CLIMATE CHANGE RESPONSE STRATEGY for WATER & SANITATION SECTOR

"WATER SECURITY IS CLIMATE SECURITY"

JANUARY 2025

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Water is Life,
Sanitation is Dignity

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Minister's Foreword

Water is essential to life, the environment, and the economy.

The water and sanitation sector is, however, the most sensitive to the impacts of climate change. Water security requires climate security. While climate change is not the only challenge for providing water security and access to sustainable sanitation systems in South Africa, it will amplify existing threats and challenges for water and sanitation, including increasing risk of floods and droughts, and declining water quality.

The Department of Water and Sanitation (the Department) business is to ensure the provision of water and sanitation services as well as ensuring its sustainability for present and future generations across the length and breadth of our country, as enshrined in the Constitution of the Republic of South Africa and ensured through the National Water Act, Water Services Act and Regulations, etc.

The Department's obligations towards responding to climate change within the water and sanitation sector are outlined in the Water and Sanitation Sector Policy on Climate Change, which is mandated by National Policies, Regional and International Policy Frameworks of which South Africa is a signatory to.

South Africa has recently been experiencing an increased frequency and intensity of extreme weather events, that lead to devastating effects on lives, livelihoods, infrastructure and local economies.

Some of these events, scientists inform us, are attributed to climate change, which further adds complexities and challenges to the water resources and sanitation systems.

These extreme weather events led to flooding, landslides, droughts, heatwaves, etc., that impacted and further exacerbated the challenge of the provision of water quality and sanitation services. These require urgent actions, as the impacts have already been experienced and also work towards reducing future impacts.

These urgent actions need coordinated efforts through the sectors, spheres of government, partnerships between state actors, Civil Society, Private Sector and multilateral nations and across shared international water bodies. This approach will lead us towards transformational adaptation pathways as a sector, that climate scientists are urging us to implement as some of the end of century projected climate change impacts are said to be already occurring, ensuring sustainable development pathways.

As the custodian of our water resources, and responsible for ensuring current and future water security and access to safe sanitation, the Department must be at the forefront of both understanding the risks posed by climate change and initiating the necessary adaptation and mitigation responses.

The Department went through a process of reviewing its National Climate Change Response Strategy for the Water and Sanitation Sector, developed in 2014, that involved a review of the state-of-the-art science on climate change, water resources and sanitation to update the 2013 Climate Change Status Quo for the Water and Sanitation Sector, and based on that review and update the 2014 National Climate Change Response Strategy for Water and Sanitation.

This updated Climate Change Response Strategy aims to address increasing climate change-related challenges to achieving the objectives of the Sustainable Development Goals by being proactive in identifying the increasing risks associated with climate change, but also recognising that South Africa has a long history of investing in the necessary critical infrastructure to provide water security in a highly variable climate.

Through recognising the strengths of the existing system of water resources planning and implementation of critical infrastructure, which includes the protection of ecological infrastructure, the DWS aims to achieve the vision outlined in this strategy of a low carbon, climate-resilient, equitable, efficient and a sustainable water and sanitation sector by 2050 for all South Africans including both current and future generations.

Miss Pemmy C.P. Majodina (MP)
Minister: Water and Sanitation

Deputy Minister's Foreword

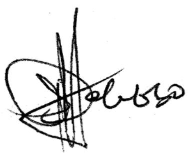
Access to sanitation has increased significantly in South Africa from 31.7% in 2002 to 84.1% in 2021. However, despite this achievement the recent green drop report indicates that the sustainability of existing sanitation service remains a challenge. This is an issue or concern as climate change will likely have an impact on the ability to treat wastewater and to meet final effluent requirements, making the existing situation worse and affecting vulnerable communities disproportionately. In addition, it is estimated that wastewater treatment works consume up to 30% of the total energy used by municipalities.

Considering that most of the electricity in South Africa is provided from coal fired power stations, reducing the electricity consumption from both the water and sanitation sectors, particularly for water and wastewater treatment could contribute significantly to reducing the overall greenhouse gas emissions from South Africa.

Improved energy efficiency of WWTW and the overall water and sanitation system will also help to reduce overall operational costs for municipalities as electricity and fuel costs continuing to increase. The likely increase in extreme events, particularly flooding, due to climate change and combined with other risk factors such as population growth, increasing pressure for land, degraded catchment areas and insufficient urban planning, also poses a significant risk to critical water and sanitation infrastructure as was experienced with the recent floods in KZN.

We now have an opportunity to implement new and innovative sanitation solutions that will reduce water consumption, reduce the impacts of sanitation on the changing climate and on the environment, and improve the climate resilience of critical infrastructure.

This however requires strong co-operation between different departments, the public and private sector. The update Climate Change Response Strategy recognises this need for improved collaborative governance in ensuring future water security and the provision of sustainable sanitation system as well as the importance of improved operation and maintenance and reducing the carbon footprint.



Mr Mbangiseni David Mahlobo (MP)
Deputy Minister: Water & Sanitation

Deputy Minister's Foreword

Water is essential to life and the Constitution of the Republic of South Africa guarantees the right to everyone to have access to sufficient water (Section 27(1) of the South African Constitution (Act 108 of 1996)). However, climate change threatens both current and future water security in South Africa and access to water as a basic human right. It also impacts on the right to a healthy environment through potential impacts on water quality and environmental systems.

Changes in climate are projected to result in increased temperatures and more variable rainfall, with some areas having an excess of water while other areas will have too little. Changes in water availability will also affect water quality, which will also impact natural eco-systems ability to cope. Declining water quality will also increase the costs for water treatment for human, agriculture, municipal and industrial use.

Excess water, in the form of floods, will impact on critical infrastructure, including water supply infrastructure. More intense rainfall events could also increase the risk of landslides, while sea level rise will contribute to increased risk of coastal flooding and saltwater intrusion affecting groundwater sources and several dependent ecosystems. Increased temperatures will lead to increased water demand from multiple sectors especially agriculture, the cooling of power stations, and for domestic consumption.

Reduced water availability due to low and/or more variable rainfall as well as increasing demand due to higher temperatures can cause water sources (including boreholes and springs) to run dry. Increasing water-scarcity and the resulting increase in the costs of water treatment will increase inequitable and access to basic services.

Mr Isaac Sello Seithlolo (MP)
Deputy Minister: Water & Sanitation

Director-General's Foreword

Water resources are critical for continued economic growth and upliftment of the South African public as well as provision of critical infrastructure. However, climate change is expected to have an impact on water security which will impact on economic growth. South Africa is also expected to feel a range of impacts that may affect different regions disproportionately, where some areas are expected to see an increase in flooding and others will see an increase in droughts. This will require investment in the upgrading and improved operation and maintenance of existing infrastructure as well as the development of new critical resilient and adaptable infrastructure.

Climate Change adaption options for water and sanitation should be put in place both through reducing vulnerability and improving resilience. Adaptation can provide multiple benefits to various sectors, especially in agriculture. These benefits include increased agricultural productivity, innovation, health and well-being, food security, livelihood security, and biodiversity conservation, as well as risk and damage reduction. As such, adaptation response actions for water and sanitation in South Africa need to be considered in the context of the existing approaches to integrated water resources management practiced in South Africa recognising that any impacts of climate change are "superimposed" upon existing climate variability and water security challenges. The identification and implementation of adaptation responses for water and sanitation must also be developed and operate within the overarching guiding principles of the South Africa's National Climate Change Adaptation Strategy.

Municipalities are responsible for the provision of water services in accordance with the Constitution, the Water Services Act and by-laws of the water services authority, and as such will play a critical role in climate change mitigation, adaptation and resilience. Implementation of this strategy will rely on Improved Collaborative Governance as outlined under the first Key Strategic Objective (KSO 1) of the Strategy.

To achieve this will require significant investment from both the public and the private sector as well as support from the international community. These investments should also be aligned with South Africa's Just Energy Transition (JET) through recognising the critical link between water and energy and the importance of water security and sanitation in adapting to the potential impacts of climate change. This will require cross-sectoral partnerships and collaboration between government, the private sector, academia, civil society organisations, communities, and the international community.

Using knowledge and information generated from partnerships both nationally and internationally will inform the actions and steps taken by municipalities and ensure resilience to adaptation, mitigation, and resilience to climate change. This will require improved monitoring of climatic variables, which will require that citizen science be improved to ensure improved data availability for research and knowledge generation.

Dr Sean Phillips
Director-General:
Department: Water & Sanitation

VISION

A low-carbon, climate-resilient, equitable,
efficient, & sustainable
water & sanitation sector by 2050.

MISSION

All water & sanitation sector institutions, partners & users are aware of, plan for, take ownership of the strategy & respond through appropriate collaboration & joined efforts to a changing climate and its impacts on water & sanitation and have the capacity to manage water resources & sanitation in a context of high levels of uncertainty.

DOCUMENT INDEX

Several reports that were produced as part of the Study and are indicated below.

Bold type indicates this Report: Final Climate Change Strategy for the Water Sector.

Scan the QR code for more on Water Security is Climate Security – Directorate Climate Change Analysis

Index	DWS Report No.	Report Title & Deliverables
1	P RSA 000/00/23221/1	Inception Report
2	P RSA 000/00/23221/2	Literature Review
3	P RSA 000/00/23221/3	Review of Global Climate Change models and scenarios
4	P RSA 000/00/23221/4	Review of Hydro-Climatic Zones
5	P RSA 000/00/23221/5	Downscaled Climate Change Scenarios for the Water Sector
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13	P RSA 000/00/23221/13	National Water Resources Management
14	P RSA 000/00/23221/14	Climate change, Water Infrastructure, and Climate Proofing
15	P RSA 000/00/23221/15	Draft Status Quo Assessment Report
16	P RSA 000/00/23221/16	Final Status Quo Assessment Report
17	P RSA 000/00/23221/17	Risk and Vulnerability Assessment for Water Sector
18	P RSA 000/00/23221/18	Adaptation (and Mitigation) Actions for Water and Sanitation
19	P RSA 000/00/23221/19	Draft Climate Change Strategy for Water Sector
20	**P RSA 000/00/23221/20**	**Final Climate Change Strategy for Water Sector**

List of Abbreviations

APPs	Annual Performance Plans
AR5	Assessment Report 5 (IPCC)
AR6	Assessment Report 6 (IPCC)
CC	Climate Change
CCAM	Conformal Cubic Atmospheric Model
CCRS&IP	Climate Change Response Strategy and Implementation Plan
CMA	Catchment Management Agency
CMIP	Coupled Model Intercomparison Project
CO2	Carbon Dioxide
CoCT	City of Cape Town
CoJ	City of Johannesburg
COL	Cut Off Lows
CRD	Climate Resilient Development
CRDP	Climate Resilient Development Pathways
CRVA	Climate Risk and Vulnerability Assessment
CSA	Climate Smart Agriculture
CWRA	City Water Resilience Approach
CWRF	City Water Resilience Framework
DBSA	Development Bank of South Africa
DEA	Department of Environmental Affairs
DHS	Department of Human Settlements
DWS	Department of Water and Sanitation
EBA	Ecosystem based Adaptation (EbA)
EI	Ecological Infrastructure
ET	Evapotranspiration
GCMs	Global Circulation Models
GCTWF	Greater Cape Town Water Fund
GHG	Greenhouse gas
HFD	Hybrid Frequency Distribution
IAPs	Invasive Alien Plants
IDAs	International Development Agencies
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
JET	Just Energy Transition
KFA	Key Focus Areas
KSO	Key Strategic Objectives
LHWP	Lesotho Highlands Water Project
LIMCOM	Limpopo Watercourse Commission
LTAS	Long-Term Adaptation Scenarios
M&E	Monitoring and Evaluation
MAP	Mean Annual Precipitation

List of Abbreviations	
MAR	Mean Annual Rainfall
NAP	National Adaptation Plan
NbS	Nature based Solutions
NCCAS	National Climate Change Adaptation Strategy
NCCRS	National Climate Change Response Strategy
NDC	Nationally Determined Contributions
NDP	National Development Plan
NIWIS	National Integrated Water Information System
NRW	Non-Revenue Water
NSSD	National Strategy for Sustainable Development
NW&SMP	National Water and Sanitation Master Plan
NWA	National Water Act
NWRS	National Water Resources Strategy
OKACOM	Okavango River Basin Water Commission
ORASECOM	Orange-Senqu River Commission
PCC	Presidential Climate Commission
PET	Potential Evapotranspiration
PFA	Priority Focus Areas
RBO	River Basin Organisation
RCPs	Representative Concentration Pathways
RVA	Risk and Vulnerability Assessment
SSP	Shared Socio-economic Pathway
TDF	Transition Dynamics Framework
TDS	Total Dissolved Solids
TMG	Table Mountain Group
TTT	Tropical Temperate Troughs
UFW	Unaccounted-for Water
VUCA	Volatile, Uncertain, Complex, and Ambiguous
WB	Water Boards
WCWSS	Western Cape Water Supply System
WfW	Working for Water
WMA	Water Management Areas
WRI	World Resources Institute
WSCI	Water Sensitive Cities Index
WTW	Water Treatment Works
WUA	Water User Association
WTP	Water Treatment Plants
WWTP	Wastewater Treatment Plants

EXECUTIVE SUMMARY

South Africa is a water-scarce country which has a long history of managing its limited water resources, without which South Africa would not have been able to achieve its current level of social and economic development. With increasing social and environmental pressures, the ability to proactively engage towards ensuring water security remains critical to South Africa achieving its national objectives for sustainable and inclusive economic growth for all South Africans. Climate change poses a significant threat to future water security in South Africa, and it is essential to consider adaptation and mitigation actions for the water and sanitation sector.

In recent years, South Africa has experienced several water security challenges that have been partly attributed to increased climate variability. These include the Cape Town "Day Zero" crisis, the Nelson Mandela Bay water crisis, the impacts of prolonged drought in the Eastern Cape and water supply challenges in Gauteng. All of these have had a severe impact on the economy of the country as well as the livelihoods of individual citizens. In addition to these major events, water security (and sanitation) challenges persist on a daily basis over the vast majority of the country, particularly affecting smaller and less well capacitated communities.

In addition to increasing water security risks, the country has also experienced an apparent increase in extreme flood events causing significant damage to critical infrastructure, damage to properties, disruption to the economy and loss of life. Increasing temperatures and increased rainfall intensity also seem to be impacting directly on sensitive sectors such as agriculture, the demand for water, and existing challenges for water quality, erosion, and sedimentation.

While these challenges are increasing as a result of climate change, there are also several other significant contributing factors that also need to be addressed. The primary concern is that the impact of most of these events has been largely increased as a result of a lack of implementation and maintenance of critical water supply (and sanitation infrastructure). For several decades, South Africa, has applied systems for the identification and planning of critical water supply and sanitation infrastructure requirements and operational systems that are based on an understanding of the existing climate variability and increasing demands. These have been supported by the National Water Act (NWA) and various Integrated Water Resources Management (IWRM) Planning processes, that are based on a principal of adaptive management. While these systems have effectively identified the necessary augmentation options, and also included the need to effectively managed increasing demand, there have been significant delays in the implementation of this critical infrastructure or maintenance of systems that is significantly contributing to the current and future climate related risks for both water supply and sanitation as well increased flooding and declining water quality risks.

Improved resilience of water and sanitation systems is a critical responsibility of the DWS as well as for District and Local Municipalities, and even individual companies and communities.

The 6th Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC AR6) was published in 2022, and examines the impacts of climate change on ecosystems, biodiversity, and human communities, globally. The AR6 presents the latest synthesis of scientific knowledge on likely impacts and the capacity of society to adapt to climate change risks and follows a three decades of international policy development on climate change dating back to the United Nations Framework Agreement in 1992. The AR6 report confirmed that there is now a consensus amongst scientists that the global climate is changing and that this is as a result of anthropogenic, or human impacts. If no action is taken, then we are likely to see a significant increase in global temperatures well beyond 1.5 or 2 C.

The IPCC also confirmed that Africa is likely to be one of the most severely impacted regions and is also one of the most vulnerable due primarily to a lack of resilience infrastructure and social and economic resources necessary to adapt to the increasing climate relate threats. It also notes that, globally, the water and sanitation sector is likely to be most severely impacted.

In South Africa, future climate scenarios suggest significant increases in temperature and increased variability in rainfall. On the whole, the western half of the country is expected to see significant drying, while the eastern half could see increased wetting, on average, but with greater variability contributing to an increased frequency of both floods and droughts. In the long term (i.e., out to 2100) all of South Africa will likely experience drying. This, combined with increasing demands for water requires immediate response so as not to have a negative impact on individual livelihoods, communities, companies, and the economy.

In addition to the direct impact on water availability, higher temperatures and reduced streamflow will also contribute to increasing water quality risks, which is already a national crisis. Increased rainfall intensity will also contribute to more flooding and threating critical water related infrastructure.

One of the challenges with adapting to the impacts of climate change is the level of uncertainty about future climate scenarios and variability particularly with regards to precipitation. This requires consideration of an adaptive management approach. In many ways, South Africa is already applying an adaptive management approach to water security with regular updates required to the national water resources strategy (NWRS) and water reconciliation plans for the development of the integrated bulk water supply systems and stand-alone schemes. There are several aspects of the National Water Act, which governs how water resources should be managed in South Africa, that support an adaptive management approach as well as ensuring reliability of supply and sustainability through providing protection for environmental flows.

In addition, individual municipalities should also be applying an adaptive management approach through regular updating of water services development plans (WSDPs). These processes need to be strengthened in the face of the impacts of climate change, as well as several other stresses to the water and sanitation sector, through the provision of reliable data through improved monitoring, hydrological modelling and analysis, technical capacity to implement and support with funding and financing the necessary interventions. This requires close collaboration between the different spheres of government as well as the private sector.

In response to the increasing climate change related risks, all sectors are required to develop a climate change response strategy (CCRS). The Department of Water and Sanitation (DWS) has undertaken to review the previous CCRS for the water sector developed in 2013 in line with the updated mandate of the Department and an updated Status Quo Assessment of both climate change and water and sanitation related challenges in South Africa. The Updated Status Quo Assessment (SQA) is presented in a series of separate technical reports but is summarised in this Report which presents the updated CCRS for water and sanitation sector.

The CCRS is summarised in the figure below including an updated vision, key strategic objectives (KSOs), and priority response actions (RAs). These KSOs and RAs are unpacked as part of the Strategy and including proposed next steps for implementation. The Strategy also includes a summary of the updated status quo assessment and proposed adaptation and mitigation actions that can inform the next steps in moving towards achieving the vision of a low-carbon, climate resilient, equitable and sustainable water, and sanitation sector by 2050.
Priority actions, potential partners and proposed timeframes and indicators for each of the five Key Strategic Objectives (KSO) of the updated strategy have been identified in the table below.

In terms of achieving the vision of a low-carbon climate resilient, equitable, efficient, and sustainable water and sanitation sector by 2050, one of the most critical priorities for South Africa is to implement critical water and sanitation infrastructure that has already been identified through the various planning process at both national and local level.

Several of these critical infrastructure projects have been delayed and as a result are contributing to the current level of water and sanitation security risks that is impacting on the economy and individual livelihoods. As a result, the priority KSO is to implement KSO 2 which includes the implementation of critical (and in many cases delayed) infrastructure as well as increased investments in protecting and rehabilitating natural systems and ecological infrastructure (EI).

Even more critical than investing in new climate resilient infrastructure is improving operations and maintenance of existing water and sanitation infrastructure (i.e., KSO 3). This will not only have a direct impact on achieving the overall vision but is also necessary to support the investment in climate resilient infrastructure systems (KSO 2) and also to achieve the objective of reducing the overall carbon footprint of the water and sanitation systems (i.e., KSO 5).
Underlying improved operations and maintenance (KSO 3), investing in climate resilient infrastructure systems (KSO 2) and reducing the carbon footprint of the water and sanitation sector (KSO 5) is improved collaboration and co-operative governance which includes training and capacity building for key stakeholders and decision makers.

Finally, the provision of knowledge and information through training, research and capacity building is critical in supporting all aspects of improved climate resilience for water and sanitation in South Africa and supporting science-based decision making for water security.

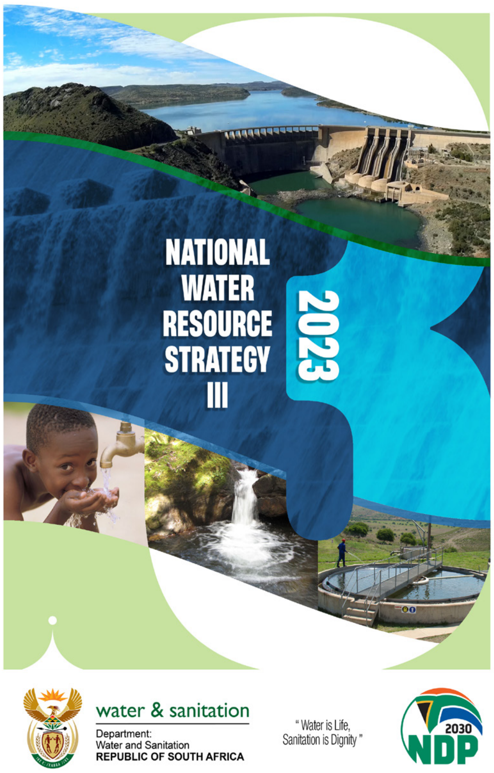
It is clear that climate change is already starting to have a major impact on water security and infrastructure in South Africa and any delays in responding to these increasing risks will make it increasingly difficult to adapt in future and result in further damage and economic impacts.

In terms of the Way Forward, the immediate priority actions for DWS (i.e., **the FIVE BOLD STEPS**) that need to be taken to advance the updated climate change strategy are as follows:

1. **Implement critical (and delayed) water supply & sanitation infrastructure.**
2. **Fast-track climate change mainstreaming & implementation of responses in the sector.**
3. **Raise awareness of climate change risks within DWS & alignment with the JET.**
4. **Identify critical areas of research & updating of IWRM guidelines & practices.**
5. **Help develop guidance on securing climate finance for water security & sanitation.**

The development of the updated NCCRS for water and sanitation has undergone extensive stakeholder engagement to try and accommodate all voices. It has also been developed in the specific context of promoting Gender, Equity and Social Inclusion (GESI).

In addition to the updating of the NCCRS, the DWS has revised the National Water Resources Strategy (NWRS)(pic below) and is currently revising the Water and Sanitation Master Plan (WSMP) with strong and aligned focus on climate action. These documents together form a comprehensive approach to improved water security in the country.



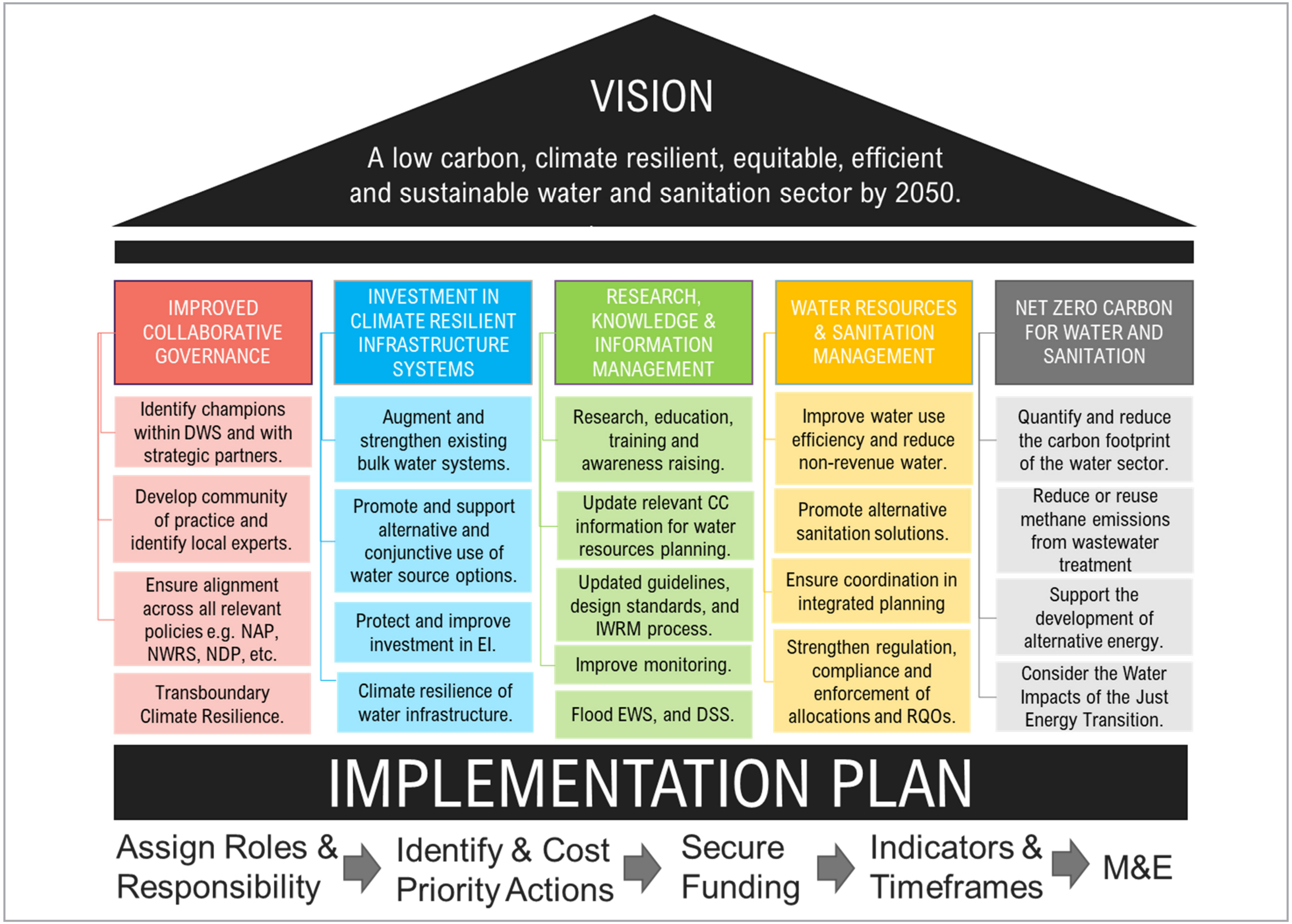


Figure E1: Strategic framework for achieving the vision of a low carbon, climate resilient water & sanitation sector.

Key Strategic Objectives (KSO)	Priority Actions	Scale	Lead Organisation (bold) and Other Potential Partners	Time Frame			Potential Indicators
				Short (< 2y)	Medium (2-5yr)	Long (>5yr)	
KSO 1: Improved collaboration and co-operative governance	Identify, train, and capacitate champions within DWS and with other strategic partners.	National, Regional and Local Levels	**DWS (D:CC, CD: IGR)**, WRC, CMAs, WSAs, WBs, PCC, DFFE, COGTA, NGOs, IDAs, etc.				Identified champions and MOUs with key partners.
	Develop community of practice and identify local experts and forums for collaboration.	National	**DWS (D:CC)**, WRC, PCC, WUAs, Academia, IDAs.				National and local level community of practice and forums established.
	Ensure alignment across all relevant policies e.g., NAP, NWRS, WSMP, NDP, JET, etc.	National	**DWS (B: WRM, SU: WRP&E)**, PCC, DFFE, DALRRD, DME, etc.				Updated NWRS, WSMP and all relevant DWS policies, and aligned with national policies.
	Improve transboundary climate resilience across SADC and with river basin organisations.	Regional	**DWS (CD: IWC),** LHWC, LIMCOM, ORASECOM, OKACOM, IDAs, etc.				Updated regional CC response strategy and agreements with RBOs.
KSO 2: Increased investments in climate resilient infrastructure.	Augment and strengthen existing integrated bulk water supply systems including the implementation of delayed infrastructure and improved operational rules and allocations.	National and Local Level	**DWS (B: WRM and B: Infrastructure),** CMAs, TCTA, DBSA, National Treasury, Municipalities, Private Sector, IDA, WBs.				Updated Reconciliation and All Town strategies and implementation of required augmentation.
	Promote and support alternative and conjunctive use of water source options at local level.	National and Local Level	**DWS (CD: IWRP),** WSPs, CMAs, TCTA, DBSA, WBs, Municipalities, Private Sector, IDAs, etc.				Percentage water use from alternative water sources. Number of municipalities with conjunctive water use.
	Increase investments in Ecological Infrastructure (EI) and Ecosystem Based Adaptation (EbA) recognising both the benefits, but also potential areas of concern.	National and Local Level	**DFFE,** DWS, CMAs, DALRRD, SANBI, WBs, Municipalities, NGOs, and Private Sector.				Hectares of IAPs removed and maintained. Number of rehabilitated wetlands.
	Improve climate resilience of existing (and new) water and sanitation infrastructure.	National and Local Level	**DWS (B: WRM and B: Infrastructure)**, TCTA, WSP, Municipalities, etc.				Climate change risk and vulnerability

Key Strategic Objectives (KSO)	Priority Actions	Scale	Lead Organisation (bold) and Other Potential Partners	Time Frame			Potential Indicators
				Short (< 2y)	Medium (2-5yr)	Long (>5yr)	
							assessments for critical water infrastructure.
KSO 3: Research, knowledge, and information management	Research, education, training, and awareness raising programs on climate change and responses for water and sanitation in South Africa.	National	**WRC,** DWS, DFFE, CMAs, Universities, Funding Partners.				Number of training and awareness raising meetings and workshops conducted. Number of climate change research studies and products produced.
	Update relevant climate change information such as NWIS and WR2012 used to inform water resources planning and design.	National	**DWS (B: WRM),** WRC, Accademia, SAWS, etc.				Climate change information on water knowledge portals.
	Develop updated design standards, IWRM process and guidelines that are aligned with climate resilience principals.	National	**DWS (B: WRM), DWS (B: Infrastructure),** WRC, SANRAL, SANCOLD, etc.				Updated IWRM process (Recon studies etc.) and design guidelines for infrastructure such as dams, roads, flood lines.
	Improved monitoring of water resources and water quality including for groundwater.	National, CMA and Local level.	**DWS (B: WRM),** CMAs, SAWS, DFFE, SAEON.				Increased number of stream gauges and availability of data. National groundwater monitoring system.
	Support the development of early warning systems (EWS) and Decision Support Systems.	National, CMA and Local level.	**DWS (B: WRM),** CMAs, SAWS, DRR, WBs, etc.				Increased number of EWS, and DSS at national and local.
KSO 4: Improved water resources and sanitation management	Improved water use efficiency and reduce non-revenue water losses across all sectors including municipalities, industry, agriculture, mining, energy, transport, and forestry.	Local	**DWS (CD: WUE)**, DALRRD, DFFE, DMME, and Municipalities, etc.				Reduced NRW and AUW. Improved water use efficiency for all sectors.
	Promote alternative and sustainable sanitation solutions.	Local	**DWS (B: Sanitation)**, SALGA, NT, and Municipalities				Implementation of alternative / low water use sanitation solutions.

Key Strategic Objectives (KSO)	Priority Actions	Scale	Lead Organisation (bold) and Other Potential Partners	Time Frame			Potential Indicators
				Short (< 2y)	Medium (2-5yr)	Long (>5yr)	
	Improved coordination and integration into planning for more water sensitive cities.	Local	**DWS (B: WRM)**, DALRRD, and Municipalities				Integration of climate change and resilience into local development plans.
	Strengthen regulation, compliance, and enforcements of allocations and RQOs.	Local	**DWS (B: WRM and B: Regulation),** CMAs, DFFE, etc.				Increased regulation of water use licenses and RQOs.
KSO 5: Net-zero carbon for water and sanitation.	Quantify and reduce the carbon footprint of the entire water and sanitation sector.	National and Local.	**DWS (B: WRM and B Sanitation),** WBs, WSA, PCC, WRC, SALGA, etc.				Research report on the carbon footprint of water.
	Identify opportunities for re-use of methane emissions from wastewater treatment plants.	Local	**DWS (B: WRM and B Sanitation),** SALGA, WSA, Municipalities.				Reduced methane emissions from wastewater treatment.
	Support the development of alternative energy solutions.	National, Regional and Local	**DME,** DWS, SALGA, ESKOM, Private Sector, etc.				Number of hydropower plants and other water linked renewable energy sources supported in SA.
	Consider the water resources impacts and WEF inter-connections of the Just Energy Transition (JET) in South Africa.	National	**DWS (CD: IWRP)**, DWS (Branch Sanitation), PCC, WRC, NGOs.				Report on the water-energy-food (WEF) links and recommendation for the water in the Just Energy Transition (JET).

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1. BACKGROUND & CONTEXT

1.1 Introduction

South Africa is a water-scarce country which has a long history of managing its limited water resources, without which South Africa would not have been able to achieve its current level of social and economic development. With increasing social and environmental pressures, the ability to proactively engage towards ensuring water security in an ever increasing volatile, uncertain, complex, and ambiguous (VUCA) world remains critical to South Africa achieving its national objectives for sustainable and inclusive economic growth for all South Africans.

In 2013, the then Department of Water Affairs (DWA), the predecessor to the current Department of Water and Sanitation (DWS), completed the development of a **Climate Change Response Strategy for the Water Sector** (DWA, 2013). The Response Strategy was informed by a comprehensive **Status Quo Analysis of Climate Change Impacts on Water Resources.** The following developments during recent years necessitate reviewing, updating, and expanding the Status Quo Analysis as well as refreshing and updating of the existing Climate Change Response Strategy for the Water Sector:

- Sanitation has been made part of the mandate of the responsible government department, DWS. The current Response Strategy does not deal with sanitation explicitly as the sanitation function was with the Department of Human Settlements in 2013.
- Increased understanding that climate change impacts on groundwater and ecosystems did not receive an adequate focus in the existing Status Quo Analysis and Response Strategy.
- Increased understanding that the six Hydro-Climatic Zones underlying the existing Status Quo Analysis are too coarse to reflect changes in climate at appropriately local scale.
- Climate change projections, via global circulation models and via local downscaling techniques and tools, have continued to improve during the past decade.
- Ongoing international collaboration on climate change adaptation, such as COP21, the Paris Agreement and the latest deliberations and outputs of the Intergovernmental Panel on Climate Change (IPCC) assessment report 6 (AR6), has continued to provide guidance and opportunities that need to be assessed and included, where appropriate, including the South African National Adaptation Plan and other regional climate change strategies.
- The extreme droughts events and water supply crisis faced by the City of Cape Town, the wider Western Cape, and also in the Eastern Cape, Gauteng and KwaZulu-Natal, have again highlighted the importance of updating hydrological information and the risks associated with climate change and the consequences of poor operation and maintenance.
- Recent flooding disasters in Southern Africa have also been attributed to climate change.

1.2 Purpose of this Report

The purpose of this report is to present the updated climate change response strategy for the water and sanitation sector in South Africa. This Report will form the basis for national and regional level stakeholder consultation before incorporating these comments in developing the final climate change response strategy to be developed for the water and sanitation sector. The updated climate change response strategy for water and sanitation forms an important part of the development of an updated national adaptation response plan for South Africa.

1.3 Alignment with the National Water Resources Strategy & the National Water & Sanitation Master Plan

The National Water Resources Strategy (NWRS) is presently the legal instrument for implementing or operationalising the National Water Act (NWA) (Act 36 of 1998). It binds all authorities and institutions implementing the Act. It is the primary mechanism to manage water across all sectors towards achieving national government's development objectives. The National Water Resource Strategy 3 has undertaken revision with the purpose to:

- Facilitate the proper management of the nation's water resources.
- Provide a framework for the protection, use, development, conservation, management, and control of water resources for the country.
- Provide a framework within which water will be managed at local, regional or catchment level, in defined water management areas.
- Provide a framework for strengthening the regulation of the water and sanitation sector.
- Provide information about all aspects of water resource management.
- Identify water-related development opportunities and constraints.
- Provide opportunities for the implementation of innovative technologies and solutions.

The purpose of the National Water Resource Strategy (NWRS-3) is to ensure the protection and management of water resources to enable equitable and sustainable access to water and sanitation services in support of socio-economic growth and development for the well-being of current and future generations in South Africa. The NWRS-3 is a strategy for all sectors and stakeholders who use and impact upon South Africa's water resources and it responds to the NWA by outlining strategic objectives and actions which are then passed forward for resourcing and implementation in the National Water and Sanitation Master Plan (NW&SMP).

The identified water sector priority focus areas in the NWRS for 2020 to 2030 are:

- Reducing water demand and increasing supply
- Redistributing water for transformation
- Managing water and sanitation services under a changing climate
- Regulating the water and sanitation sector
- Improving raw water quality
- Protecting and restoring ecological infrastructure for the green economy
- Creating effective water sector institutions
- Promoting international cooperation
- Building capacity for action
- Ensuring financial sustainability
- Managing data and information in line with 4th Industrial Revolution and global knowledge
- Enhancing research, development, and innovation
- Addressing legislative and policy gaps

Adapting to climate change is critical in ensuring future water security and sustainability. The Key Strategic Objectives from the National Climate Change Response Strategy (NCCRS) were integrated into the National Water Resources Strategy (NWRS) Strategic Objectives, indicated in Table 1. Furthermore, the Strategy Objectives of the NCCRS for water and sanitation are aligned with and/or mandated by the Water and Sanitation Sector Policy on Climate Change, Climate Change Bill, National Climate Change Adaptation Strategy (NCCAS), National Adaptation Plan (NAP), the National Development Plan (NDP), Midterm Strategic Frameworks (MTSF) Outcomes, Sustainable Development Goal (SDG), Southern Africa Development Countries (SADC) Climate Change Strategy and Africa Union Agenda 2063.

Table 1: Alignment of National Water Resource Strategy III & National Climate Change Response Strategy for Water & Sanitation

National Water Resource Strategy III	National Climate Change Response Strategy for Water & Sanitation
Strategic Objective 1: To improve & enhance water management & sanitation for enhanced adaptive capacity	**K.S.O 1: (Key Strategic Objective)** Improved collaboration & co-operative governance
	K.S.O 3: Enhance research, knowledge & information management
	K.S.O 4: Improved water resources & sanitation
Strategic Objective 2: To integrate climate change considerations into short, meduim & long-term water & sanitation planning process.	**K.S.O 1:** Improved collaboration & cooperative governance
	K.S.O 2: Increased investment in climate-resilient infrastructure
	K.S.O 3: Enhance research, knowledge & information management
	K.S.O 4: Improved water resources & sanitation
	K.S.O 5: Net-zero carbon for water & sanitation
Strategic Objective 3 : To develop appropriate adaptation measures to maximise water security & resource protection under changing climate conditions	**K.S.O 2:** Increased investment in climate-resilient infrastructure
	K.S.O 3: Enhance research, knowledge & information management
	K.S.O 4: Improved water resources & sanitation
	K.S.O 5: Net-zero carbon for water & sanitation
Strategic Objective 4 : To enhance internal capacity & provide resource for improved resilience to climate change impacts	**K.S.O 3:** Enhance research, knowledge & information management
Strategic Objective 5 : To increase awareness of & build capacity on climate change issues	**K.S.O 3:** Enhance research, knowledge & information management
Strategic Objective 6 : To ensure inter-linked climate & hydrological scenario projections representative of the complex inter-related natural systems	**K.S.O 1:** Improved collaboration & cooperative governance
	K.S.O 3: Enhance research, knowledge & information management
	K.S.O 4: Improved water resources & sanitation

2. SETTING THE SCENE

2.1 Overview of Water & Sanitation in South Africa

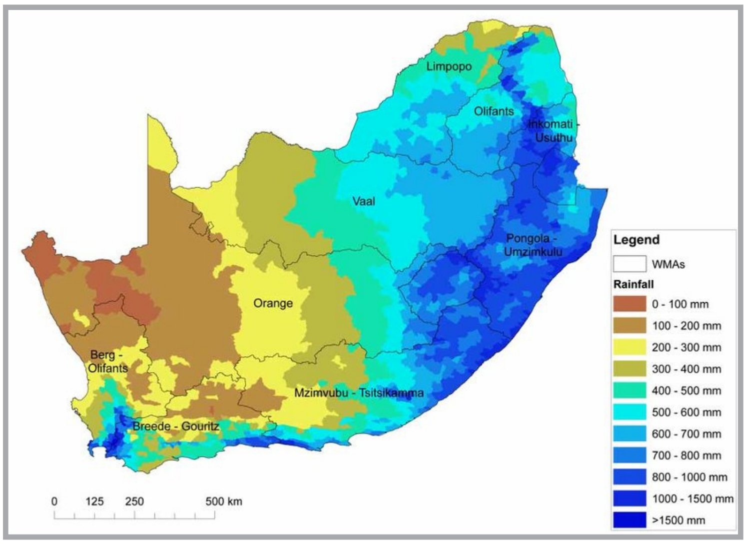

Figure 1: Mean annual precipitation (MAP) across South Africa

South Africa is, and always has been, a water-scarce country with an average annual rainfall of only 465 mm which is significantly lower than the world average of 860 mm. Rainfall is also highly variable across the country ranging from over 2000 mm per year in the east and the high lying mountains, to less than 50 mm per year on the dry west coast (Figure 1).

Rainfall is also highly seasonal and varies significantly from year to year with regular periods of drought, but also experiencing extreme floods. In addition, the majority of water demands are located far from reliable sources of water. For example, Gauteng, which is the main economic hub of the country is located on a continental divide and water has to be transported from as far away as the highlands of Lesotho in order to meet the increasing water demands.

Due to the significant spatial variability in rainfall, there is very limited areas that contribute significantly to water resource availability across the country. These areas are identified as Strategic Water Source Areas (Figure 2). Despite only representing 8% of the total land area of South Africa, they support over half of the population of the country, two-thirds of the economy activity, 70% of irrigated agriculture and 90% of urban consumers. The protection of these water source areas is essential in terms of mitigating the impacts of climate change.

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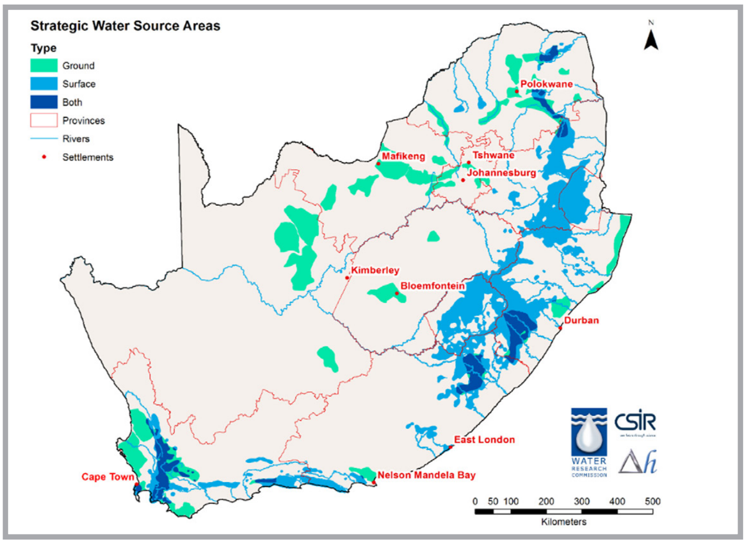


Figure 2: Strategic Water Source Areas of South Africa
(Le Maitre et al, 2018)

Despite only representing 8% of the total land area of South Africa, they support over half of the population of the country, two-thirds of the economy activity, 70% of irrigated agriculture and 90% of urban consumers. The protection of these water source areas is essential in terms of mitigating the impacts of climate change.

Despite these challenges, South Africa has been able to provide access to basic water and sanitation services for the majority of its population and to support one of the largest economies in Africa. This is largely as a result of a history of pro-active water resources planning and provision of basic services. South Africa has over 4 395 registered dams, of which 794 are considered large dams (i.e., dams with a wall height > 15 m or storage capacity exceeding 3 million m^3) with a combined storage capacity of over 31 000 million m^3 (DWS, 2018).

South Africa has a highly complex system of inter-basin transfers that provides water to support the major economic and population demand nodes of the country as shown in Figure 3. These systems are critical in supporting the majority of demands and the bulk of the economy and already provide some resilience to the potential impacts of climate change (Cullis et al, 2015). A critical requirement of the National Water Act (NWA) is that the requirements for augmentation of the national bulk water supply system be regularly updated and inform the planning and implementation of critical infrastructure. Delays in the implementation of this critical water related infrastructure contributes significantly to increasing water security risks in the country.

The provision of storage, primarily from dams, is necessary to ensure a reliable supply of water to meet the demands and becomes even more critical as streamflow becomes more variable due to climate change. However, dams also have a negative impact on the environment and there are very few suitable locations remaining for the development of new dams. The National Water Act (NWA) requires the environmental impacts of water supply infrastructure and demands to be carefully managed in order to protect the resource. This is achieved through the development of environmental water requirements (EWR) and resource quality objectives (ROQs) as well as specific technical innovation such as multi-level outlets and larger discharge capacity for dams that enable improved management of environmental flows.

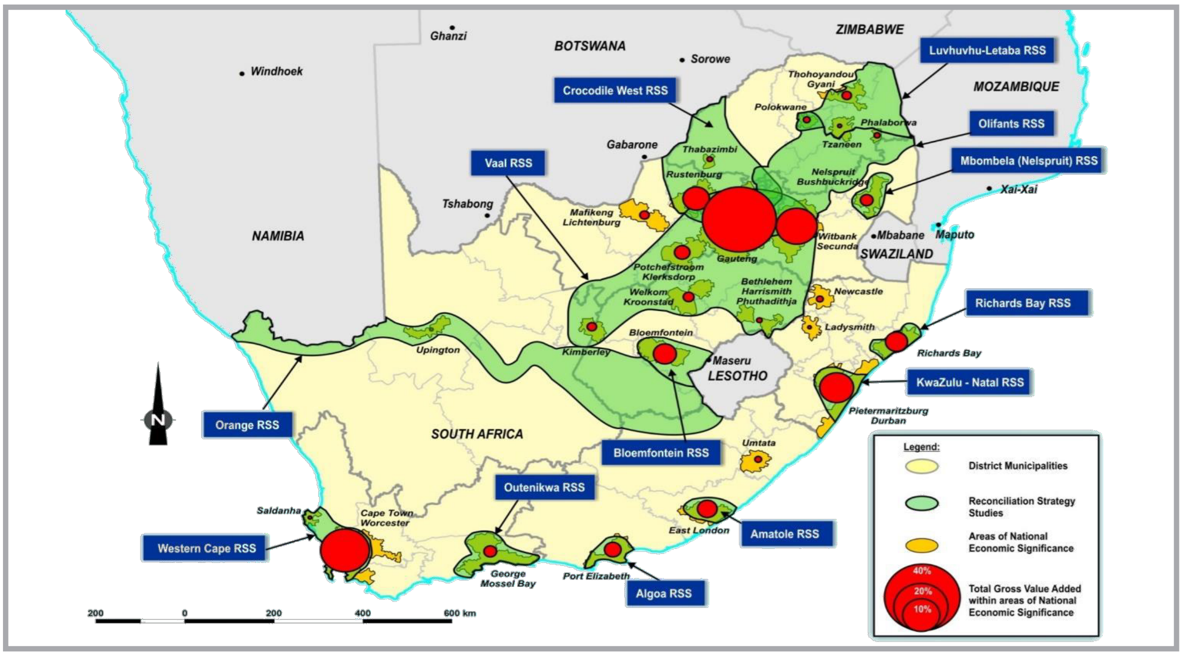


Figure 3: Summary of current integrated bulk water supply systems (WSS) for South Africa
(Source: DWS, 2018)

The need to protect the resource is also recognised through the designation of Strategic Water Source Areas (SWSAs), National Freshwater Environmental Protection Areas (NFEPAs) and the clearing of Invasive Alien Plants (IAPs) as part of the Working for Water Program which contributes not only to improved water security, but also skills development and job creation.

Over time, the DWS has undertaken regular planning studies of these major integrated bulk water supply systems that look to reconcile current and future water demands with the need for additional augmentation options which are prioritise on a least costs basis. As a result, several future water supply options have already been identified across the country and are in various stages of development, as shown in Figure 4. Based on the planning already undertaken several of these augmentation options should already have been implemented and this is contributing to the current water security crisis in South Africa (Muller, 2019). The delay in implementing critical water infrastructure poses a significant economic risk to South Africa.

A recent study of the Western Cape Water Supply System (WCWSS), the main water supply system for Cape Town, has shown the return on investment for water supply augmentation is significant, and that the risk of not preventing water shortages is severe (World Bank, 2022). While the bulk of demands, and the economy, is supported by surface water supply, approximately 9% of the demand is met from groundwater, with nearly half of all municipalities being at least partially dependent on groundwater (Figure 5) as well as several other industries and agriculture. Groundwater has the potential to provide an alternative water source during periods of drought, but it is also a scarce resource that needs to be carefully managed.
The conjunctive use of surface and groundwater can also improve water security and climate change adaptation, particularly if combined with the potential for managed aquifer recharge.

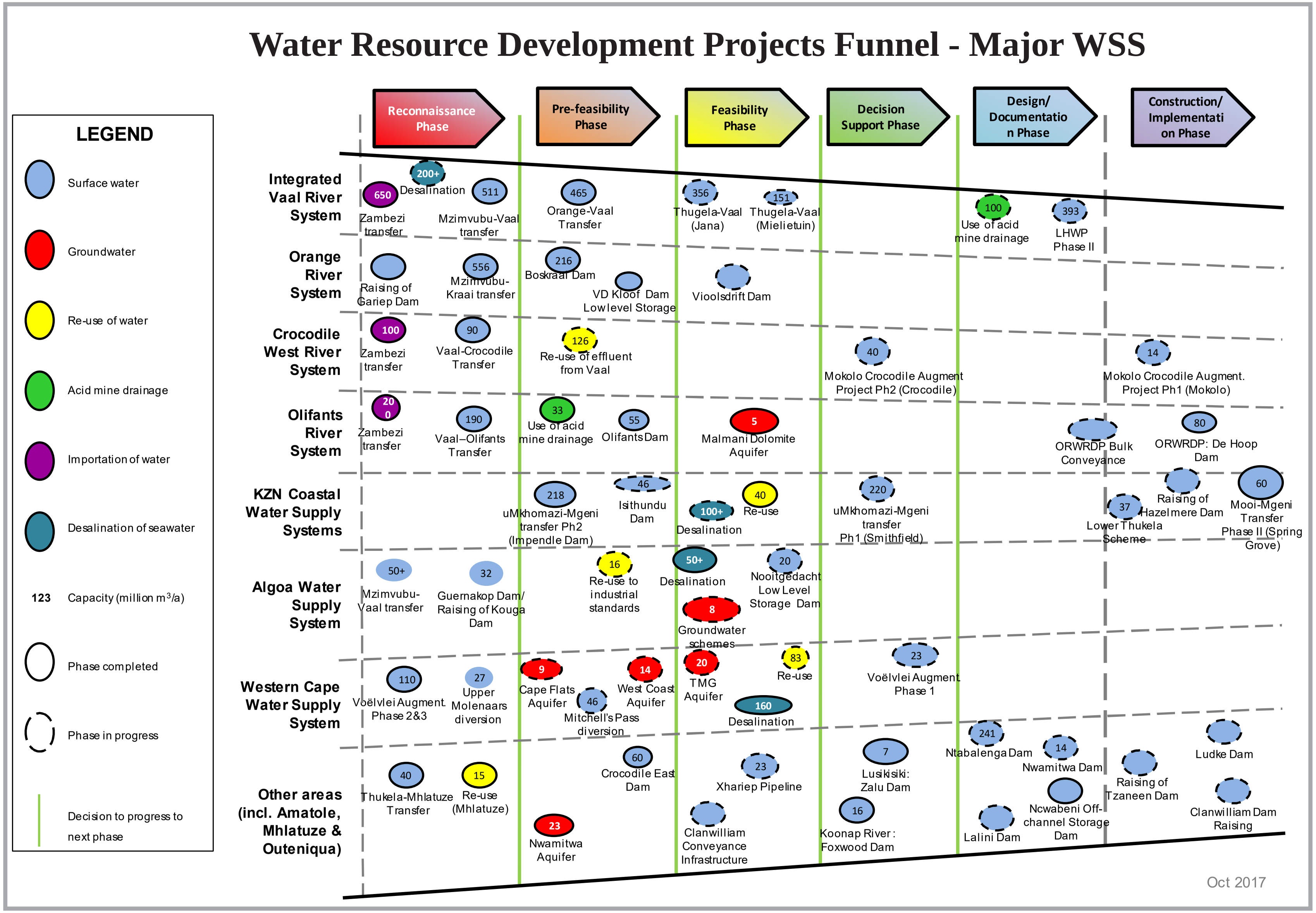


Figure 4: Current state of proposed water resources infrastructure projects in South Africa (DWS, 2017)

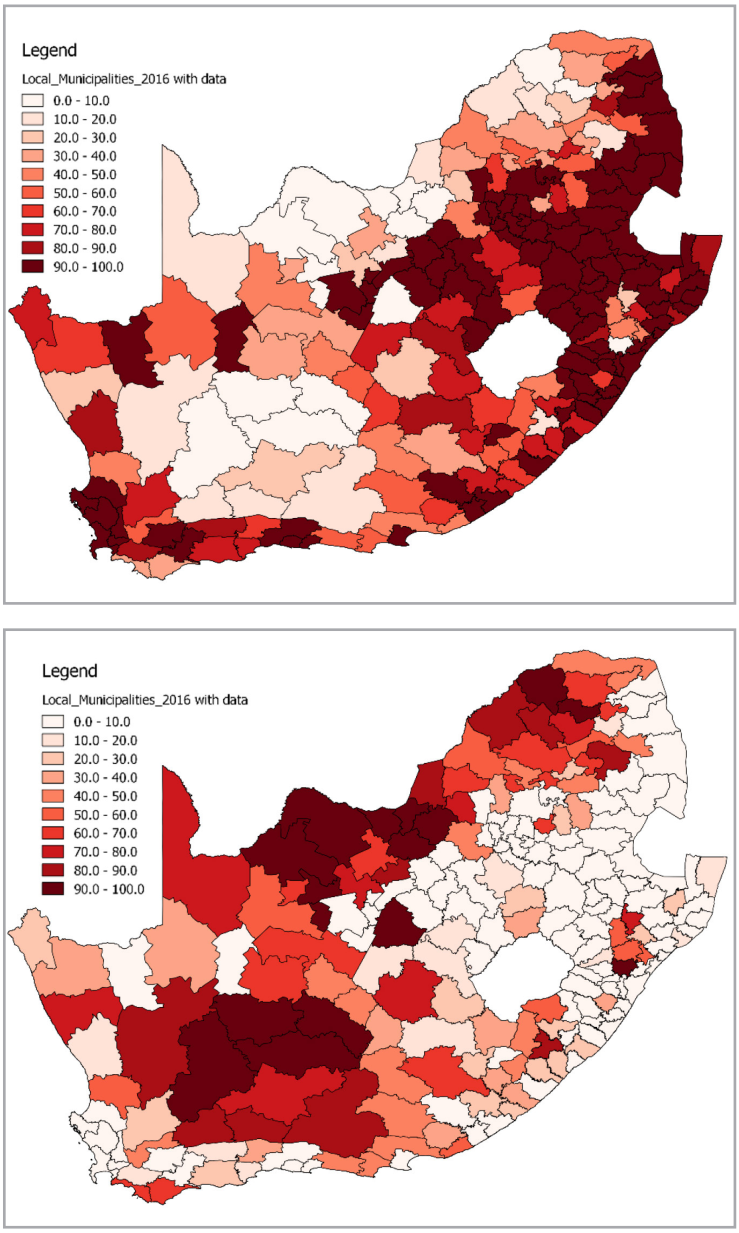


Figure 5: Individual municipality dependency on surface (left) and groundwater (right). (Cullis and Philips, 2019)

Other significant challenges for water security in South Africa include a large percentage of unaccounted for water which includes both physical losses and failure to collect revenues for water services, the poor condition of water and wastewater treatment plants as documented in the Blue and Green Drop Reports, declining water quality, the impacts of invasive alien plants, reduced monitoring, regulation and compliance of water use licence conditions, and the safeguarding of environmental water requirements and resource quality objectives. Climate change is an added stressor that is impacting on both the supply and the demand for water.

South Africa is already experiencing the impacts of climate change through recent events such as the Cape Town Day Zero crisis, persistent drought conditions in the Eastern Cape contributing to water security risks for Nelson Mandela Bay, and flood events in KZN, Eastern Cape, and most recently the Western Cape.

These events can in part be attributed to human induced climate change (Otto et al, 2018), however there are several other factors that have also contributed to these risks. There are many lessons learnt from these events that inform the development of a more climate resilient water sector including implementing of critical infrastructure and improved governance and better communication (Kaiser, 2019; Muller, 2019; Ziervogel, 2019; IPCC, 2022).

In addition to increasing climate related stresses, the current water supply crisis for Gauteng, which is not as a result of low rainfall, is also an indication of how the lack of investment in critical infrastructure including rehabilitation and maintenance, will become more critical under a potentially drier climate and with increasing demands for water and economic development.

Improving urban water resilience is critical in meeting the growing demands from towns and cities and adapting to the impacts of climate change. Several cities including Cape Town, Nelson Mandela Bay, and the City of Johannesburg have been looking to develop urban water resilience plans in line with the principals of urban water resilience for African cities (WRI, 2021).
The DWS is also currently updating the reconciliation and planning studies for the major bulk water systems as well as small supply schemes as part of the All-Towns Strategy across South Africa.

The largest water user in South Africa, like most other countries, is agriculture which accounts for around 60% of total water use. Agriculture, however, is critical in terms of providing food security to the country, is one of the country's major export commodities, and provides employment particularly in the rural areas. Agriculture is the most sensitive economic sector to the impacts of climate change and while there are still farmers who can improve their water use efficiency, the large majority are already very conscious of the importance of minimising their water use and employing sophisticated techniques such as the use of remote sensing, drip irrigation, and shading netting to manage their water use and improve crop productivity. Several farmers are also investing in the clearing of invasive alien trees on their land which is helping to protect their water sources, but also reduces the risk of wildfires and flooding.

Municipal and domestic use accounts for 27% of total water requirements (Figure 6), however recent estimates show that nearly around 43% of water produced for municipal use is lost through leaks or is unaccounted (DWS, 2023). As a result, although the net per capita water usage is on average relatively low, the gross water usage per capita by municipalities (i.e., accounting for losses) is very high and urgent interventions are required to reduce these water losses and improve water use efficiency across all sectors (Cole et al, 2017). This is critical not only in terms of adapting to climate change, but also in meeting the SDGs for 2030.

