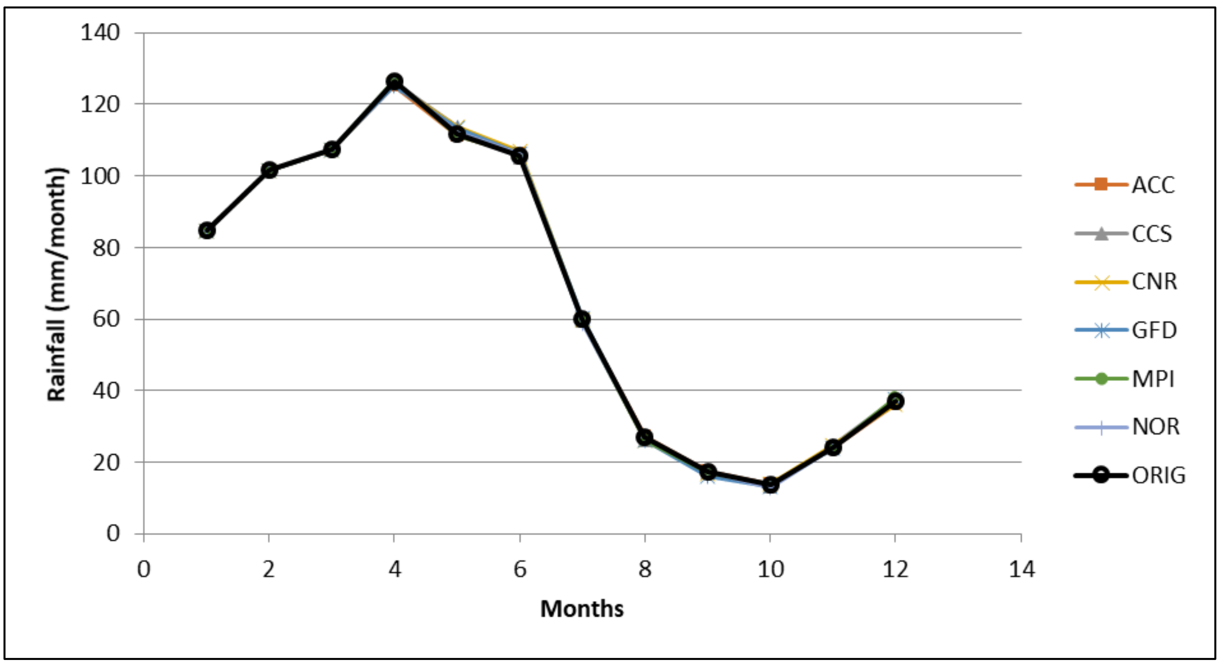
Dataset	Slope (mm/annum)	Significance of slope	Significance Test for Normal Distribution
Historical	-0.43	0.807	**0.030**
ACC	-1.18	0.189	0.770
CCS	0.71	0.425	**0.043**
CNR	0.92	0.351	0.504
GFD	-0.16	0.870	0.670
MPI	-0.57	0.559	0.168
NOR	-1.83	**0.038**	0.161

Annual rainfall averages for Caledon SC

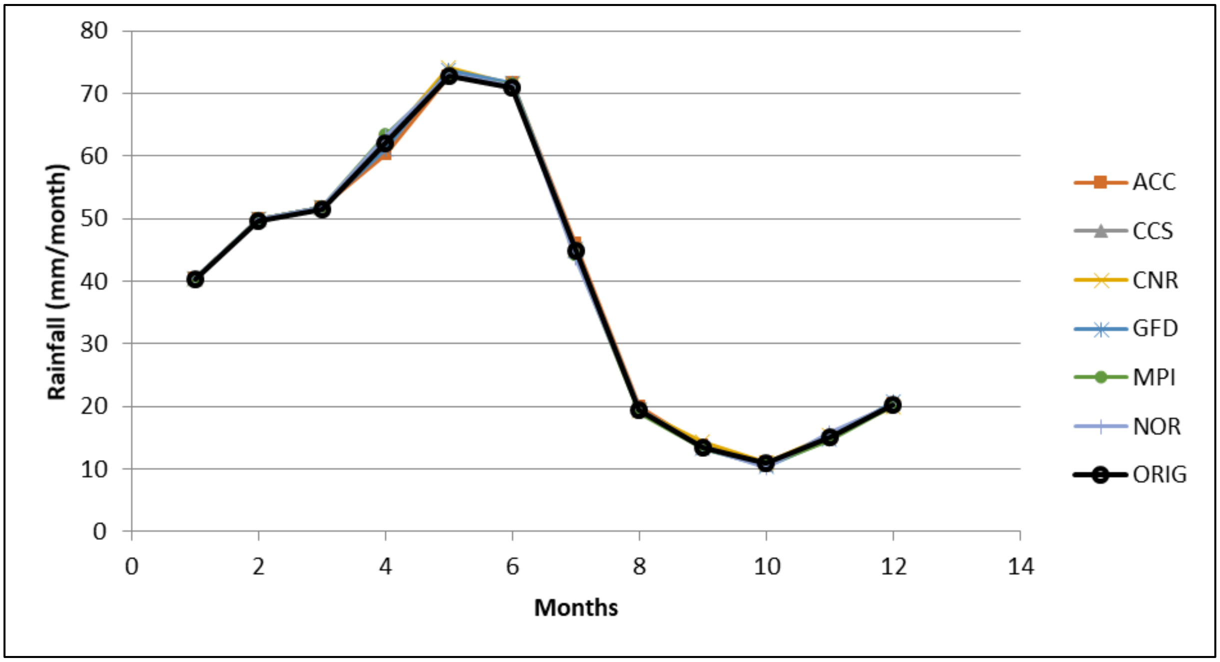
Dataset	Slope (mm/annum)	Significance of slope	Significance Test for Normal Distribution
Historical	-0.10	0.957	0.650
ACC	-1.82	0.133	0.682
CCS	0.84	0.354	0.909
CNR	0.29	0.787	0.649
GFD	0.37	0.768	0.981
MPI	-0.84	0.389	0.573
NOR	-1.38	0.203	0.335



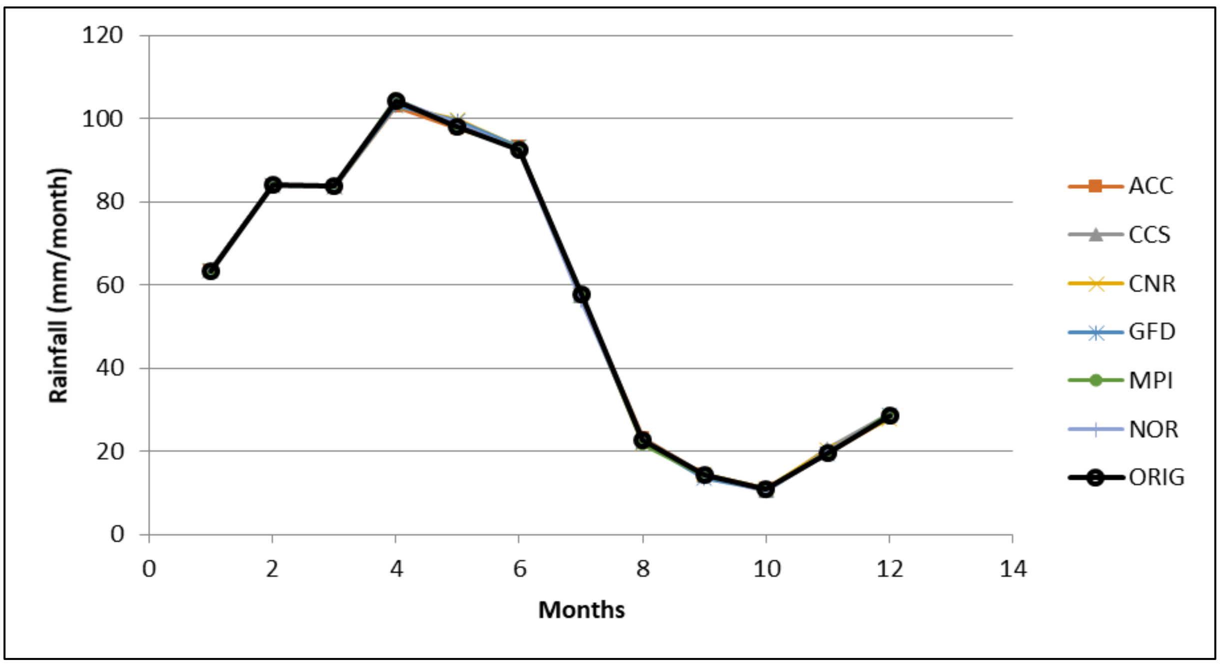
Monthly Average all catchments in the Makhaleng SC



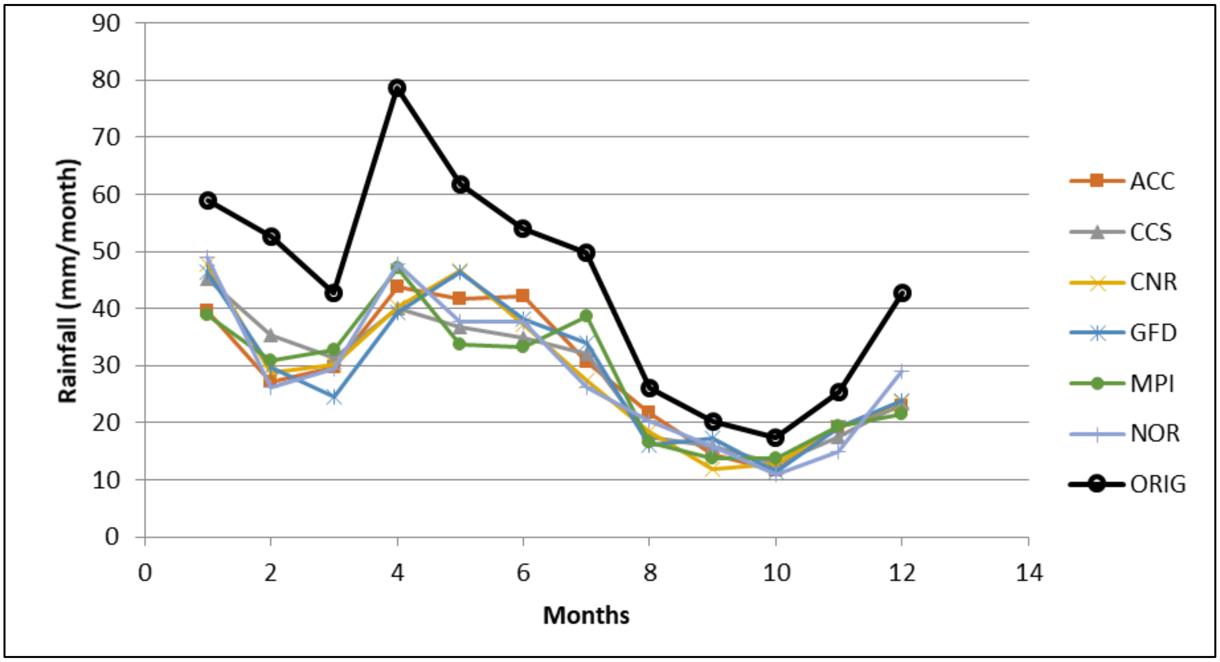
Monthly Average all catchments in the Senqu SC



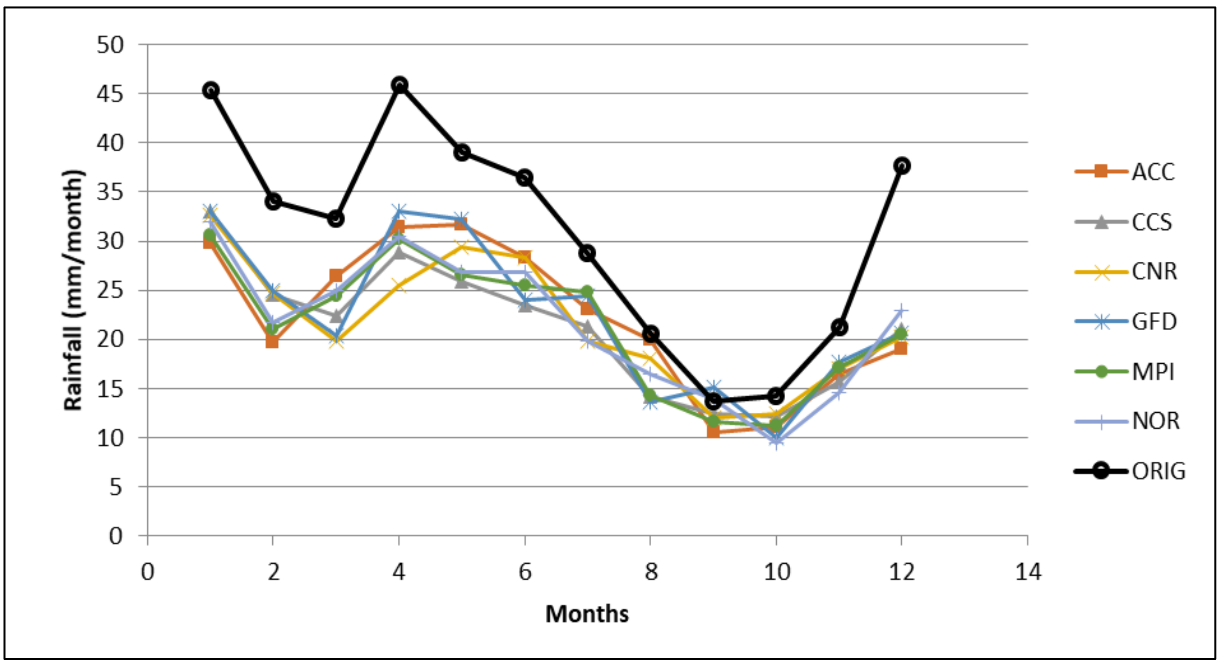
Monthly Average all catchments in the Upper Orange SC



