A National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-Climatic Zones of South Africa

Report 2
Perspectives on Adaptation to Climate Change in the South African Water Sector

Report to the
Water Research Commission

by

R E Schulze and S Schütte (Editors)

with contributions by

K R Gwena and N Nxumalo
Centre for Water Resources Research
University of KwaZulu-Natal, Pietermaritzburg

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Water Research Commission
Bloukrans Building
Lynnwood Bridge Office Park
4 Daventry Road
Lynnwood Manor
PRETORIA

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A National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-Climatic Zones of South Africa. Report 1: Methodology and Results (WRC Report No. 2833/1/22).

A National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-Climatic Zones of South Africa. Report 3: *South African and International Verification Studies of the ACRU Daily Time-Step Model across a Range of Processes, Applications and Spatial Scales* (WRC Report No. 2833/3/22).

EXECUTIVE SUMMARY

In the contract of WRC Project K5/2833 which is titled *A National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-Climatic Zones of South Africa***,** it is specified in Aim 4 of Work Package 3 that appropriate short-, medium- and long-term adaptation strategies and options be addressed on projected climate change impacts across South Africa. In terms of the contract, and following confirmation with the project's Reference Group, the following variables made up of drivers and hydrological responses of climate change were identified for analysis, mapping and assessment in regard to adaptation, *viz*. potential evaporation, rainfall, actual evapotranspiration, local runoff, accumulated streamflows, recharge to the shallow groundwater zone and yield.

With a focus on yield, **Chapter 1** of this adaptation report, titled *A Transformative Framework for Practical Technical Adaptation based on South Africa's Yield Modelling* Is essentially a literature review focussing on risk and risk management to adaptation, followed by a section on climate scenarios for adaptation, a discussion on non-technical vs technical adaptation options, with a focus on technical adaptation options for yield planning, and concluding with a section on a transformative framework for technical adaptation in yield planning.

The core of this Adaptation report revolves around **Chapter 2** titled *Adaptation to Climate Change in the South African Water Sector: Practical Perspectives, Many Questions and Some Answers*, commencing with a series of sections on *Setting the Scene on Adaptation to Climate Change Within the South African Water Sector,* the first of which is titled "Why Is the Water Sector Considered to be the Primary Medium Through Which Adaptation to Climate Change will have to be Addressed?", followed by a section titled "Getting to Grips with Adaptation-Related Terminology used Before Adaptation Options are Addressed" in which first weather- and climate-related terminology is addressed and then vulnerability and adaptation-related terminology.

The section which follows argues that within the bigger adaptation picture one should strive towards, at minimum, a no regrets approach, but ideally a more anticipatory precautionary approach. Thereafter follows a section addressing adaptation within the bigger framework of the guiding principles for the implementation of South Africa's National Climate Change Adaptation Strategy, with sections on a generic adaptation and disaster risk management approach to climate change and the water sector as well as on guiding principles for the implementation of South Africa's National Climate Change Adaptation Strategy. Still on setting the scene on adaptation to climate change within the South African water sector are discussions on long-term goals, more locally focussed approaches upon which adaptation actions should be developed and commitments by DWS to the above hydrological adaptation approach.

The next series of sections go under the broad heading of *Becoming More Practical in Regard to Adaptation to Climate Change within the South African Water Sector*, commencing with an approach to adaptation to climate change in the water-related sector by enhancing adaptive capacity through technological and structural issues, addressing issues surrounding knowledge/skills/participation, by policy instruments, issues surrounding risk sharing/spreading and by changes of land use/activities/locations. This is followed by questioning which the key impacted institutions and sectors are, and which hydrological drivers and responses they have to cope with, and adapt to, under projected climate change.

Thereafter an assessment is made on adaptation within the WRC K5/2833 contract in regard to analyses and mapping which address risk perceptions and risk narratives outlined in the adaptation section of the contract. The approach adopted here is to ask a number of key questions as a backdrop to adaptation, in most cases answered by interpreting key maps emanating from the project. The key questions include the following:

- If Adaptation to climate change in the South African water sector is to be guided by means of annual runoff derived from GCM outputs, are these valid / realistic?

- Where, across South Africa, are the projected GCM derived changes to hydrological variables significant, both they in absolute or relative terms? Are they positive or negative? And, what is the magnitude of change?
- Are there significant differences across South Africa in projected changes to hydrological variables into the future between "dry" and "wet" years which should be considered in adaptation?
- Does actual land use produce results that are more sensitive or less sensitive to those from natural vegetation under climate change scenarios in regard to affecting adaptation policy and practice?
- Why use outputs from *multiple* GCMs for hydrological assessments of climate change? Do we not have full confidence in any single GCM's hydrological responses to projected climate change?
- Do changes from any single GCM "dominate" the outcomes of multiple GCM averages?
- Given That we cannot have full confidence from outputs from multiple GCMs in a key hydrological driver of climate change, *viz*. rainfall, do we have equal lack of confidence in all hydrological drivers and responses in regard to adaptation?

Again, answers to these questions are provided by mapped evidence, mostly from this project.

Continuing with *Becoming More Practical in Regard to Adaptation to Climate Change Within the South African Water Sector,* the next section addresses challenges identified within the WRC K5/2833 contract regarding adaptation, with these challenges being that

- New climate change knowledge has to be processed into hydrological practice
- Projected climate change impacts are superimposed onto an already multi-stressed environment
- Converting new findings into actions requires administrative flexibility
- The adaptation process has to be reviewed collaboratively and transparently
- Adaptation actions are multi-faceted
- The South African geography of water-related adaptation is complex
- Any relative changes in rainfall are amplified into relative changes in runoff and
- Adaptation in the South African water sector is a very local issue

with each of the challenges discussed in depth.

Continuing with the theme of practicality, possible *First Order* adaptation options available to the South African water sector *beyond* the WRC K5/2833 mandate are identified and discussed, often backed up by maps. These options include

- Identifying temperature sensitive areas by assessing changes in maximum, minimum and other temperature-related patterns
- Changes in annual and seasonal precipitation patterns and their variability
- Changes in thresholds of rainfall exceeded, i.e. "assault rainfall events"
- Changes in enhanced reference potential evaporation rates
- Assessing changes in accumulated annual and seasonal streamflow patterns and identifying runoff sensitive areas
- Changes in thresholds of streamflows exceeded, i.e. "assault streamflow events"
- Changes in soil water content
- Changes in streamflow components.

The theme continues with possible *Second Order* adaptation options available to the South African water sector *beyond* the WRC K5/2833 mandate, *viz*.

- Changes in short duration (5 min - 24 h) design rainfalls events for the 1:2 to1:100 year return periods
- Changes in long duration (1-7 days) design rainfalls for the 1:2 to 1:100 year return periods
- Changes In long duration (1-7 days) design streamflows for the 1:2 to 1:100 year return periods
- Changes In the flood severity index
- Changes in 1:2, 10, 20, 50 or 1:100 year design peak discharge on a given day
- Changes in flash floods

- Changes in regional floods
- Changes in agricultural droughts of mild, moderate or intense severity
- Changes in hydrological droughts of mild, moderate or intense severity
- Changes in groundwater recharge, and
- Changes in water temperature

This is followed by an assessment of possible *Third Order* adaptation options available to the South African water sector *beyond* the WRC K5/2833 mandate, again illustrated where possible, including

- Changes in irrigation water demand and practices
- Effects of changes in land uses on water availability and production
- Effects of changes in water availability on land use patterns
- Changes in water rights and water allocation rules
- Changes in dynamics of water quality responses and their consequences 1: Sediments
- Changes in dynamics of water quality responses and their consequences 2: Chemical water quality
- Changes in dynamics of water quality responses and their consequences 3: Biological water quality
- Changes in water quality on human health
- Impacts on terrestrial and aquatic ecosystems
- Changes to environmental flows
- Changes in hydropower generation potential
- A re-think on surface water supplies and storage at a point from all systems
- Transboundary flows (quantity and quality) and potential conflicts over shared rivers
- Vulnerability of the poor
- Changes in migration patterns 1: rural to urban areas from within South Africa
- Changes in migration patterns 2: immigration (legal and illegal) from other African countries
- Increases in sea level
- Increases in storm surges, and
- A focus on mountainous areas

Thereafter follow sections accounting for key water engineering-related systems in regard to adaptation beyond the WRC K5/2833 mandate by asking key questions and providing answers by way of examples and maps. With the following key questions:

- Given the project title, should we not have been considering "on-the-ground" issues of adapting to climate change and the water resources yield model system?
- Which local municipalities are likely to be vulnerable to future water supplies by the 2050s?
- Digging deeper by asking which local municipalities are likely to be vulnerable to future groundwater supplies by the 2050s?
- Which local municipalities are likely to be vulnerable to future surface water (runoff) supplies by the 2050s?
- Digging deeper by asking which local municipalities are likely to be growth points of population in future and thus need special attention re. adaptation?
- Which settlements are at risk of projected increases in floods by the 2050s?
- Which settlements are at risk of projected increases in drought tendencies by the 2050s?

Chapter 2 concludes by providing suggestions on the way forward on adaptation to climate change in the South African water sector, including adaptation as a consultative and iterative process.

A final chapter is titled *An Anecdotal Perspective on Vulnerabilities of Climate Change Affecting Poor Rural Communities – A Student Contribution*.

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CHAPTER 1

A TRANSFORMATIVE FRAMEWORK FOR PRACTICAL TECHNICAL ADAPTATION BASED ON SOUTH AFRICA'S YIELD MODELLING

K.R. Gwena

1.1 INTRODUCTION

Water shortages of any form are an unacceptable risk as they negatively impact a system's water availability that is meant to serve demands for the future (Frame and Killick 2004; Martin-Carrasco *et al.*, 2013). Various elements, including lack of infrastructure for water storage or transport (Tortajada, 2014), population growth (Maharaj and Pietersen, 2004; Huo *et al.*, 2008; Satterthwaite 2009), excessive abstraction (Zhang and Lu, 2009; Galli *et al.*, 2012), constraints in water management (Bartram 2009; Serrat-Capdevila *et al.*, 2014), pollution of water bodies (Vörösmarty *et al.*, 2010; Hellawell, 2012) and climate variability/change (Elala 2011; Intergovernmental Panel for Climate Change, 2014; Döll *et al.*, 2015), to mention but a few, directly or indirectly cause water shortages. In water management, catchment yield is the expected total amount of water that can be abstracted from a catchment's runoff and maintained and stored in a hydrological facility, over a pre-determined period (Negassi *et al.*, 2002, Purcell 2003).

In general, climate variability/change is a major cause for the dynamic nature of precipitation, infiltration and evapotranspiration that may lead to the reduction of water availability, particularly in already semi-arid to arid regions, as well as the increase of extreme events such as floods and droughts that all influence a catchment's yield (Gosain *et al.*, 2006; Karlsson *et al.*, 2016; Pessacg *et al.*, 2020). As a result, the possible negative impacts of climate change on yield require adaptation strategies through adjustments to actual or expected climate and its effects (Peters 2001; Parry *et al.*, 2007; Intergovernmental Panel for Climate Change, 2014). Adaptation strategies for the water sector can be either non-technical or technical, where the former involves non-structural actions such as community participation, incentives, behavioural change and institutional reforms, while the latter involves construction of water infrastructure (Ludwig *et al.*, 2012; Annamalai 2014) and nature based solutions (Boelee *et al.*, 2017; United Nations Water, 2018). This Chapter hypothesises that in financially constrained countries, the majority of the financial resources are devoted to technical adaptation as opposed to non-technical adaptation in planning for yield. However, the technical adaptations may be impractical and might not be sufficient for long-term planning. Therefore, a transformative framework design to support practical technical adaptation strategies in South Africa's yield planning is proposed, beginning with a description of the progression from risk management to adaptation.

1.2 RISK AND RISK MANAGEMENT TO ADAPTATION

Numerous climate studies have shown that it is ineffective and incomplete to consider adaptation without understanding risk related to a catchment (Brooks, 2003; Urama and Ozor, 2010b; Department of Environmental Affairs South Africa, 2013; Martin-Carrasco *et al.*, 2013; Schiermeier, 2014; Ziervogel *et al.*, 2014; Bren, 2015; Döll *et al.*, 2015; Schulze and Davis, 2015; Vargas and Paneque, 2019). This is primarily due to catchment specific variables such as local climate, catchment size, and land use/cover that determine how a catchment responds to risk from actual or expected climate (Department of Water Affairs and Forestry 2007; Bren, 2015). The IPCC has identified climate scenarios based on four Representative Concentration Pathways (RCPs) to represent the actual and expected climate (IPCC, 2007). For each RCP, the corresponding climate scenario exposes water availability to different forms and levels of risk and, in turn, requires different management approaches (Taylor *et al.*, 2013; Lelieveld *et al.*, 2016; Kebede *et al.*, 2018; Welborn 2018). Risk is described as the identification of past and present drivers of negative change and existing hazards (Brooks, 2003) and climate change is both a noted driver of change and an existing hazard to yield in that it has led to increasing temperatures, shifting rainfall seasons, fluctuating rainfall quantities and increased magnitude and frequency of extreme events such as droughts and floods (Viney and Sivapalan, 1996; Salinger, 2005; IPCC, 2007; Urama and Ozor, 2010a; Kusangaya *et al.*, 2014; Stagl *et al.*, 2014; Ziervogel *et al.*, 2014).

An effective assessment of risk extends from an assessment of the condition of the resource to understanding risk perception and risk management. The former involves an assessment of both sensitivity and adaptive capacity concerning a particular hazard (Alwang *et al.*, 2001; de Groot *et al.*, 2006) whilst the latter involves developing responses to hazards to reduce intense changes (Gitay *et al.*, 2011), including three facets, *viz*.

- exposure to a particular risk,
- the resilience to the impact of the risk, and
- the adaptation to minimize the risk's impacts (Adger 2006).

The risk of climate change on yield, refers to the relationship between a climate-related event's impact on the yield, the risk associated with the impacts of climate change on yield, and the efforts to manage climate change (Yang 2009; Pessacg *et al.*, 2015). Risk to catchment yield occurs when the degree to which a catchment is sensitive to, and unable to adapt to, the consequences of climate change effects on its ecological character and thereby affects its yield (Bren 2015; Dalavi *et al.*, 2018). For example, in the event of a climatic extreme event such as a drought, then a catchment's yield is likely to reduce. Therefore, that catchment will require adaptation strategies based on climate scenarios discussed below to rejuvenate the yield and support its ability to match demand with its compromised supply.

1.3 CLIMATE SCENARIOS FOR ADAPTATION

As it stands, climate change is an additional challenge to an already complicated and complex suite of issues that should be considered to effectively plan for and manage water resources (Stuart-Hill and Schulze, 2010; Döll *et al.*, 2015). One such complexity is that climate change's impact on water resources is difficult to model and to predict accurately (DEA, 2013), owing to the non-stationarity of climate and climate data (Karlsson *et al.*, 2016). Nonetheless, the high uncertainty around climate change does not isolate its irrefutable impact on water resources. Fortunately, climate scenarios are useful in climate models and predictions as they represent actual and expected climates (Wilby *et al.*, 2004; Moss *et al.*, 2010; Mote *et al.*, 2011). Of the IPCC's four RCPs, RCP4.5 is based on possible reduction and management of greenhouse gas emissions, while RCP8.5 is based on a "business as usual" level of emissions, i.e. the current levels of greenhouse gas emissions (Parry *et al.*, 2007). At present, RCP4.5 would be the ideal trajectory to reduce emissions to, however, RCP8.5 is the most likely trajectory based on recent increases in greenhouse gas emissions (Taylor *et al.*, 2013; Lelieveld *et al.*, 2016; Kebede *et al.*, 2018; Welborn, 2018). Hypothetically, RCP4.5 has a corresponding lower risk on water resources and RCP8.5 has a corresponding higher risk (Intergovernmental Panel for Climate Change, 2008). Therefore, there is a need for complementary adaptation strategies for different climate scenarios, as the risk on yield most likely differs from one scenario to another and from one catchment to another (Kienzel, 2019).

In South Africa, the challenge in water resources planning is not necessarily that climate change is not considered, as water planning does consider uncertainties due to climate, but rather, that more consideration is needed for the impact of different climate scenarios on water resources and how these affect planning (DEA, 2013). As it stands, it would seem that there is a disconnect in South Africa's water planning for demand and supply, where planning for demand is focussed on climate time-scales whilst planning for supply is focussed on the provision of infrastructure. This may, in part, be due to the decentralised approach at the Department of Water and Sanitation (DWS) where the Chief Directorate: Integrated Water Resource Planning has four directorates, including the National Water Planning directorate that develops national strategies and procedures for the reconciliation of water availability and quality. On the other hand, the Climate Change directorate exists as a separate entity that develops response strategies to guide effective response to climate change while minimising its adverse effects on water resources and, offers all climate-related support to the three other directorates each with different needs (DWS). The effects of decentralisation may have cascaded into yield planning, which is undertaken using the Water Resources Yield Model (WRYM) via the country's Reconciliation Strategies (Recons) that exclude or make specific provisions for the impact of climate change in hydrological analysis, including the calculation of potential yield (DEA, 2013). In these Recons, recommendations that are presented are either based on factors such as institutional reforms and community participation (non-structural) or infrastructure (structural), which tallies with adaptation that is either non-technical or technical, as described below.

1.4 NON-TECHNICAL VS TECHNICAL ADAPTATION OPTIONS

Non-technical adaptation includes incentives and education to support behavioural change in community participation and institutional reforms such as water budgeting, allocation, pricing, scheduling, rationing, marketing, recycling and trading, whilst technical adaptation includes construction of water infrastructure such as dams, irrigation networks, flood prevention dikes, water conveyance structures, and water supply and sewer facilities (Ludwig *et al.*, 2012; Annamalai 2014). Logically, effective adaptation would require both non-technical and technical options, with the latter being the priority and the former complementary. This is so because non-technical adaptation options rely on the changes in behaviours of communities and on reforms of institutions, in order to inform which areas to target in water demand and supply. However, non-technical adaptation options alone are not sufficient for effective adaptation as the water users' uptake and implementation of the suggestions and changes will vary, based, for example, on their perceptions and understanding (Doswald and Osti, 2011; Manjoo, 2019). On the other hand, technical adaptation options are costly, usually rigid in nature, require advanced equipment or technology and may have negative environmental impacts. However, technical adaptation options inform the necessary construction requirements to facilitate meeting demand which is based on supply (Ludwig *et al.*, 2012; Annamalai 2014).

Whilst South Africa's water planning involves a combination of both non-technical and technical adaptation options, the implemented technical adaptation options often lack practicality (Schulze, 2011). For example, one common recommendation in the Recons is the building, replacing and raising of dams in the different catchments. To begin with, replacing and raising dams is already an indicator that the current dams are not coping with changes, presumably caused by climate. Furthermore, over time, climate change may lead to dams collapsing or drying out, such that dam construction may not be a practical solution for the long term (Jeuland, 2010; Fearnside and Pueyo, 2012; Null *et al.*, 2013; Fluixá-Sanmartín *et al.*, 2018; Choi *et al.*, 2020). Another example is how the All Towns Recon highlighted that poor operation and maintenance of water supply, with treatment and reticulation infrastructure resulting in significant water losses (Hay *et al.*, 2012; Department of Water Affairs South Africa, 2013). Therefore, the All Towns Recons were followed up by detailed studies to determine practical strategies such as registered and licenced water use, updated water infrastructure asset registers and efficient recording of metered water abstractions to support a positive water balance (Esterhuizen *et al.*, 2019). However, the current imbalance between low water supply and high demand suggests that there is a need to further assess the practicality of technical adaptation options, as discussed below (Hedden and Cilliers, 2014; Olivier and Xu, 2019).

1.5 TECHNICAL ADAPTATION OPTIONS FOR YIELD PLANNING

The Recons are interventions and procedures developed to reconcile water availability and quality with future water demand, based on strategic requirements such as social and economic development for an entire metropolitan judicial boundary (Esterhuizen *et al.*, 2019; Manjoo, 2019). However, Recons have seemingly failed to fully account for the influence of climate change on yield, as during planning, climate change considerations are focussed on provision of infrastructure and demand forecasting as opposed to climate time-scales. For example, the current Recons include measures such as bulk meter installation and universal metering, Water Conservation and Water Demand Management (WC/WDM), water transfer schemes, development of groundwater and desalinisation. These are recommendations from Recons where a report published by the Department of Environmental Affairs (DEA) highlighted that out of twelve regions, only four consider climate change (DEA, 2013). However, of those four, only Algoa and Western Cape included climate change in yield estimations and estimated that yield would decrease by 10% and 5%, respectively. Amatole considered climate change, but excluded it in its water balance reconciliation and KwaZulu-Natal only noted that it should be considered and at the time of the report, were awaiting results from a separate project by Umgeni Water (Department of Water Affairs South Africa, 2007; 2008a; 2008b; 2010a; 2010b; 2011; 2012a; 2012b; 2012c; 2014a; 2014b; 2014c).

The limited consideration of climate change in the Recons is a challenge because adaptation requires climate scenarios to understand how climate change impacts a catchment and, in turn, yield (Stuart-Hill and Schulze, 2010). However, due to the similarities in the distinction of non-structural and structural recommendations and of non-technical and technical adaptation options, it is possible that some of the recommendations from the Recons may constitute technical adaptation options. To investigate this, the Chapter equated a recommendation from a Recon as a technical adaptation if the recommendation involved construction of water conveyance, supply and storage structures and, influenced the impact of climate change on yield. A summary of the main recommendations, including changing operations of the relevant bulk infrastructure, of water transfer schemes, dam building and replacement arising from the twelve Recons is presented in **Table 1.5.1**. Each of these recommendations involved construction either of human-engineered infrastructure or of infrastructure to assist natural landscapes, viz. grey and green infrastructures. Grey infrastructure here refers to structures such as water and wastewater treatment plants, pipelines, and man-made reservoirs whilst green infrastructure refers to modifications of landscapes such as forests, floodplains and wetlands (Ellis, 2013; Denjean *et al.*, 2017).

Table 1.5.1 A summary of the green and grey infrastructure presented as recommendations in the Recons

Grey Infrastructures	Green Infrastructures
Potential dam sites	
Raising existing dams	
Irrigation return flows abstraction infrastructure	Purchasing of water use entitlements from farmers using water from an identified river to be supplied to municipalities through abstraction infrastructure.
Water Treatment Works (WTW)	
Waste Water Treatment Works (WWTW)	
Water recycling plant sites	
Water conveyance from dams to the abstraction works at WTWs	
Reverse osmosis plant sites	Pumping sea water via pipeline to a proposed reverse osmosis plant sites
Bulk seawater intake systems	
Pipelines between WTW and reservoirs	
Diversion weirs on rivers and pumping the water to a high point, from where the water would gravitate via pipeline into a stream that flow into dams	
Modifications to Pump Stations to an extent that the pump stations can operate efficiently under current in-take conditions	

It would seem that the majority of the recommendations are grey infrastructures as opposed to green infrastructures. However, a combination of green and grey infrastructures in an approach known as Nature-Based Solutions (NBS) are likely to be more efficient as they are a practical development of climate-resilient infrastructure that restores or emulates nature (Cohen-Shacham *et al.,* 2016). Therefore, a framework that models NBS as technical adaptations to increase the probability of assurance of supply from catchment yield in South Africa is presented below as a practical approach.

1.6 TRANSFORMATIVE FRAMEWORK FOR TECHNICAL ADAPTATION IN YIELD PLANNING

NBS are practical solutions that have added environmental, economic and social co-benefits such as increased biodiversity, economic growth associated with increasing food security and promotion of social cohesion (Thorslund *et al.*, 2017; Dushkova and Haase, 2020). In water management, NBS have the potential to address challenges such as low water availability, compromised water quality and water-related disasters caused by climate change (Boelee *et al.*, 2017; Zhang *et al.*, 2019; Martín *et al.*, 2020; Nika *et al.*, 2020). Examples include soil moisture retention and groundwater recharge to improve water availability, constructed wetlands and riparian buffer strips to improve water quality, and floodplain restoration and green roofs to reduce risks from climate induced water-related disasters (United Nations Water 2018). Models for NBS either use, or mimic, natural processes and provide a basis for testing possible impacts of implementing planned infrastructure developments (Nkwonta *et al.*, 2017). Therefore, a NBS model designed to potentially increase the assurance of supply that can sustainably be obtained from a catchment for a number of years, should be applicable in any hydrological year, and under specified conditions of catchment development and dam operation (Statistics South Africa, 2010; Department of Water Affairs South Africa, 2012a).

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CHAPTER 2

ADAPTATION TO CLIMATE CHANGE IN THE SOUTH AFRICAN WATER SECTOR: PRACTICAL PERSPECTIVES, MANY QUESTIONS AND SOME ANSWERS

R.E. Schulze

2.1 SETTING THE SCENE ON ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: WHY IS THE WATER SECTOR CONSIDERED TO BE THE PRIMARY MEDIUM THROUGH WHICH ADAPTATION TO CLIMATE CHANGE WILL HAVE TO BE ADDRESSED?