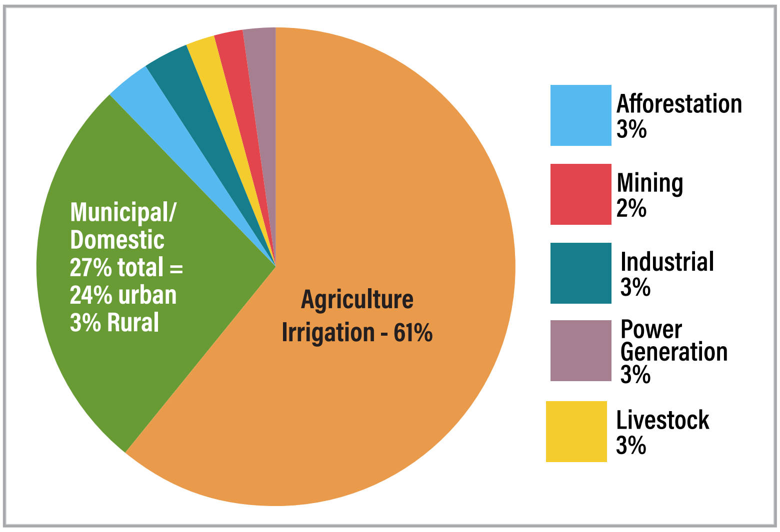


Figure 6: Water use by sector in South Africa (Source: NWRS-3)

Another major user of water in South Africa is mining and bulk industry (5%). These industries are also becoming increasingly aware of the increasing water-scarcity in the country and need to continue to improve water use efficiency and reduce their impact on the natural environment.

Similarly, the energy sector uses around 2% of water, but is critical in terms of the economy. Climate change policy in the energy sector will also impact on the water sector as the transition away from fossil fuels while lead to change in the amount and spatial location of water usage for the energy sector in South Africa (Adjum et al, 2017) as renewable technologies such as wind and solar typically use much less water than a conventional coal fired power station and are generally located in different areas of the country from the current coal fired power stations.

The current energy crisis in South Africa is also affecting water security as a reliable supply of electricity is needed to pump and treat the water needed to meet demands and to transport sewage and to operate the wastewater treatment works. Persistent load shedding is creating a major water security challenge in South Africa and also contributes to increased pollution as a result of the failure of sewerage pump stations that has a direct impact on human health as well as creating an economic risk to sensitive sectors such as agriculture and tourism.
One of the challenges with adapting to the impacts of climate change is the level of uncertainty about future climate scenarios and variability particularly with regards to precipitation. This requires consideration of an adaptive management approach. In many ways, South Africa is already applying an adaptive management approach to water security with regular updates required to the national water resources strategy (NWRS) and water reconciliation plans for the development of integrated bulk water supply systems and stand-alone schemes. There are several aspects of the National Water Act, which governs how water resources should be managed in South Africa, that support an adaptive management approach as well as ensuring reliability of supply and sustainability through providing protection for environmental flows.

In addition, individual municipalities should also be applying an adaptive management approach through regular updating of water services development plans (WSDPs). These processes need to be strengthened in the face of the impacts of climate change, as well as several other stresses to the water and sanitation sector, through the provision of reliable data through improved monitoring, hydrological modelling and analysis, technical capacity to implement and support with funding and financing the necessary interventions. This requires close collaboration between the different spheres of government as well as the private sector.

2.2 What is climate change?

Climate change is the term used to describe "long-term change in the average weather patterns that have come to define the earth's local, regional and global climates" (NASA, 2022). These changes have a range of observed impacts closely associated with the term 'climate change'. Weather refers to the short-term changes in the atmosphere's conditions.
Natural processes can contribute to climate change. It is, however, observed that recent climate change is primarily driven by human activity, particularly the burning of fossil fuels. Burning fossil fuel releases heat-trapping greenhouse gases in the Earth's atmosphere, increasing the Earth's average surface temperature, due to the 'Greenhouse effect' (Figure 7). 'Global warming' is frequently used to refer to these temperature rises caused by humans.

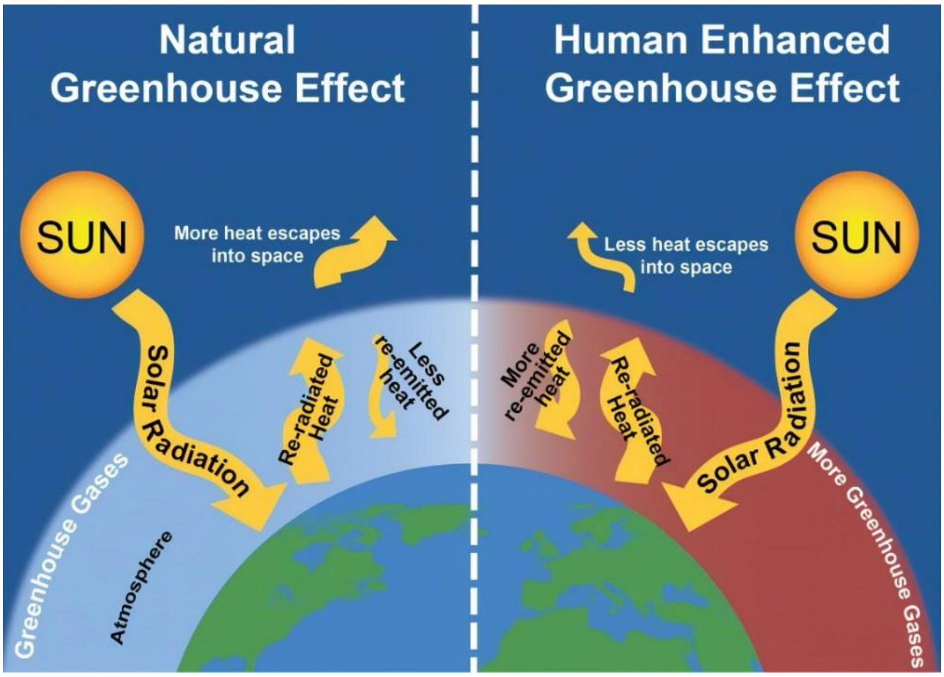


Figure 7: Greenhouse gas effect that is contributing to global warming and to global climate change.

The most important of these heat-trapping gases, due to it being the most abundant gas, is carbon dioxide (CO_2). Several other GHGs such as methane are also important as these gasses have a much higher global warming effect than CO_2 but are generally present in lower concentrations in the atmosphere. A major source of methane is the treatment of wastewater.

Historically, nearly the same quantity of CO_2 created naturally was removed from the atmosphere by photosynthesis or dissolution into the ocean. For millions of years, this has kept the amount of CO_2 in the atmosphere under check. Modern human existence and associated rapid development, however, has transformed that. Millions of tons of CO_2 have been emitted into the atmosphere because of the burning of fossil fuels such as gas, oil, and coal. This is based on the findings from NOAA and other agencies. (David Herring and Rebecca Lindsey, 2020) it is estimated that the earth is 1.2 degrees Celsius warmer now than it was in the 19th century (Figure 8), while CO_2 levels in the atmosphere have increased by 50%.

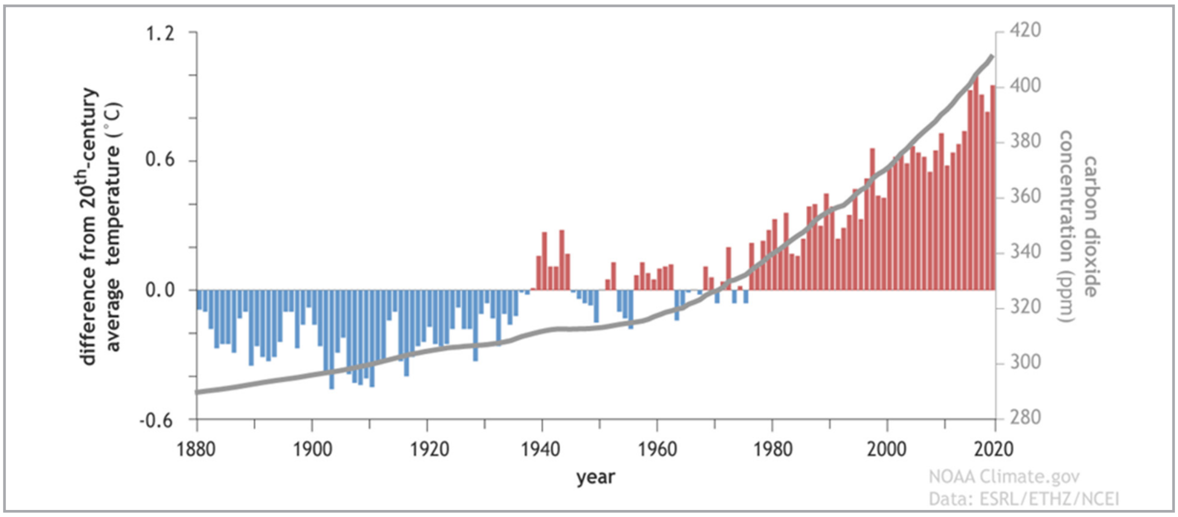


Figure 8: Atmospheric CO_2 concentration and surface temperature changes from 1880 to 2020 (Herring and Lindsey, 2020)

In 2023, several months have already surpassed the critical 1.5-degree threshold, and this has contributed to several unprecedented extreme events such as fires, floods and droughts that have resulted in a significant loss of lives and damage to critical infrastructure.

In South Africa recent extreme events such as the Cape Town "Day Zero" crisis, water supply challenges for Nelson Mandela Bay Municipality (NMBM), and the devastating floods in KwaZulu-Natal have been partially attributed to the impacts of climate change and while several other events such as the current water supply challenges in Gauteng are not directly related to climate change impacts, but rather as a result of institutional challenges and a lack of investments in critical infrastructure, these will be further stressed by the potential impacts of future climate change and increased climate variability, population growth, and demand.

Scientists suggest that if we want to avoid the worst effects of climate change, we need to drastically reduce the amount of GHG in the atmosphere which will reduce the increase in global temperatures. They propose that global warming should be kept under 1.5 degrees Celsius by 2100. This is in line with the goals of the Paris Agreement which aims to "limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels". However, according to research published in 2021 by the Climate Action Tracker Group, current mitigation efforts are insufficient, and the earth will warm by 2.4 degrees Celsius by the end of the century if serious action is not taken now (Climate Action Tracker Group, 2021).

We are already observing changing weather patterns around the world because of rising temperatures: rainfall patterns are shifting, sea levels are rising, heatwaves are emerging, floods and droughts are becoming more common, plant and animal species are being lost, and millions of people are losing their homes to increasing natural disasters.

Different regions are impacted in various ways, but the poor will suffer the most because they are often more directly exposed to the impacts of climate change and are less able to adapt.

2.2.1 Definitions of Climate Change Risk & Vulnerability

According to the Intergovernmental Panel on Climate Change (IPCC), climate risk results from the interaction of hazard, exposure, and vulnerability (Figure 9). In the IPCC online glossary the definition of Risk [used in the Special Report on Climate Change and Land and Special Report on the Ocean and Cryosphere in a Changing Climate] is shown in the boxes below.

In summary, a climate risk (e.g., drought affecting water supply) results from interactions between climate-related hazards (e.g., reduction in mean annual precipitation) with exposure (e.g., demand for water) and vulnerability (e.g., available storage capacity, alternative water sources, ability to manage dement, etc) of natural and human systems. This definition of climate change risk as a combination of hazard, exposure and vulnerability is also applied in South Africa as shown in Figure 10 and is important in terms of identifying critical risks and opportunities for adaptation.

Climate Change Risk *is defined as the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species.*

- *In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure, and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making.*

- *In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals. Risks can arise for example from uncertainty in implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions.*

The following definitions of Hazard, Exposure, Sensitivity & Adaptive Capacity are used:

- *Hazard is the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.*
- *Exposure entails the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.*
- *Vulnerability deals with the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.*
- *Sensitivity refers to the degree to which a system is affected by, or responsive to a hazard. In other words, sensitivity captures the potential of a system to be impacted by a hazard. Sometimes sensitivity is determined by the criticality of the service that the system provides. For example, a community uses a road located close to the low-lying area of the coast as its main access to a major hospital. In the past, this road has been inundated during a storm event making access to the hospital difficult. Because the hospital provides such an essential service, this community should be considered more sensitive to coastal inundation event.*
- *Adaptive Capacity is the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. Source: IPCC online glossary (https://apps.ipcc.ch/glossary/)*

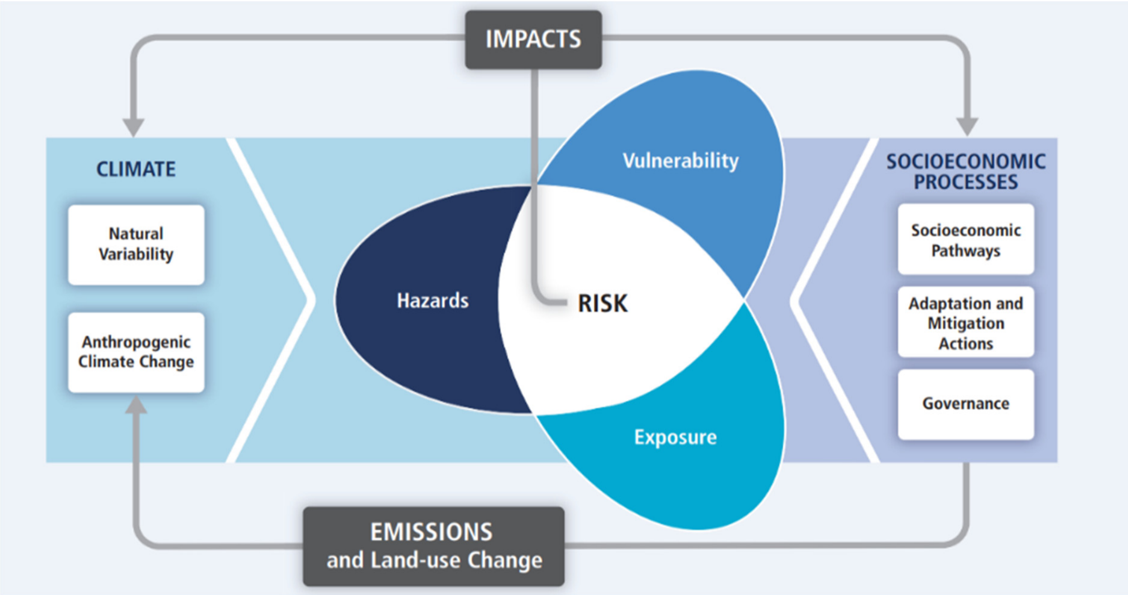


Figure 9: Risk assessment framework for evaluating climate change risks
(Source: Field et al 2014)

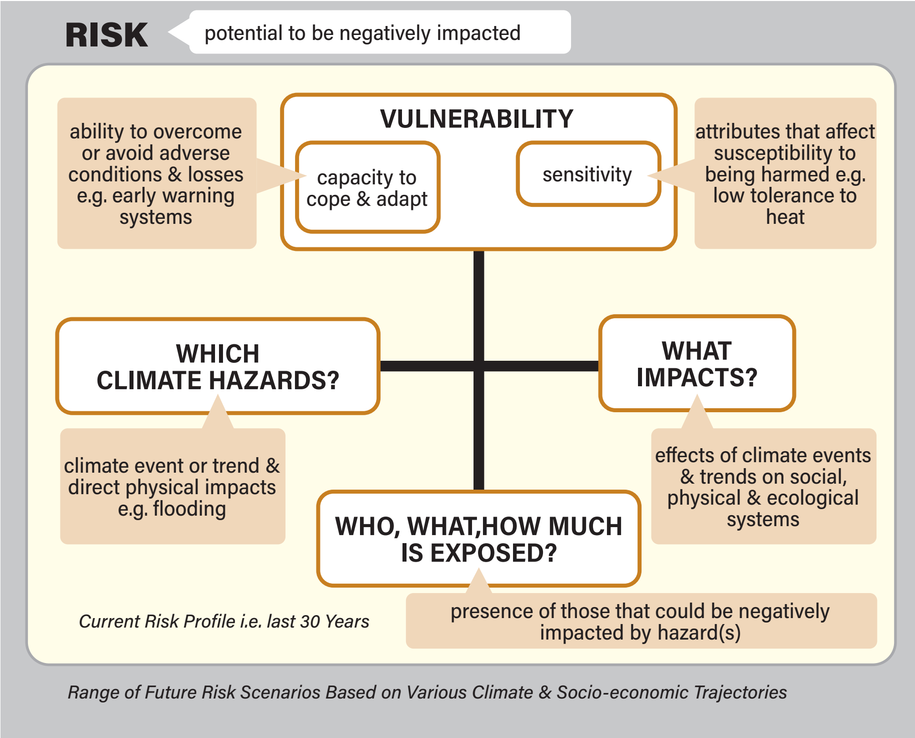


Figure 10: The component of climate vulnerability and climate risk, adapted from IPCC AR5 (Source: DFFE, 2020)

2.2.2 Modelling the Impacts of Climate Change & Uncertainty

Modelling the impacts of climate change on key sectors such as the water and sanitation is helpful in supporting decision making, however there are many challenges and uncertainty associated with this that need to be taken into consideration when using the results of modelling for decision making. The traditional approach to modelling climate change impacts is shown in Figure 11.

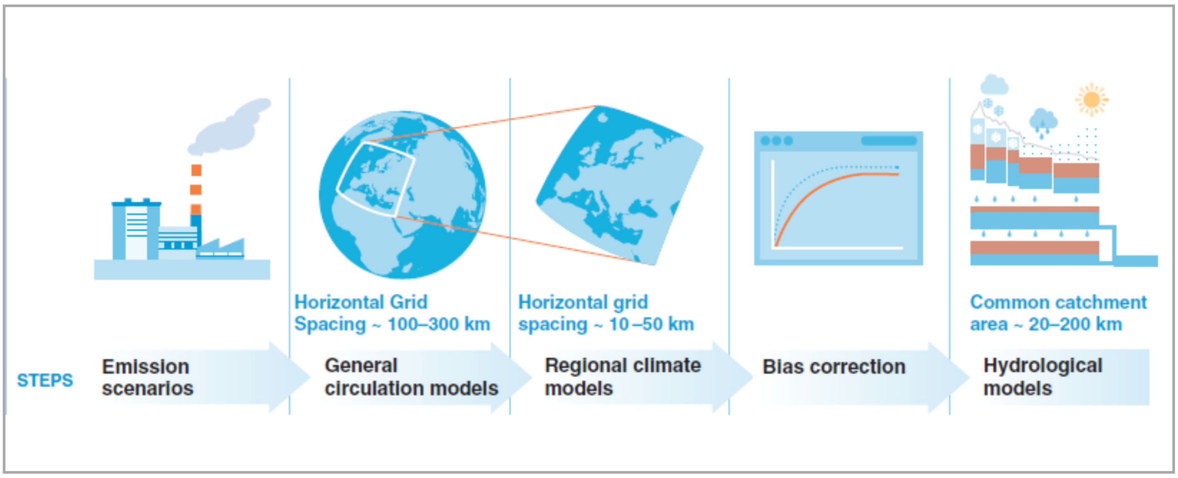


Figure 11: Schematic of a typical model chain used for the assessment of climate change impacts on streamflow. Graphics of the modelling chain are shown in the first row with the names of the steps listed in the second row. (Hakala et al, 2019)

To investigate the likely impact of climate change and water and sanitation in a traditional top-down approach projects of future climate under different global emission scenarios are required. These are typically generated using global circulation models (GCMs). Due to the coarse spatial resolution of the GCMs (horizontal grid spacing of 100 to 300 km) it is however necessary to general outputs at a much finer scale of resolution using either a regional climate model (RCM) or using statistical techniques. This process is referred to as downscaling.

Downscaling refers to the procedure of transferring large-scale information from the GCMs to a regional or local scale, whereby the spatial resolution of the data is increased (Hakala et al, 2019). Downscaling provides refined output at a higher spatial resolution which is able to represent sub-grid scale heterogeneities more explicitly. For hydrological models, downscaling is particularly critical for example in terms of determining local precipitation impacts, where regional topography and meso-scale processes are not well represented in the GCMs due to their global extent, and this could have a significant impact at the local scale particularly in mountainous regions. Downscaling is however a very complex process and as a result often only a limited number of global models can be downscaled leading to uncertainty in the results.

In addition to the downscaling of GCMs, it is also necessary to consider bias correction. The need for bias correction arises due to the number of assumptions that need to be made in running the GCMs. As a result, the actual values produced by the models could differ quite significantly from observed data. For hydrological studies, bias correction is particularly important given the sensitivity of variables such as surface water runoff to driver variables such as precipitation and evaporation. Various studies have looked at this issue in South Africa (e.g., Schutte et al 2023).

Due to the complexities of global models and the issues associated with downscaling and bias correction, several uncertainties are introduced which increase through the modelling chain. It is critically important to understand the cascade of uncertainty that results from the modelling process and as a result it is necessary to consider a range of potential impacts that supports robust decision making, i.e., decision making that is effective over a range of future scenarios.

According to Poff et al (2015) “securing the supply and equitable allocation of fresh water to support human well-being while sustaining healthy, functioning ecosystems is one of the grand environmental challenges of the twenty-first century, particularly in light of accelerating stressors from climate change, population growth and economic development”. Increasingly climate change is being incorporated into water resources and infrastructure planning across Africa (Cervigni et al, 2015). However, there remains a high degree of uncertainty in the results from individual climate models which continues to be a challenge for decision makers. This requires a change in the approach to water resources planning to account for non-stationarity.

2.2.3 Top-down & Bottom-up Approaches to Climate Change Risk

A recent review of decision-making processes undertaken as part of the Future Resilient African Cities and Lands (FRACTAL) research project identified at least three drivers of increasing complexity that provide a challenge for decision makers (Taylor et al, 2017):

- the increasing complexity of problems – the rise of "wicked problems"
- the necessary shift away from linear models of decision making
- the rise of "risk" as a central concept for dealing with uncertainty

In response to these drivers of increasing complexity, a range of decision-making processes and methods have been developed that include both normative and prescriptive concepts (support methods) as well as descriptive approaches (process methods) (Taylor et al, 2017). For climate change impact assessments these can be further characterised as top-down or bottom-up approaches, the two methods being characterised as climate model analysis-based and vulnerability analysis-based respectively (Brown, 2011). Limitations exist in the traditional top-down approaches, according to Brown (2011): "A central issue in top-down approaches to planning under climate change uncertainty is the use of GCM projections. They provide forecasts of the future that are potentially informative but also have significant uncertainties and unknown reliability." Assessing the projection reliabilities poses difficulties because the actual climate outcomes are uncertain. The uncertainty predominantly lies in that the projections are based on current understandings of climate responses to increasing greenhouse gas emissions (Brown, 2011). Bottom-up approaches, on the other hand, first assess the climate-related risk and vulnerabilities for a particular system, or systems, according to some desirable outcome or performance requirement (Poff et al, 2015).

Several bottom-up approaches to understanding climate change related risk exist, but in general all the approaches begin with a stakeholder engagement and assessment of socio-economic systems. Figure 12 shows a comparison of traditional top-down with the proposed bottom-up risk and vulnerability approach to understanding climate change risks. A system is characterised and its response to climate variation identified, based on a climate sensitivity analysis (Brown, 2011). In the final stages the key vulnerabilities of the systems are identified, and management prospects identified to mitigate as much as possible for these vulnerabilities.

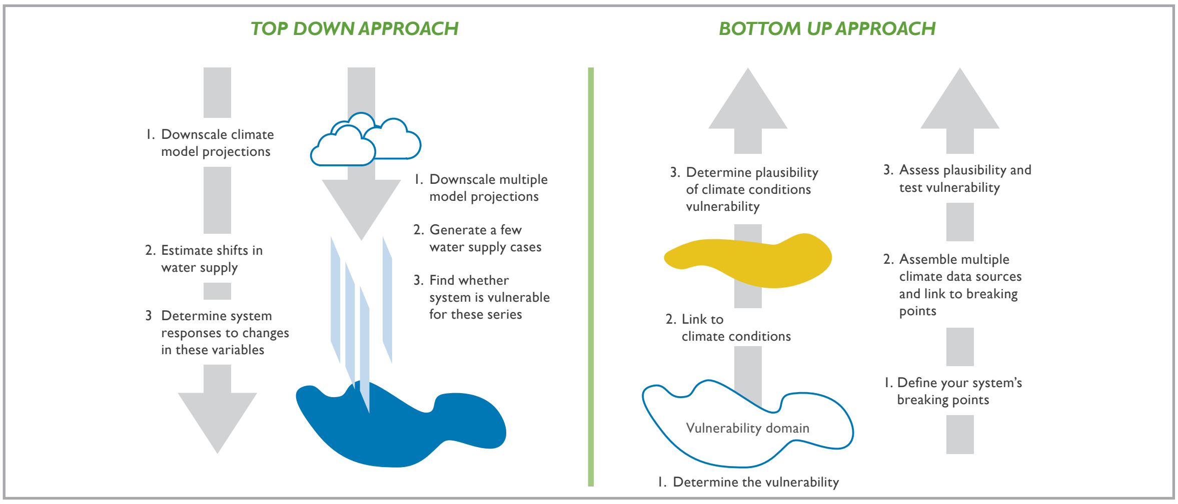


Figure 12: A comparison of top-down vs bottom-upmethods for the assessment of climate change risks (DEA, 2013).

The use of a bottom-up approach as opposed to a traditional top-down approach for decision making is particularly appropriate for application in developing countries such as those located in Sub-Sahara Africa where it is recommended that alternative and more collaborative approaches to knowledge production and decision-making be adopted (Polk, 2015).
A bottom-up approach also allows for the efficient allocation of scarce resources to focus on the most critical aspects of uncertainty relevant to decision making for the specific system. This is particularly relevant in South Africa, where resources are limited, and climate change is likely to have the greatest impact on the poorest people many of whom live in informal areas. By identifying particularly vulnerable communities and better understanding the facts that contribute to this vulnerability, it is possible to develop a more target response to address the increasing risks of climate change. In a similar way it is also important to understand the benefits that can be provided through existing systems and ensure that these are maintained.

2.2.4 Decision Making Under Uncertainty

With the available, highly uncertain, climate change projections, it is difficult to predict the assurance of supply of planned water infrastructure projects. To assist this planning under uncertainty, a Decision Tree Framework was developed by The World Bank and serves as a critical guideline for decision making under deep uncertainty such as for climate change. The framework was developed with decision scaling as a base and follows a robust, bottom-up approach (as compared to previous top-down approaches) that makes use of a stress test to identify system vulnerabilities and simplified techniques to reduce system vulnerabilities through design modifications. This framework is efficient and does not include assumptions of the future or rely on specific GCMs for direct climate input. Rather, it makes the best possible use of known climate change estimates, though uncertain, which can be valuable in some circumstances. It establishes the conditions by evaluating the relative performance and vulnerabilities of alternatives, describing future scenarios with that information, and then applying available data on local climate trends and projections, as well as historical climate variability to address specific questions that arise during the decision-making process.

The framework is made up of several phases as shown in Figure 13 and consisting of: (1) Project Screening, (2) Initial Analysis, (3) Climate Stress Test and (4) Climate Risk Management. At the end of the process, the project's vulnerabilities should have been properly examined, and the project's viability and profitability, as well as ability to adapt to future changes, should have improved as a result of the necessary adjustments made (Ray and Brown, 2015).

While the above framework provides a useful framework for climate risk screening for critical infrastructure, there are several other approaches to support decision making under uncertainty for water related infrastructure. Some of these are explored in the Enhancing Climate Resilience of African Infrastructure (ECRAI) study (Cervigni, et al 2015) and include Robust Decision Making (RDB), decision scaling, and several other approaches.

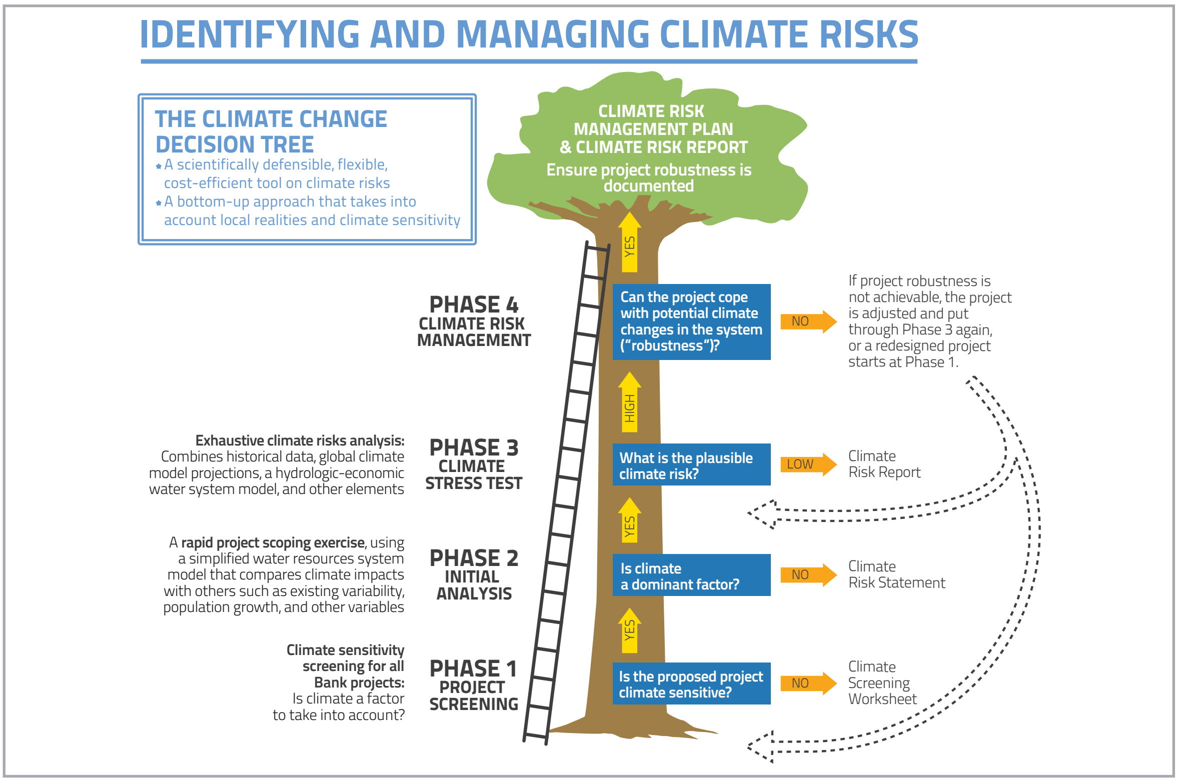


Figure 13: The Decision Tree Framework recommended for determining climate change risks for water infrastructure (Ray and Brown, 2015).

In South Africa, the regular updating of the planning for implementing critical water infrastructure undertaken as part of the Reconciliation and Planning studies already embraces several aspects of this including consideration for alternative development scenarios and also including the impact of IAPs and climate change. The current approach to the reconciliation studies, does however need to be reviewed in the context of the evolution of approaches that support decision making under uncertainty for infrastructure.

2.2.5 Climate Resilient Development Pathways (CRDP)

In a changing climate with increasing risks, a solutions framework including strategies that deal with climate change with accompanying actions to reduce greenhouse gas emissions is needed to ensure the well-being of nature and people. This solutions framework, known as Climate Resilient Development (CRD) is formally defined as "the process of implementing greenhouse gas mitigation and adaptation options to support sustainable development for all" with an emphasis on equity of sustainable development (IPCC, 2022). However, CRD is not attained via a single decision or action. It is the result of daily decisions taken to reduce climate risk, reduce greenhouse gas emissions, and promote sustainable development, which is illustrated in Figure 14 below. Decisions made can either lead to more sustainable solutions (green paths) or away from mores sustainable development dimensions (red paths) including for people, prosperity, partnership, peace, and the planet. In a changing world, CRD pathways offer the opportunity to drive change that will enhance well-being for all by decreasing climate risk, addressing numerous inequities and injustices, and renewing our relationship with nature (IPCC, 2022; Werners et al., 2021).

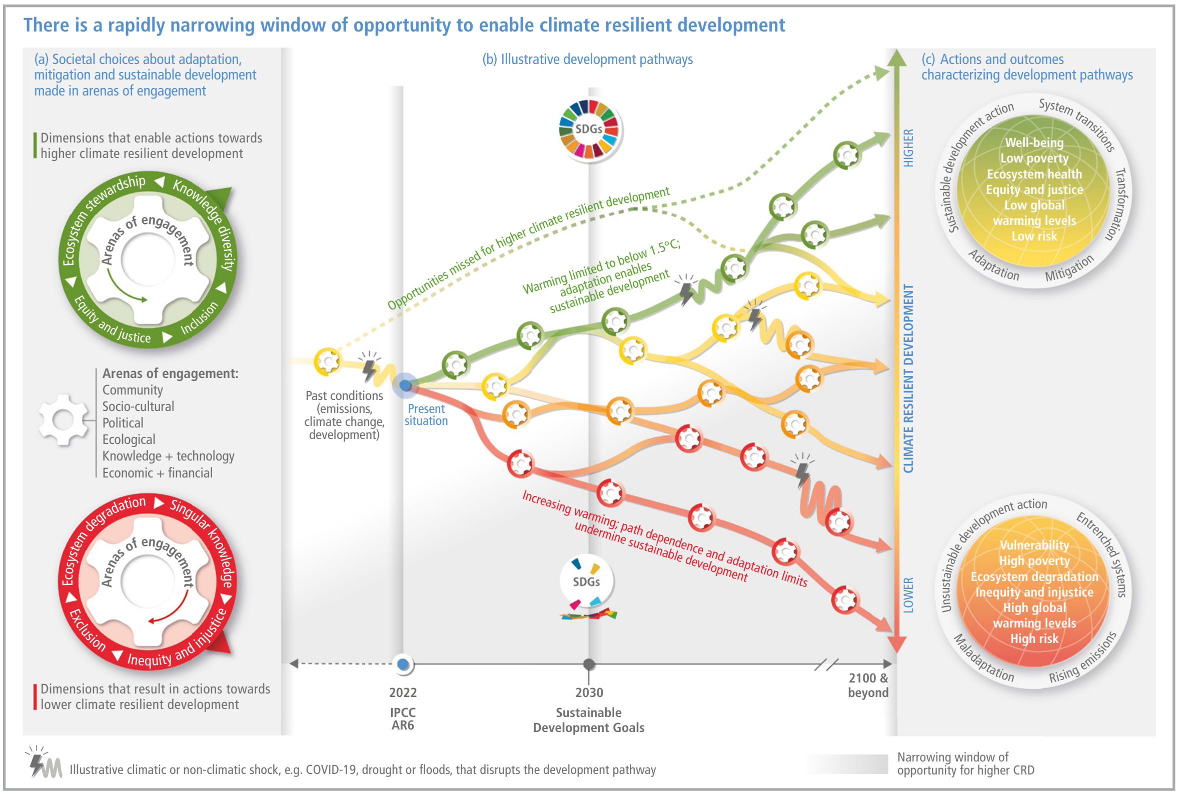


Figure 14: Climate Resilient Development pathways (Source: IPCC)

In a changing world, CRD pathways offer the opportunity to drive change that will enhance well-being for all by decreasing climate risk, addressing numerous inequities and injustices, and renewing our relationship with nature (IPCC, 2022; Werners et al., 2021). The figure above shows that the window of opportunity to move toward, rather than away from, sustainable and climate resilient futures is closing as a result of delays in implementation of adaptation and mitigation responses. The delayed implementation of solutions is also a major driver of water risk. The dotted lines represent the paths to the most climate resilient futures, which are no longer accessible due to past social choices and actions, as well as rising temperatures. The blue dot represents the current situation, from which choices and actions made in the next decade will determine whether we progress towards a liveable future or not (IPCC, 2022). The risk of further delays in implementation of critical climate change adaptation responses, such as the augmentation of our current water supply systems and improved water use efficiency, can be well illustrated using the CRD framework as the longer these delays are, the harder, and more expensive, it will be to mitigate the expected impacts of climate change for the water and sanitation sector in South Africa.

2.2.6 Incorporating Gender & Social Equity

There is increasing evidence that vulnerable groups and including women and children are disproportionally impacted by the effects of climate change and it is therefore essential that climate change response actions must also priorities issues of gender and social equity (GSE). Approaching climate adaptation and mitigation actions through a GSE lens helps to unpack the power relations that are benefiting and providing options and resources for some by harming and restricting options and resources for other groups (defined by gender, class, ethnicity, age etc.). GSE is important for resilience planning as the impacts of climate change and water-related risks perpetuate and magnify structural inequalities. Vulnerable groups are often dependent on natural resources to sustain their livelihoods and have less safeguard from physical hazards.

The schematic below (Figure 15) highlights the importance of approaching all sustainable planning with a GSE lens, and examples of this in action. GSE is particularly important with regards to water and sanitation issues, and for improving climate resilience. It is therefore important that the proposed adaptation and mitigation response actions include a GSE perspective, and that vulnerable groups and communities are prioritised as being the most impacted by climate change.

DO NO HARM	INCLUDE DIVERSE VOICES	EQUITABLE COSTS & BENEFITS	IMPROVED PROJECT OUTCOMES
Helps make sure that our project objectives, methods, activities, and outcomes do not make any individuals or communities worse off than they were before.	Helps make sure that different needs, interests and priorities are reflected in our project so that all members of the community benefit equitably.	Helps ensure that all groups share the costs fairly and that all groups benefit from the project equitably.	Helps ensure that our project outcomes are more efficient and lasting, and that they benefit from local networks, traditional knowledge and conflict mitigation mechanisms.
For instance, strict forest protection laws might prevent deforestation but may deny the local communities their traditional rights to forested land and its resources. A GSE lens would ensure that a plan is in place to mitigate such harms to communities.	For instance, while designing a public park, including local residents in stakeholder engagement, specifically women, children, elderly and people with disabilities, can ensure that the park is designed to be accessible and safe for all.	For instance, including a social lens when analysing urban green cover in a city might lead to important insights and recommendations for how historically excluded communities may also enjoy the benefits of urban green spaces.	For instance, meaningful engagement with local communities can create stronger community buy-in and better harmonization of interests and plans, reducing the risk of conflicts and reputational and financial losses in the future.

Figure 15 : The importance of considering Gender & Social Equity (GES) in climate change response actions.

2.3 Review of Climate Change Policies, Strategies, & Plans

In 2022, the 6th Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC AR6) was published, and examines the impacts of climate change on ecosystems, biodiversity, and human communities, globally. The AR6 presents the latest synthesis of scientific knowledge on likely impacts and the capacity of society to adapt to climate change risks and follows a three decades of international policy development on climate change dating back to the United Nations Framework Agreement in 1992 (Figure 16).

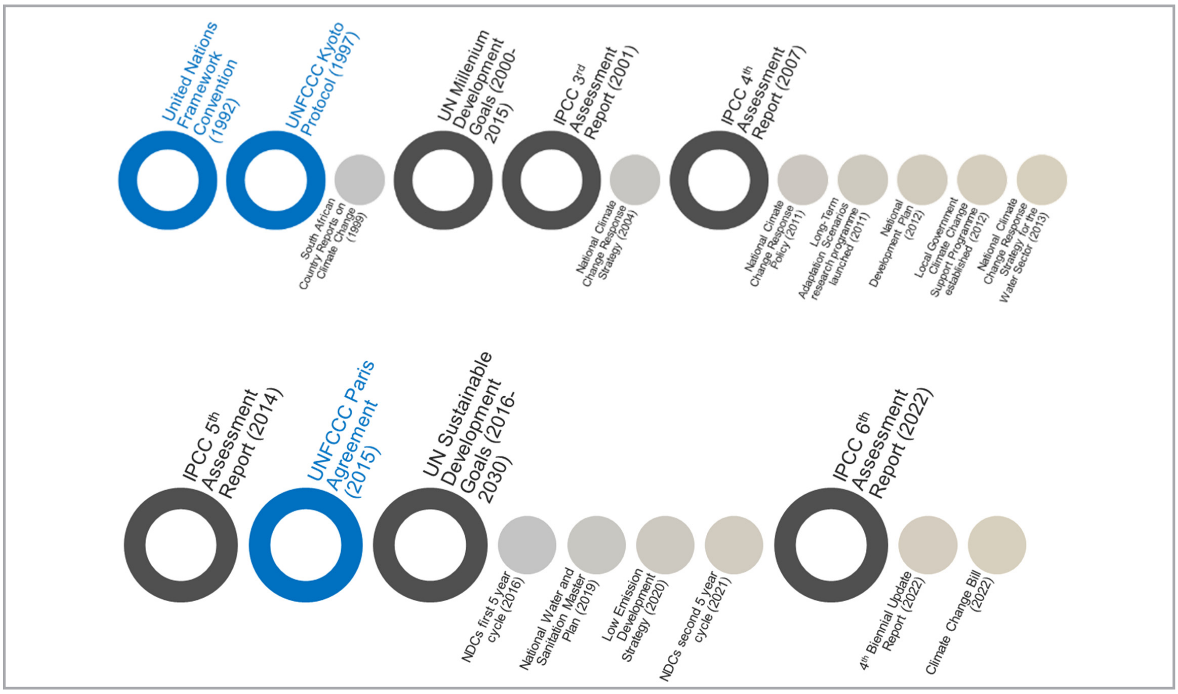


Figure 16: Timeline of international (text on the top) and national (text on the bottom) climate change policy documents, plans and agreements, highlighting the UNFCCC agreements and the South African Climate Change Bill.

At a regional level the AU Agenda 2063 Goal 7 on Environmentally sustainable and climate resilient economies and communities identifies climate resilience and natural disaster preparedness as priority areas and the Southern African Development Community (SADC) Secretariat developed a Climate Change Adaptation (CCA) Strategy (2011) which also informs appropriate regional adaptation response to climate change calls for the implementation of adaptation measures at different geographical scales (local, transboundary, SADC region).

In South Africa, the National Climate Change Response Strategy (NCCRS) was developed in 2004 and updated in 2011. The current National Climate Change Response Strategy for the Water Sector was developed in 2013. Subsequent to development of this strategy, South Africa has submitted its Nationally Determined Contributions (NDCs) under the Paris Agreement in 2016 and updated these in 2021. Following the White Paper on Climate Change, the Climate Change Bill is now currently before Parliament, and this will provide additional support to the mainstreaming of climate change into various national development plans.

The establishment of the Presidential Climate Commission (PCC), an independent, statutory, multistakeholder body, is also seen as a critical step forward in terms of implementing some of the climate change adaptation response and mitigation actions for the energy as well as the water and sanitation sector. The overall purpose of the PCC is to oversee and facilitate a just and equitable transition towards a low-emissions and climate resilient economy.

2.3.1 South African National Climate Change Policies & Plans

The National Climate Change Adaptation Strategy (NCCAS) was developed in 2020 (DFFE, 2020), and provides a common vision of climate change adaptation and climate resilience for the country. The NCCAS was developed by drawing from the National Development Plan (NDP), the National Strategy for Sustainable Development (NSSD), the adaptation commitments included in its Nationally Determined Contributions (NDC), sector adaptation plans, provincial adaptation plans and municipality adaptation plans.

The NCCAS is an important step for adaptation in South Africa, as it:

- Acts as a common reference point for climate change adaptation efforts in South Africa in the short term to medium-term, providing guidance across all levels of government, sectors and stakeholders affected by climate variability and change.
- Provides a policy instrument in which national climate change adaptation objectives can be articulated to provide overarching guidance to all sectors of the economy.
- Facilitates the degree to which initiatives at different levels of government and business integrate and reflect critical climate change adaptation priorities, and thus inform resource allocation by the various stakeholders towards climate change resilience.
- Guides stronger coherence and coordination on climate change adaptation activities.
- Supports South Africa in meeting its international obligations by defining the country's vulnerabilities, plans to reduce such vulnerabilities and leverage opportunities, outlining the required resources for such action, whilst demonstrating progress on climate change adaptation.

The NCCAS also serves as South Africa's National Adaptation Plan (NAP) fulfilling the country's international obligations as outlined in the Paris Agreement. The NCCAS forms the basis for the adaptation commitments in the NDC and will be reviewed every five years.

2.3.2 SADC Climate Change Adaptation Strategy for Water

The SADC Climate Change Adaptation Strategy for Water (SADC, 2011) recognises the need for adaptation at local, regional, and river basin level and in terms of adaptation preparation, response, and recovery. The SADC water strategy identifies adaptation response required in three key areas: Governance, Development and Management as shown in Figure 17.

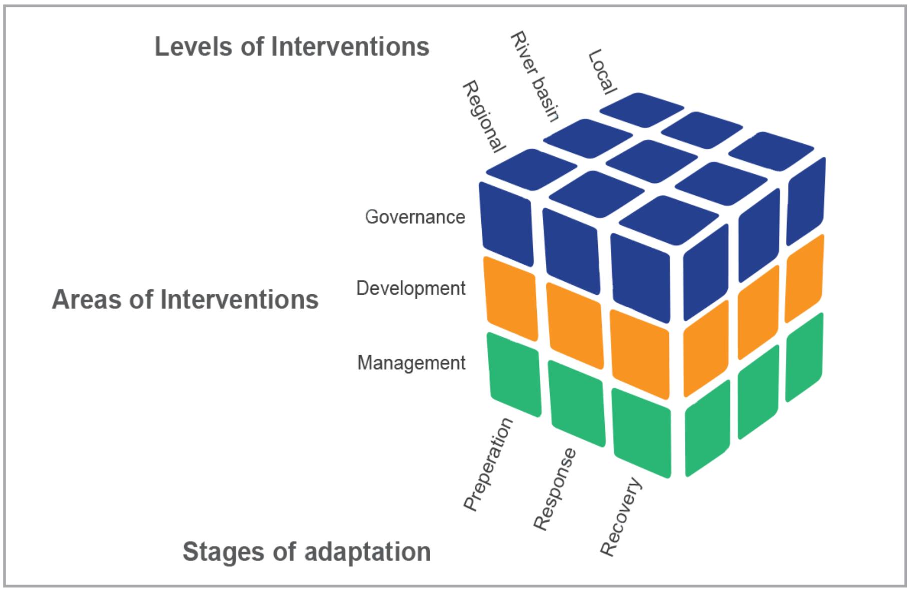


Figure 17: The SADC Water Adaptation Cube (SADC, 2011)

2.3.3 Other Related Sector Level Climate Change Strategy & Plans

In addition to the national level climate change adaptation and response strategies, several individual sectors, including the Water sector, have also developed adaptation response strategies. Several of these interact with the water and sanitation sector in South Africa and should be aligned with the proposed climate change response for water and sanitation sector.

Department of Forestry Fisheries and the Environment

The Department of Forestry Fisheries and the Environment (DFFE) as well as other non -governmental organisations (NGOs) and role players have been proactive in initiating sector related climate change strategies and scenarios to promote climate change awareness and knowledge, advocate sustainable terrestrial and aquatic ecosystems-based production practices which minimise emissions of greenhouse gases, conserve the sector's natural environments, promote adaptation and mitigate effects of climate change as far as possible.

Contributions towards reducing the levels of anthropogenic greenhouse gas production need to be actively encouraged. These include innovative alternatives in a fossil fuel-based economy. Adaptation strategies need to be developed, applied simultaneously and be sustainable, to deal with the vagaries of climatic variation and any negative impacts of severe weather events on both first and second economies. These need to be informed by vulnerability assessments and a comprehensive vulnerability audit for agriculture and forestry.

This document sets out to address the above issues in a South African agricultural context and to formalise them through this Climate Change Adaptation and Mitigation Plan (CCAMP) Changes of climate change being observed in the Agricultural sector. Farmers already perceive changes in weather and climate characteristics to have taken place in the past few years and decades including:

- Temperature and temperature derivatives observed over land, and derived temperature measures which are relevant to agriculture. These changes are consistent with, and have sometimes exceeded, the rate of mean global temperature rise.
- Rainfall, some areas of the country displayed marked increases and other areas marked decreases over time of median annual rainfall, lowest annual rainfall in 10 years, lowest and highest rainfalls in 10 years in the summer months, winter median rainfall, lowest winter rainfall in 10 years, the range between one in ten low and high summer rainfalls, and for daily rainfall events more than 25 mm.
- Runoff, The Jonkershoek (South Africa) data sets of over 70 years of detailed data show rainfall there to have declined by – 14 %, and the runoff to have declined by – 20 %. This is however not consistent across other parts of South Africa with some areas of the country experiencing increasing runoff and in particular increased flood events.
- Agricultural production and yields, A decline of 1.16% in maize production and 0.5% in wheat production for every 1 % reduction in rainfall was projected from these trends. In the winter rainfall region, export quality apple production seems to have already been adversely affected by warming trends, owing to its sensitivity to positive chill units, which have decreased significantly in recent decades.
- Forestry remained unaffected despite significantly wetter and hotter trends having been recorded. Noticeable escalation in the number of non -native pests and diseases as well as outbreaks arising from host shifts; and pathogens are spreading much faster. Increasing frequency and level of devastation of forest fires, climate change -associated pests, diseases and fire occurs at the landscape level.

Department of Human Settlements

The Human Settlements Sector Climate Change Response Strategy and Implementation Plan (CCRS&IP) was developed in 2023. Human settlements are particularly vulnerable, especially due to the long-term impacts of apartheid spatial planning, and from inadequate levels and maintenance of infrastructure. Diagnostic Analysis set out to identify the critical risk factors and vulnerabilities related to climate change for the Department of Human Settlements (DHS) and the governance and regulatory framework which these must be addressed within. This was done through the combination of Risk and Vulnerability Assessment (RVA). The analysis of governance and policy investigated the roles of different arms of government, the institutional architecture of the DHS, as well as co-development and coordination and the forecast of policy trajectory. From these two processes, key findings and recommendations were compiled. The findings and recommendations from both RVA and the analysis of relevant governance and policy will develop the CCRS&IP. The draft CCRS&IP as well as the key findings that informed its development will be presented to a broad range of cross-sphere and cross-sectoral human settlement stakeholders for validation, and for their input.

The summary observations and recommendations for the CCRS&IP, include:

- Rural human settlements are emerging as the most vulnerable to climate change, while rapid urbanisation brings critical challenges and opportunities for the big metros.
- National Department of Human Settlement programmes and instruments tend to reinforce peripheral urban development.
- Spatial transformation.
- National Department of Human Settlement programmes and instruments are focused on the supply-side.
- NDHS is beginning to prioritise the in situ upgrading of informal settlements through the new Informal Settlements Upgrading Partnership Grant.
- Human settlements strategy and support appear to be at the cusp of major change.
- Gap in governance and leadership of a human settlement climate change strategy.
- The Just Transition Framework is highly relevant for a Human Settlements CCRS&IP.

Long Term Adaptation Scenarios (LTAS) Research Program

The Long-Term Adaptation Scenarios (LTAS) flagship research program was undertaken by the Department of Environmental Affairs (DEA) and included a review of the latest downscaled climate change scenarios for South Africa as well as the potential impact and adaptation responses for various economic sectors including agriculture, environment, water, forestry, and disaster risk reduction. It also included an assessment of the economic impacts of climate change on various sectors including water, transport, and agriculture (DEA, 2013). The LTAS also consider regional impacts across the South African Development Community (SADC).

Greenbook: Climate Change Risks and Adaptation Scenarios for Municipalities

Greenbook is an on-line tool developed by the CSIR to support municipalities across South Africa with regards to understanding the latest climate change scenarios and associated risks. The Greenbook is based on high resolution (8km x 8km) downscaled climate change scenarios and the assessment of impacts on critical aspects such as floods, droughts, and wild-fire risks. The Greenbook also includes information on the potential impacts of climate change on water security as a result of both population growth scenarios and climate change.

2.3.4 National Climate Change Response Strategy for Water Sector

The National Climate Change Response Strategy (NCCRS) for the Water Sector was developed in 2013. The NCCRS brought together the most up-to-date climatological and hydrological data available at the time, to develop adaptive measures against water-related climate change impacts. The NCCRS highlights several critical issues regarding the anticipated impact of climate change on South Africa's water resources and services and recommends several actions that the sector role players including DWS should implement, as well as monitoring and evaluating (M&E) to effectively increase resilience. Thereby reducing vulnerability to water-related climate change impacts with a particular emphasis on marginalised and rural women. The primary focal areas in the NCCRS included the following:

- Lessons learnt from international best practices in relation to South Africa's climate change and water adaptive strategies, classified into three categories: process, content, and implementation.
- The national development vision in accordance with relevant policies, such as the NDP, NCCRP, National Water Resources Strategy 2 (NWRS2), and NCCAS.
- The evolving context in which the strategy is being developed, examining issues affecting various economic sectors and socio-economic development, critical climate change impacts on water, and critical vulnerabilities across the country's six regional hydro-climatic zones.
- Development of key strategic actions for building resilience and reducing vulnerability to address climate change in the water resource sector.
- Water Governance in which water management and water services organisations are tasked with protecting the poor in terms of water, both through management systems and appropriate infrastructure choices, and where clear roles are defined in terms of communication, awareness, shared learning, and financing.
- Infrastructure development, operation and maintenance in which adaption measures are outlined in terms of multi-purpose water storage, water supply and sanitation, groundwater development, alternative water supply sources, flood protection measures, infrastructure safety and hydro-meteorological monitoring systems.
- Water management using data, information, climate modelling, vulnerability assessments and forecasting to plan water allocation and authorisation, dam and groundwater operation optimisation, water conservation and water demand, groundwater, water quality, resource and disaster management.
- Implementation of the plan's strategic activities by defining clear roles and responsibilities for each action, as well as progress monitoring and assessment and finance mechanisms.

2.3.5 Progress with Implementing the NCCRS

Internationally, it has been recognised that significant progress has been made in planning and implementing adaptation across all sectors and regions, resulting in multiple benefits (IPCC, 2022). In South Africa there has been significant progress with regards to the development of updated climate change risk and adaptation policies and planning as described in the previous sections. With regards to the progress with implementing the NCCRS there has not been an official review, however it is recognised that there are many gaps that still need to be addressed and only limited progress with regards to achieving the objectives of the NCCRS since it was published in 2013. The critical aspects and changes will need to be addressed going forward.

In particular it is recognised that "No-regret", and "low-regret" measures are effective in dealing with uncertainty in projection from climate change models. Several of the proposed adaptation response actions from the NCCRS are well aligned with specific actions identified in the National Water and Resources Strategy (NWRS) and the National Water and Sanitation Master Plan (NWSMP).

Recent cooperation between various weather services, emergency services, and other organisations have resulted in improved climate services, as well as a reduction in infrastructure damage and loss of life due to climate-related disasters (DEA and SAWS, 2016).

The development of the initial NCCRS for the water sector has helped to raise awareness of the potential impacts of climate change on the water sector in South Africa. This has resulted in a renewed focus on the revision of existing water resources policies including the National Water Resources Strategy (NWRS) and the Water and Sanitation Master Plan (WSMP).
Despite having been developed over ten years ago, several of the priority actions remain relevant in terms of updating the NCCRS and further main streaming climate change into water resources planning as well as improved water security and sanitation services in South Africa.

2.3.6 Challenges to implementing the NCCRS

Several challenges have been identified with the implementation of the NCCRS, including:

- Challenge to manage water resources in the context of increasing uncertainty.
- Lack of integrated climate change response strategies to serve common sector goals and maximise the utility of water resources for the country.
- Limited implementation of adaptation technologies that collaborate to manage water resources, but also to contribute to reducing GHG emissions.
- Limited of uptake of reduced water or waterless sanitation technologies for their operation in both rural and (especially) urban settlements.
- Limited implementation of adaption strategies due to unclear targets and unclear as well as roles and responsibilities, poor monitoring and evaluation of delivery, poor funding and measuring of impacts and achievements.
- Access to climate-related information and data and effective communication platforms.
- Limited financing of climate change adaption strategies.
- Capacity within DWS is a challenge as currently there are limited technical officials within the department with no dedicated technical focal point at the regional offices.

2.4 Climate Change Risks for Water & Sanitation

There are several impacts of climate change for the water and sanitation section. The section below presents a short summary of the impacts in critical sectors including (1) surface water availability and supply, (2) groundwater, (3) sanitation, (4) water quality, (5) aquatic ecosystems.
These potential impacts on the water sector are addressed in more detailed in several additional technical reports produced as part of the development of the updated Status Quo Assessment.

2.4.1 Surface Water Availability & Supply

According to Upmanu Lall, Director of the Columbia Water Centre, “most of the climate change impacts come down to water”, posing a risk to water and sanitation systems (Fecht, 2019). The Organisation for Economic Co-operation and Development (OECD) identifies four major climate change risks categories related to water: the risk of excess water, insufficient water, polluted water, and a disrupted freshwater system (OECD, n.d.). Climate change will have direct impacts on critical infrastructure, including water supply infrastructure, through potential impacts on increased flooding and direct damage due to landslides, sea level rise and an increase in extreme events. An overview of the potential impacts on the global water cycle is shown Figure 18.

From this it is important to note that climate change will affect both the availability of water, increasing both spatial and temporal variability, as well as the demand for water, particularly in terms of increasing the demand for water from agriculture as higher temperatures results in greater evaporative demand from crops, but also potentially for domestic use due to higher temperatures and similarly for industrial water use.

In South Africa, the potential impact of higher temperatures on reduced glaciers and snowpack is not relevant as snow does not form a significant part of the natural hydrology and water security considerations for South Africa.