Monthly Average all catchments in the Caldeon SC



Monthly Standard Deviation all catchments in the Makhaleng SC



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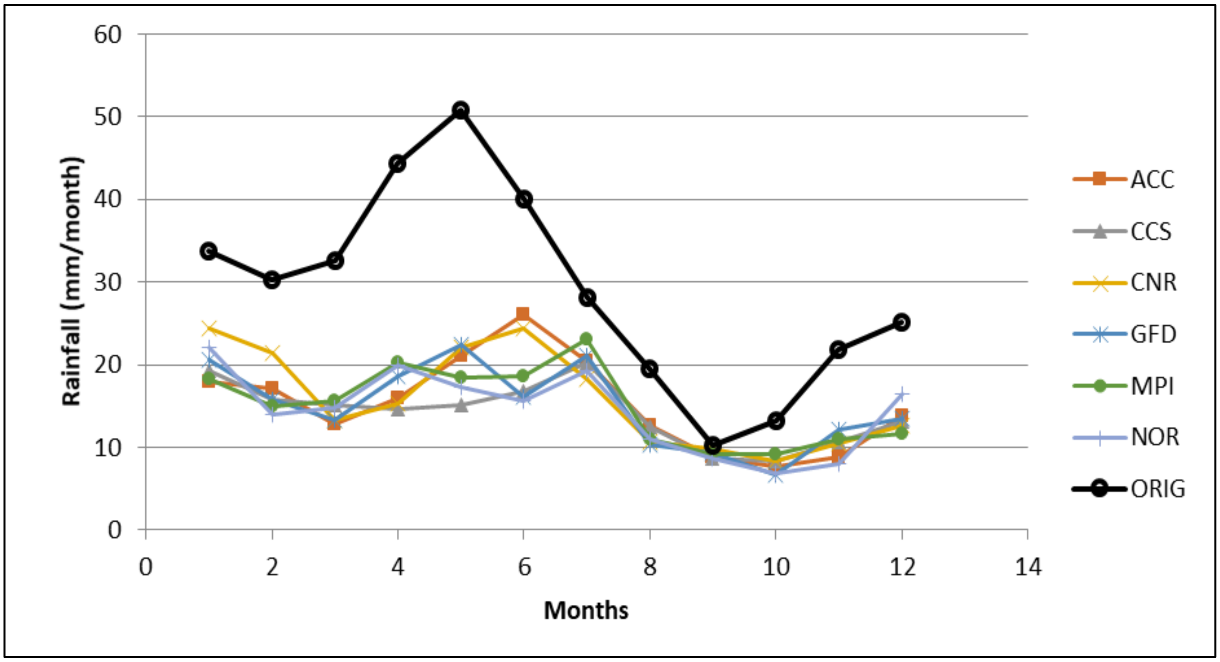
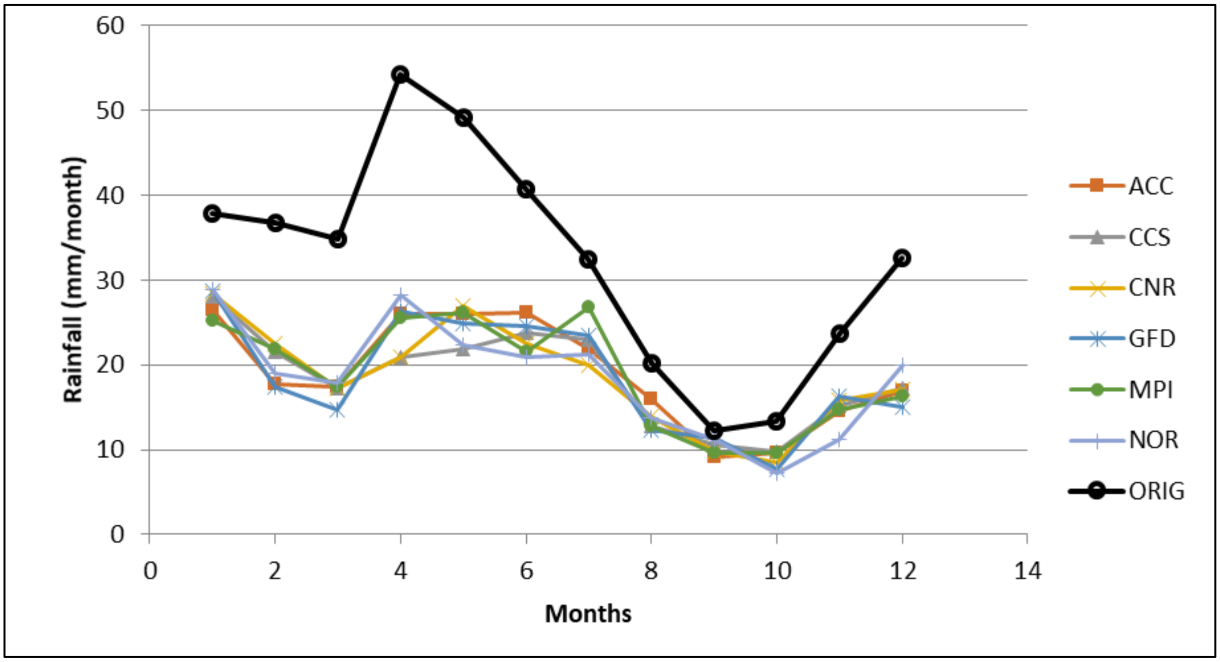
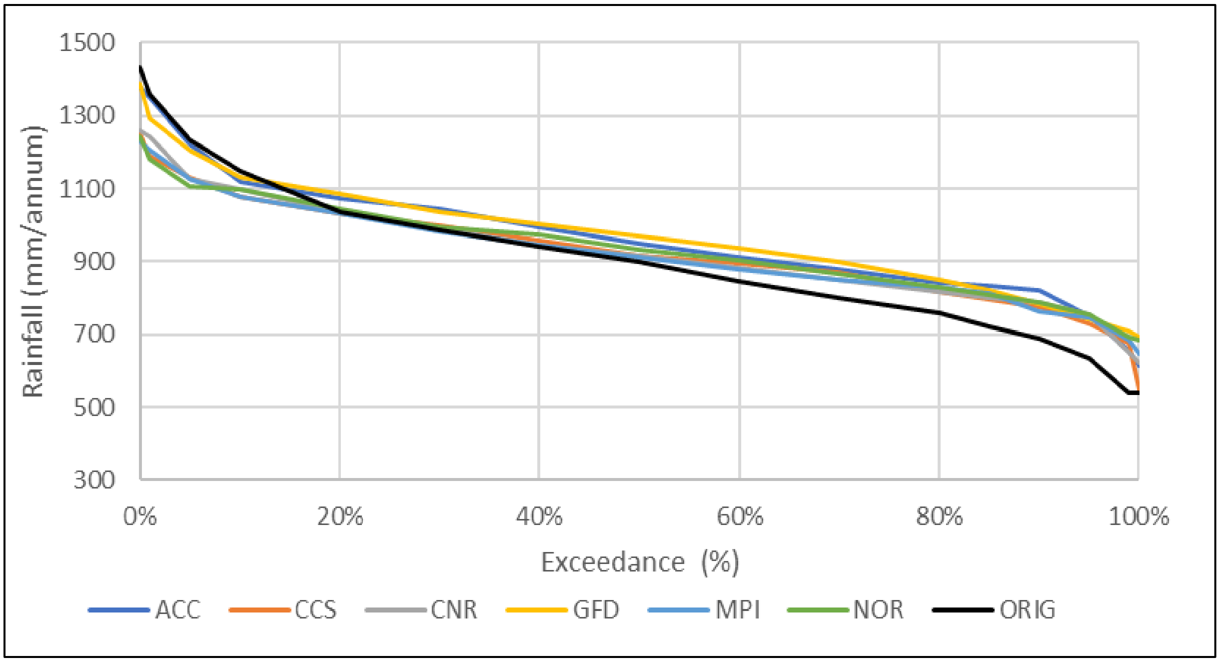


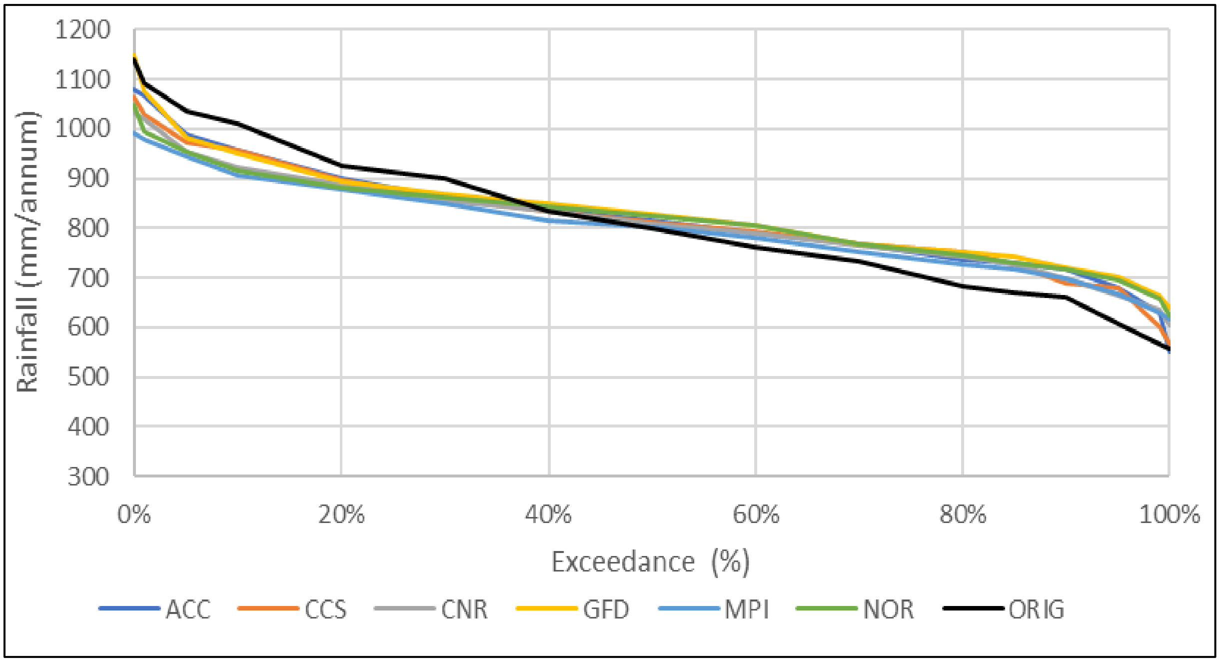
Monthly Standard Deviation all catchments in the Upper Orange SC



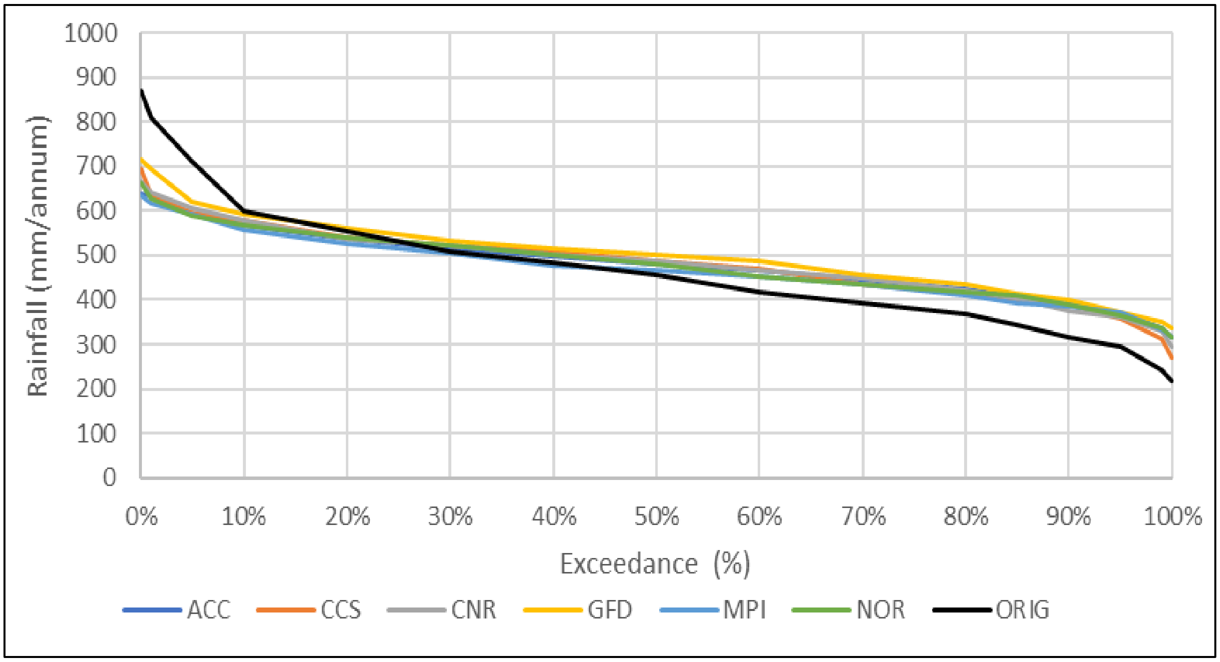
Monthly Standard Deviation all catchments in the Caledon SC



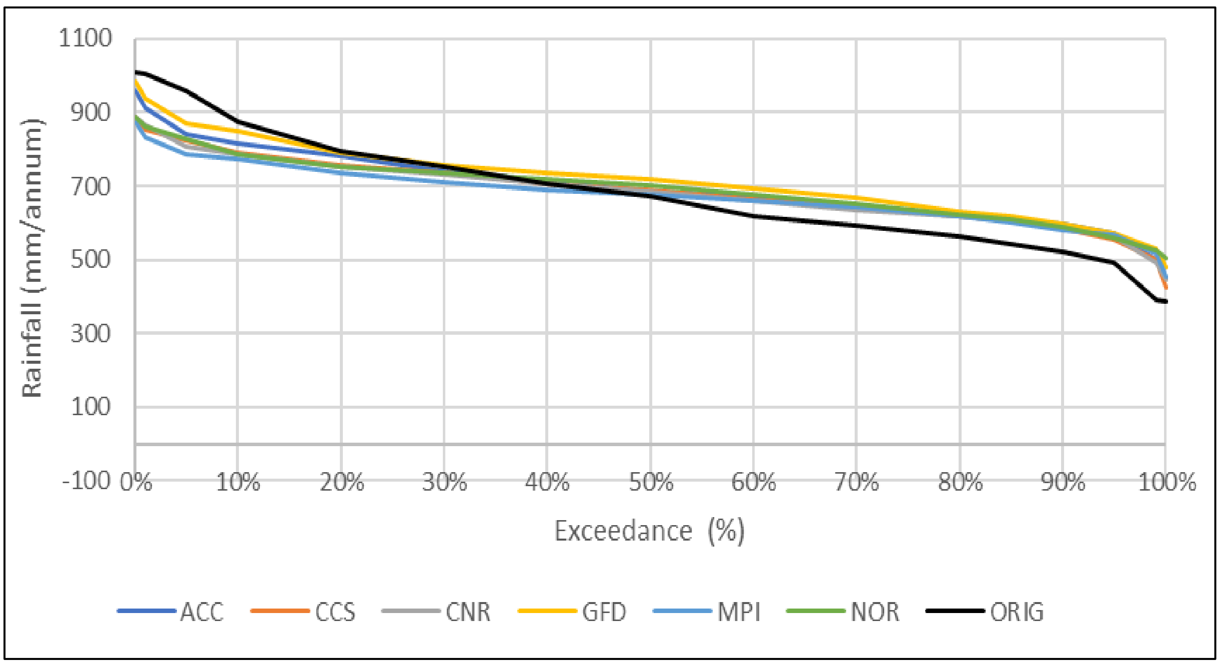
Distribution of annual totals, historical (ORIG) and six models Makhaleng SC



Distribution of annual totals, historical (ORIG) and six models Senqu SC



Distribution of annual totals, historical (ORIG) and six models Upper Orange SC



Distribution of annual totals, historical (ORIG) and six models Caledon SC

Minimum cumulative total rainfall - average Makhaleng SC

Scenario	Minimum cumulative rainfall (mm) for indicated number of months duration						
	6	12	18	24	36	48	60
His	49.4	470.6	630.4	1375.6	2326.5	3091.2	3967.5
ACC	66.0	531.8	806.8	1234.6	2043.1	2826.6	3616.6
CCS	112.8	692.1	906.5	1568.4	2407.5	3358.4	4131.3
CNR	95.8	606.1	803.7	1440.5	2322.5	3245.0	4081.3
GFD	77.4	650.0	885.2	1471.2	2355.4	3191.9	4094.7
MPI	95.6	659.8	834.5	1500.0	2289.9	3123.1	4042.6
NOR	105.5	652.3	840.8	1440.1	2353.2	3233.1	4096.4

