LONG TERM ADAPTATION SCENARIOS

TOGETHER DEVELOPING ADAPTATION RESPONSES FOR FUTURE CLIMATES

WATER

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

water affairs
Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

giz

On behalf of
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

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LONG-TERM ADAPTATION SCENARIOS FLAGSHIP RESEARCH PROGRAMME (LTAS)

CLIMATE CHANGE IMPLICATIONS FOR THE WATER SECTOR IN SOUTH AFRICA

LTAS Phase 1, Technical Report (no. 2 of 6)

The project is part of the International Climate Initiative (ICI), which is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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ABWSS	Amatole Bulk Water Supply System
ACRU	Agricultural Catchments Research Unit
ADM	Amathole District Municipality
AMD	Acid mine drainage
AWSS	Algoa Water Supply System
BOCMA	Breede-Overberg catchment management agency
CMA	Catchment management agency
CMS	Catchment management strategy
DEA	Department of Environmental Affairs
DWA	Department of Water Affairs
EC	Ecological category
EWR	Environmental water requirement
FWF WWTW	Fish Water Flats Wastewater Treatment Works
GCM	Global circulation model
GWS	Ground water strategy
HFD	Hybrid frequency distribution
IDZ	Industrial development zone
IMS	Information management system
ISP	Internal strategic perspective
KNP	Kruger National Park
L1S	level one stabilisation (emissions constrained to 450 ppm CO_2e)
LHWP	Lesotho Highlands Water Project
m3/km2/a	Cubic metres per square kilometre per annum
MAR	Mean annual runoff
NMBM	Nelson Mandela Bay Municipality
NWRS	National Water Resource Strategy
NWRS2	National Water Resource Strategy second edition
ppm	Parts per million
RSS	Reconciliation strategy study
SADC	Southern African Development Community
SDA	Sewage drainage areas
TCTA	Trans-Caledon Tunnel Authority
UCE	Unconstrained emissions
URV	Unit reference value
WC/WD	Water conservation and water demand
WC/WDM	Water conservation and water demand management
WCCS	National Climate Change Strategy for Water Resources
WCDM	Water conservation and demand management
WCWSS	Western Cape Water Supply System
WGDF	Water for Growth and Development Framework
WMA	Water management area
WRC	Water Research Commission
WRPM	Water Resources Planning Model
WRSM2000	Water Resources Simulation (Pitman) Model 2000
WRYM	Water Resources Yield Model
WSAM	Water Situation Assessment Model
WUA	Water users' association
WWTW	Wastewater treatment works

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THE LTAS PHASE 1

The Long-Term Adaptation Scenarios (LTAS) Flagship Research Programme (2012–2014) is a multi-sectoral research programme, mandated by the South African National Climate Change Response White Paper (NCCRP, para 8.8). The LTAS aims to develop national and sub-national adaptation scenarios for South Africa under plausible future climate conditions and development pathways. During its first Phase (completed in June 2013), fundamental climate modelling and related sector-based impacts and adaptation scoping were conducted and synthesised. This included an analysis of climate change trends and projections for South Africa that was compared with model projections for the same time period, and the development of a consensus view of scenarios for three time periods (short-, medium- and long-term). Scoping of impacts, adaptation options and future research needs, identified in the White Paper and guided by stakeholder engagement, was conducted for primary sectors namely **water**, agriculture and forestry, human health, marine fisheries, and biodiversity. This modelling and scoping will provide a basis for cross-sectoral and economic assessment work needed to develop plausible adaptation scenarios during Phase 2 (scheduled for completion in April 2014).

Six individual technical reports have been developed to summarise the findings from Phase 1, including one technical report on *climate trends and scenarios for South Africa* and five summarising the *climate change implications for primary sectors*, **water**, agriculture and forestry, human health, marine fisheries, and biodiversity. A description of the key messages emerging from the LTAS Phase 1 has been developed into a *summary for policy-makers*; as well as into seven factsheets constituting the LTAS *Climate and Impacts Factsheet Series.*

REPORT OVERVIEW

This technical report presents the LTAS Phase 1 findings for the water sector in South Africa. It references existing South African research to describe the status quo for water resource planning in South Africa, including the extent to which climate change is considered in the existing water resources planning framework, as well as the potential effects of climate change on the water sector. This includes an analysis of existing water resource planning tools, originally developed to address demand growth and climate variability, in the context of future climate change requirements. These tools include reconciliation studies (one of the key tools used in South Africa for assessing water use and future requirements) and water strategy policy documents. This technical report summarises climate change impacts, adaptation response options and future research needs for the water sector based on the results of relevant past and current research, including the draft National Water Resource Strategy 2 (NWRS2), the National Water Adaptation Strategy process, and new impact modelling for annual and seasonal runoff under both unconstrained and constrained pathways from recent modelling work conducted by the Treasury and the National Planning Commission (Treasury and NPC, 2013).

The NWRS2 defines the strategic direction for water management in South Africa over the next 20 years, but also the focuses on water priorities for the next five years (2013–2017). At the time of developing this technical report the draft NWRS2 had been completed and was under public review. The final NWRS2 was approved by the Minister in June 2013. Substantial changes were made to the NWRS2 based on the public review process and this should be borne in mind when reading this technical report. In particular, the Water for Growth and Development Framework (WGDF) described in Section 1.1.1 (National planning) of this report, although approved by Cabinet, has not been finalised (gazetted). The NWRS2 has adopted this framework as a primary tool for management of water resources for growth and development in South Africa, and aspects of the WGDF described in section 1.1.1 are now incorporated into the finalised NWRS2 as core strategies. It is recommended that the final NWRS2 (now available on the Department of Water Affairs (DWA) website: www.dwaf.gov.za) be read to complement certain sections of the technical report. In terms of its mandate and the strategic imperative under the National Climate Change Policy, the DWA is in the process of developing a climate change adaptation strategy for the water sector. This is being done in two phases, beginning with an Assessment Phase, which will then inform the Strategy Development Phase.

Annex 1 of this technical report provides key background detail on reconciliation studies and the All Towns Strategies which are one of the central tools for water resources planning at infrastructure system level, and are likely to be critical elements of a future national response capacity. These studies and strategies are updated annually with the latest information provided on the Department of Water Affairs website (www.dwaf.gov.za). The information presented here is based on the data available between April 2012 and March 2013.

A brief description of each chapter of the technical report is provided below.

Chapter 1 (Strategic water planning in South Africa) provides an overview of water resource planning in South Africa including at national level, water resource system level, water management area (WMA)/catchment level as well as at the sub-catchment/municipal level. The chapter has a focus on reconciliation studies, which are the central tools used at water resources infrastructure system level, and includes an assessment of the use and future requirements for water in South Africa and how these requirements can be "reconciled" with the available sources through various strategies over the next two to three decades. The chapter provides a summary of the approach and progress of existing reconciliation studies to date, with a full description presented in Annex 1.

Chapter 2 (Climate change impacts on the water sector) synthesises results from recent climate change impact assessments in relation to hydrology, water quality, water use and water supply systems. This includes climate change and hydrological modelling results for the water sector, namely impacts on national runoff, water resource system yields and high risk hydrological zones comprising reconciliation study areas.

Chapter 3 (Adaptation response options) describes adaptation responses for the water sector against the backdrop of the water resources planning framework presented in Chapter 1, Section 1.1. This includes summarising specific interventions for each level and focus area within the framework, as well as highlighting priority functions that would be beneficial for the DWA, and incorporating climate change adaptation in reconciliation studies and other water resource planning tools. An overview of the adaptation measures proposed in the Draft Climate Change Adaptation Strategy for the water sector is also included.

Chapter 4 (Research requirements) highlights areas in which research is required for supporting the development of tools, approaches and case studies that inform water planning in the context of long-term climate change.

Chapter 5 (Conclusion) concludes the report highlighting the scope of LTAS Phase 2 in exploring the socio-economic implications of a range of possible climate-water futures in South Africa.