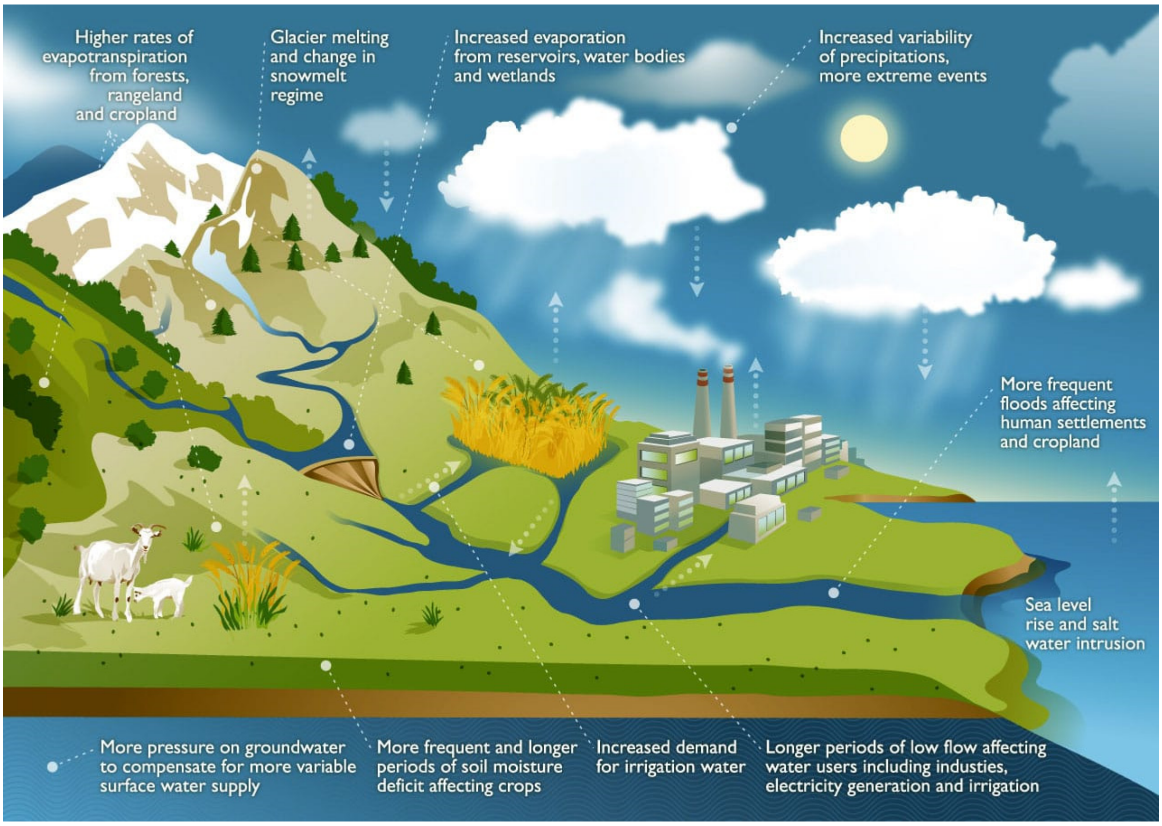


Figure 18: Summary of climate change impacts on the global water sector
(Source: IPCC)

Changes in precipitation and evaporation will have impacts on surface water runoff and stream flow as well as water quality and groundwater recharge. Increasing temperatures and evaporation will also impact on aquatic ecosystems and affect the demand for water and overall security of supply. More extreme weather events are predicted due to climate change, and these, along with land-use changes, are likely to contribute to a rise in the frequency of flood and drought events, as well as increased vulnerability of people to these events as settlements grow, and the resulting severity of the potential impacts of these events. When it comes to the effects of climate change and the changing water cycle on water resource availability, there is considerable uncertainty.
Global predictions frequently indicate increased scarcity as a result of changes in precipitation, rising temperatures, rising demand, and poor resource quality due to pollution. Uncertainty in water availability increases the likelihood that planned infrastructure projects, such as dams and hydropower in some regions, will result in lower food and energy sector productivity (IPCC, 2022).

Climate change, however, is not the only factor as water supplies will also be put under greater strain because of population growth, economic growth, and urbanization (Howard et al., 2016).

The relationship between potential climate change impacts and water supply is very complex and requires detailed analysis of individual catchments and water supply systems. A first order estimate of the potential impacts of climate change for water supply to municipalities across South Africa by 2050 and also considering the potential impacts of population growth, was however undertaken as part of the CSIR Greenbook Studies (Cullis et al, 2019). For this study a general risk equation was developed to determine the current and future surface water supply vulnerability (defined as demand average divided by available supply) that combines both climate change and development risks (i.e., due to an increase in population and associated increase in water demand). The general risk equation recognizes that risk is not just based on the direct exposure to a climate change (e.g., the change in precipitation and water availability) but is also dependent on the vulnerability of each town in terms of its current and future water demand and water source options. Future water supply risk could therefore be affected either by reduced availability of water resources or by an increase in demand and that these factors will be different for different towns.

The analysis also considered both the potential impact of climate change on local surface water availability, defined as local level exposure, E1, as well as through a regional integrated supply system, defined as regional water supply exposure, E2, which was derived from a previous study looking to model the potential impact of climate change on water supply across the whole of South Africa and using a national configuration of the water resources yield model under a wide range of future climate scenarios and associated economic impacts (Cullis et al, 2015).

The results of the analysis considering both the exposure to local level impacts (E1) as well as the potential benefits if supplied through a regional integrated bulk water supply system (E2) are shown in Figure 19. These results show that while population growth is the main driver of increasing water security risks for most cities and towns in South Africa, there are some areas that might experience a reduction in population and associated water demands. These need to be taken into consideration when balancing the potential impacts of climate change for example in a town like Oudtshoorn that is expected to experience significant drying. In contrast towns such as Musina, the impacts of regional migration, which will be further impacted by regional climate change impacts, must also be taken into consideration in terms of water resources planning.

The benefit of regional connectivity is also shown in these results in terms of reducing the overall water security risks due to climate change particularly for the major metros such as Nelson Mandela Bay, the City of Cape Town and the City of Johannesburg that receive the bulk of their water through these integrated bulk water supply systems. This again highlights the critical importance of operating, maintaining, and augmenting these critical bulk water supply systems.

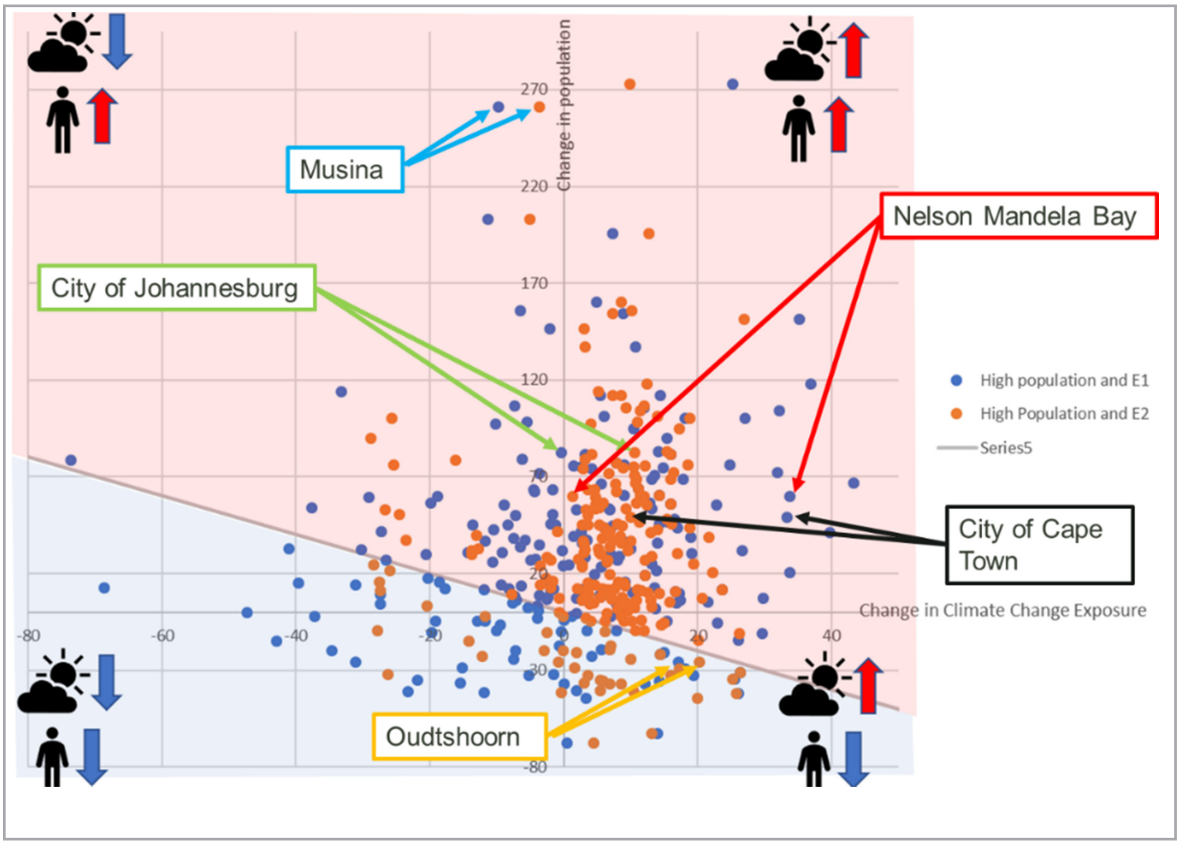


Figure 19: The relative impacts of climate change and population growth on water supply risks by 2050 for all local municipalities in RSA. (Source: CSIR Greenbook. Cullis and Philips, 2019)

While the above study considers potential impacts on average water availability based on a first order analysis derived mainly from impacts on rainfall, more detailed studies of the impact on individual systems and taking into consideration the variability of supply and the required level of assurance is needed. This has been done for a few individual systems with the most recent being for the Western Cape Water Supply System (WCSS) which shown that climate change could have a very significant impact on water availability at a 1 in 50-year level of assurance of supply, particularly when considering the potential impact on multi-year droughts as shown in Figure 20.

The results of this study were used to inform the updated water strategy for the City of Cape Town (CCT, 2019) and highlighting the critical need for additional augmentation of the WCWSS and is currently being used by DWS in the updated reconciliation planning for the WCWSS. This is not the first-time climate change has been considered in the planning of the bulk water supply systems for South Africa, but the failure to follow up with implementation of these plans is a significant contributing factor to the increasing water security risks seen in several parts of the country.

2.4.2 Sanitation

The delivery of sanitation services in South Africa faces key challenges in all provinces and across all components of the sanitation service chain.

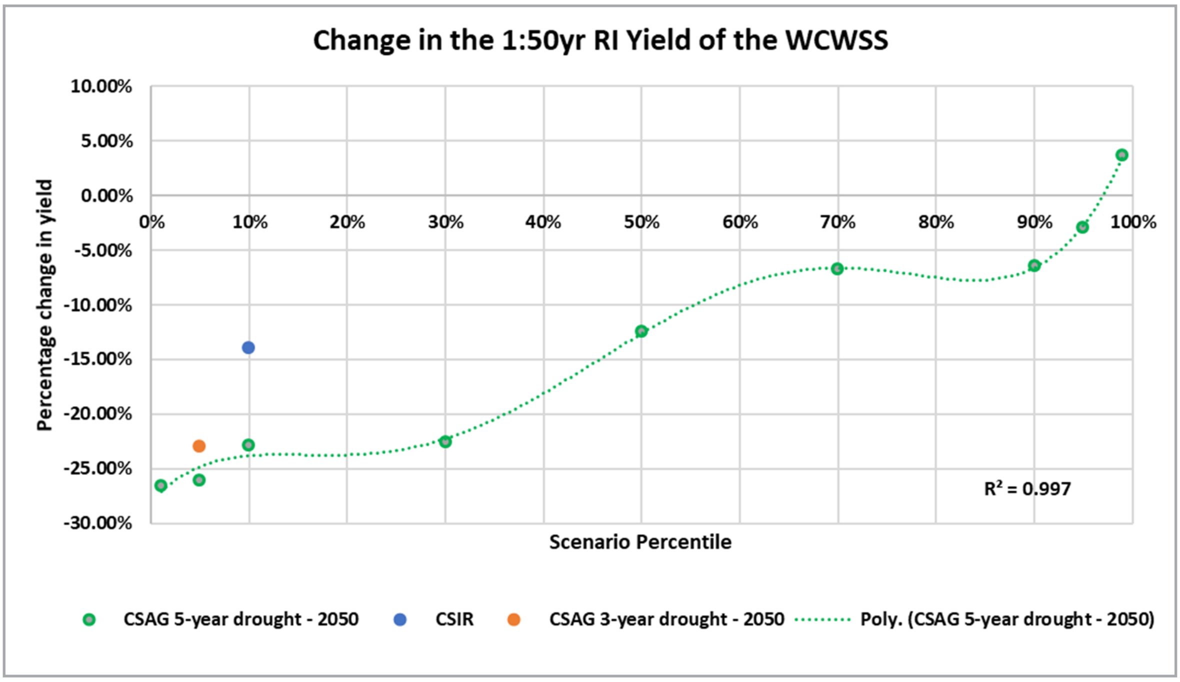


Figure 20: Likelihood of climate change impacts on the 1 in 50-year yield from the Western Cape Water Supply System (WCWSS) based on consideration of CSIR downscaled climate scenarios, and a stochastic factoring approach of potential impacts on the multi-year droughts (3 and 5 years) undertaken by the Climate Systems Analysis Group (CSAG)

Nationally, there are still backlogs in sanitation service delivery, and the systems are already being impacted by climate variability.

In addition to remaining backlogs on access to safe sanitation, it is clear that many of the existing sanitation systems are not coping with current demands, and these present a critical risk to water quality and human health. The latest Green Drop report from the DWS determined that only 9% of wastewater treatment works (WWTWs) in the country were low risk in terms of operational and compliance with effluent discharge standards, while 32% were in a critical risk category. The failure of wastewater treatment works is a critical threat to water quality in many parts of South Africa and the impact will become greater due to the impacts of climate change.

Climate change projections indicate increases in temperature and varying rainfall patterns within the next decades. Reduced water availability due to low and/or more variable rainfall as well as increasing demand due to higher temperatures can cause water sources (including boreholes and springs) to run dry. Increasing water scarcity and the resulting increase in the costs of water can lead to inequitable access. This may deprive households of opportunities to collect the amount of safe water needed for proper handwashing and hygiene, limiting children’s ability to grow up healthy and strong. Increased water scarcity will impact on households served with waterborne sanitation systems which rely heavily on water to transport human excreta from the premises into wastewater treatment works. Conversely, heavy rainfall and resulting flooding can damage water sources and sanitation facilities, carry runoff and waste into streams and lakes, and contaminate the water supply (UNICEF, 2022).

While there is a high level of confidence regarding the influence of the emissions of greenhouse gases in change in air temperature, there are knowledge gaps and uncertainty about how the increase in temperature will manifest itself at the local level through changes in rainfall, runoff, groundwater recharge, water quality, climate extremes and water availability (Oates, Ross, Calow, Carter, & Doczi, 2014). Though, there is already evidence reporting the possible effects of climate change on the water and sanitation systems depending on the climate scenarios.

Examples of the potential impacts of climate change on the Water, Sanitation and Hygiene (WASH) sector are shown in Table 2. Even though there is still uncertainty on the details of specific impact, it is clear that climate change will provide an added stressor to current challenges with regards to providing basic, reliable, and safe sanitation for all in South Africa.

Table 2: Examples of climate change impacts on the WASH sector (Source: https://unece.org/climate-change/press/climate-change-threatens-access-water-and-sanitation-warn-unece-whoeurope)

Climate Impact	Impact on WASH sector
Decrease in precipitation: Drought	Reduction in raw water availability for drinking water supplies, reduced flow in rivers, less dilution/increased concentration of pollutants in water, challenge to hygiene practices.
Increase in precipitation & severe weather: Flooding	Pollution of wells, inundation of wells, inaccesibility of water sources, flooding of latrines, damage to infrastructure,landslides around water sources, sedimentation & turbidity,challenges to sustainability of sanitation & hygiene behaviours, & waterborne diseases.
Increase in temperature: Heatwaves	Damage to infrastructure, increase in pathogens in water leading to increased risk of disease.

To minimise the risks, climate change projections and vulnerability and risk assessments should be carried out before any sanitation systems are developed in areas likely to be affected by climate-related disasters or climate impacts on the water cycle. Assessments need to identify direct risks to the sanitation system (along the entire sanitation chain), as well, as how changes in water availability, temperature, or sea level, for example, might affect sanitation systems, and how climate impacts on sanitation systems could affect water resources. This applies no matter whether sanitation is based on centralised waterborne or on-site “dry” systems. Once the risks have been identified, they should be addressed with integrated solutions (Andersson, Reckerzuegl, Michels, & Rüd, 2019). The provision of traditional waterborne systems is a challenge in areas such as much of South Africa that already have limited water resources availability and particularly in areas expected to become dryer. The increasing risk of extreme events such as floods and landslides are also a major concern and require efforts to improve the climate resilience of existing as well as new water infrastructure.

In response to concerns around the impact of poor sanitation on human health and the economy, the DWS is currently developing the National Sanitation Implementation Plan (NSIP). The NSIP recognises the critical importance of maintenance of existing systems and the need for increased investment in providing both traditional and alternative sanitation systems. as well as the need to consider alternative sanitation solutions, where applicable. A critical requirement for the provision of sustainable and climate resilient water and sanitation systems is functioning municipalities that recognise the risks associated with climate change.

The potential direct impact of increased flooding and more intense rain-events on sanitation infrastructure is an area of increasing risk as it has the potential to cause major disruption to the sanitation system through the damage to sewer pipes and wastewater treatment plants, but also as it poses a significant health and water quality risk, particularly in areas that current maintain low levels of services and also for on-site sanitation if not properly managed.

2.4.3 Groundwater

Climate change is expected to affect various groundwater processes including, but not limited to, recharge, storage, discharge, and groundwater quality. Adaptation measures include improved monitoring, more holistic conjunctive water management, managed aquifer recharge, groundwater recharge with recycled water and brackish groundwater resources use coupled with desalination. As such the previously mentioned processes need to be explored, protected, and sustainably used and managed as groundwater is central to surviving and adapting to climate change.

Variations in the quantity of precipitation, temperature and evapotranspiration affect groundwater recharge. In general, groundwater recharge increases in areas where precipitation increases and vice versa - and dependant on factors such as climatic factors, local geology, topography, and land use (Dragoni and Sukhija 2008). Recharge of aquifers in semi-arid areas such as South Africa is episodic and increasingly dominated by focused recharge, such as flood events (van Wyk 2010; Cuthbert et al. 2019). Hyetograph-hydrograph responses from the semi-arid regions show that water levels respond only after a certain precipitation threshold has been overcome. This threshold can be (i) a series of individual precipitation events which forms part of a prevailing regional weather system and (ii) a single, heavy precipitation event over a short period like the rain-week patterns. Cuthbert et al. (2019) showed how aridity controls the predominant recharge processes through analysis of multi-decadal groundwater hydrographs across sub-Saharan Africa, where local hydrogeology influences the type and sensitivity of the recharge relationships.

A key feature of the annual precipitation-recharge relationship is that some of the most significant recharge can occur during relatively low total precipitation due to extreme precipitation patterns occurring across a range of timescales dependent upon conditions on the ground. This is also reflected in potential future climate scenarios.

Future changes in variability are therefore more important than any potential changes in mean annual precipitation. The assumption that climate change reduces groundwater resources requires more observation-driven research (Cuthbert et al., 2019). Due to the potential for increased in extreme rainfall, even against the backdrop of declining mean annual precipitation, groundwater recharge to many large-scale aquifer systems may actually increase under climate change, provided that there is infiltration of these high intensity events. It is important to note that in mountainous areas, winter-rainfall hydro-climate zones, and possibly along the South Coast of South Africa, the springs feeding the Table Mountain Group (TMG) Aquifers are likely derived from continuous bulk recharge (Miller et al. 2017).

The short-term recharge-discharge cycle combined with the likely reduction in the total amount of precipitation in the greater Cape region suggests that recharge to the TMG aquifer is likely to diminish future due to climate change, directly impacting the amount of groundwater that could be abstracted (Miller et al. 2017). The El Niño–Southern Oscillation climate pattern is a dominant driver of inter-annual climate variability and large-scale extremes across much of Africa. The drought of 2015-2016 resulted in groundwater storage declines through most of the wet season in Limpopo. Even though groundwater provides a valuable buffer for periods of reduced surface water availability in drought conditions; consecutive dry years lead to marked storage reduction.

The groundwater supply system of the Verlorenvlei catchment on the west coast of South Africa has been under additional stress given the 2015–2017 El Ninõ system that led to drought conditions along the west coast of South Africa (Miller et al. 2022). Studies concluded that the reduced groundwater recharge likely impacts the low flows required to sustain the Verlorenvlei estuarine lake system (Watson et al., 2020).

An assessment of groundwater vulnerability (Van Rooyen et al, 2020) emphasised the high vulnerability of groundwater to climate change particularly in the north, northwestern, and western parts of South Africa. The study concluded that 22.4% of South Africa's groundwater is projected to have a very high vulnerability to depletion in quantity and deterioration in quality (Figure 21). The model was adjusted for climate conditions 50 years into the future, resulting in a 3% increase in very high vulnerability areas and a 6% decrease in low vulnerability areas.

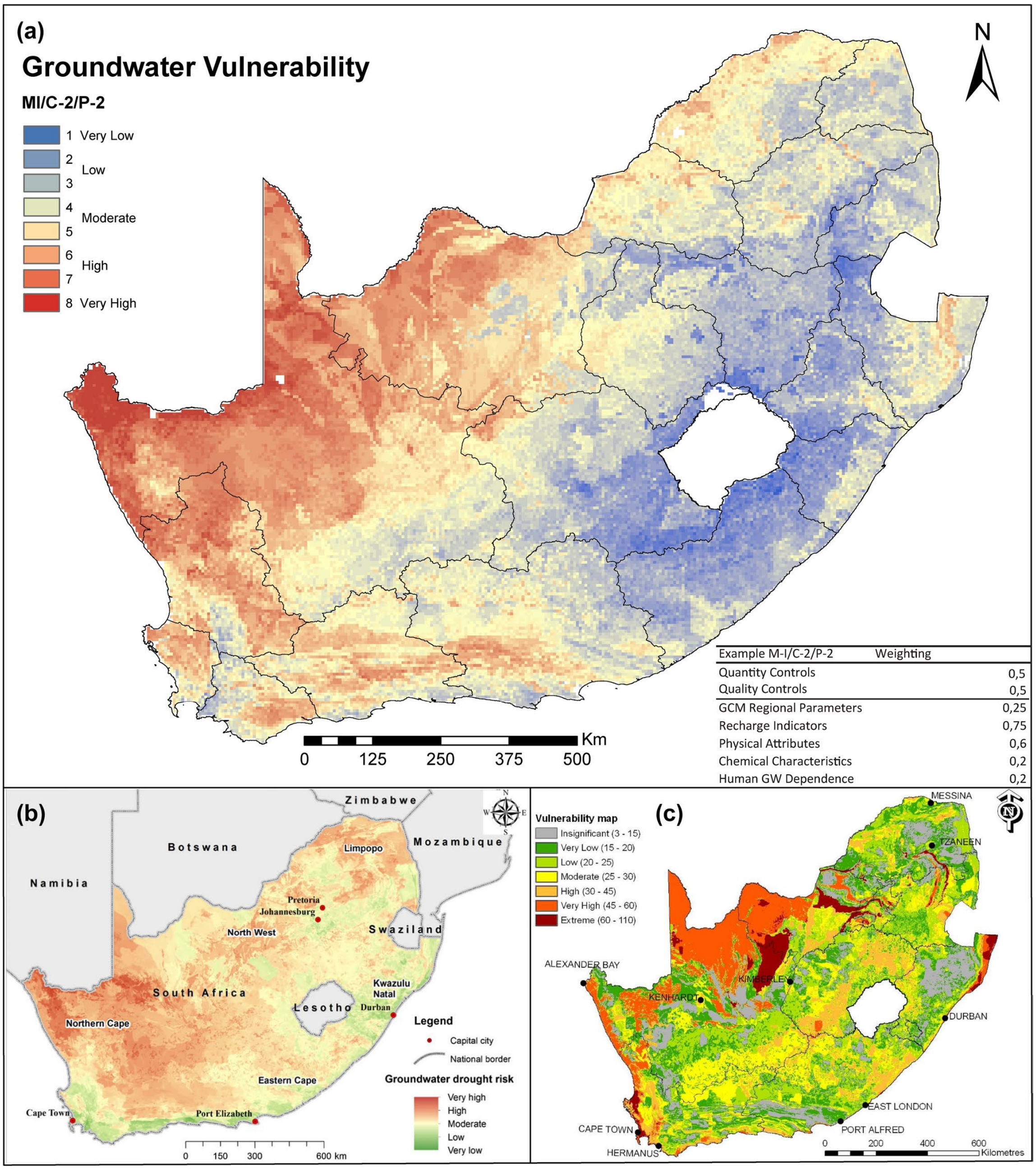


Figure 21: Distribution of (a) Groundwater vulnerability from the selected scenario MI/C-2/P-2, where major strategies are weighted equally, and minor strategies are skewed toward recharge indicators and physical attributes (water management areas shown for reference); (b) groundwater drought risk produced from Villholth et al. (2013) and (c) DRASTIC groundwater vulnerability produced by Musekiwa and Majola (2013) (van Rooyen et al. 2020)

Seawater intrusion of coastal aquifers as a result of sea level rise due to increased sea surface temperatures driven by climate change is an example of how climate change could impact on water quality of the groundwater resource. The intrusion can also be triggered by over pumping in coastal areas, perhaps due to increased demands resulting from stress factors related to climate change (e.g., too much water pumped for irrigation due to increased temperature conditions). The sea-level rise is projected to extend areas of salinisation of groundwater and estuaries, which will reduce the freshwater supply in many coastal communities.

Strategies to manage water resources conjunctively with surface water resources have to become the norm under changing climatic conditions. The potential resilience of groundwater in many areas requires an improved understanding of precipitation-recharge relationships, which is critical for informing reliable climate change impact projections and adaptation strategies (Cuthbert et al., 2019). As climate change result in increased temperatures and rainfall variability the length of dry cycles will likely increase, resulting in water resources drying up more frequently. For this reason, it is crucial to safeguard that the water resources are not over-allocated during wet cycles, hampering ecosystem regeneration and prolonging the length of these dry cycle conditions (Watson et al., 2019). Several adaptation responses are required to protect the groundwater resources of South Africa.

These include the following:

- Protection of groundwater recharge zone and strategic water source areas
- Improved groundwater monitoring and data sharing
- Analysis of groundwater level fluctuations and long-term trends
- Improved conjunctive use of surface and groundwater resources
- Managed aquifer recharge (see Figure 22)

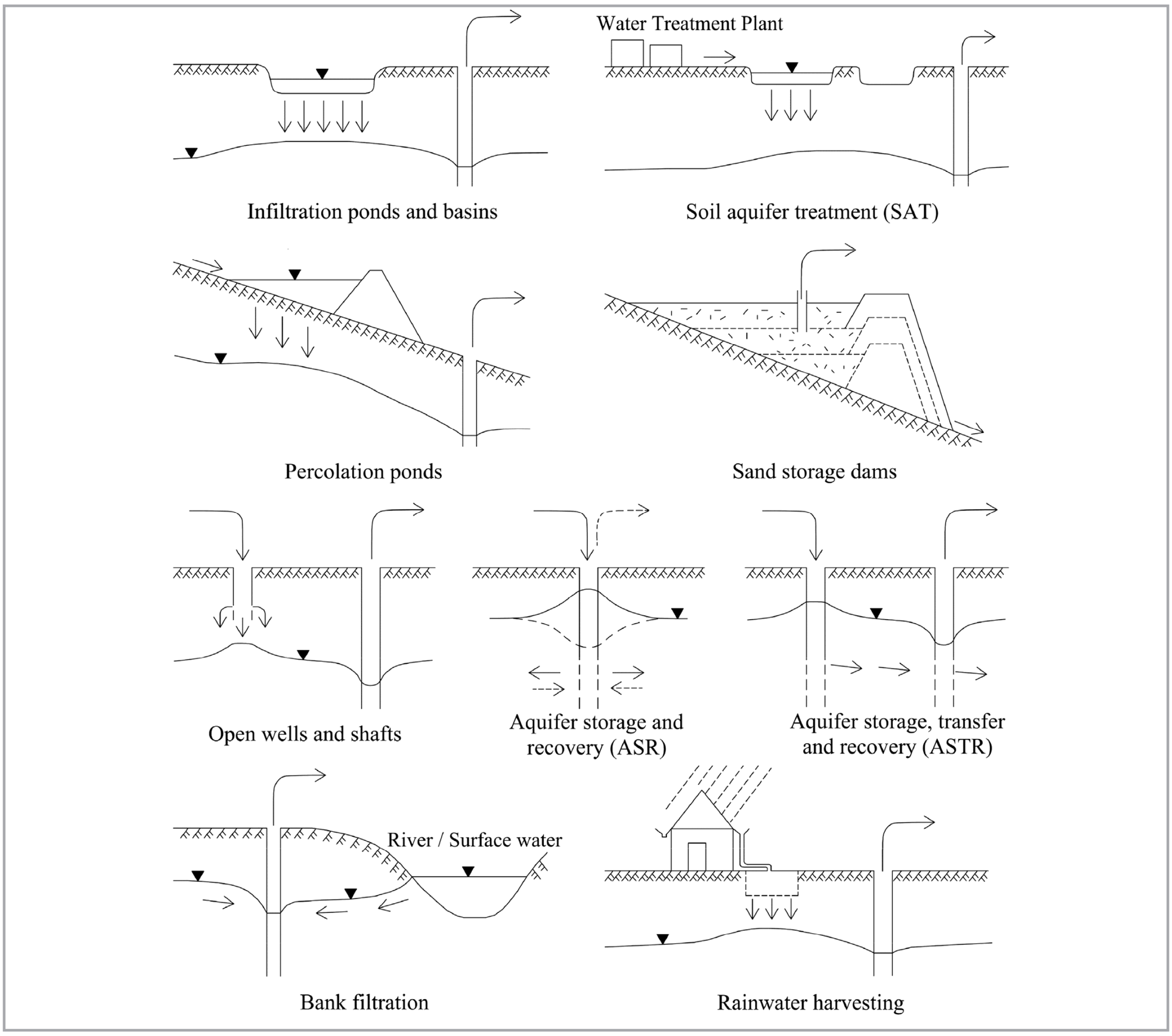


Figure 22: Schematic of types of the common manged aquifer recharge (MAR) techniques (Zhang et al. 2020)

2.4.4 Water Quality

Several aspects of climate changes may affect water quality including (after Schulze, 2011):

- Changes in water temperature
- Enhanced evaporation
- Flash floods and peak discharges
- Regional floods
- Salinisation

The likely impact of each of these on water quality are summarised below:

Changes in Water Temperature

An increase in air temperature will likely lead to an increase in water temperature although there are several other factors such as local topography, water depth and tree cover that influence this relationship. Increased water temperatures could affect, inter alia, the quality of water for irrigation, dissolved oxygen content of water, the rates of chemical and biological reactions in water as well as have wide-ranging repercussions in the health sector through the creation of favourable conditions for the incubation and transmission of water-borne diseases.

Heat waves are defined as three consecutive days with maximum temperatures exceeding 30°C on each day, while extreme heat waves have three consecutive days each exceeding 35°C. These can lead to short term water quality impacts and increased fish mortality due to low oxygen concentrations brought about by a rapid increase in decomposition processes, and temperature stress on fish. Heatwaves are expected to become more frequent in future across all parts of South Africa, but particularly in the northern parts and furthest away from the coast.

Enhanced Evaporation

Enhanced evaporation is the additional evaporation, over and above that under present climatic conditions, from open water bodies such as dams and wetlands as well as that from the soil and plant systems. Evaporation has the effect of concentrating salts and other constituents in an open water body when the water volume is reduced. It can also concentrate salts and other constituents in the soil when the soil moisture is reduced as a result of evaporation at the surface and water losses by evapotranspiration from plants.

Flash Floods and Peak Discharges

Flash floods refer to floods occurring over a short period of time and usually over a small catchment area. Frequently they result from severe convective activity from thunderstorms with high intensity rainfall. In terms of water quality impacts, flash floods are generally a concern in urban areas and are associated with intense rainstorms. The concerns described for increased rainfall intensity apply here as well as scouring and erosion of urban streams and its effect on suspended sediment and mobilising organic matter previously deposited in stream channels.

Regional Floods

Regional floods are changes in floods with high waters occurring over several days and covering substantial areas, usually in the 1 000s of km², inundating areas around the channel system, and resulting from widespread rains over a period of several consecutive days, with considerable amounts of rain often falling on already wet catchments. Regional floods can result in the flooding of low-lying water treatment and wastewater treatment works, and damage to sewerage infrastructure resulting in raw sewage being discharged to rivers. This poses a health risk to water users as the supply of safe water may be interrupted.

Salinisation

Two key processes affect salinity in water namely dilution and concentration. Water temperature and evaporation affect the concentration of salts in a water body and rainfall and floods often leads to the dilution of salts in a water body. Sea level rise could also increase the risk of salinisation of estuaries, particularly when combined with reduced streamflow and higher evaporation losses as a result of climate change or other direct human impacts.

Integrated Water Quality Management Strategy for South Africa

The Integrated Water Quality Management (IWQM) Strategy for South Africa addresses five strategic goals, nine strategic issues, and 21 strategic objectives for improved water quality management in South Africa. By addressing these, the trajectory of declining water resource quality in the country can be checked. With a focus on adaptive management, action plans can be put in place timeously to address emerging climate change quality concerns. Implementing these strategic actions will go a long way in adapting to the potential impacts of climate change on water quality in South Africa. Added to these however, it is important to also highlight the importance of investing in improved catchment management and in particular the protection and rehabilitation of critical environmental systems such as estuaries, wetlands and riparian zones that play a critical role in maintaining water quality. These ecosystem-based adaptation (EbA) solutions also have multiply co-benefits including addressing the risks associated with both droughts and floods as well as maintain biodiversity and carbon capture and storage. They also have direct social and economic benefits when appropriately managed.

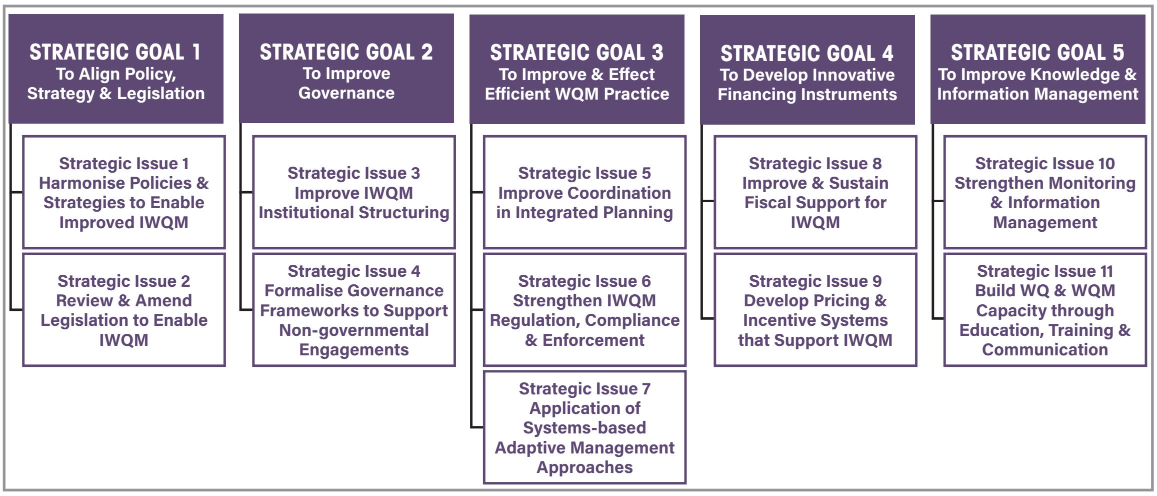


Figure 23: The IWQM strategic goals and objectives that will help in addressing climate change risks for water quality.

2.4.5 Aquatic Ecosystems

With a below average runoff to precipitation ratio, South Africa's aquatic ecosystems – rivers, wetlands and estuaries – and their habitat and biota are especially sensitive to the projected consequences of global climate change. They are expected to undergo significant transformation arising from the anticipated migration of rainfall belts and the increased frequency and intensity of floods and droughts compounded by country-wide warming and drying trends. These trends will exacerbate the existing threats to aquatic ecosystems that include competing agricultural, industrial, and domestic water demands, declining water quality, land use change and physical habitat degradation, alien species invasions and reduced connectivity. Aquatic ecosystems are already the most threatened ecosystem type in South Africa as shown in Figure 24.

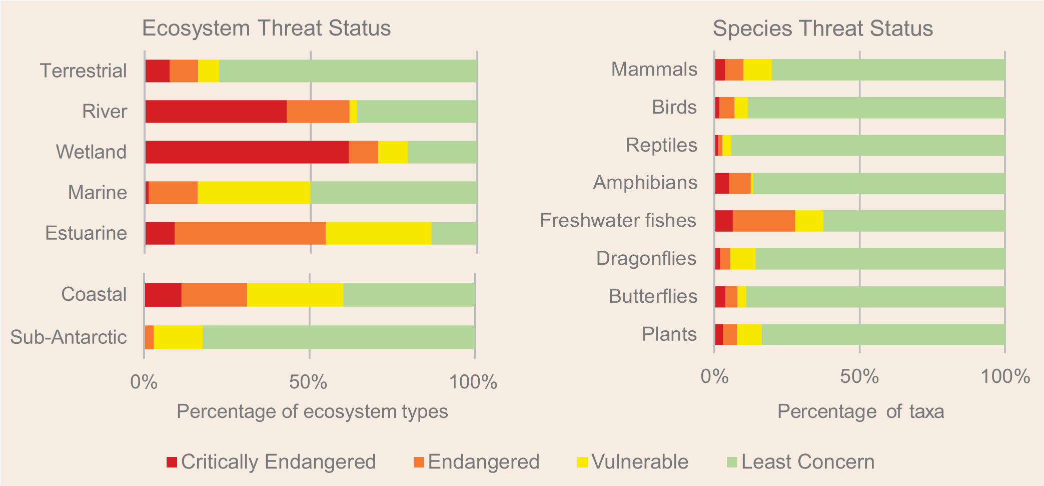


Figure 24: Ecosystem & species threat status in South Africa (Source: NBA, 2018)

Without mitigation of these threats, these ecosystems are likely to be pushed beyond their structural (organisation of biotic and abiotic components) and functional (productivity, energy flow and nutrient cycling) thresholds (Fay, et al. 2016). Reducing the threat to aquatic ecosystems from climate change will necessitate addressing the present freshwater biodiversity crisis and anticipating future climate-linked impacts. To date, both global and local responses to the decline of freshwater ecosystems have been largely inadequate, premised on the notion that measures to protect terrestrial ecosystems (e.g., increased protected area coverage) will necessarily also protect freshwater ecosystems (Tickner, et al. 2020).

Increasing levels of CO_2, rising air temperature and more variable precipitation will drive changes in water temperatures and runoff mediated through terrestrial controls (evapotranspiration and water flow paths) and changes in human activities and responses (Figure 25). These changes will in turn will have consequences for metabolic processes in individual living organisms, the geographic range of species, geomorphological and hydraulic nature of habitats, productivity and nutrient availability, and water chemistry. Numerous other interacting factors – such as the fragmentation of ecosystems by dams and an anticipated increase in demand and competition for an ever-diminishing supply of water – makes ecological responses complex and difficult to predict, requiring an interdisciplinary approach integrating ecology, biology, physiology, hydrology and climatology (Knouft and Ficklin 2017).

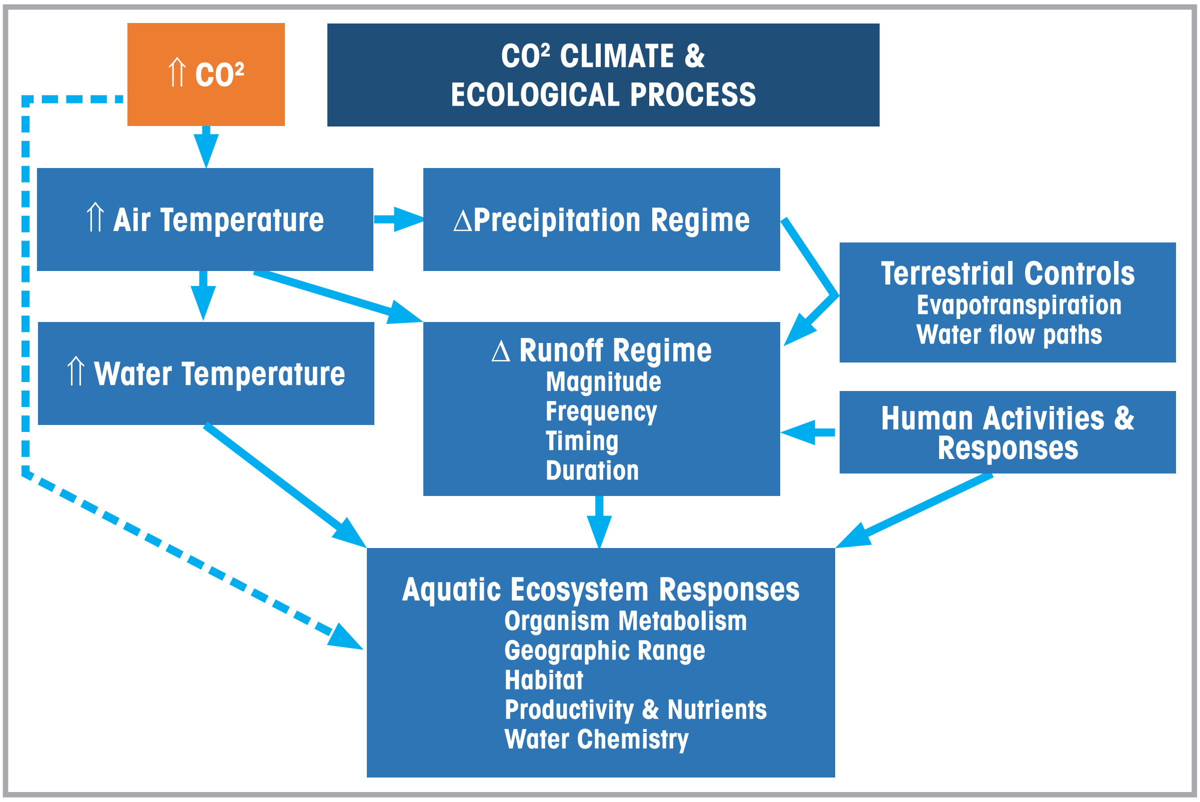


Figure 25: Links between increases in CO_2 and environmental drivers (temperature and precipitation) of ecological in inland aquatic ecosystems. Solid arrows indicate direct responses; dashed arrow indicates direct effects of lesser-known importance. (adapted from Poff, et al. 2002).

The main climate change drivers and ecological consequences for aquatic ecosystems are shown in Table 3 (Dallas and Rivers-Moore 2014). In the sections that follow, we review these drivers in a general sense before moving on to assess how they are likely to manifest at a regional scale. Note that water quality and sedimentation consequences are dealt with in a separate report and are critical in determine the climate change risk for aquatic ecosystems. Climate change is likely to increase the risk to aquatic ecosystems already faced in South Africa as a result of reduced runoff, increasing water usage, declining water quality and disruption due to the construction of dams and other water infrastructure. It is therefore critical to consider adaptation and risk mitigation measures that will not only reduce the threat of climate change, but also lead to an improvement in the current condition of aquatic ecosystems and the communities that are dependent on them. Efforts to develop and execute adaptation and risk mitigation strategies should focus on reducing the non-climatic stressors resulting from human activities on ecosystems and ecosystem services such as flow modification, unsustainable water abstraction, pollution and habitat destruction and alien species invasions. A second focus should be on implementing restoration and rehabilitation initiatives where they are most needed. Identifying priority stressors and understanding their impacts is essential to ensure that interventions serve to strengthen resilience. Key to this approach is establishing flagship demonstration cases studies in line with South Africa's Climate Change Flagship programmes to trigger large-scale transition.

Table 3: Summary of global climate change drivers and ecological consequences in inland water ecosystems in South Africa (* consequence is also biological) (Dallas and Rivers-Moore 2014).

Component	**Ecological Consequence**	
Water Quantity	△	Run-off patterns (flow variability, duration & timing)
	⇑	Frequency & intensity of extreme events (droughts & floods)
	△	Groundwater recharge rate
Water Quality	⇑	Water temperature
	⇑	Organic matter decomposition
	⇓	Concentration of dissolved oxygen
	△	Nutrient cycles (& carbon cycling) & loads
	⇑	Algal growth & change in eutrophic condition*
	⇑	Incidence of cyanotoxins*
	⇑	Sedimentation & turbidity
	⇑	Mobilisation of adsorbed pollutants such as metals & phosphorus
	⇑	Transport of dissolved pollutants such as pesticides & pathogens
	⇑	Salinisation in semi-arid & arid areas
Physical Habitat	△	Channel geomorphology
	⇓	Longitudinal & lateral connectivity
	△	Aquatic habitat
Biological Change	△	Aquatic biodiversity
	△	Phenology & life-history patterns
	△	Communities
	△	Species distribution & range
	⇓	Extinction of vulnerable species
	⇑	Invasive & pest species
	⇑	Waterborne & vector-borne diseases

As a guiding principle, Ecosystem-based Adaptation (EbA) approaches provide a framework for such implementation. The adaption and response strategies discussed in the sections that follow are broadly congruent with the principles of EbA. It must also be acknowledged that climate change is a cross-cutting issue and that no single agency can respond on its own. Climate change responses should therefore be undertaken in a spirit of cooperative governance with integrated planning and implementation occurring across all spheres of government. This must be supported by reliable data, monitoring, research and analysis.

Priority recommendations for adaptation and risk mitigation for aquatic ecosystems include:

- Adopting Ecosystem-based Adaptation (EbA)
- Operationalising the Ecological Reserve
- Improving water quality
- Retore, rehabilitate and remediate critical ecosystems
- Mitigate increasing flood risks
- Reduce sedimentation
- Safeguard and restore connectivity
- Alien invasive species removal
- Protected Areas (PAs) and refugia

2.4.6 Climate Proofing Critical Infrastructure

A likely increase in the intensity of rainfall due to climate change over most of South Africa will significantly increase the risk of damage to critical infrastructure due to flooding. This report presents the results of a provisional modelling of climate change impacts for disaster risk management in South Africa undertaken as part of the Long-Term Adaptation Scenarios (LTAS) research program. The results of this study showed that around 30% of bridges, 19% of dams and 29% of powerline crossings could experience a high to very high increase in flood risk by mid-century and that these could impact on almost all parts of the country. In addition, an expected increase in rainfall intensity across most of the country, but particularly in the eastern half will likely significantly increase urban flooding and damages for municipalities.

The risk of damage due to increased rainfall intensity and flooding is enhanced in areas of catchment degradation, or where there is a failure in the management of solid waste, the maintenance of critical infrastructure or in areas where development happens in areas already prone to flooding or landslide risks. The areas most likely affected are informal areas that often occur on flood plains due to a lack of access to alternative land in more safe areas. The ability of communities and municipalities to recover from the damaged caused by flooding further increases the risk and the potential impact as resources are limited to rebuild damaged infrastructure. As a result, it is critical that measures are implemented to reduce the risk and particularly in adapting to the likely impacts of climate change in all areas of South Africa.

The relative changes in the 1 in 100-year annual maximum flood (AMF) at more than 17,000 locations of existing key infrastructure – dams, bridges and powerline crossings – were averaged from the outcomes of the five climate models for two-time horizons, 2050 and 2100. The dam locations were extracted from the DWA Dam Safety database. The bridge locations were extracted from the SANRAL database. The powerline locations were extracted from the SA Explorer GIS database and intersected with 1 in 500,000 rivers from DWA. Figure 26 presents the resulting cumulative frequency distributions (CFDs) of the change in the 1-100-year flood.

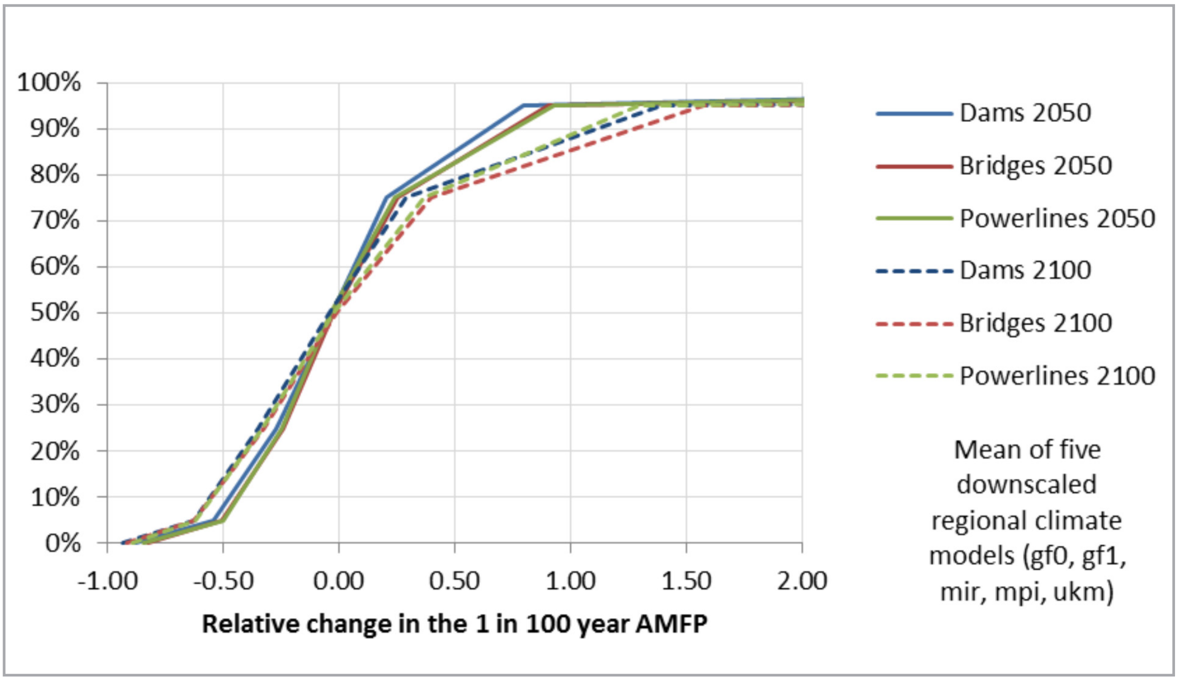


Figure 26: Cumulative frequency distributions of the relative changes in the potential design flood risk for key infrastructure across South Africa by 2050 and 2100 compared to the historical period (representing the average impacts of five climate models).

The following aspects of Figure 26 are particularly striking:

- About 50% of infrastructure locations included in this analysis are projected to potentially experience reduced design flood risk by both 2050 and 2100. The vast majority of the flood risk reduction locations fall in the -50% to 0% range for both time horizons. However, it bears noting that the exact constitution of the sample of infrastructure locations with reduced flood risk differs markedly for the two-time horizons, given the fluctuating trajectories of relative flood risk changes for different parts of the country presented in Figure 14.
- These "flip-flop" characteristics potentially pose a severe dilemma for climate change adaptation planning, with disaster risk reduction initiatives having to attempt to stay synchronised with these "flip-flop" patterns in different parts of the country.
- An increase in design flood risk of 50% or more would generally be regarded catastrophic for infrastructure security. Figure 16 indicates that the proportion of such direly threatened infrastructure locations are projected to potentially increase during the second half of the century from about 16% to about 22%.

The four flood risk categories ranging from "Low" to "Very High" presented in Table 4 allow a more nuanced analysis of increased design flood risks per infrastructure type. These numbers are based on the averages of the outcomes of the five individual climate models considered for 2050.

Table 4: Number of structures (bridges, dams and powerline crossings) with projected flood risk increases by 2050 relative to the current design flood magnitude (1:100-year RI).

Risk Category	Change in Q100 by 2050	Bridges		Dams		Powerlines	
		Count	%	Count	%	Count	%
0 Low	< 0	2271	25%	1502	30%	850	26%
1 Medium	0 to 0.5	4264	46%	2515	51%	1477	45%
2 High	0.5 to 1	1808	20%	673	14%	557	17%
3 Very High	> 1	882	10%	237	5%	379	12%
Total		**9225**		**4927**		**3263**	

The following aspects of Table 3 are particularly striking:

- Almost 1700 bridges (30%) on the SANRAL database are projected to potentially experience “High” to “Very High” flood risk increases by mid-century.
- More than 900 dams (19%) on the DWA Dam Safety database are projected to potentially experience “High” to “Very High” flood risk increases by mid-century.
- Almost 900 powerline crossings (29%) on the SA Explorer GIS database are projected to potentially experience “High” to “Very High” flood risk increases by mid-century.

The locations of infrastructure facing “High” or “Very High” increases in flood risk in the next half century are presented in Figure 17 for the climate model giving the largest flood risk increases.

The number of impacted bridges in each risk category in each province is given in Figure 18.

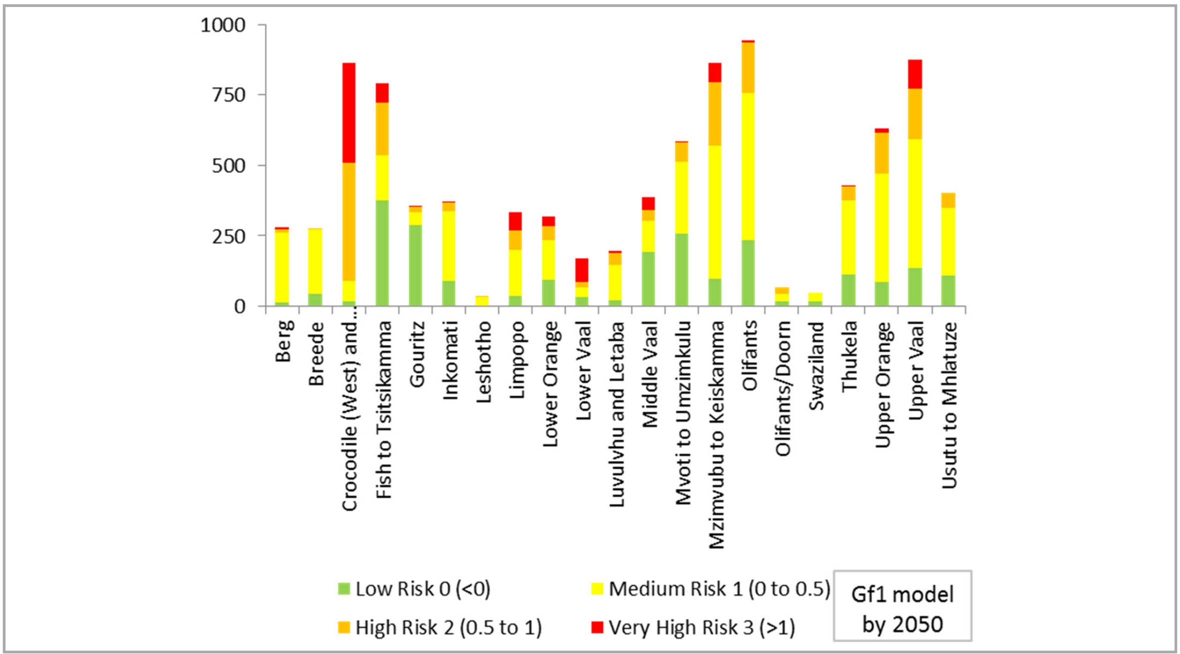


Figure 27: Number of bridges in each WMA in each risk class defined in terms of the maximum relative increase in the 1:100-year design flood by 2050 for the gf1 climate model.

The following spatial patterns of extreme design flood-related infrastructure risks by 2100 as per the single GF1 climate model results, presented in Figures 17 and 18, are particularly striking:

- Bridges: The highest general concentrations of bridges at risk by significant potential design flood increases are projected for the Gauteng, North-West and Limpopo Provinces in that order. When viewed on a WMA basis, Figure 16 illustrates that the Crocodile (West)/Marico is the WMA with the highest number of bridges with significantly increased design flood risk.
- Dams: The highest general concentrations of dams at risk by significant potential design flood increases are projected for the Gauteng and North-West Provinces, with the Limpopo and Eastern Cape Province a distant joint third.
- Powerline crossings: The highest general concentrations of powerline crossings at risk by significant potential design flood increases are projected for the Gauteng, Mpumalanga, KwaZulu-Natal and Eastern Cape Provinces, in that order.

Initial recommendations on potential adaptation response are given, including the following:

- Updating infrastructure design standards
- Maintenance of spillways and clearing of drainage structures
- Flood early warning systems (FEWS)
- Changing land use and improved stormwater attenuation
- Catchment management and Nature Based Solutions (NBS)
- Developing flood operating rules for dams across South Africa
- Climate Risk Screening and the Decision Tree Framework
- Decision making under deep uncertainty
- Investments in Cross-cutting Issue and No-regrets Options.

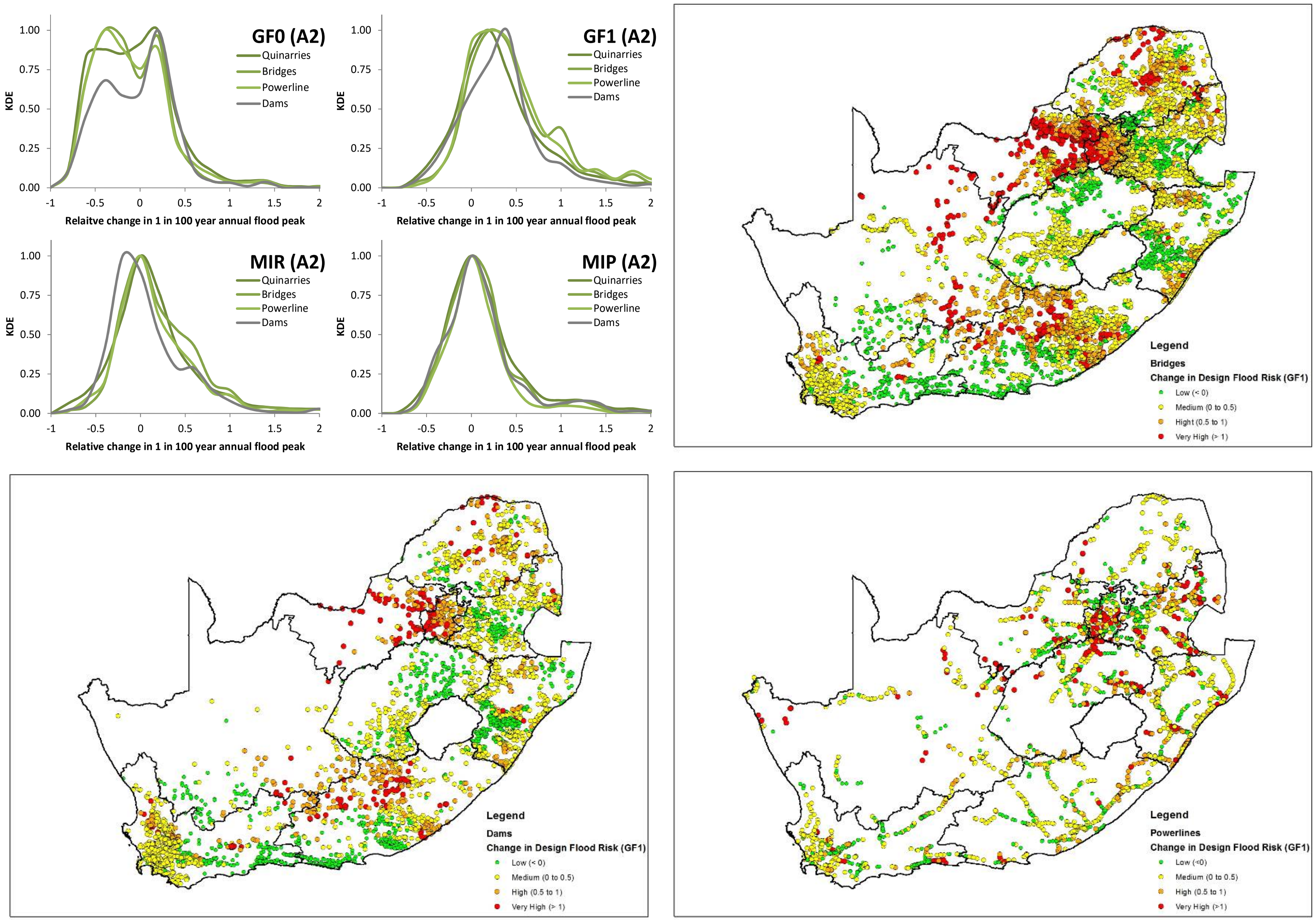


Figure 28a-d: Frequency distributions of extreme potential impacts on the design flood (1:100 year) for key infrastructure under four climate change models (top, left) and the relative risk for individual structures for the climate model with the greatest general impact up to 2100 (gf1). (Analysis based on potential changes in 1:100-year RI flood – no consideration of hydraulic characteristics of individual structures.)