Minimum cumulative total rainfall - average Senqu SC

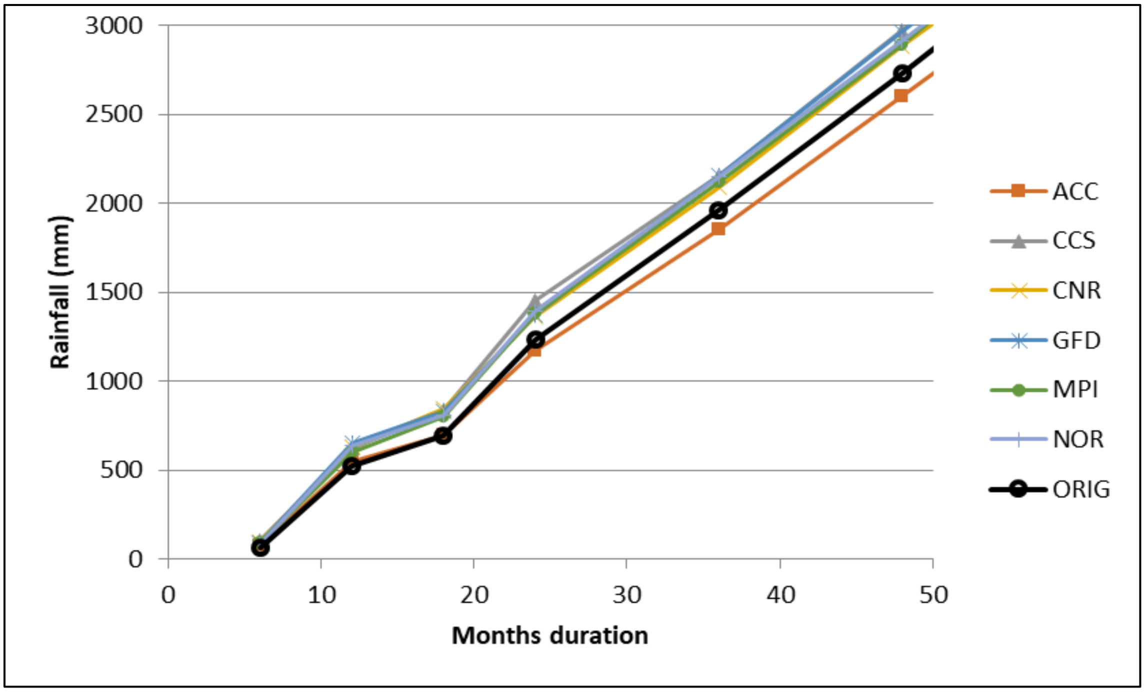
Scenario	Minimum cumulative rainfall (mm) for indicated number of months duration						
	6	12	18	24	36	48	60
His	61.9	521.0	692.1	1237.1	1959.6	2732.7	3539.9
ACC	72.3	552.0	699.7	1172.7	1854.2	2597.4	3358.0
CCS	106.3	621.7	834.1	1451.2	2152.6	2968.6	3744.6
CNR	96.3	630.0	844.4	1361.8	2089.8	2884.4	3627.8
GFD	92.1	649.2	828.2	1372.6	2153.1	2961.5	3767.6
MPI	88.3	597.5	803.1	1376.0	2119.0	2886.7	3746.8
NOR	79.2	635.7	805.8	1394.4	2149.3	2911.1	3696.7

Minimum cumulative total rainfall - average Upper Orange SC

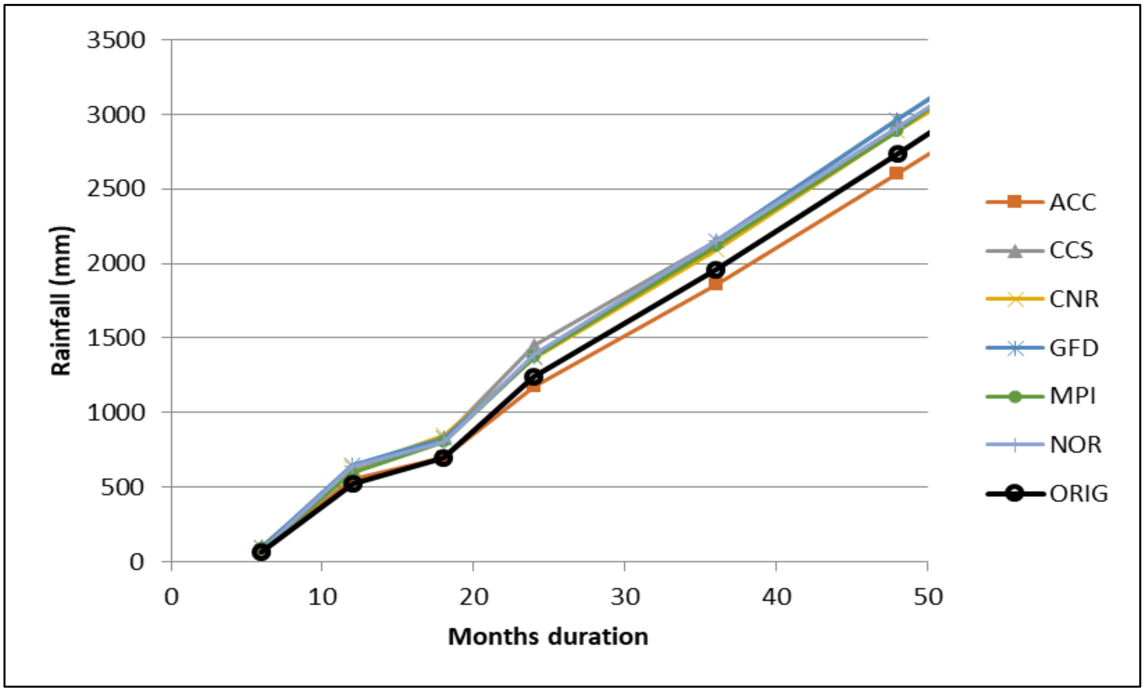
Scenario	Minimum cumulative rainfall (mm) for indicated number of months duration						
	6	12	18	24	36	48	60
His	13.8	184.6	282.6	626.7	929.1	1445.8	1873.3
ACC	45.5	296.1	425.0	694.2	1052.2	1476.6	1846.3
CCS	61.5	345.4	453.4	746.7	1166.6	1629.7	2094.1
CNR	56.5	295.0	444.9	716.4	1139.0	1593.8	1987.1
GFD	39.7	312.5	428.5	724.8	1130.9	1575.6	2043.7
MPI	42.0	317.8	442.5	723.1	1111.9	1543.2	2023.0
NOR	65.7	309.5	405.3	733.2	1181.5	1670.6	2069.3

Minimum cumulative total rainfall - average Caledon SC

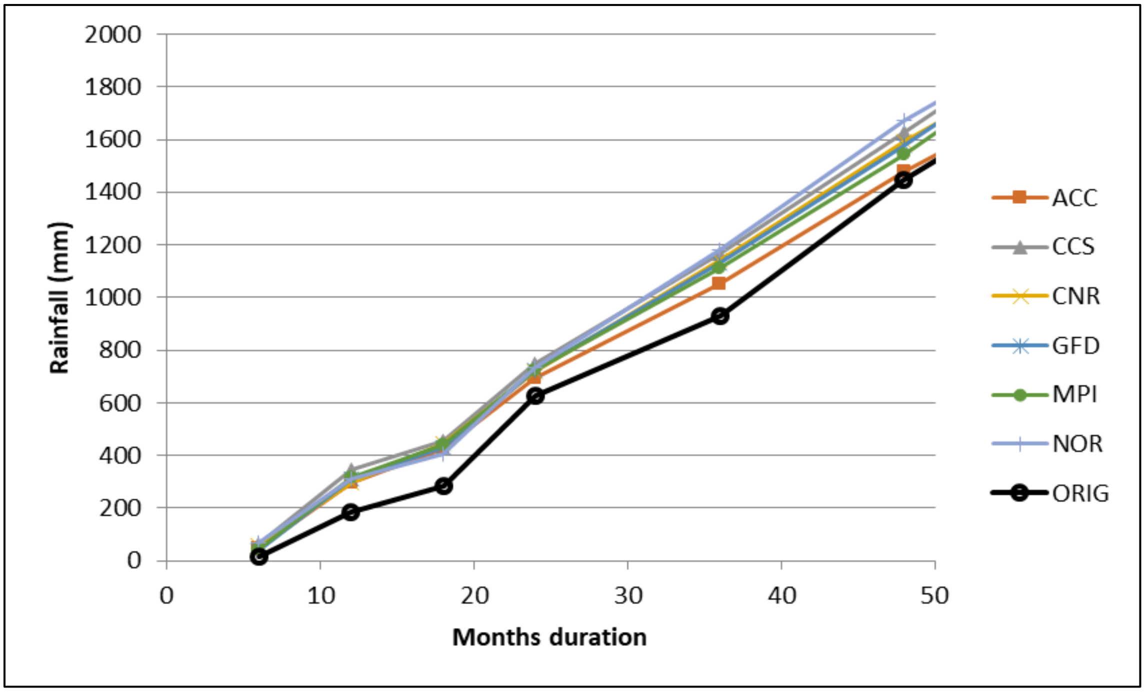
Scenario	Minimum cumulative rainfall (mm) for indicated number of months duration						
	6	12	18	24	36	48	60
His	39.5	357.6	457.0	1018.8	1548.2	2116.5	2848.4
ACC	49.9	416.2	607.8	943.4	1516.3	2155.7	2706.4
CCS	72.6	521.6	693.1	1199.1	1802.2	2476.8	3104.3
CNR	65.0	460.3	592.2	1095.1	1723.5	2388.0	3021.6
GFD	57.1	470.2	635.5	1075.2	1690.8	2303.0	2944.6
MPI	63.9	480.3	669.3	1137.3	1724.8	2340.0	3028.0
NOR	69.0	478.7	602.9	1026.1	1718.2	2319.8	2982.2



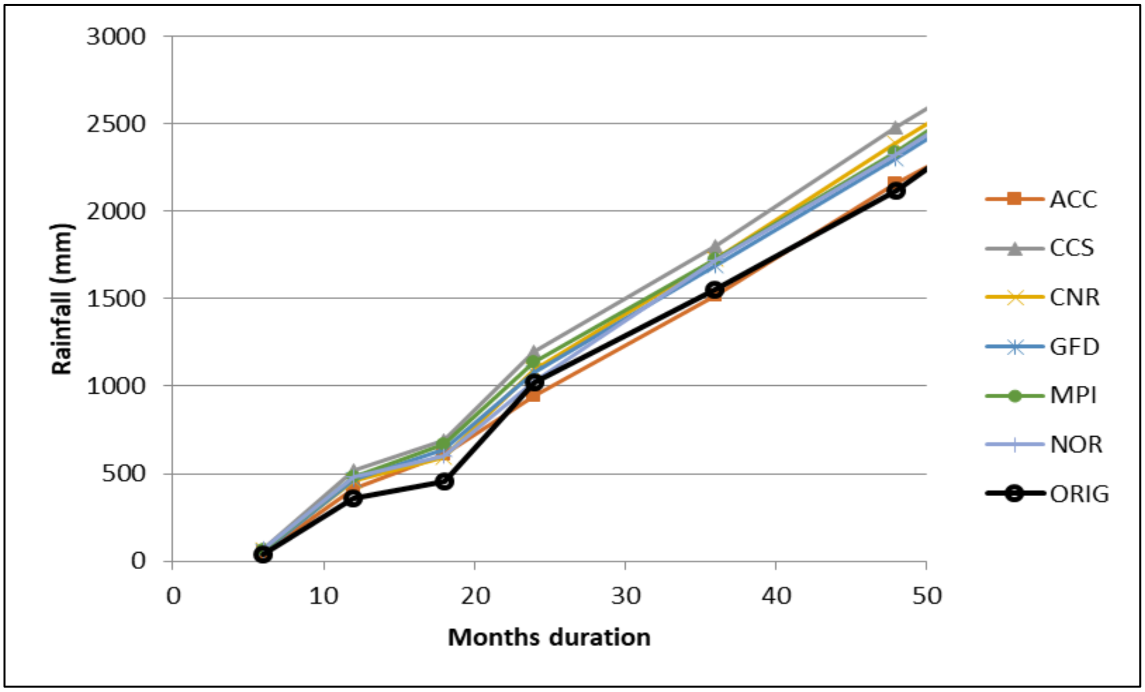
Minimum cumulative total rainfall - average of Makhaleng SC



Minimum cumulative total rainfall - average of Senqu SC



Minimum cumulative total rainfall - average of Upper Orange SC



Minimum cumulative total rainfall - average of Caledon SC

APPENDIX B - STATISTICAL COMPARATIVE RESULTS ADJUSTED RAINFALL

Annual rainfall averages for Makhaleng SC

Dataset	Mean Annual Precipitation	Minimum Annual Precipitation	Maximum Annual Precipitation	Standard Deviation of Annual Totals	Coefficient of Variance
Historical	929.0	540.6	1306.9	167.6	0.18
ACC	959.1	677.9	1237.7	133.5	0.14
CCS	918.3	678.4	1185.9	115.7	0.13
CNR	952.6	669.5	1248.2	138.2	0.15
GFD	1012.3	693.0	1313.8	143.1	0.14
MPI	924.8	708.9	1228.8	118.6	0.13
NOR	939.1	692.8	1171.5	111.1	0.12
Percentage difference compared to historical statistic					
ACC	3.2%	25.4%	-5.3%	-20.3%	-22.8%
CCS	-1.2%	25.5%	-9.3%	-31.0%	-30.2%
CNR	2.5%	23.8%	-4.5%	-17.5%	-19.6%
GFD	9.0%	28.2%	0.5%	-14.6%	-21.6%
MPI	-0.5%	31.1%	-6.0%	-29.2%	-28.9%
NOR	1.1%	28.2%	-10.4%	-33.7%	-34.4%

Annual rainfall averages for Senqu SC

Dataset	Mean Annual Precipitation	Minimum Annual Precipitation	Maximum Annual Precipitation	Standard Deviation of Annual Totals	Coefficient of Variance
Historical	817.2	592.7	1139.9	132.8	0.16
ACC	819.8	627.5	1079.5	93.7	0.11
CCS	809.9	610.9	996.7	86.9	0.11
CNR	816.0	629.6	1032.9	97.8	0.12
GFD	854.8	668.8	1086.1	96.0	0.11
MPI	798.4	617.1	991.9	86.6	0.11
NOR	820.2	655.2	990.0	76.1	0.09
Percentage difference compared to historical statistic					
ACC	0.3%	5.9%	-5.3%	-29.5%	-29.7%
CCS	-0.9%	3.1%	-12.6%	-34.6%	-34.0%
CNR	-0.2%	6.2%	-9.4%	-26.3%	-26.2%
GFD	4.6%	12.8%	-4.7%	-27.7%	-30.9%
MPI	-2.3%	4.1%	-13.0%	-34.8%	-33.3%
NOR	0.4%	10.5%	-13.1%	-42.7%	-42.9%

Annual rainfall averages for Upper Orange SC

Dataset	Mean Annual Precipitation	Minimum Annual Precipitation	Maximum Annual Precipitation	Standard Deviation of Annual Totals	Coefficient of Variance
Historical	471.6	251.4	867.5	132.4	0.28
ACC	475.9	338.9	637.1	64.1	0.13
CCS	484.7	331.9	624.3	74.0	0.15
CNR	487.3	293.6	667.5	78.4	0.16
GFD	515.6	337.8	708.5	73.4	0.14
MPI	473.7	315.4	605.5	65.5	0.14
NOR	483.7	334.7	662.9	77.5	0.16
Percentage difference compared to historical statistic					
ACC	0.9%	34.8%	-26.6%	-51.6%	-52.1%
CCS	2.8%	32.0%	-28.0%	-44.1%	-45.6%
CNR	3.3%	16.8%	-23.0%	-40.8%	-42.7%
GFD	9.3%	34.4%	-18.3%	-44.6%	-49.3%
MPI	0.5%	25.5%	-30.2%	-50.6%	-50.8%
NOR	2.6%	33.2%	-23.6%	-41.5%	-43.0%

Annual rainfall averages for Caledon SC

Dataset	Mean Annual Precipitation	Minimum Annual Precipitation	Maximum Annual Precipitation	Standard Deviation of Annual Totals	Coefficient of Variance
Historical	680.0	386.4	1007.0	136.4	0.20
ACC	697.7	498.6	925.5	86.8	0.12
CCS	682.4	523.7	857.0	75.8	0.11
CNR	697.0	445.9	888.2	89.3	0.13
GFD	745.3	535.2	937.7	92.7	0.12
MPI	670.4	511.7	875.1	72.9	0.11
NOR	696.2	550.8	852.5	78.4	0.11
Percentage difference compared to historical statistic					
ACC	2.6%	29.1%	-8.1%	-36.4%	-38.0%
CCS	0.3%	35.5%	-14.9%	-44.5%	-44.6%
CNR	2.5%	15.4%	-11.8%	-34.5%	-36.1%
GFD	9.6%	38.5%	-6.9%	-32.1%	-38.0%
MPI	-1.4%	32.4%	-13.1%	-46.6%	-45.8%
NOR	2.4%	42.5%	-15.3%	-42.5%	-43.9%