Annex 1 (Review of existing reconciliation studies for South Africa) provides a full description of existing reconciliation studies with a focus on area of supply, hydrological record, assumptions of the study, current and future water requirements, water resource planning and climate change considerations. This is linked to the summary presented in Chapter 1.

Annex 2 Provides an indicative finer scale case study on climate change impacts on water resource system yields.

EXECUTIVE SUMMARY

Because of South Africa's generally arid to semi-arid climate, rainfall and river flow are unpredictable in time and unevenly distributed in space, with only 12% of the land area generating 50% of potentially available surface water resources. Decadal rainfall variability also results in extended periodic dry and wet periods across the country. Surface water resources were already over-allocated by the year 2000 in five of the nineteen water management areas.

Demand for water is expected to increase with economic growth, increased urbanisation, higher standards of living, and population growth. Climate change impacts could exacerbate existing water-related challenges and create new ones through increased rainfall variability including more frequent extreme weather events (droughts and floods), changing rainfall seasonality and overall warming leading to greater surface water losses to the atmosphere. This would affect a wide range of economic sectors and livelihoods, impinge on the development of infrastructure and catchment management, and demand management into the future.

Current national water planning contingencies provide assurance of water supply (based on surface water resources) from 91% (for agricultural use) up to as high as 99.5% for key strategic uses under historic patterns of rainfall variability. Groundwater resources are not currently fully integrated into the national water strategy, though these currently provide about 10% of national needs, being primarily used for irrigation. A key concern for the water sector is, therefore, whether future rainfall variability will exceed patterns based on the historical record. Current modelling of future climate is uncertain with respect to rainfall variability and seasonality change, but more certain with regard to warming projections. Consequently, a scenario-based approach is a viable way forward with respect to exploring adaptation options for this sector and the cross-sectoral and economic implications. Climate modelling approaches provide guidance on the likely range of change in rainfall and temperature that must be further translated using hydrological modelling approaches of projected impacts on surface water flows and availability. Based on LTAS Phase 1 findings (see climate trends and scenarios technical report), South Africa's climate future up to 2050 and beyond can be described using four fundamental climate scenarios at national scale, with different degrees of change and likelihood that capture the impacts of global mitigation and the passing of time.

1. **warmer (<3°C above 1961–2000) and wetter** with greater frequency of extreme rainfall events.
2. **warmer (<3°C above 1961–2000) and drier**, with an increase in the frequency of drought events and somewhat greater frequency of extreme rainfall events.
3. **hotter (>3°C above 1961–2000) and wetter** with substantially greater frequency of extreme rainfall events.
4. **hotter (>3°C above 1961–2000) and drier**, with a substantial increase in the frequency of drought events and greater frequency of extreme rainfall events.

Projections for national runoff range from a 20% reduction to a 60% increase by as early as mid-century based on an unmitigated global emissions pathway. However, if global emissions are constrained to stabilise at 450 ppm CO_2, these changes are projected to lie between a 5% decrease and a 20% increase in annual runoff. Sub-nationally, projected changes range from increases along the eastern seaboard and central interior to decreases in much of the Western Cape. Areas showing highest risks of extreme runoff related events include KwaZulu-Natal, parts of southern Mpumalanga and the Eastern Cape. Other areas show neutral to reduced risk of extreme runoff events, with the exception of the central and lower Orange River region. Specific areas of high risk, where cumulative negative climate change impacts are likely to occur (including increased evaporation, decreased rainfall and decreased runoff), include the southwest of the country, the central-western parts and to some extent the extreme north. Under all four future medium and long term climate scenarios a higher frequency of flooding and drought extremes is projected, with the range of extremes exacerbated significantly under the unconstrained global emissions scenario.

Specific provisions for climate change have not yet been made in most of the water resources reconciliation studies in South Africa, these being the primary tool for strategic water resource planning to at least 2030 in South Africa. However, this planning capacity will be a key capability for adaptation planning under ongoing and future climate change. To build resilience to climate change in the water sector it would be beneficial if resource planners could develop adaptive responses that do not foreclose future options, thus retaining the ability to respond to a wide range of climate outcomes, monitor indicators so that changes can be observed with increasing certainty, and adopt flexible planning to allow appropriate responses as conditions change.

Adaptation response strategies for the water sector can usefully be identified at distinct governance levels. At national scale, the development of a strategic intent and an enabling framework for adaptation would help to ensure a coherent national response. At sub-national or system scale, key institutions could usefully engage in prioritising and allocating resources to adaptation interventions that adequately reflect the conditions at that scale. At sub-catchment or municipal scale, the design of local implementation actions would be facilitated by responding to local challenges, resources and capacities.

The following priority functions would be beneficial to the DWA: policy review for enabling flexible frameworks, flexible and robust infrastructure planning, resources directed at maintaining and rebuilding ecological infrastructure in vulnerable systems, institutional oversight to ensure water-related institutions build adaptive management capacity, effective information management and maintenance of monitoring and evaluation systems, and sustainable and locally accessible financial management.

Research and focused monitoring is required to support the development of tools, approaches and case studies that inform water planning in the context of long-term climate change. This includes understanding the way in which climate driven changes in water resources availability or demand may constrain or enable different development pathways in different parts of South Africa, particularly in terms of agricultural production and energy generation. In addition, there is value in exploring the implications of long-term hydrological change on the ecological reserve (including the appropriate definition of the reserve) and associated issues of catchment management approaches that are needed to maintain the ecological reserve in different systems.

Key decisions in development planning would benefit from considering the implications of a range of possible climate-water futures facing South Africa. Under a wetter future scenario trade-offs in water allocation between sectors are likely to be less restrictive, providing greater scope for urban-industrial economic growth and water provision for an intensive irrigated agricultural production model. Under a drier future scenario significant trade-offs are likely to occur between developmental aspirations, particularly in terms of the allocation between agricultural and urban-industrial water use, linked to the marginal costs of enhancing water supply. These constraints are most likely to be experienced in central, northern and south-western parts of South Africa. This scenario has significant social, economic and ecological consequences through restricting the range of viable national development pathways.

1. STRATEGIC WATER PLANNING IN SOUTH AFRICA

The water sector has a multifaceted planning regime which will be central in the development and implementation of adaptive responses to climate change. South Africa has a number of levels of water planning as indicated in (Figure 1).

Vertically, planning is aligned from national to local level, with consistent legal requirements and, as the figure indicates broadly, the delegation of responsibilities from national level down to local and sub-catchment levels. Horizontally, there is cooperation between the three broad sectors of water resources management, water resources infrastructure, and water services.