2.5 Updated Hydro-climatic Zones for South Africa

The National Climate Change Response Strategy for the Water Sector in South Africa (NCCRS, DWS, 2013) describes six hydro-climatic zones that are "going to be impacted differently by climate change". The basis for delineation of these zones is not described in detail in the report. Rather it was based primarily on the grouping of Water Management Areas (WMA) into regions considered likely to be influenced by similar climate drivers and the anticipated impacts of climate change. While these hydro-climatic zones are used in both the NCCRS (DWS, 2013) and Long-Term Adaptation Scenarios (LTAS) (DEA, 2013), there is a need to provide a more concrete, data-informed justification for national scale regionalisation of hydro-climatic zones that is relevant from the point of view of the understanding and summarising climate change impacts on water resources at the national scale. While specific data can be provided at a finer scale such as for individual catchments, it is useful to be able to describe general trends in climate change impacts at a national scale.

The approach to determining hydro-climatic zones was based on the combining three sources of information:

- Characteristics of current climate that are relevant from a water resources point of view such as seasonality, interannual variability and magnitude of climatic variables (or a combination of relevant climate variables, i.e., rainfall and PET or air temperature).
- Characteristics of future climate change signal in the relevant climate variables.
- Administrative boundaries, in this case - boundaries of WMAs and/or Municipalities.

The approach was also informed by an understanding of the main climate drivers of the South Africa climate and, a review of existing regionalisation scheme relevant for climate and hydrological processes in South Africa. Data analysis was also undertaken to determine the appropriate number of regions and sensitivity to the nature of the climate parameters under consideration. The data analysis considered clustering of climate zones based on both current climatic variables as well as the anticipated change using the latest CMIP6 climate model projections from the International Panel on Climate Change. The final recommended updated hydro-climatic zones for South Africa are shown in Figure 29 in relation to the existing WMAs.

It is worth stressing again that the proposed updated hydro-climatic zones are intended for synthesising climate change information at the national scale and should not be used at smaller scales (i.e., one should not attempt to derive information for a particular quaternary catchment based on which zone it falls into). To highlight this point, the homogenous hydro-climatic zones shown in Figure 29 are defined by "straight, blocky lines" in spite of the fact that some of their boundaries follow the relatively well-defined physical feature such as the escarpment which also aligns with the WMA boundaries. An example of this are the western catchments of the Breede River catchment, supplying the Theewaterskloof, Brandvlei and Kwaggaskloof dams.

These catchments fall into Breede-Gouritz WMA but are better characterised by the climatic regime of the West Coast hydro-climatic zone which aligns with the Berg-Olifants WMA. Their alignment to a climatic regime would clearly emerge in a smaller scale assessment but is somewhat mis-construed when a national scale generalisation is made. This also highlights the importance of using downscaled climate change information and scenarios in support of more detailed water resources planning on an individual water supply system basis. This would also require consideration of other aspects of climate change such as increased seasonal variability and inter-annual variability that are not always reflected in terms of mean changes.

A detailed analysis and comparison of future climate change scenarios for each of the six identified hydro-climatic zones is provided in Appendix A. The results of this analysis and recommendations for potential climate response actions in each WMA are given in Table 5.

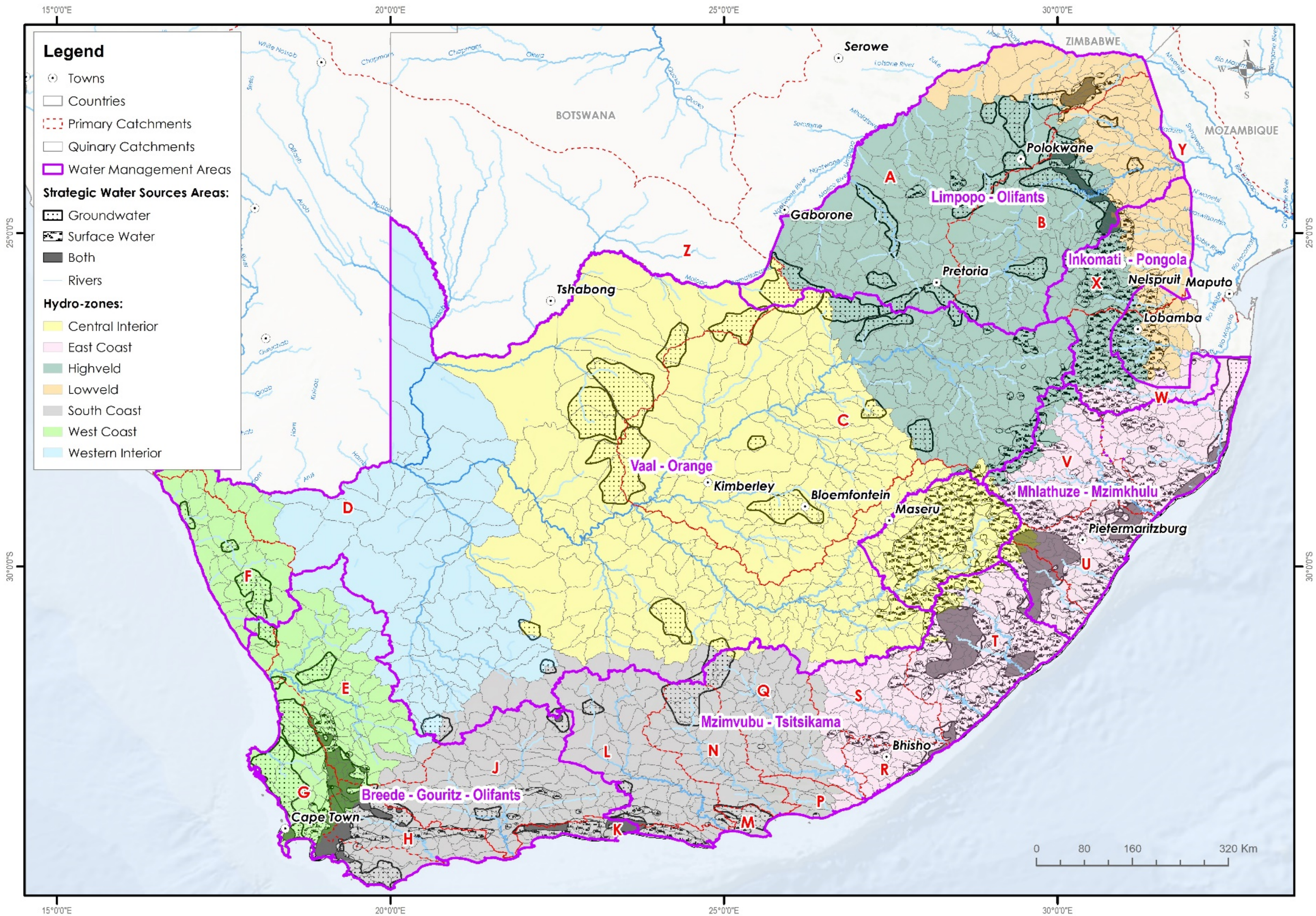


Figure 29: Final proposed homogeneous hydro-climatic zones, primary catchments (A - X), and strategic water source areas (SWSAs).

Table 5 (1-6): Summary of expected climate change impacts & potential climate change response actions for each hydro-climatic zone and water management area (WMA) in South Africa

Water Management Area (WMA) 1	Associated Hydro-climatic Zones	Associated Strategic Water Source Areas (SWSAs)	Expected Climate Change Projections	Proposed Climate Change Response Actions
Limpopo-Olifants	Lowveld & Highveld	Waterberg, Soutpansberg,Wolkberg	Decrease in precipitation in the south and north-east ranging between 2% to 6%, and in the north up to 16%. Increased uncertainty in rainfall projections. Reduced summer rainfall.	• Augment existing bulk water supply systems. • Promote water storage at household level. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation) • Ongoing/improved monitoring: rainfall, temperature, streamflow, and groundwater.
			Increased dryness of dry years.	• Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops
			Increase in summer temperatures ranging between ~1.4°C to ~2°C across the WMA by the mid-2030s, and increase in winter temperatures ranging between ~1.45°C to ~1.9°C.	• Reduce GHG emissions through improved energy efficient. • Increases areas where indigenous forests can serve as carbon sinks. • Implement NbS to capture carbon and reduce heating impacts. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants and prevent release into the atmosphere.
			Increased evaporation and crop requirements due to increased temperatures ranging between 7% to 10.5%	• Irrigate during cooler times during the day to reduce evaporative loss • Use of low flow irrigation systems (e.g., drip irrigation)
			Increased water uses and future water requirements (urban, industrial agriculture, domestic, energy, forestry, etc.).	• Implement new technologies to reduced water demand. • Implement water restrictions across all sectors, especially during periods of low water availability and based on seasonal forecasting. • Educate communities on the importance of conserving water.
			Increased uncertainty in streamflow.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Improved regulation and compliance with licences and EWRs.
			Increased variability of groundwater recharge with up to 30% increase in parts, and up to 40% decrease in others.	• Identify areas that may become flood zones and prevent development in these areas. • Increase woody vegetation to prevent areas becoming waterlogged under high rainfall • Remove non-indigenous vegetation in areas where groundwater levels will decrease • Application of NbS to improve natural storage of water
			Crop loss due to heat stress from increased temperatures and increased flooding, which results in food insecurity.	• Encourage farmers to plant drought resistant and heat tolerant crops. • Ensure adequate water storage and alternative water resources are available for use. • Ensure soils are sufficiently stabilised to prevent loss of crops from flooding.

Water Management Area (WMA) 2	Associated Hydro-climatic Zones	Associated Strategic Water Source Areas (SWSAs)	Expected Climate Change Projections	Proposed Climate Change Response Actions
Inkomati-Usuthu	Lowveld, Highveld & East Coast	Mpumalanga Drakensberg, Enkangala Grasslands, Mbabane Hills, Upper Usutu	Rainfall uncertainty, with projections indicating either a wetting or drying especially during the summer months.	• Ongoing rainfall monitoring to determine which areas are experiencing wetting & which are experiencing drying & combined with improved seasonal forecasting. • Use of low flow irrigation systems (e.g., drip irrigation) • Promote water storage at household level such as rainwater harvesting • Explore alternative and under-developed water resources
			Increased temperature ranging between~1.4°C to ~1.7°C. Increase in summer temperatures between ~4°C to ~5°C.	• Reduce GHG emissions through the use of energy efficient technologies. • Increases areas where indigenous forests can serve as carbon sinks. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants & prevent release into the atmosphere.
			Increased flooding events due to the likely increase of storm activity and more intense rainfall events.	• Identify new flood zones and prevent development at these locations. • Implement NbS (clearing of IAPs, wetlands, etc.) to reduce the impact of flooding.
			Increased temperatures, leading to increased evaporation	• Irrigate during cooler times during the day to reduce evaporative loss. • Use of low flow irrigation systems (e.g., drip irrigation). • Adapt water resources planning modes to account of higher rates of evaporation.
			Increased water use and water requirements (urban, industrial agriculture, domestic, energy, forestry, etc.).	• Implement new technologies with reduced water demand / requirements. • Implement water restrictions across all sectors during periods of drought. • Engage and educate communities on the importance of conserving water
			Projections indicate increased water scarcity due to likelihood of increased drying, especially in coastal areas.	• Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation) • Promote water storage at household and rainwater harvesting.
			Decreased streamflow during years with low and average flow and, dry years are projected to becoming even drier	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
			Variable groundwater recharge across the WMA	• Identify areas that may become flood zones and prevent development in these areas • Increase woody vegetation to prevent areas becoming waterlogged under high rainfall • Remove non-indigenous vegetation in areas where groundwater levels will decrease • Application of NbS to improve natural groundwater storage of water
			Wet years are projected to become and even wetter in places which could lead to an increased risk of flooding.	• Identify new flood zones, protect and prevent development at these locations. • Consider including flood operating rules for reservoirs and dams. • Improve urban stormwater including attenuation and water sensitive design principals. • Implement NbS to reduce the potential impact of flooding.

Water Management Area (WMA) 3	**Associated Hydro-climatic Zones**	**Associated Strategic Water Source Areas (SWSAs)**	**Expected Climate Change Projections**	**Proposed Climate Change Response Actions**
Pongola-Mzimkulu	Highveld & East Coast	Northern Drakensberg, Southern Drakensberg Enkangala Grasslands, Mfolozi Headwaters	Reduced rainfall ranging between 2% and 10%. Projected increases in the higher lying western areas.	• Implement critical water supply augmentation projects. • Explore alternative and under-developed water resources. • Promote water storage at household level such as rainwater harvesting. • Monitoring to determine which areas are experiencing wetting and/or drying. • Use of low flow irrigation systems (e.g., drip irrigation)
			Dry years are projected to becoming even drier	• Implement water restrictions during dry years • Encourage farmers to plants drought tolerant crops
			Wet years are projected to become even wetter in places Projections indicate a likely increase in summer rainfall, with increased occurrence of large events such as flooding.	• Identify new flood zones, protect and prevent development at these. • Improve urban stormwater including attenuation and water sensitive design principals. • Implement NbS to reduce impact of flooding. • Consider potential for updated operating rules for dams for flood management.
			Increased summer temperature between~1.1°C to ~1.4°C and winter temperatures ranging between 1.4°C to >1.9°C	• Reduce GHG emissions through the use of energy efficient technologies • Increases areas where indigenous forests can serve as carbon sinks
			Increase in temperatures due to proximity to the ocean	• Reduce GHG emissions through the use of energy efficient technologies • Increases areas where indigenous forests can serve as carbon sinks • Irrigate during cooler times during the day to reduce evaporative loss • Use of low flow irrigation systems (e.g., drip irrigation).
			Increase in streamflow up to 20% in the higher lying west.	• Modelling of new expanded flood zones. • Ensure adequate soil stabilisation in expanded flood zones.
			Decrease in streamflow along the coast and the interior.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops. • Increased regulation of licence conditions and protection of EWRs and ROQs.
			Variable groundwater recharge across the WMA.	• Remove non-indigenous vegetation in areas where groundwater levels will decrease. • Application of NbS to improve natural storage of water. • Increased monitoring of groundwater levels and abstractions.
			5 to 8% increase in evaporation across the WMA.	• Use of low flow irrigation systems (e.g., drip irrigation). • Incorporate increased evaporation into water resources planning models.
			Crop loss due to heat stress from increased temperatures and increased flooding, which results in food insecurity.	• Encourage farmers to plant drought resistant and heat tolerant crops • Ensure adequate water storage and alternative water resources are available. • Ensure soils are sufficiently stabilised to prevent loss of crops from flooding.

Water Management Area (WMA) 4	Associated Hydro-climatic Zones	Associated Strategic Water Source Areas (SWSAs)	Expected Climate Change Projections	Proposed Climate Change Response Actions
Vaal-Orange	Central interior, Western interior, Highveld	Upper Vaal, Maloti Drakensberg, Northern Drakensberg, Southern Drakensberg. Eastern Cape Drakensberg	High uncertainty in future rainfall, with possible wetting or drying in the summer months. Precipitation is projected to decrease in the range of 2% to 6% in the south and north-east, with reductions of up to 16% in the northern parts.	• Implement water supply augmentation projects and improved operation. • Promote water storage at household level such as rainwater harvesting. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation). • Implement catchment management activities to reduce erosion and sedimentation.
			Dry years are expected to become drier.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
			Increase in summer temperatures of ~1.1°C to >1.8°C. Increase in winter temperatures of <1°C to >1.8°C.	• Reduce GHG emissions through the use of energy efficient technologies. • Increase areas where indigenous forests can serve as carbon sinks. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants and prevent release into the atmosphere.
			Increased risk of flooding due to the likely increase of storm activity and more extreme rainfall events.	• Identify new flood zones and prevent development at these locations. • Increase woody vegetation to reduce the limit of the area of impact. • Implement catchment management activities to reduce erosion and sedimentation
			Increased water requirements (urban, agriculture, domestic, industrial, mining, energy etc.)	• Implement new technologies with reduced water demand / requirements. • Implement water restrictions across all sectors during periods of low water availability. • Engage and educate communities on the importance of conserving water.
			Increased water scarcity due to likelihood of increased drying, especially in the western and coastal areas.	• Implement critical water supply infrastructure and real time operational systems. • Ongoing rainfall monitoring to determine trends and seasonal forecasting. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation) • Promote water storage at household level such as rainwater harvesting • Explore alternative and under-developed water resources
			Decreases in streamflow ranging between 20% and 30%.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
			Increases in streamflow for the Vaal Catchment part of the WMA indicate increases of up to 25%.	• Modelling of new expanded flood zones • Ensure adequate soil stabilisation in expanded flood zones
			Uncertainty of groundwater recharge projections with some areas indicating potential decrease and other areas likely to experience a potential increase in recharge.	• Increased monitoring of groundwater levels and abstractions. • Remove non-indigenous vegetation in areas where groundwater levels will decrease. • Application of NbS to improve natural storage of water and protect recharge areas.

Water Management Area (WMA) 5A	Associated Hydro-climatic Zones	Associated Strategic Water Source Areas (SWSAs)	Expected Climate Change Projections	Proposed Climate Change Response Actions
Mzimvubu-Tsitsikamma	East coast, South coast	Eastern Cape Drakensberg, Amathole, Tsitsikamma,Kouga	Decreases in rainfall in the order of 4% to 6% in the north-east and the southern half of the WMA, and Variable driest year in year rainfall projections, with some areas indicating increases and others decreasing in the order of 10%.	• Implement critical water supply augmentation options. • Improved operational efficiencies of existing integrated bulk water systems. • Promote water storage at household level such as rainwater harvesting. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation).
			Increased summer rainfall in the western parts. Increases in rainfall in the north parts of 4%-8%. Increased wet year rainfall and increased spatial coverage.	• Identify new flood zones, protect and prevent development at these locations. • Rehabilitate and protect wetlands and remove IAPs from riparian areas. • Increase vegetation coverage to reduce the impact of flooding. • Improved catchment management to reduce erosion and sedimentation risks. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants and prevent release into the atmosphere.
			Increased summer temperatures of ~1.0 to 1.8°C.	• Reduce GHG emissions through the use of energy efficient technologies • Increases areas where indigenous forests can serve as carbon sinks
			Potential increase in extreme rainfall events and flooding.	• Identify new flood zones, protect and prevent development at these locations. • Improved urban stormwater management systems and water sensitive design (WSD). • Encourage rainwater harvesting in urban and rural areas.
			Increased water shortages and droughts, due to demand exceeding available yield and more variable rainfall.	• Promote water storage at household level such rainwater harvesting • Explore alternative and under-developed water resources such as desal and re-use. • Implement restrictions during droughts and improve use of seasonal forecasting. • Use of low flow irrigation systems (e.g., drip irrigation).
			Increased mean annual streamflow of between 5% to 15% in coastal areas, and 25% to 40% in mountainous areas.	• Modelling of new expanded flood zones. • Ensure adequate soil stabilisation in expanded flood zones.
			Some areas indicating a potential for decreases in mean annual streamflow raining between 10% to 30%.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops. • Improved monitoring and compliance with licences and protecting of EWRs.
			Variable groundwater recharge with some areas indicating 30% to 35% increase and other areas indicating decrease.	• Remove non-indigenous vegetation in areas where groundwater levels will decrease • Application of NbS to improve natural storage of water and protect recharge zones. • Improved monitoring of groundwater level and abstraction.

Water Management Area (WMA) 5B	Associated Hydro-climatic Zones	Associated Strategic Water Source Areas (SWSAs)	Expected Climate Change Projections	Proposed Climate Change Response Actions
Mzimvubu-Tsitsikamma	East coast, South coast	Eastern Cape Drakensberg, Amathole, Tsitsikamma,Kouga	High exposure to flooding in rural and tribal areas.	• Educate locals on flood zones within rural and tribal areas • Identify flood zones in rural and tribal areas and including safe zones. • Ensure adequate storage of roof runoff to prevent flooding and water logging. • Improve vegetation cover to absorb rainfall during high intensity events. • Develop flood early warning systems (EWS) and advanced warning for communities.
			Loss of agricultural crops and fertile soil due to flooding.	• Ensure soil stabilisation by planting annual indigenous vegetation. • Create barriers to slow surface runoff.
			Crop loss due to heat stress from increased temperatures and increased flooding, which results in food insecurity.	• Encourage farmers to plant drought resistant and heat tolerant crops • Adequate water storage and alternative water resources are available for use. • Ensure soils are sufficiently stabilised to prevent loss of crops from flooding.
			Increased evaporation from 5% to 9%.	• Irrigate during cooler times during the day to reduce evaporative loss. • Ensure increased evaporation is including in water resources and planning models. • Use of low flow irrigation systems (e.g., drip irrigation).

Water Management Area (WMA) 6A	Associated Hydro-climatic Zones	Associated Strategic Water Source Areas (SWSAs)	Expected Climate Change Projections	Proposed Climate Change Response Actions
Breede- Olifants	South coast, West coast, Western interior	Groot WinterhoekTable Mountain, Boland, Langeberg, Swartberg, Outeniqua	Increased summer temperatures from ~0.8°C to 1.8°C and, increased winter temperatures from ~0.7°C to 1.3°C.	• Reduce GHG emissions through the use of energy efficient technologies. • Increases areas where indigenous forests can serve as carbon sinks. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants and prevent release into the atmosphere.
			Potential change in rainfall seasonality, with a possibility of winter rainfall extending into other seasons and increase in extreme events that affect vulnerable communities.	• Improved modelling of seasonal regimes under climate change. • Modification of planting season and crops to account for changes in the growing season. • Ensure increased water storage is available to capture additional available water.
			Increased risk of prolonged droughts due to rainfall uncertainty and failure of expected rainfall return times.	• Implement critical water supply infrastructure and improved operational efficiencies. • Explore alternative and under-developed water resources such as re-use and desalination. • Promote water storage at household level such as rainwater harvesting. • Use of low flow irrigation systems (e.g., drip irrigation) and smart technologies. • Improved water use efficiency across all sectors (Urban and industrial). • Implement restrictions during periods of drought and improve seasonal forecasting. • Engage and educate communities on the importance of conserving water.
			Increased temperature and increased evaporative losses.	• Irrigate during cooler times during the day to reduce evaporative loss. • Use of low flow irrigation systems (e.g., drip irrigation).
			Decreased streamflow in the Breede system up to 30%.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation to increase surface runoff to streams. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
			Increased streamflow in the Gouritz system up to 30%.	• Modelling of new expanded flood zones. • Ensure adequate soil stabilisation in expanded flood zones.
			Decreased groundwater recharge in west and south-east.	• Remove non-indigenous vegetation in areas where groundwater levels will decrease. • Application of NbS to improve natural storage of water. • Improved monitoring of groundwater levels and abstraction.
			Increased groundwater recharge in the north-east.	• Identify areas that may become flood zones and prevent development in these areas. • Increase woody vegetation to prevent areas becoming waterlogged under high rainfall. • Application of NbS to improve natural storage of water.

Water Management Area (WMA) 6B	Associated Hydro-climatic Zones	Associated Strategic Water Source Areas (SWSAs)	Expected Climate Change Projections	Proposed Climate Change Response Actions
Breede- Olifants	South coast, West coast, Western interior	Groot WinterhoekTable Mountain, Boland, Langeberg, Swartberg, Outeniqua	Streamflow decreases in the Berg system 20% to 60%.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years and improve operational efficiency. • Encourage farmers to plants drought tolerant crops.
			Reduced baseflow contributions during the dry season due to decreased groundwater availability and IAP impacts.	• Promote water storage at household level such as rainwater harvesting. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation). • Removal of alien vegetation in catchment areas and replace with indigenous vegetation.
			Increased evaporative losses in the order of 6% to 10%.	• Ensure evaporation losses are updated in water resources planning models. • Irrigate during cooler times during the day to reduce evaporative loss. • Use of low flow irrigation systems (e.g., drip irrigation).
			Infrastructure damage due to increased flooding.	• Reinforce infrastructure based on updated design flood and rainfall models. • Integrate NbS to reduce the impact of flooding on grey infrastructure. • Implement required additional infrastructure for flood protection. • Allow room-for the river in areas likely to experience repeated flooding impacts.

2.6 Climate Change Scenarios for Water & Sanitation

2.6.1 Increasing Climate Change Risk & Vulnerability in Africa

Much of Africa, including Southern Africa, will be impacted by climate change (Figure 30) and is considered to be particularly vulnerable to the impacts of climate change largely due to limited financial capacity to adapt to the impacts of climate change. According to the Notre Dame Global Adaption Initiative (ND-GAIN) index, South Africa is currently ranked 96 out of 182 countries in terms of their vulnerability to climate change and their preparedness for adaptation and to enhance resilience. The worst performing indicators for South Africa are the projected change of cereal yields, agriculture capacity and dam capacity in terms of the low level of average storage capacity per capita, despite South Africa having several large dams.

This vulnerability is reflective of South Africa having one of the lowest rates of per capita runoff and without the large rivers that can provide significant storage including in countries such as Zimbabwe and Zambia which has fewer dams, but a few very large dams on the Zambezi.

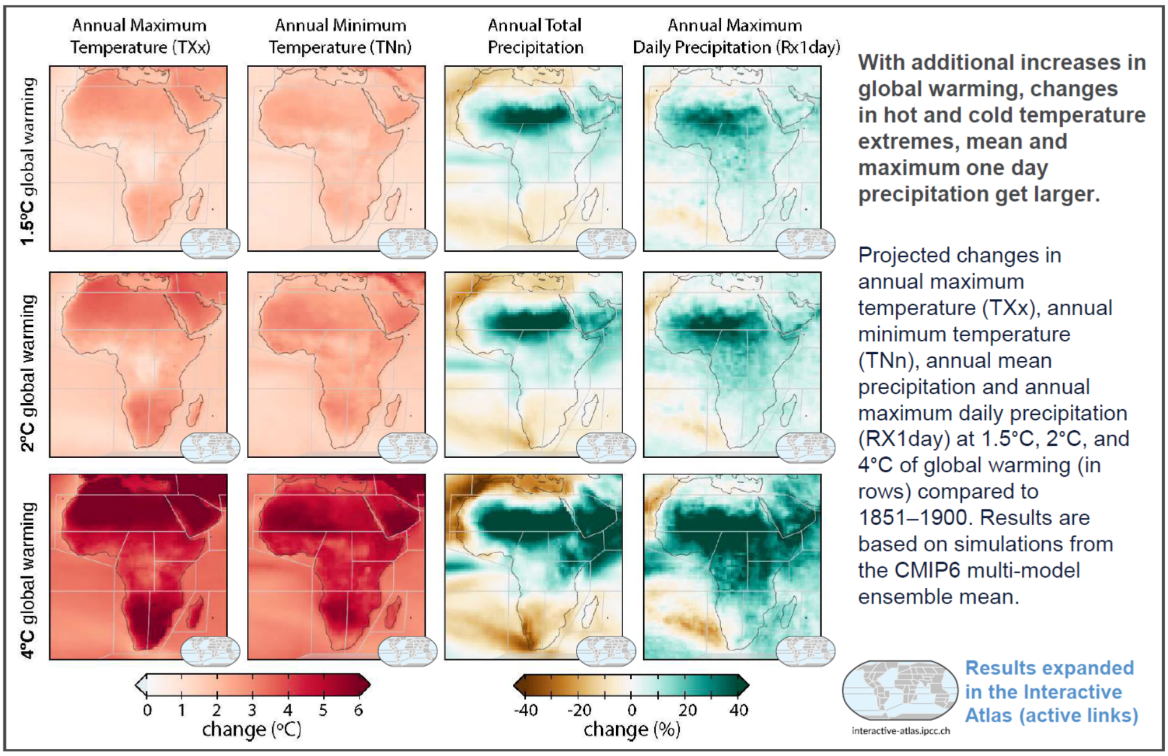


Figure 30: Increasing Climate Change Risks for Africa (IPCC, 2022)

2.6.2 Latest Global Climate Change Scenarios for South Africa

The latest climate change scenarios from the IPCC 6th Assessment Report (Figure 31), indicate an increase in average temperature from around 18.54 °C to a median value of between 18.89 °C and 23.37 °C for South Africa by 2100 depending on the resulting global emission scenarios, but with much hotter temperatures expected in the north and inland areas and cooler by the coast.

There is a similar significant increase in the number of very hot days.
Overall, there is an expected small decrease in precipitation nationally, but with significant spatial variability as shown in Figure 32. The eastern half of the country is expected to see an overall increase in mean annual precipitation, while the western half, and in particularly the southwest is expected to experience drying. It is also expected that the number of very hot days and the maximum daily rainfall will increase across almost all of the country which suggests and increased risk of flooding and there will be increased variability in precipitation contributing to more droughts. In contrast, there is an expected significant increase in the maximum daily rainfall over most of the country, but particularly over the eastern half.

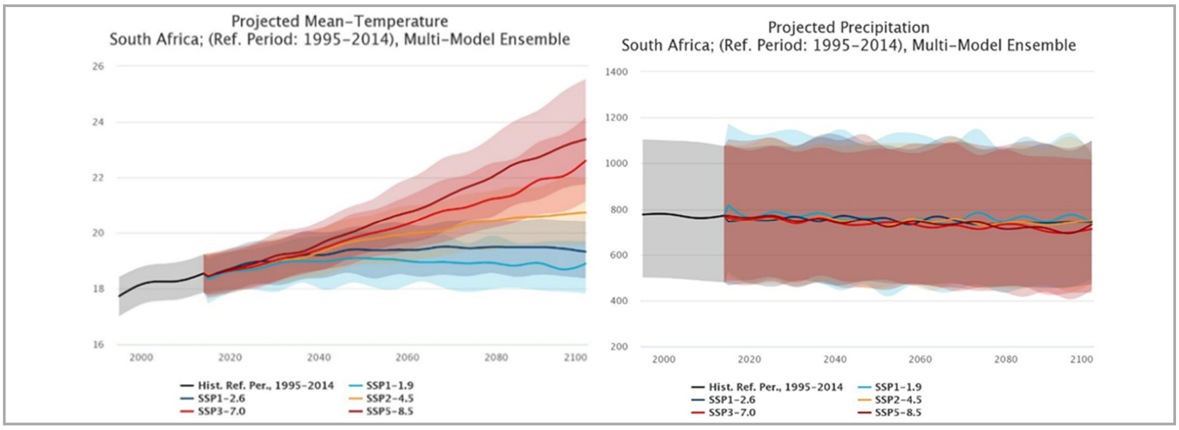


Figure 31: CIMP6 projected changes in mean temperature & mean annual precipitation for South Africa.

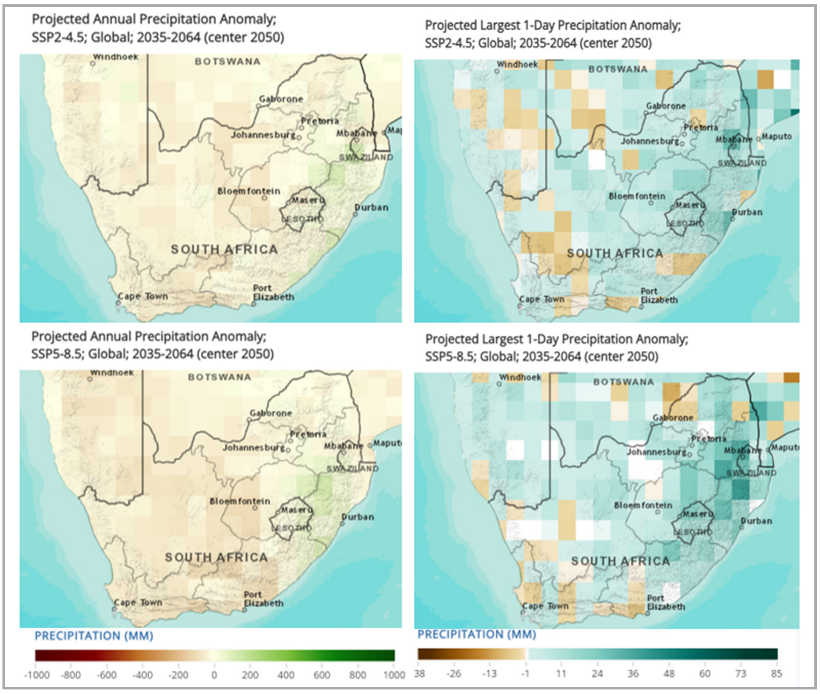


Figure 32: Projected change in average annual precipitation (left) and largest 1 day rainfall (right) under two different global emission scenarios for the period 2035-2064 across South Africa (Source: CCKP).

2.6.3 Downscaled Climate Change Scenarios for South Africa

To date there has been no work on downscaling the latest CIMP 6 data, and the currently available downscaled climate scenarios, such as those used in the CSIR Greenbook and described below are based here to see how these compared to the available downscaled climate scenarios and analysis relevant for each of the different hydro-climatic zones. High resolution (8km x 8km) downscaled climate scenarios have been produced for South Africa and are presented in the CSIR Greenbook (www.greenbook.co.za) for the CMIP5 RCP4.5 and RCP8.5 climate scenarios. The median value for key variables by 2050 as shown in Figure 33.

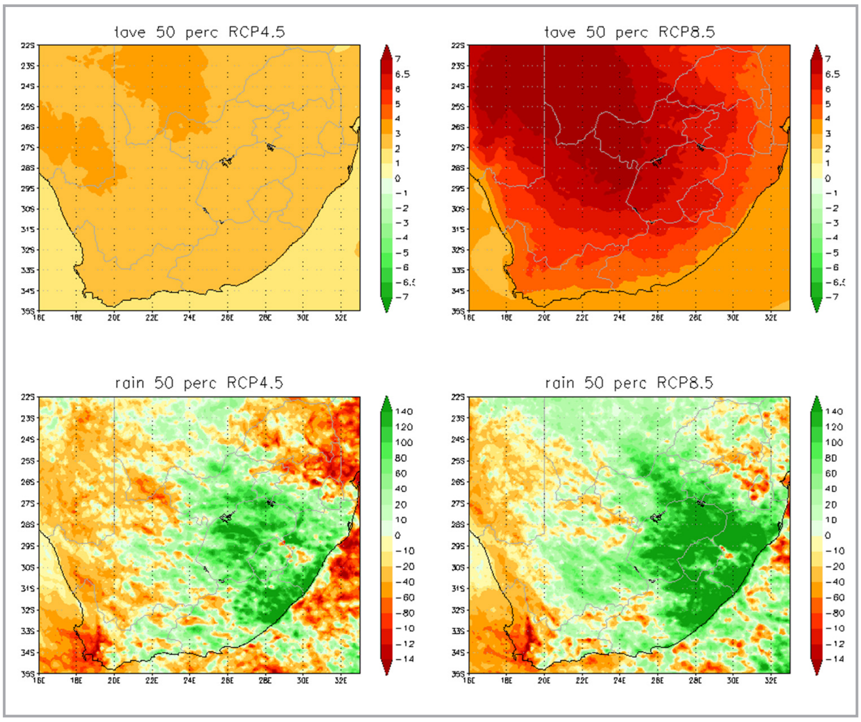


Figure 33: Summary of downscaled climate change scenarios for South Africa (Source: CSIR Greenbook)

The CSIR climate scenarios are derived using the Conformal Cubic Atmospheric Model (CCAM) regional climate model from six GCMs considered to be representative of the local South African climate conditions (Engelbrecht, 2019).

The six GCMs used in the CSIR projections are the following:

1. Australian Community Climate and Earth Systems Simulator (ACCESS1-0)
2. Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3)
3. National Centre for Meteorological Research Coupled Global Climate Model v 5 (NRM-CM5)
4. Max Plank Institute Coupled Earth System Model (Mpi-ESM-LR)
5. Norwegian Earth System Model (NorESm1-M)
6. Community Climate System model (CCSM4)

The CCAM model's ability to realistically simulate present day Southern African climate has been extensively demonstrated (Engelbrecht et al, 2015). An important feature of the downscaling done by CSIR was that the model was forced with bias-corrected sea-surface temperatures (SSTs) and sea-ice fields from the GCMs (Katzfey et al., 2009). In addition, a simple monthly scale mean bias-correction procedure was also applied using average monthly temperature and rainfall. The daily minimum and maximum temperatures were also bias corrected using a similar procedure as these impact on changes in evaporation and runoff.

These detailed downscaled scenarios have been used to make provisional estimates on the likely impact of climate change on water security for all municipalities across South Africa as part of the Greenbook (Cullis and Philips, 2019) as well as in a recent study by the Water Research Commission (Schutte et al, 2022) to produce downscaled climate scenarios for hydrological impacts in RSA at the scale of individual quinary catchments in the next Section.

2.6.4 Impact on Surface Water Availability

Several studies have looked at the potential impacts of various climate change scenarios on surface water runoff and availability across the country. The most recent downscaled climate scenarios were also averaged at quaternary catchment scale and used to derive estimates of the potential impact on precipitation and runoff and used to undertake a first order estimate of the potential impact on future water security for the Greenbook (Cullis et al, 2019). The results from the six different climate models were used to derive an estimate of the mean and 10th (dry) and 90th (wet) percentile scenarios for changes in mean annual runoff at quaternary catchment scale by 2050 (see figures below) as well as for mean precipitation and evaporation.

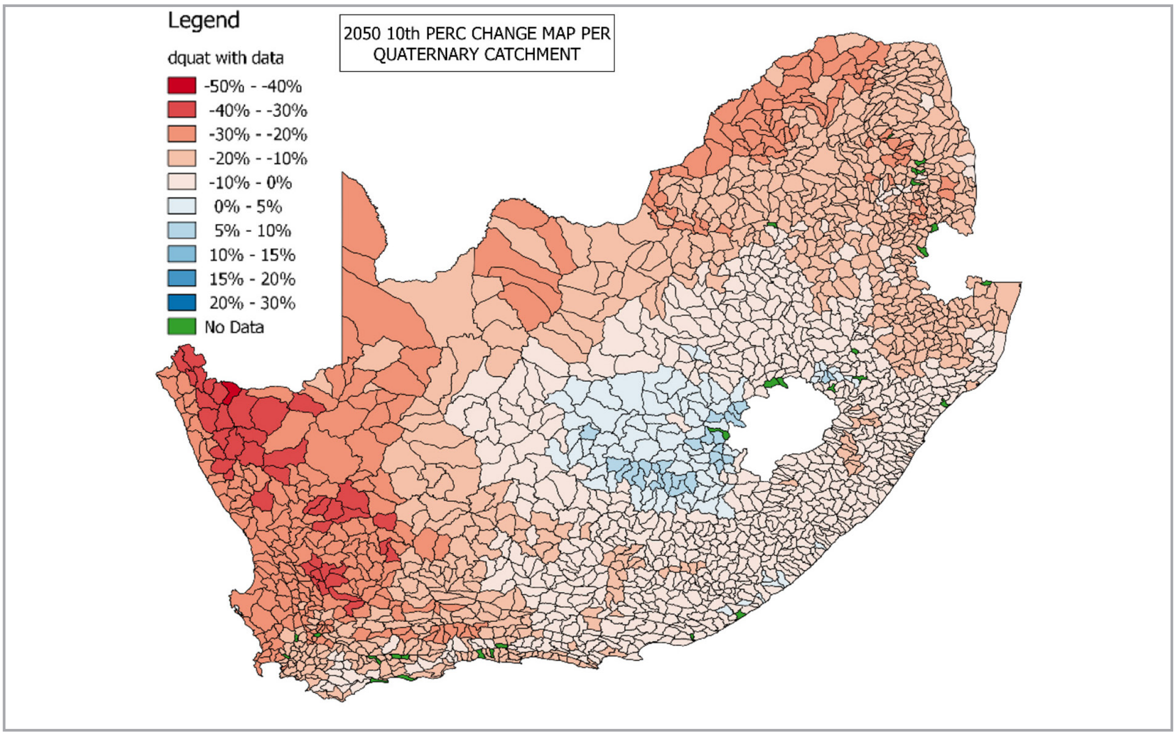


Figure 34: 2050 10th (dry) percentile change in MAP (Source: Cullis et al., 2019)

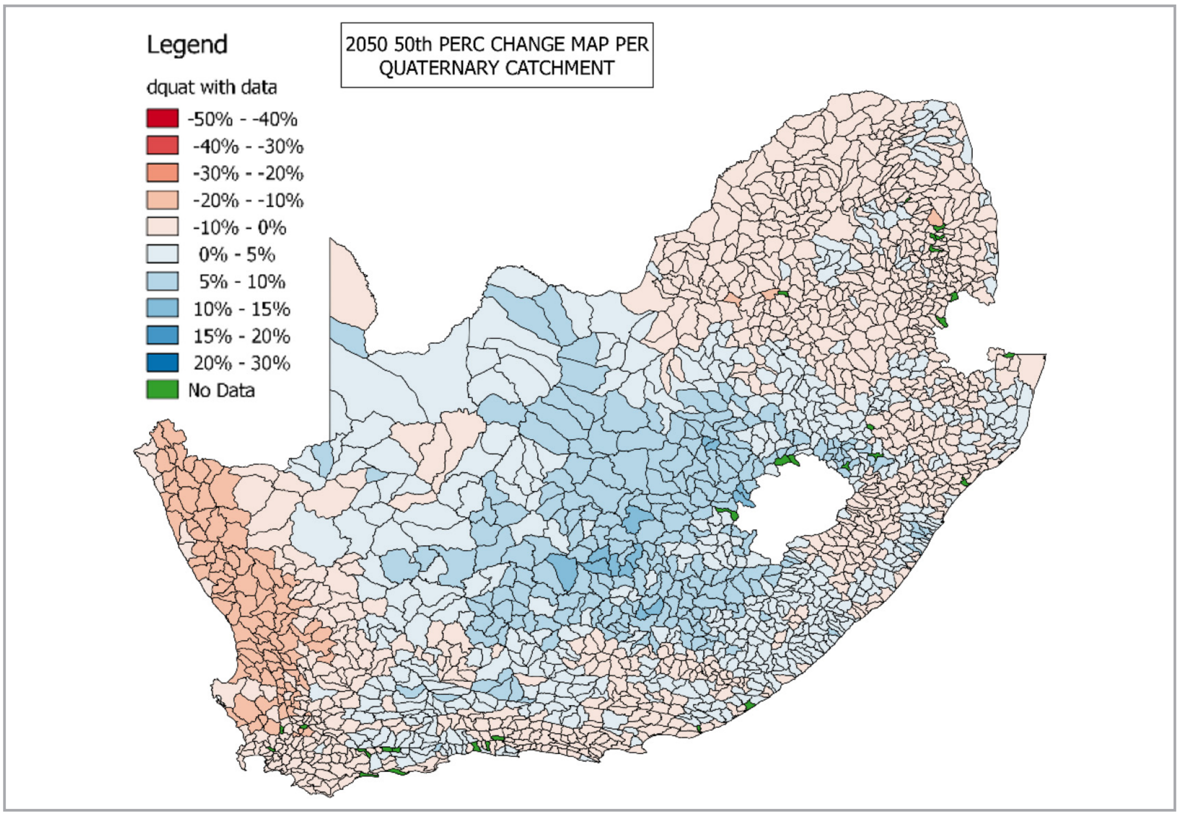


Figure 35: 2050 50th (median) percentile change in MAP (Source: Cullis et al., 2019

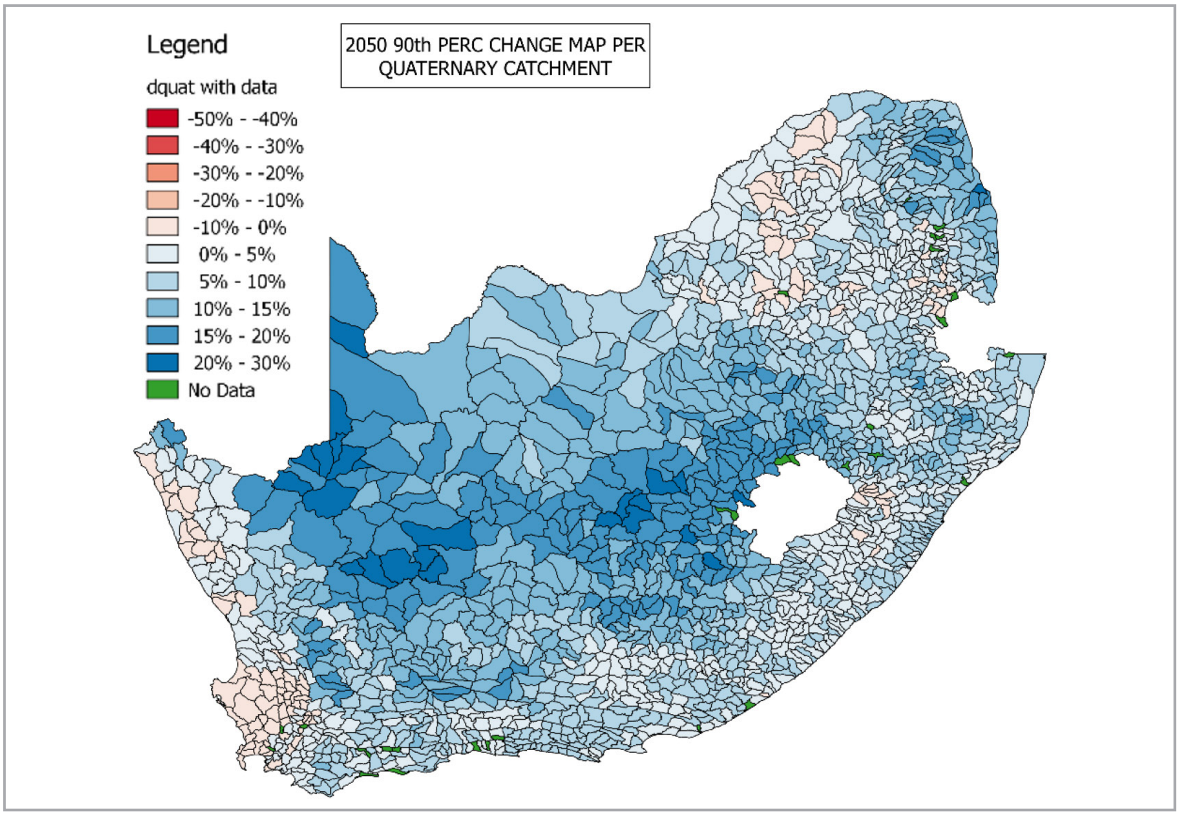


Figure 36: 2050 90th (wet) percentile change in MAP (Source: Cullis et al., 2019)

A recent study by the Water Research Commission (WRC K5/2833) undertook additional downscaling of the CSIR climate scenarios and hydrological modelling using ACRU to determine potential climate change impacts on the hydrological yield of different hydro-climatic zones in South Africa (Schutte et al, 2021). This study considered the resulting daily climate simulations for both RCP 4.5 and RCP 8.5 but was only able to undertake further analysis on the RCP 8.5 scenario. This additional analysis included additional downscaling and bias correction of daily rainfall and temperature projections at quinary catchment scale across the whole of South Africa and including Lesotho and eSwatini (Figure 37). The resulting daily climate scenarios where then combined with an updated ACRU database of natural and current day land cover types to produce daily time series data for not only precipitation and temperature but also potential (PET) and actual evapotranspiration (ET). These where then used to determine the likely impact on daily catchment runoff, accumulated streamflow, design streamflow events representing both high and low flow conditions, soil water drainage to groundwater, baseflow and hydrological yield under both natural and current land cover. While the results of the bias correction showed very little impact in terms of precipitation, there was significant difference in terms of bias correction for temperature. This is relevant in terms of the potential impact on evapotranspiration which impacts on streamflow as well as infiltration and the recharge potential for groundwater, as well as the impact on water demand.

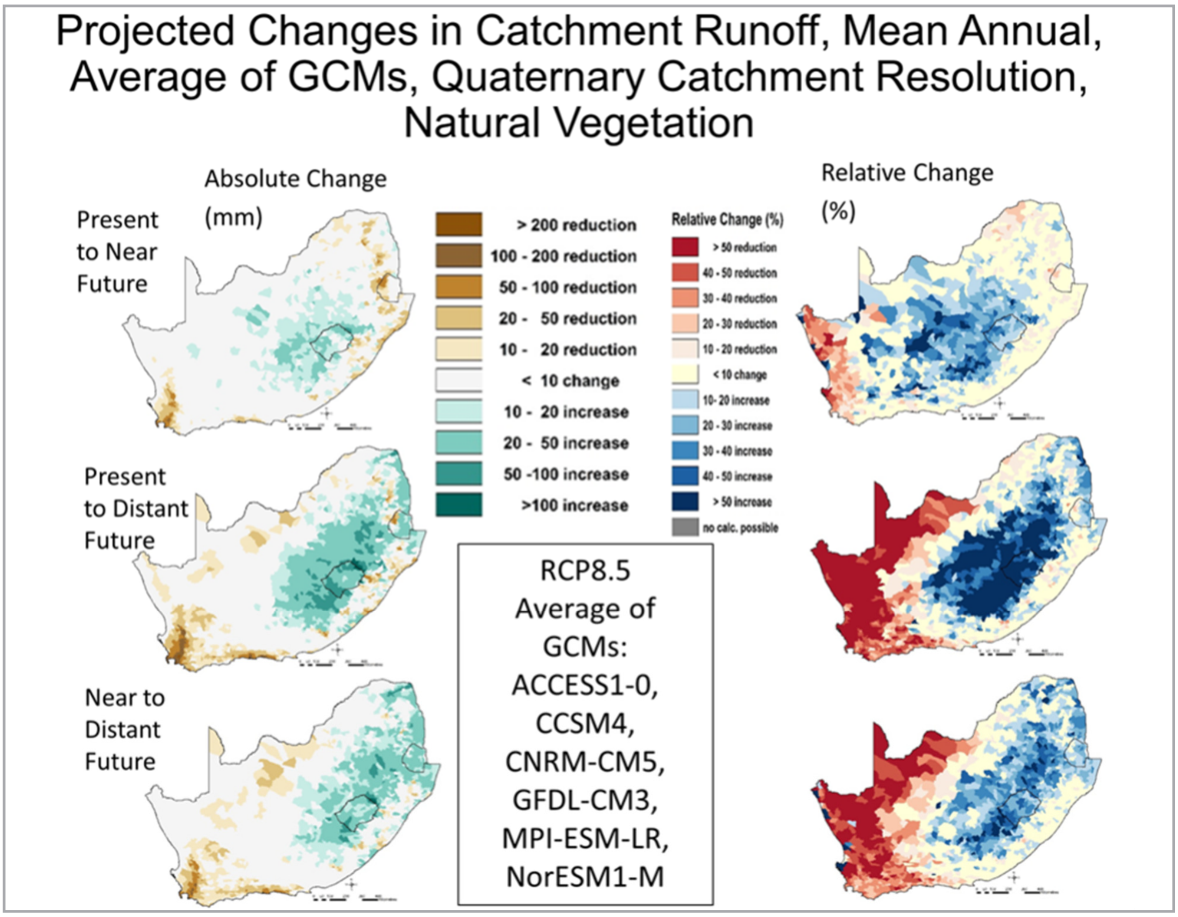


Figure 37: Projected absolute (mm) [left] and relative (%) [right] changes in mean annual individual Catchment runoff, from the present (1961-1990) to the near future (2015-2044) [top row], from the present to the distant future (2070-2099) [middle row] and from the near to the distant future (bottom row) (Source: Schutte et al, 20210).

2.6.5 Hybrid Frequency Distribution Climate Scenarios & Impacts

As an alternative to producing selected individual global climate models to downscale, a study undertaken in support of determining the economic impacts of climate change in South Africa (Cullis et al, 2015) and the Long Term Adaptation Scenarios (DEA, 2015) consider a hybrid frequency distribution (HFD) approach to evaluating climate change risk across a wide range of possible climate scenarios that was also then modelled in terms of the potential impact on surface water runoff as well as reliability of water supply taking into account the ability to manage and move water across the country with the integrated bulk water supply system (Cullis et al, 2015). The results of this study were used to assess the overall economic impacts of climate change and highlighted the critical importance of the integrated bulk water system.

The HFD approach considers to global emission scenarios, namely an unconstrained emission scenario (UCE) which is the equivalent to a low mitigation scenario such as SSP5-RCP8.5 and a Level 1 stabilisation (L1S) scenario which is representative of a lower emission scenarios equivalent to SSP2-RCP2.5. Figure 38 shows the range of possible impact (i.e., relative change) on MAP across each of the secondary catchments under the UCE scenario.

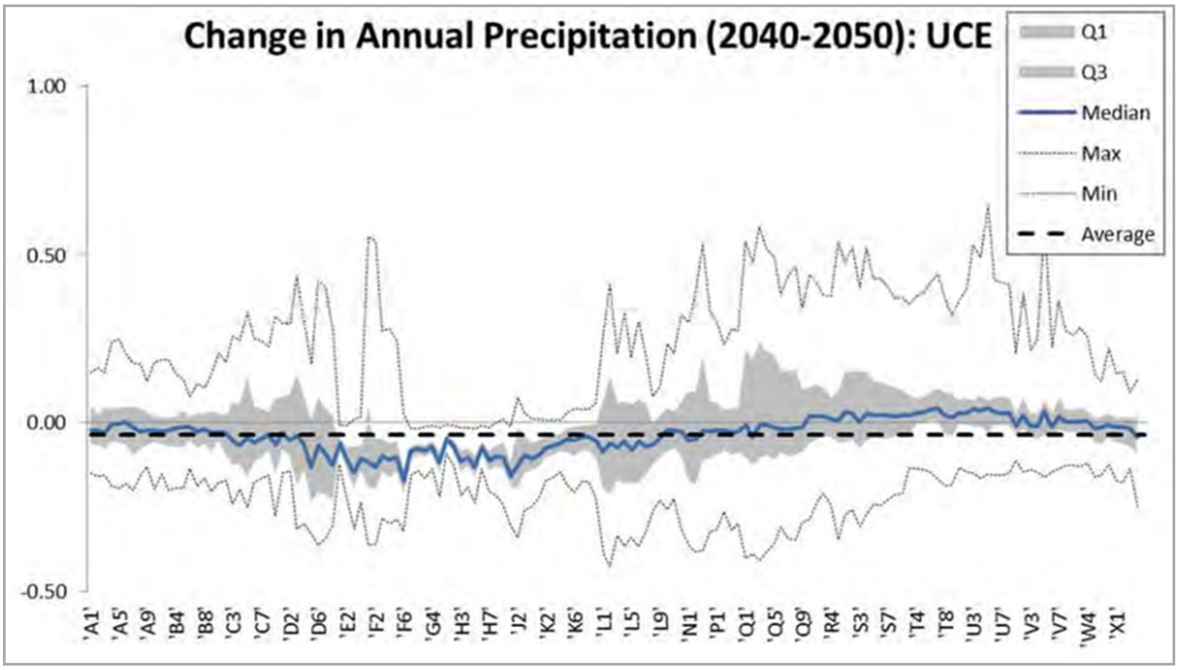


Figure 38: Range of possible impact of climate change on mean annual precipitation across all secondary catchments in South Africa under the UCE scenario for the period 2040-2050 relative to the base period. The solid line indicates the median value in each section.

The impact of the different climate change scenarios on surface water runoff was determined using the Pitman model (Pitman, 1973) at quaternary catchment scale across South Africa using existing calibrated Pitman parameters contained in Water Resources 2012 (WR2012) and used to generate monthly streamflow impacts at quaternary catchment scale for the two global emission scenarios (UCE and LS1). The Pitman model is a monthly rainfall-runoff model that is the standard for water resources planning in South Africa (Pitman, 2006; DWA, 2012) and is widely used for hydrological modelling across Southern Africa (Hughes et al, 2006).

The variation in the impact on the mean annual rainfall (MAR) across the country is shown in Figure 39 for the UCE scenario. These results show a reduction in streamflow for the western half of the country (D to K) particularly the Western Cape (F, G and H) where all the climate models show a reduction in streamflow. In contrast, there are some very large potential increases in runoff for the east coast (Q to W) which could result in increased flooding risks.

The impact of the L1S scenario in terms of reducing the potential risk for both large increases in catchment runoff and large reductions in catchment runoff becomes more obvious at the secondary catchment scale (Figure 40). While some models were showing the potential doubling in annual MAR in selected secondary catchments in the eastern half of the country, under the L1S scenario the additional risk is only half, but still shows possible increases up to 100% of the base scenario under some of the more extreme (but less likely) model results. The spatial variations are projected change in the median, 5th and 95th percentile of MAR by 2050 relative to the base period at secondary catchment scale. Results show that even under a very wet scenario there is still likely drying in the Western Cape.