Monthly and annual average rainfall for the Makhaleng SC

Scenario	Monthly and annual average rainfall (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	95	110	113	146	127	126	78	31	22	15	27	39	929
ACC	92	110	135	168	129	126	70	27	31	13	25	33	959
CCS	81	112	114	140	132	123	89	30	23	17	24	34	918
CNR	112	123	109	150	134	122	82	28	26	13	26	28	953
GFD	102	115	127	182	157	129	74	26	27	15	20	38	1012
MPI	85	135	111	144	127	126	79	37	22	14	18	27	925
NOR	99	110	118	153	126	125	81	37	20	13	24	33	939
	Percentage difference compared to the historical record:												
ACC	-4%	0%	19%	15%	2%	1%	-11%	-12%	37%	-16%	-6%	-14%	3%
CCS	-15%	2%	0%	-5%	4%	-2%	14%	-3%	5%	11%	-9%	-13%	-1%
CNR	18%	12%	-4%	3%	5%	-3%	5%	-9%	16%	-18%	-2%	-27%	3%
GFD	7%	5%	12%	24%	24%	3%	-5%	-17%	21%	-1%	-27%	0%	9%
MPI	-10%	23%	-2%	-1%	0%	0%	1%	19%	-3%	-7%	-32%	-29%	0%
NOR	4%	0%	4%	5%	-1%	0%	3%	20%	-9%	-13%	-9%	-15%	1%

Monthly and annual average rainfall for the Senqu SC

Scenario	Monthly and annual average rainfall (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	85	102	107	127	112	106	60	27	17	14	24	37	817
ACC	78	105	112	132	116	107	57	24	23	12	21	31	820
CCS	75	102	107	128	115	98	71	27	17	16	21	34	810
CNR	92	108	105	121	116	102	63	26	19	11	23	30	816
GFD	90	107	112	140	134	103	57	22	22	14	19	35	855
MPI	77	110	105	126	112	105	59	29	17	13	17	28	798
NOR	89	100	107	131	107	104	66	31	16	15	22	32	820
	Percentage difference compared to the historical record:												
ACC	-8%	3%	5%	5%	4%	2%	-6%	-10%	34%	-16%	-13%	-16%	0%
CCS	-11%	1%	0%	1%	2%	-8%	19%	-1%	-2%	14%	-12%	-10%	-1%
CNR	8%	6%	-2%	-5%	4%	-3%	4%	-2%	10%	-19%	-6%	-19%	0%
GFD	6%	5%	4%	11%	20%	-2%	-5%	-19%	24%	4%	-22%	-6%	5%
MPI	-9%	8%	-2%	0%	0%	0%	-3%	9%	-3%	-2%	-31%	-24%	-2%
NOR	5%	-2%	0%	4%	-5%	-2%	10%	15%	-9%	12%	-10%	-14%	0%

Monthly and annual average rainfall for the Upper Orange SC

Scenario	Monthly and annual average rainfall (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	40	50	51	62	73	71	45	19	14	11	15	20	472
ACC	30	51	63	65	78	72	42	17	16	10	16	17	476
CCS	29	53	55	66	83	71	50	19	16	13	14	17	485
CNR	42	57	52	60	77	72	48	20	17	10	18	16	487
GFD	41	60	61	71	91	74	45	16	15	11	12	19	516
MPI	35	54	54	65	75	71	43	25	12	13	11	15	474
NOR	41	49	53	69	69	73	46	25	12	11	19	16	484
	Percentage difference compared to the historical record:												
ACC	-25%	2%	22%	5%	6%	2%	-7%	-13%	16%	-10%	9%	-19%	1%
CCS	-28%	7%	7%	7%	13%	0%	11%	-5%	18%	16%	-4%	-18%	3%
CNR	4%	15%	1%	-4%	6%	1%	6%	2%	25%	-7%	17%	-22%	3%
GFD	2%	20%	19%	14%	24%	4%	1%	-17%	13%	-2%	-19%	-8%	9%
MPI	-13%	8%	5%	4%	4%	0%	-4%	27%	-11%	21%	-28%	-24%	0%
NOR	3%	-2%	3%	10%	-5%	4%	2%	30%	-14%	3%	26%	-21%	3%

Monthly and annual average rainfall for the Caledon SC

Scenario	Monthly and annual average rainfall (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	63	84	84	104	98	93	58	23	14	11	20	29	680
ACC	59	88	96	113	105	93	55	19	19	9	19	22	698
CCS	54	89	85	102	102	90	70	21	15	12	17	26	682
CNR	68	92	83	109	108	90	61	22	15	9	18	23	697
GFD	72	91	92	123	126	96	58	19	17	11	15	27	745
MPI	56	93	82	110	95	94	55	25	14	12	14	22	670
NOR	71	83	86	107	101	94	63	25	12	11	19	24	696
	Percentage difference compared to the historical record:												
ACC	-8%	5%	14%	9%	7%	0%	-4%	-15%	33%	-19%	-2%	-22%	3%
CCS	-14%	5%	1%	-3%	4%	-3%	22%	-6%	6%	7%	-14%	-10%	0%
CNR	7%	10%	-1%	5%	11%	-3%	5%	-4%	6%	-21%	-11%	-19%	2%
GFD	13%	8%	10%	18%	28%	4%	0%	-16%	20%	-3%	-22%	-5%	10%
MPI	-12%	11%	-2%	6%	-4%	2%	-6%	11%	-2%	6%	-30%	-24%	-1%
NOR	12%	-2%	3%	3%	3%	2%	8%	12%	-16%	-1%	-2%	-16%	2%

APPENDIX C - STATISTICAL COMPARATIVE RESULTS ADJUSTED EVAPORATION

Monthly and annual average Simons Pan Evaporation for Makhaleng SC

Scenario	Monthly and annual average S-Pan Evaporation (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	157	170	195	184	143	124	86	67	51	59	87	126	1449
ACC	202	179	179	175	139	124	92	70	53	66	94	156	1531
CCS	196	181	197	183	143	129	89	71	54	63	96	147	1550
CNR	164	166	201	192	141	126	85	70	52	64	95	145	1502
GFD	162	166	188	178	132	122	89	72	54	65	99	140	1467
MPI	196	175	190	189	143	126	89	70	55	63	98	158	1551
NOR	163	181	194	179	148	126	89	70	54	63	94	143	1503
	Percentage difference compared to the historical data												
ACC	29%	5%	-8%	-5%	-3%	0%	8%	5%	4%	12%	9%	24%	6%
CCS	25%	7%	1%	-1%	0%	4%	4%	6%	6%	7%	10%	17%	7%
CNR	4%	-3%	3%	4%	-1%	2%	-1%	5%	3%	8%	9%	15%	4%
GFD	3%	-2%	-4%	-4%	-8%	-2%	4%	8%	6%	11%	14%	11%	1%
MPI	25%	3%	-2%	2%	0%	1%	3%	4%	8%	6%	12%	25%	7%
NOR	4%	6%	-1%	-3%	4%	2%	3%	4%	6%	6%	8%	13%	4%

Notes: The monthly averages for the six climate models were derived from the 2000 to 2050 simulated datasets.

Monthly and annual average Simons Pan Evaporation for Senqu SC

Scenario	Monthly and annual average S-Pan Evaporation (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	145	157	181	170	132	115	79	62	47	55	80	117	1340
ACC	185	169	174	168	131	117	84	64	50	62	91	143	1439
CCS	177	167	185	173	133	120	81	66	50	60	93	139	1442
CNR	157	153	190	179	133	117	80	64	48	59	93	139	1413
GFD	155	158	181	170	129	117	83	66	50	62	100	136	1408
MPI	178	163	182	175	134	118	82	64	52	59	95	151	1453
NOR	151	169	182	171	136	119	81	66	51	58	94	136	1413
	Percentage difference compared to the historical data												
ACC	27%	8%	-4%	-1%	-1%	2%	6%	4%	6%	13%	13%	22%	7%
CCS	22%	6%	3%	1%	0%	4%	2%	6%	5%	9%	16%	19%	8%
CNR	8%	-3%	5%	5%	1%	2%	1%	3%	2%	8%	16%	20%	5%
GFD	6%	1%	1%	0%	-2%	2%	5%	7%	7%	14%	24%	17%	5%
MPI	23%	4%	1%	3%	2%	3%	3%	3%	9%	8%	19%	30%	8%
NOR	4%	8%	1%	1%	3%	3%	1%	6%	8%	6%	16%	17%	5%

Notes: The monthly averages for the six climate models were derived from the 2000 to 2050 simulated datasets.

Monthly and annual average Simons Pan Evaporation for Upper Orange SC

Scenario	Monthly and annual average S-Pan Evaporation (mm)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	181	207	237	228	173	149	104	77	60	69	100	139	1723
ACC	218	226	217	215	173	148	110	81	63	78	116	162	1804
CCS	220	224	240	223	173	154	106	80	61	75	115	154	1825
CNR	188	196	249	238	173	151	102	78	60	76	110	156	1779
GFD	187	200	225	214	158	144	105	77	58	73	116	154	1711
MPI	210	216	235	227	171	154	111	76	63	73	110	170	1817
NOR	187	222	243	227	175	152	111	79	63	75	118	149	1801
Percentage difference compared to the historical data													
ACC	20%	9%	-9%	-6%	0%	-1%	6%	6%	5%	13%	16%	17%	5%
CCS	22%	8%	1%	-2%	0%	3%	2%	4%	2%	9%	15%	11%	6%
CNR	4%	-5%	5%	4%	0%	2%	-1%	1%	0%	10%	10%	12%	3%
GFD	3%	-4%	-5%	-6%	-9%	-3%	1%	0%	-3%	5%	16%	11%	-1%
MPI	16%	4%	-1%	-1%	-1%	3%	7%	-1%	5%	6%	10%	23%	5%
NOR	3%	7%	2%	0%	1%	2%	7%	3%	5%	8%	18%	7%	5%

Notes: The monthly averages for the six climate models were derived from the 2000 to 2050 simulated datasets.

Monthly and annual average Simons Pan Evaporation for Caledon SC

Scenario	Monthly and annual average S-Pan Evaporation (mm)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	157	174	199	189	145	126	87	66	51	59	87	124	1463
ACC	197	185	186	180	143	126	91	68	51	63	95	150	1537
CCS	191	183	200	188	146	129	89	69	53	64	96	144	1553
CNR	166	164	207	192	144	127	88	67	51	63	98	144	1510
GFD	157	167	192	179	135	121	89	68	50	61	95	135	1449
MPI	193	180	197	190	143	127	90	67	52	61	98	154	1552
NOR	161	185	201	186	149	129	90	68	53	61	99	140	1522
Percentage difference compared to the historical data													
ACC	25%	6%	-7%	-4%	-2%	0%	5%	3%	1%	8%	10%	21%	5%
CCS	21%	6%	1%	0%	0%	2%	2%	4%	5%	9%	11%	16%	6%
CNR	5%	-6%	4%	2%	-1%	1%	0%	2%	1%	7%	13%	16%	3%
GFD	0%	-4%	-3%	-5%	-7%	-4%	1%	2%	-1%	4%	9%	9%	-1%
MPI	23%	4%	-1%	1%	-2%	1%	3%	2%	3%	4%	13%	24%	6%
NOR	2%	6%	1%	-2%	2%	3%	3%	3%	4%	4%	15%	13%	4%

Notes: The monthly averages for the six climate models were derived from the 2000 to 2050 simulated datasets.

APPENDIX D - STATISTICAL COMPARATIVE RESULTS ADJUSTED RUNOFF SCENARIO 1

Annual average runoff for Makhaleng catchment - undeveloped

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	**St dev**	**CV**	**Minimum**	**Maximum**
Historical	526	211	0.402	168	1269
ACC	560	221	0.394	203	1303
CCS	515	209	0.407	168	1175
CNR	555	221	0.398	176	1333
GFD	626	243	0.388	222	1315
MPI	527	218	0.414	162	1275
NOR	544	221	0.406	183	1335
	Percentage difference compared to the historical record:				
ACC	6%	4%	-2%	20%	3%
CCS	-2%	-1%	1%	0%	-7%
CNR	6%	4%	-1%	5%	5%
GFD	19%	15%	-3%	31%	4%
MPI	0%	3%	3%	-4%	0%
NOR	3%	5%	1%	9%	5%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

Annual average runoff for Senqu catchment - undeveloped

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	**St dev**	**CV**	**Minimum**	**Maximum**
Historical	3604	1523	0.423	1060	7958
ACC	3670	1526	0.416	1150	8393
CCS	3603	1532	0.425	1057	7975
CNR	3628	1521	0.419	1084	7770
GFD	4152	1656	0.399	1274	9236
MPI	3548	1510	0.426	1072	7926
NOR	3690	1569	0.425	1046	7930
	Percentage difference compared to the historical record:				
ACC	2%	0%	-2%	8%	5%
CCS	0%	1%	1%	0%	0%
CNR	1%	0%	-1%	2%	-2%
GFD	15%	9%	-6%	20%	16%
MPI	-2%	-1%	1%	1%	0%
NOR	2%	3%	1%	-1%	0%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

Annual average runoff for Upper Orange catchment - undeveloped

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	St dev	CV	Minimum	Maximum
Historical	1178	1159	0.984	143	6501
ACC	1246	1250	1.003	142	7242
CCS	1323	1332	1.007	140	7536
CNR	1284	1263	0.983	142	7035
GFD	1566	1518	0.969	150	8697
MPI	1241	1225	0.987	132	6852
NOR	1335	1328	0.995	143	7771
	Percentage difference compared to the historical record:				
ACC	6%	8%	2%	-1%	11%
CCS	12%	15%	2%	-2%	16%
CNR	9%	9%	0%	-1%	8%
GFD	33%	31%	-1%	5%	34%
MPI	5%	6%	0%	-8%	5%
NOR	13%	15%	1%	0%	20%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

Annual average runoff for Caledon catchment - undeveloped

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	St dev	CV	Minimum	Maximum
Historical	1377	962	0.699	214	4953
ACC	1578	1084	0.687	209	5142
CCS	1426	1036	0.726	200	5481
CNR	1534	1064	0.693	197	5459
GFD	1958	1294	0.661	256	6752
MPI	1400	1018	0.727	210	4866
NOR	1558	1056	0.678	230	5195
	Percentage difference compared to the historical record:				
ACC	15%	13%	-2%	-3%	4%
CCS	4%	8%	4%	-6%	11%
CNR	11%	11%	-1%	-8%	10%
GFD	42%	34%	-5%	20%	36%
MPI	2%	6%	4%	-2%	-2%
NOR	13%	10%	-3%	7%	5%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

Monthly and annual average runoff Makhaleng catchment – undeveloped

Scenario	Monthly and annual Runoff (million m3/a)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	41	46	42	61	74	89	65	35	19	16	18	21	526
ACC	36	45	58	87	84	91	58	29	22	16	16	16	560
CCS	30	43	42	56	76	88	73	37	19	17	17	17	515
CNR	52	59	43	64	83	87	67	34	20	15	17	14	555
GFD	45	53	54	97	115	101	63	29	19	16	14	19	626
MPI	31	62	47	59	72	89	67	41	21	15	13	12	527
NOR	41	46	47	69	76	88	68	42	21	14	16	16	544
Percentage difference compared to the historical data													
ACC	-12%	-2%	37%	42%	14%	3%	-11%	-16%	19%	2%	-9%	-20%	6%
CCS	-26%	-5%	0%	-8%	3%	-1%	12%	6%	1%	7%	-7%	-19%	-2%
CNR	28%	29%	1%	4%	13%	-2%	3%	-2%	5%	-6%	-7%	-31%	6%
GFD	12%	16%	28%	58%	55%	14%	-3%	-16%	1%	5%	-24%	-9%	19%
MPI	-24%	36%	10%	-4%	-3%	0%	3%	17%	9%	-5%	-29%	-42%	0%
NOR	2%	0%	10%	13%	3%	-1%	5%	20%	8%	-10%	-12%	-22%	3%

Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

Monthly and annual average runoff Senqu catchment – undeveloped

Scenario	Monthly and annual Runoff (million m3/a)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	257	342	376	499	550	579	397	207	103	75	90	128	3604
ACC	196	337	434	573	616	609	378	172	113	78	74	92	3670
CCS	179	315	382	521	596	538	452	247	106	86	83	98	3603
CNR	292	421	384	444	564	573	402	210	108	67	77	85	3628
GFD	274	387	446	655	817	669	370	166	104	87	70	106	4152
MPI	187	379	384	483	564	601	398	233	118	75	60	66	3548
NOR	266	343	385	550	521	546	424	268	124	81	85	96	3690
Percentage difference compared to the historical data													
ACC	-24%	-1%	15%	15%	12%	5%	-5%	-17%	9%	5%	-18%	-28%	2%
CCS	-31%	-8%	1%	4%	8%	-7%	14%	19%	3%	15%	-8%	-23%	0%
CNR	14%	23%	2%	-11%	3%	-1%	1%	2%	4%	-10%	-15%	-34%	1%
GFD	7%	13%	19%	31%	48%	16%	-7%	-20%	1%	16%	-22%	-17%	15%
MPI	-27%	11%	2%	-3%	2%	4%	0%	13%	15%	1%	-34%	-48%	-2%
NOR	3%	0%	2%	10%	-5%	-6%	7%	30%	21%	9%	-6%	-25%	2%

Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

Monthly and annual average runoff: Upper Orange catchment – undeveloped

Scenario	Monthly and annual Runoff (million m3/a)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	52	82	88	121	179	255	172	84	41	28	36	41	1178
ACC	27	70	131	150	209	286	171	68	36	27	40	33	1246
CCS	23	76	99	142	242	282	205	105	46	38	38	28	1323
CNR	49	107	103	112	197	278	190	94	46	28	46	34	1284
GFD	50	122	151	191	311	339	198	77	36	31	28	32	1566
MPI	31	92	102	133	194	260	165	118	61	35	29	21	1241
NOR	47	77	97	152	172	269	186	134	67	31	60	42	1335
Percentage difference compared to the historical data													
ACC	-49%	-15%	48%	24%	17%	12%	-1%	-19%	-12%	-4%	11%	-18%	6%
CCS	-57%	-8%	12%	18%	35%	11%	19%	25%	14%	36%	7%	-32%	12%
CNR	-6%	31%	16%	-7%	10%	9%	10%	11%	12%	2%	28%	-16%	9%
GFD	-5%	49%	71%	58%	74%	33%	15%	-8%	-12%	12%	-22%	-21%	33%
MPI	-42%	12%	16%	10%	8%	2%	-4%	40%	52%	29%	-21%	-48%	5%
NOR	-9%	-6%	9%	26%	-4%	5%	8%	59%	66%	14%	66%	4%	13%

Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

Monthly and annual average runoff: Caledon catchment – undeveloped

Scenario	Monthly and annual Runoff (million m3/a)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	71	131	134	229	225	245	152	77	36	19	21	36	1377
ACC	54	140	198	320	299	263	144	61	36	20	19	22	1578
CCS	46	135	145	207	231	241	210	104	39	21	18	28	1426
CNR	79	171	144	266	295	246	159	83	36	18	16	23	1534
GFD	104	177	183	371	437	345	174	72	32	19	15	28	1958
MPI	40	170	142	253	216	252	148	82	41	21	15	18	1400
NOR	94	139	140	257	250	274	189	104	43	21	21	26	1558
Percentage difference compared to the historical data													
ACC	-24%	7%	48%	40%	33%	7%	-5%	-20%	0%	5%	-8%	-39%	15%
CCS	-35%	3%	8%	-10%	3%	-2%	39%	36%	9%	12%	-14%	-23%	4%
CNR	11%	30%	7%	16%	31%	0%	5%	7%	-1%	-8%	-22%	-37%	11%
GFD	46%	35%	36%	62%	94%	41%	15%	-6%	-10%	1%	-28%	-22%	42%
MPI	-43%	30%	6%	10%	-4%	3%	-2%	7%	15%	11%	-28%	-51%	2%
NOR	32%	6%	4%	12%	11%	12%	25%	35%	20%	7%	0%	-28%	13%

Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

APPENDIX E - STATISTICAL COMPARATIVE RESULTS ADJUSTED RUNOFF SCENARIO 2

Annual average runoff for Makhaleng catchment - undeveloped

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	**St dev**	**CV**	**Minimum**	**Maximum**
Historical	526	211	0.40	168	1269
ACC	537	219	0.41	179	1249
CCS	487	204	0.42	159	1104
CNR	549	220	0.40	174	1310
GFD	630	244	0.39	227	1300
MPI	498	214	0.43	148	1208
NOR	527	217	0.41	178	1293
	Percentage difference compared to the historical record:				
ACC	2%	4%	2%	6%	-2%
CCS	-7%	-3%	4%	-6%	-13%
CNR	4%	4%	0%	4%	3%
GFD	20%	15%	-4%	35%	2%
MPI	-5%	1%	7%	-12%	-5%
NOR	0%	3%	3%	6%	2%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

Annual average runoff for Senqu catchment - undeveloped

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	**St dev**	**CV**	**Minimum**	**Maximum**
Historical	3604	1523	0.42	1060	7958
ACC	3472	1488	0.43	1073	8151
CCS	3416	1484	0.43	998	7718
CNR	3530	1490	0.42	1062	7632
GFD	4043	1627	0.40	1234	9071
MPI	3353	1461	0.44	1003	7680
NOR	3532	1524	0.43	986	7691
	Percentage difference compared to the historical record:				
ACC	-4%	-2%	1%	1%	2%
CCS	-5%	-3%	3%	-6%	-3%
CNR	-2%	-2%	0%	0%	-4%
GFD	12%	7%	-5%	16%	14%
MPI	-7%	-4%	3%	-5%	-3%
NOR	-2%	0%	2%	-7%	-3%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

Annual average runoff for Upper Orange catchment - undeveloped

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	**St dev**	**CV**	**Minimum**	**Maximum**
Historical	1178	1159	0.98	143	6501
ACC	1200	1234	1.03	122	7096
CCS	1276	1307	1.02	126	7368
CNR	1271	1251	0.98	139	6863
GFD	1584	1569	0.99	143	9073
MPI	1197	1200	1.00	117	6725
NOR	1287	1281	1.00	135	7431
	Percentage difference compared to the historical record:				
ACC	2%	6%	5%	-15%	9%
CCS	8%	13%	4%	-12%	13%
CNR	8%	8%	0%	-2%	6%
GFD	34%	35%	1%	0%	40%
MPI	2%	4%	2%	-18%	3%
NOR	9%	10%	1%	-5%	14%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

Annual average runoff for Caledon catchment- undeveloped

Scenario	Annual Runoff Statistics (in million m^3/a except for CV)				
	Mean	**St dev**	**CV**	**Minimum**	**Maximum**
Historical	1377	962	0.70	214	4953
ACC	1538	1077	0.70	199	5007
CCS	1374	1014	0.74	189	5329
CNR	1515	1059	0.70	194	5383
GFD	1995	1328	0.67	258	6826
MPI	1358	1003	0.74	197	4797
NOR	1512	1034	0.68	221	5064
	Percentage difference compared to the historical record:				
ACC	12%	12%	0%	-7%	1%
CCS	0%	5%	6%	-12%	8%
CNR	10%	10%	0%	-9%	9%
GFD	45%	38%	-5%	20%	38%
MPI	-1%	4%	6%	-8%	-3%
NOR	10%	7%	-2%	3%	2%

Notes: Stdev: Standard Deviation, CV: Coefficient of Variance.

Period length 85 years. Historical record period 1920 to 2004

Monthly and annual average runoff Makhaleng catchment – undeveloped

Scenario	Monthly and annual Runoff (million m3/a)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	41	46	42	61	74	89	65	35	19	16	18	21	526
ACC	24	36	60	93	87	91	56	27	21	15	15	12	537
CCS	21	37	40	56	76	86	71	36	18	16	15	14	487
CNR	49	61	42	62	84	88	68	34	20	14	16	12	549
GFD	43	53	56	100	121	104	63	28	18	15	12	16	630
MPI	21	55	46	58	72	88	66	39	20	14	11	8	498
NOR	38	42	45	71	76	86	67	41	20	13	14	13	527
Percentage difference compared to the historical data													
ACC	-41%	-22%	43%	51%	17%	2%	-14%	-22%	12%	-5%	-19%	-40%	2%
CCS	-48%	-20%	-5%	-9%	3%	-3%	10%	3%	-4%	2%	-14%	-34%	-7%
CNR	19%	33%	0%	1%	14%	-1%	4%	-2%	4%	-9%	-13%	-41%	4%
GFD	5%	16%	33%	63%	63%	17%	-3%	-20%	-5%	-1%	-33%	-22%	20%
MPI	-49%	20%	9%	-5%	-3%	-1%	1%	13%	3%	-11%	-37%	-59%	-5%
NOR	-6%	-9%	7%	16%	2%	-3%	2%	17%	4%	-14%	-20%	-35%	0%

Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

Monthly and annual average runoff Senqu catchment – undeveloped

Scenario	Monthly and annual Runoff (million m3/a)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Historical	257	342	376	499	550	579	397	207	103	75	90	128	3604
ACC	141	289	427	580	618	597	358	159	104	69	61	69	3472
CCS	136	280	367	515	593	523	438	237	99	79	71	77	3416
CNR	263	418	381	431	558	566	400	208	106	65	67	67	3530
GFD	246	373	444	657	829	669	359	155	95	77	56	83	4043
MPI	138	343	373	474	555	586	385	224	112	68	50	44	3353
NOR	244	318	373	547	513	528	412	257	116	75	73	76	3532
Percentage difference compared to the historical data													
ACC	-45%	-15%	13%	16%	12%	3%	-10%	-23%	1%	-8%	-32%	-46%	-4%
CCS	-47%	-18%	-2%	3%	8%	-10%	10%	14%	-4%	6%	-21%	-40%	-5%
CNR	2%	22%	1%	-14%	1%	-2%	1%	1%	3%	-13%	-26%	-48%	-2%
GFD	-4%	9%	18%	32%	51%	16%	-9%	-25%	-8%	3%	-38%	-35%	12%
MPI	-46%	0%	-1%	-5%	1%	1%	-3%	8%	8%	-8%	-45%	-65%	-7%
NOR	-5%	-7%	-1%	10%	-7%	-9%	4%	24%	12%	0%	-20%	-40%	-2%

Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

Monthly and annual average runoff: Upper Orange catchment – undeveloped

Scenario	Monthly and annual Runoff (million m3/a)												
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Total**
Historical	52	82	88	121	179	255	172	84	41	28	36	41	1178
ACC	20	64	129	151	209	283	165	62	33	24	33	26	1200
CCS	17	70	97	142	242	276	198	100	44	35	33	23	1276
CNR	44	107	103	111	198	278	192	95	46	27	41	29	1271
GFD	45	120	151	192	328	357	201	75	34	29	25	27	1584
MPI	23	88	101	133	194	255	156	113	59	33	26	17	1197
NOR	44	74	95	152	172	265	179	126	63	29	51	36	1287
Percentage difference compared to the historical data													
ACC	-62%	-22%	46%	26%	17%	11%	-4%	-26%	-20%	-13%	-9%	-35%	2%
CCS	-68%	-14%	10%	18%	35%	8%	15%	19%	8%	26%	-8%	-45%	8%
CNR	-15%	31%	17%	-8%	10%	9%	11%	12%	13%	-1%	14%	-30%	8%
GFD	-13%	47%	71%	59%	83%	40%	17%	-11%	-16%	6%	-31%	-34%	34%
MPI	-56%	7%	14%	10%	9%	0%	-9%	34%	46%	20%	-29%	-59%	2%
NOR	-15%	-9%	8%	26%	-4%	4%	4%	50%	56%	6%	41%	-11%	9%

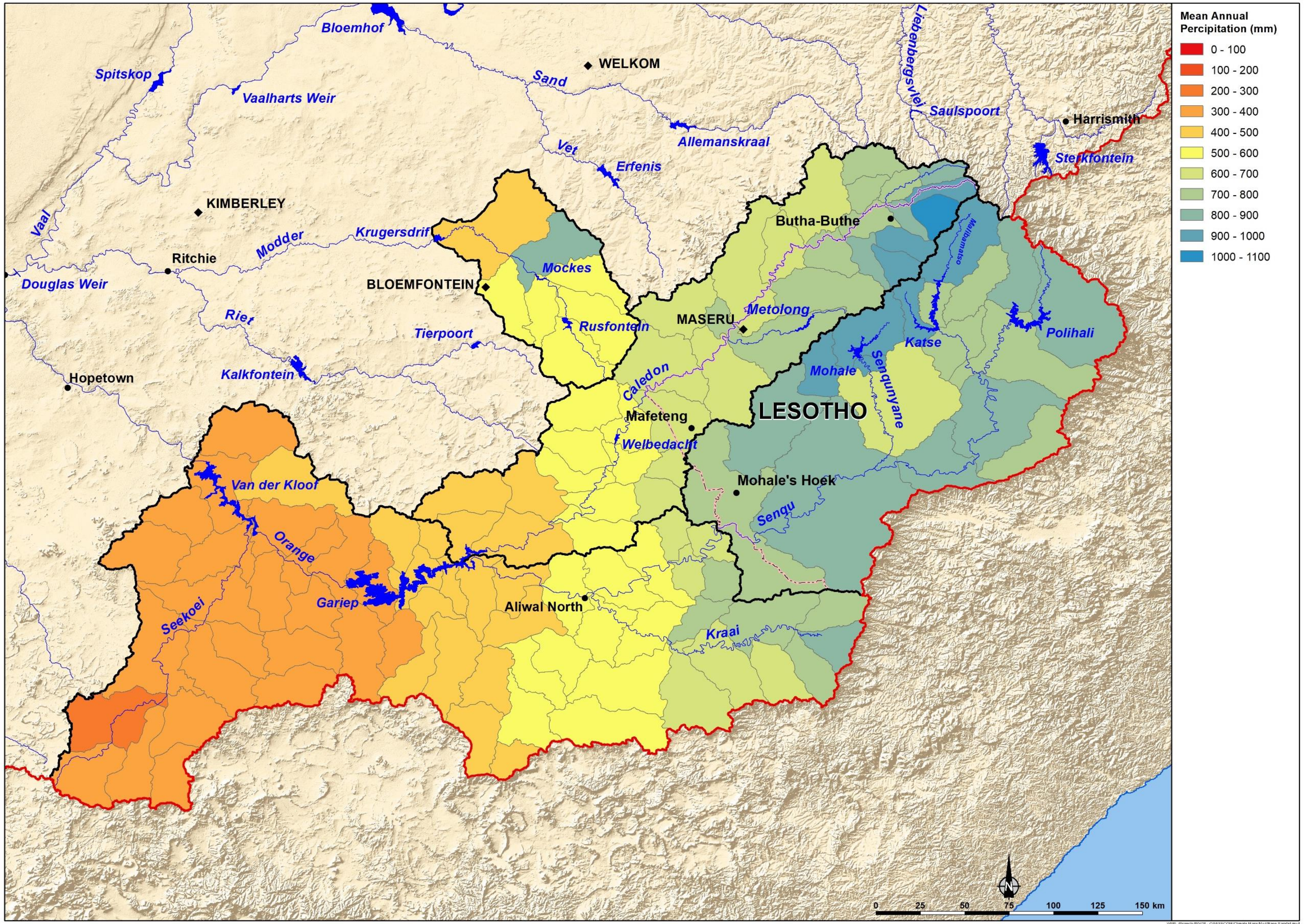
Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