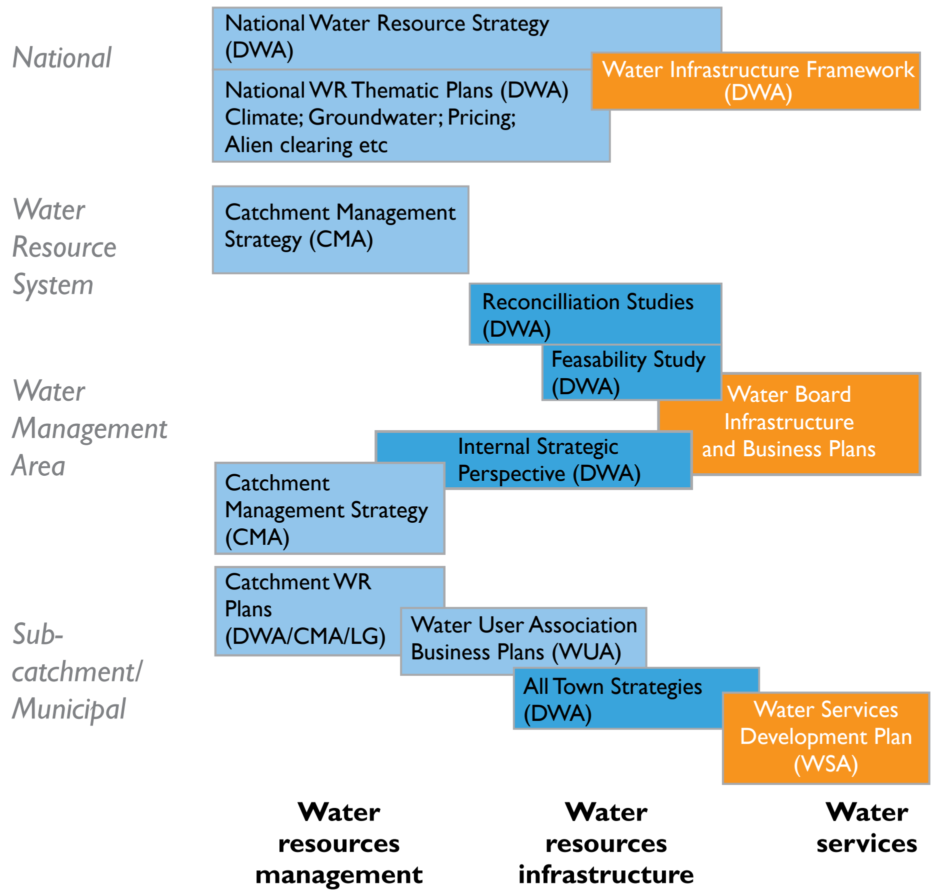

Figure 1. Water resources planning framework in South Africa (light blue – management; blue – infrastructure; Orange – services)

1.1 National planning

National planning provides the strategic framework for local planning. The overarching plan is the National Water Resource Strategy (NWRS). This strategy is required by the National Water Act (Act 36 of 1998) and defines the strategic direction for water management in South Africa over the next 20 years, but also the focus on water priorities for the next five years. Under the NWRS there are a number of national thematic plans such as the National Climate Change Strategy for Water Resources (WCCS) and the Ground Water Strategy (GWS).

National water services planning is focused largely on financing and monitoring, and on providing a framework with norms and standards for local government to provide water services in terms of its Constitutional Mandate.

1.1.1 Water for Growth and Development Framework

The draft Water for Growth and Development Framework (WGDF), version 7, was released in 2009 and is described by the National Climate Change Response White Paper as the long-term tool for the water sector to deal with climate change. The WGDF although approved by Cabinet, has not been finalised (gazetted). The framework describes the current water resources as being insufficient to satisfy the projected increase in demand, as indicated in Figure 2, and proposes a number of high-level recommendations. One such recommendation is to increase the supply of water by diversifying the water mix using desalination in coastal areas and recycling in inland areas as a strategy to increase water security. The framework describes the threat of climate change on water resources, and proposes

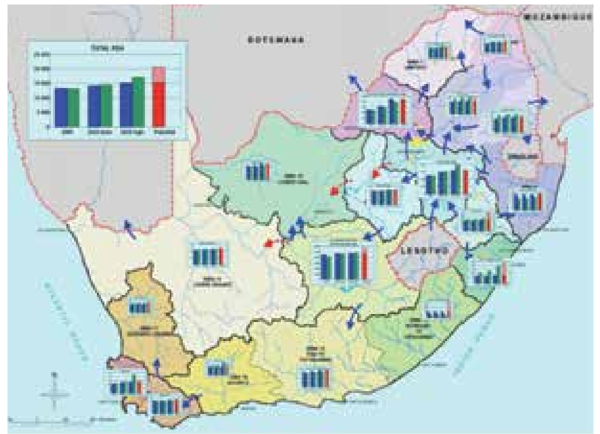

Figure 2. Water availability (blue) and use (green) (DWA, 2009b).

that the DWA should focus on adaptation responses, as the mitigation potential in the sector may be relatively small (the water sector contributes 1% to total national emissions), despite the fact that adaptive responses such as desalination have mitigation implications through their energy demands, and that national mitigation responses will have implications for the water sector.

The framework does not describe an integrated national approach to the effects of climate change on water resources, and provides a suite of broad options similar to those described in the National Climate Change Response White Paper. The issue of extreme events such as droughts and floods is only implicitly addressed with reference to potential risks and threats.

Box 1 describes the three options for the water sector to deal with climate change from the framework, which is yet to be finalised and published by the DWA.

Box 1. Options for dealing with climate change

To address the potential risks and threats posed by climate change with respect to water security, the following actions should be seriously considered:

- Develop a water sector response strategy comprising adaptation plans and mitigation measures
- Stimulate a shift in focus from climatic prediction and mitigation to response and adaptation options.
- Focus on those WMAs or catchments likely to face the greatest risk of water shortages or with high runoff and erosion potential, and develop an appropriate and reliable understanding so that risk and disaster management plans can be drawn up and implemented.

1.1.2 National Water Resource Strategy

The National Water Resource Strategy 2 (NWRS2), required by the National Water Act (Act 36 of 1998), defines the strategic direction for water management in South Africa over the next 20 years and the focus on water priorities for the next five years (2013–2017).

The NWRS2 assumes that climate change will increase the pressure on already stressed water resources, and thus that there is a crucial requirement for the effective management, use, allocation and re-allocation of available water resources. The strategy further sets out particular climate change objectives which are required to be integrated into the short-, medium- and long-term planning for water resources as indicated in Box 2 below.

Box 2. Core climate change objectives of NWRS2

Integrating climate change considerations in the short-, medium- and long-term water planning processes:

- Implementing the best catchment and water management practices to maximise the degree of water security and resource protection under changing climatic conditions.
- Reducing the vulnerability and enhancing the resilience to water-related impacts of climate change in communities/sectors at greatest risk.
- Providing human, legal, regulatory, institutional, governance and financial resources and capacity to deal with the long-term effects of climate change.
- Undertaking focused monitoring and research in order to ensure the efficacy of water adaptation approaches over the long-term.

The enabling strategies that have been identified to enable the implementation of the NWRS2 fall broadly under the following headings:

- Water finance and funding
- Water sector capacity building
- Monitoring and information
- Research and innovation

Unfortunately, climate change objectives feature explicitly only for monitoring and evaluation, leaving significant gaps in elements of the strategy that are necessary for a long-term, sustainable adaptive response under climate change. The National Climate Change Strategy for Water Resources (see below) could also benefit from consideration of further enabling strategies, addressing issues such as catchment management, to enhance the planning of hard infrastructure to adapt to climate change.

1.1.3 Climate change strategy for water resources

Currently, the DWA is working on a climate change strategy for South Africa's water resources. The first part of the process, which is now complete, examines the status quo of water resources in South Africa and the additional dimension climate change adds to various aspects of managing water resources.

The base assumption about the water impacts of climate change informing the strategic responses is that South Africa's water resources are highly developed, highly stressed and suffer from a certain level of degradation. High water demand and high levels of pollution from a variety of sources have added to the complexities of a fundamentally high risk hydrology. Thus climate change adds a layer of increased stress onto an already stressed system. A key message is that better optimised management of the current situation would be beneficial in addressing the longer-term impacts of climate change.

1.1.4 Groundwater management strategy

The National Groundwater Strategy, completed in 2010, recognises the importance of groundwater as an underutilised water resource (DWA, 2010c). The strategy aims to quantify groundwater as a resource, as indicated in Figure 3, and provide direction for its management.

Currently, about 10% of South Africa's water resources are sourced from groundwater. The sectoral use of groundwater is indicated in Figure 4 below, where use for irrigation accounts for the most groundwater usage.

The strategy not only recognises the need to ensure that groundwater should be protected, but it should also form part of the climate change adaptation strategy to assure the continuity of water supplies.