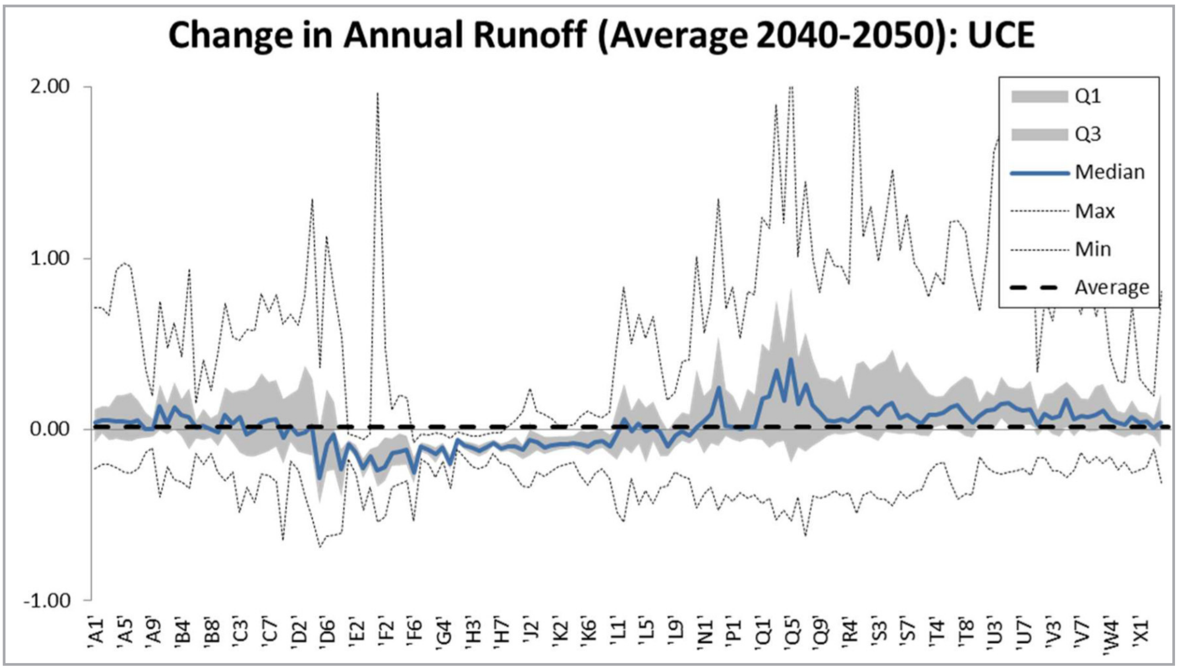


Figure 39: Range (i.e., mean, Q1, Q3, max and min) of potential impacts of climate change on the mean annual catchment runoff for all secondary catchments for the period 2040 to 2050 under the UCE scenario.

A comparison of HFD results for the change in the national average annual catchment runoff for the whole of South Africa resulting from the UCE and L1S scenarios relative to the base scenario for the period 2040 to 2050 is given in Figure 41.

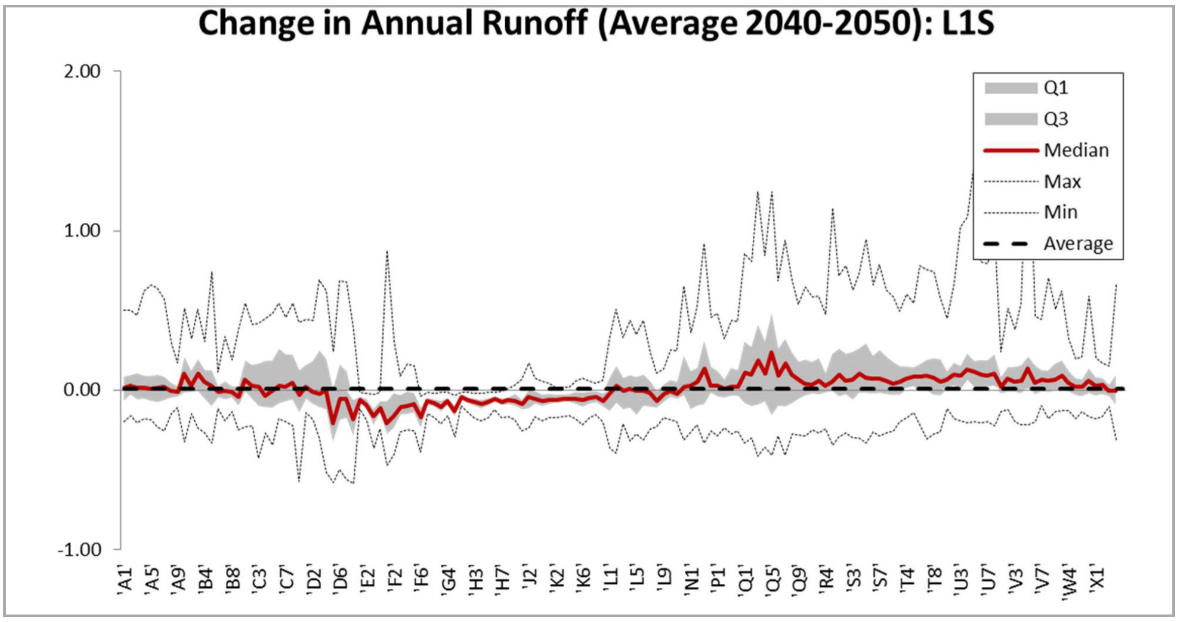


Figure 40: Range of potential impacts of climate change on the average annual catchment runoff for all secondary catchments for the period 2040 to 2050 due to the L1S scenario relative to the base scenario.

The results show that the median impact of the UCE scenario is an increase in the annual catchment runoff over the whole country of around 4.4% over the baseline, while the median impact of the L1S scenario is an increase in the total catchment runoff of only 2.6%. For both scenarios there is a wide range of potential impacts. The risk of extreme impacts at both ends of the spectrum (wet and dry) is significantly reduced under the L1S climate scenario. For the UCE scenarios, the potential impacts on total catchment runoff range from 13% reduction to a 48% increase, while under the L1S scenario the range is markedly smaller from a 10% reduction to a 30% increase.

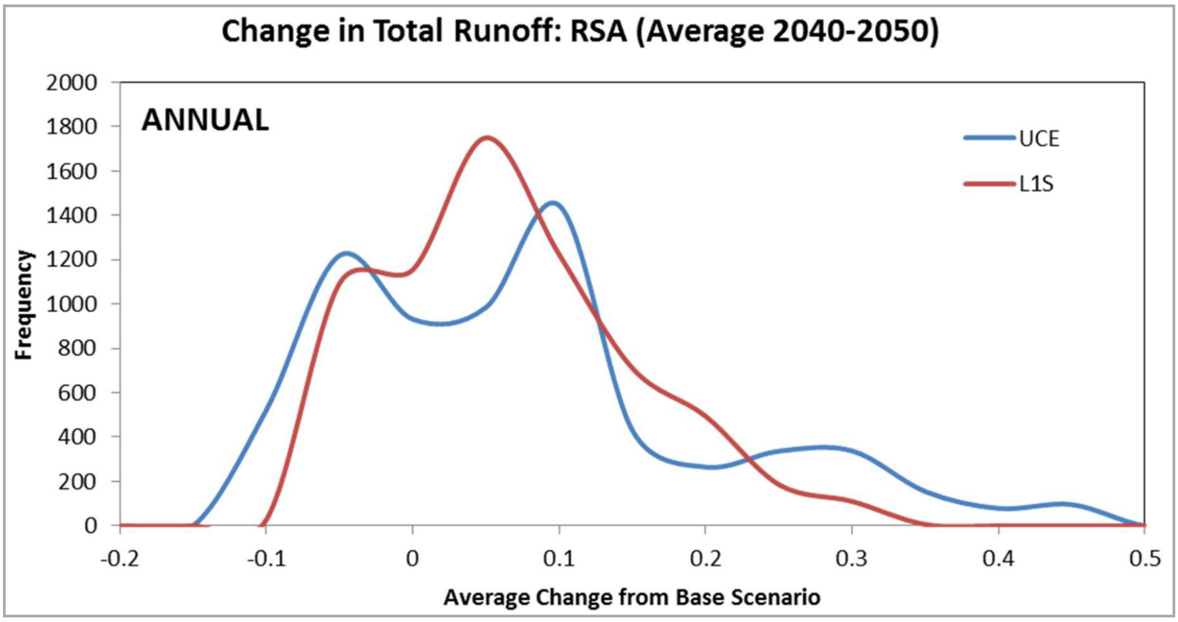


Figure 41: Hybrid frequency distributions (HFDs) of the impacts of the UCE and L1S climate scenarios on the national average annual catchment runoff for the period 2040-2050 relative to the base scenario.

The following general observations can be made based on these results for different catchments across South Africa that represent the different hydro-climatic zones:

Mokholo River: Even chance of increases and decreases in annual precipitation with the impact being most significant in the early part of the wet season (December and January).

Modder River: A general drying with only a few scenarios showing the potential for increases in annual runoff with the potential impacts relatively evenly spread during the year.

Berg River: All models show drying. The likely impacts are relatively consistent for each month, but the magnitude of the impact is greatest during the winter rainy season.

Koega River: A roughly equal chance of either wetting or drying with the median close to zero change in the MAR. The wettest scenarios show the greatest impact in April.

Mfolozi River: A greater possibility of wetting than drying, but still some dry scenarios are possible. The greatest impact is likely to occur in January showing a potential shift in the early period of the high flow season. There is a significant risk of increased flooding.

Sabi River: Possibility for increased runoff outside of current variability with the greatest impact being during the wetter months (December and January). As a result, there is an expected increase in the risk of flooding and greater variability in mean annual runoff (MAR).

2.6.6 Future downscaling of CMIP6 climate model projections

As noted above, the currently available downscaled climate change scenarios for South Africa are based on the CMIP 5 global climate model results. The CSIR and Wits Global Change Institute (GCI) are currently undertaking downscaling of the updated CMIP6 climate model results (Engelbrecht, pers. comm). However, these will require further downscaling and bias correction before they can be applied in terms of determining the potential impacts on water resources availability and supply in South Africa. The South African Weather Services (SAWS) have indicated their intention to also produce downscaled climate change scenarios for South Africa based on the latest CMIP6 global climate models. These downscaled scenarios, however, will still require further validation and bias correction to be used for hydrological modelling and to inform the improved climate resilience of critical water infrastructure.

3. CLIMATE CHANGE ADAPTATION & MITIGATION OPTIONS

3.1 Potential Adaptation Options for Water & Sanitation

Climate Change adaption options for water and sanitation should be put in place both through reducing vulnerability and improving resilience. In addition, adaptation can result in a variety of benefits, including increased agricultural productivity, innovation, health and well-being, food security, livelihood security, and biodiversity conservation, as well as risk and damage reduction (IPCC, 2022). A provisional list of adaptation possibilities based on an examination of observed climate adaptation responses in the literature and in applied practice include:

- Integrated Water Resources Management and Planning
- Implementing critical water and sanitation infrastructure
- Improved monitoring and decision support systems
- Diversification of water supply options
- Climate resilient water and sanitation systems
- Reducing Unaccounted and Non-Revenue Water
- Improved Water Use Efficiency in All Sectors
- Climate Smart Agriculture
- Innovative Sanitation Technologies and Solutions
- Ecosystem-based Adaptation
- Water Sensitive Cities and Urban Water Resilience

In addition to the list of general adaptation response options described below, there are several individual adaptation response actions that individuals or institutions can implement to reduce water security risks in the context of climate change. These are presented in various documents including the CSIR Greenbook, and a recent WRC Report (Schulze, et al, 2023). All adaptation response actions for water and sanitation in South Africa need to be considered in the context of the existing approaches to integrated water resources management practiced in South Africa recognising that any impacts of climate change are “superimposed” upon existing climate variability and water security challenges (Schultze, et al, 2023). The identification and implementation of adaptation responses for water and sanitation must also be developed and operate within the overarching guiding principles of the South Africa’s National Climate Change Adaptation Strategy (NCCAS).

These are that adaptation must:

- Be a country-driven approach
- Be based on the best available science and traditional knowledge
- Be participatory, with a bottom-up approach
- Be people-centred
- Be equity driven
- Be gender-responsive
- Be considerate of vulnerable groups
- Promote environmental support for climate adaptation
- Facilitate the mainstreaming of adaptation
- Be a continuous, progress and iterative process
- Support transformative change.

3.1.1 Integrated Water Resources Management & Planning

The Department of Water and Sanitation has recently initiated an update to the Reconciliation Plans for all the major bulk water supply systems in South Africa (Figure 42). These studies, combined with an update of the National Water Balances Study will update the underlying hydrology and demand projections, but also include the impacts of climate change. Previous studies have however already identified critical water resources infrastructure requirements for each of the main systems as well as for several smaller supply systems. These need to be urgently implemented as further delays in implementation further increase the water security risks and will make it even harder to adapt to further changes as a result of climate change.

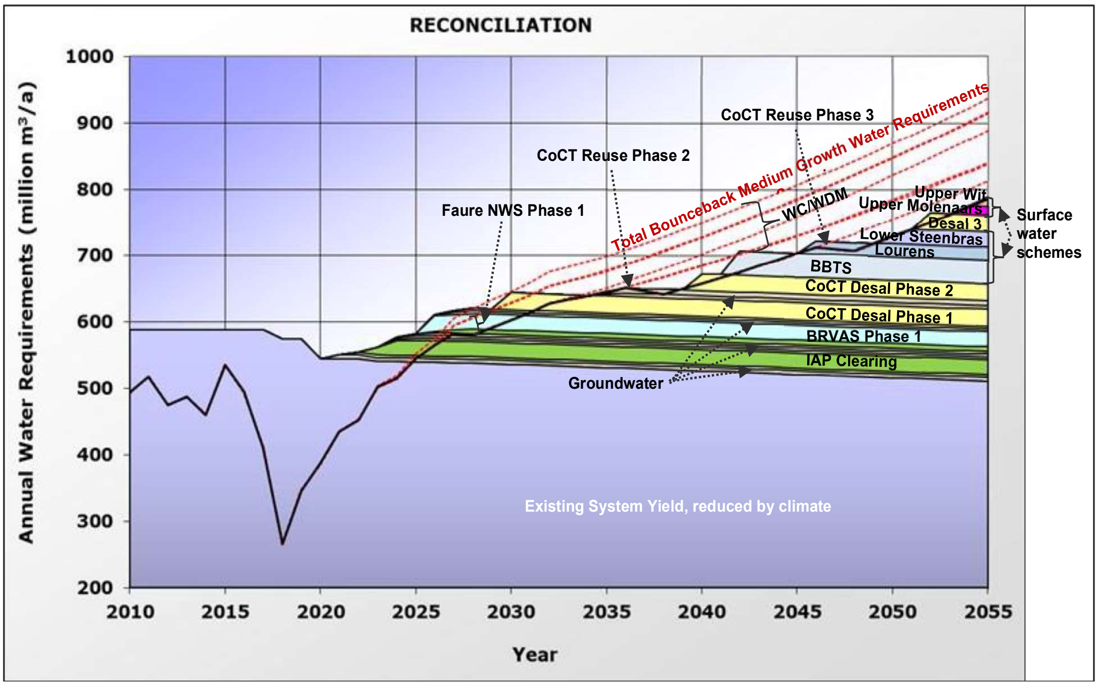


Figure 42: Updated reconciliation plan for the Western Cape Water Supply System (Source: DWS, 2022)

In addition to implementing identified water resources augmentation options as part of the updated Reconciliation Strategies and Plans, it is also necessary to consider additional enhancements to the way in which water resources are managed. This is based on the observation of increasing uncertainty in future climate scenarios and also considering water user behaviour change. Several potential changes to the approach to IWRM planning are being explored including an increase in the required level of assurance of supply for both urban and agricultural users, consideration of alternative approaches to water banking.

This is a critical area of research in terms of how to address the issue of over allocation of systems. The IWRM processes should also include activities related to watershed restoration and rainwater harvesting to further increase the water mix. As water is shared resource between many users (including environmental and anthropogenic) and should be managed in an integrated manner which allows minimisation of pollution from the source, community-based water resource management, collaboration with other stakeholders to implement large scale interventions. Interventions are costly and need to be implemented at large scale to yield impacts and tangible outcomes. In this way collaboration allows for sharing of costs and for maximised benefits for everyone.

3.1.2 Implementing Critical Water & Sanitation Infrastructure

Several critical water resources infrastructure requirements have already been identified through the water resources planning process implemented by the DWS. These have been identified as being necessary to meet growing water demands and in some cases are already accounting for changes in the available yield from existing systems possibly as a result of climate change. It is critical that these already identified infrastructure projects be implemented as further delays are not only increasing the risks, but they are also becoming more expensive.

Progress is currently underway with the development of the Lesotho Highlands Phase 2 Water Project and several projects including the uMkhomazi Water Project, the Berg River Voëlvlei Augmentation Scheme are undergoing final detailed design. Other critical projects such as the raising of Clanwilliam Dam, which is necessary due to dam safety concerns as well as to meet increasing demands and adaptation to climate change, and the Tzaneen Dam, are still delayed due to a lack of sufficient resources. Innovative public-private partnerships are however being considered to help with the implementation of some of these SIPs, including the Mokolo Crocodile Water Augmentation Project (MC-WAP) and the Vaal-Gamagara pipeline.

Top Priority Strategic Integrated Infrastructure Projects (SIPS)	**SIP no 19 includes the following Projects** • Vaal River System including Phase 2 of the Lesotho Highlands Water Project Gauteng • Phase 2A of the Mokolo Crocodile River (West) Augmentation Project: Limpopo • Olifants River Water Resource Development Project - Phase 2: Limpopo • Groot Letaba River Water Development Project - Nwamita Dam: Limpopo • uMkhomazi Water Project: KwaZulu Natal • Umzimvubu Water Project: Eastern Cape • Berg River Voelvlei Augmentation Scheme: Western Cape • Orange-Riet Canal Increase of Bulk Raw Water Supply: Free State • Rustfontein Water Treatment Works: Free State • Vaal-Gamagara scheme to improve water security for mines in Northern Cape • Rehabilitation of the Vaalharts-taung Irrigation Scheme: N.Cape & North West
	SIP No 19 will be reviewed & potentially augmented with the following priorities • Dam raising projects for Tzaneen & Clanwillian dams • Review need for projects in ensuring viability of municipal wastewater treatment plant, as done for Emfuleni • Expand Sundays Rover sub-system 7 other projects to service Gqeberha • Water supply augmentation for Mbombela, Mpumalanga

Figure 43: SIP No 19 list of water related projects in the national Sustainable Infrastructure Development Systems (SIDS).

3.1.3 Improved Monitoring & Decision Support Systems

Monitoring is essential for maintaining the long-term effectiveness of climate adaptation since it allows for improved planning and decision-making, as well as learning, accountability, and information gathering for reporting (IIED, 2018). Monitoring entails dealing with data, and the more data collected through monitoring, the better scientists will be able to forecast and predict our future (Coast Adapt, 2018; Hudson, 2022). As climate variability rises and historical patterns shift, this has become increasingly significant in the context of climate change (CTCN, 2022). Monitoring streamflow, for example, may be used to investigate the changing effects of climate change on water resources, as well as to better understand trends in natural hazards such as flash floods, to plan effectively and to determine if climate action is worsening or enhancing present and past situations (Dobriyal et al., 2017).

The fact that the number of stream gauges in South Africa, and globally, is decreasing, reducing monitoring, calibration and forecasting accuracy, is concerning. Since 1970, the number of stream flow gauging stations has decreased significantly across South Africa, and the country now has the same number of stations as it did in 1920 (Turton, 2016). “If this trend continues into the future, it will be a serious cause for concern,” writes (Pitman, 2011). While the importance of strengthening the surface and groundwater monitoring system has been identified as a priority in the NWRS, there continues to be a lack of investment in new monitoring systems, this despite a growing number of new technologies to improve monitoring.

Monitoring and information regarding climate change can only take users to a certain point, namely an understanding of current or potential future climate conditions. This data is then used to assess the impacts on specific areas or sectors of interest and to make decisions about appropriate adaptation or mitigation measures, which is where climate change adaptation decision support comes into play (Palutikof et al., 2019). As water authorities and decision-makers become more aware of the fact that hazards such as flooding result in significant loss of life, property damage, and environmental degradation, they are realising the importance of implementing early warning systems and decision support systems (SICE, n.d.).

As seen in Figure 44, early warning systems offer the highest benefit-cost ratio when used as an adaptation strategy. These early warning systems include detection, analysis, prediction, and broadcast of warnings, followed by decision-making and responses. Several initiatives are already underway to develop and implement in particular drought and flood early warning systems both by local municipalities, at provincial level, and by the South African Weather Servies which is improving its services to develop specific climate impact warnings.

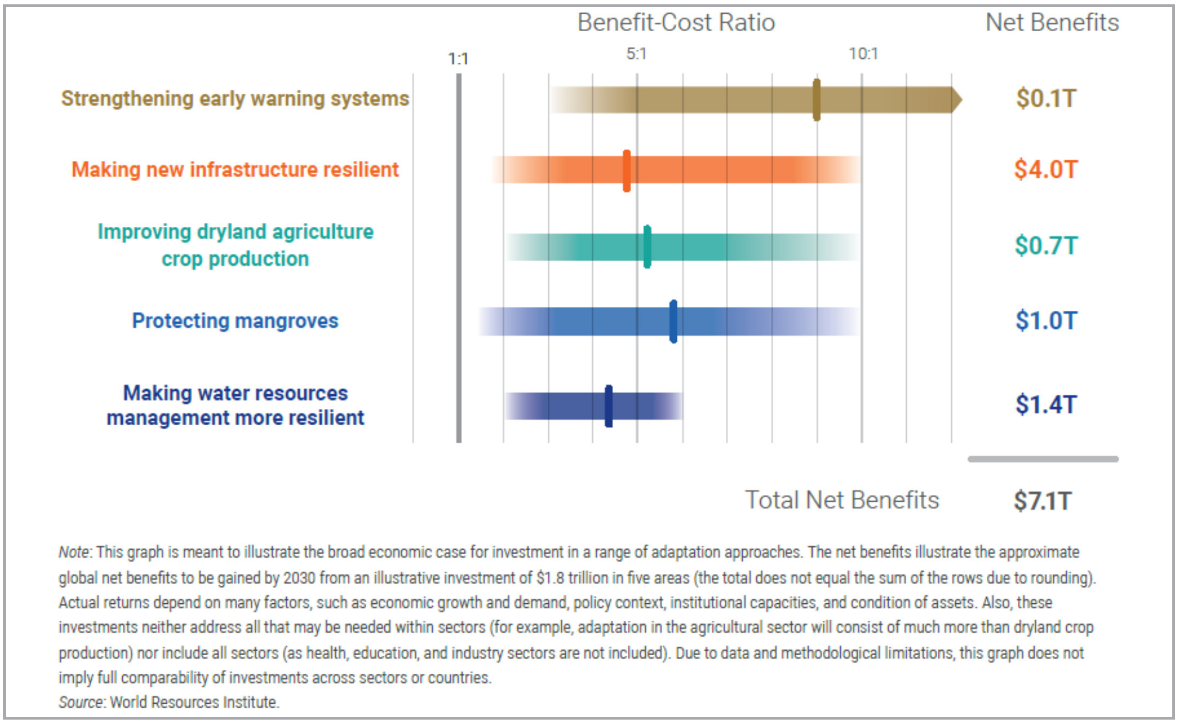


Figure 44: Estimated cost-benefit ratios for climate adaptation options (Source: GCA, 2019)

3.1.4 Diversification of Water Supply Options

South Africa has high levels of surface water impoundment and already allocates most available surface water for domestic and agricultural use. South Africa meets roughly 77% of its demand from surface water, 9% from groundwater and 14% from recycled water. Given the over-allocation of water in many catchments and a high reliance on surface water resources, the changing climatic conditions increases the risk of South Africa not meeting its water supply needs. To mitigate the associated risks, it is essential that South Africa diversifies its water sources for enhanced resilience and adaptation of the system. Unlocking alternative sources of water supply (including reuse, improved groundwater utilisation, desalination and harnessing of storm water) is key to this. Alternatives to freshwater resources as well as the potential for new technology should be explored. Rainwater harvesting, watershed restoration, water conservation, less water-intensive cropping, and the use of dry or very low-water-use sanitation systems, such as composting toilets and container-based sanitation, are only a few of the many sustainable water management adaptation options available (IPCC, 2022).

In addition to increasing the amount of water used from alternative sources such as desalination and re-use at a national level, individual water users and cities are also encouraged to diversify their own water supply mix, with the City of Cape Town for example looking to commit to 25% alternative water, which includes increased groundwater usage from both the shallow Cape Flats Aquifer as well as the deeper Table Mountain Group (TMG) aquifer, desalination and direct potable re-use. Other coastal cities such as eThekwini and Nelson Mandela Bay are also looking to develop desalination plants, while the City of Johannesburg is looking at options for improve water re-use as well as options for the treatment and re-use of water affected by pollution from Acid Mine Drainage (AMD). Several small towns across South Africa are looking to further developed groundwater supply options.

3.1.5 Reducing Unaccounted for Water & Non-Revenue Water

Unaccounted-for Water (UAW) is the difference between the quantity of water supplied to a network and the metered quantity used by customers, this is crucial because unaccounted water creates a barrier to sustainability through energy and water loss (Farouk et al., 2021). Unaccounted-for Water is made up of two main parts: physical losses due to leakages and administrative losses due to illegal water use. Physical losses are influenced by pipe network conditions, the amount of water used, system pressures and supply continuity. Administrative losses on the other hand are influenced by the failure to identify illegal water usage and damaged meter repairs (The World Bank Group, 2022). Thus, UAW could be reduced by maintaining infrastructure, managing pressures within the system, identifying/detecting leaks and by monitoring water use. Reducing UAW has various obvious benefits of which a higher water supply is most apparent. A World Bank Study estimates a physical water loss of 32 billion cubic meters per annum of which approximately 16 billion is lost in developing countries. To put this into perspective, if the losses in developing countries could be halved, approximately 90 million additional people could be supplied with water (Kingdom et al., 2016).

In South Africa, the most recent No-Drop Reports indicate that the average non-revenue water (NRW) across South Africa is around 47% (DWS, 2023), while the average water use efficiency (l/capita/day) is around 280 l/capita/day. Addressing the high levels of NRW which includes both physical losses, accounting losses and illegal access and use, is critical in terms of improving water use efficiency which will mitigate some of the potential impacts of climate change in terms of reduced water availability and also in terms of declining water quality.

The use of new digital technologies and smart water-metering solutions can also help in reducing unaccounted for water and physical losses. There are also innovative solutions to support improved operation and asset maintenance including public-private partnerships, performance-based contracts (PBC) that contribute both financing and expertise to assist in addressing current water and sanitation management challenges particularly at local level.
Reducing the level of UAW and NRW, will also help in reducing the cost of water supply as it will reduce, or at least postpone the need for expensive augmentation options and it will also benefit in terms of reducing the overall carbon footprint of the water and sanitation sector.

3.1.6 Climate Smart Agriculture & Improved Irrigation Efficiency

In many smallholder farming systems, agricultural intensification (including mixed cropping, mixed farming, little soil disturbance, and mulching) remains a critical response option for ensuring food security for Africa's expanding population (Nziguheba et al., 2015). It is necessary to identify suitable areas for urban agriculture, as well as adjusting to more sustainable agricultural activities such as changing unit crop management decisions, according to Howden et al. (2007). Adjusting crop selections, planting times, or the size, variety, and location of planted areas are all examples of improved crop management (Altieri et al., 2015). Adaptation options include changing inputs such as varieties with more appropriate thermal thresholds and vernalisation requirements and/or increased resistance to heat shock and drought, changing fertiliser rates and amounts, and irrigation timing; exploring water "harvesting" technologies to conserve soil moisture and transport water more effectively to drier areas; managing water to prevent erosion and nutrient leaching in areas with increased rainfall; using previous and current climate data to reduce crop production risks.

Irrigation efficiency refers to the measure of irrigation performance relative to the water requirements of either a field, farm, basin, irrigation district or a watershed to better promote and implement improved irrigation water use (Howell, 2003). Irrigation efficiency is measured as 1) the irrigation system performance, 2) the uniformity of the water application, and 3) the response of the crop to irrigation, each of these vary in time and space (Howell, 2003). To improve irrigation efficiency an understanding of the water balance is required. Improved irrigation efficiency can reduce overall water demand, and this can increase water availability for the environment (eco-systems) and people and reduce the potential impacts of climate change. Improved irrigation methods were found to reduce water demand from the Nile River Basin (Multsch et al., 2017) was also observed in Saudi Arabia (Multsch et al., 2016).

The potential trade-off in water allocations between agriculture and domestic and industrial use while still needing to meet environmental and social reserve requirements is already a concern in many catchments and will become increasingly more of a challenge in areas where water availability will be impacted by climate change. This requires strong alignment between different sector policies and overall strategic planning to manage these conflicting demands.

3.1.7 Alternative Sanitation Technologies

In adapting to climate change, sanitation and hygiene infrastructure should integrate technologies to improve health infrastructure, prevent contamination and pollution of water (IPCC, 2022). Currently, under the Water Research Commission (WRC) of South Africa several technologies for more resilient water and sanitation systems have been developed which have also contributed to the global search for solutions as part of the global Re-inventing the Toilet Program (RiTP). Some of the unique innovations from South Africa include the Pour-flush toilet, the Arumloo and social franchising (Amis and Lugogo, 2018). Social franchising is an example of how innovation is not only limited to technology developments as it is a system which involves small enterprises which enter into a business partnership as franchisees with a franchisor using a "tried and tested" approach for undertaking the activities required to ensure that sanitation, water facilities and other systems are operating in a reliable manner and to sustainable hygiene standards (Wall & Ive, 2013). Addressing existing social concerns in promoting the use of alternative and "dry sanitation" systems has been identified as a critical barrier to implementation as part of the National Sanitation Implementation Plan (NSIP).

The inclusion of climate change risk is also critical in terms of water and sanitation planning for municipalities and has been included in guidelines for water safety planning in South Africa and internationally based on guidelines developed by the International Water Association.

3.1.8 Ecosystem based Adaptation (EbA)

Climate change impacts can be reduced by maintaining healthy ecosystems, wetlands provide improved water supply, water quality enhancement/water purification, climate regulation, flood attenuation, drought mitigation; well-protected lakes can retain water during prolonged drought events; healthy forests reduce the risk of devastating wildfires and increase the rate of groundwater infiltration (UNEP, 2022). Ecosystem based Adaptation techniques utilises ecosystem services to adapt to the negative impacts of climate change and communities can potentially adapt to the observed changing climatic conditions in South Africa (SANBI, 2020).

The clearing of Invasive Alien Plants (IAPs) is one type of EbA due to the negative impacts caused by IAPs. For example, pasture production is often reduced when native palatable plants are outcompeted by unpalatable invasive plants (O'Connor and van Wilgen, 2020, Nkambule et al., 2017). Similarly, the production of native wild food and traditional herbs for human consumption may also be reduced with heavy invasions (O'Connor and van Wilgen, 2020). Some invasive alien plant species consume larger amounts of water than natives, which can reduce river flow and underground water supplies (Tererai et al., 2015, Cullis et al, 2007, Le Maitre, 2013). Alien invasions may also result in land degradation and denudation, which is often irreversible (Dehnen-Schmutz and Touza, 2008, Jardine and Sanchirico, 2018).

In South Africa, it is estimated that IAPs cover approximately 10% of the country, growing at an exponential rate. Such that 1.44–2.44 billion m3 of water (surface flows and groundwater) is lost to invasive species each year, which is enough to supply water to 3.38 million families with four members for a year or to irrigate 120 000 hectares of crops (Burgiel et al., 2010).

It is expected that with warmer temperatures and variations in CO_2 concentrations more IAPs will spread and increase their impacts on biodiversity and fire risk. It has been estimated that they currently account for approximately 4% of the total registered water use in South Africa and that this could increase to around 16% if further invasions are not managed (Cullis et al, 2007). The future impact could be as much as 66% of registered water use in some WMAs.

The Working for Water (WfW) initiative, which began in 1995 under the then Department of Water Affairs (DWA), is at the forefront of the fight against invasive alien plants. Currently, the initiative sits under the National Department of Forestry, Fisheries, and the Environment (DFFE). Since its beginning, the initiative has cleared over one million hectares of IAPs, resulting in the employment and training of roughly 20 000 persons from the most marginalised sectors of society each year. Working for Water presently manages over 300 projects in South Africa.

To combat the spread of IAPs, field workers employ a variety of techniques including:
- Felling, removal or burning of IAPs using mechanical methods.
- Use of herbicides (chemicals used to manipulate or control undesirable) in chemical approaches that are safe for the environment.
- Biological management by making use of species-specific insects and diseases native to the alien plant's home country.
- Integrated control using a combination of the three approaches mentioned above (to avoid massive consequences, an integrated approach is frequently required).

The WfW initiative is regarded as one of the continent's most impressive environmental protection endeavours (DFFE, 2022). In addition to its contribution to improve resilience to climate change, it has received support for its efforts to create jobs and combat poverty.
Through WfW, short-term contract jobs are created mainly for IAPs clearing activities, with a focus on recruiting women (target of 60 percent), adolescents (20 percent), and disabled people (5 percent). The employed labour is often from local communities adjacent to clearing sites, this is done to provide skills training for the rural communities. Working for Water uses these criteria because people's development is a critical component of environmental conservation. Implementing HIV/AIDS projects as well as other socio-development initiatives are also considered to be critical components that can also contribute to EbA (DFFE, 2022).

The Greater Cape Town Water Fund (GCTWF) also shares a goal of removing IAPs to restore water surface catchments and aquifers responsible for water supply (The Nature Conservancy, 2019) . Through these actions, the GCTWF enhances security for all Western Cape Water Supply System (WCWSS) users while protecting the diversity of indigenous flora in the Cape Floral Kingdom (South African National Biodiversity Institute, n.d.). In addition, the GCTWF will boost funding and execution of catchment restoration initiatives, creating employment and empowerment in the process to safeguard native species and construct more climate-resilient communities. While this business case focuses on invasive alien plant removal to restore seven key sub-catchments that supply the WCWSS, the water fund's scope is broader, funding additional ecological infrastructure interventions to ensure water supply. Restoration of four key wetlands, management of IAPs in former forestry regions, and restoration of natural vegetation on the Atlantis Aquifer is also the focus of the efforts of the GCTWF.

Studies indicate that, IAPs can increase evaporation and transpiration losses, reducing river flows and Mean Annual Runoff (MAR) (le Maitre et al., 2020; van Wilgen et al., 2020). Due to invasions, mean annual runoff has declined by >5% in the Western and Eastern Cape, as well as KwaZulu-Natal primary catchments (Le Maitre et al., 2020). Surface water runoff reductions might climb to 2.59–3.15 billion m3 per year (around 50% more than existing reductions) if no corrective action is done (Figure 45). This will have a significant impact on water security across South Africa (Cullis et al, 2007). It is estimated that currently IAPs in the mountain catchments and riparian zones account for around 4% of registered water use nationally, but that this could increase to over 16% if there is no control and the IAP invasions spread. The impact will vary between WMA, with the greatest impact expected in the grassland catchment such as the Tugela catchment, but also significant impact in the Western Cape mountains where increasing IAPs also contributed to loss of biodiverse and increased fire risks. Water resource managers should utilise this information to help them prioritise regions for clearing and rehabilitation, as well as species to target for control methods (le Maitre et al., 2020).

Aquatic weeds should also be removed as part of IAP removal, as they are already a challenge in most eutrophic water supply dams and are likely to be exacerbated under climate change as aquatic weeds thrive in high temperatures. These weeds are an even bigger threat because they grow exponentially and are associated with high transpiration rates which leads to decreased water storage in dams and may lead to less water availability to meet the growing demand. Furthermore, aquatic weeds affect the quality of water resources as they release toxins and harmful chemicals which can lead to increased water treatment costs. In the case pf aquatic weeds such as water hyacinth, the importance of minimising pollution from sources through sewer maintenance sustainable agricultural practices can assist in reducing nutrient loads into downstream water resources thereby avoiding the proliferation of aquatic weeds which are mainly driven by high nutrient loads and hight temperatures. An integrated approach may be required to include all relevant stakeholders to play their role to support the fight against alien invasive plants and aquatic weeds.

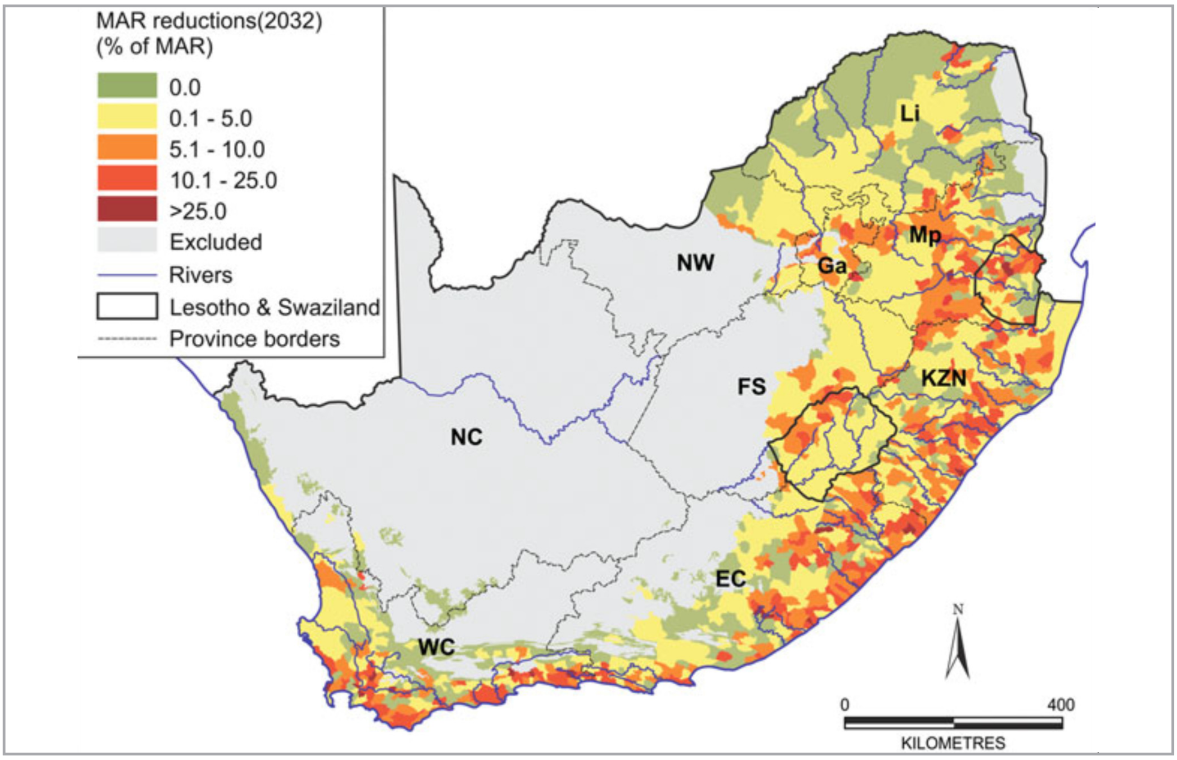


Figure 45: The projected reductions in pre-development MAR by 2032 if invasions of natural vegetation are allowed to continue unmanaged at annual expansion rate of 5% and densification of 1%
(Source: Le Maitre et al. 2020)

Other forms of Ecosystem based Adaptation (EbA) such as protection and rehabilitation of wetlands, catchments and riparian banks also help in adaptation to the potential impacts of climate change for water and sanitation through support for flood amelioration, reducing sediment loads and reducing water quality and pollution risks. These benefits are recognised through various existing programs such as the Working for Wetlands Program as well as the Transformative Rivers Management Program (TRMP) developed in eThekwini (C40, 2019) with similar programs being initiated in several other municipalities across South Africa. Additionally, the benefits and risks of the implementing EbA to supplement or replace grey infrastructure where applicable, as EbA can offset the GHG emissions and have no energy requirements.

3.1.9 Water Sensitive Cities & Urban Water Resilience

Water system services are becoming increasingly important in improving a city’s living standards, sustainability, resilience, and productivity around the world. However, reaching these goals, especially in the face of climate change and rising urbanisation, would necessitate a fundamental shift in how water system services are planned, developed, and provided. The Water Sensitive Cities Index (WSCI) was created to allow cities to be benchmarked across seven categories that describe the fundamental characteristics of a water sensitive city (Chesterfield et al., 2016).

The specific goals of the WSCI are as follows:

1. Ensure good water sensitive governance
2. Increase community capital
3. Achieve equity of essential services
4. Improve productivity and resource efficiency
5. Improve ecological health
6. Ensure quality urban spaces, and
7. Promote adaptive infrastructure

The seven goals, which are made up of 34 indicators, were created to track progress toward reaching water-sensitive municipal goals and to help decision-makers prioritise water-related initiatives. In South Africa, the approach to developing Water Sensitive Cities needs to take into consideration the presence of informal settlements and the legacy of apartheid era spatial planning, as shown in Figure 46, and in particularly focusing on vulnerable communities.

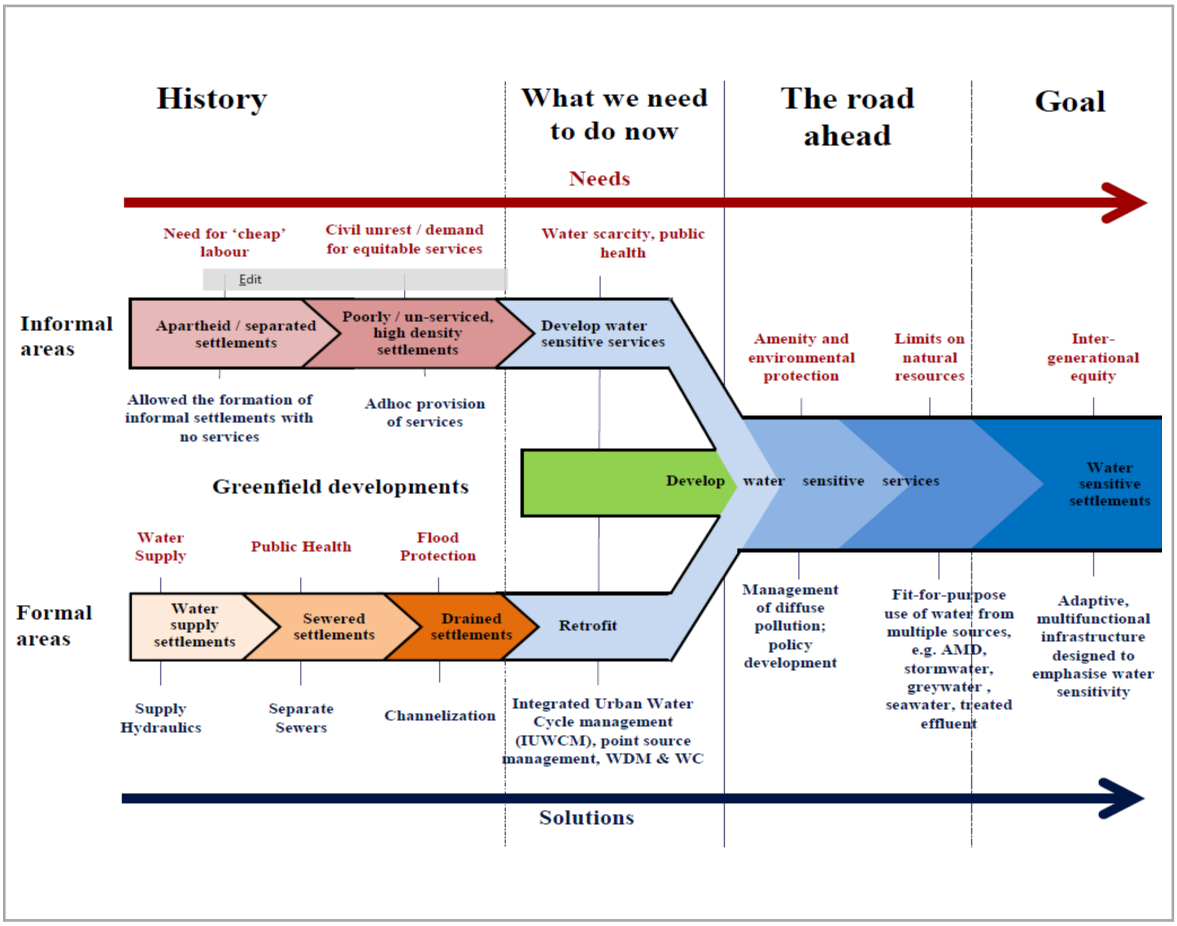


Figure 46: The "Two Cities" Water Sensitive Cities Framework for South African Cities (Fisher-Jeffes et al., 2017)

To date, the WSCI has been applied to the City of Cape Town (CoCT) and the City of Johannesburg (CoJ) and in both cases the outcome from this study have contributed to the development of the relevant update city water security and resilience plan. The lessons learnt about adapting to this index in the unique context of an African city, especially the climate risks that affect informal areas may be applicable to other towns and cities in South Africa.

This should also be combined with thinking regards to broader urban water resilience and lessons learnt from the application of the City Water Resilience Approach which has been applied in several cities in Africa including Cape Town, Johannesburg, and Nelson Mandela Bay (NMBM) and is also reflected in the updated Cape Town Water Strategy (CoCT, 2019). The City Water Resilience Approach (CWRA) has been developed in response to cities' need for tools and approaches to help them and their stakeholders navigate the process of building resilience and applied to several global cities. It is used by public and private organisations, representatives from national and regional government, cities, utilities, catchment and basin authorities, and civil society groups. The CWRA has been developed to be a robust peer-reviewed approach with custom-designed tools to benefit those making decisions to assure water resilience for their city and applied in several cities in South Africa.

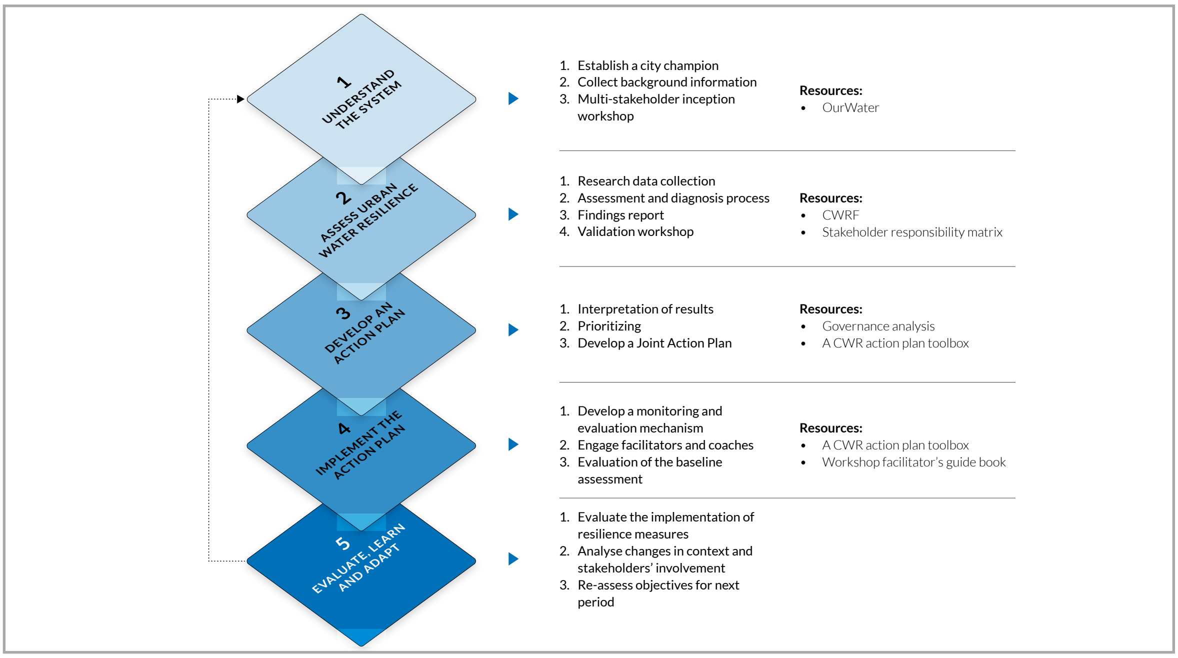


Figure 47: City Water Resilience Approach (CWRA) methodology

The CWRA is developed with the aim to help cities to view their water systems as a whole and build urban water resilience. The CWRA provides a step-by-step guide for cities to manage their water systems in a sustainable and resilient way. The tools used as part of the CWRA include the City Water Resilience Framework (CWRF), which is a globally applicable water resilience framework to assess the strengths and weakness of the urban water system and Our Water, an online tool to improve water governance through coordination and knowledge-sharing between actors working in the water system. The CWRA has successfully been applied in the African cities of CoCT, Addis Ababa, Kigali, and others outside of Africa.

The World Resources Institute are currently looking to apply the CWRF to the cities of Johannesburg and Gqeberha as part of their African Urban Water Initiative (WRI, 2023). The study will result in recommendations for improved water resilience of these cities which can then also be applied to other towns in cities facing similar climate related risks. A particular focus of the AUWI is to promote the use of nature-based solutions (NbS) in improving urban water resilience in Africa.

3.2 Potential Mitigation Options for Water & Sanitation

3.2.1 Overview of the Water-Energy nexus

Although the energy sector accounts for only around 2% of total water usage in South Africa, it is a critical sector of the economy, it is still a significant water user and as such any changes in the energy sector will likely have significant impact for the overall water and sanitation sector. It is also important to note that energy is a critical requirement for the water sector, particularly when it comes to alternative water supply options such as desalination and re-use.

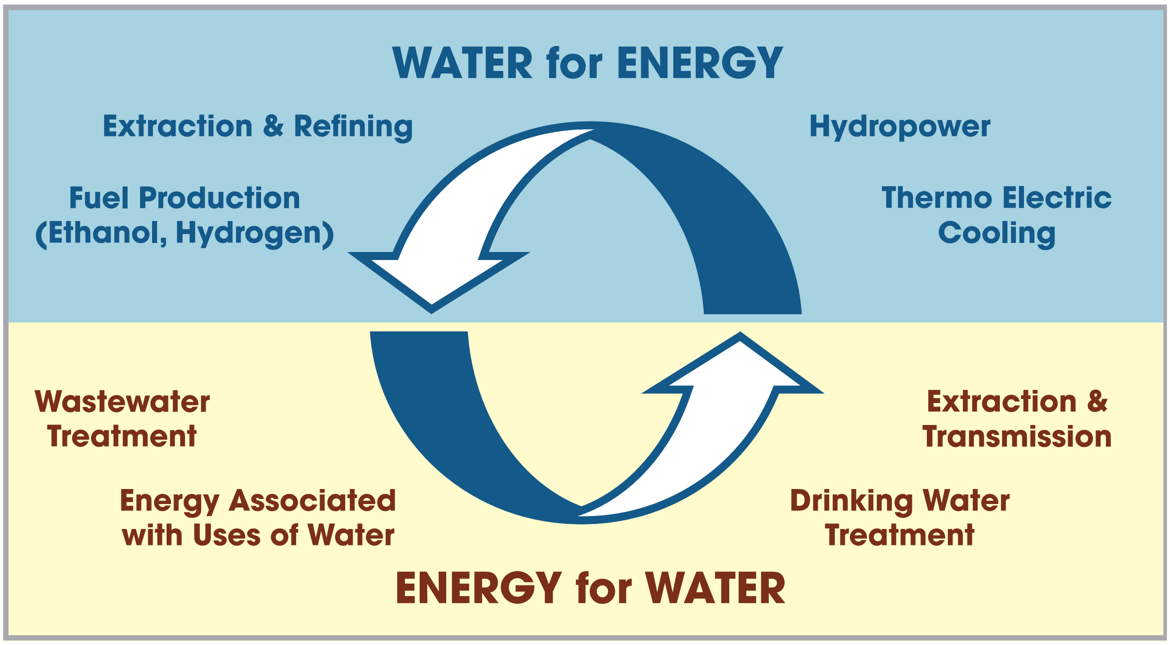


Figure 48: Links between water & energy as part of the Water Energy Nexus.

3.2.2 Reducing the Carbon Footprint of the Water Sector

Although combined solid and wastewater is estimated to account for less than 5% of global GHG emissions, it was predicted that emissions from wastewater will almost double from 1990 to 2020 under unchanging circumstances, with developing countries being the primary contributors. The water and sanitation sector contributes to GHG emissions due to energy used in pumping water to Water Treatment Works (WTWs) and Wastewater Treatment Plants (WWTPs), as well as in the treatment process and through the breakdown of organic matter. South Africa's national GHG emissions could be much lower if mitigation measures, such as energy efficient technologies, are put in place in the water and sanitation sector. Because of the lower energy requirements, onsite sanitation systems in South Africa for example are projected to create less GHG than traditional sewerage and wastewater treatment. When compared to the base condition or the development of new infrastructure, a study by Friedrich et al. (2009) indicated that sanitation alternatives that recycled water to meet increasing demand had the lowest carbon impact when utilising a lifecycle assessment approach.
Other wastewater treatment mitigation options include decentralised sanitation, low-flush toilets, and ecological sanitation approaches. These options encourage smaller wastewater treatment plants with lower nutrient loads and proportionally lower GHG emissions (IPCC, 2022). Several alternative sanitation solutions are being explored in South Africa by the WRC.

The ideal mitigation option is to improve WWTPs and the overall water and sanitation system to achieve net zero energy. This can be accomplished by a variety of methods, including extracting thermal energy from warm water, obtaining energy from the nutrients in the water through various chemical reactions, the capturing of biogas which can then be used to produce energy, and generating kinetic energy from the water flowing in gravity pipelines and energy recovery. The challenge of achieving net zero as a mitigation, is that every WWTP is different in terms of operations, and requirements and as such each facility requires a different solution and the cost effectiveness of this needs to be evaluated separately (Casey, 2015). Several municipalities in South Africa have already considered implementing biogas and energy saving technologies at their WWTPs and the DWS is currently engaging with selected municipalities to identify additional energy saving options and to secure the funds needed for implementation.

3.2.3 Improving Energy Efficiency for Water & Sanitation

It is estimated that WWTW in South Africa consume 17% of the total energy used by municipalities (Wille et al, 2020), and that electricity consumption can be as high as 30% for activated sludge type WWTW. Given that most of the electricity in South Africa is provided from coal fired power stations, reducing the electricity consumption of the water and sanitation sectors, particularly for water and wastewater treatment could contribute significantly to reducing the overall GHG emissions from South Africa. Improved energy efficiency of WWTW and the overall water and sanitation system will also help to reduce overall operational costs for municipalities due to increasing electricity fuel costs which are continuing to increase. To facilitate the process of improving energy efficiency and the development of alternative energy options, energy audits should be conducted at individual WTW and WWTW, across the country.

According to an article by ESI Africa (2016), the biogas potential in South Africa is capable of producing 2 500 MW, which is the same as the Arnott power station. It should be noted that the use of biogas has significant environmental and cost saving benefits (Mukumba et al., 2016). However, specific cost and benefits need to be evaluated on an individual plant basis.

3.2.4 Support for Alternative Energy Supply Solutions

The development of alternative energy supply options is critical in reducing GHGs emissions and reducing the potential impacts of climate change for the water and sanitation sector. While current energy supply options, particularly coal fired power stations, require significant volumes of water, mainly for cooling, several alternative energy supply options, particularly wind and solar PV, have very low water use requirements. Other options such as hydropower, however, are very dependent on sufficient water availability and reliability. Currently, South Africa has relatively limited hydropower potential and without any dedicated large hydropower dams.

There are however several existing and proposed large hydropower developments within the SADC region and these are highly sensitive to the potential impacts of climate change (Cervigni et al, 2014). A priority action for reducing the overall carbon footprint of South Africa is to identify and support opportunities for alternative energy supply options. This would include exploring new and potential hydropower opportunities including not only run-of river schemes, but also opportunities for pump-storage which can be used to help balance the contribution from more variable energy supply options such as wind and solar. The World Bank World Energy Outlook Report estimates that the technical feasible hydropower potential for South Africa is only 14,000 GWh/year, of which about 90% has already been developed. A study funded by the WRC to develop a South African Hydropower Atlas (van Dijk et al, 2023), aims to identify potential opportunities for micro-hydro generation particularly in the rural areas.

Distributed micro-hydropower installations can also contribute to the provision of electricity in water distribution and sanitation systems, especially in rural areas. Several examples have already been implemented in South Africa such as Pump as Turbine (PAT) technologies. Pressure reducing valves, maintaining optimal pressure distribution in distribution systems, could be replaced by turbines driven by hydropower (Samora et al., 2016).

The water demands from alternative energy sources such as concentrated solar power (CSP) as well as Green Hydrogen, which are mostly located along the Orange River in the Northern Cape, will need to be evaluate as part of the strategic decision making for water resources allocation in the different water supply systems and the need for additional water infrastructure.

3.2.5 Impacts of National Energy Policy & the Just Energy Transition

The Just Energy Transition (JET) requires South Africa to transition away from a fossil fuel dominated economy and energy production system. This will include, amongst other things, the closing down of older thermal power stations and a transition to renewable energy sources.

By implementing the Just Transition, it is likely that water currently used for energy production and coal mining could be re-allocated to other water use sectors to better support economic growth and transformation. The potential opportunities for this should be explored, as well as the very significant benefits of a just transition in terms of improved water quality and water availability for environmental flows in rivers. However, this needs to be balanced with regards to maintaining local economies and access to services for communities affected by the JET.

A study undertaken by the World Bank as part of the Thirsty Energy research program, showed how the regional variability in water availability affects the cost of water supply for the different energy supply options that is not typically taken into account as part of national energy planning (which assumes a single standard price for water for the different energy sources, irrespective of the fact that these are located in very different parts of the country where the provision of water can be significantly more or less expensive depending on availability. As a result of the difference in the water prices, the costs of providing energy from different sources (e.g. from concentrated solar versus coal or natural gas), will vary and this should also be included in national energy policy decision making along with other indirect impacts such as the impacts on water quality, aquatic health and water availability for other purposes. Similarly, any changes to energy policy, such as the Just Energy Transition (JET), could also impact on the demand for water for energy in different regions. In particular, the move away from existing coal fired power stations in Mpumalanga could be significant as in this region the water used for energy production represents a very large percentage of the overall water requirements.