Water is the key to continued socio-economic development and environmental sustainability in South Africa because:

- water is a key driver of domestic and industrial supply, of river flows and water quality, of dryland and irrigated agriculture, of many facets of the insurance industry, of health, disaster risk management and of economic development, of biodiversity, the energy and food security sectors and of the many fragile ecosystems, both on land and in water; with
- water arguably being the primary medium through which early climate change impacts will be felt by people, ecosystems and economies, and because
- water management is a complex and interlinked business **(Figure 2.1.1)**, be it from
  - an engineering perspective under current and future developments, or from
  - an ecological perspective of in-stream and off-stream issues, or from
  - governance perspectives within the country as a whole, within each specific WMA, at local government level and at community level,

  in regard to both existing and future conditions;

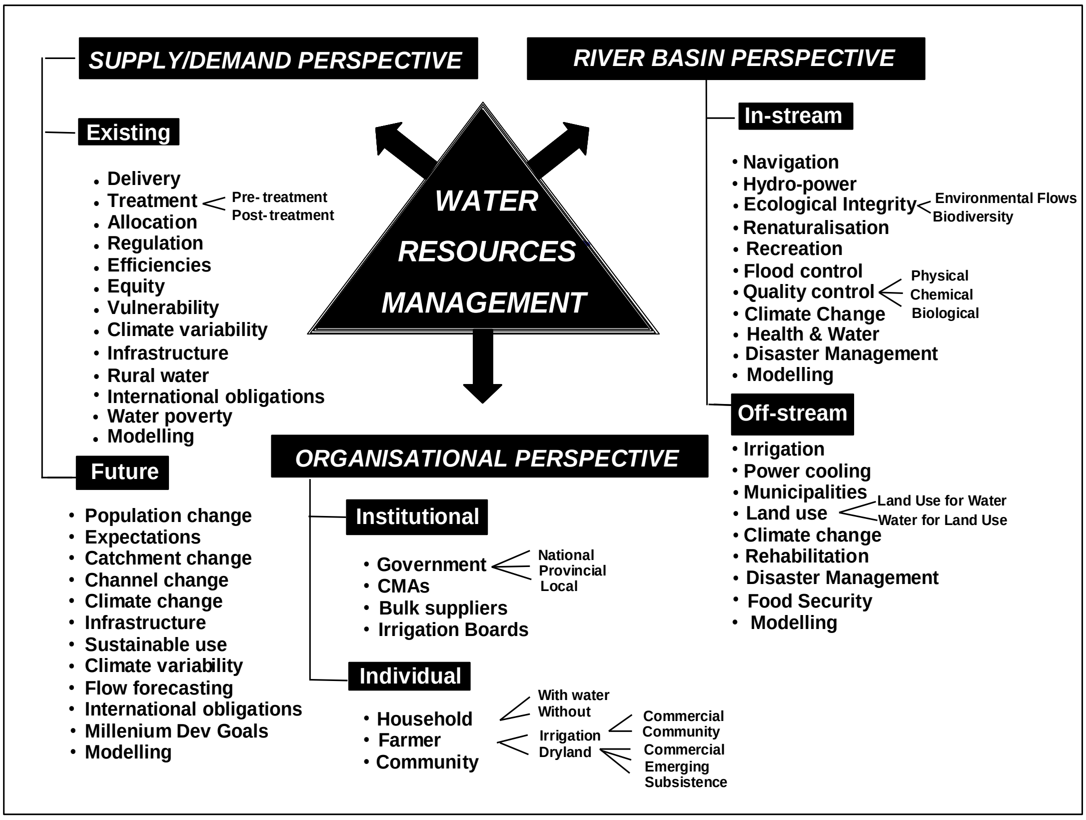

Figure 2.1.1 The complexity and interlinked nature of water resource management in South Africa and because

- water resources development is based primarily on hydrological modelling, which needs to consider climate, including climate change, in terms of the catchment's
  - landscape component, on which the hydrological processes consist of
    - drivers (such as rainfall and evaporation), and its
    - responses (such as runoff, recharge and extreme events), as in **Figure 2.1.2**, also the
  - environmental concerns of the reserve, wetlands, riparian zones and estuaries, and the
- channel component of water storages, releases and routing (**Figure 2.1.2**), which largely control the management of the water resource in regard to water allocation via
  - supply of water (surface and groundwater, dams, transfers, return flows) and
  - demand for water (for humans, the environment, industry, irrigation or power),

  where each of these components experiences different issues around climate change; that
- the real impacts of climate change show up primarily through changes in "pulses" of individual events such as thresholds of rainfall or dry spells being exceeded, rather than merely the "push" of annual values changing; and that
- many people in specific areas within each WMA or municipality are highly vulnerable to impacts of climate change.

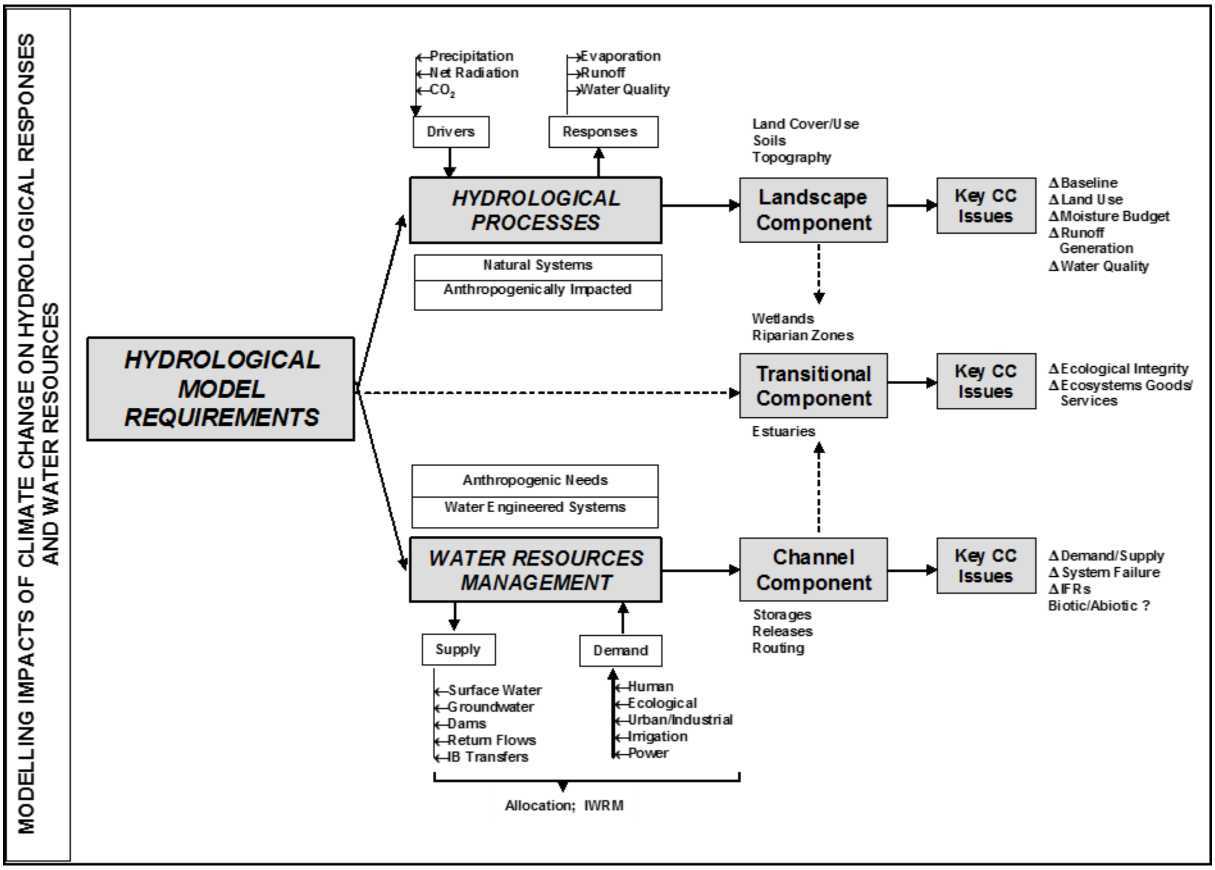

Figure 2.1.2 Key climate change issues of the landscape, channel and transitional zone

It is for above reasons that the water sector is considered to be the primary medium through which adaptation to climate change will have to be addressed.

2.2 SETTING THE SCENE ON ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: GETTING TO GRIPS WITH ADAPTATION-RELATED TERMINOLOGY USED BEFORE ADAPTATION OPTIONS ARE ADDRESSED

Because different user communities often interpret terms and concepts related to climate change (CC) adaptation differently, this section serves to clarify some key terms used, commencing with some fundamentals.

Weather and Climate-Related Terminology

Weather

Weather is the sum total of prevailing atmospheric variables at a given place and at, wind movement, lightning, rainbows, fog, clouds, any instant or brief period of time. Weather is an everyday experience – one talks of "today's weather". Weather is made up of real phenomena, which we can observe and experience with our senses and which we can, in part, measure with accuracy. Such weather phenomena include heat, warmth, humidity, rain, snow or hail.

Climate

Climate refers to a more enduring regime of the atmosphere and it represents a composite of day-to-day weather conditions and atmospheric elements within a specified place or region and over a long period of time. It is, however, more than just "average weather", for it also includes the dynamic and intricate variations occurring diurnally (i.e. day vs. night), daily, monthly, seasonally and annually and in addition includes evaluations of extreme events and the variability about the norm. *Climate* consists of figures. For that reason, climate as such can neither be "experienced", nor is it measurable in the true sense of the word. Climate is, therefore, really a mathematical construct, or term, which does not occur in reality.

Climate Variability

This signifies any deviation from the long-term expected value. It is an entirely natural phenomenon, and it is *reversible* and *non-permanent*, for example droughts in southern Africa, which are associated with the El Niño-Southern Ocean phenomenon. Climate variability has time scales that can range from

- diurnal (within the course of a day (e.g. when during the day thunderstorms occur), to
- daily (i.e. variations from one day to the next) to
- intra-seasonal (e.g. the variability within a year, and from one year to the next), to
- inter-annual (e.g. year-to-year variability) and
- decadal (e.g. consecutive wet years or dry years).

Climate Change

Climate change, on the other hand, is *irreversible* and *permanent.* It consists of a trend over time (either positive or negative) that is overlaid over naturally occurring variability. The most common example of climate change nowadays is global warming resulting from human activities which increase temperatures through increased emissions of greenhouse gases into the atmosphere. The time scale of this climate change is decades to centuries and the trend is more likely to occur in steps than linearly over time. A key feature of climate change is that while there are projected changes in *means* of climatic variables over time, there are, more importantly in hydrology, changes in *critical thresholds* that may be exceeded (e.g. days with rainfall > 10 mm or with daytime temperatures > 35°C) and / or changes in *extreme events* such as the 1:10 year rainfall or flood magnitude.

Climate Scenarios and Climate Projections

These are projections following on from a set of basic 'what if' assumptions which are made in Global Climate Models, or GCMs.

- Nowadays we most commonly apply *scenarios from GCM output* called Representative Concentration Pathways (RCPs), of which the most commonly used is RCP 8.5, assuming "business as usual", but others are RCP 6.0, 4.5 and 2.6, as shown in **Figure 2.2.1**.

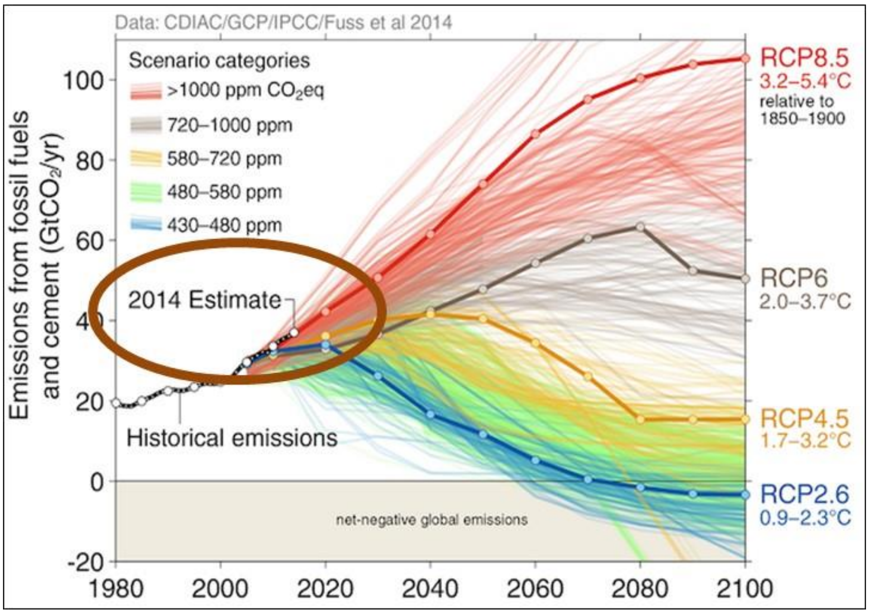

Figure 2.2.1 Illustration of scenarios of future estimated emissions for different RCPs

- It should be borne in mind that
  - uncertainties exist within each of the scenarios, according to their own assumptions on greenhouse gas emissions dependent on technology, politics and development, that
  - no one scenario is "a more likely future", or a "best guess", that
  - uncertainties occur due to differences among GCMs assuming the same RCP (e.g. the thin red curves of individual GCMs vs. the solid line of the overall RCP 8.5), with no single GCM being the "best", and that
  - "best" in agriculture is not necessarily the "best" in regard to hydrology, and that
  - uncertainties associated with changes in rainfall (the main "driver" of hydrological responses) are greater than uncertainties in temperature, that
  - uncertainty is greater in regard to amount (i.e. magnitude) of change than direction, and
  - changes in variability and extremes are greater than changes in means, while
  - uncertainties associated with downscaling from global to hydrologically relevant local catchments remain a source of concern, despite bias correction being applied.

Climate Change Impacts

Climate change impacts are the *consequences* of climate change on any natural and human system and when one considers adaptation, one can distinguish between

- *Potential Impacts*, which imply all impacts that may occur given a projected change in climate, without considering adaptation, while
- *Residual Impacts* are the impacts of climate change that would occur after adaptation.

Mainstreaming Climate Change

Mainstreaming, here, refers to integration of climate change vulnerabilities or adaptation into some aspect of related government policy such as water management, disaster preparedness and emergency planning or land use planning.

- Actions that promote the mainstreaming of climate change adaptation include
  - integration of climate information into environmental data sets,
  - preparing climate change-related vulnerability or hazard assessments,

- factoring climate change into broad development strategies, as well as into
- macro policies and / or sector policies, as well as into
- institutional or organizational structures, or
- development project design and implementation.

- By implementing mainstreaming initiatives, adaptation to climate change will become part of other well established programmes, particularly sustainable development planning, but that mainstreaming needs to include a broader set of measures to reduce vulnerability.
- Mainstreaming of climate change initiatives have been classified at various levels:
  - At the international level, mainstreaming can occur through policy formulation, project approval and country-level implementation of projects, often internationally funded.
  - At the WMA level, for example, mainstreaming assesses the likely impacts of climate change on key local economic sectors such as water, agriculture or health, while
  - Responses may also be defined at the community level.

Vulnerability and Adaptation-Related Terminology

Vulnerability

Vulnerability to CC is the degree to which various systems such as physical, biological or socio-economic systems are susceptible to, and unable to cope with, adverse impacts of CC, including climate variability and extremes.

- It is a measure of a system's susceptibility to the type (e.g. drought), the magnitude (e.g. how bad will it be) and the rate (how quickly will it set in) of CC. It therefore depends on what the system (e.g. a poor community, or an estuary) is exposed to (e.g. flooding), what it is sensitive to (e.g. sustained inundation of at least 2 days), and whether it has the capacity to adapt to CC.
- Vulnerability can thus be
  - an occasional stress to a potential event (e.g. an occasional flood), or
  - a constant stress that increases over time (e.g. more water-borne diseases).
- Vulnerability need not always be negative; indeed, it may lead to beneficial development.
- The term vulnerability, in the CC literature, may refer to
  - the vulnerable system itself (e.g. a riparian zone adjacent to a river),
  - the impact to this system (e.g. prone to flooding), or to
  - the mechanism causing these impacts (e.g. a higher frequency of cyclones with CC).
- Assessment of key vulnerabilities involves not only
  - substantial scientific uncertainties, but also
  - value judgements.
- It requires consideration of the response of
  - biophysical and socio-economic systems to CC over time (e.g. more floods), and
  - non-climatic conditions over time (e.g. changes in population, economy or technology),
  - important non-climatic developments that affect adaptive capacity (e.g. a civil war),
  - the potential that may exist for effective adaptation in a region or sector or group,
  - value judgements about the acceptability of potential risks, and
  - potential adaptation and mitigation measures.
- To be transparent when making such complex assessments, scientists and analysts need to be able to account, in a traceable way, for all relevant assumptions.

On Exposure, Sensitivity and Resilience

Exposure is the extent (i.e. the nature and degree) to which a climate-sensitive sector (e.g. water) is in contact with, or is exposed to, significant climatic variations (e.g. of rainfall).

Sensitivity, on the other hand, is the degree to which a system is affected, either negatively (i.e. adversely) or positively (i.e. beneficially), by a climate-related variable (e.g. rainfall change).

- Effectively it is the magnitude of change in a response (e.g. runoff) to a change in the driver of that response (e.g. rainfall).

- The effect may be
  - direct (e.g. a change in evaporation in response to a change in temperature), or
  - indirect (e.g. damages caused by an increase in the frequency of flooding due to CC),

  and the response to an event or exposure can be
  - positive, i.e. direct (e.g. as rainfall increases, so does runoff), or
  - negative, i.e. inverse (e.g. as evaporation from the soil surface increases between rainfall events, so the runoff from a certain amount of rainfall will decrease).

Resilience is the ability to absorb shocks and recover from them – the "bounce-back-ability".

- An example would be the capacity of a system (e.g. a dam) to absorb (e.g. a flood), and recover from a hazardous event (e.g. a drought).
- Resilience thus implies that there are thresholds which, when exceeded, result in a system being vulnerable.

On Adaptation and Related Concepts

Adaptation may be defined as actual adjustments in natural or human systems, or changes in decisions, in response to actual or expected climatic stimuli or their effects, which could moderate harm and which might therefore ultimately enhance resilience or reduce vulnerability to observed or expected changes in climate, or exploit beneficial opportunities.

- It is *a process through which societies make themselves better able to cope with an uncertain future. Adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes"*.
- Various *types of adaptation* can be distinguished:
  - *Anticipatory Adaptation* is adaptation that takes place before impacts of climate change are observed. It is also referred to as proactive adaptation.
  - *Autonomous Adaptation* is adaptation that is not a conscious response to a climatic stimulus, but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. This is also referred to as spontaneous adaptation.
  - *Planned Adaptation* is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.
  - *Private Adaptation* is initiated and implemented by individuals, households or private companies, usually in their self-interest.
  - *Public Adaptation* is initiated and implemented by governments at all levels and is usually directed to what is needed overall, or collectively.
  - *Reactive Adaptation* takes place after impacts of CC have been observed. Reactive approaches are seen as inefficient and not always successful.
- Adaptation at "higher" levels (e.g. central government) is usually planned and is driven by
  - meeting in-country environmental policy targets,
  - meeting international obligations and commitments (e.g. to UNFCCC), and
  - co-ordination across agencies with climate change agendas.
- Adaptation at higher levels is usually intentional, anticipatory, pro-active, long term and strategic.
- At "lower" levels (e.g. local government) adaptation is generally *autonomous* and driven by
  - hydro-climatic drivers such as experiences of floods and droughts
  - with often rules and procedures put in place to facilitate technical coping solutions
  - with a mix of climate and non-climate factors and
  - with bottom-up initiatives by NGOs and / or local media and
  - blending indigenous experience / knowledge with anticipated change.
- Adaptation at lower levels is thus more spontaneous, reactive, short term and practical.
- A distinction has to be made between *adaptive management* and *adaptive governance*, where
  - adaptive management is more about the operational aspects of water allocation, while
  - adaptive governance refers to the making of rules (e.g. assigning water rights, handling trade-offs, centralized vs decentralized water management).

- Adaptation practices can be differentiated along several dimensions, for example,
  - by spatial scale (local, regional, national);
  - by sector (e.g. water resources, agriculture, tourism, health);
  - by type of action (physical, technological, investment, regulatory, market);
  - by actor (national / local government, donors, private sector, communities, individuals);
  - by climatic zone (arid, humid, winter / summer rainfall, floodplains, mountains, etc.);
  - by baseline income / development level of the systems in which they are implemented (least-developed communities, middle income communities or countries); or
  - by some combination of these and other categories.
- From the perspective of time, adaptation to CC includes responses at three levels, *viz*. to:
  - current variability (which also reflects learning from past adaptations to climate); to
  - medium and long-term trends in climate which have been observed; and to
  - anticipatory planning in response to scenarios of long-term climate change.
- The responses across the three levels are often intertwined, or might form a continuum.

Adaptive Capacity

- Closely related to the concept of adaptation as such is the capacity to adapt. This may be defined as the ability or potential of a system to respond successfully (i.e. adjust in both behaviour and in resources and technologies) to CC (including climate variability and extremes), to moderate potential damages (by changing exposure or sensitivity), to take advantage of opportunities, or to cope with the consequences of impacts (by recovering or maintaining welfare / system function in the face of climatic change) and to profit from new opportunities (assuming climate change affects agents differentially).
- The presence of adaptive capacity is a necessary condition for the design and implementation of effective adaptation strategies so as to reduce the likelihood and the magnitude of harmful outcomes resulting from climate change.
- Technology can potentially play an important role in adapting to CC, with engineering solutions representing some options that can lead to improved outcomes and increased coping under conditions of climate change.
- Adaptive capacity is influenced not only by economic development and technology, but also by social factors such as human capital and governance structures.
- Adaptive capacity is uneven across societies or hydrological regions, and while national-level indicators of vulnerability and adaptive capacity may be used by CC negotiators in determining policies or allocating priorities for funding and interventions, the usefulness of indicators of generic adaptive capacity and the robustness of the results is not convincing.
- Adaptive capacity is unevenly distributed within the RSA due to multiple processes (stresses) of change interacting to influence vulnerability and shape outcomes from CC.
- Social and economic processes determine the distribution of adaptive capacity, which can be highly heterogeneous within a society or locality, and for individuals and communities it is differentiated by age, class, gender, health and social status.
- Adaptive capacity can change over time, because it may be enhanced or constrained or eroded by factors such as regulations or economic policies determined at the regional or national level that either limit or enhance the freedom of individuals and communities to act, or that make certain potential adaptation strategies either viable or unviable, including violent conflict or the spread of infectious diseases or urbanization.

2.3 SETTING THE SCENE ON ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: WITHIN THE BIGGER ADAPTATION PICTURE, STRIVING FOR AT MINIMUM A NO REGRETS APPROACH; IDEALLY A MORE ANTICIPATORY PRECAUTIONARY APPROACH

In regards to issues of climate change and the water sector in South Africa it may be argued that

- hydrological and hydraulic design is, at best, still an approximation only, with safety factors already built in, or that
- South Africa has more pressing water problems than those related to climate change, or that
- impacts of
    - the water engineered landscape (e.g. of irrigation, channel modifications, water storages, releases, diversions or inter-basin transfers) on river flows are generally greater than those of
    - land use changes (e.g. afforestation or urbanisation), and that the impacts of land use change on streamflows, in turn, may be greater than those resulting from climate change.

However, and on the other hand, any impacts of climate change are "superimposed" upon all other impacts on river flows and overall water problems we already face in South Africa and that these impacts become an additional, overarching stressor.

Currently, there are few management options in the RSA that are uniquely related to adaptation to climate change that would be measurably different to those already employed for coping with present climate variability. The substantive difference when factoring in climate change is whether one adopts

- a more conventional and incremental *no regrets approach*, where no regrets measures are those whose benefits equal or exceed their cost to society, i.e. measures worth doing anyway whether or not climate change poses additional pressures, or whether one adopts
- the more anticipatory *precautionary principle*, i.e. a process through which stakeholders influence and share control over development initiatives and the decision and resources which affect them, by taking account explicitly of climate change, and where the precautionary principle is a process which can improve the quality, effectiveness and sustainability of projects and strengthen ownership and commitment of government and stakeholders.

Despite uncertainties that still abound surrounding local impacts of climate change, there are sound reasons to adopt at minimum a no-regrets approach to potential hydrological impacts of climate change, but more ideally to opt for the more pre-emptive participatory principle, if for no other reasons that

- hydrological structures
    - have long lead times,
    - are often designed for lifespans of 50-100 years,
    - are very expensive and essentially irreversible investments, which
    - are designed to operate close to their design limits in times of major floods or droughts as we currently project them from historical climate records;

and furthermore, that the

- hydrological system amplifies any changes in rainfall when these changes are converted to changes in runoff, implying that the assumption of climatic stationarity, used in current hydrological design, is invalidated; that
- the public expects efficient, robust designs of hydrological infrastructure to function into a future which may include climate change; and that
- decision makers need to justify their decisions on water structures *now*, and for *local* hydroclimatic conditions, and cannot stall decisions until more certainty is available on climate change.

To ignore projected impacts of climate change on hydrological responses is, therefore, done at peril, and a *practical approach* to adaptation is needed in the water-related sector, which goes beyond having only strategies for adaptation.

2.4 SETTING THE SCENE ON ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: ADAPTATION WITHIN THE BIGGER FRAMEWORK OF THE GUIDING PRINCIPLES FOR THE IMPLEMENTATION OF SOUTH AFRICA'S NATIONAL CLIMATE CHANGE ADAPTATION STRATEGY

A Generic Adaptation and Disaster Risk Management Approach to Climate Change and the Water Sector

Adaptation and disaster risk management approaches for reducing and managing disaster risk in a changing climate include assessing a wide range of complementary adaptation and disaster risk management approaches that can reduce the risks of climate extremes and disasters and increase resilience to remaining risks as they change over time, as shown in **Figure 2.4.1**, remembering that these approaches can be overlapping and can be pursued simultaneously.