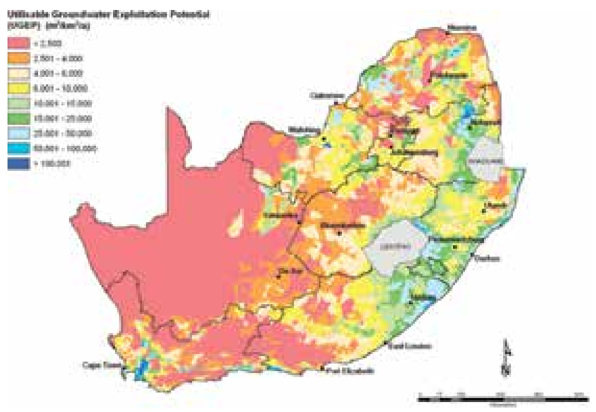

Figure 3. Groundwater exploitation potential (National Groundwater Strategy, 2010)

The strategy recognises that groundwater is not consistently managed or assessed as with other sources such as surface water potential, and may not feature prominently in water resource plans. As a result, more expensive options may be implemented where groundwater may be a viable and more cost effective option. A key advantage of groundwater in a climate change context is that it is buffered to some extent from rainfall variability, and impacts may have a slower onset as the replenishment of groundwater is controlled by long-term climatic conditions.

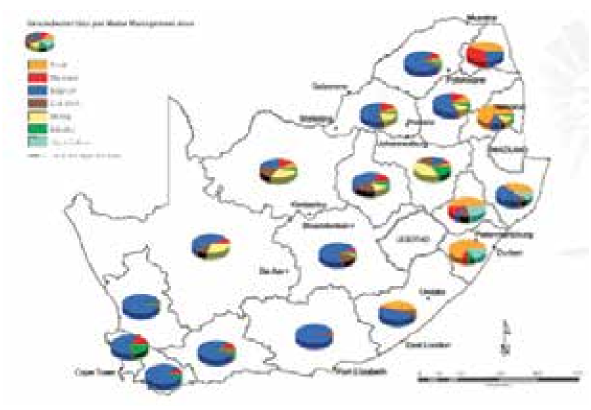

Figure 4 Groundwater use per WMA (Groundwater Strategy, 2010)

The report recognises that artificial recharge is a groundwater management technique that may play an increasing role in maintaining South Africa's water security. Artificial recharge is the transfer of surplus surface water underground by injecting it into aquifers through boreholes. The advantages include lower evaporation losses, which will become especially critical as higher temperatures increase evaporation of stored surface water.

The strategy recognises the need for more research into the effects of climate change on technical issues such as groundwater recharge. There is limited understanding of the origin, recharge and availability of groundwater. This is further hampered by the reduction in both skills and infrastructure for monitoring groundwater. Furthermore, groundwater quality under climate change and the effects of long-term droughts on groundwater need further research to improve understanding.

1.1.5 Alien invasive species clearing

The Department of Environmental Affairs is leading a multi-departmental process to remove invading alien plant species under the "Working for Water" (WFW) banner. Removal of alien invasive species has multiple benefits, including maintaining natural biodiversity, improving water security and creating jobs. There are currently 300 active programmes using chemical, mechanical and biological methods either singly or in combination to remove alien species. Figure 5 below indicates priority areas for clearing. This is currently being revised.

There are distinct benefits to using WFW as an adaptation measure, especially as climate change exacerbates water scarcity. However, resources will be required for ongoing management to keep areas alien free and to rehabilitate natural vegetation to ensure that water services are maintained.

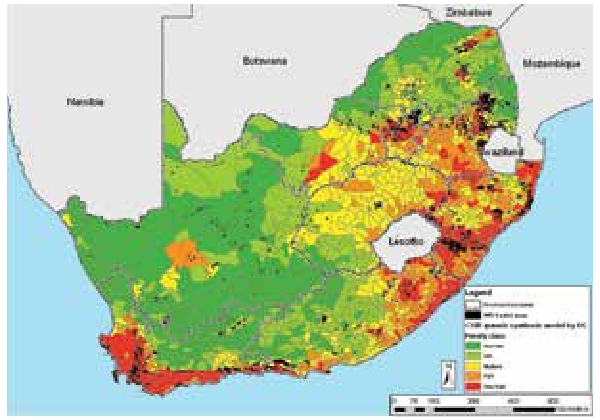

Figure 5. Map for removal of invasive alien species based on a prioritisation model (Le Maitre et al., 2012)

1.2 Water resource system planning

South Africa has developed a sophisticated methodology to consider historical climate and hydrological variability in water resources infrastructure planning. The main tools for system planning are reconciliation studies, which guide water infrastructure planning and comprise detailed planning and operational considerations, informed by assumptions of water demand trajectories. These studies are supported by the application of a number of modelling tools that will be central in assessing adaptive responses under future climate change. An overview of the reconciliation study method and its focus areas is described in Annex 1, as these could usefully form a central pillar of adaptation responses to climate variability and change.

A number of thematic plans also exist at the system planning level, which are commissioned on an "as needed" basis and tend to be specific to a single system, such as the acid mine drainage (AMD) plans which affect particular water systems in South Africa. These tools could also usefully be further developed to support climate change adaptation responses.

1.2.2 Reconciliation studies

Water resource planning requires an understanding of the key drivers of water demand and how different development futures will impact on water resource availability and use. The most common approach to incorporating different development futures in water resource planning is to firstly understand the trends in current water use and to quantify the available resources, and then to account for future demand under different scenarios.

The key drivers of water use are to a large extent linked to population growth rates, and water use in specific sectors such as industry, domestic use and irrigation. For example, in South Africa rapid growth in urbanisation, coupled with economic development in general, will increase water demand. This, however, depends on the local context, for example, in the Lephalale water supply system future water demand will be driven largely by industrialisation as a result of energy production and mining, whereas in the Western Cape rapid urbanisation will drive future water demands.

The general trend has been to construct different scenarios that can be synthesised into a low water demand scenario and a high demand scenario These are based either on population growth rates, or water demand in key sectors of the economy that are expected to grow with significant water requirements.

Water resource reconciliation studies involve an assessment of the use and future requirements for water, and how these can be "reconciled" with the available sources through various strategies for the next two to three decades. The main aim is to determine when the next water infrastructure system would be required and when it should be built. Adaptation is inherent in the planning approach but it does not take a long-term strategic perspective. These studies address:

- Future water requirement scenarios for and within the metropolitan area.
- Water resources and other interventions that could add to water availability.
- Possible methods for reconciling the requirements for water with the available resources.
- Recommendations on the development and implementation of required interventions and actions.
- Monitoring and updating of the strategies into the future.

The potential key strategies for climate change adaptation include:

- Water conservation and demand management
- Re-using water
- Using groundwater
- Desalinating seawater (applicable to coastal areas)
- Building dams
- Transfers between dams
- Rehabilitating catchments by clearing invasive alien plants and restoration
- Harvesting rainwater
- Changing water use
- Improving management and operations.

The planning of water resources requires the consideration of many uncertainties, including the extent and nature of future requirements, and knowledge of both rainfall and runoff; knowledge that slowly improves as the historical record grows.

Climate change exacerbates climate variability, which in turn increases the uncertainty around water resource planning. In order to assess the impact of climate change, knowledge about the components of the hydrological cycle that are impacted on by climate and determining trends distilled from historical records become crucial. The key components of the hydrological cycle are:

- Changing precipitation patterns
- Increasing atmospheric water vapour
- Changing temperature patterns such as increasing evaporation
- Changes in soil moisture and runoff
- Changing water quality conditions.