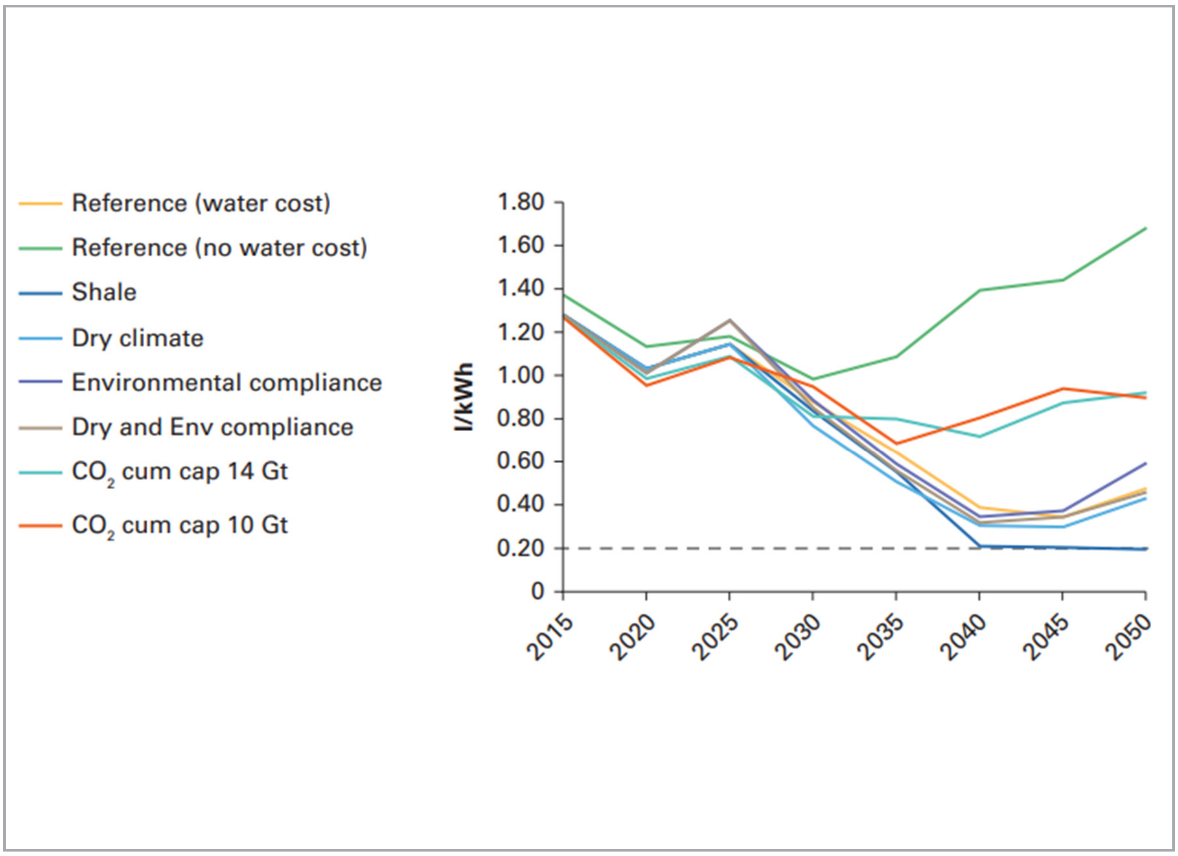


Figure 49: Impact on Power Sector Water Consumption under Various Scenarios
(Source: WB Thirsty Energy Report)

The Just Energy Transition (JET) also considers the further development of carbon capture and storage sites and technologies across South Africa. The potential water requirements and negative impacts of these and other technologies such as fracking for natural gas on water quality and human health as well as aquatic ecosystems needs to be carefully considered as part of the planning for the JET to ensure sustainability of the resource and prevent maladaptation. The potential for increased carbon capture through tree planting also needs to be considered in the context of the potential impact on water resource availability and quality.

4. UPDATED CLIMATE CHANGE RESPONSE STRATEGY

4.1 Vision

The vision for the updated climate change response strategy builds on the previous vision and is strongly aligned with the vision of the National Water Resources Strategy, the National Development Plan (NDP) and the National Climate Change Response Strategy (Box 1) and was informed by input from various stakeholders in the water and sanitation sector (Box 2). The updated vision for the climate change response strategy for water is as follows:
A low carbon, climate resilient, efficient, equitable, and sustainable, water and sanitation sector for South Africa by 2050.

A short explanation for each of the key components of the vision are given in Table 6 below.

Table 6: Summary descriptions for key components of the Vision

Vision Component	Description/Definition of Component
Low-carbon	Causing or resulting in only a relatively small net release of carbon dioxide into the atmosphere which is contributing to climate change.
Climate resilient	The ability to prepare for, recover from, and adapt to the impacts of climate change. Capacity to absorb stresses and maintain function.
Efficient	Achieving maximum productivity with minimum wastage or expense.
Equitable	Fair and impartial. Prioritising the needs of the most vulnerable.
Sustainable	Protecting an ecological base by avoiding depletion of the resource.

4.2 Strategic Framework & Key Strategic Objectives

To achieve this vision five key pillars, or key strategic objectives (KSOs) were identified and supported by several priority action areas and sub-actions. These KSOs and priority action areas are elaborated on in the subsequent sections. These will then be used to identify specific sub-actions and to assign responsibility for these actions as part of an Implementation Plan to be developed after the Strategy and incorporated into the Annual Performance Plans (APPs). The overall strategic framework, vision, KSOs, and priority actions are shown in Figure 50.

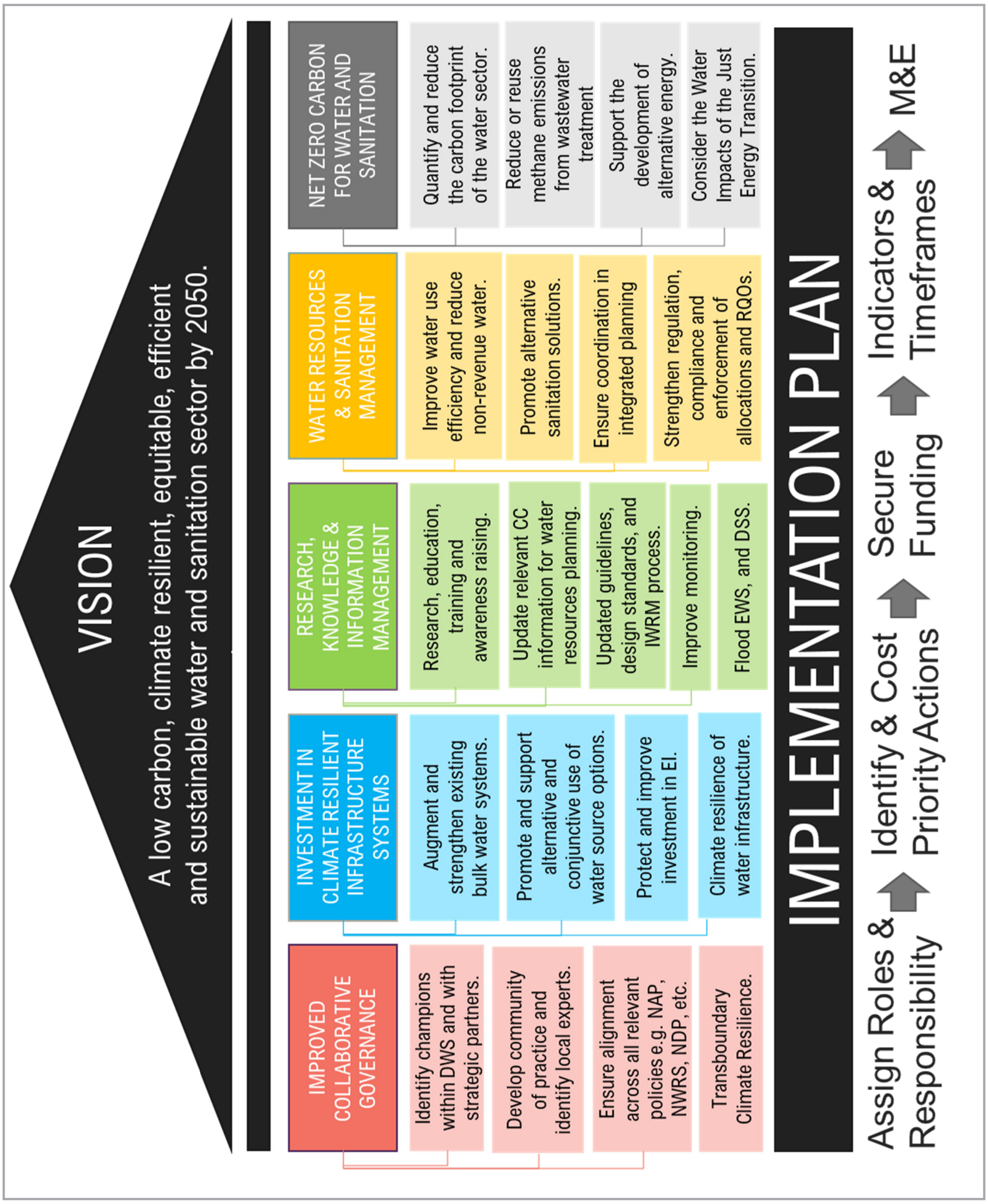


Figure 50: Strategic framework for achieving the vision of a low carbon, climate resilient water & sanitation sector.

Box 1: Alignment with the visions of the current NCCRS for Water and the NWRS (see. Table 1).

Current National Climate Change Response Strategy Vision (DWA, 2013)

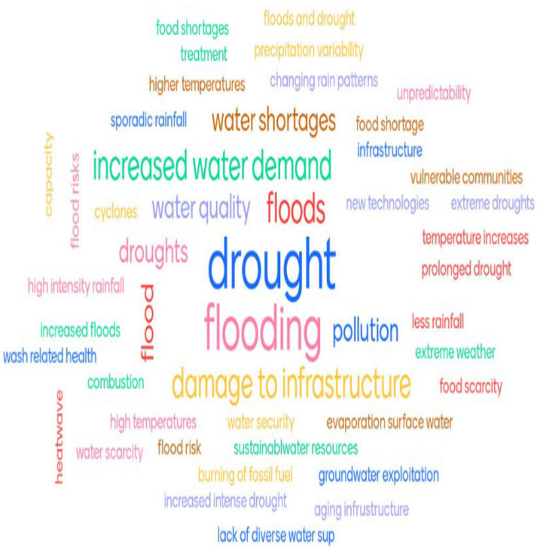
"All water sector institutions and water users are aware of, plan for and respond as appropriate to a changing climate and its impacts on water and have the capacity to manage water resources in a context of high levels of uncertainty."

National Water Resource Strategy III – Vision (DWS, 2023)

"The protection and management of water resources to enable equitable and sustainable access to water and sanitation services in support of socio-economic growth and development for the well-being of current and future generations."

Box 2: Inputs from stakeholders to help inform the updated climate response strategy.

What are the three main climate related threats to water and sanitation in South Africa?



What do you think are the greatest threats to future water security in South Africa?

4.3 KSO 1: Improved Collaboration & Governance

Collaborative governance is the process whereby various stakeholders ranging from national government, private sector, and community members, work together to achieve a common goal/s. Collaborative governance provides an inclusive platform to address issues and to achieve goals, as the different stakeholders' skills may complement each other. As such this may result in more achievements than if stakeholders operated alone or in silos.

The priority action areas identified for KSO 1 are:

- Identify and collaborate with champions within DWS and other strategic partners.
- Develop a community of practice and identify local key experts and organisations.
- Ensure alignment across policies and prioritisation of water and sanitation issues.
- Transboundary water governance and resilience.

4.3.1 Action 1.1: Identify & Collaborate with Champions

Champions within the various Department within DWS and across the various strategic partners need be identified and a platform for engagement must be implemented, to ensure that all issues are captured, prioritised, and addressed. Champions need to be adequately capacitated, especially at the community level, to ensure understanding of the issues.

Collaboration with the private sector and representative bodies, as well as with NGOs, academia, donor agencies, and community-based organisation is also critical in terms of finding innovative solutions to improving climate resilience of water and sanitation sector.

Champions need to have the ability to mobilise resources (funding and human resources), to ensure that the climate objectives are met. Within their relevant area, champions need to establish the water and sanitation status quo and the impact climate change. When establishing the various champions, care must be taken to ensure that the climate objectives can be achieved without having too many champions. A large group may actually result in slow or possibly no action and fewer, more focused champions is potentially better.

Improved collaboration is critical between national, regional, and local level organisations particularly with regards to improving the performance of municipalities and other water service providers (WSP) to help reduce current and future water and sanitation climate related risks.

4.3.2 Action 1.2: Develop a Community of Practice & Local Experts

Collaborative governance is key for climate change adaptation, response, and implementation as it is transversal issue that requires input from various sectors and stakeholders. To achieve this requires strengthening mutually beneficial public sector, private sector, and community collaboration. Environmental ownership by communities will be key both now and, in the future, as such active citizen science and capacitated and empowered youth will be required to lead change, especially for on the ground implementation of required actions. The actions should be prioritised in the Integrated Development Plans and Water Services Develop Plans to identify the priorities for the implementation for adaptation and resilience. Building a community of practice for improved climate resilience of the water and sanitation sector also involves engagement with research organisation and international development agencies as well as support for public-private partnerships and non-governmental organisations both in the water sector and also more broadly in relation to climate change impacts and adaption potential.

A key partner in developing a community of practice for climate resilience would be the Presidential Climate Commission (PCC) and the Water Research Commission for research.

4.3.3 Action 1.3: Policy Alignment on Water & Sanitation Issues

Policies across and within all spheres of government need to be aligned and be mutually supportive and reinforcing. Gaps and discrepancies in policies need to be identified and must be addressed especially where stakeholder/actor engagement is weak, as well inter- and intra-departmental collaboration and communication. Additionally, and where required, governance frameworks need to be reviewed and updated with the inclusion of Climate change issues. Emphasis is required on this to ensure that, as far as possible, common definitions are used amongst various stakeholder/actor. This will ensure that there is cohesive management between priorities and practice between stakeholders and across all spheres. However, locally specific understanding and needs should not be dismissed, as climate challenges and impacts may differ significantly. Alignment with municipalities and water services providers is critical.

4.3.4 Action 1.4: Transboundary Water Governance & Resilience

South Africa shares several international river basins including the Orange and the Limpopo. Strong transboundary collaboration and institutions are required to ensure the sustainable management of these transboundary rivers and support holistic river basin planning and resilience. South Africa should also review its international obligations in light of climate change and the potential impact that this might have on both water flowing in to, and out of South Africa. Migration into South Africa could also contribute to increasing water demands and this can be increased as a result of the impacts of climate change which might have more negative impacts on South Africa’s neighbours including Botswana and Zimbabwe. The potential impacts of climate change on water supply from Lesotho needs to be evaluated as this could have a significant impact on water availability for South Africa, particularly for Gauteng.

4.4 KSO 2: Resilient Water & Sanitation Infrastructure

This requires reducing the vulnerability of existing and new infrastructure to both current and anticipated impacts of climate change, through the planning and design, construction as well as operation and maintenance. However, design guidelines need to be updated to include climate considerations. The benefits of this include, improved productivity, innovation, health and well-being, food security, livelihood security, and biodiversity conservation, as well as risk and damage reduction (IPCC, 2022). Diversification of the water supply mix, information, and updated approaches to IWRM that incorporate key concepts of decision making under uncertainty and climate change adaptation/mitigation. The use of alternative and innovative sanitation technology and solutions could also contribute towards increasing climate resilience.

The priority action areas identified for KSO 2 are:

- Augment and strengthening the existing bulk water systems.
- Promote and support alternative and conjunctive us of water source options.
- Protect and improve investments in ecological infrastructure (EI).
- Improved climate resilience of existing (and new) water and sanitation infrastructure.

4.4.1 Action 2.1: Augment & Strengthen Bulk Water Supply Systems

South Africa has a highly developed and integrated bulk water supply system that has been developed over time to deal with the challenge of high spatial and temporal variability in rainfall.

This integrated system and the ability to move water from one catchment to another and to manage the storage and distribution has been critical in ensuring water availability can keep pace with demand in the past and limiting any disruptions to the growth of the economy.

This integrated systems and the associated storage capacity provides some resilience to the impacts of climate change, however it is critical that it is operated efficiently and that the necessary investments to augment and strengthen the operation of this system are made and that they are made well in advance of any crisis. Several projects have already been identified that need to be implemented to continue to strengthen and develop the integrated bulk system and delays in the implementation is significantly increasing the water security risks for South Africa. In addition to implementing the necessary augmentation options (several of which have been identified as strategic projects), it is critical that the analysis of the systems is regularly updated, and that reconciliation and planning studies are updated on a regular basis. Options for improving the efficiency of the bulk water supply systems through, for example, the development of real time operating, and decision support systems should also be considered.

At the local level, individual municipalities, and water service provider (WSP) need to also make the necessary investments to protect, strengthen, and augment existing water supply and sanitation systems as well as ensure the sufficient maintenance and operation of these systems. This requires financial resources and increased collaboration and technical support. Key to supporting the implementation of critical water and sanitation infrastructure is that this must be done in a sustainable way and taking into consideration the expected impacts of climate change and embracing the latest technologies and innovations. Investing in ecological infrastructure, such as the clearing of invasive alien plants or implementing catchment management practices to reduce sedimentation is also necessary for critical infrastructure.

4.4.2 Action 2.2: Promote & Support Alternative Water Sources

South Africa is still largely dependent on surface water sources, and it is critical to promote and support the development of alternative water sources such as groundwater, rainwater harvesting, greywater, desalination and both direct and indirect potable re-use. Developing these alternative water sources and critically improving the management of conjunctive use from the different sources will also improve resilience to climate change as the different sources are impacted often on different time frames and with different recovery period. In this regard it is also important to consider adding in additional redundant systems and infrastructure that enables water to be distributed to all parts of the systems from the different sources. This improves the flexibility of the water system and ability to adapt to climate change. Collaboration between different users is also required to optimise the use of conjunctive water sources, while there are several technical and social challenges that need to be overcome before re-use, in particularly direct-potable re-use, and feature more strongly as an alternative water source. In the Gauteng region, the potential to treat and re-use acid mine drainage water has already been identified as a critical need from a water quality and sustainability perspective, but challenges remain including the cost of treatment and finding sufficient users of the water.

4.4.3 Action 2.3: Increase Investments in Ecological Infrastructure

Investment should be increased to take advantage of the benefits provided by Ecological Infrastructure (EI) and Nature based Solutions (NbS). EI and NbS, can provide multiple functions such as the removal of pollutants from air and water, water storage, social benefits such as jobs and raw materials, whereas ‘grey’ infrastructure may only provide one function such as water treatment. EI and NbS, can also support and protect ‘grey’ infrastructure from damage by weather related events such as storms by storing water in rivers, lakes, or groundwater. EI can also be used to sequester carbon generated from ‘grey’ infrastructure, especially when used together and is also critical in reducing some of the direct physical risks to water infrastructure such as flooding and sedimentation. The maintenance and operation requirements of EI and NbS may also be significantly lower than ‘grey’ infrastructure and may also be used to generate revenue such as through the sustainable use of natural resources.

Protecting the ecological infrastructure in the Strategic Water Source Areas (SWSAs) of South Africa is particularly important in terms of mitigating the potential impacts of climate change.

While investing in ecological infrastructure (EI) through the clearing of IAPs, catchment restoration, and the rehabilitation and protection of wetlands, is critical in terms of protecting the water resource and mitigating some of the potential impacts of climate change, it is also important to consider these in the context of the need to still invest in hard infrastructure solutions and most importantly in terms of the improved operation and maintenance of water and sanitation infrastructure. The failure of wastewater treatment plants or sewerage pumpstations for example poses a significant threat to both human and environmental health. Investment in the rehabilitation of wetlands and as part of water use licence conditions for water quality related water uses should also be implemented. By way of example, incorporation of biodiversity offsets for all water uses that results in the disturbance of and degradation of biodiversity of ecological infrastructure, as in the case of dam development / construction and can also apply in the case of wetland crossings by bulk water pipelines.

The need to investment in EI should not distract from the need to also invest in the augmentation, maintenance and operation of critical water supply and sanitation infrastructure.

4.4.4 Action 2.4: Improve Climate Resilience of Critical Infrastructure

As the population increases so will the water demand, across various sectors. Consumption must be managed, and a change in behaviour will be required to ensure that water demand does not exceed water availability. Additionally, new water resources must be developed, and the water mix must be diversified to reduce the stress and over-abstraction of only one resource. Over-abstraction of any one resource may harm the environment through reduction of local biodiversity which may result in a change in the local climate, which could reduce water availability (i.e., drought conditions) or create an abundance of water (i.e., flood conditions).

Just as important as developing alternative water infrastructure options, is the improved integration of existing and new sources and improved operations of the existing system. It has been shown that South Africa's current integrated bulk water supply system provides some level of resilience to climate variability (both spatially and temporally) and this needs to be recognised and enhanced as part of improved operation and more conjunctive use.
Ensuring that water infrastructure and other infrastructure are protected from the increasing physical risks due to climate change such as flooding, sedimentation, and direct temperature impacts, is also essential to avoid a significant increase in costs and disruptions.

4.5 KSO 3: Research, Knowledge & Information Management

A critical part of supporting a transition to a more climate resilient water and sanitation sector is to improve access to climate data and information including the latest climate change scenarios and support for undertaking risk and vulnerability assessments and alignment with existing IWRM process and design standards. Data must be made available on readily accessible platforms, be updated and managed regularly (i.e., online data platforms) and be appropriate for use. Furthermore, interdepartmental data and information must be instituted. Knowledge generation is also required to guide the sector and identify priority research areas.

4.5.1 Action 3.1: Research, Education, Training, & Capacity Building

Awareness of various data sources must be communicated. A key challenge is that though there are several data and information platforms available, however there is a lack of awareness of these sources and data and information is fragmented. Communication of these data and information sources is required, as it may support and encourage research within various institutions, which may further existing knowledge. The data and information must be provided in a manner that is easily understood and sued by all stakeholders especially as not all stakeholders may have the technical capacity to analyse raw data. Training and education of how to use these data and information sources across various sectors must also be implemented. This will encourage the use of data and information in decision support.

Several research priorities have been identified including those listed in Table 7 from the WRC.

Table 7: Research priorities identified by the Water Research Commission (WRC) for improved climate resilience.

Building Climate Resilient Systems for the Water & Sanitation Sector
Scope: The basis for a climate resilient society lies with improving adaptive capacity, increasing resilience, improvement of the early warning systems, while reducing vulnerability and strengthening the ability to respond to this new normal through proactive planning, risk reduction and disaster preparedness. Focus should be on mainstreaming catchment and site-specific responses, adaptive management, and local scale planning to incorporate climate resilient approaches, while reducing emissions. This entail addressing practical adaptation options with a focus at catchment, municipal and national scale while translating the findings of research to aid operational response/local scale adaptation through mainstreaming adaptive actions to enhance resilience and response to the overall impacts of climate change.
Regional & Transboundary Climate Impacts & Cooperative Response
Transboundary river systems play a fundamental role in the economies of the adjoining riparian countries. Climate systems as well do not observe political boundaries and the impacts thereof are experienced across different countries. The impacts of climate change therefore are not confined or experienced to specific nationalities. They impact international trade and supply chains, capital flows, human mobility and natural resources shared between countries, regionally and globally. Actions to respond and adapt to the impacts of climate change can have effects far beyond the jurisdiction of governments implementing them. Therefore, research in this case should support cooperative and multilateral actions that support resilience and continued sustenance of these transboundary river systems and better coordinated efforts in dealing with the consequences of climate change.
Resilience, Proactive Planning & National Scale Adaptation
The National Climate Change Response Strategy for the Water Sector guides and inform the mainstreaming of climate change considerations into water management and planning. The primary focus is to ensure effective management of climate change impacts as well as extreme events on the country's water and sanitation through interventions that build and sustain South Africa's social, economic, and environmental resilience and emergency response capacity. Research in this case therefore seeks to support actions that will encourage resilience of the water sector at a practical scale which advances proactive planning so that climate induced disasters are dealt with through a well capacitated disaster preparedness programme which contributes to water security despite the changing climate. Coordinated subsector and systematic adaptation programmes will culminate into an improved national adaptation capacity supported through evidence-based research.
Resilient Infrastructure & Local Scale Adaptation
It is crucial that attention be given to measures that will increase the resilience of water-linked sectors and implement adaptive options that will improve and sustain the water sectors' adaptive capacity to deal with future climate scenarios. The aim is to implement practical, yet effective adaptation solutions at local, community and catchment scale in order to improve water security and resilience to climate change, thereby strengthening local and catchment level systems and access to infrastructure. Focus should also be on the vulnerability of infrastructure to climate change. The overall purpose is to provide practical adaptive solutions to deal with the consequences of climate change in rural communities and municipalities with rural-urban interface while addressing catchment specific challenges.

4.5.2 Action 3.2: Update Climate Change Information & Scenarios

For climate readiness to be effective relevant and up-to-date data and information is required. This may require collaboration between various sectors such as Government departments, industry, policy makers, academic institutions, and citizen science to support data collection. This will ensure the relevance of data, and importantly assist in identifying trends in data at various spatial and temporal scales. A mechanism to achieve this may be through the development and maintenance of a climate data and information hub, which makes data and information easily accessible for all stakeholders. The use of Artificial Intelligence and Machine Learning must be promoted to derive a deeper understanding of the information. The updated climate change data, information and scenarios should be fully integrated with existing information systems and decision-making platforms such as the National Integrated Water Information System (NIWIS) and the Water Resources Information Systems for WR2012, etc.

A critical priority for providing updated climate change information and scenarios is to follow up on current initiatives to downscale the latest CMIP6 global climate model projections and then apply these to South African hydrological models to determine the potential impact on water resources availability and demands. This should consider the full range of possible scenarios as well as the added uncertainty related to the hydrological modelling process. In addition, it is important to initiate new research to identify particularly climate parameters that are relevant to the water sector, such as the potential impact on multi-year droughts, that can be analysed for application in South Africa. This analysis should also consider possible extreme scenarios and potential "tipping points" for the water sector.

Regular coordination between different stakeholders, such as SAWS (data providers) and decision makers to inform decision and planning, especially during emergencies. Ensure that the risk and vulnerability is understood, and that adequate risk plans are developed and promote incremental improvement. For improved coordination of efforts and planning, a single platform where the data providers and decision makers can store, access and analyse the data into usable outputs (dashboards or reports etc.) that can rapidly inform decision making.

Furthermore, a single platform makes access data by different stakeholder easier and prevents time wasting through the sourcing of data and information across multiple platforms.

4.5.3 Action 3.3: Updated Design Standards & IWRM Process

For infrastructure to be climate resilient, the design standards need to be reviewed and updated. But for this to be successful, policies at all levels also need to be aligned. Existing infrastructure may require refurbishment to ensure resilience to climate change and the impacts. Climate models should be used to determine new risk areas/locations, which should be used to inform development and design. Standards for design and retrofitting water and sanitation facilities, especially where reduction in water consumption needs to be developed. Environmental Impact Assessments (EIA) should take climate information into consideration for all new infrastructure developments and include Climate Impact Assessment (CIA) studies.

Updating current IWRM process such as the approach used to undertake the reconciliation and planning studies also need to be updated to account for increasing uncertainty and changes due to climate change. These approaches should consider bottom-up methods and methods derived to support decision making under uncertainty such as decision scaling.
The National Water Act (NWA) currently requires the updating of national water related strategies and studies to be done every 5 years. The need to do regular updates of these national (and regional) studies is becoming even more critical as a result of climate change.

While South Africa already has a well-developed set of design standards and guidelines that incorporate climate related risks such as flooding and temperature, these are currently based on historical climate data, and these urgently need to be reviewed and where necessary updated. Some municipalities for example already require additional safety factors to be added to account for a potential increase in design rainfall when determining flood lines, but this is not applied in standardised way and so is subject to interpretation by different users.

A review of the SANCOLD guidelines on dam safety in the context of floods undertaken by the WRC over a decade ago showed that in some regions we have already experience extreme events in excess of current design curves and recommended that additional risk-based measures be taken into consideration when determine design flood estimates including consideration of potential climate change impacts. The current National Flood Studies Research program, supported by the DWS, SANCOLD and the WRC has a research focus on design flood estimates and technics particularly in the context of increasing uncertainty and has already contribute to research on updating the 1-day Probable Maximum Precipitation (PMP) for South Africa (Johnston and Smithers, 2020) and also re-analysis and updated regionalisation for the Regional Maximum Flood (RMF) (Du Plessis and Masule, 2023).

These studies however need to be expanded to cover all aspects of design flood estimation and the evaluated in terms of recommended updated to existing design standards and guidelines.

4.5.4 Action 3.4: Improved Monitoring of Water Resources

Currently, South Africa has a reasonable high level of monitoring and information including several active weather stations as well as streamflow monitoring, dam level monitoring, water quality and groundwater data. However, the number of monitoring stations are declining, just at the time when more data is needed to detect emerging trends and for early response. It is critical that the existing monitoring networks and systems are maintained and where possible expanded and also enhancing new technologies and data storage and management systems. Improving the existing monitoring network is critical, but new technologies such as remote sensing should also be used, especially for areas where infrastructure is likely to get damaged.

As noted in KSO 1, alternative data sources should also be considered such as citizen science and local level knowledge which can be an excellent source of information. To support these improvements awareness and education at a local level should be enhanced and promoted. Additionally, where monitoring stations are required the use of anti-theft or anti-vandalism methods should be implemented. Monitoring networks should also be automatically updated to a local server, to improve near-real time observations as well as forecasts to support EWS.

4.5.5 Action 3.5: Early Warning & Decision Support Systems

Flood early warning systems (EWS) have been shown to be one of the most cost-effective responses to increased climate change related risks and several EWS are being implemented in South Africa at a local level. In addition, at a national level the South Africa Weather Services (SAWS) is using impact-based reporting to issue early warnings for critical risks such as floods and droughts which is based on improved seasonal forecasting and analysis. The communication of information is a critical component of a successful EWS and needs to take into consideration the unique conditions in South Africa and challenges particularly relating to sophisticated monitoring and information systems in order for them to be sustainable.

Developing new and updated decision support systems (DSS) that better incorporate climate change related risks will also help in improved decision maker for the allocation of limited resources and the development of new infrastructure as well as in terms of making decision related to short term operational issues such as maintenance and repairs of critical infrastructure and the implementing of restrictions in periods of drought. Several DSS have been developed for use in South Africa including real-time operating systems that have improved water use along the Sundays River system and also by the City of Cape Town for better managing its water supply infrastructure and network to improve operational efficiencies.

4.6 KSO 4: Water Resources & Sanitation Management

The key focus of KSO 4 is on the poor maintenance and management of water and sanitation infrastructure and systems which is a significant water security, climate change, human health, and economic risk for South Africa. Ensuring that municipalities improve the maintenance and management of water and sanitation infrastructure is critical. At the same time, DWS must ensure the maintenance and operation of the existing bulk water and sanitation systems – this is critical. It is equally important to encourage municipalities to maintain onsite sanitation systems by emptying and transporting faecal sludge that has accumulated in containments in households 'premises to minimise the risk of groundwater pollution and vulnerability of households in case of floods (National Faecal Sludge Management Strategy, 2023).

The use and dissemination of forecasting information to determine seasonal water availability may be key to managing water resources and putting measures to reduce water demand. Using forecasted information can provide the WSA with a sufficient window to implement mitigative measures proactively rather than reactively, especially when droughts are predicted. This can ensure that there is an adequate quantity of water available for the dry season. Overall improved integration of water and sanitation needs with regional and strategic planning is necessary to improved climate resilience and to address potential trade-offs for water supply.

4.6.1 Action 4.1: Improve Coordination & Integrated Planning

Several water security and sanitation challenges are linked to a lack of integrated planning. This includes planning for increasing demands as well as a lack of urban planning that results in the development, particularly of informal settlements, in high flood risk areas. In order to improve climate resilience, it is necessary to support improved co-ordinated and integrated planning. This is also critical in addressing increasing water quality and pollution risks as well as helping to better integrated water sensitive design (WSD) principles into urban planning.

4.6.2 Action 4.2: Improved Water-use Efficiency for all Sectors

Water losses are very high in South Africa and need to be addressed as a priority and particularly in the context of increasing water scarcity due to climate change. One of the main reasons for high water losses is due to poor maintenance, particular at municipal scale. This requires not only significant investment and capacity building but also improvements in overall governance as often a major contributor to the lack of maintenance is the inability to collect revenues from water sales which could then be allocated to improve maintenance and delivery.

It is also important to continually improve water use efficiency across all sectors, but particularly in the agriculture sector which is the largest water user in the country. The need to improve water use efficiency in the agricultural sector is already recognised and several individual farmers are already looking at options to improved water use efficiency of different crop types and implementing systems such as drip irrigation as well as the use of shade netting and even remote sensing (e.g., Fruit Look) to improved water use efficiency. There is however a need to consider revising the standard benchmarks used by some irrigation boards, particularly as several still refer to allocations in terms of equivalent hectares of crop types that can be grown and that these might be based on outdated estimates of efficient crop water requirements.

4.6.3 Action 4.3: Promote Alternative Sanitation Solutions

Alternative sanitation solutions, particularly including dry, no-flow and low-flow solutions need to be developed to reduce the water demands with providing access to sanitation services. Several new technologies have been developed through programs such as Reinventing the Toilet Campaign but are not widely implemented due to challenges with costs, technologies, and social acceptance. This requires not only innovative solutions, but also extensive stakeholder engagement and institutional support to find sustainable solutions. It is important to also note that differences in climate and geography will influence the choice of solutions.

4.6.4 Action 4.4: Strengthen Regulation, Compliance & Enforcement

Updated regulations to include climate considerations across all sectors. Updated regulation should take climate projections up to 2100 into consideration, to ensure that sector level planning and development covers long term climate projections. Existing regulation especially the Drop programmes need to be updated to determine whether water and wastewater infrastructure across the value chains are climate resilient. For compliance to be successful, requires that design standards are developed and updated. At the local level, bylaws must be updated and approved to address climate specific incidences, such has high water usage during times of drought. increased human and financial resources to carry out compliance and enforcement of regulations. Local level reporting must also improve to support enforcement.

Increased monitoring and compliance with environmental flow requirements (EWRs) and Resource Quality Objectives (RQOs) as well as other water use licencing conditions are critical in terms of mitigating the negative impacts of climate change on aquatic ecology and the associated benefits and ecosystem goods and services associated with these resources. The regulation of compliance with EWRs and RQOs requires collaboration with municipalities and WSPs who are responsible for local level planning and maintenance of critical infrastructure.

4.7 KSO 5: Net-zero Carbon for Water & Sanitation

The water and sanitation sector also contributes to Greenhouse Gas (GHG) emissions mainly as a result of the energy required for the abstraction, conveyance, and treatment of water and wastewater, but also through direct emissions, particularly methane from the wastewater treatment process. The impounding of reservoirs and release of gases from decay of vegetation and other biological process is also considered to be a source of GHG emissions. Despite only representing approximately 6% of the GHG contributions globally, improvements in the water and sanitation sector are necessary to help in achieving national and international climate change commitments. This requires this use of technologies that are powered by alternative energy sources such as solar power, or the use of onsite generation of clean energy through hydropower or wastewater treatment by-products such as methane/ biogas. The use of ecological infrastructure (such as artificial wetlands) could help reduce carbon emissions and may also reduce the energy and operation and maintenance costs for municipalities. The reduction of losses and improved water use efficiency would also reduce overall energy requirements and hence contribute to reducing the carbon footprint of the water sector.

4.7.1 Action 5.1: Quantify & Reduce the Carbon Footprint

The treatment and distribution of both drinking water and wastewater requires energy throughout each of their respective value chains. Currently the total contribution of the water and sanitation sector to GHG emissions for South Africa has not been well quantified. It is therefore critical that the carbon-footprint of the water and sanitation sector both at a national level, but also at a local level is determined in order to identify opportunities for reducing the contribution to GHG from the water sector and that a road map is developed to reduce these emission and result in an overall transition to net-Zero energy for water and sanitation sector as part of the Just Energy Transition (JET) and Nationally Determined Commitments (NDCs).

Reducing physical water losses can also contribute to the overall reduction of GHG emissions from the sector by reducing the need for treatment and conveyance of water that is then lost to the system. This is particularly important as new and alternative water supply options such as desalination and re-use are typically more energy intensive than current technologies such as surface water and gravity fed systems. A carbon budget for drinking water and wastewater systems, can be used to determine the allowable quantity of carbon that can be released over time, and facilitate the need for alternative 'green' or 'grey' technologies to reduce GHGs.
To facilitate carbon budgeting, energy audits of both Drinking water and Wastewater systems should be conducted either as part of the Blue and Green Drop processes or as a separate process and also included in design considerations. An energy audit can assist in identifying systems that would make good candidates for renewable energy projects (e.g., Solar, hydropower, wind or biogas etc.), which can contribute to reduced GHG emissions. In addition, it could identify systems where EI and NbS can be implemented as alternative infrastructure.

Having evaluated the baseline of the current contribution of the water and sanitation sector to the national and individual municipality carbon budget, as well as that of individual water service providers (WSP), specific targets can be set for reducing this carbon footprint and identifying options for achieving the objective of net-Zero energy for the water sector based on sound economic and social accounting practices to avoid any potential for mal-adaptation.

4.7.2 Action 5.2: Reduce/Reuse Methane Emissions from Wastewater

Methane gas is a byproduct of the wastewater treatment process. According to Daelman et al (2012) Methane is a potent greenhouse that will require management by way of reduction or re-use to mitigate the contributions to climate change. This requires that methane be quantified from all sources within WWTPs. As noted above both water and wastewater treatment require energy for treatment. Methane can be utilised as an energy source supplement the coal power energy especially at WWTP (or at other facilities), where is it produced and can be more easily captured. Macdonald (1990) indicates that methane as an energy source is a fuel source that has environmental benefits since it has low sulphur dioxide levels, hydrocarbons and carbon monoxide when combusted. To facilitate the rollout of using methane or biogas as an energy resource an audit of the methane production should be done, to identify which WWTP would serve as candidates where methane capture and re-use projects can be implemented.

4.7.3 Action 5.3: Support Alternative Energy Supply Options

Opportunity for alternative energy production through biogas production and hydropower should be explored where possible including mini-and micro installations in existing distribution networks and innovative multi-purpose solutions such as the installation of Pump as Turbine (PAT) scheme. The potential to generate energy from wastewater treatment works should be encourage but requires a detailed up-front assessment of the current condition of the wastewater treatment plant and consideration for an optimal solution. All water utilities should consider targeting Net Zero Energy by improving energy efficiency and using renewables.

Opportunities for new hydropower projects are limited in South Africa, but there is significant opportunity to consider implement small scheme and also to consider the potential for additional pump-storage facilities which can assist in improving the reliability of other renewable sources such as wind and solar. The development of new hydro-power schemes and improved integration across the South African Power Pool (SAPP) can also help in improving energy security across the whole region and in reducing the overall reliance on fossil fuels, but this needs to be done in consideration of the potential impacts that climate change will have on the region and how this will affect the reliability of future hydropower generation.

Individual municipalities should consider the opportunities for energy recovery from the treatment of wastewater and use this to offset the energy requirements of the water sector.

4.7.4 Action 5.4: Water Links of the Just Energy Transition

The Just Energy Transition (JET) requires South Africa to transition away from a fossil fuel dominated economy and energy production system. This will include, amongst other things, the closing down of older thermal power stations and a transition to renewable energy sources. Energy production currently accounts for around 2% of total water consumption in South Africa and is a very significant user in certain catchments where the coal reserves are located.

By implementing the JET, it is likely that water currently used for energy production and coal mining could be re-allocated to other water use sectors to better support economic growth and transformation. The potential opportunities for this should be explored, as well as the very significant benefits of a just transition in terms of improved water quality and water availability for environmental flows in rivers. However, this needs to be balanced with regards to maintaining local economies and access to services for communities affected by the JET. The potential benefits of the JET in terms of reducing water quality pollution must also be noted as further motivation for supporting the transition away from coal fired power stations and embracing alternative energy sources such as wind and solar. However, the potential negative impacts of other alternative energy sources such as natural gas and green hydrogen, must also be taken into consideration as well as the increased demand for water from these sources.

4.8 Review & Updating of Status Quo Analysis on Climate Change & National Climate Change Strategy for Water & Sanitation

The Climate Change Bill sets out powers and duties for every organ of state that exercises a power or performs a function that is affected by climate change, or is entrusted with powers and duties aimed at the achievement, promotion and protection of a sustainable environment, must review and if necessary revise, amend, coordinate and harmonise their policies and measures, programmes and decisions in order to—

1. ensure that the risks of climate change impacts and associated vulnerabilities are taken into consideration; and
2. give effect to the principles and objects set out in this Act.

This requires that policies, strategies, legislation, regulations and plans should be reviewed when necessary or when the current measures are not sufficient to address the below mentions. This is in line with recent best practices to ensure climate resilience. Therefore, the water and sanitation sector will review their status quo analysis and NCCRS when new knowledge and information that of material impact and/or when measures set-out the in the strategy are not sufficient to realise a low carbon, climate resilient, equitable, efficient and sustainable water and sanitation sector.

5. IMPLEMENTATION OF THE STRATEGY

5.1 A Theory of Change

Achieving the overall objectives of the update climate change response plan requires connection between the individual KSOs and supporting priority actions shown in Figure 51. In terms of achieving the vision of a low-carbon climate resilient, equitable, efficient, and sustainable water and sanitation sector by 2050, one of the most critical priorities for South Africa is to implement critical water and sanitation infrastructure that has already been identified through the various planning process at both national and local level. Several of these critical infrastructure projects have been delayed and as a result are contributing to the current level of water and sanitation security risks that is impacting on the economy and individual livelihoods. As a result, the priority KSO is to implement KSO2 which includes the implementation of critical (and in many cases delayed) infrastructure as well as increased investments in protecting and rehabilitating natural systems and ecological infrastructure (EI).

Even more critical than investing in new climate resilient infrastructure is improving operations and maintenance of existing water and sanitation infrastructure (i.e., KSO 3). This will not only have a direct impact on achieving the overall vision but is also necessary to support the investment in climate resilient infrastructure systems (KSO 2) and also to achieve the objective of reducing the overall carbon footprint of the water and sanitation systems (i.e., KSO 5).

Underlying improved operations and maintenance (KSO 3), investing in climate resilient infrastructure systems (KSO 2) and reducing the carbon footprint of the water and sanitation sector (KSO 5) is improved collaboration and co-operative governance which includes training and capacity building for key stakeholders and decision makers. Feedback loops, indicated by the dotted lines in Figure 51 are also required to support an adaptive management and climate resilient development pathways approach with regular information updates and learning.

Finally, the provision of knowledge and information through training, research and capacity building is critical in supporting all aspects of improved climate resilience for water and sanitation in South Africa and supporting science-based decision making for water security.

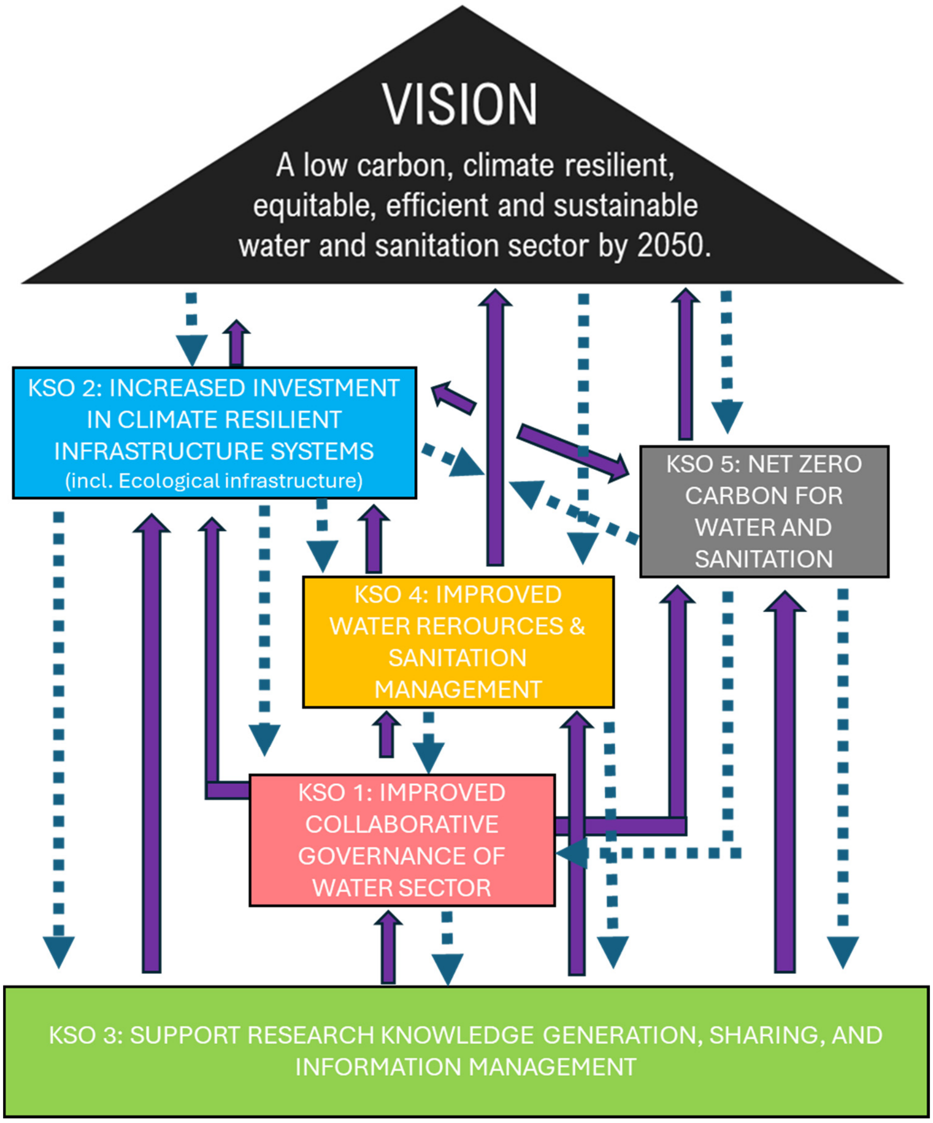


Figure 51: Connections between KSOs necessary to support the implementation of the climate change response plan and including information pathways and feedback loops that support and adaptive management approach.

5.2 Implementation Plan

The proposed implementation plan for the update climate change response strategy for water and sanitation is shown in Table 8. This includes the identified priority actions under each of the five KSOs, the relevant lead organisation, including the specific branch (B), directorate (D) or chief directorate (CD) within DWS, and potential partners, the proposed timeframe for implementation and proposed indicators for measuring success. The implementation plan will be championed by the DWS Climate Change department, but with support from various other departments within DWS and in collaboration with other partners including from different government departments, research, and academia as well as with NGOs, CBOs, IDAs and the private sector through established forums such as the Strategic Water Partners Network, etc.

Key Strategic Objective (KSO)	Priority Actions	Scale	Lead Organisation (bold) & Other Potential Partners	Time Frame (Yr)			Indicators
				Short <2	Medium 2-5	Long >5	
KSO 1: Improved collaboration & co-operative governance	Identify, train, and capacitate champions within DWS and with strategic partners.	National	**DWS (D:CC, CD: IGR)**, WRC, CMAs, WSAs, PCC, DFFE, COGTA, NGOs, IDAs, etc.				Identified champions and MOUs with key partners.
	Develop community of practice and identify local experts and forums for collaboration.	National	**DWS (D:CC, CD: IGR)**, WRC, PCC, Academia.				National and local level community of practice and forums established.
	Ensure alignment across all relevant policies e.g., NAP, NWRS, WSMP, NDP, etc.	National	**DWS (B: WRM, SU: WRP&E,)**, PCC, DFFE, DALRRD, etc.				Updated NWRS, WSMP, and all relevant DWS policies and aligned with national policies.
	Improve transboundary climate resilience across SADC and river basin organisations.	Regional	**DWS (CD: IWC)**, LHWC, LIMCOM, ORASECOM, etc.				Updated regional CC response strategy and agreements with RBOs.
	Monitoring, Evaluation and Learning (utilizing existing mechanisms and platforms).	Regional, National & Local	**Regional (RBOs), national (DWS SU: WRPS&E, CD: IGR, CD: CP&OP)**				Monitoring and feedback report and engagements
KSO 2: Increased investments in climate resilient infrastructure	Augment and strengthen existing integrated bulk water supply systems including the implementation of delayed infrastructure and improved operational rules and allocations.	National and Local Level	**DWS (B: WRM and B: Infrastructure)**, CMAs, TCTA, DBSA, National Treasury, Municipalities, Private Sector, IDAs, etc.				Updated Reconciliation and All Town strategies and implementation of required augmentation.
	Promote and support alternative and conjunctive use of surface and ground water source options.	National and Local Level	**DWS (CD: IWRP)**, CMAs, TCTA, DBSA, Municipalities, Private Sector, IDAs, etc.				Percentage water use from alternative water sources. Number of municipalities with conjunctive water use.
	Protect and improve investments in Ecological Infrastructure (EI) and Ecosystem Based Adaptation (EbA) recognising the benefits, but also potential areas of concern.	National and Local Level	**DFFE**, DWS, CMAs, DALRRD, SANBI, Municipalities, NGOs, and Private Sector.				Hectares of IAPs removed and maintained. Number of rehabilitated wetlands.
	Improve climate resilience of existing (and new) water and sanitation infrastructure.	National and Local Level	**DWS (B: WRM and B: Infrastructure)**, TCTA, WSP, Municipalities, etc.				Climate change risk and vulnerability assessments for critical water infrastructure.

Key Strategic Objective (KSO)	Priopity Actions	Scale	Lead Organisation (bold) & Other Potential Partners	Time Frame (Yr)			Indicators
				Short <2	Medium 2-5	Long >5	
KSO 3: Research, knowledge, & information management	Research, education, training, and awareness raising programs on climate change and responses for water and sanitation in Africa.	National	**WRC, DWS (B: WRM)**, DFFE, CMAs, Universities, Funding Partners.				Number of training and awareness raising meetings and workshops conducted. Number of climate change research studies and products produced.
	Update relevant climate change information systems such as NWIS and WR2012 used to inform water resources planning and design.	National	**DWS (B: WRM)**, WRC, Accademia, PCC, NGOs.				Climate change information on water knowledge portals.
	Develop updated design standards and IWRM process that are based on CRDP.	National	**DWS (B: WRM), DWS (B: Infrastructure)**, WRC, SANRAL, SANCOLD, etc.				Updated IWRM process (Recon studies etc.) and design guidelines for infrastructure such as dams, roads, flood lines.
	Improved monitoring of water resources and water quality, Early Warning Systems (EWS), and Decision Support Systems (DSS).	National and Local	**DWS (B: WRM)**, CMAs, SAWS, DRR, DFFE, SAEON.				Increased number of stream gauges, EWS, and DSS at national and local.
KSO 4: Improved water resources & sanitation management	Improved water use efficiency and reduce non-revenue water losses across all sectors including municipalities, industry, agriculture, mining, energy, transport, and forestry.	Local	**DWS (CD: WUE)**, DALRRD, DFFE, DMME, and Municipalities, etc.				Reduced NRW and AUW. Improved water use efficiency for all sectors.
	Promote alternative sanitation solutions.	Local	**DWS (B: Sanitation)**, SALGA, NT, and Municipalities				Implementation of alternative/ low water use sanitation solutions.
	Improved coordination and integration into planning for more water sensitive cities.	Local	**DWS (B: WRM)**, DALRRD, and Municipalities				Integration of climate change and resilience into local development plans.
	Strengthen regulation, compliance, and enforcements of allocations and RQOs.	Local	**DWS (B: WRM and B: Regulation)**, CMAs, DFFE, etc.				Increased regulation of water use licenses and RQOs.

Key Strategic Objective	Prioprity Actions	Scale	Lead Organisation (bold) & Other Potential Partners	Time Frame (Yr)			Indicators
				Short <2	Medium 2-5	Long >5	
KSO 5: Net-zero carbon for water & sanitation.	Quantify and reduce the carbon footprint of the entire water and sanitation sector.	National and Local.	**DWS (B: WRM and B Sanitation)**, PCC, WRC, SALGA, etc.				Report on the carbon footprint of water and sanitation sector in SA.
	Identify opportunities for re-use of methane emissions from wastewater treatment plants.	Local	DWS (B: WRM and B Sanitation), SALGA, WSA, Municipalities.				Reduced methane emissions from wastewater treatment.
	Support the development of water linked alternative energy sources.	National	DME, DWS, SALGA, ESKOM, Private, etc.				Number of hydropower plants and other water linked renewable energy sources supported in SA.
	Consider the water resources impacts and WEF inter-connections of the Just Energy Transition (JET) in South Africa.	National	DWS (CD: IWRP), DWS (Branch Sanitation), PCC, WRC, NGOs,				Report on the water-energy-food (WEF) links and recommendation for the water in the Just Energy Transition (JET).

5.3 Defining Roles & Responsibilities

There are several critical role players necessary in adapting to the potential impacts of climate change for water and sanitation in South Africa as indicated in the implementation plan shown above (Table 8). The roles and responsibilities of each of these organisations needs to be determined in order for each organisation to identify specific activities that they can undertake to assist with achieving the objectives of the updated Climate Change Response Strategy.

Assigning responsibility is an important step to prioritising and implementing the relevant actions and sub-activities, in accordance with the requirements and timelines. Responsibility should be assigned in accordance with the applicable mandates (e.g., departmental mandates). As such it should be noted that the responsible party has to take ownership, and as such is accountable for implementing the actions assigned to them and also for engaging with other key stakeholders and strategic partners. A RACI framework matrix (Table 9) can be used to assign responsibility to different persons, organisations or government departments.

Table 9: Example of a RACI Matrix

	Responsible	**Accountable**	**Consulted**	**Informed**
List of Actions	**Team member 1**	**Team member 2**	**Team member 3**	**Team member 4**
Action 1	R	A	C	I
Action 2	I	A	R	C
Action 3	RA	C	I	
Action 4	A	R	C	I
Action…	R	I	A	C

5.4 Prioritising Actions & Sub-actions

Several potential actions for improving climate resilience of the water and sanitation sector in South Africa have been identified under each of the fiver KSOs for the updated climate change response strategy. Individual actions should be identified and prioritised through a consultative process with multiple stakeholders across all spheres of government as well as the public.

Actions identified through the consultative process should be compared with other plans from other departments to avoid duplication of efforts. Actions should be refined and ensure that future scenarios are considered in the actions. It is understandable that some actions are long term may take many years before they can be implemented (e.g., development of a new water resource), and as such where applicable these long-term actions must be coupled with short terms solutions until such a time the long-term action can be implemented.
Where required the enabling environment may require strengthening to facilitate the implementing of actions, and as such a review of policy may be necessitated. Where appropriate, actions which are easy to implement and provide significant change should be considered first, however those actions which may be slow and provide complexity when implementing, should not be disregarded as they may be foundational actions that create the enabling environment for further actions to be implemented (Figure 52).

The following should be considered when identifying and prioritising actions:

- Stakeholder identified priorities and actions to brainstorm further possible actions.
- Compare possibilities with existing plans.
- Explore and refine actions – including testing against future scenarios.
- Identify enabling conditions.
- Prioritise adaptation actions.

Implementation Ease					Speed of Change
Difficult	Low impact -difficult/slow	Moderate impact - difficult/slow	High impact - difficult/slow	Change in paradigms	**Slow**
	Low impact -hard/moderately slow	Moderate impact - hard/moderately slow	Culture, power, unwritten rules, ways of working	Significant impact -hard/ moderately slow	
	Low impact -medium/ moderately quick	Relationships & Interactions (Governance)	High impact -medium/ moderately quick	Significant impact -medium/ moderately quick	
Easy	Policies, practices, & resources flows	Moderate impact -easy/quick	High impact -easy/quick	Significant impact -easy/quick	**Quick**
	Low	**Impact/System Change**		**Significant**	

Figure 52: Ease with which actions can be implemented, the speed of implementation and the degree of impact. (The State of Victoria Department of Environment, Land, Water and Planning, 2020).

5.5 Secure Resources & Funding

Securing the funding for implementing the specific actions and in particular for investing in the critical infrastructure, systems and process is critical. There are several possible sources of funding that will need to be explored in terms of each of the identified priority actions. These could include both public sector funding as part of the normal department allocations and budgeting processes, or alternative funding either through the private sector or from international donors and agencies. Securing the necessary financing and funding for implementing the necessary actions to ensure future water security as part of the National Water Security Strategy (NWRS) has been identified as a priority and has led to several innovations including the establishment of the Water Partnerships Office (WPO).
A significant area of opportunity in this regard is access to global climate financing as well as examples of other innovative funding solutions such as the development of Water Funds, Performance Based Contracts (PBC) and Public Private Partnership (PPP) models. Several of these sources of funding require information on climate change risks and adaptation benefits which will be supported through improved information gathering and case studies in South Africa. Support is also needed in the drafting of successful business plans to receive funding.
In addition to securing the funding for implementation of specific actions (and including for critical infrastructure), it is necessary to maintain critical resources in each of the relevant departments. This would require the appointment of key positions and additional training and capacity building of existing DWS, TCTA and municipality staff to fulfil their role in ensuring current and future water security and sustainable sanitation in the face of climate change.

A critical next step for implantation of the Climate Change Response Strategy for Water and Sanitation is to engage with key role players such as the PCC, DBSA, National Treasury and the WPO to develop a guidance note for the leveraging of climate financing options to support implementation and adaptation of critical water and sanitation infrastructure in South Africa.

A recent study by the Development Bank of South Africa (DBSA), has estimated that the South Africa requires around R256 bn per year to close the gaps on meeting the Sustainable Development Goals for water and sanitation. Under a dryer climate scenario (e.g., SSP5-8.5) the total funding requirement could increase by around 8% and in addition investments would be needed much early to prevent growing demand from resulting in failures of water supply.

There are also several options for financing the water and sanitation sector, including access to climate financing. These have been explored by the DBSA (DBSA, 2018), but should be reviewed and updated as part of the implementation of the climate change responses strategy and also in support of implementing the national water and sanitation masterplan (WSMP).