Monthly and annual average runoff: Caledon catchment – undeveloped

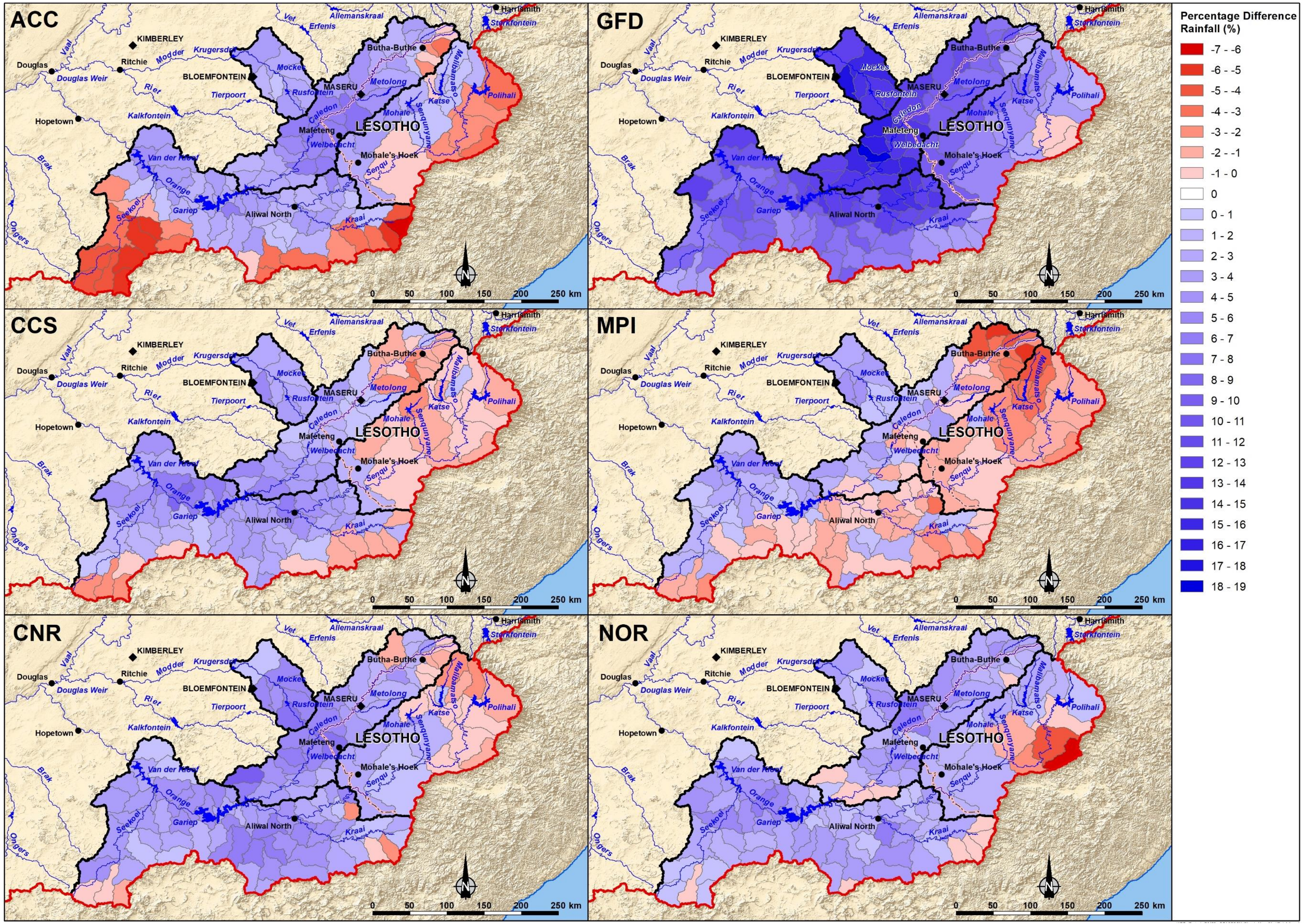
Scenario	Monthly and annual Runoff (million m3/a)												
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Total**
Historical	71	131	134	229	225	245	152	77	36	19	21	36	1377
ACC	43	127	196	322	303	266	139	57	33	18	16	17	1538
CCS	38	125	141	205	230	237	203	99	37	20	16	24	1374
CNR	73	168	143	263	294	246	160	82	35	17	14	20	1515
GFD	99	176	184	374	452	365	183	73	32	19	13	25	1995
MPI	33	161	139	250	215	250	144	79	39	20	14	14	1358
NOR	88	133	138	257	248	267	182	99	41	19	18	22	1512
Percentage difference compared to the historical data													
ACC	-40%	-3%	46%	41%	35%	8%	-9%	-26%	-8%	-4%	-21%	-52%	12%
CCS	-47%	-5%	5%	-10%	2%	-4%	34%	29%	2%	3%	-25%	-34%	0%
CNR	2%	28%	6%	15%	31%	0%	5%	7%	-2%	-10%	-30%	-46%	10%
GFD	39%	34%	37%	63%	101%	49%	20%	-6%	-12%	-4%	-35%	-30%	45%
MPI	-54%	23%	3%	9%	-4%	2%	-5%	2%	9%	4%	-35%	-61%	-1%
NOR	24%	2%	2%	12%	10%	9%	20%	28%	13%	0%	-14%	-38%	10%

Notes: The monthly averages for the six climate models were derived from the 1920 to 2004 simulated datasets.

APPENDIX F – COMPARATIVE RAINFALL MAPS

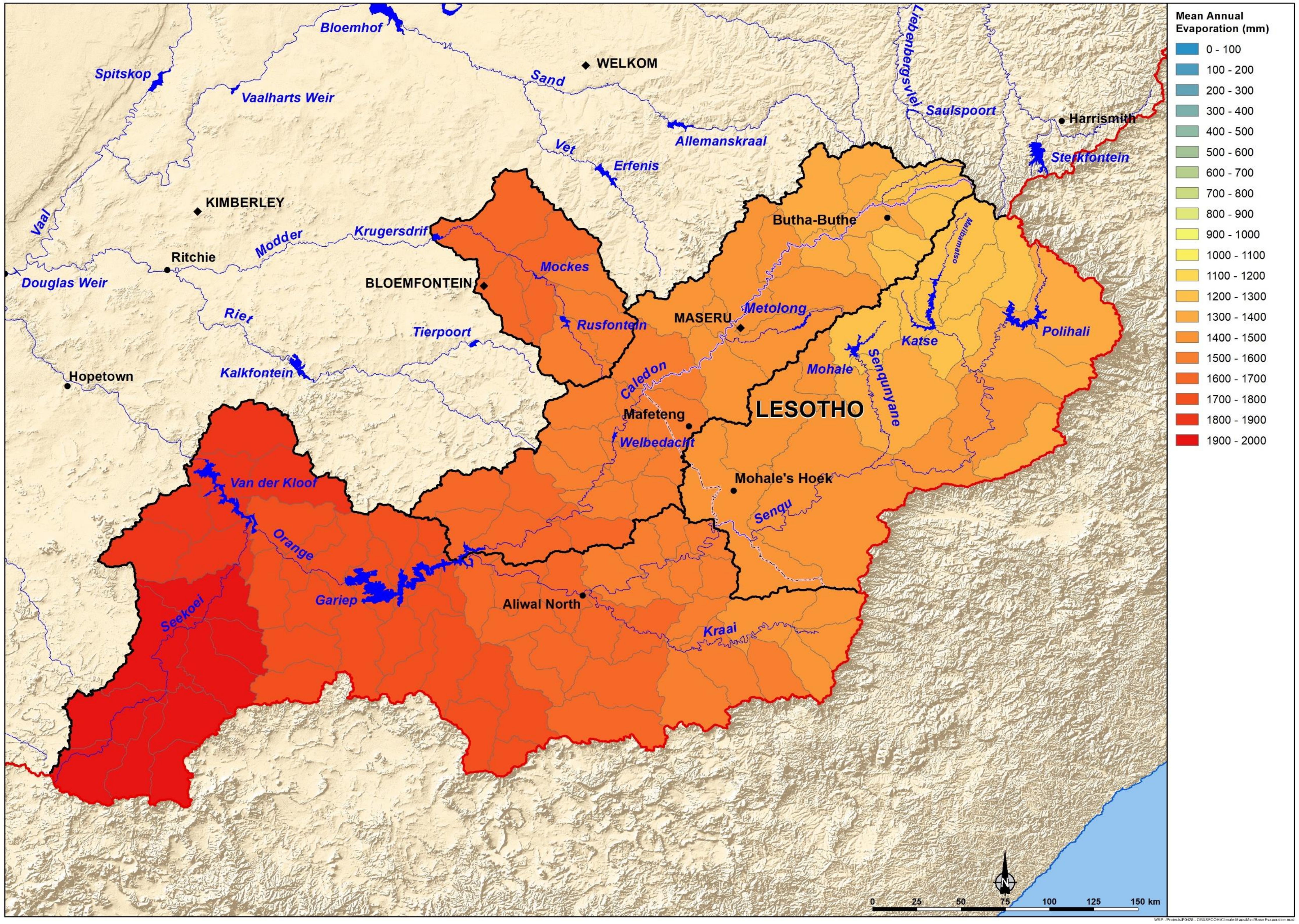


MAP base map for Study Area

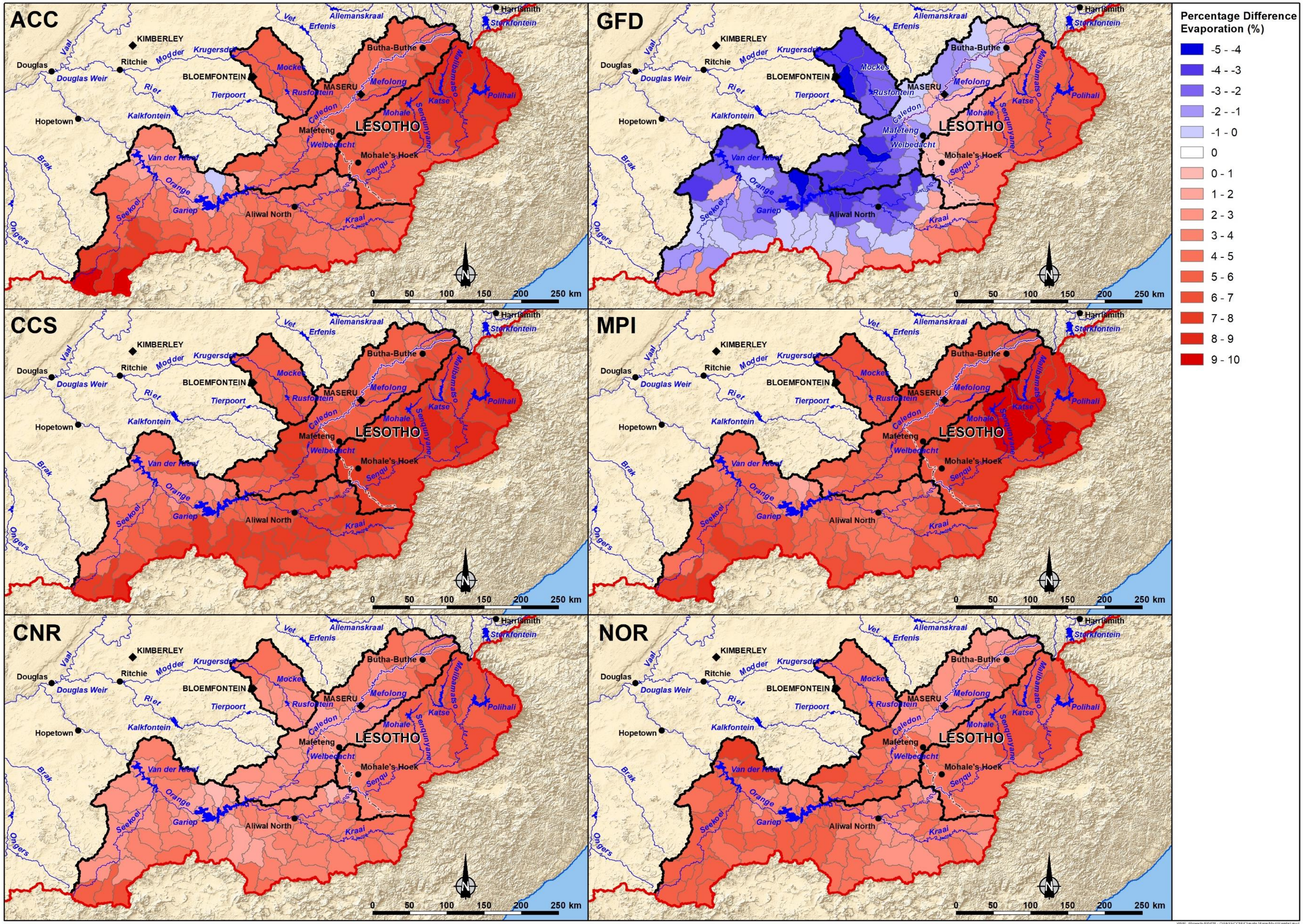


MAP Percentage Differences CCMs for Study Area

APPENDIX G – COMPARATIVE EVAPORATION MAPS (S-PAN)