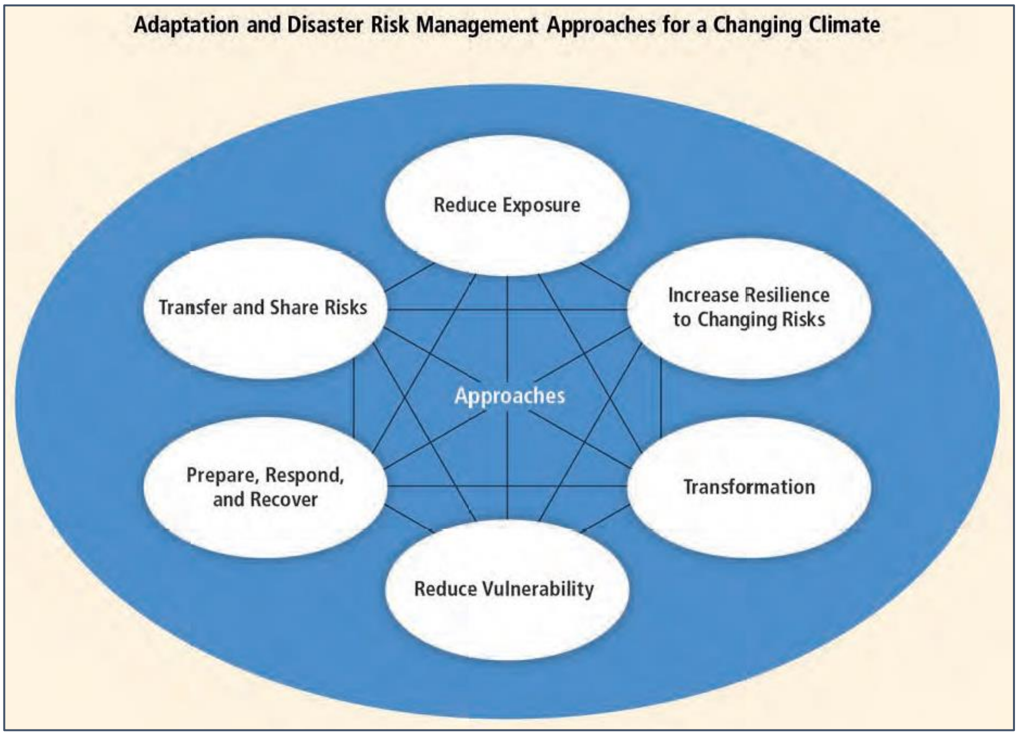

Figure 2.4.1 Generic adaptation and disaster risk management approaches to be considered for the South African water sector

Guiding Principles for the Implementation of South Africa's National Climate Change Adaptation Strategy

In the South African water sector any proposed and/or implemented adaptation action has to operate within, and be guided by, the overarching principles of the country's National Climate Change Adaptation Strategy (NCCAS). These are that adaptation …

- ***Be a country-driven approach***
  … with the development and implementation of the NCCAS driven by South Africa and the NCCAS be coordinated with national sustainable development objectives, plans, policies, programmes;
- ***Be based on best available science and traditional knowledge***
  … with its development and implementation being based on best available science on observed climate and projected climate changes, as well as relevant traditional knowledge on climate impacts and potential responses;

- ***Be participatory, with a bottom up approach***
  … involving a wide range of stakeholders, including government, communities, civil society organisations, the research community and private sector actors in the NCCAS's development and implementation;
- ***Be people-centred***
  … with the development and implementation of the NCCAS placing people, their needs and their rights at the forefront and serving their physical, developmental, cultural and social interests equitably;
- ***Be equity driven***
  … in supporting and promoting equity in South Africa;
- ***Be gender-responsive***
  … in promoting the participation of women, in taking gender differences in vulnerability to climate change into account, addressing the needs and priorities of both women and men and will not exacerbate gender inequalities;
- ***Be considerate of vulnerable groups***
  … by promote the participation of vulnerable groups and building resilience and adaptive capacity of the most vulnerable people such as women, and especially poor and/or rural women; children, especially infants and child-headed families; the aged; the sick; and the physically challenged;
- ***Promote environmental support for climate adaptation***
  … by promoting the protection of ecosystems and biological diversity because of the role they play in supporting South Africa's adaptation to climate change;
- ***Address capacity gaps***
  … by promoting the development of capacity in climate change adaptation throughout South Africa;
- ***Facilitate the mainstreaming of adaptation***
  … by promoting the integration of adaptation in the policies and planning of sectors as well as all three spheres of government;
- ***Be a continuous, progressive and iterative process***
  … with a strong Monitoring and Evaluation (M&E) System and any further iterations of the NCCAS being influenced by outcomes of M&E; and
- ***Support transformative change***
  … with this entailing the promotion of advancements in technology that consider social and economic factors and that result in system-wide change.

These principles need to be adhered to but are, on occasion, challenging to adaptation to climate change in the South African water sector, as in the case of adaptation adhering to a country-wide approach.

2.5 SETTING THE SCENE ON ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: LONG-TERM GOALS, MORE LOCALLY FOCUSSED APPROACHES UPON WHICH ADAPTATION ACTIONS SHOULD BE DEVELOPED AND COMMITMENTS BY DWS TO THE ABOVE HYDROLOGICAL ADAPTATION APPROACH

A Preamble to Long-Term Goals of a South African Water Sector Adaptation Strategy

Given mapped evidence from the spatially detailed databases/inputs at Quinary catchments resolution across South Africa, including Lesotho and Eswatini, on
- historical climate

and the mapped evidence when using daily climate outputs from equally spatially detailed
- multiple and bias-corrected RCP8.5 climate change scenarios for different periods of time,

which include maps on projected
- changes in annual and more extreme rainfalls and their spatial patterns across South Africa, including confidence bands of these projections,
- changes in annual and seasonal temperatures and their spatial patterns across South Africa, including confidence bands of these projections, and
- changes in annual reference potential evaporation across the country, again including confidence assessments of these,

and, by using daily time-step simulations with the *ACRU* physical-conceptual and process-based hydrological model, producing maps of
- projected changes in mean and more extreme annual
- total runoff (i.e. stormflow plus baseflow) per Quinary catchment, as well as
- accumulated streamflows from the runoff of all upstream Quinaries

again, with confidence assessments of each,

the ***long-term goals of a hydrologically-related adaptation strategy for South Africa*** are to utilise the above mapped information to
- develop
- support,
- maintain and
- enhance

the adaptation capacity from hydrologically-related
- *natural systems*, as well as from
- *anthropogenic* (i.e. human) *systems* which include societal, engineering, governance and economic systems across the country.

More Locally Focussed Approaches Upon Which Adaptation Actions Should be Developed for the South African Water Sector

Further to the approaches shown in **Figure 2.1.1**, the approaches and goals upon which adaptation actions for the South African water sector should be developed need to include:
- Identifying and naming hydrologically-related dangers and risks within the uniquely South African hydrological set-up, and
- Communicating these dangers and risks to relevant public authorities such as the DWS, the WMAs and to private authorities, in a transparent manner, in regard to
  - their likelihood of occurrence,
  - their damage potential and

  - the uncertainties surrounding them;
- Raising awareness of these and sensitising relevant decision makers and society at large;
- Presenting the scientific foundations upon which rational and pre-emptive hydrologically-related decisions can be made, which will enable the various actors to take precautions and to make provisions for the incorporation of consequences / impacts of climate change in a step-wise manner in
  - private,
  - economic/business and
  - governmental

  planning and actions,
- Identifying possibilities of adaptation actions,
- Identifying responsibilities and making proposals on the delegation of these responsibilities to enable the adaptive measures to be put into practice, and
- Formulating steps of action for the above.

Commitments Foreseen by the DWS to the Above Hydrological Adaptation Approach

Such a hydrological adaptation strategy for South Africa has to have the DWS committing itself
- to the principles of transparency
- to intra-departmental co-operation within DWS and to
- to inter-departmental co-operation within government structures at
  - national
  - provincial
  - WMA and
  - Municipal (District and Local) levels

with this
- on the basis of the sound science and knowledge provided, *inter alia*, by this Project,
- on flexibility and being oriented towards foresight and precaution,
- on the relative and sometimes unique needs across the municipalities, provinces and WMAs of South Africa, as well as on the needs of the country as a whole,
- on any proposed initiatives by authorities
  - being undertaken with integrity,
  - being actually implementable and then actually implemented, and
  - being maintained, and
- on initiatives being based on the principle of sustainability,

with all of this also
- in light of international initiatives and goals (e.g. CoP, IPCC, Paris Agreement) and South Africa's interactions with, and commitments / responsibilities towards those.

2.6 BECOMING MORE PRACTICAL IN REGARD TO ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: TOWARDS AN APPROACH TO ADAPTATION TO CLIMATE CHANGE IN THE WATER-RELATED SECTOR

The approach adopted here is to

- first, identify the ***major categories*** in which adaptive capacity can be enhanced, to
- secondly, identify ***important sectors*** within the broader water-related community in South Africa which are likely to be impacted, and then to
- thirdly, identify what the various sectors would have to be coping with, and adapting to, in regard to projected
  - ***changes in the drivers*** of the hydrological system (e.g. changes in temperature, evaporation and / or rainfall characteristics) and
  - ***changes in the responses*** of the hydrological system (e.g. in streamflow, or droughts, or irrigation requirements)

Enhancing Adaptive Capacity

Following Appleton *et al.* (2003) and Schulze (2005), five major categories of enhancing adaptive capacity may be identified, *viz*. those relating to

- technological and structural issues,
- knowledge, skills and participation,
- policy instruments,
- risk sharing and risk spreading, and to adaptation around changes in
- uses of land, activities on the land and the location of activities.

These five major categories are then divided into sub-categories which are considered relevant to the South African water-related sector and these are, in turn, further sub-divided for consideration in climate change adaptation practices, as shown in the breakdown below.

- ***Technological and Structural Issues***
  - Storage and Reticulation
    - Surface Water
      - Large Reservoirs
      - Small Reservoirs
    - Groundwater
      - Artificial Recharge
      - Borehole Drilling
      - Sand Dams
    - System Maintenance
      - Supply Leakage Control
      - Irrigation Equipment Maintenance
      - Irrigation Canal Leakage / Losses
    - Rainwater Harvesting
    - Water Re-use / Recycling
  - Water Quality and Quantity Monitoring Systems
  - Desalination
  - Flood / Storm Surge Control
    - Structures (i.e. Dams, spillways, stormwater systems, levees, sand bags, wave breaks, vegetative planting)
  - Early Warning Systems
    - Near Real-Time (Hours to one day)
    - Short-Term (Days to weeks)

    - Medium-Term (Month to season)
    - Long-Term (Years to decades)
  - Communication of Forecasts to End Users
    - Awareness Creation at Higher Decision-Making Level
    - Awareness Creation at Operational Level (e.g. Municipal wastewater treatment, i.e. WWT)
    - Training at Middle Management Level
    - Training at Local Level (e.g. Municipal WWT operators)
  - Operations / System Improvements
    - Reservoir Operating Rules
    - Retrofitting Existing Structures
    - Irrigation Scheduling
    - Wastewater Treatment Works
    - Sanitation
  - Water Demand Management
  - Indigenous Coping Strategies
  - Precipitation Enhancement
- ***Issues Surrounding Knowledge / Skills / Participation***
  - Research and Development
    - Efficient Technologies
    - Upgrading of Climate Models
      - Improvements to Downscaling of GCMs / Regional Climate Models
      - Fine Scale Information Provision Relevant to Local Water Managers
    - Improve Forecast Skill / Dissemination
    - Development of Drought Resistant Crops
  - Development of Risk Maps / Floodlines
  - Communication, Training, Dissemination
    - Awareness Creation at Higher Decision-Making Level
    - Awareness Creation at Operational Level (e.g. Municipal wastewater treatment, i.e. WWT)
    - Training at Middle Management Level
    - Training at Local Level (e.g. Municipal WWT operators)
    - Knowledge Management to Influence Decision Making (e.g. Synthesising; re-assessing; sectorising)
  - Participatory Approach in Decision-Making
    - Establishment of Inter-Departmental Learning Platforms (e.g. Task teams)
    - Establishment of an Integrated Communication System (Trends, priorities, activities, risks)
    - Creation of Ongoing Learning and Communication Platforms among Main Water Users (e.g. Water Research Commission Reference Group meetings)
- ***Policy Instruments***
  - International Conventions (e.g. UNFCCC)
  - International Water Agreements
  - International Trade
  - National Water Master Plans
    - National Water Act of 1998
    - Water Services Act of 1997
    - National Water Resource Strategies of 2004 and of 2013 and updates thereof
    - Water for Growth and Development Framework of 2009
    - Catchment Management Strategies (CMS)
    - Estuary Management Plans
  - Other National Master Plans
    - National Environmental Management Act (NEMA)
    - Conservation of Agricultural Resources Act (CARA)
    - Integrated Development Plans (IDPs)

- Provincial Strategies
  - Provincial Growth and Development Strategies (PGDS)
  - Provincial Water Reconciliation Strategies
- Local Strategies
  - Municipal Bye-Laws
- Disaster Management Policies / Action Plans

- ***Issues Surrounding Risk Sharing / Spreading***
  - Private Sector Strategies
    - Insurance
      - Primary Insurers
      - Re-Insurance
      - Micro-Insurance
    - Banks
      - Development
      - Private
      - Micro-Lenders
    - Stock Exchange
  - Public Sector Strategies
    - Drought Relief by Government
    - Flood Relief by Government
- ***Changes of Land Use / Activities / Locations***
  - Land Use Measures
    - Conservation Structures
    - Adaptive Spatial Planning
    - Tillage Practices
    - Use of Organic (instead of chemical) Fertilizers
    - Alien Invasive Clearing Activities
  - Crop Changes
  - Resettlement
  - Maintenance or Re-establishment of Natural Capital (e.g. wetlands, estuaries, buffers zones, etc.)

2.7 BECOMING MORE PRACTICAL IN REGARD TO ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: WHICH ARE THE KEY IMPACTED INSTITUTIONS AND SECTORS, AND WHICH HYDROLOGICAL DRIVERS AND RESPONSES DO THEY HAVE TO COPE WITH, AND ADAPT TO, UNDER PROJECTED CLIMATE CHANGE??

Which are the Key Institutions and Sectors Impacted Upon by Climate Change?

Many water-related institutions and sectors in South Africa are likely to be impacted upon by climate change, and at minimum the following key ones have been identified:

- National Water Planners (e.g. Department of Water and Sanitation, DWS)
- Regional Water Planners (e.g. Water Management Agencies, WMAs)
- Bulk Water Suppliers (e.g. Umgeni Water; Rand Water)
- WUAs / Irrigation Boards (e.g. LORWUA; water availability)
- Municipalities (e.g. in regard to infrastructure)
- Disaster Risk Management (e.g. flooding, evacuation)
- Rainfed Agriculture (including Afforestation and Livestock Activities)
- Irrigated Agriculture (re. magnitude and frequency of irrigation applications)
- Insurance Industry (e.g. infrastructure damage from high rainfalls, flooding)
- Road Transport Sector (e.g. SANRAL; damage to roads, culverts, bridges)
- Thermal Electric Power Industry (e.g. Eskom; water for cooling)
- Hydro-Electric Power
- Informal Urban Communities
- Individual Households
- Aquatic Ecosystems (e.g. estuaries, wetlands, buffers, environmental flows)
- Terrestrial Ecosystems (e.g. biodiversity, land degradation, fire, alien invasives)

Which Hydrological Drivers and Responses do These Sectors have to Cope with, and Adapt to, Under Projected Climate Change?

The above sectors making up the wider water community in South Africa and those who manage the water will need to cope with, and adapt to, a range of changes which are foreseen to both climate drivers and to the hydrological responses to the changes of those drivers. Anticipated changes to the following are considered in this adaptation approach, noting that this list below is not exhaustive and that the distinction between what are considered drivers and what are seen as naturally occurring vs. anthropogenically impacted responses is not always clear-cut.

In **Table 2.7.1** a check list is made as to which of the (selection of) water sectors identified in South Africa needs to adapt in some way or other to the climate and hydrological drivers identified as being important within the country. It is important to note that not all of the water sectors identified need necessarily adapt to all of the drivers of climate change. Note also that different water specialists may interpret the table differently!

Table 2.7.1 Water sectors within South Africa which need to adapt to different climate drivers and / or hydrological responses

Adapting to Changes in …	National Water Planners in DWS	WMA Planners	Bulk Water Suppliers	WUAs & Irrigation Boards	Munici-palities	Disaster Risk Manage-ment	Aquatic Eco-Systems	Terres-trial Eco-Systems
CLIMATE DRIVERS								
Enhanced Evaporation	√	√		√			√	√
Heat Waves			√	√	√	√	√	√
Annual Rainfall & CV	√	√	√	√	√		√	√
Seasonal Rainfall & CV	√	√	√	√				√
Threshold Rainfall >>	√	√	√	√	√	√		√
Design Rainfall < 24h	√	√	√		√	√		√
Design Rainfall 1-7 Days	√	√	√		√	√		√
HYDROLOGICAL DRIVERS – NATURAL								
Water Temperature	√	√	√	√	√		√	
Soil Water Content				√				
Ann GW Recharge & CV	√	√	√		√			
Threshold Runoff >>	√	√	√	√	√	√	√	
Flash Floods		√	√	√	√	√	√	√
Regional Floods	√	√	√	√	√	√	√	√
Annual Runoff & CV	√	√	√	√	√		√	
Seasonal Runoff & CV	√	√	√	√			√	
Design Streamflows	√	√	√	√	√	√	√	
Design Peak Discharge		√	√	√	√	√	√	√
Agricultural Drought	√	√	√	√		√		
Meteorological Drought	√	√	√	√	√			√
Hydrological Drought	√	√	√	√	√		√	
HYDROLOGICAL RESPONSES – ANTHROPOGENIC								
Hydrological Yield	√	√	√	√				
Surface Water Supplies	√	√	√	√	√		√	
Transboundary Flows	√	√						
Environmental Flows	√	√		√			√	
Water Quality – Sediments	√	√	√	√	√		√	
Water Quality – Chemical	√	√	√	√	√		√	
Water Quality – Biological	√	√	√	√	√		√	

2.8 BECOMING MORE PRACTICAL IN REGARD TO ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: ADAPTATION WITHIN THE WRC K5/2833 CONTRACT IN REGARD TO ANALYSES AND MAPPING TO ADDRESS THE RISK PERCEPTIONS AND THE RISK NARRATIVES OUTLINED IN THE ADAPTATION SECTION OF THE CONTRACT

The Approach Adopted

Within the Contract and in consultation with the Project's Reference Group the following variables made up of drivers and hydrological responses of climate change were identified for analysis, mapping and assessment in regard to adaptation:

- Potential Evaporation
- Rainfall
- Actual Evapotranspiration
- Local Runoff
- Accumulated Streamflow
- Recharge to Shallow Groundwater and
- Yield

with, in each case, assessments of outputs made at the spatial resolution of the 5 838 Quinary catchments covering the RSA and the geographically imbedded countries of Lesotho and Eswatini for the

- *Historica*l (observed) *period* (HI), i.e. 1950-1999; the
- *Present period* (PR) of 30 years from outputs of multiple GCMs, i.e. 1961-1990; the
- *Immediate future* (IF) period, also termed the *near future*, of 30 years from outputs of multiple GCMs, i.e. 2015-2044; and the
- *Distant future* (DF) period of 30 years from outputs of multiple GCMs, i.e. 2070-2099,

using daily climate inputs from the following spatially downscaled and bias-corrected RCP 8.5 Global Circulation Models (GCMs), *viz.*

- ACCESS1-0,
- CCSM4,
- CNRM-CM5,
- GFDL-CM3,
- MPI-ESM-LR, and
- NorESM1-M

and then averaging results from the outputs from the 6 GCMs.

For each of the 7 variables the following analyses were undertaken as a backdrop for interpreting in regard to adaptation, with the examples below taken from this study at local (i.e. either Quinary or Quaternary catchments) resolution.

Question 1 as a Backdrop to Adaptation: If Adaptation to Climate Change in the South African Water Sector is to be Guided by the Means of Annual Runoff Derived from GCM Outputs, are these Valid / Realistic?

Here comparisons are made, both visual and statistical, to see whether the output computed from the average of the 6 GCMs reflects the output derived from the historical record. While country-wide mapping was undertaken at Quinary catchment resolution, for the sake of visual comparisons results are shown below at Quaternary catchments resolution. Using the variable of local runoff (i.e. without any upstream contributions) as the example, the visual similarities in **Figure 2.8.1** between mean annual runoff derived from historical climate data and that derived from the average of the 6 GCMs used for the period 1961-1990 is clear to the eye, and the statistics with an r^2 of ~ 0.95, the slope of 0.95 close to unity and the intercept at a very low 4.3 mm indicate that the outputs from the GCMs, at this resolution at least, can be used with confidence.

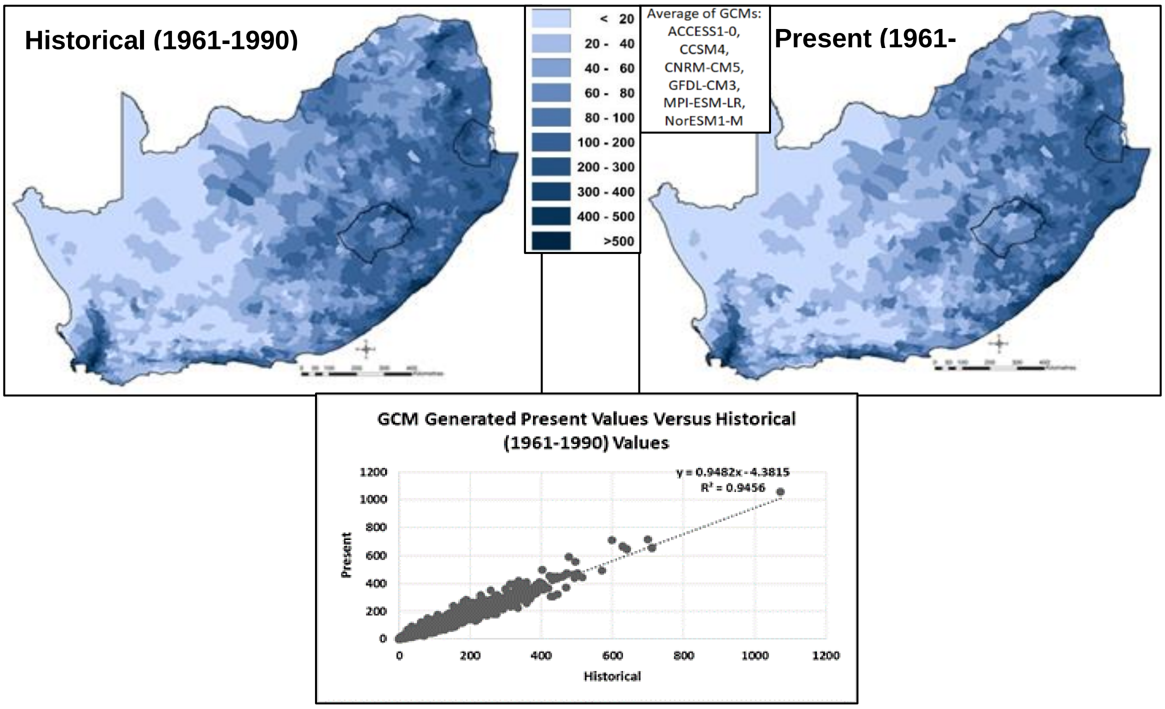

Figure 2.8.1 Mean annual catchment runoff (mm) under natural vegetation conditions derived for the same period from historical climate (top left) and from multiple GCM derived climates (top right), together with a statistical comparison between the two (bottom)

Question 2 as a Backdrop to Adaptation: Where, Across South Africa, are the Projected GCM Derived Changes to Hydrological Variables Significant, Both they in Absolute or Relative Terms? Are They Positive or Negative? And, what is the Magnitude of Change?

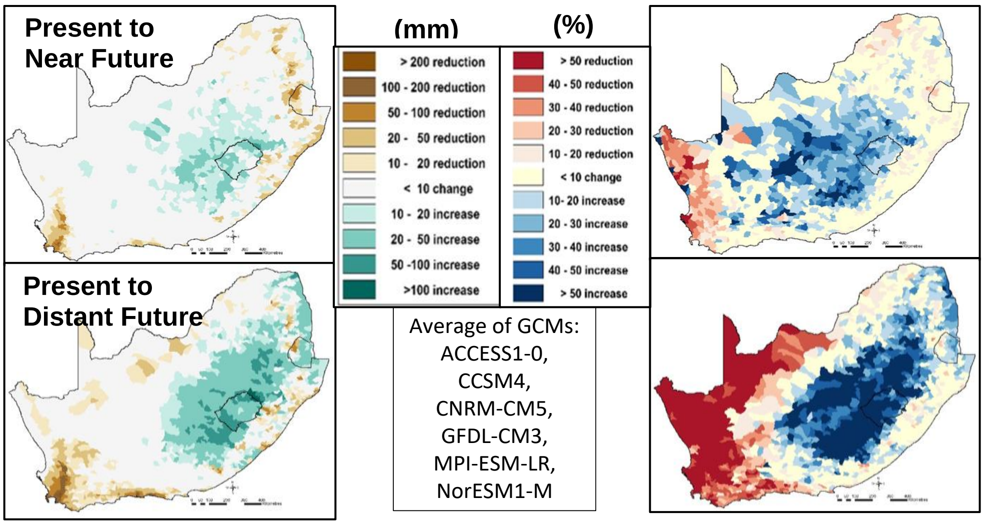

Figure 2.8.2 Projected absolute (mm; left column of maps) and relative (%; right column) changes in mean annual catchment runoff under natural vegetation conditions from the present to the near future (top maps) and the present to the distant future (bottom maps), derived from averages of 6 RCP 8.5 GCMs

In the example of catchment runoff shown in **Figure 2.8.2**, reductions in runoff in absolute (mm) terms are projected into the near future in the south-west, along the east coast and along the mountain ranges of Mpumalanga and Limpopo provinces, while increases are projected parts of the Free State the eastern Cape and Lesotho, with both reductions and increases increasing in magnitude into the distant future. Note that in interpreting such maps in regard to adaptation options, not only mm changes, but also percentage changes become important indicators of potential local adaptation.