5.6 Develop indicators & timelines for monitoring

Indicators for actions should be developed and should be linked to timelines. Indicators may be linked to climatic variables or may be specific to an action or associated project. By way of example and indicator may be 20% reduction of GHG by 2050. It should be noted that when developing indicators, a baseline whereby performance can be measured against should be done. The baseline can be done either by using existing conditions as the baseline or by developing a benchmark. Furthermore, the relevant data source should also be identified which can be used to inform indicators. The Specific Measurable Attainable Relevant Time (SMART) process can be used to develop good indicators to track successful implementation.
The SMART process is described in the image below (Figure 53):

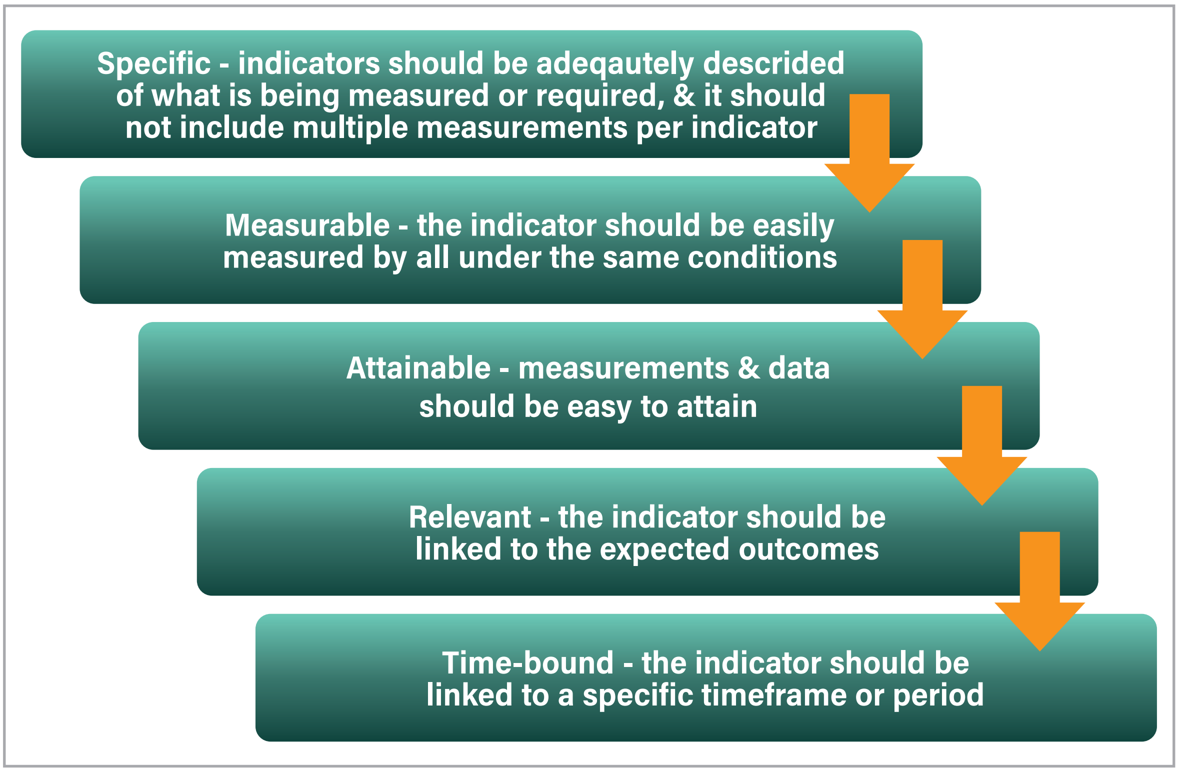


Figure 53: SMART process description

5.7 Establish a Monitoring & Evaluation (M&E) Framework

A provisional monitoring, evaluation, and learning (MEL) framework for the updated national climate change response strategy for the water and sanitation, as presented in Table 10, will enable the sector (with the DWS as the lead) to be able to track progress of the actions against the established indicators. Additionally, it can provide scope whereby timelines and actions need to be adjusted or redefined. The MEL framework should be closely linked to the actions identified, responsible person/institution, and the indicators and timelines. The outcomes and outputs from the M&E framework should be clearly stated, and the reporting processes and frequency should also be determined. The MEL framework can then be used to develop individual annul performance plans (APP) for implementing the priority adaptation actions.

Table 10: Monitoring & Evaluation Frameworl (M&E) Framework

Key Strategic Objective (KSO)	Priority Actions	Indicators	Outcome	Responsible	Time Frame			Data Source	Reporting
					Baseline	Target	Frequency		
KSO 1: Improved collaboration and co-operative governance	Identify, train, and capacitate champions within DWS and with strategic partners.	Identified champions and MOUs with key partners.	A database champion across sector	**DWS (D:CC)**	50 % (Some in place)	80 % (Expand, refresh and develop a database)	Annual	DWS, WRC, CMAs, WSAs, PCC, DFFE, COGTA, NGOs, IDAs, etc.	Monthly entry into the database
	Develop community of practice and identify local experts and forums for collaboration.	National and local level community of practice and forums established.	A platform or forum were expert exchange knowledge and etc.	**DWS (D:CC, CD: IGR)**	40 %	70 %	Biannual	DWS (D:CC, CD: IGR), WRC, PCC, Academia.	Annual meeting or engagements reports
	Ensure alignment across all relevant policies e.g., NAP, NWRS, WSMP, NDP, etc.	Updated NWRS, WSMP, and aligned with national policies.	Aligned sectors policies	**DWS (B: WRM, SU: WRP&E)**	50 %	100 %	Biennial	DWS (B: WRM), PCC, DFFE, DALRRD, etc.	Biennial or as policies is developed or reviewed
	Improve transboundary climate resilience across SADC and river basin organisations.	Updated regional CC response strategy and agreements with RBOs.	Updated regional and developed RBOs CC response strategy	**DWS (CD: IWC)**	40%	70%	Annual	DWS (CD: IWC), LHWC, LIMCOM, ORASECOM, etc.	Annual progress reports
	Monitoring Evaluation and Learning (utilising existing mechanisms and platforms)	Monitoring and feedback report and engagements	All spheres (regional, national and local)	**Regional (river commissions), national (DWS SU: WRPS&E, CD: IGR, CD: CP&OP)**	40%	70%	Annual	Regional (river commissions), national (DWS SU: WRPS&E, CD: IGR, CD: CP&OP)	Annual reports, indicating implementation of feedback and impact
KSO 2: Increased investments in climate resilient infrastructure.	Augment and strengthen existing integrated bulk water supply systems including	Updated Reconciliation and All Town strategies and implementation	National and Local Level	**DWS (B: WRM and B: Infrastructure),** CMAs, TCTA, DBSA, National	TBD (from reconciliation reports and implementation plans)	100%	Biennial	Updated Reconciliation and All Town strategies and implementation of	Reports, indicating implementation of feedback and impact

Key Strategic Objective (KSO)	Priority Actions	Indicators	Outcome	Responsible	Time Frame			Data Source	Reporting
					Baseline	Target	Frequency		
	the implementation of delayed infrastructure and improved operational rules and allocations.	of required augmentation.		Treasury, Municipalities, Private Sector, IDAs, etc.				required augmentation.	
	Promote and support alternative and conjunctive use of water source options.	Percentage water use from alternative water sources. Number of municipalities with conjunctive water use.	National and Local Level	**DWS (CD: IWRP),** CMAs, TCTA, DBSA, Municipalities, Private Sector, IDAs, etc.	23%	37% (by 2040)	Annual	Percentage water use from alternative water sources. Number of municipalities with conjunctive water use.	Reports, indicating implementation of feedback and impact
	Protect and improve investments in Ecological Infrastructure (EI) and Ecosystem Based Adaptation (EbA) recognising both the benefits, but also potential areas of concern.	Hectares of IAPs removed and maintained. Number of rehabilitated wetlands.	National and Local Level	**DFFE,** DWS, CMAs, DALRRD, SANBI, Municipalities, NGOs, and Private Sector.	11% (well protected; 70% have no protection)	100%	Biannual	Hectares of IAPs removed and maintained. Number of rehabilitated wetlands.	Reports, indicating implementation of feedback and impact
	Improve climate resilience of existing (and new) water and sanitation infrastructure.	Climate change risk and vulnerability assessments for critical water infrastructure.	National and Local Level	**DWS (B: WRM and B: Infrastructure)**, TCTA, WSP, Municipalities, etc.	TBD (from Climate change risk and vulnerability assessments)	100%	Annual	Climate change risk and vulnerability assessments for critical water infrastructure.	Reports, indicating implementation of feedback and impact
KSO 3: Research, knowledge, and information management	Research, education, training, and awareness raising programs on	Number of training and awareness raising meetings	National	**WRC,** DWS, DFFE, CMAs, Universities, Funding Partners.	43% (have heard of climate change)	57% (have not heard of climate change)	Annual	Number of training and awareness raising meetings and	Reports, indicating implementation of feedback and impact

Key Strategic Objective (KSO)	Priority Actions	Indicators	Outcome	Responsible	Time Frame			Data Source	Reporting
					Baseline	Target	Frequency		
	climate change and responses for water and sanitation in South Africa.	and workshops conducted.						workshops conducted.	
	Update relevant climate change information systems such as NWIS and WR2012 used to inform water resources planning and design.	Climate change information on water knowledge portals.	National	**DWS (B: WRM),** WRC, Accademia.	50%	100% (all systems updated)	Annual	Climate change information on water knowledge portals.	Reports, indicating implementation of feedback and impact
	Develop updated design standards and IWRM process that are based on CRDP.	Updated IWRM process (Recon studies etc.) and design guidelines for infrastructure such as dams, roads, flood lines.	National	**DWS (B: WRM), DWS (B: Infrastructure),** WRC, SANRAL, SANCOLD, etc.	TBD from recon studies and design guidelines	100%	Annual	Updated IWRM process (Recon studies etc.) and design guidelines for infrastructure such as dams, roads, flood lines.	Reports, indicating implementation of feedback and impact
	Improved monitoring of water resources and water quality, Early Warning Systems (EWS), and Decision Support Systems (DSS).	Increased number of stream gauges, EWS, and DSS at national and local.	National and Local.	**DWS (B: WRM),** CMAs, SAWS, DRR, DFFE, SAEON.	TBD from DWS and development of EWS and DSS	100%	Annual	Increased number of stream gauges, EWS, and DSS at national and local.	Reports, indicating implementation of feedback and impact
KSO 4: Improved water resources and	Improved water use efficiency and reduce non-revenue water	Reduced NRW and AUW.	Local	**DWS (CD: WUE)**, DALRRD, DFFE, DMME, and	40.7%	10%	Annual	Reduced NRW and AUW.	Reports, indicating implementation

Key Strategic Objective (KSO)	Priority Actions	Indicators	Outcome	Responsible	Time Frame			Data Source	Reporting
					Baseline	Target	Frequency		
sanitation management	losses across all sectors including municipalities, industry, agriculture, mining, energy, transport, and forestry.	Improved water use efficiency for all sectors.		Municipalities, etc.				Improved water use efficiency for all sectors.	of feedback and impact
	Promote alternative sanitation solutions.	Implementation of alternative/low water use sanitation solutions.	Local	**DWS (B: Sanitation)**, SALGA, NT, and Municipalities	17% (based on safe sanitation in-place)	40%	Annual	Implementation of alternative/low water use sanitation solutions.	Reports, indicating implementation of feedback and impact
	Improved coordination and integration into planning for more water sensitive cities.	Integration of climate change and resilience into local development plans.	Local	**DWS (B: WRM)**, DALRRD, and Municipalities	TBD from baseline report	100%	Biennial	Integration of climate change and resilience into local development plans.	Reports, indicating implementation of feedback and impact
	Strengthen regulation, compliance, and enforcements of allocations and RQOs.	Increased regulation of water use licenses and RQOs.	Local	**DWS (B: WRM and B: Regulation),** CMAs, DFFE, etc.	63% (WULA applications processed)	100%	Annual	Increased regulation of water use licenses and RQOs.	Reports, indicating implementation of feedback and impact
KSO 5: Net-zero carbon for water and sanitation.	Quantify and reduce the carbon footprint of the entire water and sanitation sector.	Report on the carbon footprint of water and sanitation sector in SA.	National and Local.	**DWS (B: WRM and B: Sanitation),** PCC, WRC, SALGA, etc.	TBD from quantification reports	Net-zero	Biennial	Report on the carbon footprint of water and sanitation sector in SA.	Reports, indicating implementation of feedback and impact
	Identify opportunities for re-use of methane emissions from	Reduced methane emissions from wastewater treatment.	Local	**DWS (B: WRM and B: Sanitation),** SALGA, WSA, Municipalities.	TBD based on report where re-use projects are in development	TBD based on feasibility studies of WWTW	Annual	Reduced methane emissions from wastewater treatment.	Reports, indicating implementation of feedback and impact

Key Strategic Objective (KSO)	Priority Actions	Indicators	Outcome	Responsible	Time Frame			Data Source	Reporting
					Baseline	Target	Frequency		
	wastewater treatment plants.								
	Support the development of water linked alternative energy sources.	Number of hydropower plants and other water linked renewable energy sources supported in SA.	National	**DME,** DWS, SALGA, ESKOM, Private, etc.	39 (number of hydropower plants)	TBD based on feasibility studies	Biennial	Number of hydropower plants and other water linked renewable energy sources supported in SA.	Reports, indicating implementation of feedback and impact
	Consider the water resources impacts and WEF inter-connections of the Just Energy Transition (JET) in South Africa.	Report on the water-energy-food (WEF) links and recommendation for the water in the Just Energy Transition (JET).	National	**DWS (CD: IWRP)**, DWS (Branch Sanitation), PCC, WRC, NGOs,	Requires reporting on multiple indicators	TBD	Annual	Report on the water-energy-food (WEF) links and recommendation for the water in the Just Energy Transition (JET).	Reports, indicating implementation of feedback and impact

5.8 Water & Sanitation Sector's Milestones towards 2050

The NCCRS seeks to realise the vision of "a low-carbon, climate-resilient, equitable, efficient and sustainable water and sanitation sector by 2050", through the milestones presented in the Table 11.

Table 11: Water & Sanitation Sector's Milestones towards 2050

Key Strategic Objective (KSO)	By 2025	By 2030	By 2040
KSO 1: Improved collaboration & co-operative governance	• Champions identified and engaged in DWS regional offices and CMAs and with other strategic partners. • Mainstreaming of Climate Change (including climate adaptation and mitigation) in the water and sanitation sectors strategies, planning, operations, and budgeting. To manage the climate change in the sector and interactions across all sectors • Contribute towards watering of the nationally determined contributions (NDCs) and national adaptation plans (NAPs), to include resilient water management approaches.	• Community of practice established for climate resilience for water. • Support the NDCs and NAPs to have specific water plan and budget that addresses the climate–water interactions across all sectors • Strengthened collaboration on water resources management and climate resilience actions from national down to local level (i.e., municipalities, CMAs, and water boards).	• Seamless collaboration and planning for water resilience across all relevant departments and with strong national to local level collaboration for planning, operations, and management. • Active and engaged community of practice that contribute towards climate change adaptive management.
KSO 2: Increased investments in climate resilient infrastructure.	• Progress with implementation of strategic infrastructure projects (SIPs) for water and sanitation. • Identify priority locations of ecological infrastructure (EI) for enhanced climate resilience. • Explore investment mechanisms for local and international climate financing for the water and sanitation sector towards building a climate resilient infrastructure and EI (Water Partnership Office).	• Completion of SIPs and identification of additional strategic infrastructure. Ensure protection of all ecological infrastructure and climate resilient infrastructure in the sector. • Updated standards and guidelines for climate resilient infrastructure and IWRM process including reconciliation studies, RQOs, and municipality water safety planning.	• Additional augmentation options identified, and infrastructure operating rules adapted to account for continued climate change. • Full protection of SWSA and continue maintenance of EI.
KSO 3: Research, knowledge, information management	• Identify priority research areas and establish strategic partnerships. • Updated climate change scenarios on existing information platforms and adapted for use in water resources planning, and water safety planning by municipalities. • Review existing decision support systems, early warning systems and real-time operation systems already implemented in RSA.	• Infrastructure design guidelines and IWRM process updated to better include climate change. • Improved monitoring of climate and water resources information. • Scale up decision support systems (DSS) and real time operating systems for improved operations	• Fully integrated water resources and climate change information systems that support resilient planning and near real time operations for improved water use efficiency, disaster reduction and long-term infrastructure planning. • Readily accessible information and research products related to climate resilience for water.

5.8 Water & Sanitation Sector's Milestones towards 2050 (continued)

Table 11: Water & Sanitation Sector's Milestones towards 2050

Key Strategic Objective (KSO)	By 2025	By 2030	By 2040
KSO 4: Improved water resources & sanitation management	• Several cities in South Africa have been benchmarked using the water sensitive cities index (WSCI) adapted for application in Africa. • Urban Water Resilience Plans developed for major metros in SA to test the concept and to provide guidance on application in RSA. • Alignment of existing Urban Water Resilience Plans with urban Water Services Development Plans.	• Ensure water and wastewater utilities improve climate resilience through better climate risk management practices. • Improve universal and equitable access to safe, affordable, and climate-resilient drinking water and sanitation services. • Updated operating rules for existing infrastructure to included additional flood risk management.	• Ensure local municipalities are no longer water stressed but water resilient and adaptable. • Ensure that 100 per cent of all municipal, industrial, and agricultural wastewater is treated for reuse or discharged safely into the environment. • Non-revenue water is reduced to 20 percent, over 80 % of the system. • Several cities in South Africa recognized as water sensitive.
KSO 5: Net-zero carbon for water & sanitation	• Quantification of the carbon footprint of the water and sanitation sector and opportunities develop a Net-zero plan for the water sector. • Incorporate water resources, water supply and sanitation links in the Just Energy Transition (JET) plan. • Contribute towards the nationally determined contributions (NDCs) and national adaptation plans (NAPs) updates, and the inclusion of tools for GHG mitigation, such as low carbon urban water supply systems and wastewater management and carbon sequestration through restoration of catchments and protection of aquatic ecosystems.	• Increase the use of renewable energy in water extraction, transfer, treatment, and reuse. At the same time, ensure that the consumption of non-renewable energy does not increase with an increase in alternative water supply sources such as desal and re-use. • Ensure water and wastewater utilities reach 50 % or net-zero energy. • Protection and restoration of water-related natural ecosystems to maximise carbon sequestration and ecosystem services by natural ecosystems.	• Water and wastewater utilities reach net-zero energy usage. • Overall water use efficiency for the energy sector is reduced.

6. CONCLUSION & THE WAY FORWARD

It is clear that climate change is already starting to have a major impact on water security and infrastructure in South Africa and any delays in responding to these increasing risks will make it increasingly difficult to adapt in future and result in further damage and economic impacts.

Additionally, the various effects and hazards are likely to be unevenly distributed across the country. By way of example some areas are expected to experience (worsened) prolonged drought but little flooding, whereas other areas may experience (worsened) flooding but little drought. Many areas are likely to experience both increased floods and droughts. Additionally, demand is expected to increase under the influence of climate related drivers and population growth and that demand will also be unevenly distributed. Monitoring of various climate variables will be crucial in understanding the effects of climate change at the ground level.

Adaptation to climate change will likely require a change in behaviour and practices across various sectors and at the household level as well as a greater awareness of the importance of maintaining critical water infrastructure and sanitation systems. While the DWS and its partners have a clear role to support the implementation of critical (and in many cases already delayed) water resources infrastructure, there is also a responsibility of individual municipalities and water services providers to also support the implementation of critical water and sanitation infrastructure as well as improved operations and maintenance. There is also a responsibility for individual users in all sectors to become more efficient in their use of water.

A greater awareness of the increasing water security risks faced across much of the country and the impact that this will have on the economy and livelihoods is forcing increased collaboration between different parties. This requires increased collaboration and access to reliable information and decision-making capabilities, as well as sustainable funding solutions.

The full effects of climate change on sanitation are not very well understood, but the failure to implement sustainable sanitation solutions is becoming increasingly more obvious and challenge for the DWS, municipalities, and other partners, and will also need to be addressed in the Climate Change Strategy. The main climate change threat to sanitation due to lack of availability of water and sufficient water supply infrastructure to improve the reliability of supply.

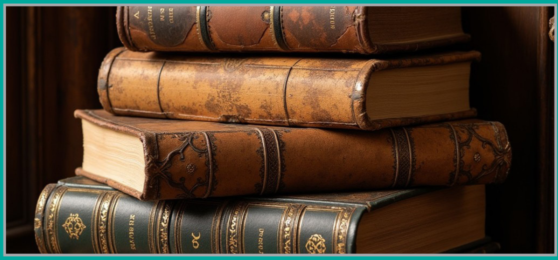
The potential for increased flooding and landslides as a result of climate change also poses a direct threat to the sustainability of critical water and sanitation infrastructure that needs to be addressed through the development of more climate resilient infrastructure and also putting in place measure to reduce the potential impact such as through investing in ecological infrastructure, improved catchment management and improved urban planning for resilience

In terms of the Way Forward, the immediate priority actions for DWS (i.e., the FIVE BOLD STEPS) that need to be taken to advance the updated climate change strategy are as follows:

- Implement critical (and delayed) water supply and sanitation infrastructure.
- Integrated climate change response actions into the NWRS and WSMP and the NAP.
- Raise awareness of climate change risks within DWS and alignment with the JET.
- Identify critical areas of research including updating of IWRM guidelines and practices.
- Help develop guidance on securing climate finance for water security and sanitation.

The development of the updated NCCRS for water and sanitation has undergone extensive stakeholder engagement to try and accommodate all voices. It has also been developed in the specific context of promoting Gender, Equity and Social Inclusion (GESI). In addition to the updating of the NCCRS, the DWS is also currently revising the latest version of the National Water Resources Strategy (NWRS) and the Water and Sanitation Master Plan (WSMP). These documents together form a comprehensive approach to improved water security in the country.

7. REFERENCES



Adjum F, Bazilian M, Cullis JDS, DeLaquil P, Delgado A, Goldstein G, Liden R, Merven B, FMiralles-Wilhelm F, Rodriguez D, Sohns A, Stone A, and Toman M, 2017. "Water Constrains South Africa's Energy Future: A Case Study on Integrated Energy-Water Nexus Modelling and Analysis". The International Journal of Engineering and Science (IJES), Vol. 6(10) pp. 01-25 2017 ISSN (e): 2319-1813 ISSN (p): 2319-1805.

Altieri, M.A., Nicholls, C.I., Henao, A., Lana, M.A., 2015. Agroecology and the design of climate change-resilient farming systems. Agronomy for Sustainable Development. https://doi.org/10.1007/s13593-015-0285-2

Amanambu AC, Obarein OA, Mossa J, et al (2020) Groundwater system and climate change: Present status and future considerations. J Hydrol (Amst) 589:125163

Andersson, K., Reckerzuegl, T., Michels, A., & Rüd, S. (2019). Opportunities for sustainable sanitation in climate action - Factsheet of Working Group 3. Retrieved from https://www.susana.org/en/knowledgehub/resources-and-publications/library/details/3678

Amis, M. and Lugogo, S. 2018. The South Africa Water Innovation Story. Water Research Commission. http://africancentre. org/AfC2/wp-content/uploads/2018/08/SP-126-Water-Innovation-story-web. pdf

Batchelor, C., Lovell, C., Murata, M., 1996. Simple microirrigation techniques for improving irrigation efficiency on vegetable gardens. Agricultural Water Management 32, 37–48. https://doi.org/10.1016/S0378-3774(96)01257-7

BBC, 2021. What is climate change? A really simple guide.

Berga, L., 2016. The Role of Hydropower in Climate Change Mitigation and Adaptation: A Review. Engineering 2, 313–318. https://doi.org/10.1016/J.ENG.2016.03.004

Bopape, M.-J.M., Sebego, E., Ndarana, T., Maseko, B., Netshilema, M., Gijben, M., Landman, S., Phaduli, E., Rambuwani, G., van Hemert, L., Mkhwanazi, M., 2021. Evaluating South African Weather Service information on Idai tropical cyclone and KwaZulu- Natal flood events. South African Journal of Science 117. https://doi.org/10.17159/sajs.2021/7911

Burgiel, S.W., Muir, A.A., Global Invasive Species Programme., 2010. Invasive species, climate change and ecosystem-based adaptation: addressing multiple drivers of global change. Global Invasive Species Programme.

C40 Cities Finance Facility (2019) Transformative Riverine Management Projects in Durban: Background and Structuring. Source: wwwc40cff.org.

California-Nevada Climate Applications Program, 2022. EVAPORATIVE DEMAND.

Casey, T., 2015. Net Zero Lessons From A Wastewater Treatment Plant [WWW Document].

Cervigni, Raffaello; Liden, Rikard; Neumann, James E.; Strzepek, Kenneth M. 2015. Enhancing the Climate Resilience of Africa's Infrastructure: The Power and Water Sectors. Africa Development Forum. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/21875

Chesterfield, C., Urich, C., Beck, L., Burge, K., Castonguay, A., Brown, R.R., Dunn, G., de Haan, F., S Lloyd, S., Rogers, B.C., Wong, T.H.F., 2016. A Water Sensitive Cities Index -Benchmarking cities in developed and developing countries.

Climate Action Tracker Group, 2021. Temperatures.

Coast Adapt, 2018. Monitoring and Evaluation in climate change adaptation [WWW Document]. URL https://coastadapt.com.au/how-to-pages/monitoring-and-evaluation-climate-change-adaptation (accessed 4.6.22).

Cole, M.J., Bailey, R.M, Cullis, J.D.S. and New, M.G. 2017. Spatial inequality in water access and water use in South Africa. Water Policy 1-16. Doi: 10.2166/wp.2017.111.

CTCN, 2022. Climate change monitoring [WWW Document]. URL https://www.ctc-n.org/technologies/climate-change-monitoring (accessed 4.6.22).

Cullis, J., Alton, T., Arndt, C., Cartwright, A., Chang, A., Gabriel, S., Gebretsadik, Y., Hartley, F., de Jager, G., Makrelov, K., Robertson, G., Schlosser, C.A., Strzepek, K., Thurlow, J., 2015. An uncertainty approach to modelling climate change risk in South Africa. UNU-WIDER. https://doi.org/10.35188/UNU-WIDER/2015/934-3

Cullis, J., Phillips, M., 2019. Green Book. Surface Water Supply. Water supply climate risk narrative for South Africa.

Cuthbert MO, Taylor RG, Favreau G, et al (2019) Observed controls on resilience of groundwater to climate variability in sub-Saharan Africa. Nature 572:230–234. **https://doi.org/10.1038/s41586-019- 1441-7**

David Herring, Rebecca Lindsey, 2020. What evidence exists that Earth is warming and that humans are the main cause? [WWW Document].

Davies, R., 2021. South Africa – Over 30 Fatalities Reported After Weeks of Flooding [WWW Document]. URL https://floodlist.com/africa/south-africa-floods-january-february-2021 (accessed 4.7.22).

DEA, 2013. Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Pretoria.

DEA and SAWS, 2016. National Framework for Climate Services-South Africa (NFCS-SA).

Dehnen-Schmutz, K. and Touza, J. 2008. Plant invasions and ornamental horticulture: pathway, propagule pressure and the legal framework. Floriculture, Ornamental and Plant biotechnology 5, 15-21.

DFFE, 2022. Working for Water (WfW) programme [WWW Document]. URL https://www.dffe.gov.za/projectsprogrammes/wfw (accessed 3.25.22).

DFFE, 2019. National Climate Change Adaptation Strategy Republic of South Africa.

DFFE, 2020. National Climate Change Adaptation Strategy Republic of South Africa

Dobriyal, P., Badola, R., Tuboi, C., Hussain, S.A., 2017. A review of methods for monitoring streamflow for sustainable water resource management. Applied Water Science 7, 2617–2628. https://doi.org/10.1007/s13201-016-0488-y

Dragoni W, Sukhija BS (2008) Climate change and groundwater: A short review. Geol Soc Spec Publ 288:1–12. https://doi.org/10.1144/SP288.1/ASSET/09EACB5D-DBC6-4583-A686-C72DC780A566/ASSETS/IMAGES/LARGE/1297CH01F01.JPG

Du Plessis J.A. and Masule S. 2023. Revised Regional Maximum Flood (RMF) method and regionalisation. J.S.Afr.Inst. Civ. Eng. Vol.65 n.3. September 2023.

DWS, 2013. National Climate Change Response Strategy for the Water Sector.

DWS, 2018. Water and Sanitation Master Plan. Call to Action. October 2018.

DWS, 2021. National Water Resources Strategy 3. DRAFT 2.6. November 2021.

DWS, 2023. Green Drop, Blue Drop and No-Drop Assessment Report.

ESI Africa. (2016). Biogas – South Africa's great untapped potential. https://www.esi-africa.com/magazine-article/biogas-south-africas-great-untapped-potential/

Farouk, A.M., Rahman, R.A., Romali, N.S., 2021. Non-Revenue Water Reduction Strategies: A Systematic Review. Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-04-2021-0071

Fecht, S., 2019. How Climate Change Impacts Our Water [WWW Document].

Friedrich, E., Pillay, S., Buckley, C.A., 2009. Carbon footprint analysis for increasing water supply and sanitation in South Africa: a case study. Journal of Cleaner Production 17, 1–12. https://doi.org/10.1016/j.jclepro.2008.03.004

GreenAgri, 2022. Smart Agri plan [WWW Document]. URL https://www.greenagri.org.za/smartagri-2/smartagri-plan/ (accessed 4.5.22).

Hohne, D., Esterhuyse, C., Fourie, F., Gericke, H., Esterhuyse, S., 2021. Enhancing groundwater recharge in the main Karoo, South Africa during periods of drought through managed aquifer recharge. Journal of African Earth Sciences 176, 104007. https://doi.org/10.1016/j.jafrearsci.2020.104007

Howard, G., Calow, R., Macdonald, A., Bartram, J., 2016. Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. Annual Review of Environment and Resources 41, 253–276. https://doi.org/10.1146/annurev-environ-110615-085856

Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H., 2007. Adapting agriculture to climate change. Proc Natl Acad Sci U S A. https://doi.org/10.1073/pnas.0701890104

Howell, T.A., 2003. Irrigation Efficiency. Encyclopaedia of Water Science 467–472.

Hudson, O., 2022. How Does Climate Change Affect Environmental Monitoring? [WWW Document]. URL https://www.azocleantech.com/article.aspx?ArticleID=1477 (accessed 4.6.22).

Hughes D A, Andersson L. Wilk J, Savenije, H. (2006) “Regional calibration of the Pitman model for the Okavango River” Journal of Hydrology 333/1 30-42.

IIED, 2018. Supporting national monitoring and evaluation systems to enable adaptation assessment and reporting [WWW Document]. URL https://www.iied.org/supporting-national-monitoring-evaluation-systems-enable-adaptation-assessment-reporting (accessed 4.6.22).

IPCC, 2022. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Jardine, S.L. and Sanchirico, J.N. 2018. Estimating the cost of invasive species control. Journal of Environmental Economics and Management 87, 242-257.

Johnson, KA and Smithers, JC. 2020. Updating the estimation of 1-day probable maximum precipitation in South Africa. Journal of Hydrology: Regional Studies 32 100736. https://doi.org/10.1016/j.ejrh.2020.100736.

Kaiser G. (2019), Building Water Resilience into strategy: The Cape Town Drought. Chapter in *Resilience of Water Supply in Practice: Experiences from the Frontline. Leslie Morris-Iverson and St John Day (Eds)*

Kihila, J.M., 2017. Indigenous coping and adaptation strategies to climate change of local communities in Tanzania: a review. Climate and Development 406–416.

Kingdom, B., Soppe, G., Sy, J., 2016. What is non-revenue water? How can we reduce it for better water service? [WWW Document]. URL https://blogs.worldbank.org/water/what-non-revenue-water-how-can-we-reduce-it-better-water-service (accessed 4.4.22).

le Maitre, D.C., Blignaut, J.N., Clulow, A., Dzikiti, S., Everson, C.S., Görgens, A.H.M., Gush, M.B., 2020. Impacts of Plant Invasions on Terrestrial Water Flows in South Africa, in: Biological Invasions in South Africa. Springer International Publishing, Cham, pp. 431–457.

Macdonald, G, J. (1990). The Future Of Methane As An Energy Resource. Annual Reviews. Energy. 15:53-83

Daelman, M.R.J. van Voorhuizen, E.M. van Dogen, U.G.J.M. Volcke, E.I.P. van Loosdrecht, M.C.M. (2012). Methane emission during municipal wastewater treatment. Water Research. 46: 3657-3670

Miller JA, Dunford AJ, Swana KA, et al (2017) Stable isotope and noble gas constraints on the source and residence time of spring water from the Table Mountain Group Aquifer, Paarl, South Africa, and implications for large scale abstraction. J Hydrol (Amst) 551:100–115. https://doi.org/10.1016/J.JHYDROL.2017.05.036

Miller JA, Turner KB, Watson A, et al (2022) Characterisation of groundwater types and residence times in the Verlorenvlei catchment, South Africa to constrain recharge dynamics and hydrological resilience. J Hydrol (Amst) 613:128280.

Mukumba, P. Makaka, G. Mamphweli, S. (2016). Biogas Technology In South Africa, Problems, Challenges And Solutions. International Journal of sustainable energy and environmental research. Vol 5, No 4. Pp 58-69. https:// DOI: 10.18488/journal.13/2016.5.4/13.4.58.69

Muller M (2018) Lessons from Cape Town's Drought. *Nature* 559 (7713):174-176.

Muller M (2021). Managing Current Climate Variability can Ensure Water Security Under Climate Change. in W. Leal Filho et al (eds), *African Handbook of Climate Change Adaptation.*

Multsch, S., Elshamy, M.E., Batarseh, S., Seid, A.H., Frede, H.-G., Breuer, L., 2017. Improving irrigation efficiency will be insufficient to meet future water demand in the Nile Basin. Journal of Hydrology: Regional Studies 12, 315–330. https://doi.org/10.1016/j.ejrh.2017.04.007

NASA, 2022. Overview: Weather, Global Warming and Climate Change [WWW Document].

Nziguheba, G., Zingore, S., Merckx, R., Kihara, J., Njoroge, S., Otinga, A., Vandamme, E., Vanlauwe, B., 2015. Phosphorus in smallholder farming systems of sub-Saharan Africa: implications for agricultural intensification. Springer Link 321–340.

O'Connor, T.G. and van Wilgen, B.W. 2020. The impact of invasive alien plants on rangelands in South Africa. Biological Invasions in South Africa 14, 459-487.

Oates, N., Ross, I., Calow, R., Carter, R., & Doczi, J. (2014). Adaptation to Climate Change in Water, Sanitation and Hygiene - Assessing risks and appraising options in Africa. London: Overseas Development Institute.

Otto, F. E. L. *et al.* (2018) 'Anthropogenic influence on the drivers of the Western Cape drought 2015-2017', *Environmental Research Letters*, 13(12).

OECD, n.d. Water risks, disasters and climate change [WWW Document]. URL https://www.oecd.org/water/risks-disasters-and-climate-change.htm (accessed 3.17.22).

Palutikof, J.P., Street, R.B., Gardiner, E.P., 2019. Decision support platforms for climate change adaptation: an overview and introduction. Climatic Change 153, 459–476. https://doi.org/10.1007/s10584-019-02445-2

Pitman, W., 2011. Overview of water resource assessment in South Africa: Current state and future challenges. Water SA 37. https://doi.org/10.4314/wsa.v37i5.3

Pitman, W. V. (1973). A mathematical model for generating monthly river flows from meteorological data in South Africa. Report No. 2/73, Hydrological Research Unit, University of the Witwatersrand, Johannesburg.

Ray, P.A., Brown, C.M., 2015. Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework. The World Bank. https://doi.org/10.1596/978-1-4648-0477-9

Riedel T (2019) Temperature-associated changes in groundwater quality. J Hydrol (Amst) 572:206–212. https://doi.org/10.1016/J.JHYDROL.2019.02.059

SANBI (2020) Ecosystem-based Adaptation in South Africa. Fact Sheet. DFFE and SANBI.

Samora, I., Manso, P., Franca, M.J., Schleiss, A.J., Ramos, H.M., 2016. Energy recovery using micro-hydropower technology in water supply systems: The case study of the city of Fribourg. Water (Switzerland) 8. https://doi.org/10.3390/w8080344

Schlosser, C.A., Gao, X., Strzepek, K., Sokolov, A., Forest, C.E., Awadalla, S., Farmer, W., 2013. Quantifying the Likelihood of Regional Climate Change: A Hybridized Approach. Journal of Climate 26, 3394–3414. https://doi.org/10.1175/JCLI-D-11-00730.1

Schulze, R.E. (2011). A 2011 perspective on climate change and the South African water sector.

Schütte, S, Schulze, RE and Clark, DJ (eds.). 2023. 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. Water Research Commission, Pretoria, RSA. 271pp. **https://www.wrc.org.za/wp-content/uploads/mdocs/2833%20Report%201%20Methodology%20and%20Results.pdf**

Schulze, RE and Schütte, S (eds.) 2023. 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 WRC Report No. 2833/2/22. Water Research Commission, Pretoria, RSA. 76pp. **https://www.wrc.org.za/wp-content/uploads/mdocs/2833%20Report%202%20Adaptation%20Perspectives.pdf**

Schulze RE (ed.) 2023. 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. Water Research Commission, Pretoria, RSA. 215pp. **https://www.wrc.org.za/wp-content/uploads/mdocs/2833%20Report%203%20Verification%20Final.pdf**

SICE, n.d. EARLY WARNING SYSTEMS AND DECISION SUPPORT SYSTEM.

Smith, H., 2022. As drought ligers, larger and more destructive wildfires pose new threats to water supply. Los Angeles Times.

South Africa, 2019. South Africa’s Low Emission Development Strategy.

South African National Biodiversity Institute, n.d. What is Ecosystem-based Adaptation?

South African National Biodiversity Institute, n.d. A GREATER CAPE TOWN WATER FUND FOR ECOLOGICAL INFRASTRUCTURE [WWW Document].

South African Weather Service, 2021. Annual State of the Climate of South Africa 2020.

Stringer, L.C., Fraser, E.D.G., Harris, D., Lyon, C., Pereira, L., Ward, C.F.M., Simelton, E., 2020. Adaptation and development pathways for different types of farmers. Environmental Science and Policy 104, 174–189. https://doi.org/10.1016/j.envsci.2019.10.007

The World Bank Group, 2022. UNACCOUNTED-FOR WATER [WWW Document]. URL http://web.worldbank.org/archive/website00857/WEB/OTHER/6C586003.HTM?OpenDocument#:~:text=Unaccounted%2Dfor%20Water%20(UFW),water%20used%20by%20the%20customers. (accessed 4.4.22).

Tererai, F., Gaertner, M., Jacobs, S. and Richardson, D. 2015. Eucalyptus camaldulensis invasion in riparian zones reveals few significant effects on soil physico-chemical properties. River Research and Applications 31(5), 590-601.

The State of Victoria Department of Environment, Land, Water and Planning. (2020). Regional Climate Change Adaptation Strategy: Guidance Note 6. https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0042/489687/RAS-GN6_Identifying-and-prioritising-actions-.pdf

Turton, A., 2016. South Africa and the drought that exposed a young democracy. Water Policy 18, 210–227. https://doi.org/10.2166/wp.2016.020

UN environment programme, 2022. What is ecosystem-based adaptation? [WWW Document].

UNDESA, n.d. International Decade for Acrion “Water for Life” [WWW Document]. URL https://www.un.org/waterforlifedecade/water_and_sustainable_development.shtml (accessed 3.15.22).

UNICEF. (2022). Water, sanitation, and hygiene (WASH) and climate change. Retrieved from UNICEF: https://www.unicef.org/wash/climate

United Nations Independent Expert. (2010). Climate Change and the Human Rights to Water and Sanitation - Position Paper. Office of the United Nations High Commissioner for Human Rights. Retrieved from https://www.ohchr.org/sites/default/files/Documents/Issues/Water/Climate_Change_Right_Water_Sanitation.pdf

U.S. Department of Commerce, n.d. What is an invasive species? [WWW Document].

USGCRP, 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.

Van Wyk M. Hansen C.D, Bekker A and Mahamba NN (2023) The South African Hydropower Atlas. Report to the Water Research Commission. TT 916/23.

van Wilgen, B.W., Measey, J., Richardson, D.M., Wilson, J.R., Zengeya, T.A. (Eds.), 2020. Biological Invasions in South Africa. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-030-32394-3 van Wyk E (2010) Estimation of episodic groundwater recharge in semi-arid fractured hard rock aquifers. University of the Free State

Vinke, K., Bergmann, J., Blocher, J., Upadhyay, H., Hoffmann, R., 2020. Migration as Adaptation? Migration Studies 8, 626–634. https://doi.org/10.1093/migration/mnaa029

Watson A, Eilers A, Miller JA (2020) Recharge Estimation Using CMB and Environmental Isotopes in the Verlorenvlei Estuarine System, South Africa, and Implications for Groundwater Sustainability in a Semi-Arid Agricultural Region. Water 2020, Vol 12, Page 1362 12:1362. https://doi.org/10.3390/W12051362

Werners, S.E., Sparkes, E., Totin, E., Abel, N., Bhadwal, S., Butler, J.R.A., Douxchamps, S., James, H., Methner, N., Siebeneck, J., Stringer, L.C., Vincent, K., Wise, R.M., Tebboth, M.G.L., 2021. Advancing climate resilient development pathways since the IPCC's fifth assessment report. Environmental Science & Policy 126, 168–176. https://doi.org/10.1016/j.envsci.2021.09.017

Wille, P. van der Merwe-Botha, M. Steytler, B. (2020). A Practical Guideline for Energy Efficiency Audits at Wastewater Treatment Works: guideline for wastewater practitioners and energy managers involved in the planning, design, operation, maintenance and management of energy in wastewater treatment. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and South African German Energy Programme (SAGEN)

World Bank (2022). "The Economic Implications of Water Resources Management in the Western Cape Water Supply System." World Bank, Washington, DC.

World Resources Institute (2021). Water Resilience in a Changing Urban Context. Africa's challenge and Pathways for Action. World Resources Institute. Washington DC, USA.

Van Niekerk, (W). Pieterse, A. (2021). Green Book [WWW Document].

WRC Report No. 1843/2/11. Water Research Commission, Pretoria.

Ziervogel G. (2019) *Unpacking the Cape Town Drought; Lessons Learnt.* Report for the Cities Support Program undertaken by African Centre for Cities. February 2019.

APPENDIX: COMPARISON OF FUTURE CLIMATE CHANGE SCENARIOS

A comparison of the potential impacts of different climate change scenarios and projections for each of the hydro-climatic zones of South Africa are presented here in the form of “plume plots”. The plume plots represent the range of potential impacts (10th to 90th percentile) of the different climate model projections for each of the future global emission scenarios. This comparison allows for a general consideration of the range of potential impacts and the comparison between the different projects and selected model scenarios used in South Africa. Analysis of Plume Plots is undertaken for each of the hydro-climatic zones shown in Figure A1.

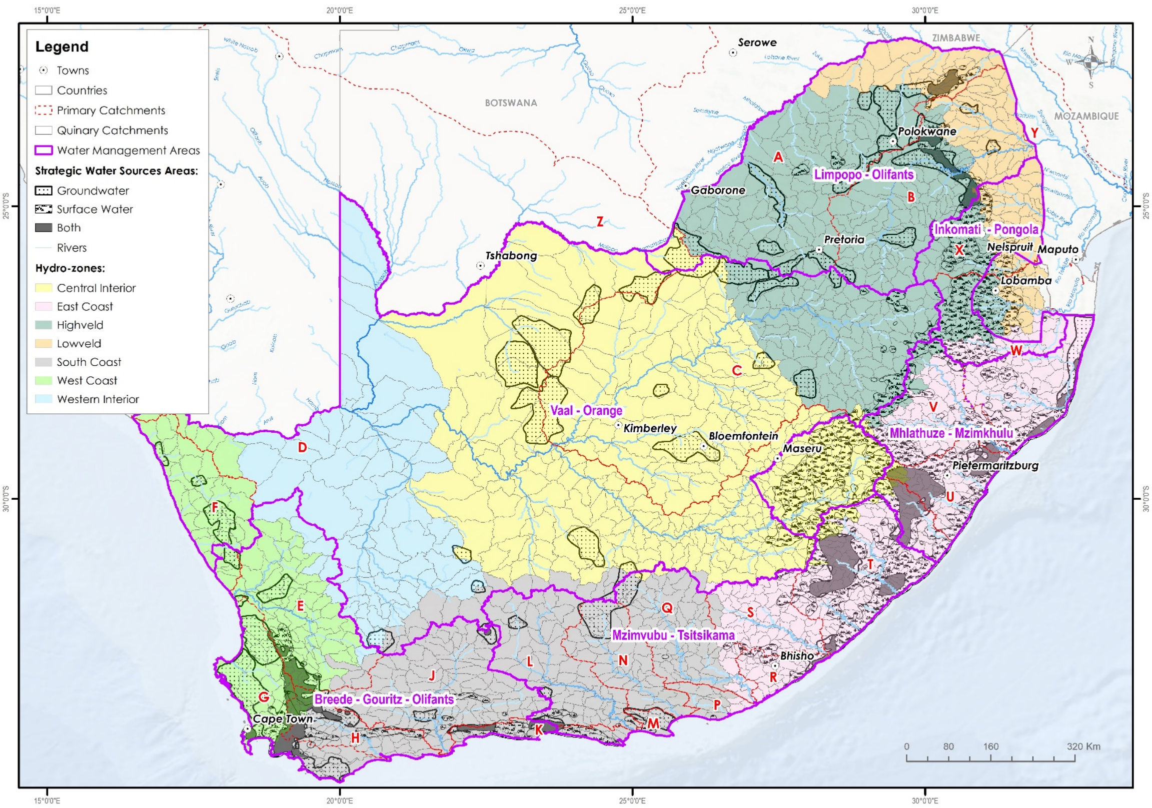


Figure A1: Seven hydro-climatic zones of South Africa with strategic water source areas

The following observational and reanalysis datasets are used:

- CHIRPS – a blended satellite-station rainfall dataset providing daily rainfall over the period of 1981-present at 0.25° spatial resolution
- CRU 4.05 – gridded station-based data products including monthly rainfall, minimum and maximum air temperature over the period of 1901-2021 at 0.5° spatial resolution
- GPCC 2021 – gridded station-based rainfall dataset providing monthly rainfall over the period of 1900-2021 at 0.5° resolution
- ERA5 – the latest high resolution atmospheric reanalysis from ECMWF and represents the state of the art in observational assimilation coupled to dynamical modelling. ERA5 provides a set of 3-hourly atmospheric variables including rainfall and air temperature at spatial resolution of 31 km over the period of 1979 to present.

Out of the above, CRU and GPCC have data at monthly resolution and contain data spanning a long-term period (~1900-present) and are thus suitable for the analyses of long-term variability patterns. These are also datasets that are based on interpolation of data from stations and thus reflect only this source of information. Both datasets were considered suitable for analyses in the context of climate change (Atiah, Amekudzi et al. 2020).
CHIRPS rainfall data, in contrast, are satellite-based (although with station input) and cover only the recent, post-1981 period. It has been shown, however, that CHIRPS is superior to other available satellite-based rainfall data products in capturing rainfall seasonality and interannual trends (Atiah, Amekudzi et al. 2020) and rainfall extremes (Atiah, Tsidu et al. 2020).

The following datasets are used for evaluation of future climate:

- CMIP6 ensemble of GCM projections. It is the primary basis of the climate projections analysed under the IPCC 6th assessment report released in 2021/2022.
- CMIP5 ensemble of GCM projections. It is the primary basis of the climate projections analysed under the IPCC 5th assessment report released in 2013-2014.
- CORDEX-Africa ensemble of dynamically downscaled projections. CORDEX regional climate models provide all relevant atmospheric data at a grid resolution of around 0.44° horizontally (~50km) and CORDEX-Core ensemble at a grid resolution of around 0.22° horizontally (~25km). The CORDEX models are driven by CMIP5 GCMs and are used in the IPCC AR5 report.
- CSIR-CCAM RCP 8.5 scenarios used for further analysis and bias correction as part of the recent WRC study titled "A National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-climatic Zones of South Africa" (WRC Project K5/2833).

In these analyses plume plots are prepared only for 0.44° CORDEX-Africa, as this ensemble includes a relatively large number of members (13-22). CORDEX-Core (0.22°) has much fewer members (e.g., RCP4.5 has only 1 member), which can negatively affect the evaluation.

The CMIP5 (and consequently CORDEX) experiment utilised RCPs (Van Vuuren et al., 2011) to describe different future socio-economic scenarios and their associated emissions-related scenarios (greenhouse gases, aerosols, and land use change). Included is RCP 4.5, which represents a middle of the road scenario with fairly strong mitigation action culminating in an increase of 4.5W/m2 in equivalent radiative forcing by 2100 and RCP 8.5 (increase of ~8.5 W/m2 of radiative forcing by 2100) which represents a very pessimistic scenario with very little mitigation of emissions into the future, which represents an optimistic scenario with intensive mitigation that has increased probability of achieving targets of the Paris Agreement, i.e. global warming at 1.5 deg C at the end of 2100. While deploying a different approach to future emissions scenarios, called Shared Socio-economic Pathways (SSPs) in CMIP6, SSPs are aligned with the CMIP5 RCPs in terms of radiative forcing. In this case we analyse SSP5-8.5 and SSP2-4.5 as equivalent to RCP 8.5 and RCP 4.5 respectively out to 2100.

Comparison of climate change scenarios – SSP2-RCP4.5

Figure shows the range of climate change impacts on annual temperature (30-year mean) for each hydro-zone under the RCP 4.5 and SSP2 emission scenarios. The results show consistency across all the model scenarios with higher increases for the inland climate zones and lower increases for the coastal zones and the winter rainfall zone. The impact on monthly temperatures by mid-century period (2035-2065) relative to the base are shown Figure A3.

Figure A shows the range of possible climate change impacts on mean annual precipitation (MAP) (30-year mean) for each hydro-zone under the RCP 4.5 and SSP2 emission scenarios. The results show consistency across all model scenarios in terms of the range of potential impacts, and a general downward trend in all hydro-climatic zones with the greatest impact on the winter rainfall region and the Arid Interior and South Coast. The impact on the expected average monthly rainfall for the mid-century period (2035-2065) relative to the base period (1980 – 2010) are shown in Figure A5.

Comparison of climate change scenarios – SSP5-RCP8.5

Figure presents a comparison of expected climate change projections include the IPCC CMIP 5 and CMIP 6 results as well as CORDEX and the six CSIR scenarios used in the WRC Study for average annual temperature over each of the identified seven hydro-climatic zones. The expected impacts on the mean monthly temperature for the mid-century period are shown in Figure A7.

Figure presents a comparison of these projections include the IPCC CMIP 5 and CMIP 6 models as well as CORDEX and the six CSIR scenarios used in the WRC Study for rainfall (as the most critical variable for water resources) averaged over each of the identified seven hydro-climatic zones. The impact on the expected average monthly rainfall for the mid-century period (2035-2065) relative to the base period (1980 – 2010) are shown in Figure A9.

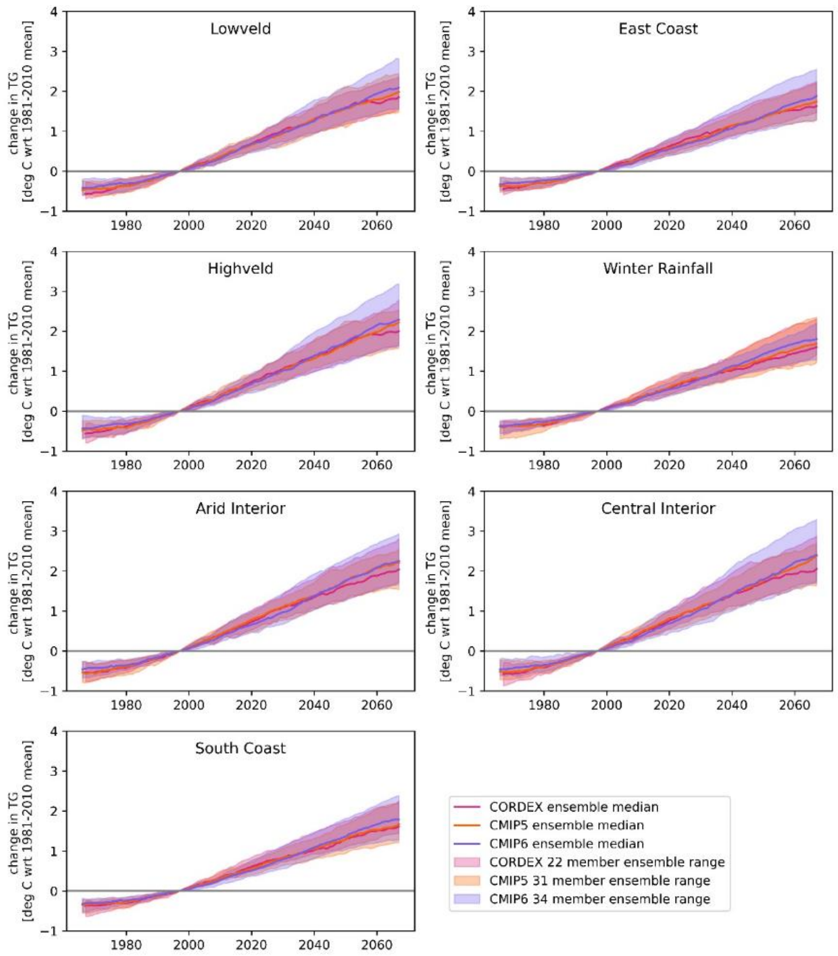


Figure A2: Plume plots comparing multi-generation, multi-model ensemble projections of temperature under SSP2-RCP45 emission scenario for each hydro-zone. Shaded areas mark 90 percentile range for individual ensembles, calculated based on 30-year running means of average annual temperature averaged over each hydro-zone in

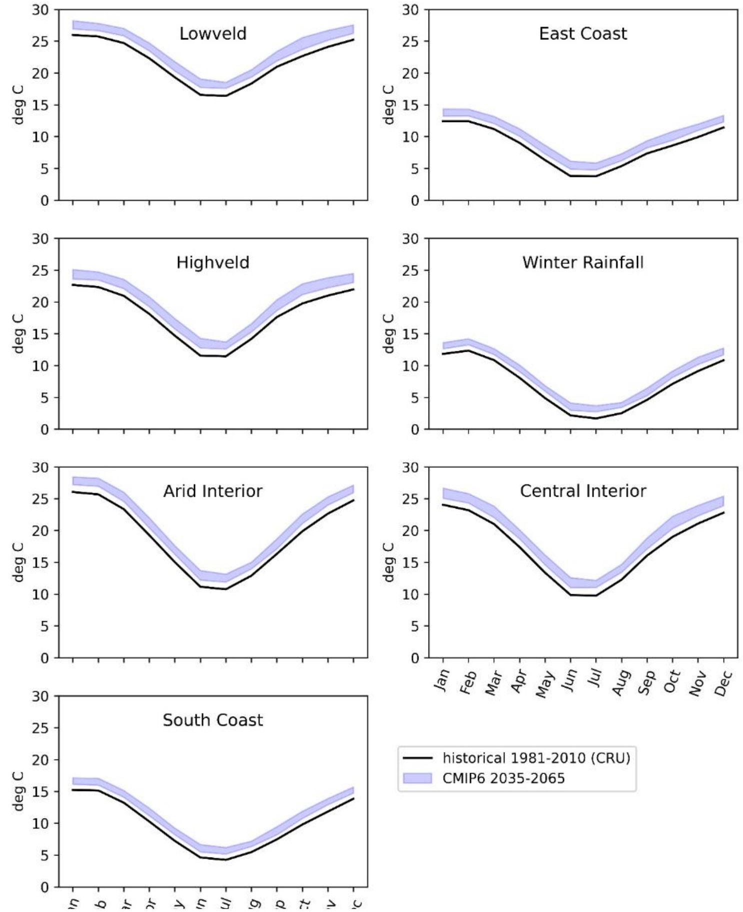


Figure A3: Comparison of the expected mean monthly temperatures for mid-century (2035-2065) with the base period (1981-2010) from the CIMP6 climate models for the different hydro-climatic zones under the SSP2-RCP4.4 emissions scenarios.

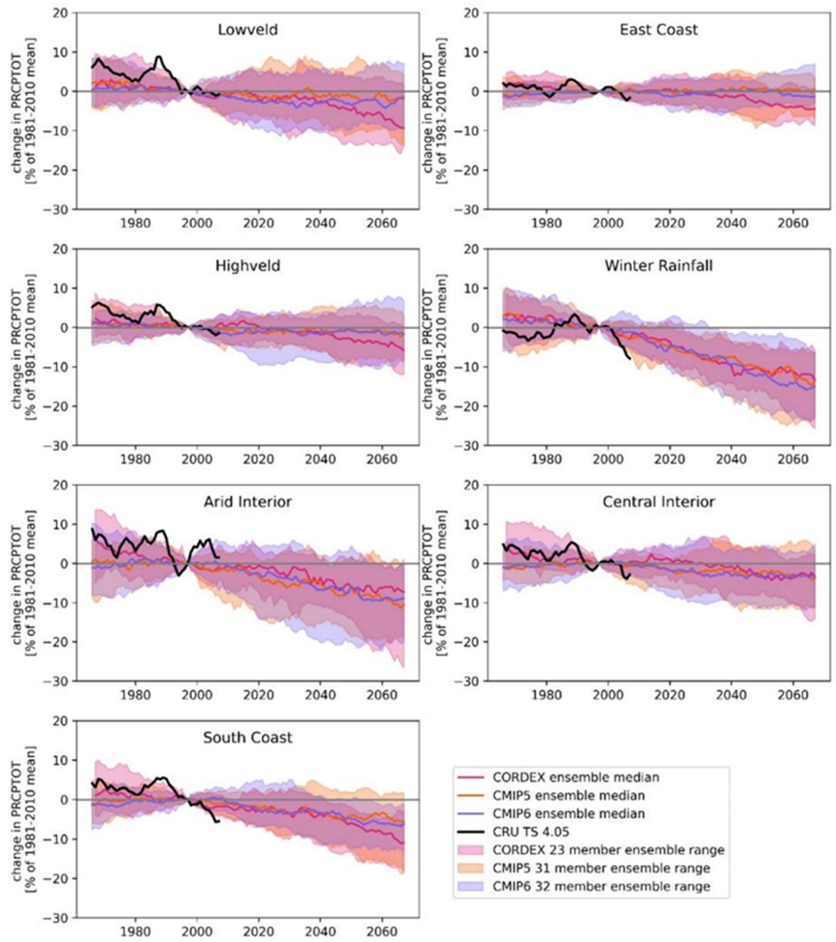


Figure A4: Plume plots comparing multi-generation, multi-model ensemble projections of rainfall under SSP2-RCP45 emission scenario for each hydro-zone. Shaded areas mark 90 percentile range for individual ensembles, calculated based on 30-year running means of total annual rainfall averaged over each hydro-zone in each of the ensemble models.