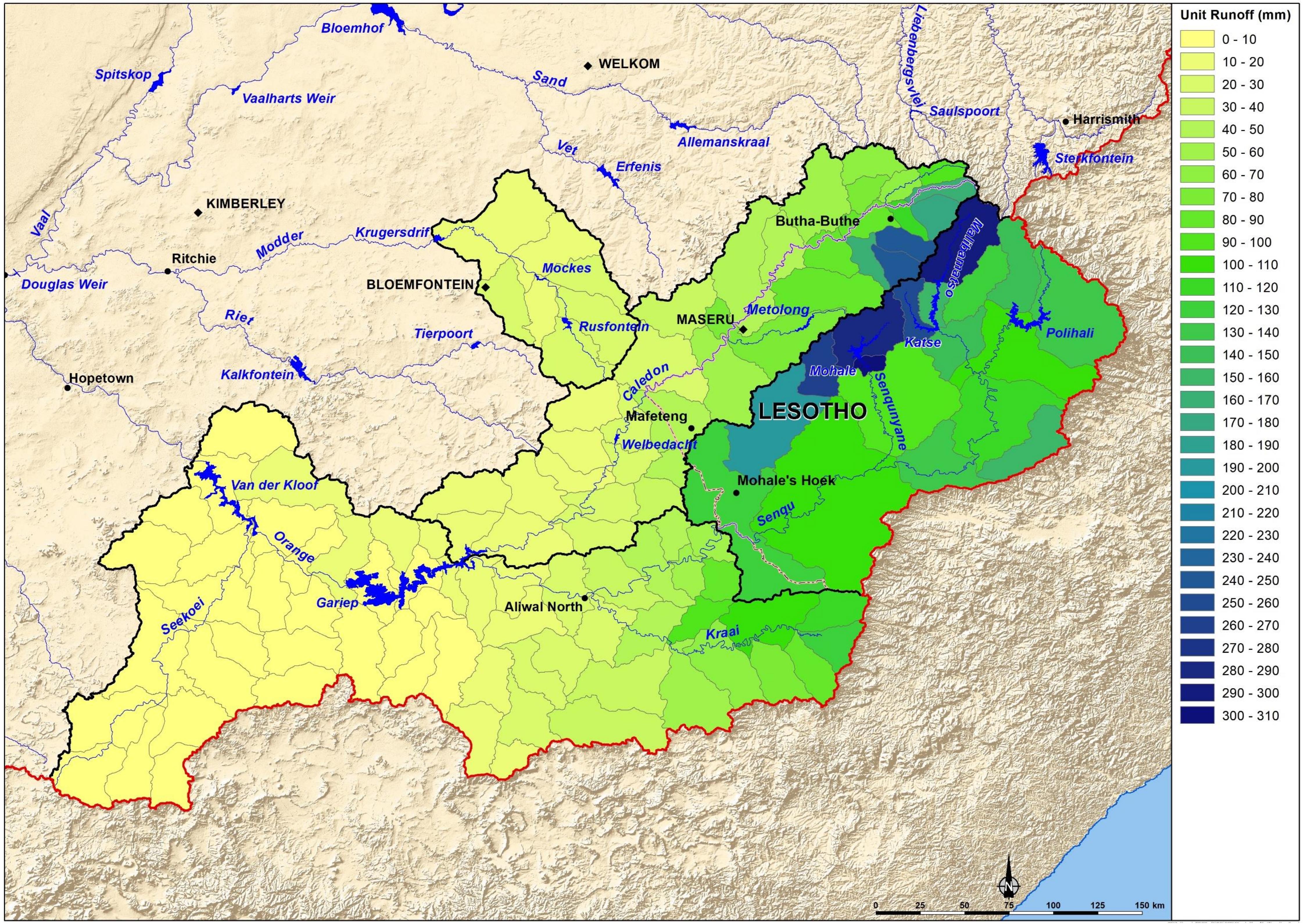


MAE base map for Study Area

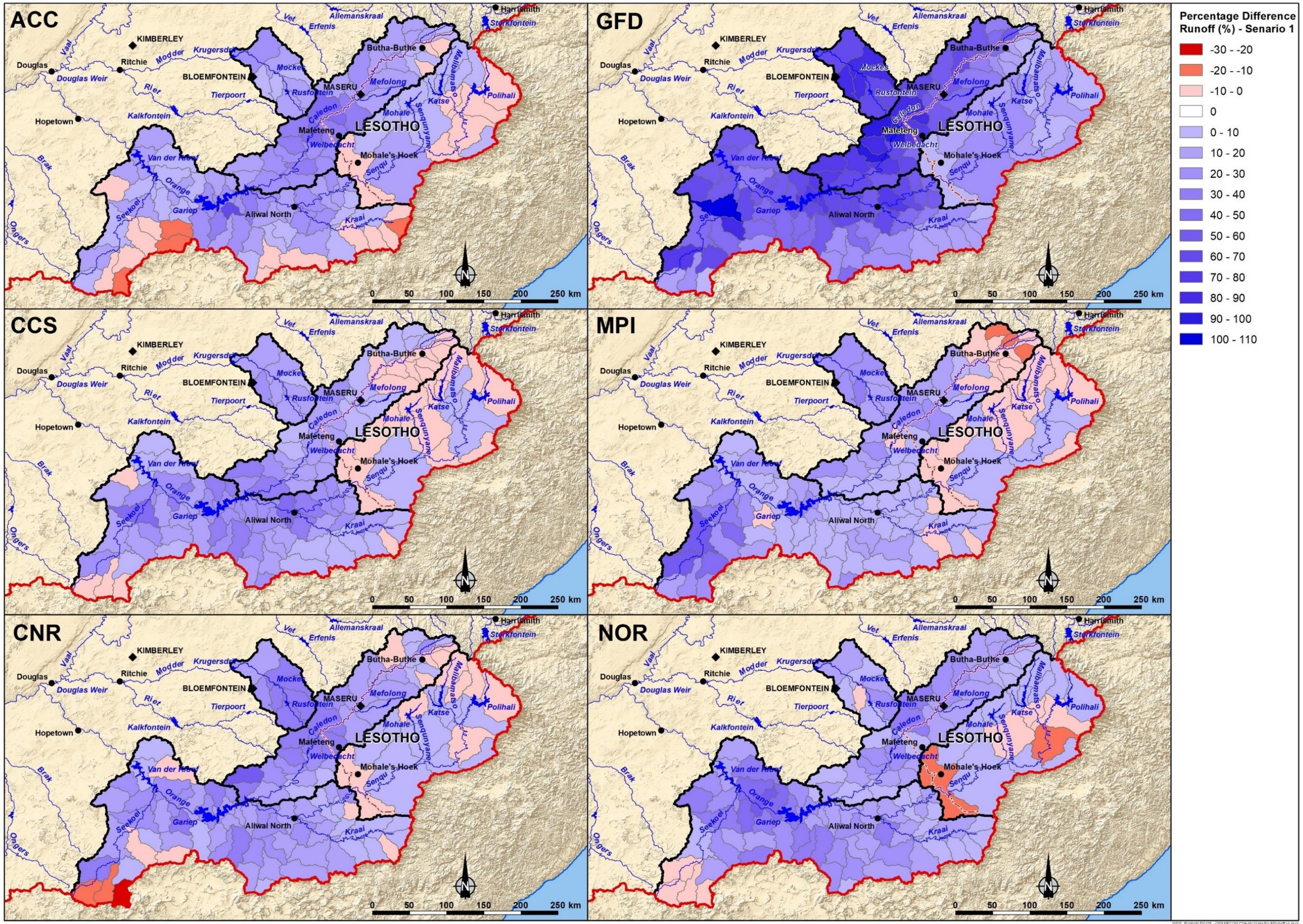


MAE Percentage Differences CCMs for Study Area

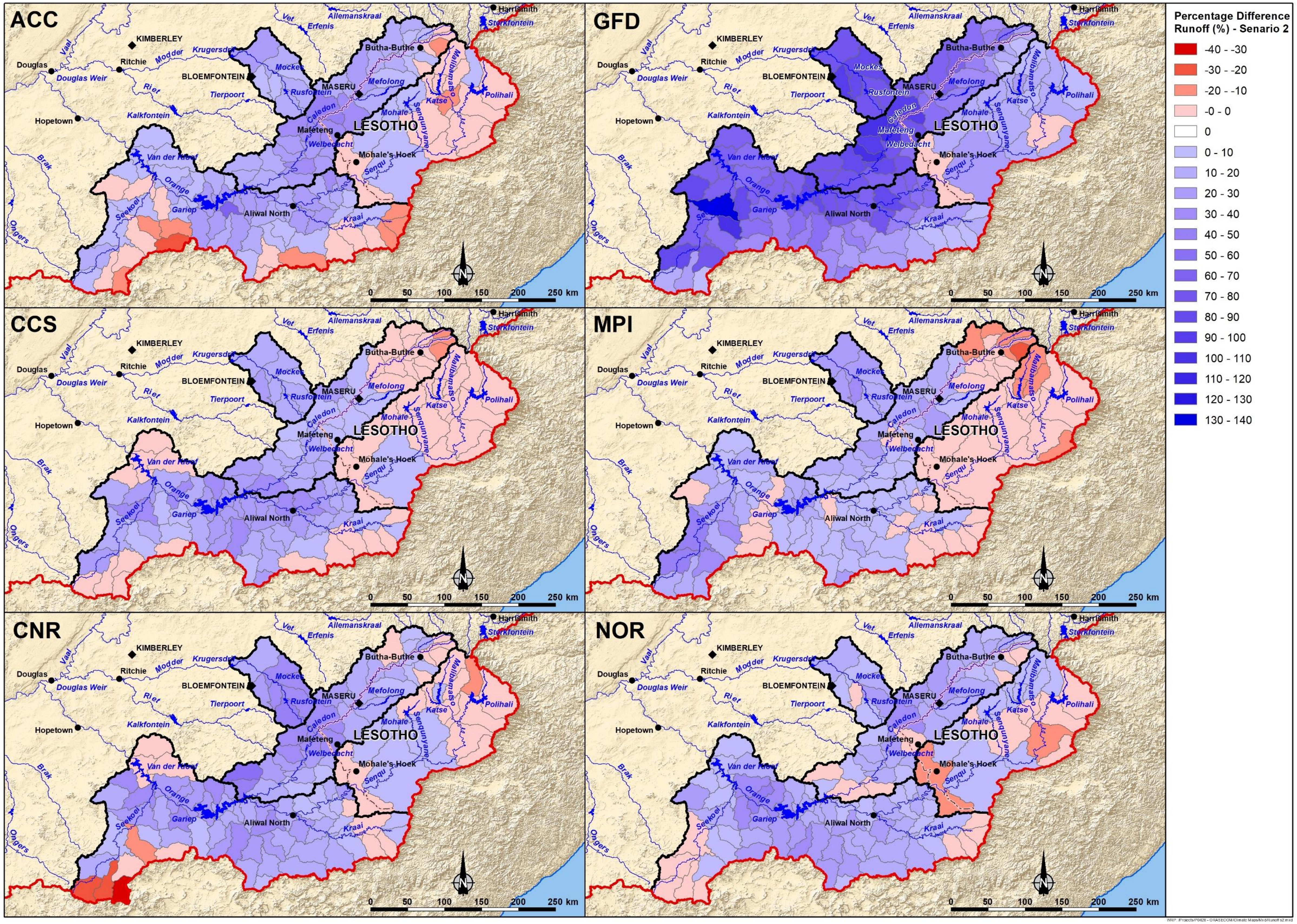
APPENDIX H – COMPARATIVE RUNOFF MAPS



Unit Runoff base map for Study Area

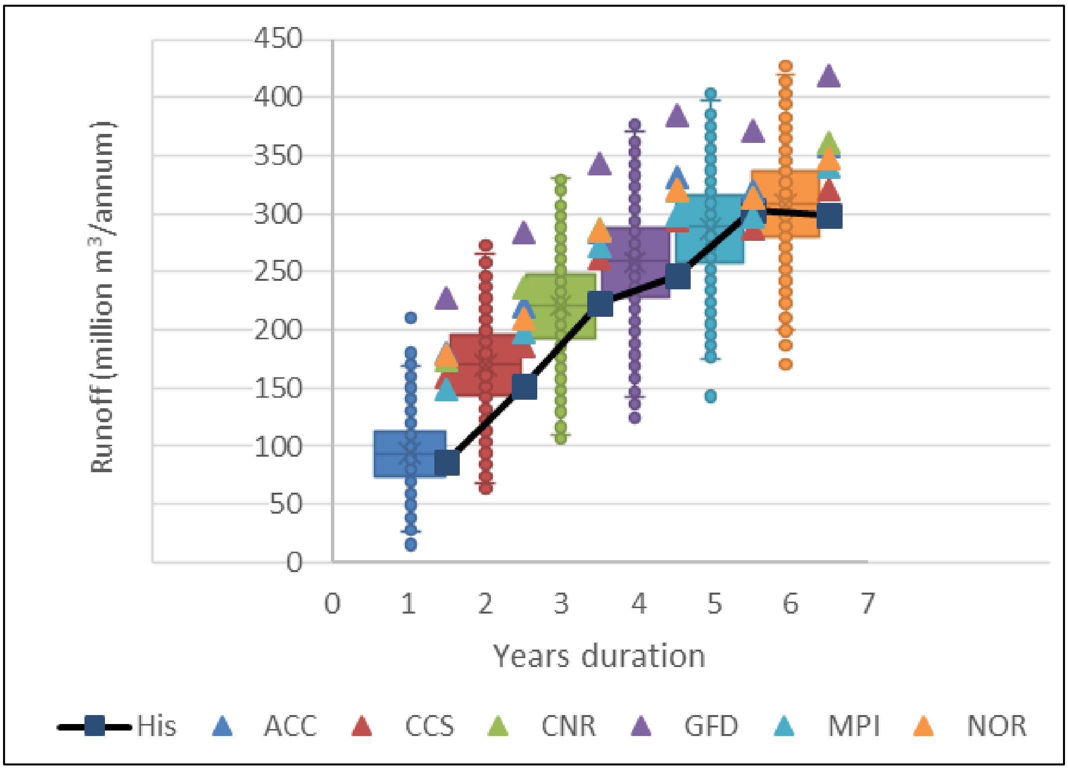


Unit Runoff Scenario 1 Percentage Differences CCMs for Study Area

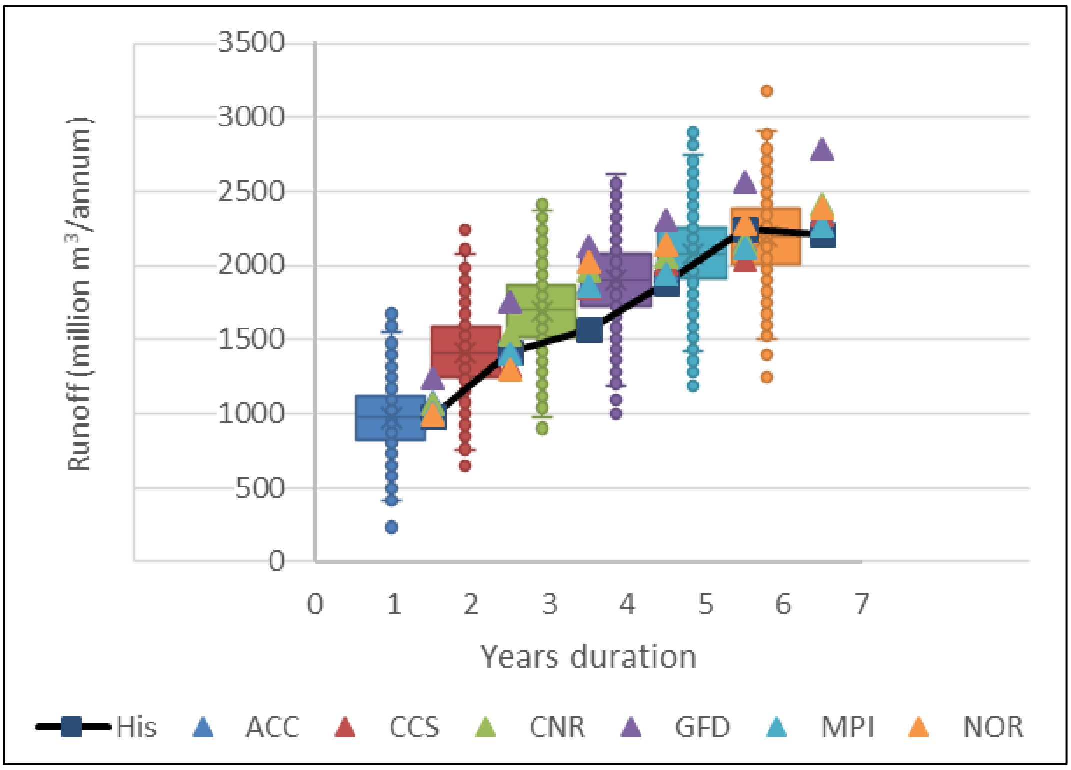


Unit Runoff Scenario 1 Percentage Differences CCMs for Study Area