Question 3 as a Backdrop to Adaptation: Are there Significant Differences Across South Africa in Projected Changes to Hydrological Variables into the Future Between "Dry" and "Wet" Years which Should be Considered in Adaptation?

While changes to annual means of a hydrological variable may be important, even more significant to practical adaptation may be projected changes to that variable under dry or wet conditions, represented here by changes in the driest (lowest yielding) year in 10 and the wettest (highest yielding) year in 10. This may be particularly important in South Africa with its exceptionally high inter-annual variability of runoff, as shown in the left-hand maps of **Figure 2.8.3** by the significant differences in historical annual runoff between the lowest flows in 10 years (top left map) vs. the highest flows in 10 years (bottom left map).

An important feature for adaptation planning from the maps showing ratios of near future (2030s-2040s) to present (1980s) annual runoff is that for dry years the changes, be they additional runoff or reduced runoff, are much more marked than for wet years, when the changes are more muted. The implication is that planning and adapting for years with water deficits is more crucial than adapting for high flow years in regard to water resources.

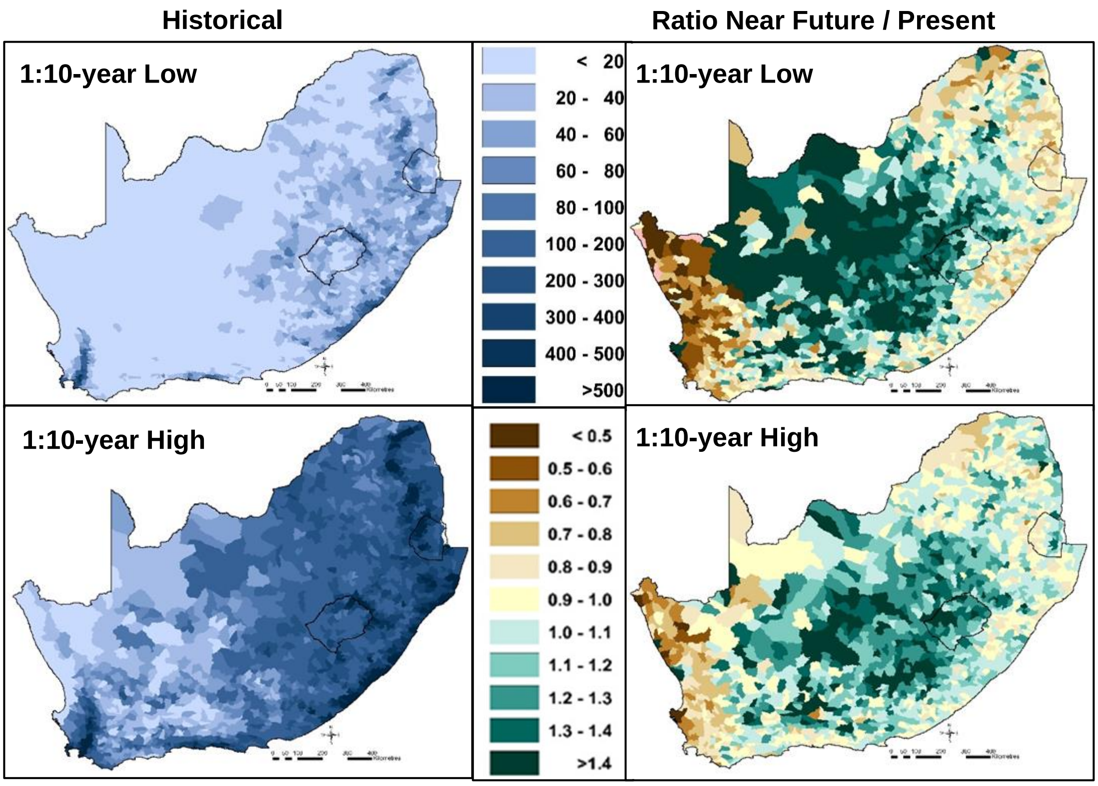

Figure 2.8.3 Ratio changes in annual catchment runoff into the future under natural vegetation conditions in the 1:10 year low flow year (top right) and the 1:10 year high flow year (bottom right) compared to equivalent conditions of annual runoff under historical climatic conditions (left maps)

Question 4 as a Backdrop to Adaptation: Does Actual Land Use Produce Results that are More Sensitive or Less Sensitive to Those from Natural Vegetation Under Climate Change Scenarios in Regard to Affecting Adaptation Policy and Practice?

By way of convention, projected changes to hydrological responses as a result of climate change are generally assessed assuming a land cover of natural vegetation. The “real world” has, however, altered natural vegetation by converting it into many different actual land uses including agriculture, urbanisation and, in the South African case, degraded areas, all of which affect hydrological responses such as runoff to a greater or lesser extent. In **Figure 2.8.4** absolute changes (in mm) and relative changes (as a %) to annual runoff from the present to the near future are shown assuming natural vegetation (top maps) and actual land use represented by the 2018 National Land Cover.

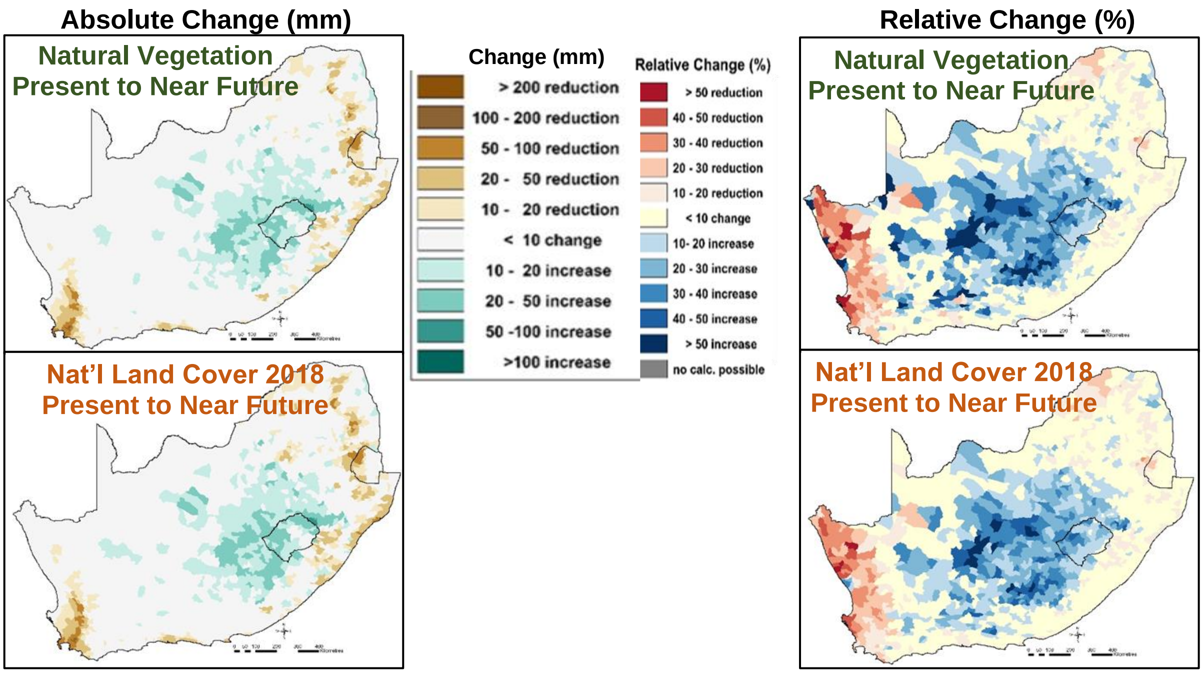

Figure 2.8.4 Projected absolute changes (in mm; left column of maps) and relative changes (in %; right column) in mean annual runoff from the present to the near future of the 2030s, mapped assuming natural vegetation (top maps) vs. assuming actual land cover from the 2018 National Land Cover map

At first glance to the naked eye the maps in **Figure 2.8.4** derived from natural vegetation vs. those derived from actual land uses, both in absolute and in relative terms, appear remarkably similar. However, upon closer inspection the maps do reveal differences in both the degree of change and in the spatial distribution as a result of conversion from natural vegetation. As a ratio change, the impacts of actual land uses on climate change responses are shown in **Figure 2.8.5**, with shades of green indicating that actual land uses are more sensitive in runoff responses to climate change than natural vegetation, while yellow to brown shading indicates that actual land uses would be less sensitive than natural vegetation to climate change.

The significant general findings across South Africa are that

- *actual land uses on runoff responses are more sensitive to climate change than natural vegetation*, shown by most areas across South Africa in **Figure 2.8.5** being in shades of green, that
- actual land use impacts on runoff are *more sensitive in low flow years*, i.e. under dry conditions, when vegetation cover is sparse than under average or high flow / wet conditions when vegetation cover is denser (*cf*. larger circle in top left map vs. smaller circle in top right map of **Figure 2.8.5**), that

- actual land use impacts under climate change are *more sensitive in urban nodes with their impervious surfaces* than in rural areas of similar climates (e.g. yellow circles) and where there are large dams (e.g. blue circles), while
- actual land use impacts under climate change appear *less sensitive than natural vegetation under intensive commercial afforestation* with their higher biomass (dark green circles).

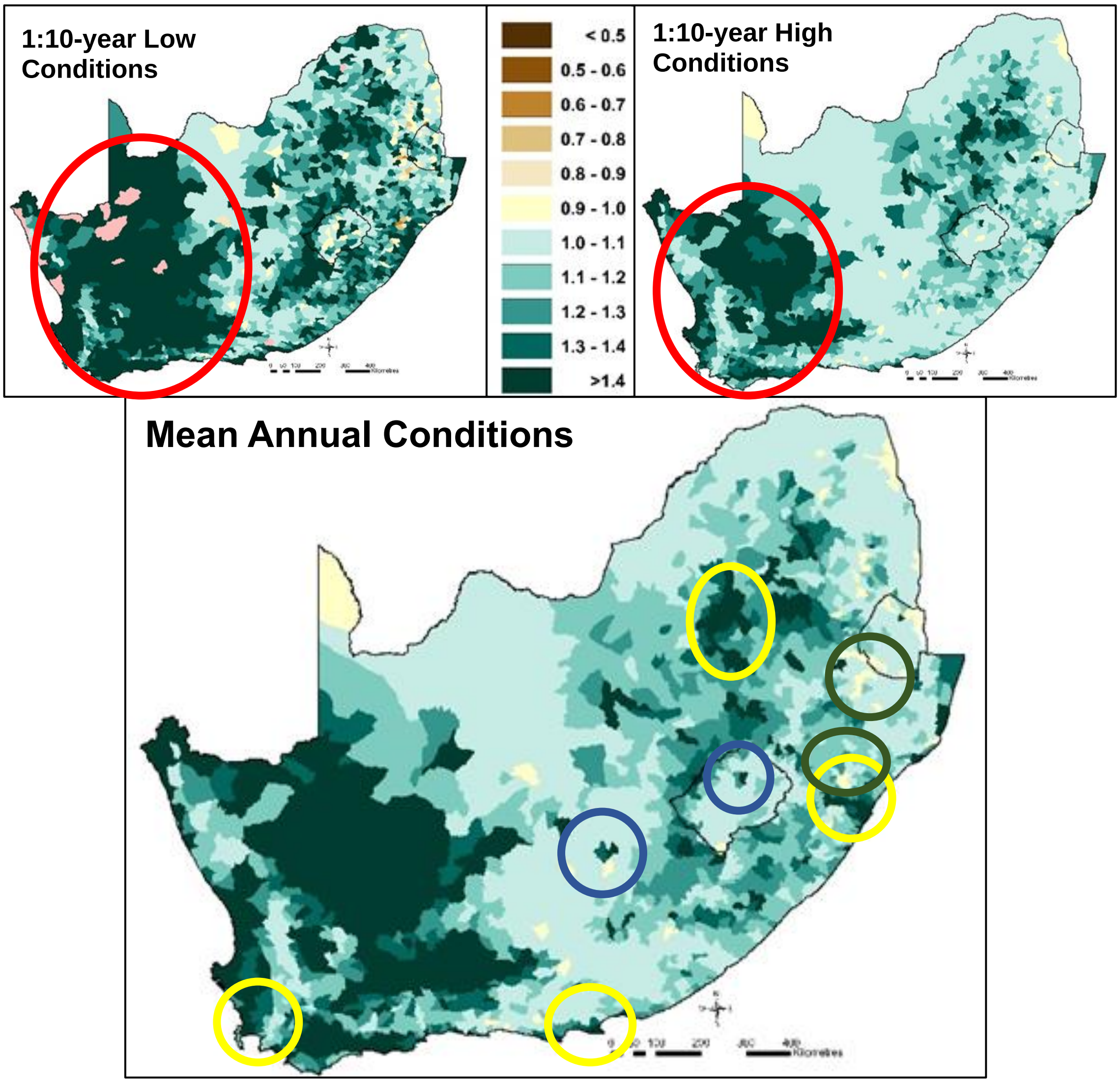

Figure 2.8.5 Sensitivity of actual land uses vs. natural vegetation to runoff responses under climate change, with shades of green indicating the degree of sensitivity to actual land uses

- Note that the hydrological impacts of land uses in the maps above are highly generalised as they were averaged over the spatial resolution of Quaternary catchments, and that in reality they are far more localised with major differences in land use sensitivity to climate change in close proximity to one another.

Question 5 as a Backdrop to Adaptation: Why Use Outputs from *Multiple* GCMs for Hydrological Assessments of Climate Change? Do We Not Have Full Confidence in Any Single GCM's Hydrological Responses to Projected Climate Change?

- Hydrological responses such as runoff depend, *inter alia*, on climate drivers, primarily rainfall. Rainfall, however, is not a primary, but is rather a secondary output of many GCMs. With GCMs all based, at least partially, on differing vertical, synoptic and hence spatial assumptions in their internal calculations into the future, it stands to reason that different GCMs yield different outputs of daily and hence of annual rainfall into the future.

- This is manifest in **Figure 2.8.6**, which shows the following:
- Projected relative (i.e. %) changes in mean annual rainfall (MAP) by the 6 GCMs used are shown from the present to the near future in the left set of maps and from the present to the distant future in the right set of maps.
- While, among the present to near future projected changes in MAP of the 6 specific GCMs used in this study, there are some broad commonalities with MAP set to increase in some central parts of South Africa and set to decrease along the west coast, a key feature is that the 6 GCMs display significant spatial differences in projected changes in annual rainfall.

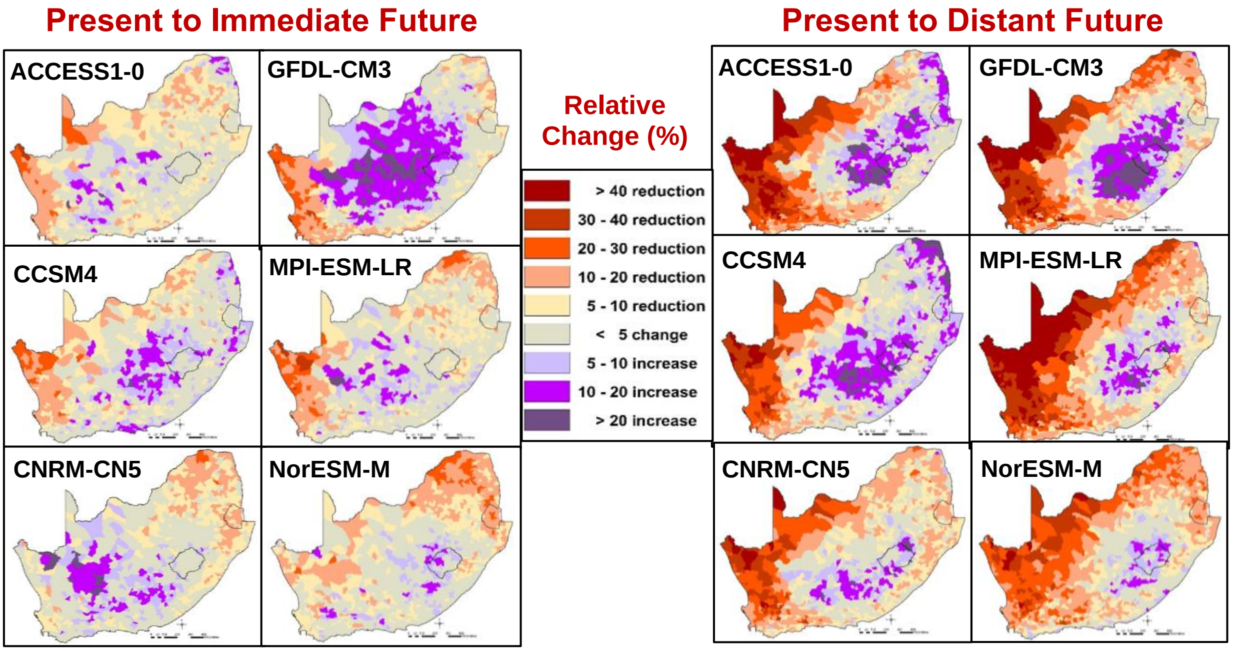

Figure 2.8.6 Projected relative (%) changes in mean annual rainfall by the 6 GCMs used, from the present to the near future (left set of maps) and from the present to the distant future (right set of maps)

- The spatial differences among the maps are less evident into the distant future than into the near future.
- While annual rainfalls from the GCMs are already partially at variance with one another, it has to be assumed that key hydrological conditions such as intermittency between rainfall events and numbers of rainfall events above certain daily thresholds will also be quite different among the GCMs.
- Hence, from an adaptation perspective, we cannot have full confidence in hydrological responses to climate change.
- When differences in mean annual rainfall among GCMs are already evident, as in **Figure 2.8.6**, then differences in runoff derived from the different GCMs will be even higher, given the amplification effect in hydrology.

Question 6 as a Backdrop to Adaptation: Do Changes from Any Single GCM "Dominate" the Outcomes of Multiple GCM Averages?

Does any single GCM "dominate" spatially in consistently displaying the highest and/or lowest absolute (mm) or relative (%) changes in MAP and other statistics between the present and the immediate future? This has not yet been assessed. If so, what are the implications of this in risk and adaptation? If patterns are spatially clustered vs random, is caution in further interpretations needed?

Question 7 as a Backdrop to Adaptation: Given that We Cannot have Full Confidence from Outputs from Multiple GCMs in a Key Hydrological Driver of Climate Change, *viz*. Rainfall, Do We Have Equal Lack of Confidence in All Hydrological Drivers and Responses in Regard to Adaptation?

Statistically, in this Project, confidence in multiple GCM derived hydrological drivers (e.g. rainfall) and responses (e.g. runoff or recharge to the groundwater zone) is expressed through the coefficient of variability (CV%) of the inputs or outputs from the 6 GCMs used. A low CV indicates relative uniformity of results from the GCMs, and hence high confidence in results, while conversely a high CV indicates a high dispersion (i.e. big differences) among GCM derived outputs, hence indicating low confidence in the results. Categories of confidence from "very high" with a CV < 5% through "medium" with a CV of 20-30% to "very high" with a CV > 50% are shown in **Figure 2.8.7**.

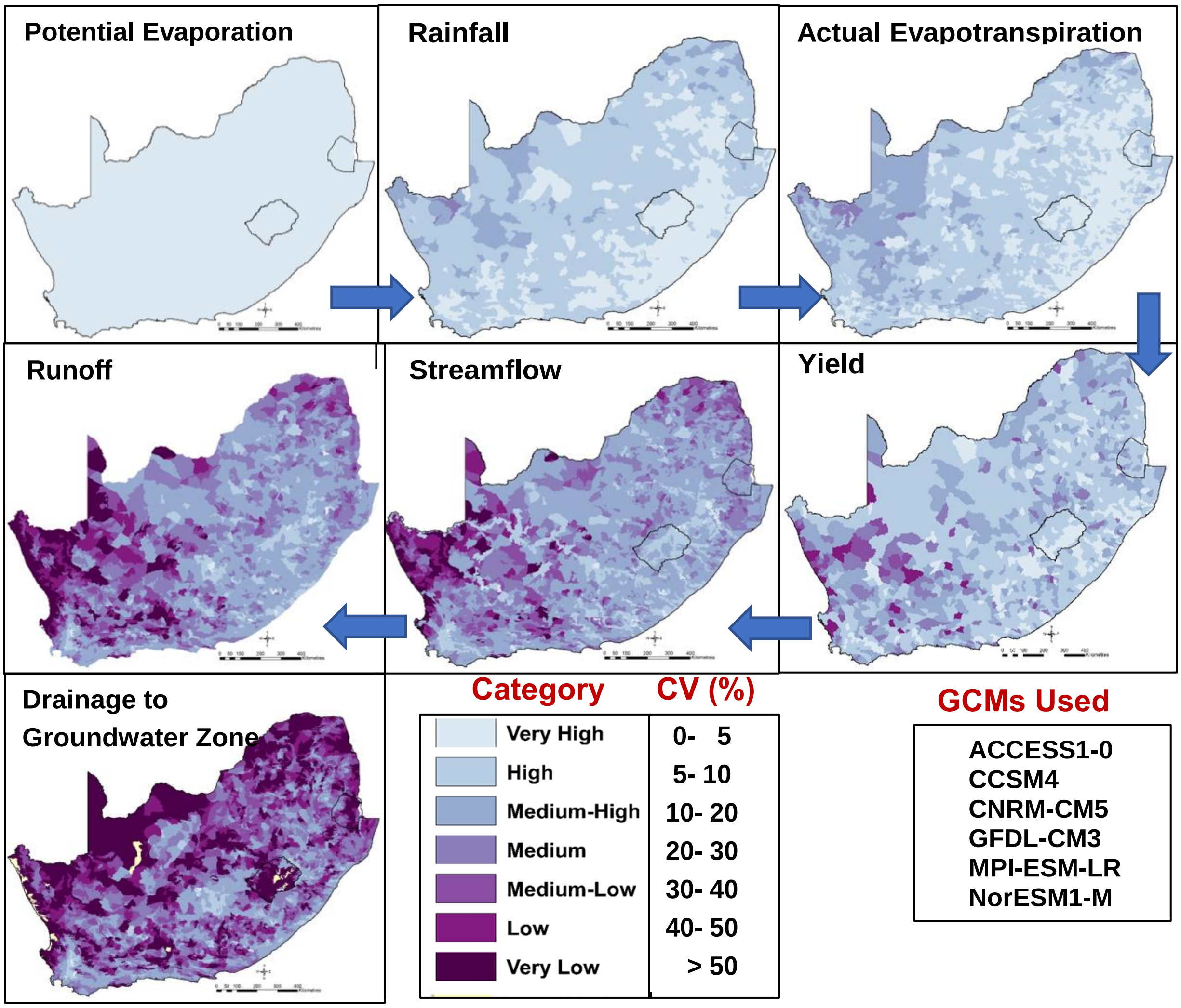

Figure 2.8.7 Confidence in mean annual values of multiple GCM derived hydrological climate change drivers and responses (From Schütte *et al.*, 2021)

In **Figure 2.8.7** results from a confidence assessment based on the 6 GCMs used in this Study are shown, in each case for mean annual values of the hydrological variable. Evident in **Figure 2.8.7** is a "hierarchy" of confidences in the hydrological variables selected in this Project, with

- ***Potential Evaporation***, i.e. so-called atmospheric demand, displaying the highest confidence, with the reason for that being that it is based mainly on temperature, the changes into the future of which are well established, and with one adaptation-related consequence being that increases in irrigation demand can be projected with high confidence; this followed by

- ***Rainfall***, with confidence ranging from “very high” to “medium-high”, but with greater confidence along the coast than in the far interior; then
- ***Actual Evapotranspiration***, which reflects the interaction of rainfall, soils properties and atmospheric demand, and as such the growth potential of dryland crops, with confidence again ranging from “very high” to “medium-high”, but with greater spatial variation than that of rainfall because the other factors come into play; followed by
- ***Yield***, ranging from “very high” in the Lesotho highlands and KwaZulu-Natal as well as Western Cape major river systems, for example, to “medium-low” in the arid west, using accumulated streamflows as a major input, but without accounting for impacts of dams, irrigation or of abstractions; thereafter
- ***Accumulated Streamflows***, made up at any point of local runoff plus runoff from all upstream Quinary catchments, with confidence ranging from “very high” to “very low”, but predominantly “medium-high”, with lower confidence in streamflows in the semi-arid north and west and highest confidence along the major river systems, which have the benefit of more consistent flows from upstream accumulations from higher rainfall areas; then
- ***Runoff***, which represents only the local runoff from the contributing Quinary catchment, with no benefit of the steadying effect of upstream contributions, ranging in confidence from “very high” to “very low”, but displaying some very local effects; and lastly,
- ***Drainage/Recharge to the Groundwater Zone***, a function not only of rainfall thresholds being exceeded, but also of properties down the soil profile, and a very important adaptation consideration to the many smaller urban areas in the semi-arid zones which depend on groundwater as their water supply, with confidence of its being computed into a climate change future ranging from “medium-high” to “very low”, with the latter category predominantly there where groundwater recharge is economically important.