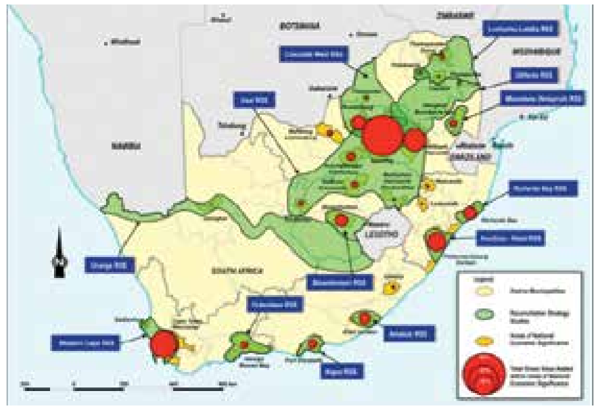

Figure 6. Key economic areas in relation to existing water supply system studies (RSS – reconciliation strategy study)

In the reconciliation strategies for the metropolitan areas, the possible impacts of climate change on available water are included in future scenarios to ensure timeous study of augmentation options. Adaptation measures can then be introduced when they become necessary. An example would be the predicted drying of the west coast and the effect this would have on the water supply to Cape Town.

Presented below and in Annex 1 is a high level assessment of the reconciliation studies that have been conducted in South Africa, looking specifically at how climate variability and/or climate change has been incorporated into the assumptions made for the different scenarios and the water demand and supply projections. Reconciliation studies (and the all towns strategies – see Section 1.1.4) are updated annually with the latest information provided on the DWA website (www.dwaf.gov.za). The information presented here is based on the data available between April 2012 and March 2013.

1.2.2.1 Approach to the Reconciliation Studies

There are thirteen reconciliation studies for South Africa. In addition to these, the all towns strategies are reconciliation studies for smaller water supply areas. Currently nine of the bulk water studies have been completed. All 914 all towns strategies have also been completed.

In general, the assessments of water availability were based on current infrastructure, current levels of development and accurate accounting for surface water, groundwater, return flows and inter-basin transfers. Implementation of the ecological reserve and availability of water from desalination was also considered. It should be noted that water conservation and water demand management is the priority strategy in all large reconciliation areas, and in the all towns strategies (further described in Section 1.1.4). The specific measures differ from area to area depending on the local context.

DWA (2010a) provides an overview of the future water resources and the water balance situation in South Africa, which should serve as input to national strategic spatial and sectoral development planning. This includes assessment of the remaining potential for water resource development in South Africa and the means to extend the utility of the resources, all with associated costs and estimated energy requirements. The report provides a clear perspective on water resources and future water requirements, and scenarios on how these could be reconciled for various key areas in the country. Special care was taken over inter-basin transfers and provision of water supply to future power stations to avoid duplication or omission. Projections of future requirements are made for the period to 2035, and then extrapolated to 2050. Instead of a spectrum of high and low scenarios, a reference scenario was selected. The expected growth in water requirements is predominantly in the urban, industrial, mining and power generation sectors. There were no growth projections for irrigation developments, unless otherwise stated in the NWRS (DWA, 2010a).

It should be noted that while the possible impacts of climate change are taken into account during the detailed planning of water resources developments, specific provisions for climate change may not have been included in the reconciliation studies. This is further explored in the review of the case studies summarised below in Table 1 with full details provided in Annex 1. It should also be noted that limited detailed information on the potential impacts of climate change on hydrology was available when the existing reconciliation studies were developed. DWA has indicated that the methodology will be revisited with the research and information that has been generated during the National Water Adaptation Strategy process.

The unit cost of water is the basis for comparing the various augmentation options that inform the development pathway. For comparative purposes, the marginal cost was expressed in terms of unit reference value (URV) as a first order economic indicator. It should be noted that the URV does not consider the costs of rehabilitation and maintenance of the catchment. The energy requirements for the various options is another key variable, therefore, the marginal energy costs were also determined for use in the URV calculations. It should be noted that growth in future water requirements as well as the sizing and scheduling of a development option can have a major influence on the URV (DWA, 2010a).

1.2.2.2 Prioritisation criteria

When looking at the development pathways for the reconciliation studies a number of decisions need to be made, for example, new schemes or interventions have been introduced only when dictated by the growth in water requirements. These developments would then be prioritised and phased for each area according to the following criteria:

- Ranking of options according to the unit cost of water, with the highest ranking afforded to the option with the lowest URV.
- When two options have the same URV, the one with the lowest unit energy requirement is prioritised.
- Options to meet the growth in water requirements would be phased in by first using the highest ranked option, and then those with progressively lower rankings.
- Should the highest ranked scheme not be able to deliver water in time (due to its status in the development cycle), then the next-ranked scheme that could be implemented in time would be used.

The development of new water resources infrastructure is a complex and time-consuming process that typically takes more than a decade from inception to commissioning. For larger and more complex projects with environmental and political sensitivities lead times may be more than two decades. It is essential therefore to identify development needs and undertake preparatory work well ahead of the time a project needs to deliver water. Figure 7 below shows the typical programme for water resources development.

Typical Programme for Water Resource Developments

1 1–5 years (1)	2 1–3 years (2)	3 2–4 years (3)	4 2–5 years (4)	5 2–6 years (5)	6 4–8 years (6)
Reconnaissance Phase	Pre-feasibility Phase	Feasibility Phase	Decision Support Phase	Design/ Documentation Phase	Construction/ Implementation Phase
• Needs identification	• Preliminary investigation	• Detail investigation and assessment of best options(s), sizing and configuration (technical, environmental and cost)	• Environmental approval	• Formalise institutional arrangements	• Procurement
• Identification and selection of possible interventions	• Identify best options for detail study	• Recommendation of project	• Reserve determination	• Secure funding	• Resettlement and compensation
			• Public involvement	• Procurement procedures	• Construction
			• Initial funding and institutional arrangements	• Engineering design and construction documentation	• Impounding and commissioning
			• Some optimisation		
			• Decision to implement		

Notes: 1) Numbers in brackets indicative of average periods.
2) Some of the activities typically extend over more than one phase.
3) Determination of the Reserve should be independent from any specific project development. However, where the Reserve has not previously been determined, it may be included under the development programme. It is therefore not restricted to a specific phase.

Figure 7. Water resource development diagram (DWA, 2010a)

1.2.2.3 Review of existing reconciliation studies

Table 1 provides a summary of the progress of reconciliation studies to date, with an indication of the way climate change has been considered. See Annex 1 for a full description of existing reconciliation studies with a focus on area of supply, hydrological record, assumptions of the study, current and future water requirements, water resource planning and climate change considerations. As limited detailed information on the potential impacts of climate change on hydrology was available when the reconciliation studies were developed, the DWA focused on developing crude scenarios only where there were indications that the yield could decrease. This included the Western Cape and Algoa areas. These scenarios were based on the assumed drop in yield and ensured that appropriate interventions were brought into the planning cycle. This methodology will be revisited with the research and information that has been generated during the National Water Adaptation Strategy process.