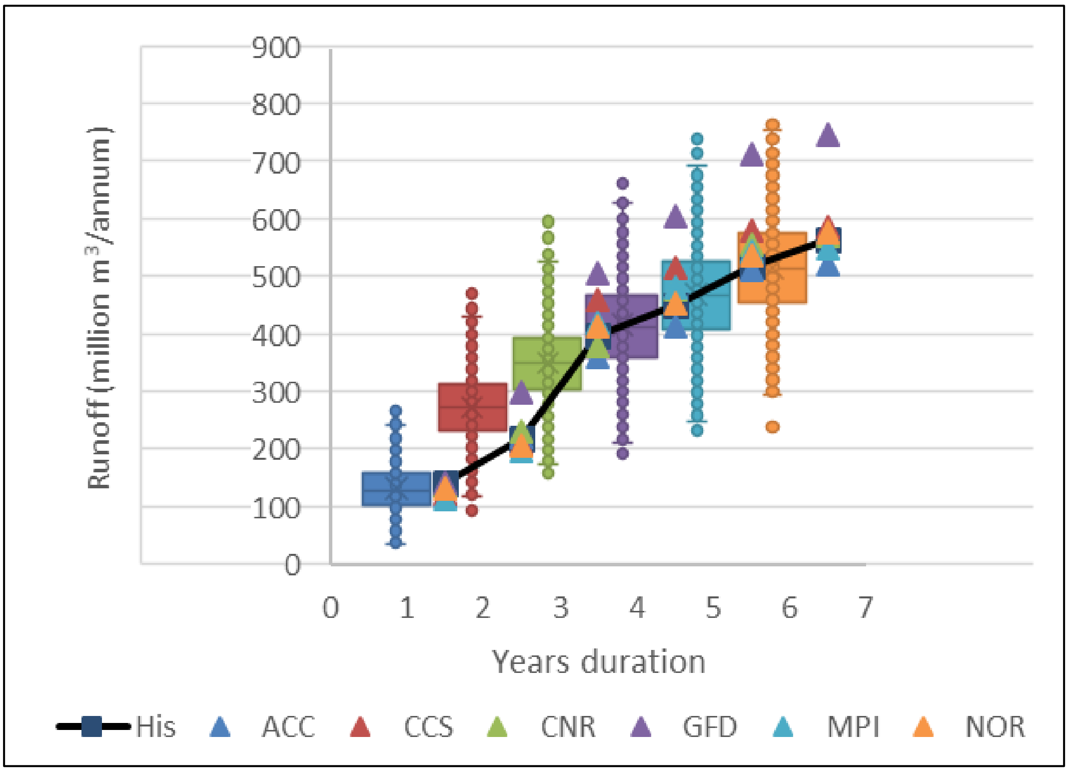
APPENDIX I – N-MONTH RUN SUMS



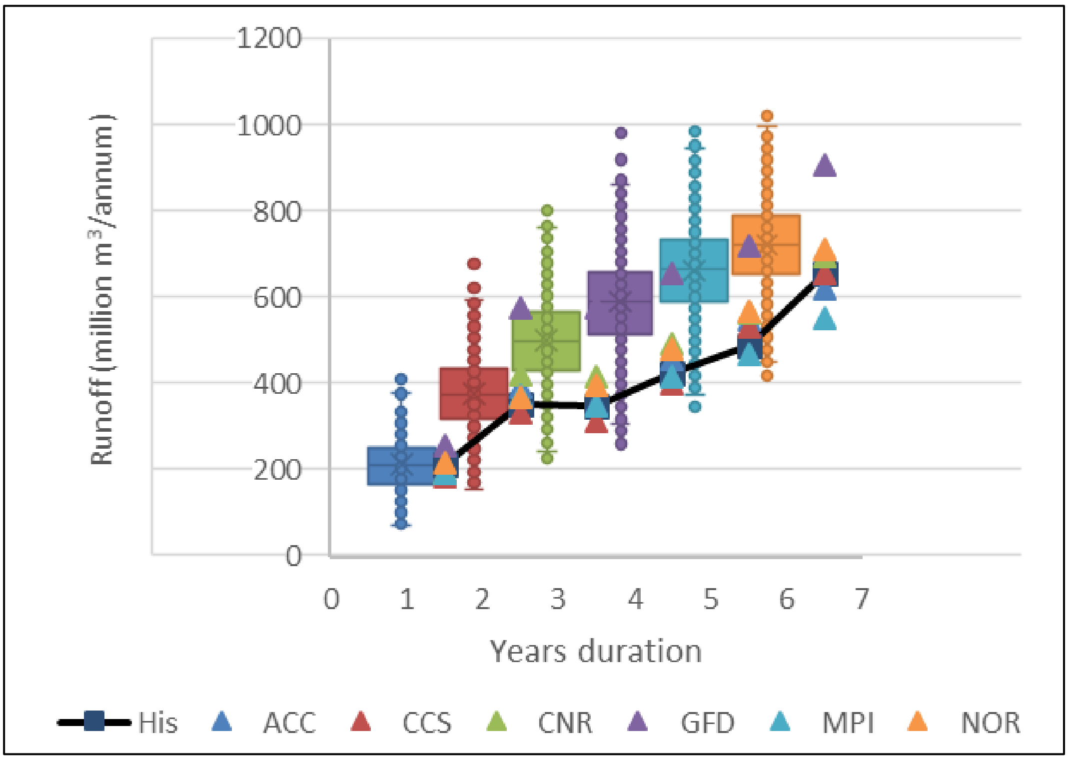
N-month run sums for Makhaleng SC



N-month run sums for Senqu SC

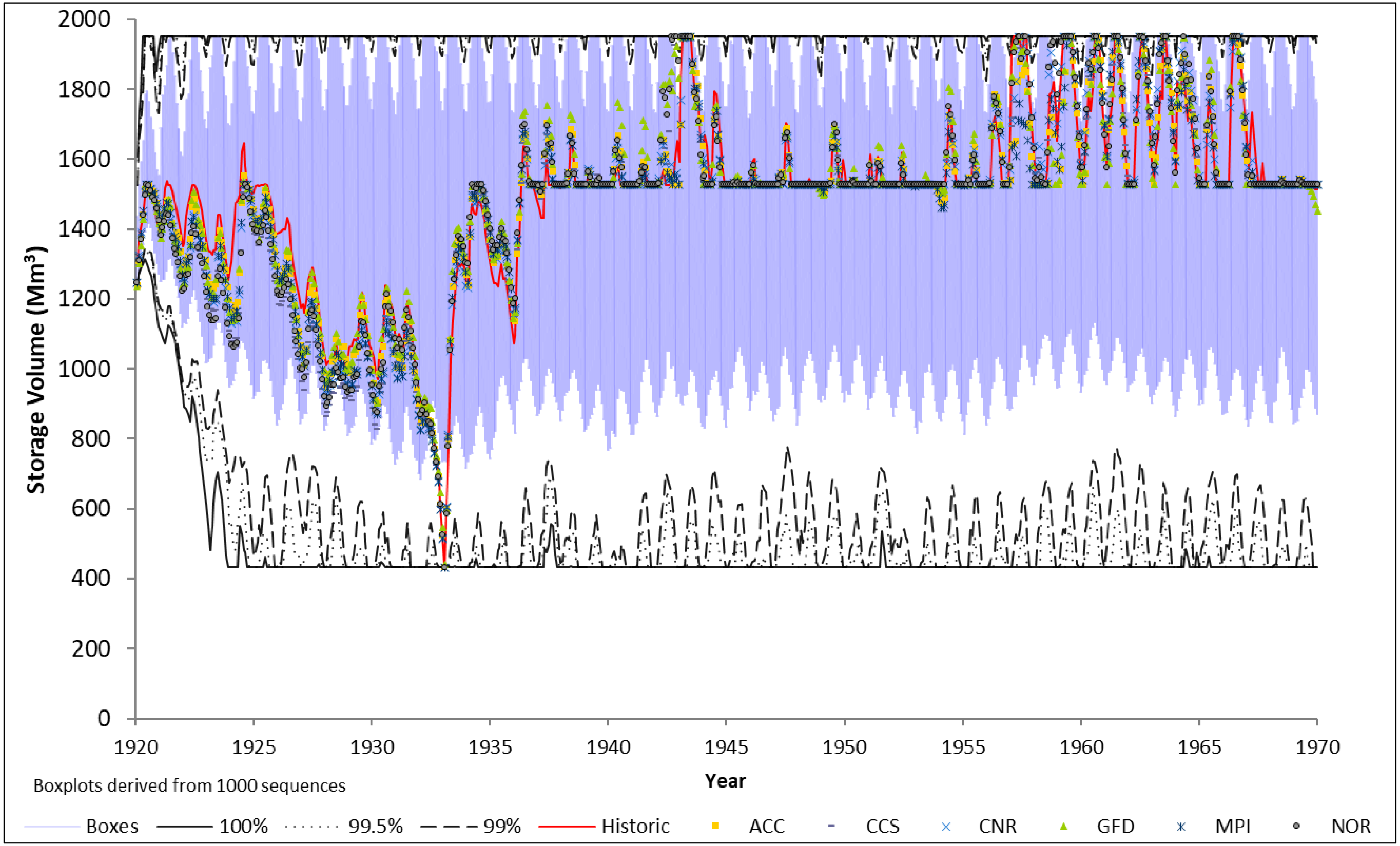


N-month run sums for Upper Orange SC

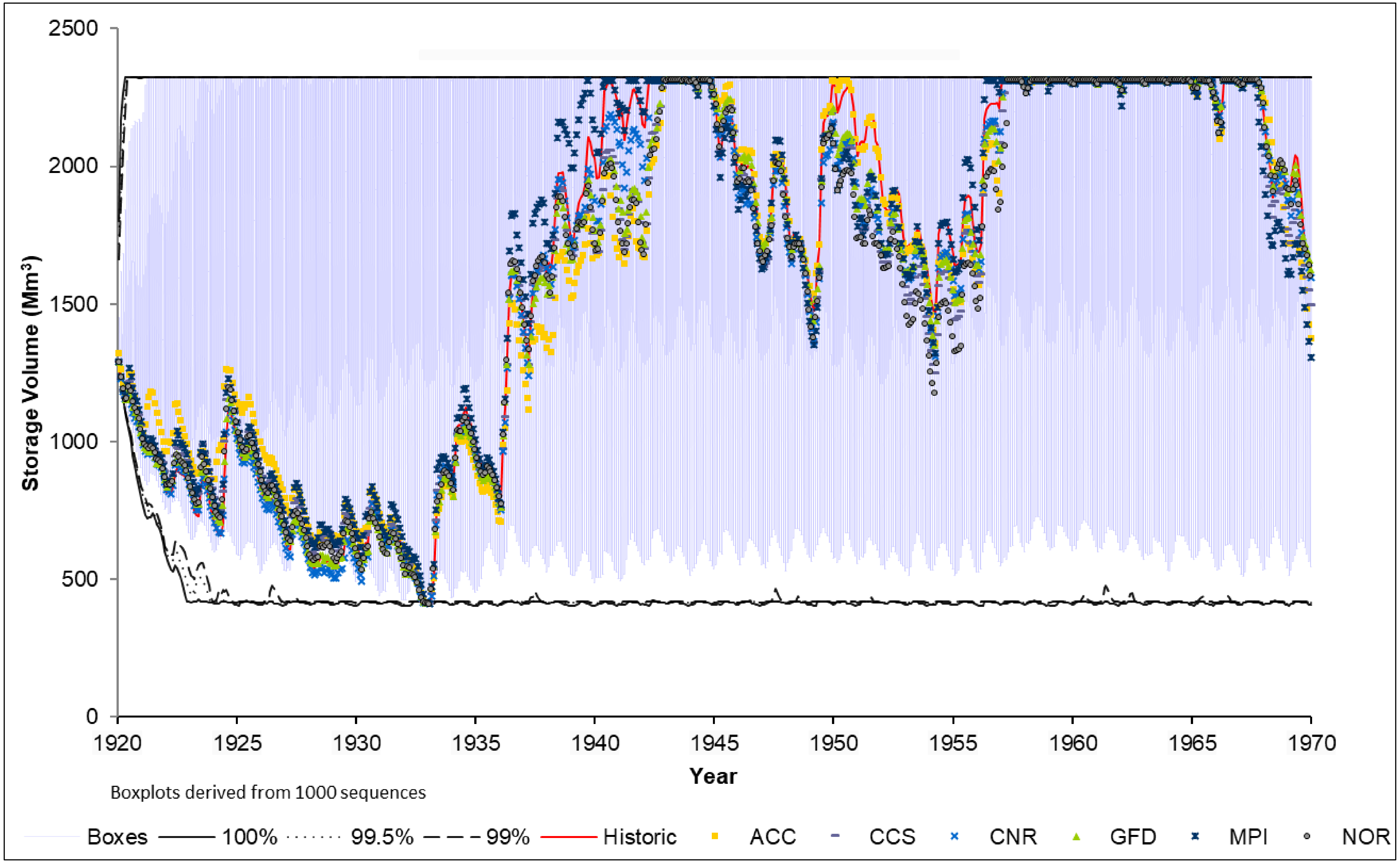


N-month run sums for Caledon SC

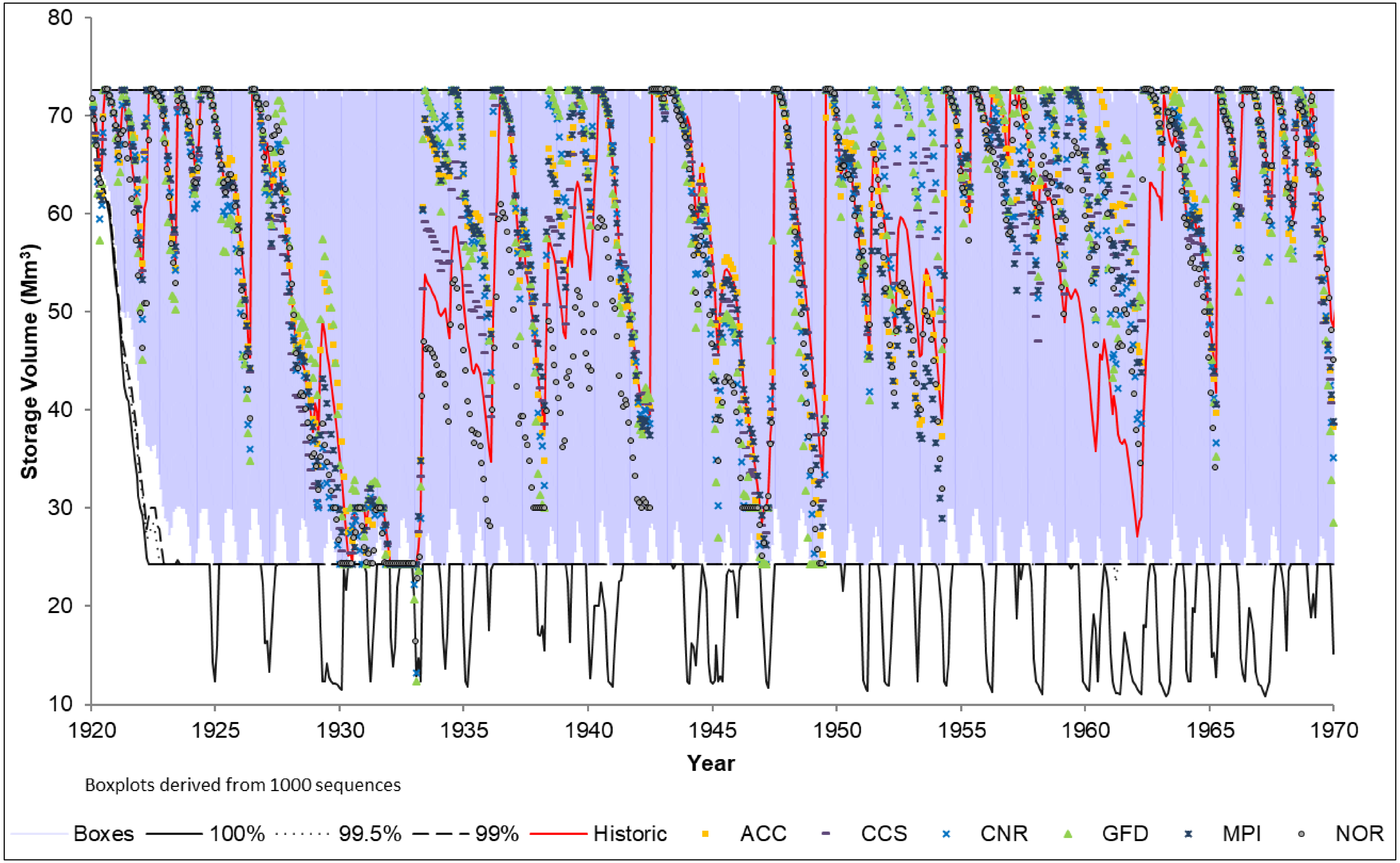
APPENDIX J – DAM TRAJECTORIES



Katse Dam Trajectory



Polihali Dam Trajectory



Rustfontein Dam Trajectory