Confidence in the in- and outputs from the multiple GCM used in this Study thus varies considerably by variable and spatially within South Africa. It is, however, the overall lack of confidence from the multiple GCMs of especially the “higher order” hydrological responses, which are crucial in planning the country’s water resources into the future, that need careful consideration when making adaptation recommendations. Furthermore, as **Figure 2.8.8** shows for mean annual runoff, confidence reduces as one moves into the more distant future.

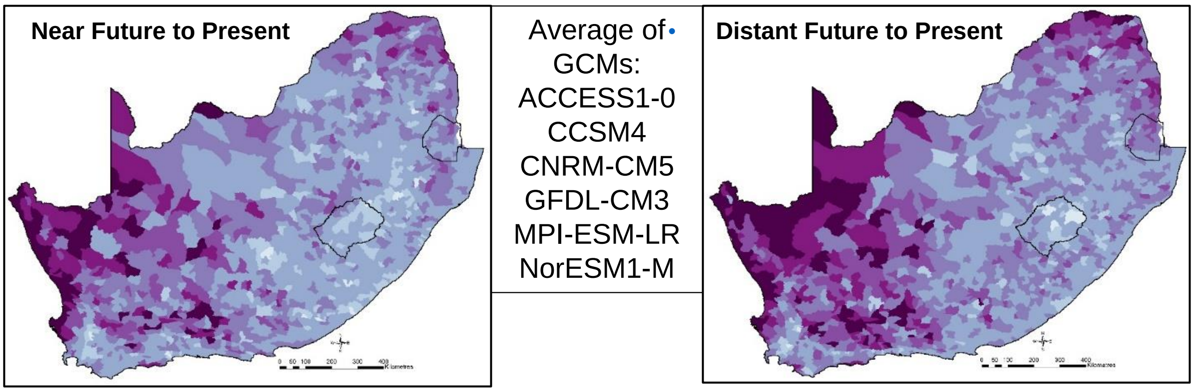

Figure 2.8.8 Reductions in confidence of outputs from multiple GCMs as one moves from the near future (left) to the more distant future (right): Example of annual runoff

2.9 BECOMING MORE PRACTICAL IN REGARD TO ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: CHALLENGES IDENTIFIED WITHIN THE WRC k5/2833 CONTRACT REGARDING ADAPTATION

Aim 4 of Work Package 3 of the Contract recommends appropriate short, medium- and long-term adaptation strategies and options to address projected climate change impacts across South Africa. These come with numerous challenges, however.

Challenge 1: New Climate Change Knowledge has to be Processed into Hydrological Practice

A major challenge in the climate change field, particularly in a water scarce country such as South Africa, is to process new knowledge, new findings and new research results into practice by mainstreaming these into specific planning and implementation realms such as

- hydrological yield,
- the National Water Act's aim of "some for all for ever",
- infrastructure development and
- issuing of water use-related licences

in the near-, the mid- and the long-term future.

Challenge 2: Projected Climate Change Impacts are Superimposed onto an Already Multi-Stressed Environment

In South Africa, impacts of climate change are superimposed onto an already multi-stressed hydrological environment, illustrated by the high inter-annual CVs of streamflow in **Figure 2.9.1**, by being an overarching stressor that further impacts on all spheres of water-related activities. Consequently, adaptation to climate change will have to focus on the way in which the spatially and temporally highly variable water resources are used and managed, and adaptation will thus need a strong emphasis on the design of ***actual*** management interventions and the mainstreaming of those, rather than addressing only on broad-based conceptual issues.

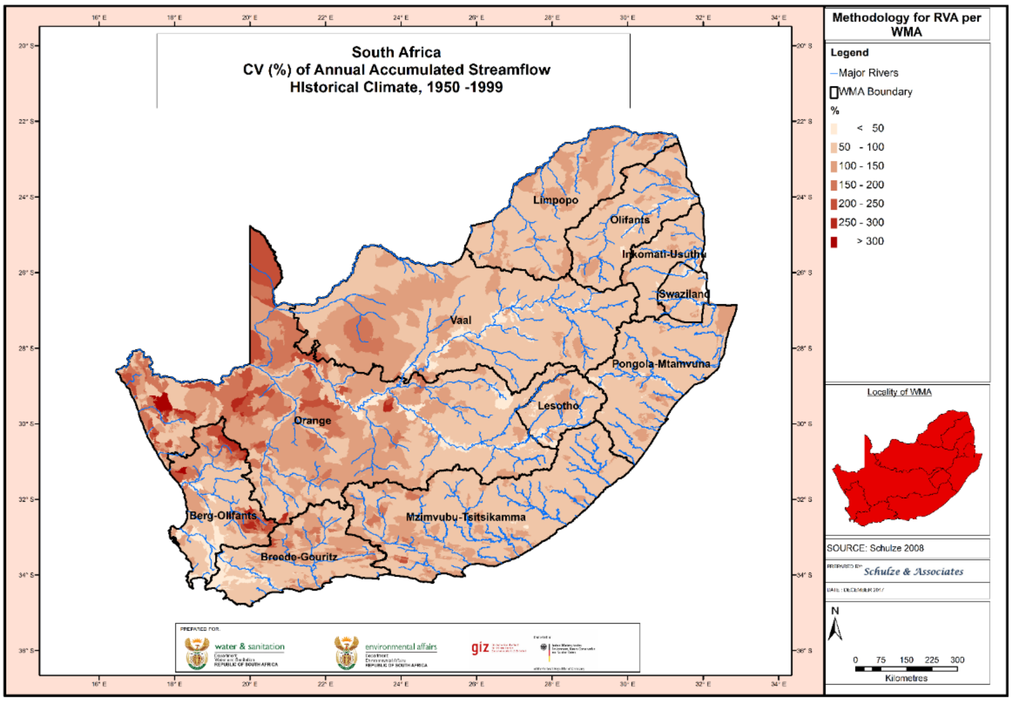

Figure 2.9.1 Inter-annual coefficient of variation of streamflow, illustrating the already highly stressed hydrological environment

Challenge 3: Converting New Findings into Actions Requires Administrative Flexibility

Adaptation requires not only the uptake of hydrological modelling outputs derived from new climate inputs of the most recent bias-corrected GCMs into decision making processes, but will require also the administrative flexibility in the broader South African water sector to change and be responsive to change when provided with outcomes from the new climate models. This is therefore a call for water and allied sectors/disciplines from national to local levels to be dynamic in being not only well informed, but to also offer leadership to create effective strategies of adaptation within the highly complex water sector.

Challenge 4: The Adaptation Process has to be Reviewed Collaboratively and Transparently

In the adaptation process the water-related climate change responses and indicators that have been identified to possibly affect adaptation within the sector will have to be reviewed through a collaborative and open process with the government decision makers at all levels and with other experts in the South African water sector. The point of departure here would be the DWS project team members, with whom potential adaptation strategies would be co-explored.

Challenge 5: Adaptation Actions are Multi-Faceted

Adaptation actions, in addition to the technologically oriented

- bio-physical and
- engineering ones,

would have to include consideration of

- value judgements,
- social issues,
- economic aspects,
- environmental characteristics / considerations and of
- politico-legal aspects

thereby rendering adaptation actions to be highly multi-faceted and, within a South African context, highly complex.

Challenge 6: The South African Geography of Water-Related Adaptation is Complex

Geographically, water sector-related adaptation in South Africa is highly challenging, given that

- we cover a climatically volatile latitudinal range that experiences rainfalls (and hence runoff and flooding) ranging from
    - South Atlantic frontal systems in the south of the country to the
    - inter-tropical convergence zone storms in the north and
    - tropical cyclones in the east, that
- we already experience within one country summer, winter and all-year rainfall regions, and
- already have a very high inter- and intra-annual regime of rainfall variability,
- with all of these projected to shift geographically with climate change and /or in intensity.

Challenge 7: Any Relative Changes in Rainfall are Amplified into Relative Changes in Runoff

Notable for adaptation in the water sector is that the impacts of all of these are amplified when changes in rainfall are converted to changes in streamflow or groundwater recharge.

Challenge 8: Adaptation in the South African Water Sector is a Very Local Issue

Furthermore, unlike the case in many first-world situations, broad country- or region-wide adaptation-related statements are frequently meaningless in the "South African real world" as adaptation to any change in rainfall or runoff, even within the same hydro-climatic regime, becomes a local, sometimes a very local, issue as a result of the

- spatial juxta-positioning of "haves and have-nots", of
- areas with well vs. poorly serviced water infrastructure, or of
- living within vs. beyond flood-prone river frontages.

Broad textbook and research paper type conceptual and governance issues on adaptation then become less of a key issue in the South African situation than practical and local acts of adaptation.

Given these complexities, meaningful practical adaptation design to climate change in South Africa's water sector, and mainstreaming thereof, then frequently becomes an issue of working at case study level.

2.10 BECOMING MORE PRACTICAL IN REGARD TO ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: POSSIBLE *FIRST ORDER* ADAPTATION OPTIONS AVAILABLE TO THE SOUTH AFRICAN WATER SECTOR *BEYOND* THE WRC K5/2833 MANDATE

Background

Practitioners deciding on adaptation options, be they at national level, at WMA level, at local government level and even at community or farm level will have to decide which of the hydrological changes listed in the three categories below are relevant to them, with these being

- *first order* hydrological changes which include the drivers of climate change and resultant changes in streamflow patterns,
- *second order* changes which consider extreme events and groundwater recharge, and
- *third order* human-related hydrological changes re. water allocation, demand, use or quality.

In the examples which follow below there is some repetition of maps already shown elsewhere in this Project's documents, but this time within a context of adaptation, with some of the maps at national level and others at WMA level. Some mapped information is already available from this and other projects, while considerable future / follow-up projects are still required in regard to identifying further adaptation needs. ***Highlights in green*** present an interpretation of results with respect to adaptation.

First order changes to which adaptation options should be considered in South Africa include the following:

Identifying Temperature Sensitive Areas by Assessing Changes in Maximum, Minimum and Other Temperature-Related Patterns

From a hydrological perspective these revolve, for example, around magnitudes of changes in mid-summer temperature maxima and mid-winter minima, their variability and confidence in results, including heat waves, defined here as 3 consecutive days with maximum temperatures exceeding 30°C on each day and extreme heat waves have 3 consecutive days each exceeding 35°C, and where, hydrologically, any increases in heat waves into the future affect household and irrigation water use as well as evaporation losses from rivers and dams, and what should be considered to adapt to these changes.

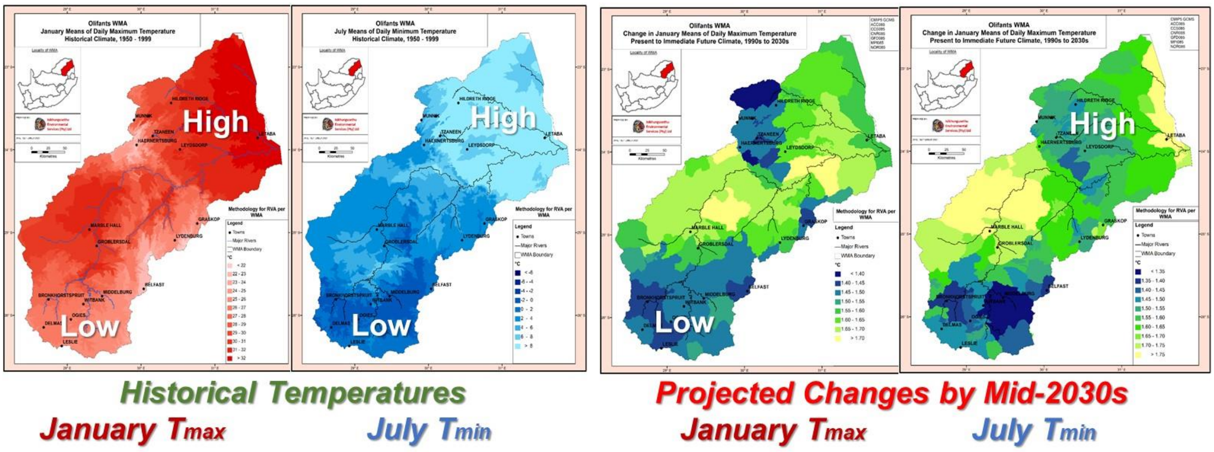

Figure 2.10.1 Example from the Olifants WMA of historical January maximum and July minimum temperatures (left set of maps) and projected changes from the present (mid-1970s) to the immediate future (mid-2030s; right set of maps), the latter derived from an average of 6 CMIP5 GCMs (From Schulze *et al.*, 2021)

In **Figure 2.10.1** it is already shown from just one WMA that projected changes in summer maximum and winter minimum temperatures are not spatially uniform and that this must be considered in local adaptation strategies.

Changes in Annual and Seasonal Precipitation Patterns and Their Variability

Included here are their magnitudes, concentrations, seasonal distributions, frequencies and variability, and including confidence in results, bearing in mind that in climate change studies it is the seasonal changes between winter and spring, spring and summer, summer and autumn and autumn and winter, and their changes in variability which may be more important locally in regard to adaptation. Furthermore, what are the ratio changes in inter-annual as well as mid-summer (January) and mid-winter (July) CVs of rainfall between the future and present, where are they relatively higher or lower and how does one respond/adapt?

In **Figure 2.10.2** it is shown for South Africa that projected changes in mean annual rainfall, whether expressed as percentage changes (left map) or in mm (middle), are not spatially uniform, with both increases and decreases in MAP projected, which must be considered in local adaptation strategies, and with confidence in the projected changes being relatively high (right map), especially in the wetter areas.

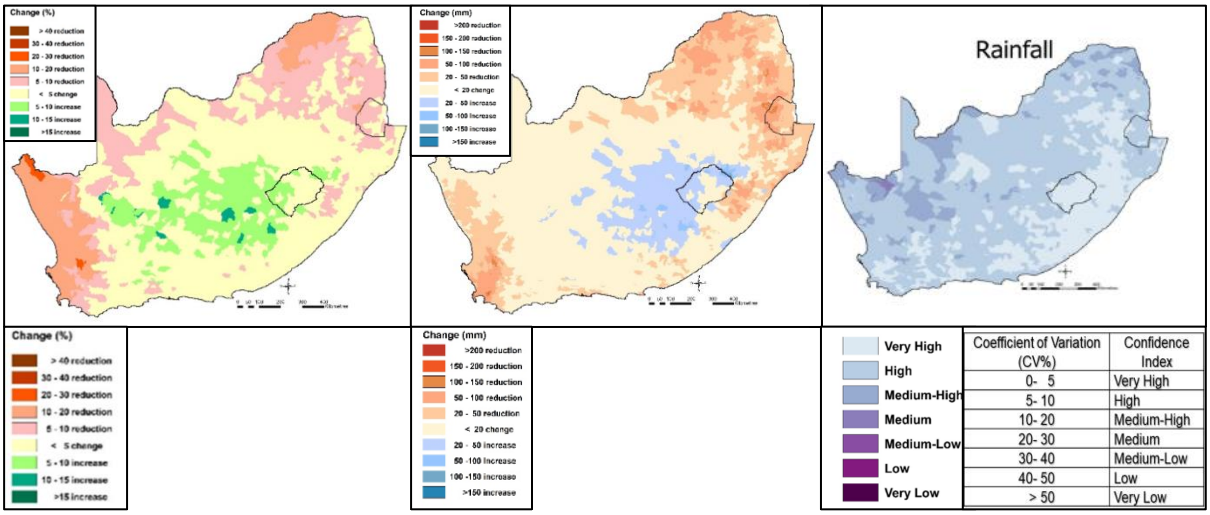

Figure 2.10.2 Projected changes in mean annual rainfall from the present (mid-1970s) to the immediate future (mid-2030s) as a percentage (left) and in mm (middle), together with confidence in the results (right), derived from an average of 6 CMIP5 GCMs (From Schütte *et al.*, 2021)

Changes in Thresholds of Rainfall Exceeded, i.e. "Assault Rainfall Events"

These are the changes, expressed in mm and as a %age, from historical climatic conditions into the future in the number of days per year and in the summer and winter seasons with daily rainfalls exceeding hydrologically critical amounts / thresholds such as 10 mm or 25 or 50 mm/day in regard to changes in the generation of runoff and sediment yield generation. The relevance to risk and adaptation is to identify hotspots of potential damage from high rainfall events in different seasons. Changes may be higher or lower and more vs less important/significant in certain regions or seasons. The key question is whether one needs to adapt to these changes, and if so, where? and how?

Changes in Enhanced Reference Potential Evaporation Rates

Considered here are their magnitude, including confidence in results. This is the evaporation from open water bodies such as rivers, dams and wetlands, as well as from the soil-plant system, over and above that evaporated under present climatic conditions.

In **Figure 2.10.3** it is shown for South Africa that projected percentage changes in mean annual potential evaporation into the immediate future of the mid-2030s (middle map) are not spatially uniform, with increases ranging from ~ 7% to 12%. This needs to be considered in regard to local adaptation strategies re. additional dam, wetland, river and soil evaporation losses. Confidence in the projected potential evaporation changes are very high (right map; see **Figure 2.10.2** for interpretation of legend).

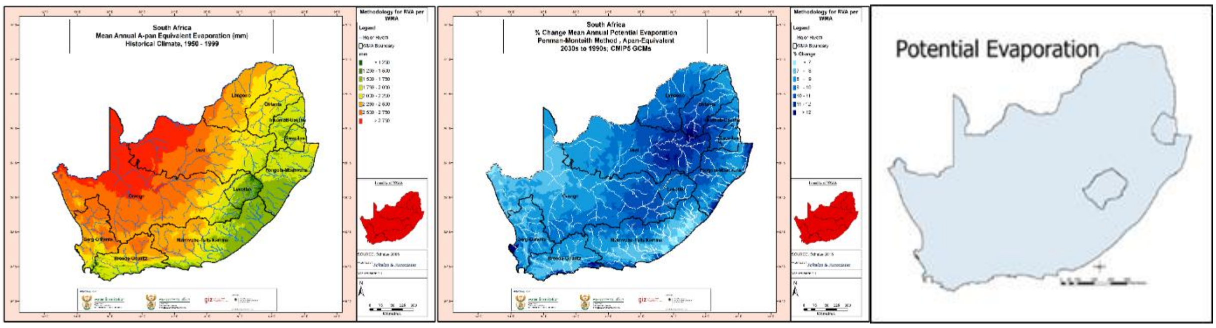

Figure 2.10.3 Mean annual potential evaporation under historical climatic conditions (left), projected changes from the present (mid-1970s) to the immediate future (mid-2030s) as a percentage (middle), together with confidence in the results (right), the latter two derived from an average of 6 CMIP5 GCMs (From Schulze and Davis, 2018; Schütte *et al.*, 2021)

Assessing Changes in Accumulated Annual and Seasonal Streamflow Patterns and Identifying Runoff Sensitive Areas

These include projected changes in regard to their magnitudes, seasonality, shifts in timing, variability, exceedances of thresholds of flow, and including confidence in results. Additionally, areas which in regard to runoff are sensitive to changes in rainfall could be identified by adding / subtracting 10% to daily rainfall in the Quinaries data files and assessing where irrigation demand, runoff and accumulated streamflow outputs would change the most. Furthermore, what are the ratio changes in inter-annual as well as mid-summer (Jan) and mid-winter (Jul) CVs of streamflows between the future and present, where are they relatively higher or lower and how does one respond/adapt?

In **Figure 2.10.4** annual accumulated streamflows across South Africa are shown in the top set of maps in millions of m^3 under 1:10 year low and 1:10 year high flow conditions, as are projected changes (again in $10^6 m^3$) from the present of the mid-1970s to the immediate future of the mid-2030s. Larger than surrounding accumulated flows are clearly visible for the larger river systems such as the Orange-Vaal, the Olifants, the Thukela and the other larger rivers. The major adaptation challenges arise where flow reductions are projected (bottom set of maps), *viz*. in the far north, the east and the south-west of the country, and particularly in the Western Cape which is a growth point with heavy populations and has a largely irrigation dependent agriculture, and further economic development in those areas could be heavily curtailed into the future. Water-related migration could become a major adaptation challenge in decades to come. Adaptation is made a little more difficult in regard to streamflows as the confidence in the projections is only medium to high over much of the country and only medium to low in the more arid north-west, but fortunately with the larger river systems displaying higher confidences in their future projections.

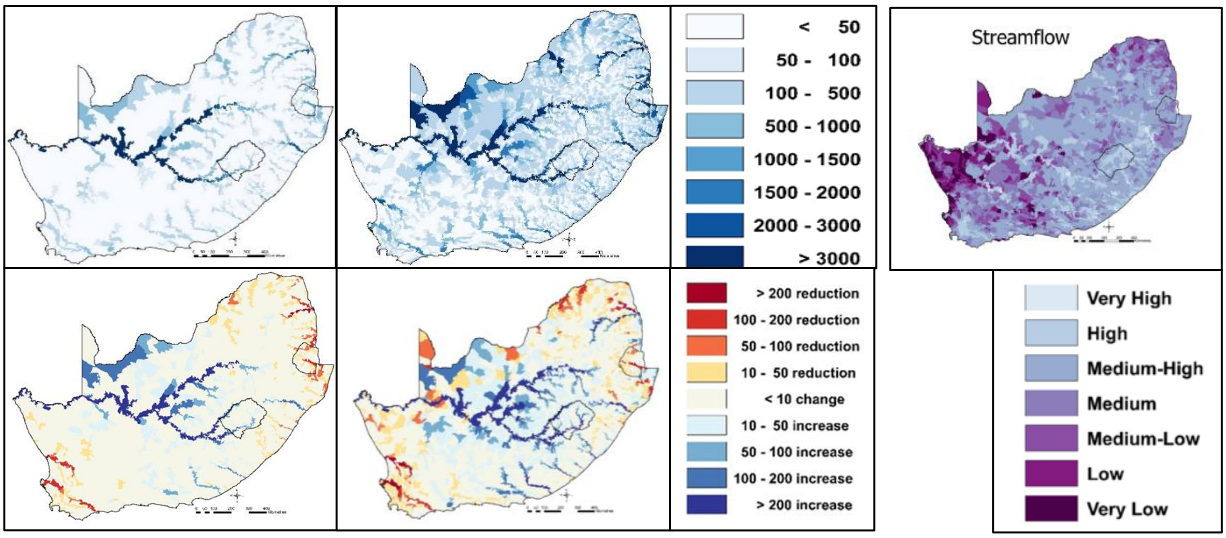

Figure 2.10.4 The lowest historical annual accumulated streamflow ($10^6 m^3$) across South Africa in 10 years and the highest in 10 years (top left and middle), with projected streamflow changes (also in $10^6 m^3$) from the present (mid-2070s) to the immediate future of the mid-2030s for 1:10 year low and 1:10 year high streamflow (bottom left and middle), with confidence in the streamflow projections in the right-hand map (From Schütte *et al.*, 2021)

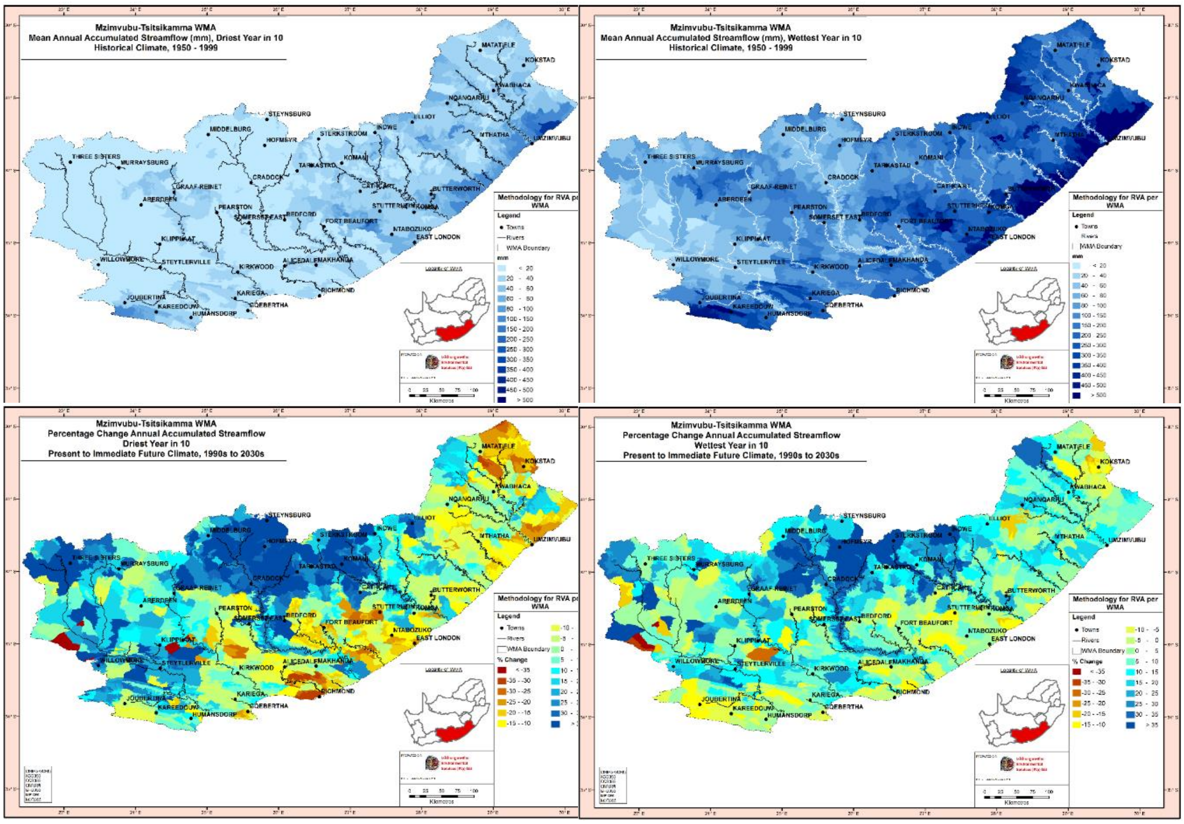

Figure 2.10.5 A more detailed spatial assessment, at the level of the Mzimvubu-Tsitsikamma WMA, of lowest and highest historical annual streamflows in 10 years in mm equivalents across the WMA (top left and right), with projected percentage streamflow changes from the present (mid-2070s) to the immediate future of the mid-2030s for 1:10 year low and 1:10 year high streamflows (bottom left and right), with the bottom two derived from an average of 6 CMIP5 GCMs (From Schulze *et al.*, 2021)

A more detailed spatial assessment, at WMA level for the Mzimvubu-Tsitsikamma WMA by way of example, of lowest and highest historical annual streamflows in 10 years is shown in **Figure 2.10.5** (top left and right), with projected percentage streamflow changes from the present (mid-2070s) to the immediate future of the mid-2030s for 1:10 year low and 1:10 year high streamflows also shown in **Figure 2.10.5 (**bottom left and right). Of relevance to adaptation is that even within a single WMA there may be areas of potential *increased* flows as well as *decreased* flows into the future, and that each WMA may be unique in regard to spatially differential adaptation. In this particular example the generally high runoff coastal areas display potential decreases in flows, and while the larger rivers have projected increased flows derived from the interior (**Figure 2.10.5** bottom maps) it is the areas away from the larger rivers that will have to utilise water more carefully / sparingly than at present.