Table 1. Summary of reconciliation studies to date

NO	STUDY	AREA OF SUPPLY	PROGRESS	CLIMATE CHANGE CONSIDERATIONS	HYDROLOGY CONSIDERATIONS
1	Algoa	Nelson Mandela Bay Municipality (NMBM), several smaller towns within the Kouga Local Municipality and the Gamtoos Irrigation Board.	Completed in 2011	The study highlighted the need to monitor the impacts of climate change and conduct an impact assessment study to determine the expected regional impact of climate change on the Algoa water supply system (AWSS) water balance. It was assumed that climate change would reduce the yields by 10%.	Data were used for the period between 1927 and 1991. There were large discrepancies between the above period and recent hydrology. Further investigations are underway.
2	Amatole	The system supplies the Buffalo City Municipality, including East London, King Williams Town, Bisho, and part of the Amathole District Municipality area.	Completed in 2008	Climate change was considered, but was not incorporated into the water balance reconciliation.	The initial analysis looked at the period from 1920 to 1996. This was extended and a hydrological record from 1920 to 2003 was used.
3	Bloem	This system provides most of the water required by the towns located within the Mangaung Metro Municipality, namely Bloemfontein, Thaba Nchu, Botshabelo, Dewetsdorp, Reddersburg, Wepener, Edenburg and Excelsior.	Completed in 2012	No climate change considerations have been made.	Assumed data records to start from the 1920s.
4	Crocodile West	This study covers the northern areas of Gauteng, the platinum mines, other developments around Rustenburg and Brits and further north to Thabazimbi and large-scale energy-related developments that are planned for the Waterberg coalfields in the vicinity of Lephalale.	Completed in 2010	No climate change considerations were found in the report.	The simulated flow data for the Crocodile (West) River Catchment covers the hydrological record for 1920 to 2003.
5	KwaZulu-Natal Coastal Metropolitan	This study looks at the area between Pietermaritzburg, Durban, Kwadukuza and Amanzimtoti. It includes the eThekwini Metropolitan, Msunduzi and Illembe municipalities.	Completed in 2010	The study notes that climate change should be monitored and that current models show no reduction in rainfall patterns, but there may be variability. Umgeni Water is in the process of conducting a study on the impacts that climate change could have on the water resources. These results are not yet available.	
6	Luvuvhu & Letaba	The whole of the Luvuvhu and Letaba WMA and parts of the adjacent WMAs.	In progress, completion date is May 2013	No climate change considerations thus far.	
7	Mbombela Municipal Area	The municipal area straddles the Sabie and Crocodile River catchment	In progress, completion date is 2014	No climate change considerations thus far.	
8	Mhlatuze	Mhlatuze Local Municipality, comprising Empangeni, Ngwelezana, Nseleni, Esikhaweni and a number of rural villages.	In progress	No climate change considerations thus far.	

Table 1. Summary of reconciliation studies to date

NO	STUDY	AREA OF SUPPLY	PROGRESS	CLIMATE CHANGE CONSIDERATIONS	HYDROLOGY CONSIDERATIONS
9	Olifants	This study covers the entire Olifants WMA and the adjacent areas of Polokwane and Mogalakwena, which are supplied from the Olifants.	Completed in 2012	No climate change considerations were made.	Assumed data records to start from the 1920s.
10	Orange	The study consists of the Upper and Lower Orange River WMAs, while also considering all the tributary rivers and transfers affecting the water balance of the system. This core area forms part of the Orange-Senqu River Basin.	In progress, completion date is 2014	No climate change considerations thus far.	
11	Vaal	This study includes most of Gauteng, Eskom & Sasol's industries in Mpumalanga, North West and Free State, gold fields around Welkom, mines in the Northern Cape, Kimberly and small towns along the river.	Completed in 2008	No climate change considerations.	Assumed data records start from 1920s
12	Western Cape	This study looks at the City of Cape Town, certain Overberg, Boland, West Coast and Swartland towns and irrigation along the Berg, Eerste and Riviersonderend rivers.	Completed in 2007	The first strategy noted that climate change should be monitored. The revised strategy looked at a scenario with a 5% decrease in yield over 25 years.	Long-term stream flow, rainfall, water quality and climate records are available for 80 years.
13	All Towns	This study includes over 800 reports and is available either per province, per district municipality or per local municipality.	In progress		

1.3 Water management area/ catchment planning

While the management of water resources and adaptation to climate change happens through all levels of planning, it can be facilitated directly at catchment level, the scale at which the effects of climate variability and change play out on a micro-level. However, catchment management agencies (CMAs) are still being developed, with only two being functional. There are capacity constraints at this local level to providing the necessary implementation and management of strategies. Furthermore, the CMAs have been amalgamated from 19 to 9, and once the amalgamated CMAs are functional catchment management strategies (CMSs) will need to be developed. The CMA and its CMS represent an opportunity to support adaptation, with inputs from catchment forums and water users' associations (WUAs) at a more localised level that could help implement the risk and disaster management plans for the catchment.

1.3.1 Breede-Overberg Catchment Management Strategy.

The Breede-Overberg CMA (BOCMA) is located in the Western Cape. A scenario based on a median climate response drawn from a set of climate projections for 2050 shows climate change leading to progressive drying with an increase in extreme rainfall events.

Figure 8. Location of the Breede-Overberg WMA (DWAF)

The catchment has a strongly water-dependent economy based on intensive irrigated agriculture, and therefore the strategy focuses on two components, namely building climate change resilience and ensuring climate change is considered in disaster risk management. While the response is not comprehensive, it indicates the need for more research and better understanding of climate change in order to provide a more coherent approach. The response is described in Box 3 below.

Box 3. The objective for climate change resilience in the catchment:

Make robust water resources management decisions that build natural ecosystem, infrastructural and institutional resilience to climate variability and change.

- Monitoring changes and developing information to indicate expected change and variability is critical.
- As information is better understood, key natural ecosystems, infrastructure, and institutional developments should be identified, prioritised, and steps taken toward building resilience in the identified areas.
- While BOCMA will play a lead role in this action collaboration, primarily with the DWA and the Provincial Government, it will be necessary for natural ecosystem and infrastructural resilience, and coordination with additional institutions will be required for building institutional capacity.
- Does this include increasing the efficiency of water use?

The main objective of climate change adaptation and disaster risk management is to develop and improve resilience to hydrological variability and disaster risk through an improved understanding of trends and events, their impacts upon the social economy and the necessary strategic responses.

Achieving this includes:

- Strengthening information acquisition and assessment related to climate variability and change and development (trends).
- Building institutional flexibility for resilience.
- Mainstreaming water and cooperating with provincial and local disaster bodies.
- Assessing water disaster risk and developing a WMA flood and drought strategy aligned to national disaster management.

1.3.2 *Internal strategic perspectives*

The DWA developed internal strategic perspectives (ISPs) in order to document its understanding of water resources management and relevant water management issues within each water management area in South Africa. The ISPs, completed in 2004, are considered to be the forerunners of the catchment management strategies and provided a framework for water management.

These strategies focused on the current water situation and described the following:

- Water availability
- Water requirements and use
- Water reconciliation (including water conservation and demand management (WCDM))
- Water quality management
- Infrastructure system management
- Institutional aspects.

These documents did not typically consider climate change, and are now best viewed as baseline studies.

1.4 Sub-catchment/municipal planning

1.4.1 *All Towns Strategies*

The All Towns Strategies (completed between 2010 and 2012) comprise over 800 reports and are available either per province, per district municipality or per local municipality. The purpose of the strategies is to give the municipal managers a clear situation assessment of the area and its water supply, and ways in which to secure water supply. These studies assess water demand projections for each town for 2010, 2020 and 2035, in order to identify when supply constraints are likely to occur and what possible sources are available to meet the projected demands. Climate impacts were not considered, but as with the reconciliation planning, the assurance of supply was assessed (thereby incorporating climate variability considerations).

An example of the type of information generated is presented for the Central Breede area in Figure 9 below. It distinguishes the demands associated with various towns in the area for the three time periods.

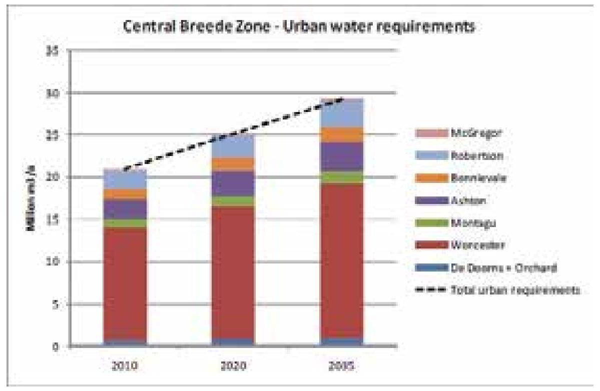

Figure 9. Western Cape Water Supply System (WCWSS) augmentation options taking into account a 15% reduction in yield (DWA, 2010a)

The following concerns have come to light during the course of these studies:

- Municipalities have little or no knowledge of the population in their areas and their water usage
- Water meters are missing in some areas
- Groundwater is an important source of water, but it is not recognised
- Municipalities do not understand the need and importance of water conservation and water demand (WC/WD) management
- Shortages of funds and skills (specifically in rural areas).
- Lack of infrastructure, proper management and institutional capacity.