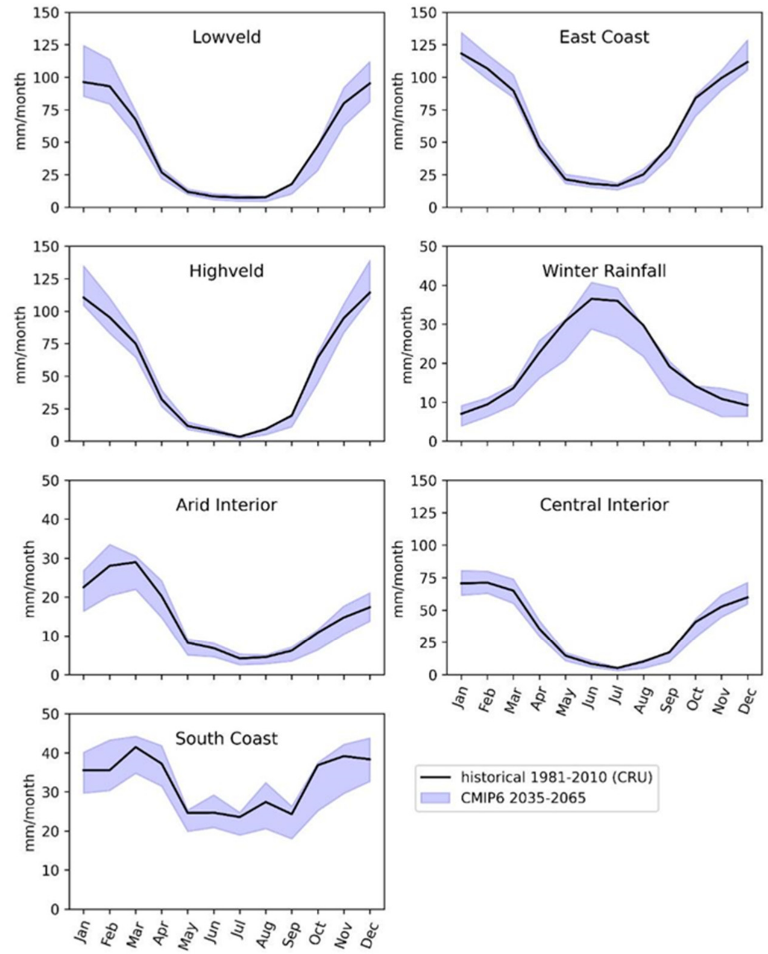


Figure A5: Comparison of the expected mean monthly precipitation for mid-century (2035-2065) with the base period (1981-2010) from the CIMP6 climate models for the different hydro-climatic zones under the SSP2-RCP4.4 emissions scenarios.

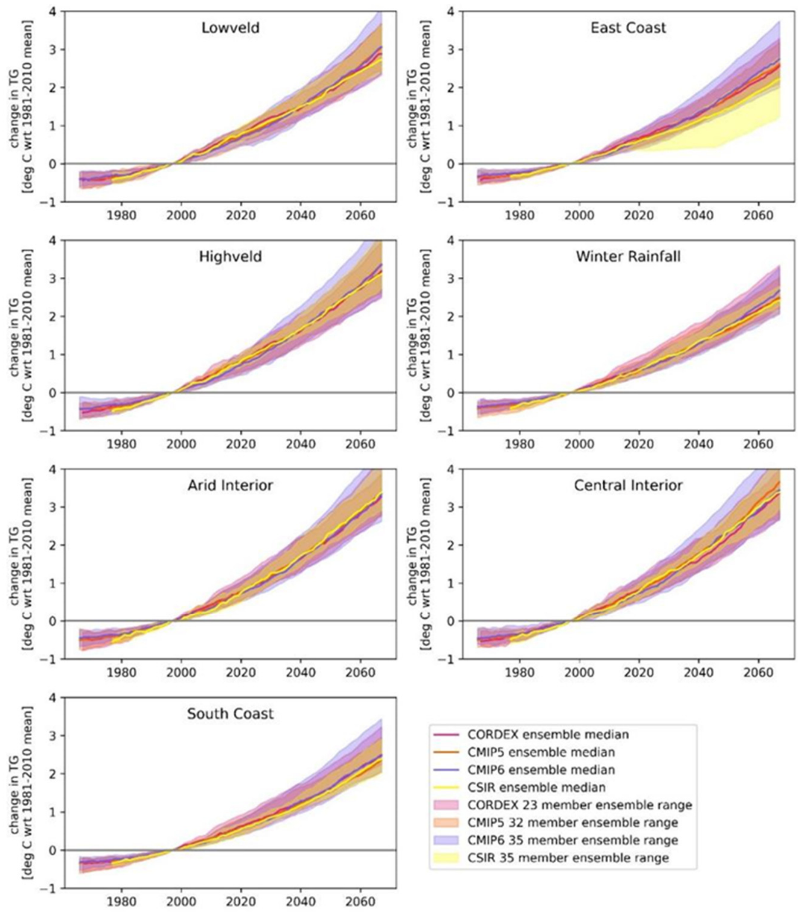


Figure A6: Plume plots comparing multi-generation, multi-model ensemble projections of temperature under SSP5-RCP85 emission scenario for each hydro-zone. Shaded areas mark 90 percentile range for individual ensembles, calculated based on 30-year running means of average annual temperature averaged over each hydro-zone in each of the ensemble models.

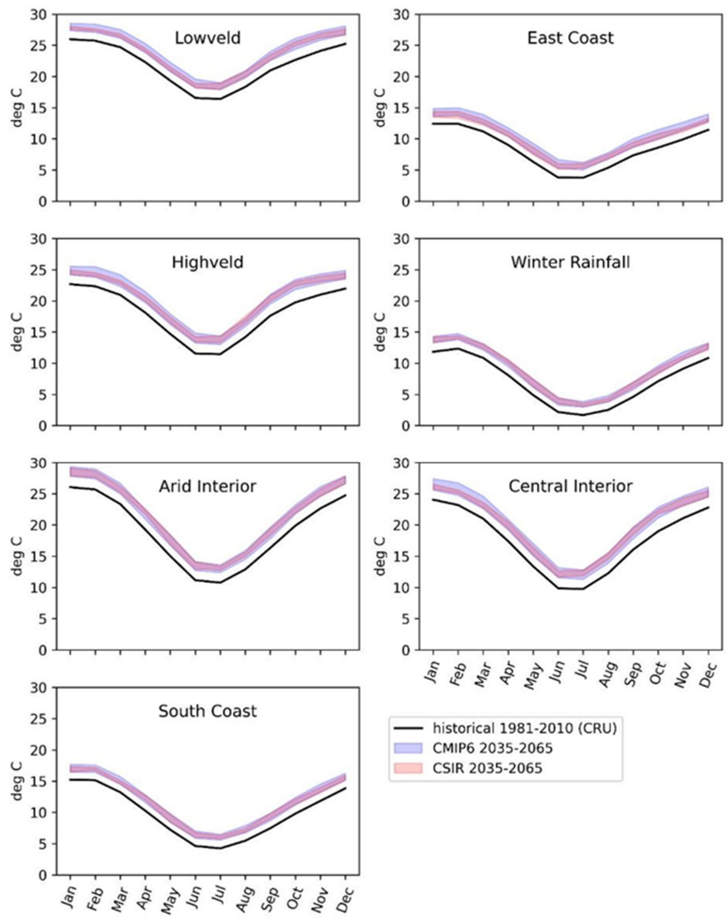


Figure A7: Comparison of the expected average monthly temperature for mid-century (2035-2065) with the base period (1981-2010) from the CIMP6 and CSIR/WRC scenarios for the hydro-climatic zones under the SSP5-RCP8.5 emissions scenarios.

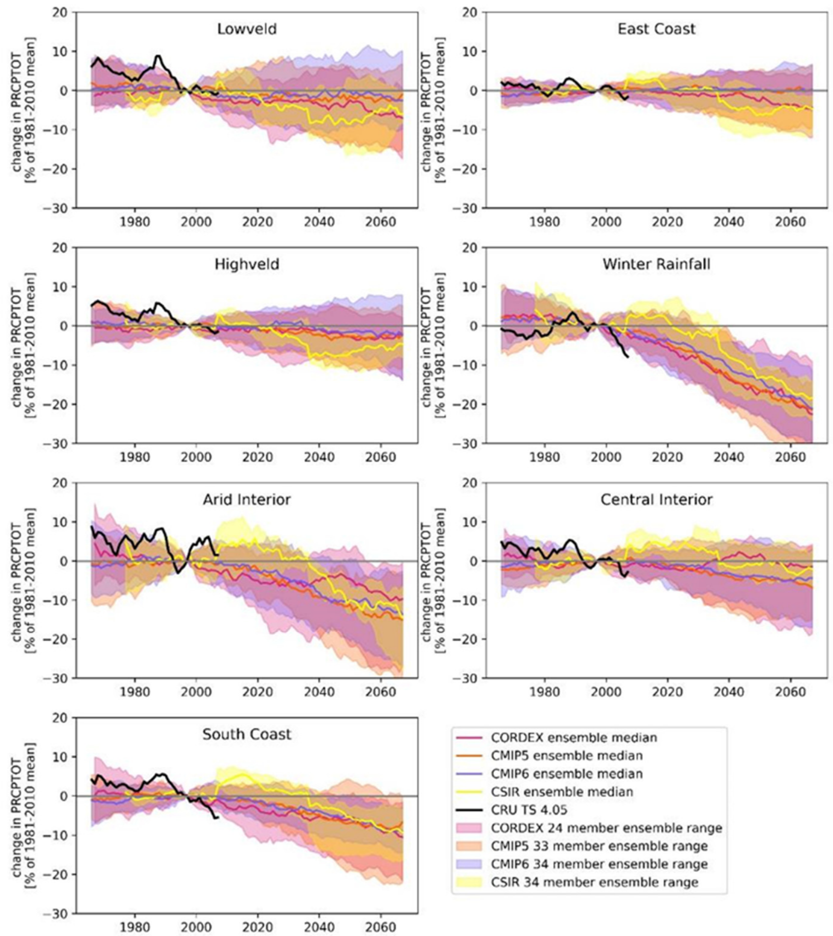


Figure A8: Plume plots comparing multi-generation, multi-model ensemble projections of rainfall under SSP5-RCP85 emission scenario for each hydro-zone. Shaded areas mark 90 percentile range for individual ensembles, calculated based on 30-year running means of total annual rainfall averaged over each hydro-zone in each of the ensemble models.

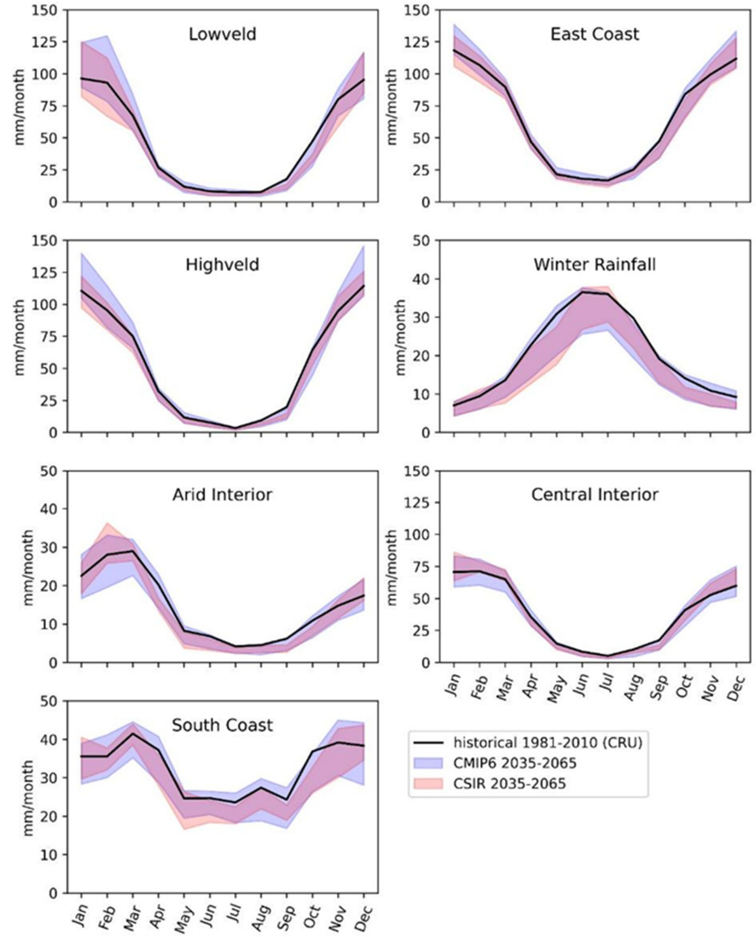


Figure A9: Comparison of the expected average monthly precipitation for mid-century (2035-2065) with the base period (1981-2010) from the CIMP6 and CSIR/WRC scenarios for the hydro-climatic zones under the SSP5-RCP8.5 emissions scenarios.

3.1 LIMPOPO-OLIFANTS WATER MANAGEMENT AREA

3.1.1 Location & Socio-economic Overview

The Limpopo-Olifants Water Management Area (WMA) is in the north-western part of South Africa and falls within the Gauteng, Mpumalanga, and Limpopo Provinces. The WMA forms part of the internationally shared Limpopo River Basin that is also shared with Botswana, Zimbabwe, and Mozambique. With the reconfiguration of the former Limpopo and Olifants into one WMA, the Limpopo-Olifants WMA consists of the total catchment area of the Limpopo River and the Olifants River (DWS, 2022a).

This WMA has a combination of towns and rural settlements, with some commercial agriculture and mining, and dryland on the Highveld. Most of the Limpopo-Olifants WMA population live in rural areas. Approximately, 3.5% of South Africa's population live in the Limpopo catchment of the WMA (DWS, 2022a). Meanwhile, in the Olifants catchment of the WMA, approximately 3.5 million people live in the South African side and 700 000 people live in the Mozambique side (AWARD, 2019). Overall, the main economic activities are mining, industries, irrigation, and livestock farming. DWS (2022a) states that activities within the Limpopo-Olifants WMA have contributed a significant portion to South Africa's Gross Domestic Product (GDP), which makes water supply very important for the catchment.

3.1.2 Current & Future Climate Change Scenarios

Climatic conditions within the Limpopo-Olifants WMA vary. The Limpopo catchment of the WMA is semi-arid and has climatic conditions that range from the Waterberg Mountains to the hot, dry Limpopo River valley on the border of Zimbabwe (DWS, 2022a). The mean annual precipitation ranges from 200-300 mm to 1200mm across the WMA, whereas the highveld areas experiences a mean annual precipitation of ~700mm. Meanwhile, the Olifants catchment of the WMA has a climate that varies from cool in the southern Highveld region to temperate in the central parts. Rainfall in the WMA falls within the summer months and maximum temperatures experienced in January and minimum temperatures occurring in July (DWS, 2022b).

By the mid-2030s that multiple GCMs indicate that in the Olifants catchment, there is uncertainty in precipitation with decreases of up to 10% and increases of up to 5%. However, overall annual precipitation in the Olifants catchment is projected to decrease. In the Limpopo catchment, overall precipitation projections are expected to decrease in the range of 2% to 6% in the south and north-east, while the North can expect decreases of ~16%. It further projected that dry years will become drier. Historical temperatures for the WMA indicate that summer mean maximum temperatures ranges between 22 °C in the central eastern highveld an ~24 °C in the Louis Trichardt area, to highs of >32°C in the Lowveld in the northeast and the Limpopo valley in the west and north, with variations experienced due to location and topography. Average summer mean temperatures are projected to increase in the order of ~1.4 °C in the south and parts of the north to 1.7 °C in the central areas.

In the Limpopo Valley increases of ~2 °C, in the south and north-east of the WMA increases are expected to range between ~1.3 °C to 1.5 °C. Note that into the more distant future of the 2080s the average increases from the multiple GCMs range from 4-5°C across the WMA.

Historical temperatures across the entire WMA indicate that winter mean minimum temperatures ranges between -2 °C to -0.6 °Cin the central areas and in the highveld, respectively. Whereas, in the north-eastern area of Sibasa and the north eastern lowveld temperatures range between 7°Cto 8°C. By the mid-2030s winter temperatures are expected to increase. In the immediate, some areas of the former Olifants catchment area, are expected to increase in patterns similar to January maxima with smaller area of lower increases and a larger area of higher increases. In the Limpopo catchment area, winter temperatures are expected to increase by ~1.45 °C to 1.9 °C with the south and north-east having the lowest increases and highest increases in the west. The Limpopo-Olifants WMA consists of areas projected to get wetter (central and eastern South Africa) and areas projected to get drier (Zimbabwe and Botswana). The projections further indicate general drying (with possible slight wetting), that is dependent on the representation of the regional climate gradient, which suggests that this is an area of great uncertainty.

3.1.3 Water Availability & Requirements

The Limpopo-Olifants WMA has high water requirements and under climate change will see increased water demand. This is mainly caused by the current levels of development within the WMA. Population and economic growth within the WMA will have a greater impact on increasing water demand. Water requirements are growing rapidly in the Limpopo-Olifants WMA and for this reason, there has been an investment in the water resource infrastructure (McCartney and Arranz, 2007). The WMA has several numbers of major and minor reservoirs that are developed mainly for irrigation, livestock watering domestic water supply. The main rivers in the Limpopo catchment of the WMA are the Crocodile, Marico, Matlabas, Mokolo, Lephalale, Mogalakwena, Sand and Nzhelele Rivers, which all discharge into the Limpopo Rivers. On the other hand, the main tributaries of Olifants River are the Wilge, Elands and Ge-Selati Rivers on the left bank and the Klein Olifants, Steelpoort, Blyde, Klaserie and Timbavati Rivers on the right bank (Pollard and Laporte, 2014). The groundwater in the Limpopo catchment of the WMA assists in augmentation of surface water for domestic supply, irrigation, and stock watering. Approximately 40% of the groundwater is used for the water supply from local resources and most rural domestic users rely on it (DWS, 2017). In the Olifants catchment of the WMA, the groundwater used for partial fulfilment of agricultural and mining activities. In the north west side of the Olifants catchment, the groundwater is extensively used for irrigation and domestic supply. In the mid-2030s, in response to rainfall streamflow is expected to be uncertain with both increases and decreases projected. Groundwater recharge is expected to vary across the catchment with some regions indicating increase of 30%. Some areas indicating a decrease ranging between 30% and 40%, however these decreases may be the result of other factors such as prevailing soil properties and topographic variables.

3.1.4 Exposure to Climate Change Risks & Vulnerability

The Limpopo-Olifants WMA is in an area of uncertainty especially were rainfall and streamflow. This makes it challenging to determine impacts of climate change on water supply and demand. However, water demand is estimated to increase due to population growth, and as previously mentioned, the economic activities in this WMA contribute a great portion in the country's GDP. This suggests that high amounts of water will be required to meet needs of each activity done in the WMA. Therefore, it is predicted that population and economic growth within this WMA will make it a high exposure to climate change. Increases in temperature may affect water availability due to increased evaporative losses in the order of 7% to 10.5% across the expanse of the WMA. Increased temperatures may also affect the food security due to increased heat stress on crops. Furthermore, changes in temperature coupled with increased population, may result in increased instances of water shortages and possibly drought.

Expected Climate Change Impacts	Proposed Climate Change Response Actions
1. WMA: Limpopo-Olifants Hydro-climatic zones: Lowveld, Highveld SWSAs: Waterberg, Soutpansberg, Wolkberg	
Decrease in precipitation in the south and north-east ranging between 2% to 6%, and in the north up to 16%. Increased uncertainty in rainfall projections. Reduced summer rainfall.	• Augment existing bulk water supply systems. • Promote water storage at household level. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation). • Ongoing/improved monitoring: rainfall, temperature, streamflow, and groundwater.
Increased dryness of dry years.	• Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
Increase in summer temperatures ranging between ~1.4°C to ~2°C across the WMA by the mid-2030s, and increase in winter temperatures ranging between ~1.45°C to ~1.9°C.	• Reduce GHG emissions through improved energy efficient. • Increases areas where indigenous forests can serve as carbon sinks. • Implement NbS to capture carbon and reduce heating impacts. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants and prevent release into the atmosphere.
Increased evaporation and crop requirements due to increased temperatures ranging between 7% to 10.5%	• Irrigate during cooler times during the day to reduce evaporative loss. • Use of low flow irrigation systems (e.g., drip irrigation)
Increased water use and future water requirements (urban, industrial agriculture, domestic, energy, forestry, etc.).	• Implement new technologies to reduced water demand. • Implement water restrictions across all sectors, especially during periods of low water availability and based on seasonal forecasting. • Educate communities on the importance of conserving water.
Increased uncertainty in streamflow.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Improved regulation and compliance with licences and EWRs.
Increased variability of groundwater recharge with up to 30% increase in parts, and up to 40% decrease in others.	• Identify areas that may become flood zones and prevent development in these areas. • Increase woody vegetation to prevent areas becoming water logged under high rainfall. • Remove non-indigenous vegetation in areas where groundwater levels will decrease. • Application of NbS to improve natural storage of water.
Crop loss due to heat stress from increased temperatures and increased flooding, which results in food insecurity.	• Encourage farmers to plant drought resistant and heat tolerant crops. • Ensure adequate water storage and alternative water resources are available for use. • Ensure soils are sufficiently stabilised to prevent loss of crops from flooding.

3.2 INKOMATI-USUTHU WATER MANAGEMENT AREA

3.2.1 Location & Socio-Economic Overview

The Inkomati catchment of the WMA is found in Mpumalanga, the north-eastern part of South Africa, bordering Swaziland and Mozambique and covers an area of 28 757 Km2. This catchment shares its south-eastern border with eSwatini, and Mozambique on the east. The majority of the population in WMA lives in rural areas and Chibwe et al., (2012) estimated the population to be 2 208 771. The main economic activities in the WMA include manufacturing, agriculture, government services and trade. The catchment contributes approximately 1.3% to the Gross Domestic Product (GDP).

3.2.2 Current & Future Climate Change Scenarios

Climatic conditions within Inkomati-Usuthu WMA are generally influenced by its topography. The catchment normally experiences cold winters with occasional snow on the western side and tropical climate conditions in the Lowveld areas in the eastern side (Chibwe et al., 2012). Historical rainfall records indicate that rainfall varies across the WMA with the lowveld of the north-east experiencing <400 mm of rainfall, with the mountainous areas experiencing >1500mm. By the mid-2030s climate projections from multiple GCMs indicate that most of the WMA is likely to have a reduction in rainfall between 2% and 8%, with patches exhibiting reductions in the order of ~10%. Historical temperature records the WMA indicate that summer means highest in the north-east at > 32°C and lowest at < 24°C in parts of the south and west. By the mid-2030s, multiple GCMs indicate that increases in the order of ~1.4°C to 1.7°C are likely, with lowest values in the south and highest projected increases in the north-east of the WMA. Historical winter temperatures indicate that average temperatures range between 8°C to 10°C in places in the north, with parts of the south experiencing lows down to -2°C.

By the mid-2030s, minimum winter temperatures are projected to increase by 1.4°C to 1.8°C, with the south experiencing the highest of these increases and the central north experiencing the lower end of these increases. Note that into the more distant future of the 2080s, the average increases from the multiple GCMs range from 4-5°C across the WMA.

3.2.3 Water Availability & Requirements

The Mzimvubu-Tsitsikamma WMA is prone to water shortages and droughts mainly in the western part of the WMA. The Inkomati catchment of the WMA consists of many water resource infrastructures such as the Inyaka Dam that was constructed in the 1990s. This dam was constructed mainly to supply domestic and ecological water requirements in the catchment area. Other significant dams in the Inkomati catchment include the Vygeboom, Nooitgedacht, Maguga, Driekoppies and Kwena (Chibwe et al., 2012). There are three (3) main rivers in the WMA namely, Sabie, Crocodile and Komati Rivers. By the mid-2030s, multiple GCMs indicate that streamflow indicate decreases are expected during years with low and average flows, only the north-east is projected to increase in streamflow. Groundwater is expected to vary across the WMA by the mid-2030s. In the north-east projections indicate that increases of >25% are expected, whereas as a patchwork of areas display decreases of around 30%, however not all of these decreases are climate related.

3.2.4 Exposure to Climate Change Risk & Vulnerability

Dry years are projected to becoming even drier into the future, while wet years are projected to become and even wetter in places. This may impact anthropogenic activities such as agriculture, household use and energy generation which may have not have the water requirements fulfilled due to increased competition. Furthermore, increased evaporation as a result of increased temperatures is likely to lead to reduced water availability, further impacting the ability to meet demand.

Expected Climate Change Impacts	Proposed Climate Change Response Actions
2. WMA: Inkomati-Usuthu **Hydro-climatic zones:** Lowveld, Highveld, East Coast **SWSAs:** Mpumalanga, Drakensberg, Enkangala Grasslands, Mbabane Hills, Upper Usutu	
Rainfall uncertainty, with projections indicating either a wetting or drying especially during the summer months.	• Ongoing rainfall monitoring to determine which areas are experiencing wetting and which are experiencing drying and combined with improved seasonal forecasting. • Use of low flow irrigation systems (e.g., drip irrigation). • Promote water storage at household level such as rainwater harvesting. • Explore alternative and under-developed water resources.
Increased temperature ranging between~1.4°C to ~1.7°C. Increase in summer temperatures between ~4°C to ~5°C.	• Reduce GHG emissions through the use of energy efficient technologies. • Increases areas where indigenous forests can serve as carbon sinks. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants and prevent release into the atmosphere.
Increased flooding events due to the likely increase of storm activity and more intense rainfall events.	• Identify new flood zones and prevent development at these locations. • Implement NbS (clearing of IAPs, wetlands, etc.) to reduce the impact of flooding.
Increased temperatures, leading to increased evaporation.	• Irrigate during cooler times during the day to reduce evaporative loss. • Use of low flow irrigation systems (e.g., drip irrigation). • Adapt water resources planning modes to account of higher rates of evaporation.
Increased water use and water requirements (urban, industrial agriculture, domestic, energy, forestry, etc.).	• Implement new technologies with reduced water demand / requirements. • Implement water restrictions across all sectors during periods of drought. • Engage and educate communities on the importance of conserving water.
Projections indicate increased water scarcity due to likelihood of increased drying, especially in coastal areas.	• Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation). • Promote water storage at household and rainwater harvesting.
Decreased streamflow during years with low and average flow and, dry years are projected to becoming even drier.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
Variable groundwater recharge across the WMA	• Identify areas that may become flood zones and prevent development in these areas. • Increase woody vegetation to prevent areas becoming water logged under high rainfall. • Remove non-indigenous vegetation in areas where groundwater levels will decrease. • Application of NbS to improve natural groundwater storage of water.
Wet years are projected to become and even wetter in places which could lead to an increased risk of flooding.	• Identify new flood zones, protect and prevent development at these locations. • Consider including flood operating rules for reservoirs and dams. • Improve urban stormwater including attenuation and water sensitive design principles. • Implement NbS to reduce the potential impact of flooding.

3.3 PONGOLA-MZIMKULU WATER MANAGEMENT AREA

3.3.1 Location & Socio-economic Overview

The Pongola-Mzimkulu Water Management Area (WMA) is largely comprised of the KwaZulu-Natal Province and is the result of the merging of the Usuthu-Mhlathuze, Thukela and Mvoti-Umzimkulu WMAs. The Pongola-Mzimkulu is bounded by the Indian Ocean to the east, Mozambique, Swaziland and the Inkomati-Usuthu WMA to the north, Lesotho and the Vaal/Orange WMA to the west and the Mzimvubu-Tsitsikamma WMA to the south. The population in the Mhlathuze-Mzimkulu is estimated to be 10.6 million people. Population is characterised by high rural, low-density distribution, with some pockets of high-density urban areas. 54% of the population is classified as being rural and predominantly comprising of women and children. This is a concern for and may create challenges for social and infrastructure service provision, especially since it is expected that about 3.5 million people will migrate to urban areas by 2030. Economic activity within the WMA comprises of manufacturing, mining and agriculture. Economic activity in the northern and southern parts of the WMA are made up of heavy industry, agriculture and coal mining.

The major industrial complex (aluminium smelting, pulp, paper and fertilizer) is situated in the Richards Bay/Empangeni Complex along the Mhlathuze River. The Durban-Pietermaritzburg complex is the second biggest, with industries focused on machinery, leather, basic steel and non-ferrous metals, sugar, timber, and oil refinery processing. Other industries include banking, insurance and other type of financial institutions.

3.3.2 Current & Future Climate Change Projections

Due to the varying typology, differences in temperature and climatic conditions are observed. By way of example, in coastal regions conditions are typically sub-tropical and becomes progressively colder moving towards the mountainous areas. Rainfall in the CMA is relatively high and far exceeds the national average of 450mm/a. Historical rainfall records indicate that the region experiences summer rainfall and ranges between < 600 mm the mid-Thukela valley to > 1 500 mm along the high Drakensberg mountains, and about 80% of rainfall experienced as summer thunderstorms. By the mid-2030s, multiple GCMs indicate that most of the WMA will have reductions mean annual precipitation in the order of 2 to 8% with patches of ~10% reductions, compensated by projected increases in the higher lying west. Dry years, however, are projected to becoming even drier, while wet years are projected to become even wetter in places. Historical records for summer indicate that temperature is variable across the entire expanse of the WMA with the highest temperatures experienced along the north-east coastal areas and in the upper Thukela catchment around Bergville. By the mid-2030s, temperatures are expected to increase in the order of ~1.1°C to 1.4°C. The lowest temperature increases are expected along the coast where temperature changes are moderated by the warm ocean, and highest in the far inland of the WMA. Historical winter temperatures indicate that temperatures range from 8°C to 10°C along the north-eastern coastal areas. Parts of the Drakensberg in the west experience temperatures as low as -2°C.

By the mid-2030s winter temperatures are projected to increase based on multiple GCMs. Increases of 1.4°C to >1.9°C are expected, with lowest increases in the high Drakensberg region, along the southern coast and the north-east, with the highest projected increases in the upper Thukela / Sunday's catchments. Note that into the more distant future of the 2080s, the average increases from the multiple GCMs range from 4-5°C across the WMA.

3.3.3 Water Availability & Requirements

Irrigation accounts for about 32% of water requirements, whereas urban only accounts for 20%. Furthermore, 28% of water is transferred out of the system and mining and bulk industrial requirements are only 8%. Thought the WMA has a high-water yield as characterised by the relatively high rainfall, there are several areas within the WMA that "outstrip" the yield. The area that has the greatest deficit is the Umgeni area, due to the expansion of Durban which is an urban and industrial hub. Water quality within the WMA ranges from excellent to poor for microbiological compliance, whereas for chemical compliance is typically bad with on some areas having good or excellent compliance (BDWR, 2023). This could be attributed to rivers being exposed to various contaminants from industrial effluent and pathogens. Point source pollution which ranges from poorly treated wastewater to discharge from different industries have an impact on rivers especially the Umgeni River.

By the mid-2030s, streamflow projections indicate that low flow years will likely experience increases of up to 20%, in the higher-lying west, while areas along the coast and the interior display flow reductions, again up to 20%. Groundwater recharge projections indicate a wide range of possibilities. Increases of > 30 mm/ year mainly in the upper Thukela system are likely, while in a patchwork of areas along the coast and interior decreases of >30% are expected.

3.3.4 Exposure to Climate Change Risks & Vulnerability

Under the impacts of climate change, temperatures are expected to increase. There is uncertainty around rainfall, however considering modelling and observations this uncertainty is typically spread well around mean rainfall observations. However, some projections do indicate a significant increase in rainfall which may ultimately result in increased flooding within the CMA. Into the immediate future of the 2030s, a 5 to 8% increase in evaporation is projected which may lead to rapidly drying of soils, evaporative losses from dams and to higher irrigation water demands. This may impact agriculture and capacity to meet water demand.

Expected Climate Change Impacts	Proposed Climate Change Response Actions
3. WMA: Pongola-Mzimkulu **Hydro-climatic Zones:** Highveld, East Coast **SWSAs:** Northern Drakensberg, Southern Drakensberg, Enkangala Grasslands**,** Mfolozi Headwaters	
Reduced rainfall ranging between 2% and 10%. Projected increases in the higher lying western areas.	• Implement critical water supply augmentation projects. • Explore alternative and under-developed water resources. • Promote water storage at household level such as rainwater harvesting. • Monitoring to determine which areas are experiencing wetting and/or drying. • Use of low flow irrigation systems (e.g., drip irrigation).
Dry years are projected to becoming even drier.	• Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
Wet years are projected to become even wetter in places. Projections indicate a likely increase in summer rainfall, with increased occurrence of large events such as flooding.	• Identify new flood zones, protect and prevent development at these. • Improve urban stormwater including attenuation and water sensitive design principals. • Implement NbS to reduce impact of flooding. • Consider potential for updated operating rules for dams for flood management.
Increased summer temperature between~1.1°C to ~1.4°C and winter temperatures ranging between 1.4°C to >1.9°C.	• Reduce GHG emissions through the use of energy efficient technologies. • Increases areas where indigenous forests can serve as carbon sinks.
Increase in temperatures due to proximity to the ocean.	• Reduce GHG emissions through the use of energy efficient technologies. • Increases areas where indigenous forests can serve as carbon sinks. • Irrigate during cooler times during the day to reduce evaporative loss. • Use of low flow irrigation systems (e.g., drip irrigation).
Increase in streamflow up to 20% in the higher lying west.	• Modelling of new expanded flood zones. • Ensure adequate soil stabilisation in expanded flood zones.
Decrease in streamflow along the coast and the interior.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops. • Increased regulation of licence conditions and protection of EWRs and ROQs.
Variable groundwater recharge across the WMA.	• Remove non-indigenous vegetation in areas where groundwater levels will decrease. • Application of NbS to improve natural storage of water. • Increased monitoring of groundwater levels and abstractions.
5 to 8% increase in evaporation across the WMA.	• Irrigate during cooler times during the day to reduce evaporative loss. • Use of low flow irrigation systems (e.g., drip irrigation). • Incorporate increased evaporation into water resources planning models.
Crop loss due to heat stress from increased temperatures and increased flooding, which results in food insecurity.	• Encourage farmers to plant drought resistant and heat tolerant crops. • Ensure adequate water storage and alternative water resources are available. • Ensure soils are sufficiently stabilised to prevent loss of crops from flooding.

3.4 VAAL-ORANGE WATER MANAGEMENT AREA

3.4.1 Location & Socio-economic Overview

The Vaal-Orange Water Management Area (WMA) is situated in the Central-eastern part of South Africa. It extends from Mpumalanga to the west of the Northern Cape; to the North West and borders Botswana and the Limpopo-Olifants WMA, while Gauteng sits on the boundary of the WMA. To the south-east it is bounded by Lesotho, the Orange River system in mainly in the Free State and spreads over to Eastern Cape and Northern Cape. With the reconfiguration of the former Limpopo and Olifants into one WMA, the Limpopo-Olifants WMA consists of the total catchment area 240 128 km^2 of the Vaal River system and 1 000 000 km^2 of the Orange River System (DWS, 2022).

Demographics in the Vaal-Orange WMA have significantly increased in the urban areas. While the Vaal River System supplies water to a total population of 20 million people, the estimated population residing within the Vaal-Orange WMA is approximately 12.6 million (DWS, 2022). Overall, the main economic activities in the Vaal-Orange WMA are domestic use, mining, industries, irrigation, and livestock farming. DWS (2022) states that activities within the Vaal-Orange WMA have contributed approximately 50% of South Africa's Gross Domestic Product (GDP). Ongoing economic growth and continued urbanisation within the Vaal catchment of the WMA show that further growth in water demand is expected.

3.4.2 Current & Future Climate Projections

Considerable variations in climatic conditions occur over the Vaal-Orange WMA. Precipitation has a spatial variability and varies from ~200mm in the west and increases to 800mmn in the east. Meanwhile, in the Orange catchment of the WMA, there are variable annual rainfall patterns that range from ~50mm in the Orange river valley downstream of Pofadder to > 1 200 mm (in fact ~ 1 500 mm) along the high Drakensberg mountains, with a general east to west decrease. Lesotho is the biggest water contributor in the Orange catchment, where rainfall varies between 600 – 1500 mm per year (DWS, 2022). The climate models in the Vaal catchment of the WMA suggests that there is high uncertainty in future rainfall, with possible wetting or drying conditions during the summer months. There are likely increases in storm activities. In the mid-2030s, mean annual precipitation is projected to decrease in the range of 2% to 6% in the south and north-east, with reductions of up to 16% in the north and dry years are expected to become drier. Climate models of the Orange catchment indicate increases ranging between 4% to 12% in the eastern parts, whereas reductions in the western quarter are projected. The historical temperatures for the Vaal catchment indicate 25-26°C from east and south-east at > 33°C in the west and north-west. Whereas, in the Orange WMA summer temperatures indicate mid-summer highs averaging only around 16°C in the high Drakensberg to > 34°C in the lower Orange valley, with local variations related to local topography. In the mid-2030s, summer temperatures across the Orange catchment are projected to increase in the range of ~1.1 to 1.4°C in the east, with this increasing to ~ 1.7°C around Rietfontein-Pofadder, but with the increase dropping markedly along the west coast where the cold Benguella current modifies increases. In the Vaal catchment, temperatures are projected to increase in the range of ~1.3 in the south-east to > 1.8°C in the north-west. Note that into the more distant future of the 2080s, the average increases from the multiple GCMs range from 4-5°C across the WMA. Historical winter temperatures for the Orange catchment are 8°C around Springbok, with lows down to -6°C along parts of the high east Drakensberg.

Whereas, in the Vaal catchment conditions are more complex and dependent on local topography. Mornings are typically cold and temperatures average -4°C in parts of the east, to 4°C in places in both the east and the west of the catchment. In the mid-2030s, winter temperatures indicate <1°C in the south and west and > 1.8°C projected in the northern Kalahari. In the Vaal catchment winter temperatures indicate similar south-east to north-west trend of increases, but not quite as marked as for January maximum temperatures.

3.4.3 Water Availability & Requirements

This Vaal-Orange WMA has high water requirements and under climate change will see increased water demand from agriculture, power generation, domestic demand. This Orange catchment of the WMA is already a water-scarce area in the west and is projected to become drier. While population and economic growth in the Vaal catchment of the WMA will have a greater impact on increasing water demand. The Vaal catchment of the WMA consists of the Vaal, Grootdraai and Sterkfontein Dams. Meanwhile, the two largest dams in South Africa, Vanderkloof and Gariep dams are situated in the Orange catchment of the WMA, and are utilised for river flow control, flood control, hydro power generation and storage of water for urban and irrigation use. The main rivers in the Vaal catchment of the WMA are the Vaal and its tributaries the Wilge River, Klip River, Liebenbergsvlei River and Mooi River. On the other hand, the major rivers found in the Orange catchment of the WMA are the Orange river which is the longest river is South Africa that is also an international resource shared by three countries (Lesotho, Botswana and Namibia) (DWS, 2022); the Modder River, Riet River, Kraai River and Caledon River. In the mid-2030s, streamflow projections in the Orange catchment indicate increases of 20 to 30% projected for the eastern parts and decreases projected for arid west, with the exception to the area along the mainstem of the Orange river, where projected flow increase persists, fed by the projected increases upstream. Whereas in the Vaal WMA projections for streamflow indicate increases up to 25% could occur across the south and over much of the west in a low flow year. In the mid-20230s groundwater recharge projections are expected to vary with increases of up to 35 mm/year in central areas of the Orange catchment where rainfall is projected to increase, however decreases up to 35 mm/year are likely in the west and east. It should be noted that not all these decreases are related to climate change. In the Vaal catchment groundwater recharge projections are uncertain. Projections indicate increases by > 30%, to decreases of > 30% in a patchwork of very local changes, with marked positive and marked negative projections of groundwater recharge often in close proximity to one another. The groundwater resources in the Vaal-Orange WMA are limited and used for partial fulfilment of rural water supplies.

3.4.4 Exposure to Climate Change Risks & Vulnerability

The Vaal-Orange WMA is in an area of great uncertainty in terms of future rainfalls. The high-water requirements in this WMA under climate change will see demand from agriculture, power generation and domestic demand. With water scarcity issues in the Orange catchment of the WMA, the area is projected to become drier. Population growth will further increase water demands, especially in urban areas, suggesting that this WMA will have a high exposure to climate change.

Expected Climate Change Impacts	Proposed Climate Change Response Actions
4. WMA: Vaal-Orange **Hydro-climatic Zones:** Central interior, Western interior, Highveld **SWSAs:** Upper Vaal, Maloti Drakensberg, Northern Drakensberg, Southern Drakensberg, Eastern Cape Drakensberg	
High uncertainty in future rainfall, with possible wetting or drying in the summer months. Precipitation is projected to decrease in the range of 2% to 6% in the south and north-east, with reductions of up to 16% in the northern parts.	• Implement water supply augmentation projects and improved operation. • Promote water storage at household level such as rainwater harvesting. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation). • Implement catchment management activities to reduce erosion and sedimentation.
Dry years are expected to become drier.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
Increase in summer temperatures of ~1.1°C to >1.8°C. Increase in winter temperatures of <1°C to >1.8°C.	• Reduce GHG emissions through the use of energy efficient technologies. • Increases areas where indigenous forests can serve as carbon sinks. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants and prevent release into the atmosphere.
Increased risk of flooding due to the likely increase of storm activity and more extreme rainfall events.	• Identify new flood zones and prevent development at these locations. • Increase woody vegetation to reduce the limit the area of impact. • Implement catchment management activities to reduce erosion and sedimentation
Increased water requirements (urban, agriculture, domestic, industrial, mining, energy etc.)	• Implement new technologies with reduced water demand / requirements. • Implement water restrictions across all sectors during periods of low water availability. • Engage and educate communities on the importance of conserving water.
Increased water scarcity due to likelihood of increased drying, especially in the western and coastal areas	• Implement critical water supply infrastructure and real time operational systems. • Ongoing rainfall monitoring to determine trends and seasonal forecasting. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation). • Promote water storage at household level such as rainwater harvesting. • Explore alternative and under-developed water resources.
Decreases in streamflow ranging between 20% and 30%.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
Increases in streamflow for the Vaal Catchment part of the WMA indicate increases of up to 25%.	• Modelling of new expanded flood zones. • Ensure adequate soil stabilisation in expanded flood zones.
Uncertainty of groundwater recharge projections with some areas indicating potential decrease and other areas likely to experience a potential increase in recharge.	• Increased monitoring of groundwater levels and abstractions. • Remove non-indigenous vegetation in areas where groundwater levels will decrease. • Application of NbS to improve natural storage of water and protect recharge areas.

3.5 MZIMVUBU-TSITSIKAMMA WATER MANAGEMENT AREA

3.5.1 Location & Socio-economic Overview

The Mzimvubu-Tsitsikamma Water Management Area (WMA) is situated mainly in the Eastern Cape and includes portions of KwaZulu-Natal, Western Cape and Northern Cape. The Mzimvubu-Tsitsikamma WMA is classified as being one of the most disadvantaged in the country and experiences high levels of poverty and unemployment. The population of the CMA is approximately 6.36 million people, with the majority living in the eastern half typically in tribal or farming environments. Whereas the western half is characterised by people typically urban areas. Primary economic activities are centred around crop and livestock agriculture, coal mining, manufacturing and tourism.

3.5.2 Current & Future Climate Change Projections

The Mzimvubu Tsitsikamma WMA area displays two types of climates including semi-arid western portion and changing to a humid sub-tropical and is a predominantly summer rainfall region. Historical rainfall records indicate that rainfall varies across the WMA with the western portion receiving on average ~200mm/year and moving to the east and extreme south increases to ~ 1100mm/yr. In the mid-2030s, climate projections from multiple GCMs indicate that a patchwork of dry areas is likely. However, increase of up to ~10% in the north and south, and decreases of up to ~10% are expected in the south-west regions. Projections into the immediate future of the mid-2030s, based on outputs of the multiple GCMs used, indicate that in the driest year in 10 (Figure 6.4.6 top right map) projected changes in rainfall are spatially quite patchy, but with increases up to ~ 10% projected in the north and south and decreases up to 10% in the south-west of the WMA. In average years patterns of change are more consistent, with increases in the north of the order of 4-8% and decreases generally of 4-6% in the north-east and the southern half of the WMA. In wet years the areas of projected rainfall increase expand while those of decreases contract. Historical records for the Mzimvubu-Tsitsikamma WMA indicate that summer temperatures range from < 20 oC in the cooler mountainous areas to 32 oC in the Karoo region. In the mid-2030s, climate projections from multiple GCMs indicate that summer temperatures are expected to increase in the order of ~1.0 oC to 1.8 oC, with lowest increases in the western third of the WMA and high increases in the north-east of the WMA.

Historical winter temperatures indicate the east coast experiences temperatures of ~8°C and is influenced by the warm Indian ocean current, whereas in the northern boundary temperatures of -4°C are exhibited. In the mid-2030s, summer temperatures are projected to increase in the order of ~1.0 to 1.8°C, with the western portion experiencing the lowest of these increases and the north-east area experiencing the highest of these increases. Note that into the more distant future of the 2080s the average increases from the multiple GCMs range from 4-5°C across the WMA.

3.5.3 Water Availability & Requirements

Water resources within the WMA are in the form of both surface water and groundwater. 58% of towns are reliant surface water resources, and 42% of towns relying on groundwater. It should be noted that most town rely on a water mix of booth surface water and groundwater. Existing available Yield for the WMA is 260 million m3/annum, which is far less than the actual water requirements of 1358 million m3/annum. This disparity between water availability and requirement means that the WMA is prone to water shortages and droughts, especially in the western parts. Water requirements are expected to increase as the population and economic activity is expected to increase in the future. Water availability is affected by high salinity, instances of eutrophication in rivers and high prevalence of alien invasive vegetation. Groundwater across the WMA is underdeveloped and underutilized. This makes it a valuable resource to improve the water mix and increase the available yield. In the mid-2030s, streamflow is projected to increase in the order of 25% to 40% in the mountainous northern areas, the south-west as well as the southward flowing major rivers. Coastal areas are expected also expected to increase, however, only by an order of 5% to 15%. It should be noted that patchwork decreases may also be observed across the entire WMA ranging between 10% to 30%. In the mid-2030s, groundwater recharge is expected to vary with patchwork of areas indicating a decrease of up to 35%, whereas in the north and parts of the south increases of >30% are projected. It should be noted that these changes are dependent on the prevailing and local of climate, soils and topography.

3.5.4 Exposure to Climate Change Risk & Vulnerability

Areas of high exposure include the rural and tribal areas, where flooding and high temperatures may impact infrastructure, human health due to heat stress, crop production to due increased erosion from flooding and heat stress. Changes in rainfall will increase due to increased moisture availability for both inland convection rainfall as well as coastal orographic rainfall. There is considerable uncertainty in the implications of rainfall in the south-western parts of the area. Evaporation is projected to increase by a range of 5% to 9%, with the lower increases in the coastal areas.

Expected Climate Change Impacts	Proposed Climate Change Response Actions
5. WMA: Mzimvubu-Tsitsikamma **Hydro-climatic Zones:** East coast, South coast **SWSAs:** Eastern Cape Drakensberg, Amathole, Tsitsikamma, Kouga	
Decreases in rainfall in the order of 4% to 6% in the north-east and the southern half of the WMA, and Variable driest year in year rainfall projections, with some areas indicating increases and others decreasing in the order of 10%.	• Implement critical water supply augmentation options. • Improved operational efficiencies of existing integrated bulk water systems. • Promote water storage at household level such as rainwater harvesting. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation).
Increased summer rainfall in the western parts. Increases in rainfall in the north parts of 4%-8%. Increased wet year rainfall and increased spatial coverage.	• Identify new flood zones, protect and prevent development at these locations. • Rehabilitate and protect wetlands and remove IAPs from riparian areas. • Increase vegetation coverage to reduce the impact of flooding. • Improved catchment management to reduce erosion and sedimentation risks. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants and prevent release into the atmosphere.
Increased summer temperatures of ~1.0 to 1.8°C.	• Reduce GHG emissions through the use of energy efficient technologies. • Increases areas where indigenous forests can serve as carbon sinks.
Potential increase in extreme rainfall events and flooding.	• Identify new flood zones, protect and prevent development at these locations. • Improved urban stormwater management systems and water sensitive design (WSD). • Encourage rainwater harvesting in urban and rural areas.
Increased water shortages and droughts, due to demand exceeding available yield and more variable rainfall.	• Promote water storage at household level such rainwater harvesting. • Explore alternative and under-developed water resources such as desal and re-use. • Implement restrictions during droughts and improve use of seasonal forecasting. • Use of low flow irrigation systems (e.g., drip irrigation).
Increased mean annual streamflow of between 5% to 15% in coastal areas, and 25% to 40% in mountainous areas.	• Modelling of new expanded flood zones. • Ensure adequate soil stabilisation in expanded flood zones.
Some areas indicating a potential for decreases in mean annual streamflow raining between 10% to 30%.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops. • Improved monitoring and compliance with licences and protecting of EWRs.
Variable groundwater recharge with some areas indicating 30% to 35% increase and other areas indicating decrease.	• Remove non-indigenous vegetation in areas where groundwater levels will decrease. • Application of NbS to improve natural storage of water and protect recharge zones. • Improved monitoring of groundwater level and abstraction.
High exposure to flooding in rural and tribal areas.	• Educate locals on flood zones within rural and tribal areas. • Identify flood zones in rural and tribal areas and including safe zones. • Ensure adequate storage of roof runoff to prevent flooding and water logging. • Improve vegetation cover to absorb rainfall during high intensity events. • Develop flood early warning systems (EWS) and advanced warning for communities.
Loss of agricultural crops and fertile soil due to flooding.	• Ensure soil stabilisation by planting annual indigenous vegetation. • Create barriers to slow surface runoff.
Crop loss due to heat stress from increased temperatures and increased flooding, which results in food insecurity.	• Encourage farmers to plant drought resistant and heat tolerant crops. • Adequate water storage and alternative water resources are available for use. • Ensure soils are sufficiently stabilised to prevent loss of crops from flooding.
Increased evaporation ranging from 5% to 9%.	• Irrigate during cooler times during the day to reduce evaporative loss. • Ensure increased evaporation is including in water resources and planning models. • Use of low flow irrigation systems (e.g., drip irrigation).

3.6 BREEDE-OLIFANTS WATER MANAGEMENT AREA

3.6.1 Location & Socio-economic Overview

The Breede- Olifants Water Management Area (WMA) is situated largely in the Western Cape Province, with portions of the upper catchment of the Olifants River falling in the Eastern Cape, and northern section within the Northern Cape. With the reconfiguration of the former Breede-Gouritz and Berg-Olifants into one WMA, the Breede-Olifants WMA is bounded by the Atlantic Ocean to the southwest, the Vaal-Orange WMA to the north and the Mzimvubu-Tsitsikama WMA to the east. The population in the Breede-Olifants WMA is estimated to be 7 262 734 million, with the majority residing in areas where most of the economic activities occur, in the urban and coastal areas of the WMA (DWS, 2021). It is anticipated that future population trends are likely to be influenced by economic growth, which will result in significant population increases in urban areas and a decrease in rural areas (BGCMA, 2017). The economy of the Breede-Olifants WMA dependent on the agricultural economy that provides 58% jobs to the people in rural areas. Trade and accommodation are the second largest sector and contribute to retirement and tourism in the area.

3.6.2 Current & Future Climate Change Projections

The Breede-Olifants experiences considerable variations in precipitation that ranges from 100mm (typically in the karoo area) and can exceed 1200mm while some mountainous areas in the south can experience up to 2500mm. The Great Karoo and Olifants River catchment of the WMA are categorised as a very late summer rainfall region, that has a large proportion of annual rainfall falling between March and May and October through storm events, meanwhile in the Breede, Olifants and Berg areas rainfall occurs between May and September. Historical temperatures for the WMA indicate that summer mean maximum temperatures ranges between ~16°C to 34°C, with variations experienced due to location and topography. By the mid-2030s temperatures are expected to increase. In the summer temperatures are expected to increase ~0.8°C (coastal areas) to 1.8°C. Note that into the more distant future of the 2080s the average increases from the multiple GCMs range from 4-5°C across the WMA. Historical temperatures across the entire WMA indicate that winter mean minimum temperatures ranges between -3°C (high altitude mountainous regions) to 8°C (along the coast). In the mid-2030s, minimum temperatures are expected to increase, in the range of 0.7°C to ~1.3°C. This is expected to vary across the by location and topography. The climate models in the Breede-Olifants WMA suggests that there will be uncertainty in climatic impacts on winter rainfall, and an increase in orographic activity. Projected spread of rainfall beyond the historical winter rainfall period, moderate temperature increases and an increase in extreme events that will affect vulnerable communities. Under the influence of climate change temperatures are projected to increase but are likely to differ spatially.

3.6.3 Water Availability & Requirements

With the economy of the Breede-Olifants highly dependent on the availability and health of water resources, this WMA has high water requirements and under climate change will see increased water demand from agriculture and domestic demand (DWS, 2021). This WMA is already in a water scarce area, and it is projected that population and economic growth will have a greater impact on increasing water demand, both natural and built (BGCMA, 2017). There are four large rivers within the Breede-Olifants WMA, the Breede, Berg, Gouritz and Olifants Rivers. The Olifants River is highly used for irrigation in the upper catchment of the WMA. While this WMA has many dams, there are plans to either expand the current or construction of new dams to assist with the issues of water scarcity in the catchment (BGCMA, 2022). In the mid-2030s, under the influence of climate change streamflow the Breede system is expected to experience decreases ranging in the order of 30%, whereas the Gouritz system is expected to experience increases in flow in the order of 30%. Similarly, groundwater is expected to decrease by 30% in the west and south-east parts and in the north-east parts groundwater is expected to increase. In the Berg system decreases in streamflow are projected to decrease in the order of 20% to 60%. Furthermore, increases are projected for the east of the system which is a key source of several important rivers. Into the future, the groundwater is expected to decrease in the order of 10 to 20% and up to 40% in places, which may have an impact on baseflows which is responsible for continued flow during the dry season.

3.6.4 Exposure to Climate Change Risk & Vulnerability

There are uncertainties regarding future climatic conditions in the Breede-Olifants WMA. Increases in temperature may affect water availability due to increased evaporative losses in the order of 6% to 10% across the expanse of the WMA. Increased temperatures may also affect the food security due to increased heat stress on crops. With water scarcity issues and population growth, this WMA will experience increased water requirements from agriculture and domestic use, under climate change. The increase in extreme events such as flood and drought, may also lead to infrastructure damage. This suggests that this WMA has high exposure to climate change. Increased atmospheric water holding capacity

Expected Climate Change Impacts	Proposed Climate Change Response Actions
6. WMA: Breede-Olifants **Hydro-climatic Zones:** South coast, West coast, Western Interior **SWSAs:** Groot Windhoek, table Mountain, Boland, Langeberg, Swartberg, Outeniqua	
Increased summer temperatures from ~0.8°C to 1.8°C and, increased winter temperatures from ~0.7°C to 1.3°C.	• Reduce GHG emissions through the use of energy efficient technologies. • Increases areas where indigenous forests can serve as carbon sinks. • Implementation of alternative energy generation technologies, such as energy from methane at wastewater treatment plants and prevent release into the atmosphere.
Potential change in rainfall seasonality, with a possibility of winter rainfall extending into other seasons and increase in extreme events that affect vulnerable communities.	• Improved modelling of seasonal regimes under climate change. • Modification of planting season and crops to account for changes in the growing season. • Ensure increased water storage is available to capture additional available water.
Increased risk of prolonged droughts due to rainfall uncertainty and failure of expected rainfall return times.	• Implement critical water supply infrastructure and improved operational efficiencies. • Explore alternative and under-developed water resources such as re-use and desal. • Promote water storage at household level such as rainwater harvesting. • Use of low flow irrigation systems (e.g., drip irrigation) and smart technologies. • Improved water use efficiency across all sectors (Urban and industrial). • Implement restrictions during periods of drought and improve seasonal forecasting. • Engage and educate communities on the importance of conserving water.
Increased temperature and increased evaporative losses.	• Irrigate during cooler times during the day to reduce evaporative loss. • Use of low flow irrigation systems (e.g., drip irrigation),
Decreased streamflow in the Breede system up to 30%.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation to increase surface runoff to streams. • Implement water restrictions during dry years. • Encourage farmers to plants drought tolerant crops.
Increased streamflow in the Gouritz system up to 30%	• Modelling of new expanded flood zones. • Ensure adequate soil stabilisation in expanded flood zones.
Decreased groundwater recharge in west and south-east.	• Remove non-indigenous vegetation in areas where groundwater levels will decrease. • Application of NbS to improve natural storage of water. • Improved monitoring of groundwater levels and abstraction.
Increased groundwater recharge in the north-east.	• Identify areas that may become flood zones and prevent development in these areas. • Increase woody vegetation to prevent areas becoming water logged under high rainfall. • Application of NbS to improve natural storage of water.
Streamflow decreases in the Berg system 20% to 60%.	• Removal of alien vegetation in catchment areas and replace with indigenous vegetation. • Implement water restrictions during dry years and improve operational efficiency. • Encourage farmers to plant drought tolerant crops.
Reduced baseflow contributions during the dry season due to decreased groundwater availability and IAP impacts.	• Promote water storage at household level such as rainwater harvesting. • Explore alternative and under-developed water resources. • Use of low flow irrigation systems (e.g., drip irrigation). • Removal of alien vegetation in catchment areas and replace with indigenous vegetation
Increased evaporative losses in the order of 6% to 10%.	• Ensure evaporation losses are updated in water resources planning models. • Irrigate during cooler times during the day to reduce evaporative loss. • Use of low flow irrigation systems (e.g., drip irrigation).
Infrastructure damage due to increased flooding.	• Reinforce infrastructure based on updated design flood and rainfall models. • Integrate NbS to reduce the impact of flooding on grey infrastructure. • Implement required additional infrastructure for flood protection. • Allow room-for the river in areas likely to experience repeated flooding impacts.