Changes in Thresholds of Streamflows Exceeded, i.e. "Assault Streamflow Events"

These thresholds represent the number of days per year, per summer and/or per winter season on which daily streamflows at a point, accumulated from all upstream catchments, exceed hydrologically critical flow amounts such as 5 mm equivalent per day, or 10 or 20 mm, under historical and projected future climates, expressed in absolute (numbers) and/or relative (%) terms. Changes may be higher or lower and more vs less important / significant in certain regions or seasons in regard, for example, to environmental flow criteria or inflows into dams. They include days with no flow or with insignificant amounts of flows. Unlike rainfall, streamflows above thresholds are also dependent on antecedent conditions. Key questions include whether one has to adapt, and if so, how and where?

Changes in Soil Water Content

This is the day-by-day water content in the soil profile under future vs. present climates, where the soil water content affects runoff generation for a given amount of rainfall, as well as determining whether a plant experiences no water stress, mild stress or severe stress because of a lack of soil water, or stress to plants when the soil becomes waterlogged.

Changes in Streamflow Components

These are projected changes to stormflows and baseflows, as well as confidence in results.

2.11 BECOMING MORE PRACTICAL IN REGARD TO ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: POSSIBLE *SECOND ORDER* ADAPTATION OPTIONS AVAILABLE TO THE SOUTH AFRICAN WATER SECTOR *BEYOND* THE WRC K5/2833 *MANDATE*

By second order changes to which adaptation options should be considered in South Africa, the following are understood:

Changes in Short Duration (5 min - 24 h) Design Rainfalls Events for the 1:2 to1:100 year Return Periods

The rainfall expected statistically only once in 2 or 5 or 10 or 20 years for a period of time ranging from anything between 5 minutes and 24 hours, is used in the sizing / design of, for example, stormwater systems. While critically important in engineering design, any durations of rainfall below 1 day cannot be explicitly derived from the type of GCM output this Project had at its disposal.

Changes in Long Duration (1-7 days) Design Rainfalls for the 1:2 to 1:100 year Return Periods

This is the rainfall, under present/historical and under projected future climatic conditions, expected statistically only once in 2 or 5 or 10 or 20 or 50 years falling over a period of time ranging from one day to seven consecutive days and used, for example, in regional flood analyses or in the spillway design of dams on large catchments. Any changes to these, especially if values increase into the future, are crucial to future hydrological design. What is the confidence in GCM outputs of extremes? What are the ratio changes between immediate future and present design rainfalls? Where are these ratio changes > 1 (higher extremes in future) vs. < 1 (lower extremes projected in future)? How do we inform design hydrologists of possible reductions into the future? How does one adapt to higher future extremes?

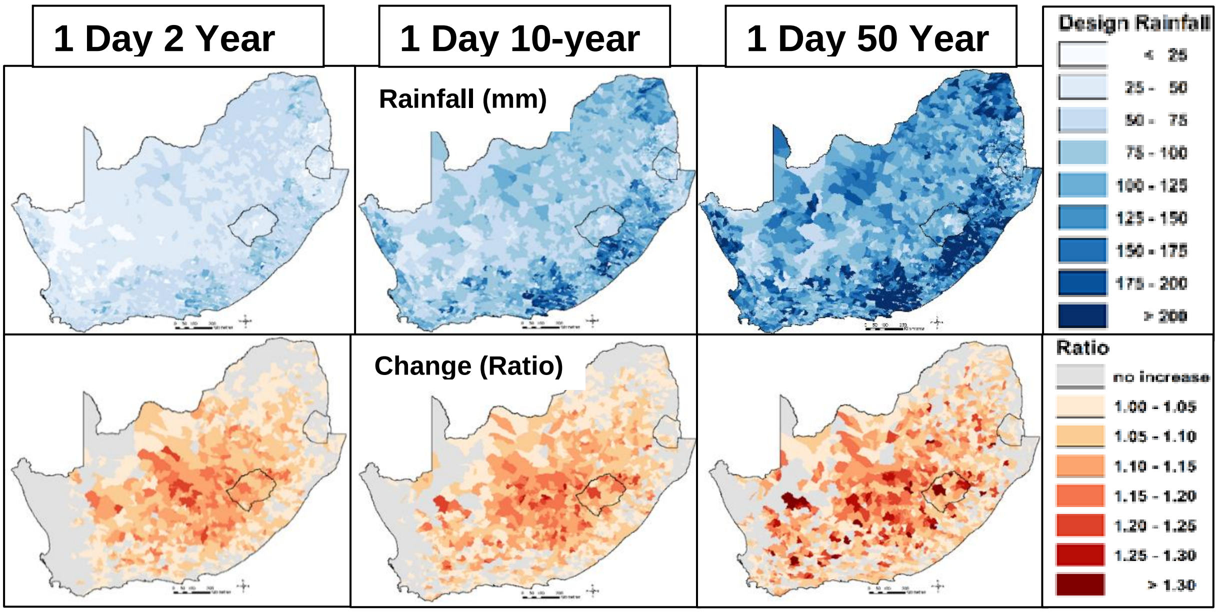

Figure 2.11.1 One day 2, 10 and 50 year return period rainfall (mm; top left to right) and corresponding ratio changes from the present to the immediate future, the latter derived from outputs of multiple GCMs

Shown in **Figure 2.11.1** are the 1 day 2, 10 and 50 year return period rainfalls (mm) in the top row, and corresponding ratio changes in the bottom row from the present (1961-1990) to the immediate future (2015-2044), the latter derived from outputs of multiple GCMs. The top figures illustrate the increase in design rainfall with increasing recurrence interval (i.e. return period). More importantly from an adaptation perspective is that most of the interior of the RSA is projected to experience ***increases in design rainfall*** of between 10 and 30%, with more severe increases visible for the 50 year event, with those areas displaying increases needing to adapt by more rigorous infrastructure designs.

Changes in Long Duration (1-7 days) Design Streamflows for the 1:2 to 1:100 year Return Periods

The streamflow at a location accumulated from all upstream catchments which is expected statistically only once in 2 or 5 or 10 or 20 or 50 or 100 years and is experienced over a period of time ranging from one day to seven consecutive days is used, for example, in the spillway design of dams on large catchments. These major, regional flooding events are expected to change with global warming. What are the ratio changes in GCM means of design streamflows between the present and the immediate future? And, what is the confidence in GCM outputs of extremes? Where are these ratio changes > 1 (higher extremes in future) vs < 1 (lower extremes projected in future). How do we inform design hydrologists of possible reductions into the future? Can the GCMs "capture" extremes adequately when one compares historical and GCM present results? How does one adapt to higher future extremes? What is done where ratios are < 1?

Figure 2.11.2 shows the 1 day 2, 10 and 50 year return period accumulated streamflows (mm) in the top row under natural vegetation conditions, and corresponding ratio changes in the bottom row from the present (1961-1990) to the immediate future (2015-2044), the latter derived from outputs of multiple GCMs. The figure illustrates the increase in design streamflows with increasing recurrence interval (i.e. return period), especially along the eastern border of South Africa. More importantly from an adaptation perspective is that most of the interior of the RSA is projected to experience increases in design streamflows of between 10 and 60%, compared with the increases of 10-30% for design rainfall, illustrating first the amplification effect and secondly, that much of the interior will have to adapt to climate change by more rigorous infrastructure designs.

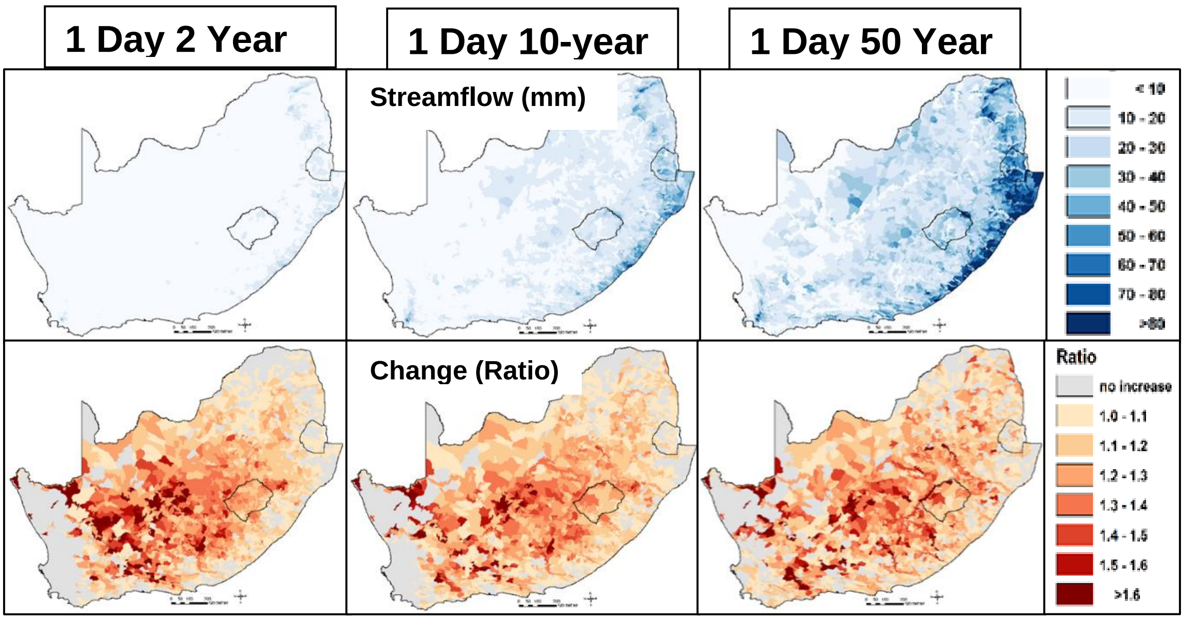

Figure 2.11.2 One day 2, 10 and 50 year return period streamflow (mm; top left to right) and corresponding ratio changes from the present to the immediate future, the latter derived from outputs of multiple GCMs

Changes in the Flood Severity Index

The flood severity index is defined here as the ratio between 1:50 year to the 1:2 year return period rainfall and the 1:50 year to the 1:2 year return period runoff. Where this ratio is high, the “big” rain or the “big” flood is much more severe than the “small” rain or flood, indicating flood sensitive areas, with implications on floodplain activities. To what extent do these change with global warming?

Changes in 1:2, 10, 20, 50 or 1:100 year Design Peak Discharge on a Given Day

This represents the peak discharge, in m^3/s, on a given day at the exit of a Quinary Catchment, which is expected statistically only once in 2 or 5 or 10 or 20 or 50 or 100 years and which is used, for example, in the spillway design of dams. This is expected to change under future climatic conditions.

Changes in Flash Floods

Flash floods are severe floods with high peak discharges occurring over a short period of time and usually locally only over a small catchment area. They are frequently the result of severe convective activity from thunderstorms with high intensity rainfall, with may be enhanced under more energized atmospheric conditions in future. Given the degree of downscaling undertaken from the GCMs, flash floods *per se* cannot be identified from the GCMs.

Changes in Regional Floods

These are floods with high waters occurring over several days and covering substantial areas, usually in the 1000s of km^2, inundating areas around the channel system, and resulting from widespread rains over a period of several consecutive days with considerable amounts of rain falling on already wet catchments, the magnitudes and frequencies of which are likely to change into the future.

Changes in Agricultural Droughts of Mild, Moderate or Intense Severity

These are droughts of different severities such as *mild* (worst in 3 years or less frequently), *moderate* (worst in 5 years or less frequently) or *intense* (worst in 10 years or less frequently), which are experienced over a period of either months or seasons (e.g. DJF for summer; JJA for winter) or entire hydrological years (October-September), in which soil moisture deficits result in crop yield losses of different severities. Associated with climate change and agricultural droughts are changes in numbers of dry spells of several months, changes to soil water content, changes to frequencies of meteorological and hydrological droughts for a range of durations and severities as well as changes to net irrigation requirements. Assess where risks of changes are high by assessing ratio changes between future and present climates and what the local adaptation options could be if droughts were to increase (or decrease).

Changes in Hydrological Droughts of Mild, Moderate or Intense Severity

Hydrological droughts can have different severities such as being *mild* (worst in 3 years or less frequently), *moderate* (worst in 5 years or less frequently) or *intense* (worst in 10 years or less frequently), which are experienced over a period of either months or seasons (e.g. DJF for summer; JJA for winter) or entire hydrological years (October-September). In hydrological droughts accumulated streamflows at a location within a catchment are below the expected. They may result in water shortages or curtailments / water rationing being applied. Associated with hydrological droughts are projected changes to the number of times per year that thresholds of specified streamflows are exceeded, and what changes to the frequencies of hydrological droughts for a range of durations and severities have on net irrigation requirements. Assess where risks of changes are high by assessing ratio changes between future and present climates and relate to what the local adaptation options could be if hydrological droughts were to increase (or decrease).

Changes in Groundwater Recharge

Recharge into the groundwater zone emanates from soil water percolating through the soil profile of a landscape under wet conditions to beyond the root zone of plants into the shallow groundwater zone, which is then recharged, with this water also becoming available through slow release into the stream as baseflow. Any changes in baseflow magnitudes and seasonality with climate change are crucial as environmental flows and as a dry season water supply in areas not yet supplied with potable water. Analyses should include recharge magnitude, seasonality and confidence in results.

In **Figure 2.11.3** recharge through the soil profile into the groundwater zone is shown under historical climatic conditions (top row) for a 1:10 low recharge year (left), median annual conditions (middle) and a 1:10 high recharge year (right), with corresponding ratio changes in recharge projected from the immediate future to the present, the latter based on simulations with the *ACRU* model with inputs from multiple GCMs. Clearly evident from an adaptation perspective are the significant amplification in recharge between dry and wet years, that there is no recharge across ~ half the country in a dry year (pink colouration on maps), that there are decreases in recharge projected in the west and the east in an average year by 30-50%, but with increases in recharge projected in the central parts of South Africa (shades of green) of up to 30-40%.

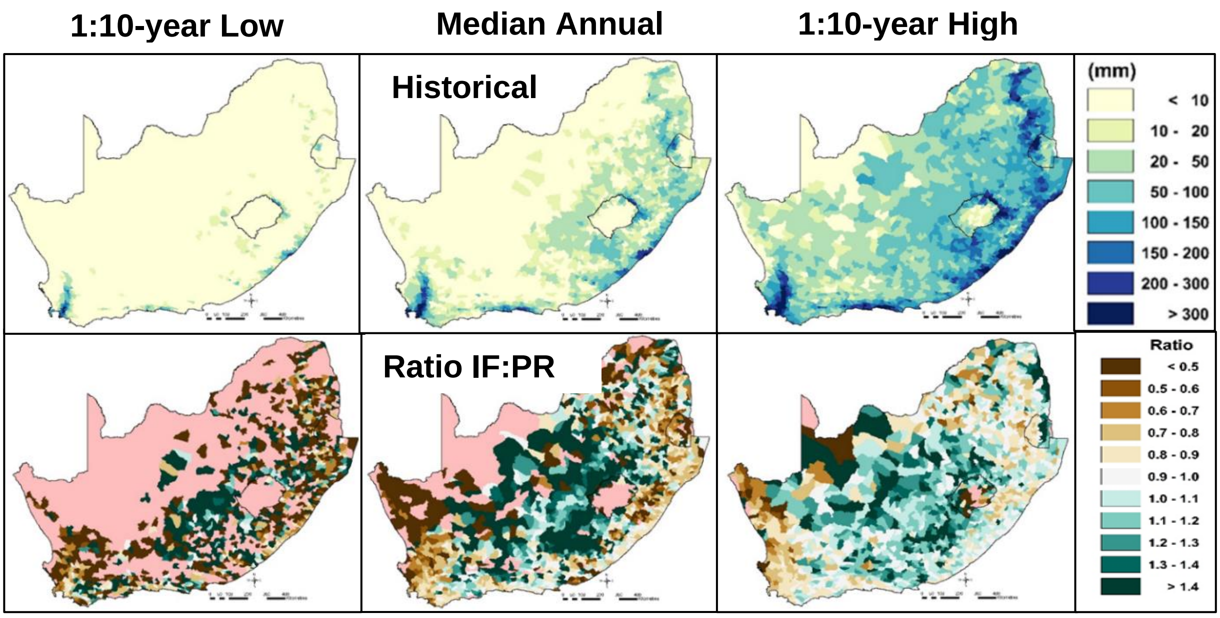

Figure 2.11.3 Recharge through the soil profile into the groundwater zone under historical climatic conditions (top row) for a 1:10 low recharge year (left), median annual (middle) and a 1:10 high recharge year (right), and corresponding ratio changes in recharge from the immediate future (IF) to the present (PR), with pink colour denoting that no calculations are possible (After Schütte *et al.*, 2021)

Changes in Water Temperature

An oft forgotten spin-off of global warming is that not only air temperature, but also water temperature, will rise. Increasing river water temperature has serious hydrological, environmental, economic and human consequences, with water temperature affecting, *inter alia*, human health (e.g. water-borne diseases such as bilharzia), aquatic ecosystem health, power cooling and municipal water quality.

Water temperature can be computed for each day and for each Quinary Catchment from a maximum air temperature-related empirical equation developed under South African conditions. This computed daily water temperature is then combined with the computed water temperatures from any upstream Quinary Catchments, assuming perfect mixing of the waters where the Quinary outflows join. Maximum temperatures used in the equation would be those projected under future climatic conditions. Water temperature remains one of the most under-researched aspects of climate change in the South African water sector.

In possibly the only South African study on climate change impacts on water temperatures, **Figure 2.11.4** from a 2012 study shows how projected water temperatures in the Thukela catchment increase from the present (1971-1990; left map) to the intermediate future (2046-2065; middle) to the distant future (2081-2100; right map). Note that larger rivers with sources in high altitude cool areas display lower water temperatures downstream than rivers with sources at lower altitudes with higher air temperatures.

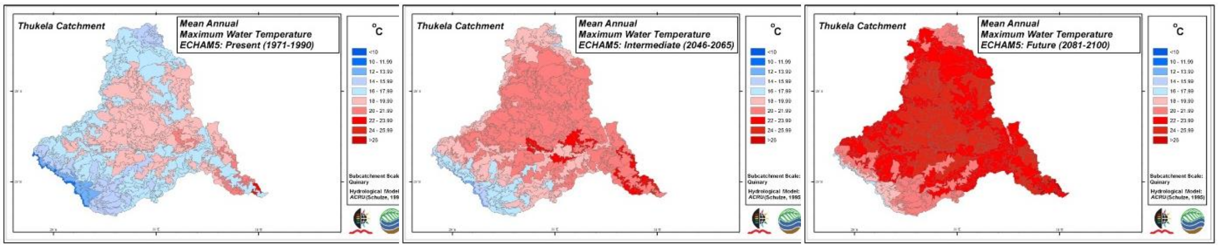

Figure 2.11.4 Modelled mean annual water temperatures in the Thukela catchment under present (left), intermediate future and more distant future climatic conditions (Barichievy and Schulze, 2010)

2.12. BECOMING MORE PRACTICAL IN REGARD TO ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: POSSIBLE *THIRD ORDER* ADAPTATION OPTIONS AVAILABLE TO THE SOUTH AFRICAN WATER SECTOR *BEYOND THE WRC K5/2833 MANDATE*

Third order climate change impacts will affect not only water *supply*, but also the *demand* for water, with projected changes to the availability, timing and assurance of water supply affecting all water user sectors, e.g. agriculture, hydro-power, urban areas, water for sanitation, the poor and the environment. Changes will also affect the broader dynamics of the economy, including water scarcity, water-related disasters, spatial patterns of development, or structural changes in economies. Risks and vulnerabilities will include those related to changes in irrigation demands, effects of available water on different land uses and, conversely, land uses on water, to supply and demand, water quality in its various manifestations, terrestrial / aquatic ecosystems and the goods and services they render, impacts on infrastructure, integrated catchment assessments, transboundary waters and vulnerability of poorer communities

Furthermore, since impacts which are considered are in the future, many uncertainties prevail, and because some responses are particularly long-lived, it is timely to now already focus on strengthening management, information and water infrastructure. Third order changes to which adaptation to climate change have to be addressed thus also include the following:

Changes in Irrigation Water Demand and Practices

These include climate change-related changes in the magnitude of irrigation water demands, effects of different modes of scheduling on water use efficiency, environmental consequences of irrigation through losses to percolation beyond the root zone (e.g. nitrate leaching) and surface runoff (e.g. phosphate removal), and confidence in results. An important irrigation adaptation practice would be to change the mode of water scheduling to reduce irrigation applications, and **Figure 2.12.1** illustrates water savings by changing from demand irrigation once soil water has dried to 50% of plant available water (**Figure 2.12.1** left) to deficit irrigation (middle map) to drip irrigation (**Figure 2.12.1** right map).

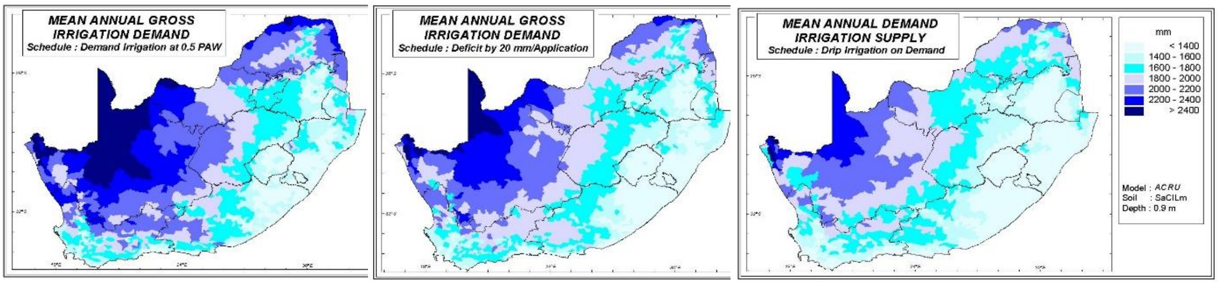

Figure 2.12.1 Comparisons between mean annual gross water demand for an all-year crop irrigated by demand irrigation (left) or by deficit irrigation (middle) or by drip irrigation (right)

Effects of Changes in Land Uses on Water Availability and Production

Examples of land uses which enhance water availability include urbanisation as well as overgrazing and other forms of land degradation which also enhance soil erosion, while reductions in runoff occur through plantation forestry, certain types of land reform, agricultural land use management such as conservation and tillage practices and the presence of alien invasive species. Such changes in land use usually alter the relationship between the stormflow and baseflow components of runoff. Hydrologically, such changes in land use can be expressed in different ways, such as percentage (i.e. relative) changes in accumulated streamflows from the baseline land cover to the actual land use (**Figure 2.12.2** left map), or as absolute changes expressed either in mm equivalents (middle map) or in m³ (**Figure 2.12.2** right map). From an adaptation perspective overgrazing and other forms of land degradation can be halted / reversed to produce cleaner and more sustainable water supplies.