2. CLIMATE CHANGE IMPACTS ON THE WATER SECTOR

Specific areas of high risk have been identified where cumulative negative climate change impacts are likely to occur (increased evaporation, decreased rainfall and decreased runoff). These include the southwest of the country, the central-western parts and to some extent the extreme north of the country. Furthermore, climate induced changes under average year conditions often differ from changes under wet or dry conditions. The transitional zone between the winter and summer rainfall areas is highly sensitive with large (yet inconsistent) changes occurring. The changes in hydrological drivers show acceleration in the period between the intermediate and distant futures thus amplifying the impacts. The results show a general increase in inter-annual variability of most of the drivers (rainfall and streamflows), with the southwest of the country being the exception. Patterns of change can vary over relatively small distances within the country. While hydrology directly affects aquatic environmental conditions, the configuration of water use and supply systems has as significant an impact on the availability of water to meet demands.

2.1 Climate change impacts modelling for the water sector

South African hydrology has developed sophisticated toolkits to explore the hydrological impacts of climatic conditions, and considerable expertise exists in the fundamental modelling of these processes. Two main approaches are implemented routinely in South Africa, namely the Agricultural Catchments Research Unit (ACRU) and the Pitman models. The ACRU approach uses a fine spatial and temporal scale (quinary catchment and sub-daily scale) while the Pitman model uses a coarser spatial and temporal scale (quaternary catchment and monthly scale).

The ACRU approach is especially valuable for understanding extreme events and for fine scale understanding for a number of sectors such as agriculture, while the Pitman approach is useful for cross-sectoral integrated assessment. For the purposes of Phase 1 of the LTAS process, the Pitman modelling approach has been applied to allow initial assessment of the impacts of multiple climate scenarios on water yields of the South Africa hydrological system. Some fundamental modelling has been initiated using the ACRU approach during Phase 1 and this will be extended during LTAS Phase 2 in order to gain insights into extreme events. Both the ACRU and Pitman approaches will be used during LTAS Phase 2 to assess impacts on key sectors such as urban settlements and key integrating issues such as food security.

Incorporating climate change into water resources planning has commonly used a top down approach. This process involves downscaling global circulation models (GCMs) used to project changes in global climate to a smaller scale, and estimating the change in water supply by applying hydrological modelling techniques. The water system can then be tested to determine potential vulnerabilities. However, due to the nature of climate change modelling and the downscaling process, this procedure generally amplifies uncertainty. For this reason, we have summarised here the initial results of the Treasury and National Planning Commission approach (Treasury and NPC, 2013) that uses the so-called hybrid frequency distribution (HFD) approach. This approach takes a very wide range of climate scenarios into account, and thus presents the decision maker with a clearer picture of the range of uncertainty in the projections. A key advantage of such an approach is that the potential benefits of different mitigation pathways can be assessed.

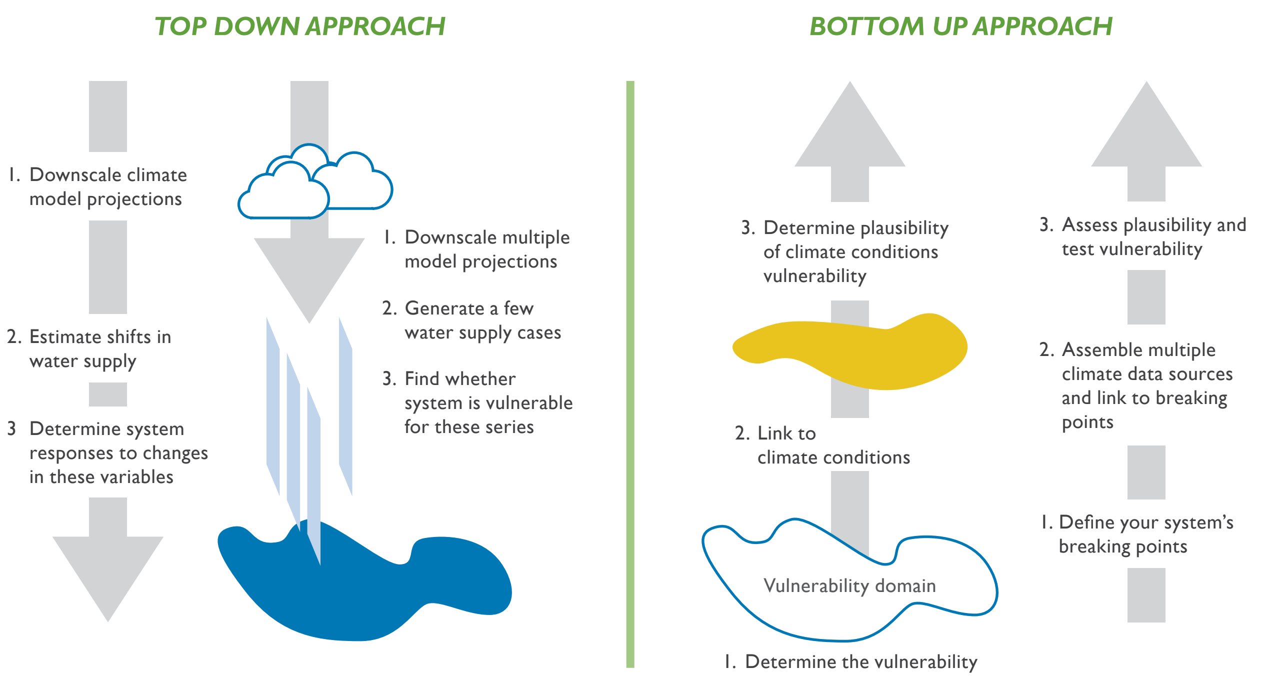

Figure 10. Top down versus bottom up approach to planning

An alternative approach (sometimes referred to as a bottom-up approach) attempts to constrain uncertainty by developing an understanding of the key vulnerabilities in the water system in order to determine potential limits to the system's adaptive capacity. Figure 10 below compares the bottom-up approach to the top-down approach to testing systems under climate change. While the bottom-up approach is in the process of evolving, internationally it is gaining traction as a better planning tool to understand climate change impacts on water resources. Most of the work on the pilot schemes and climate modelling focused on the top down approach, however, the bottom up approach has been used, for instance, in the Berg River pilot study described in Annex 2.

2.2 Climate change impacts on national runoff

Preliminary results for national runoff using the Pitman modelling approach suggest a change that lies between a 20% reduction to a 60% increase under an unconstrained greenhouse gas emissions scenario (UCE emissions scenario). If global emissions are constrained to stabilise at 450 ppm CO_2 equivalent, (L1S emissions scenario) the risk of extreme increases and reductions in runoff are sharply reduced, and the impacts lie between a 5% decrease and a 20% increase in annual runoff (Figure 11). Using a different suite of modelling approaches would change these results slightly but the range is so wide that it would be unlikely to result in a material change in the overall message.