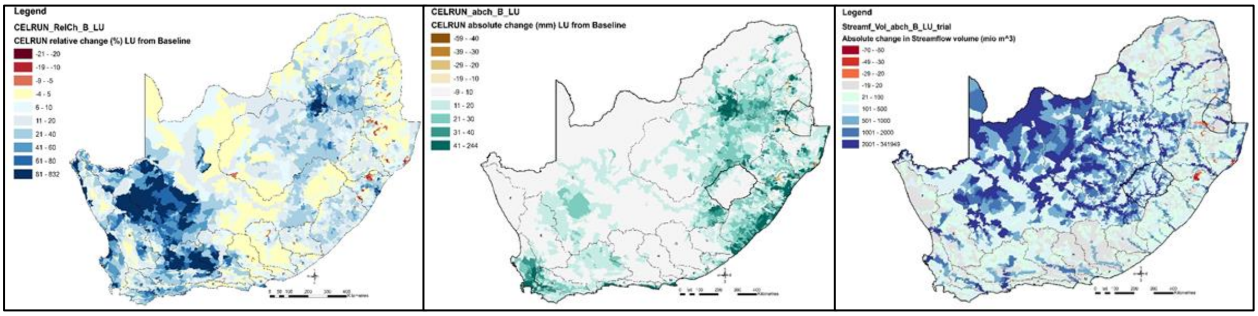

Figure 2.12.2 Positive and negative impacts on accumulated streamflows of changing from baseline land cover to human influenced land uses, expressed as relative (%) changes (left map) or as absolute changes in mm equivalents (middle map) or in m³ (right map)

Effects of Changes in Water Availability on Land Use Patterns

These refer, e.g. to shifts in cropping patterns and yields re. food security and biofuels, and intensification or extensification of land uses.

Changes in Water Rights and Water Allocation Rules

Water rights and allocation rules are subject not only to the National Water Act of 1998, but will also be affected by the realities of climate change in regard, for example, of biofuel production, commercial forest land and of food security.

Changes in Dynamics of Water Quality Responses and their Consequences 1: Sediments

This category implies the deterioration of water quality as a result of turbid waters and high silt content resulting from a sediment load emanating from the landscape component of a catchment. While dependent on soil characteristics, slope, vegetative cover above as well as on the ground (likely to change) and land management practices, the main hydrological drivers of sediment yield are related to runoff events, both to peak discharge as an indicator of dislodging soil particles and to flow volumes as the sediment transporting mechanism from the landscape component of the catchment. Both peak discharge and runoff volumes are projected to alter with climate change, due to increased rainfall amounts and / or intensities. It should, furthermore, be noted that land degradation and land use changes can affect the livelihoods of rural communities living off agriculture, which can lead to sedimentation in reservoirs, affecting the operation of multi-purpose facilities and the sustainability of watersheds.

Changes in Dynamics of Water Quality Responses and their Consequences 2: Chemical Water Quality

Chemical water quality includes the deterioration of water quality as a result, *inter alia*, of point source pollutants or non-point source pollutants from agricultural chemicals (e.g. eutrophication through nitrate leaching and phosphorous wash-off), metals from mining, acid atmospheric deposits, to the detriment of the aquatic habitat and downstream water users. Many of these drivers of chemical water quality are expected to change under future climatic conditions.

Changes in Dynamics of Water Quality Responses and their Consequences 3: Biological Water Quality

This category implies the deterioration of water quality as a result, *inter alia*, of pathogens and organics from urban and rural areas, often from sewage effluent discharges into non-existent or dysfunctional wastewater treatment plants in many of the formal and informal urban areas. Biological water quality deterioration frequently manifests itself as excessively high *E. coli* concentrations in rivers and stored water, and with often severe health consequences. Climate change is likely to exacerbate *E. coli* concentrations.

Changes in Water Quality on Human Health

These need special attention re. adaptation and include

- *Water-borne diseases* which result from the contamination of water by human or animal faeces, or by urine infected by pathogenic viruses or bacteria, in which case the disease is transmitted directly when the water is drunk or used in the preparation of food,
- *Water-washed diseases*, resulting from inadequate personal hygiene because of scarcity or inaccessibility of water and which includes water-borne diseases and typhus,
- *Water-based diseases*, i.e. those arising from parasites that use an intermediate host that lives in or near water (e.g. guinea worm),
- *Water-related diseases*, i.e. those diseases borne by insect vectors and which have habitats in or near water (e.g. malaria), and / or
- *Water-dispersed diseases,* with these being infections whose agents proliferate in fresh water and enter the human body through the respiratory tract (e.g. Legionella).

Other third order impacts to which adaptation actions have to be considered and assessed also include the following:

Impacts on Terrestrial and Aquatic Ecosystems

These include changes in water-related ecosystems goods and services, environmental integrity, baselines against which to assess impacts, wetlands responses and functioning, estuary responses and functioning, impacts of increased water temperatures, or changes to Indicators of Hydrological Alteration.

Changes to Environmental Flows

Environmental flows are minimum flow requirements in river reaches to sustain aquatic habitats. They are functions of magnitudes, frequencies, durations, timing and rates of change of flows in a river reach, all of which are likely to alter under future climatic conditions.

Changes in Hydropower Generation Potential

This can change with increased variability in river flows, reducing the stability and reliability of power supply, with consequent effects on the economy.

A Re-think on Surface Water Supplies and Storage at a Point from All Systems

Surface water supplies here refer to natural, man-made and virtual storages, i.e. water that is available from streams at a point within a catchment, made up of accumulated stormflows and baseflows from all areas upstream of the point of interest, as well as from storage dams with their losses and environmental / urban / irrigation releases, run-of-river abstractions or via inter-basin water transfers. Being water supply and demand driven, all of the above are affected by climate change.

Transboundary Flows (Quantity and Quality) and Potential Conflicts over Shared Rivers

Transboundary flows include flows emanating

- *from* another country and entering South Africa, e.g. the Orange-Senqu from Lesotho and the Fish from Namibia (**Figure 2.12.3**), or flows from South Africa exiting
- *into* another country, e.g. the Sabie or Olifants flowing into Mozambique (**Figure 2.12.3**), or rivers
- *shared between* South Africa and another country through a common border, e.g. the Limpopo with Zimbabwe or the Orange with Namibia (**Figure 2.12.3**).

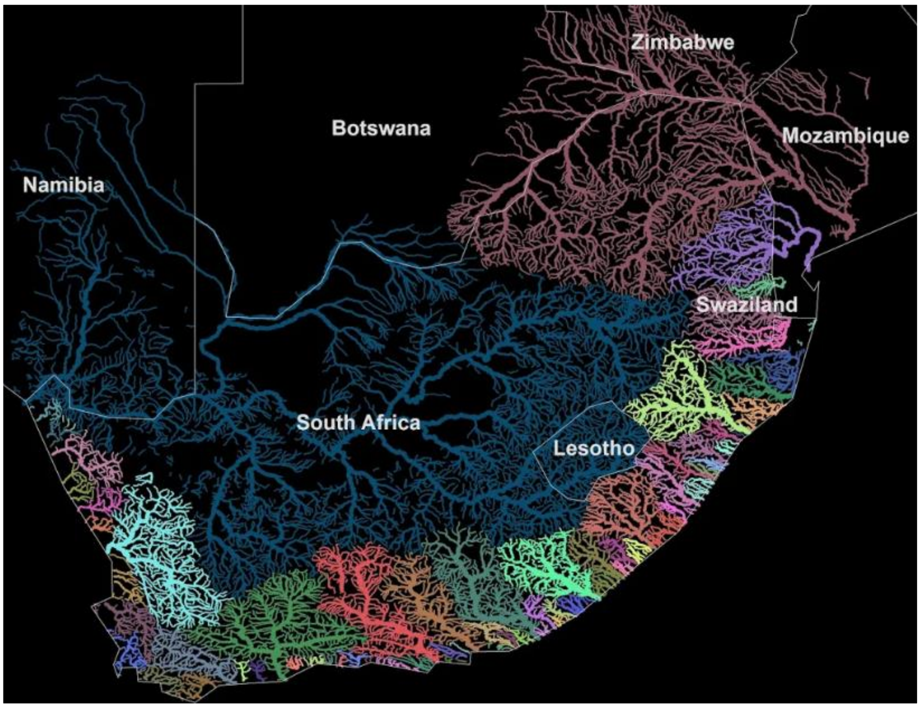

Figure 2.12.3 Transboundary river systems affecting South Africa's water resources (Source: DWS, 2019)

These flows are expected to change with climate change. Considerations in this regard include projected changes to accumulated streamflows, to the number of times per year that thresholds of specified streamflows are exceeded, to sediment yield, hydrological droughts, changes to long duration design rainfalls and streamflows, as well as to projected changes in net irrigation demand and in percolation and runoff losses from irrigated areas. Since volumes and intra-annual distributions of transboundary flows may be subject to legal international agreements, such agreement may need to be amended in light of climate change.

Vulnerability of the Poor

Water-related vulnerabilities of the poor which are likely to be affected by climate change include those living in flood prone riparian zones in urban areas, while in rural areas climate change may affect the availability of potable water.

Changes in Migration Patterns 1: Rural to Urban Areas from Within South Africa

In regard to climate change, rural to urban migration could be a result of either enhanced climate / water variability and / or a reduction in rural water resources.

Changes in Migration Patterns 2: Immigration (Legal and Illegal) from other African Countries

Again, this migration could be as a result of either enhanced climate / water variability and / or a reduction of water resources.

Increases in Sea Level

Sea level rise at between 1.5 and 7.0 mm/a as a result of expansion of oceanic waters due to higher temperatures and melting ice masses can have hydrological consequences, *inter alia* through sea water intrusion into coastal freshwater lenses and soil salinization of water sources provided by coastal aquifers.

Increases in Storm Surges

Storm surges are a coastal / near coastal phenomenon in which water surges upstream into estuaries and river channels, resulting in the widening of river banks or allowing rivers to expand sideways, with implications on, *inter alia*, estuarine functioning and river bank infrastructure. With arise in sea levels anticipated under future climatic conditions, impacts of surges are projected to be exacerbated over time.

A Focus on Mountainous Areas

Mountainous areas are the RSA's runoff producing areas ('water towers'), and they are particularly sensitive / vulnerable to CC. Special attention needs to be given to these high runoff-producing / high water yielding areas in regard to improving the poor monitoring networks and understanding better the runoff producing dynamics on rainfall and runoff under conditions of climate change, plus downstream water resources availability. These strategic mountain water source areas of South Africa, as identified by the WWF (2013) and shown in **Figure 2.12.4**, are found essentially in the

- high lying eastern escarpment areas of the Eastern Cape, KwaZulu-Natal and Limpopo, these being (from south to north) the
  - Amatola mountains
  - Eastern Cape Drakensberg
  - Maloti Drakensberg
  - South and North Drakensberg
  - Enkangala Drakensberg and the
  - Mpumalanga Drakensberg, plus the
  - Mbabane Hills in Eswatini, the
  - Wolkeberg and the
  - Soutpansberg plus the
  - Mfolozi Headwaters and the
- fold mountain belt along the south and west coast of the Western Cape, from east to west
  - Tsitsikamma Mountains, the
  - Kougaberg,
  - Outeniqua Mountains,
  - Swartberg,
  - Langeberg, the
  - Boland Mountains,
  - Table Mountain and the
  - Groot Winterberg.

Special attention needs to be given to these high runoff-producing / high water yielding areas in regard to monitoring and understanding better the runoff producing dynamics under conditions of climate change, plus downstream water resources availability.

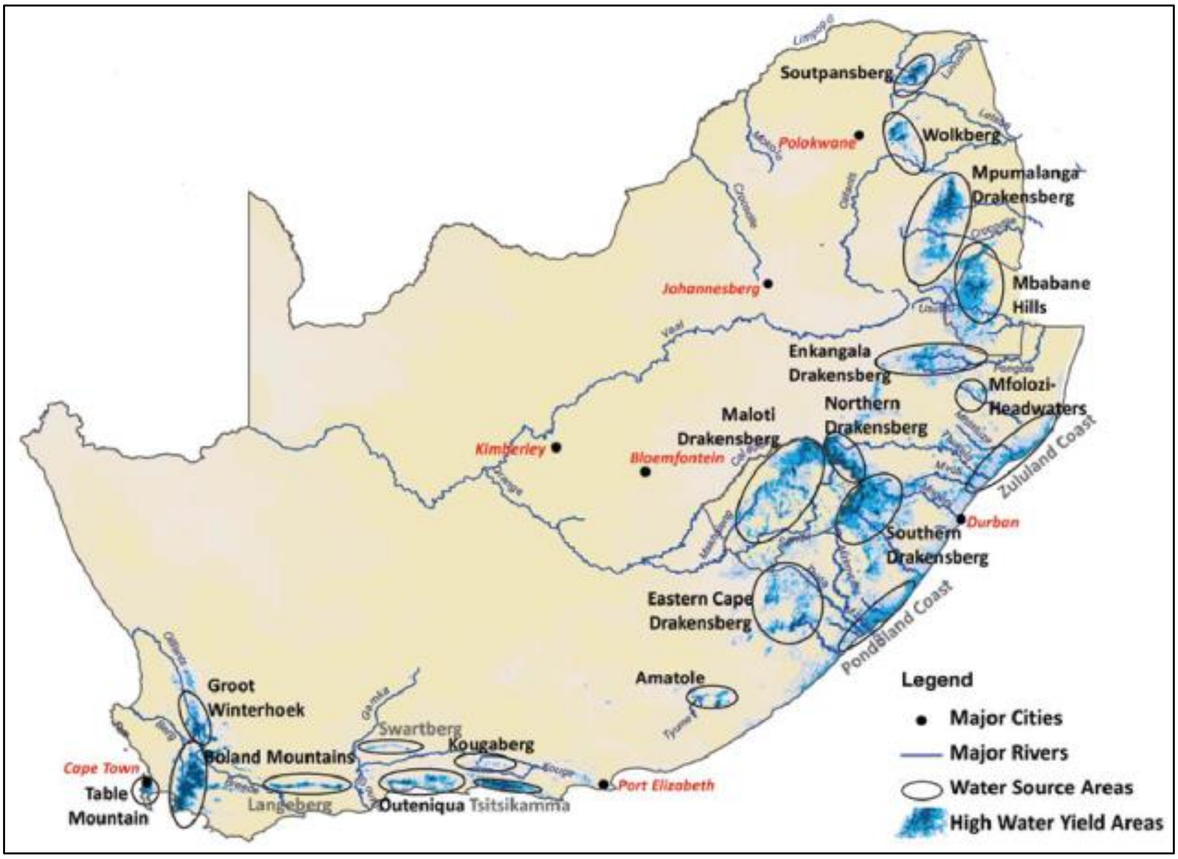

Figure 2.12.4 Strategic water source areas of South Africa (Source: WWF, 2013)

Responses to changes in climate in water management activities thus include not only considerations on infrastructure, but also considerations regarding the institutions that govern water use within sectors (e.g. water in the agricultural sector), between sectors (e.g. water for industry vs water for irrigation), and even across international borders (e.g. inter-country water agreements and the recognition of virtual water).

Strong statements such as those above are a motivation to re-visit some further needs for assessing projected impacts of climate change on the South African water-related sector in light of having to adapt to anticipated future climate scenarios. In Sections which follow, the focus is, therefore, on practical approaches to adaptation to climate change for the South African water-related sector.

2.13 BECOMING MORE PRACTICAL IN REGARD TO ADAPTATION TO CLIMATE CHANGE WITHIN THE SOUTH AFRICAN WATER SECTOR: ACCOUNTING FOR KEY WATER ENGINEERING-RELATED SYSTEMS IN REGARD TO ADAPTATION BEYOND THE WRC K5/2833 MANDATE

Whilst not by any means exhaustive, a number of key questions relating primarily to climate change in regard to water engineered systems are posed below.

Key Question 1: Given the Project title, Should We Not Have Been Considering "On-the-Ground" Issues of Adapting to Climate Change and the Water Resources Yield Model System?

At the end of the day in a Project titled

> *"A National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydroclimatic Zones of South Africa"*

a major focus should have been on potential climate change impacts of the "on-the-ground" water flows through the nodes and links of the national Water Resources Yield Model System which represent both natural stream channels and inter-basin transfers across South Africa, as shown in **Figure 2.13.1** for the entire country plus Lesotho and Eswatini, and in more detail in **Figure 2.13.2** for the Mgeni system.

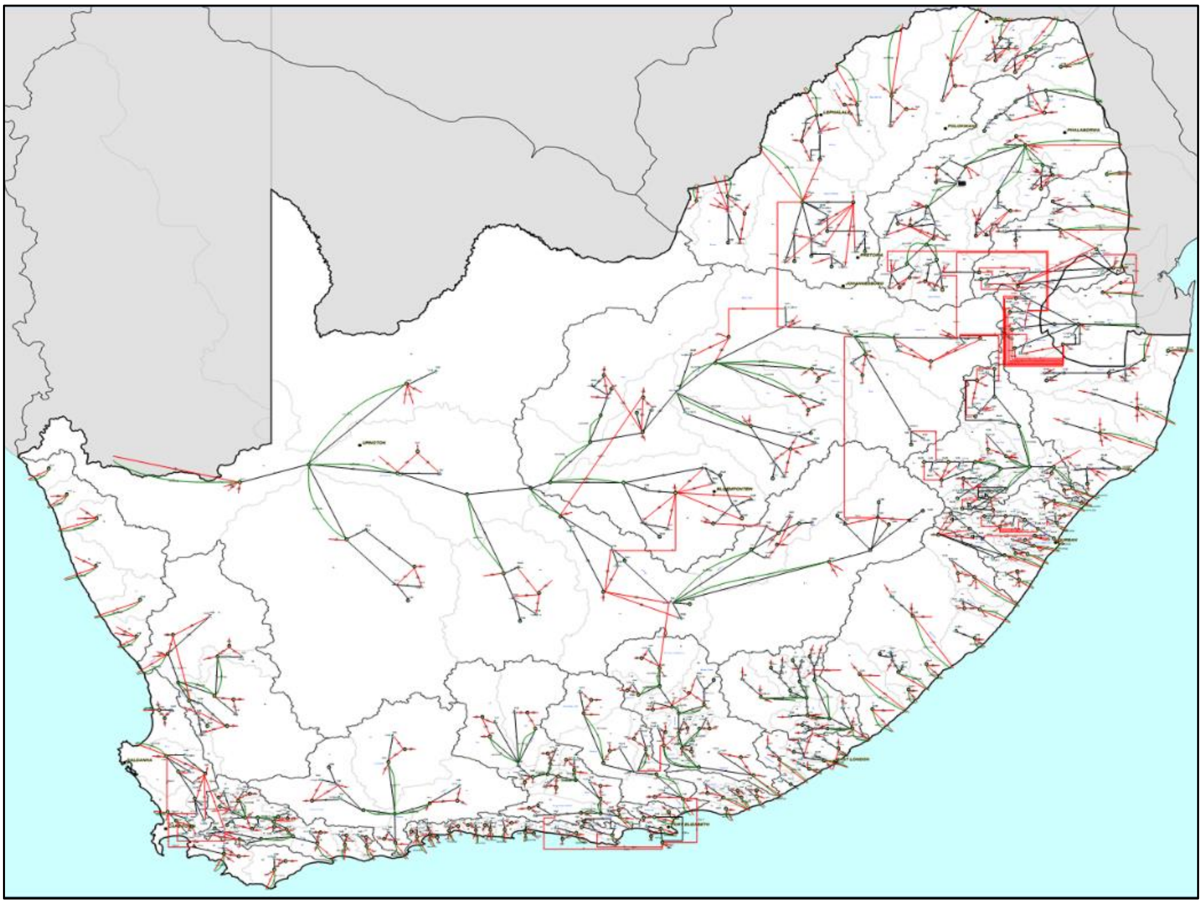

Figure 2.13.1 Schematic diagram of the national WRYM system model developed for South Africa, showing the main nodes and links which represent both natural stream channels and inter-basin transfers (DEA, 2015a)

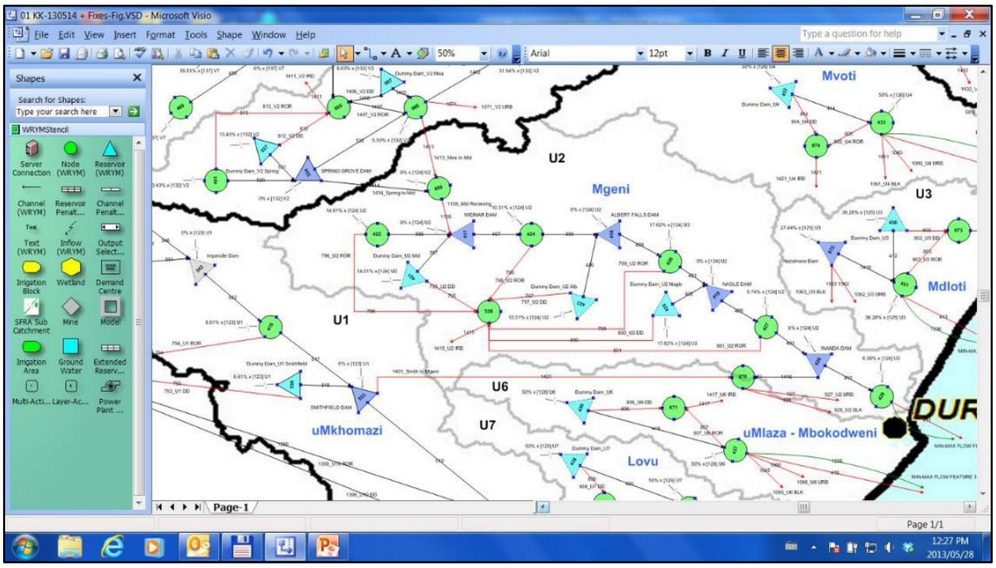

Figure 2.13.2 Detail of part of the national WRYM system model showing the Mooi-Mgeni River System (DEA, 2015a)

Key Question 2: Which Local Municipalities are Likely to be Vulnerable to Future Water Supplies by the 2050s?

In **Figure 2.13.3** the estimated future (2050s) water supply vulnerability for Local Municipalities under a medium projected growth scenario is shown, with a value of 1 indicating that the water demand and supply of the Local Municipality are equal, with a value < 1 indicating that there is surplus supply and a value > 1 indicating that either the demand is too high and/or the supply is too low (Cullis and Phillips, 2019 in CSIR, 2019).

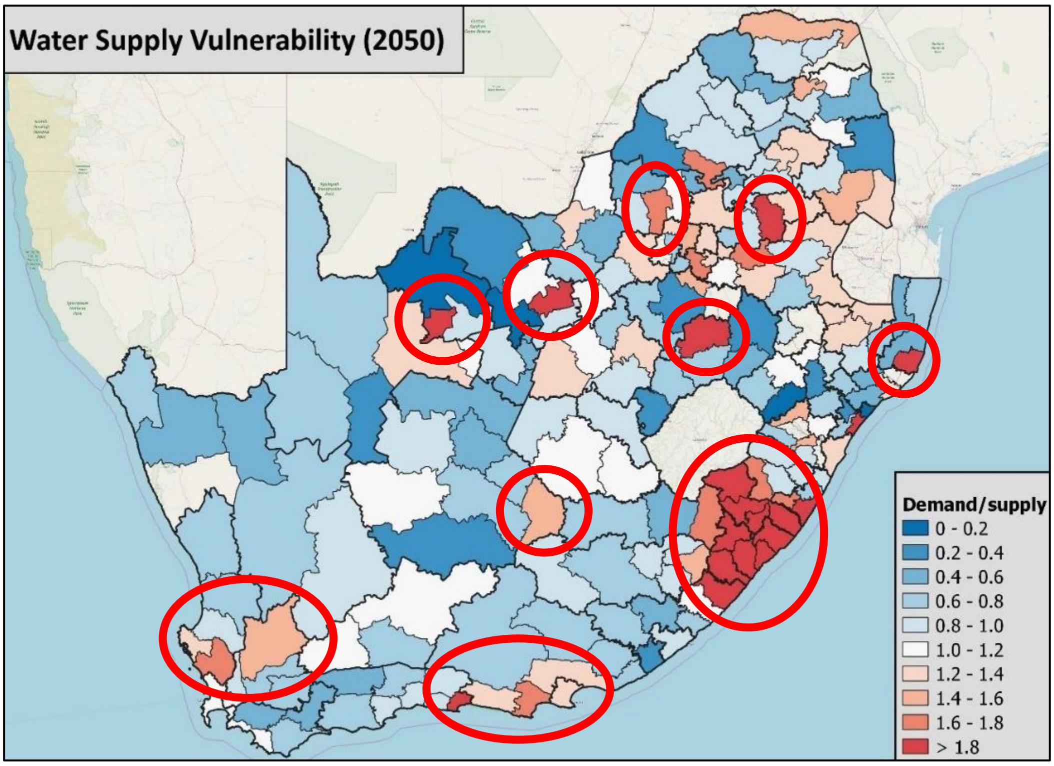

Figure 2.13.3 Estimated future water supply vulnerability by 2050 for Local Municipalities under a medium projected growth scenario

Key Question 3: Digging Deeper by Asking which Local Municipalities are Likely to be Vulnerable to Future Groundwater Supplies by the 2050s?

With decreases in groundwater recharge projected into the near future along the west coast of the Western Cape and the north-west border areas of the RSA (**Figure 2.13.4** bottom right), and these being areas where local municipalities are partially or entirely dependent on groundwater supplies, those are the areas which will have to adapt to projected climate change through possibly declining groundwater supplies.

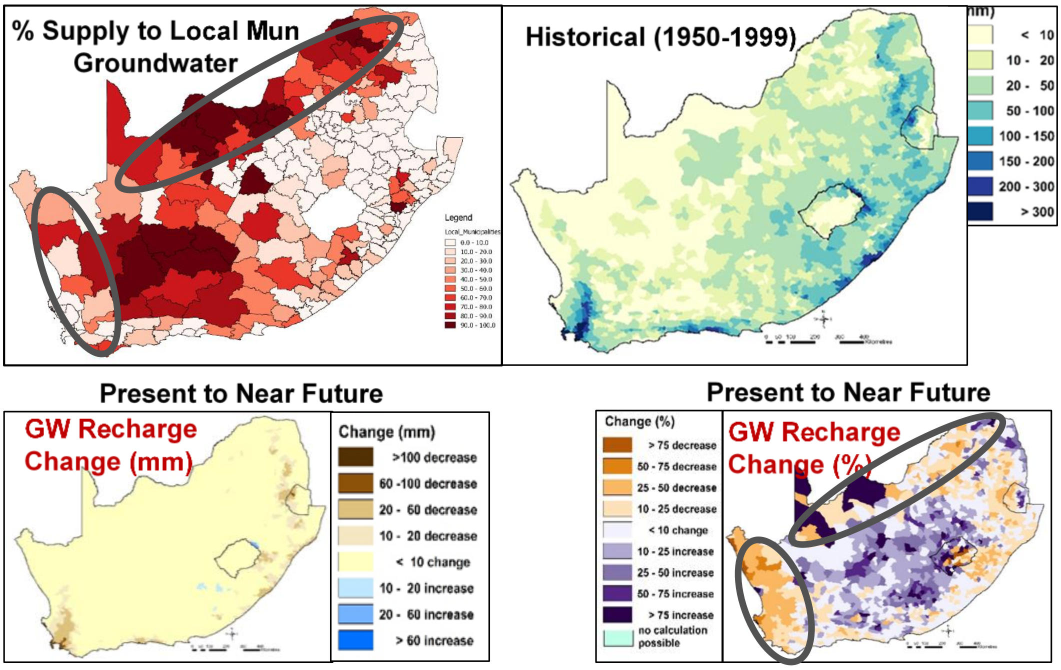

Figure 2.13.4 Percentage of water supply per Local Municipality (2016) from groundwater (top left), historical mean annual groundwater recharge (top right) and projected changes in recharge in mm (bottom left) and as a percentage (bottom right)

Key Question 4: Digging Deeper by Asking which Local Municipalities are Likely to be Vulnerable to Future Surface Water (Runoff) Supplies by the 2050s?

Given that surface water supplies through runoff is projected to reduce in absolute (mm; m^3) terms in the south-west and the north-east of the country by the near future of the 2030s (**Figure 2.13.5** bottom left), and in relative (%) terms especially along the west coast (**Figure 2.13.5** bottom right), it is the local municipalities in the south-west of the Western Cape and in the east of especially Mpumalanga that will need to plan carefully into the future in regard to their local water supplies.

Key Question 5: Digging Deeper by Asking which Local Municipalities are Likely to be Growth Points of Population in Future and thus Need Special Attention re. Adaptation?

Adapting South African settlements to increasing water supply risks includes not only adapting to climate change impacts *per se*, but often even more so to future growth and development. **Figure 2.13.6** shows medium (left) and high (right) population growth projections for 2050 (Green Book, 2019), and the local Municipalities ringed are likely to need special attention in their planning /adaptation into the future. This will have to be done bearing in mind their sources of water and the projected changes shown previously in regard to groundwater recharge and to surface runoff.

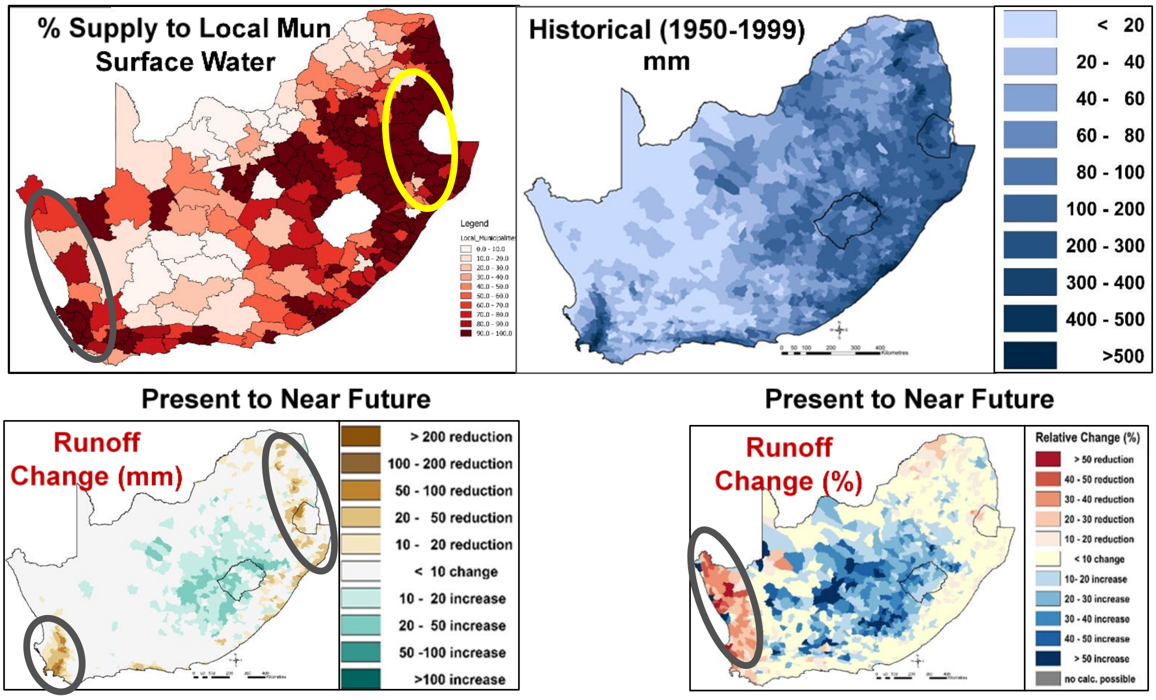

Figure 2.13.5 Percentage of water supply per Local Municipality (2016) from surface water, i.e. runoff (top left), historical mean annual runoff (top right) and projected changes in runoff in mm (bottom left) and as a percentage (bottom right)

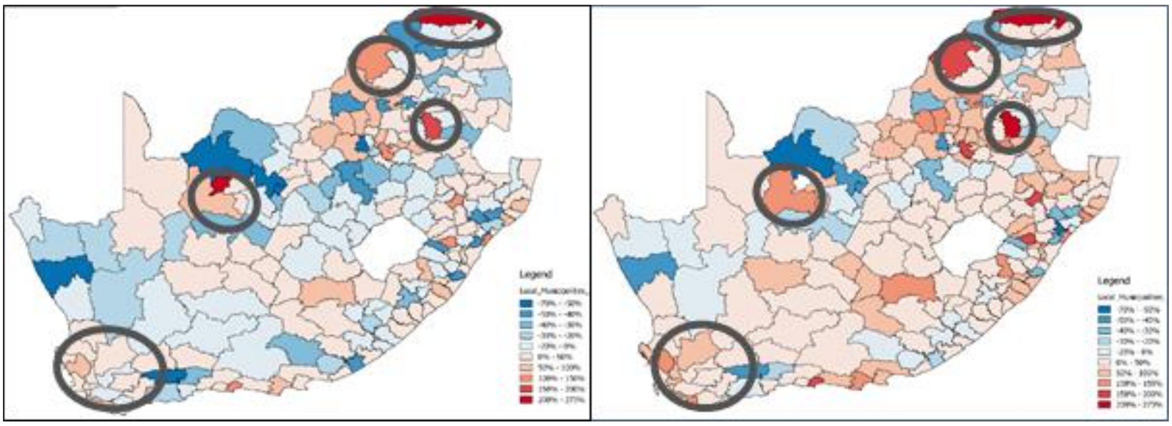

Figure 2.13.6 Medium (left) and high (right) population growth projections for 2050 (Green Book, 2019)

Key Question 6: Which Settlements are at Risk of Projected Increases in Floods by the 2050s?

The settlements at risk of projected increases in floods using a risk matrix (low, medium, high or extreme) that considered a calculated flood hazard index and the projected change in extreme rainfall days for 2050 (le Maitre *et al.*, 2019 in CSIR, 2019) are shown in **Figure 2.13.7**.

It should be noted that virtually every settlement is at risk of increases in flooding by mid-century, but with the Durban area at higher risk than Cape Town and with the Witwatersrand featuring strongly, as does Phuthaditjhaba in the former QwaQwa homeland. These observations confirm that adaptation to climate change is frequently a very local issue, and that any broader, regional findings of flooding potential into the future should home in on densely settled areas where adaptation has to do largely with engineering infrastructure issues.

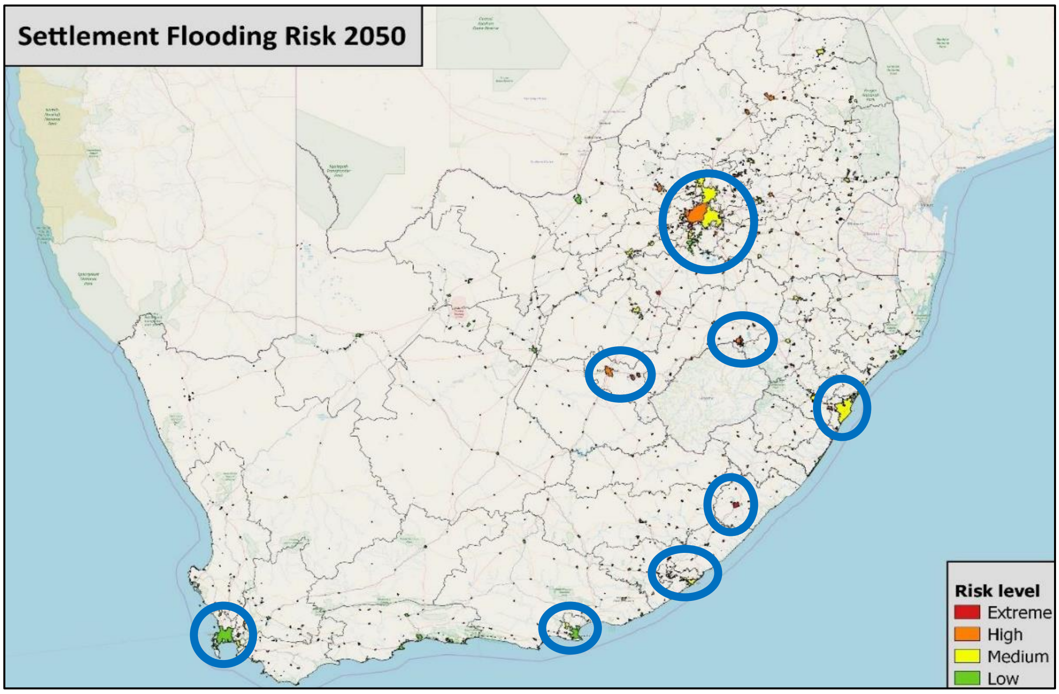

Figure 2.13.7 Settlements at risk of projected increases in floods by the 2050s (le Maitre *et al.*, 2019 in CSIR, 2019)

Key Question 7: Which Settlements are at Risk of Projected Increases in Drought Tendencies by the 2050s?

In **Figure 2.13.8** the settlements across South Africa are highlighted that are considered to be at risk of projected drought tendencies using a risk matrix (low, medium, high or extreme) that also accounted for the different values within a drought index and whether they indicated an increase or decrease in drought tendencies (Beraki *et al.*, 2019 in CSIR, 2019).

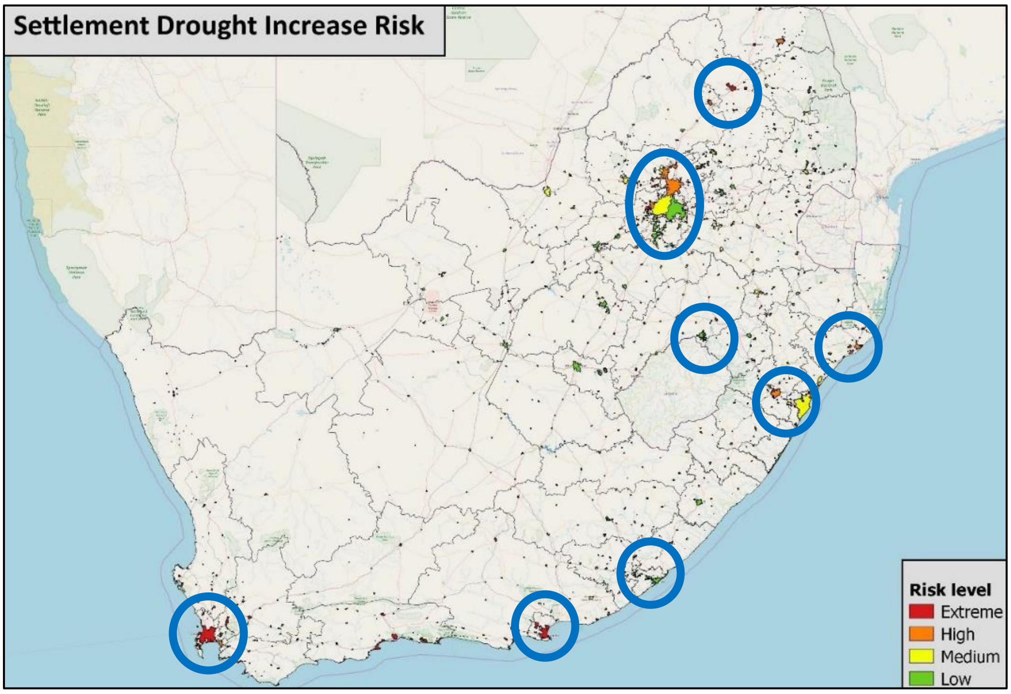

Figure 2.13.8 Settlements in South Africa considered at risk of projected drought tendencies by the 2050s (Beraki *et al.*, 2019 in CSIR, 2019)

Significantly, when the two maps of future flooding risk and drought tendency risks are compared, it is often the same settlements that feature, although sometimes in a complementary manner. Hence, in **Figure 2.13.8** the Cape Town environs display extreme risk levels of drought tendencies while **Figure 2.13.7** shows the same area to have a low risk of flooding into the future.

2.14 GOING FORWARD

WRC Project K5/2833 identified a number of key hydrological drivers and responses for which adaptation options were to be assessed, with these being

- Rainfall
- Potential evaporation
- Actual evapotranspiration
- Runoff
- Accumulated streamflows
- Recharge to the groundwater zone and
- Yield.

While these seven hydrological drivers and responses are important, they provide but a narrow view of adaptation needs in the real world of managing South Africa's water resources into a climate changed future, and this document has identified, *inter alia*, the following issues which need attention in regard to adaptation, *viz*.:

First order response and adaptation issues

- Identifying and mapping temperature sensitive areas in regard to hydrological processes
- Assessing thresholds of daily rainfalls exceeded (i.e. the "rainfall assault events")
- Identifying changes in seasonal (and not only annual) streamflow patterns
- Identifying and mapping runoff sensitive areas to climate change for special attention
- Assessing thresholds of daily streamflows exceeded (i.e. the "runoff assault events")

Second order response and adaptation issues

- Assessing projected changes in short duration (minutes to hours) design rainfall
- Assessing changes to design rainfalls longer than just one day (e.g. 2 or 3 or 7 consecutive days)
- Assessing changes to design streamflow longer than just one day (e.g. 2 or 3 or 7 consecutive days)
- Assessing changes to the flood severity index
- Assessing changes in design peak discharges
- Assessing changes in flash flood magnitudes, frequency and geography
- Assessing changes in regional flood magnitudes, frequency and geography (e.g. tropical cyclones)
- Changes in hydrological droughts of mild, moderate and intense severity
- Changes in water temperatures

Third order response and adaptation issues

- Significances of land use vs climate change patterns
- Changes in water rights and allocation rules, *inter alia,* the issue of forest permits
- Changes in the dynamics of water quality responses re. physical, chemical and biological water quality
- Changes in water quality on human health
- Assessing climate change impacts on terrestrial and aquatic ecosystems
- Climate change and hydropower generation
- Climate change and transboundary flows
- Climate change-related migration patterns from rural to urban within South Africa and from other countries to the RSA
- Increases in sea level rise and storm surges on coastal freshwater resources and
- Climate change and hydrological responses in mountainous areas, the "water towers" of the RSA.

Adaptation as a Consultative Process

While the above sections are but one perspective on adaptation in the South African water sector, it must be emphasised that any adaptation plans, strategies and policies must of necessity include interdisciplinary consultation. Such consultation would be with affected and impacted stakeholders of both the public and private sectors which deal with wider water-related issues, *inter alia* water resource supply and demand, as well as land use change. This approach would ensure buy-in to proposed strategies and would help to work towards what is known as Intentional Transformative Adaptation that has been forced upon the water-related sector by climate change impacts already being felt. Such an approach would need to be internalised by the DWS. Enhancing adaptive capacity further benefits from iterative interactions on interventions currently already being implemented or considered.

CHAPTER 3

AN ANECDOTAL PERSPECTIVE ON VULNERABILITIES OF CLIMATE CHANGE AFFECTING POOR RURAL COMMUNITIES – A STUDENT CONTRIBUTION

N. Nxumalo

3.1 INTRODUCTION

Resource security is essential for socio-economic development and sustainability and can be defined as the adequate access to resources that support livelihoods, especially at local community/household scale. Activities undertaken to increase resource security are challenged by technological biases which emphasise production activities while neglecting to address equitable and stable access, as well the utilization and affordability of resources. Thus, there is a large gap in the knowledge between biophysical and socio-economic aspects of resources management relative to climate change.

Climate change is a phenomenon that impacts on different climatically sensitive sectors such as the water sector. Global processes that significantly drive risks further create vulnerability; these include globalization trends such as population growth, land use changes (including rapid urban expansion), natural resources degradation, persistent socio-economic inequalities, and failure in governance structures (e.g. corruption and resources mismanagement).

When studying the various scales of resource security interventions, solutions may lack the necessary local scale perspectives. It is at the local scale where resource insecurity is most prevalent and is the standard lived experience. To fully understand the complexities of climate change-related risks, exposure, vulnerability and adaptation, there needs to be an integrated approach that involves different knowledge and experiences, that will address the link between socio-economic, environmental, and political factors for better resources management and equitable benefits. This will further highlight the challenges at different scales and opportunities for improved resources management and planning which will also allow for the development of practical local scale interventions.

Numerous studies have focused on climate change, its impacts, mitigation and adaptation strategies. However, much of the focus on implementation has been on the technical infrastructure, ranging from increasing storage capacity through dam constructions and water transfers from neighbouring rivers catchments. Traditional adaptation strategies as noted above have water quality implications and may further lead to the vulnerability of local communities. Vulnerabilities, because of inadequate resource management strategies, can be further compounded by cases of historical inequitable access, for example, where commercial water users are given preferential access over smallholder farmers who practice permaculture to sustain their livelihoods. In climate change-related impact assessments, the integration of underlying causes of vulnerability and adaptive capacity is needed in tandem with engineering infrastructure aspects-related solutions.

3.2 VULNERABILITY OF LOCAL COMMUNITIES TO CLIMATE-RELATED RISKS AND EXPOSURE (FURTHER IMPACTS ON SUSTAINABLE LIVELIHOODS)

Poor households are mostly vulnerable to changes that threatens their livelihoods and well-being, an example being the Covid 19 pandemic outbreak, which forced rather strict measures of safety and precautional protocols (lock down) as a response were put in place. Although the response to the pandemic was to try and maximise human health, it left a lot of people without jobs. This further affected their livelihoods. Now, for the poor communities and households the situation turned out to be worse than for many other communities because they generally lacked the sustainable livelihood assets.

One of the conversations that was going on in a taxi was shocking, but also understandable, with one woman saying that

"*if I were to choose between staying at home during lock down, or taking the risk of exposure looking for work, I would take that risk, because most of my family members are just sitting at home and it is hard to feed everyone and we do not have anything to fall back onto, nor do we have any technological skills that maybe can help us look for work that we can do while at home."*

This reflection shows that the livelihoods of local communities, especially in the townships, may be deemed to be unsustainable. This further creates more challenges for the impoverish communities when it comes to climate change impacts, because lacking the sustainable livelihoods assets implies that those households are unable to adapt to the changes.

A study carried out by Maponya and Mpandeli (2013) in Limpopo province, South Africa, investigated the role played by the aid given by extension services in climate change adaptation. The finding showed that there was a strong link between gender, adaptation capacity, access to climate change data, food scarcity and the agricultural sector. This finding shows that livelihood assets play a significant role in climate change adaptation. This is so, because in the literature women are said to be more vulnerable than men to climate change. There is a lack of human capital, due to high level of illiteracy and inadequate skills development which allows people to compete in the job market. This further reflects on the financial capital, which also influences climate change adaptation, especially for local communities that live under the poverty line. Further, paying for services, i.e. water and electricity, reduces the capacity for adaptation actions for the local communities. This is further attributed to the fact that, decisions and actions taken at a local level are short term (daily to a month) and highly influenced by the means of providing food for that time.

3.3 HIGH DEPENDENCE ON NATURAL RESOURCES

Rural communities and those located in urban areas, sometimes referred to as the townships, they are highly dependent on natural resources to sustain their livelihoods (Balbi *et al.*, 2019; Halder *et al.*, 2012). Even though most people have migrated to the cities, they are still connected to the rural areas and hence uses local natural resources for basic needs. Ideally, one would suggest that every strategy and policy addressing climate chance adaptation, should cater for the local communities, to help improve their adaptive capacity. However, due to the knowledge gap and lack of communication, informed policies do not mean that greater of a deal for local communities, because it is not a practical solution and the implementation may take long, and it does not speak more to what they have, know and what they can use for them to be more resilient to the climate change impacts. Different views have suggested that adaptive management and community-based management of resources can help the society increase their adaptive capacity and be more resilient. However, Tompkins, and Adger (2004) argues that policy and adaptation strategies may improve resilience of local communities dependent of natural resources. Instead, the communities must be able to enhance their own coping methods even outside their knowledge. One of the ways that the society can improve its adaptive capacity even beyond what they know, is through social learning, knowledge transformation, co-learning, and empowerment. Thus, there is an opportunity for the policy and decision makers, different institutions, local communities, and a range of diverse stakeholders to engage and co-design practical methods that can improve adaptive capacity of local communities.

3.4 CLIMATE CHANGE-RELATED INFORMATION AVAILABILITY TO THE COMMUNITIES AND HOUSEHOLDS

Decision making around resources management and allocations, requires availability of reliable data, regardless of whether the decision is made a higher level or local level. For climate change adaptation, climatic information, needs to be available and accessible to everyone who's livelihoods are dependent on it. Studies have been done highlighting the challenges linked to climate change data and information but is has always looked at smallholder farmers as the reference for the local scale. Further the adaptation strategies and methods that come out of these studies, are more relevant to people that are farmers, this is good because the farmers get an opportunity to improve their adaptation capacity, while also feeding their families and improving their produce. However, the coping strategy for a community may differ from the coping strategies needed for a household.

3.5 DIFFERENTIATION BETWEEN COMMUNITY AND HOUSEHOLD ADAPTATION

Community-based Adaptation (CBA)

This is a community led initiative, that gathers people in the community to tackle issues of climate change and how best the community can adapt. This initiative aims to include the vulnerable people as well. According to McNamara and Buggy (2017), the focus on climate change adaptation has increase more than the mitigation and there has been a shift (Mees *et al.*, 2019) or consideration of the CBA to better understanding the climate change impacts of the local communities and further, investigate the adaptation strategies appropriate for this scale. Further, the study highlights that the shift was seen in the early 2000s where the importance of human factor with indigenous knowledge became more evident and vital for adaptation capacity.

Household Adaptation

According to Carman and Zint (2020), personal or household adaptation can be classified as, household-protection, learning, public engagement, etc. however, (Carman and Zint, 2020) further emphasize more research that will clearly define this concept. With climate change impact evident and affecting people every day in one way or the other, it is clear that climate chance adaptation is a social matter. Whether each person equip him/herself or each household to be resilient and able to cope with the shocks and hazards, exposing them to climate-related risks, it is a challenge that is highly linked to socio-economic impacts. Further, poor household are often vulnerable and exposed to changing climate, through floods and droughts. To improve the adaptation capacity of these households, the housing infrastructure is highly important. Adequate building material plays a huge role, especially during flood events. This further brings back the issues of inequality as a symptom to vulnerability and inability to cope with changes that threaten the livelihoods of the local communities.

3.6 TOOLS TO USE TO ENGAGE THE COMMUNITY IN BUILDING CAPACITY

To engage a community or household in building capacity, it is important to use the participatory tools that are not exploitive but empowering to the most vulnerable. For instance, if one were to engage the community or household in matters that are not familiar to them such as climate change, a digital story telling compiled by both the researcher and community members would be a good start. Here, one would be documenting all changes around the area of interest through time, from what it used to be as described by the local stakeholders who has the indigenous knowledge and the history of that area. This will help create a picture of how the area has changed through time due to climate change, and then this will provide an opportunity to take the conversation further, to how do we then adapt collectively. Different knowledge of tools and methods can be discussed and exchanged among different stakeholders.

3.7 WHAT TOOLS CAN BE USED TO PROVIDE MORE CAPACITY

- Financial support
- Learning and awareness programmes
- Climate change information, that is easily understood at the local level
- Participatory tools that acknowledge the local knowledge and experience
- Digital storytelling and photo voice.