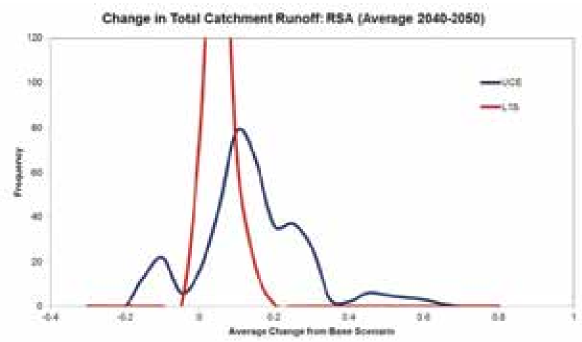

Figure 11. Preliminary projected changes in annual runoff for South Africa under an unconstrained greenhouse gas emissions scenario (blue line unconstrained CO_2 emissions (UCE)), and an emissions scenario constrained to stabilise at 450 ppm CO_2 equivalent (red line level 1 stabilisation (L1S))

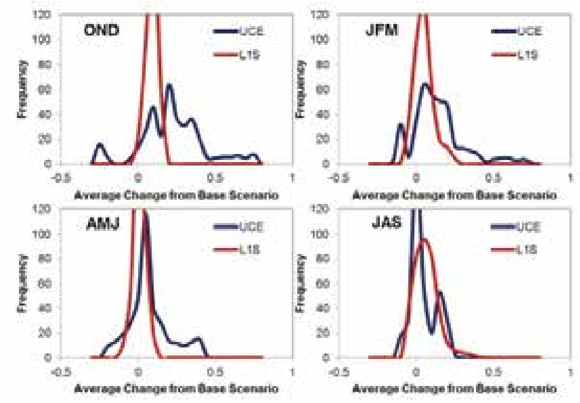

Figure 12. Preliminary projected changes in seasonal runoff for South Africa under an unconstrained greenhouse gas emissions scenario (blue line, unconstrained CO2 emissions (UCE)), and an emissions scenario constrained to stabilise at 450 ppm CO2 equivalent (red line, level 1 stabilisation(L1S)). The graphs represent the months of the four seasons spring (OND), summer (JFM), autumn (AMJ) and winter (JAS)

Spatially, the impacts on annual runoff vary strongly, with median impacts very positive along the eastern seaboard and in the central interior, and negative in parts of the Western Cape. Areas showing the highest risks of extreme runoff related events include Kwazulu-Natal, parts of southern Mpumalanga and the Eastern Cape. Other areas show neutral to reduced risk in runoff, with the exception of the central and lower Orange River region (Figure 13). Specific areas of high risk where cumulative negative climate change impacts are likely to occur (including increased evaporation, decreased rainfall and decreased runoff) include the southwest of the country, the central-western parts and to some extent the extreme north.

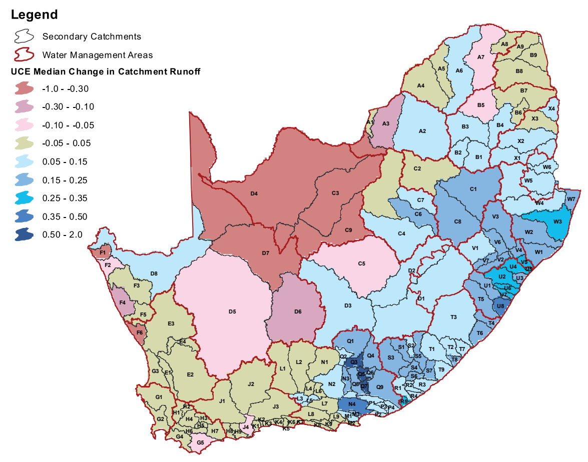

Figure 13. Median impact of climate change on the average annual catchment runoff for the period 2040–2050 relative to the base scenario average for 1990–2000 for all secondary catchments in South Africa derived from a Hybrid Frequency Distribution (HFD) analysis of all possible global circulation model (GCM) outputs (+6000 scenarios) for the unconstrained emissions scenario (UCE).

2.3 Climate change impacts on water quality

The impacts of climate change on water quality are generally not well studied either globally or in southern Africa. In general the impacts are descriptive in nature and based on knowledge of how water quality responds to predicted changes in climatic drivers, namely temperature, evaporation, rainfall and hydrology. The responses to these climatic drivers are described below.

2.3.1 *Changes in ambient temperature and water temperature*

An increase in air temperature will lead to an increase in water temperature. 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, and could 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 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 stress on temperature-sensitive fish species.

2.3.2 Enhanced evaporation

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

2.3.3 Changes in rainfall intensity

This is the change in rainfall expected statistically only once in 2, 5, 10 or 20 years for a period of time ranging from anything between 5 minutes and 24 hours. The resulting values are used in the sizing and design of hydraulic structures, for example, of stormwater drainage systems. Rainfall intensity affects catchment wash-off processes as it increases the erosion of soil and other pollutants that accumulate on the surface of the catchment. It can also lead to surcharging sewers when sewage pipes become blocked with washed-off debris, or the discharge of partially treated wastewater from over-loaded wastewater treatment works (WWTW). This in turn poses a health risk to humans and can impact on aquatic ecosystems when the increased organic loads decompose and consume oxygen in the process.

2.3.4 Flash floods and peak discharges

Flash floods refer to changes to severe floods occurring over a short period of time and usually over a small catchment area only. Frequently these are the result of 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 the resulting effect on suspended sediment, and mobilisation of organic matter previously deposited in stream channels.

2.3.5 Regional floods

Regional floods are the result of widespread rains over a period of several consecutive days often falling on catchments that are already wet. The resulting high waters inundate substantial areas, usually in the thousands of square kilometres. They can result in the flooding of low lying water and wastewater treatment works, and damage to sewerage infrastructure resulting in the discharge of raw sewage into rivers. This poses a health risk to water users as the supply of safe domestic water is interrupted.

2.3.6 Droughts

Although Schulze (2011) makes a distinction between agricultural droughts and hydrological droughts, the water quality impacts would probably be quite similar and no such distinction was made in the water quality discussion. One of the strategies for dealing with droughts is to store more water for use during periods of water shortages. During droughts less water is available to dilute wastewater discharges and irrigation return flows resulting in aggravated impacts on downstream users and aquatic ecosystems.

2.4 Climate change impacts on infrastructure

The impacts of climate change are already being felt in South Africa and will exacerbate existing challenges and create new ones in relation to climate variability, extreme weather events and changing rainfall patterns. This will affect a wide range of economic sectors and livelihoods and impact in major ways on the development of infrastructure into the future. Infrastructure asset management needs to play an important role in both maintaining existing infrastructure and modifying existing infrastructure or constructing new infrastructure to ensure optimum performance under climate change, as well as looking at cost effective ecological infrastructure options to enhance or replace hard infrastructure.

2.5 Climate change impacts on water services

Urban and rural water supply currently accounts for 23% and 4% of the national water resource allocation respectively. The Water for Growth and Development Framework (DWAF, 2009b) estimates that due to the projected growth in population, domestic water use will increase from 27% of total national water use to between 30% and 35%. DWAF (2009b) also states that urban municipal areas account for 23% of the national water use, while rural settlements use only 4%. This is partly because service levels in urban areas are much higher, but also because 20% to 30% of water use in urban areas is industrial.

Climate change, however, will have a smaller effect on increasing domestic demand, as compared to population growth and rural-urban migration. International studies have indicated that the increase in household water demand (e.g., for garden watering) and industrial water demand due to climate change is likely to be rather small, e.g., less than 5% by the 2050s at selected locations (Mote et al., 1999; Downing et al., 2003). An indirect but small secondary effect on water demand would be the increased electricity demand for cooling buildings, which would tend to increase water withdrawals for cooling thermal power plants. A statistical analysis of water use in New York City showed that above 25°C, daily per capita water use increases by 11 litres/1°C (roughly 2% of current daily per capita use) (Protopapas et al., 2000).

2.6 Climate change impacts on human security

The effect climate change has on human security is an important consideration as it not only increases health risks, but it has socio-economic impacts, especially in vulnerable and marginalised communities.

2.6.1 Water-related health risks

Populations with poor infrastructure and high burdens of infectious disease often experience increased rates of diarrhoeal diseases after flood events. Flooding and heavy rainfall may lead to contamination of water with chemicals, heavy metals or other hazardous substances. Climate change increases both the probability of future disasters and the potential for mass human exposure to hazardous materials during these events. Climate influences the spatial distribution, intensity of transmission, and seasonality of diseases transmitted by vectors.

2.6.2 Socio-economic impacts

Climate change causes variations in rainfall, which affect a number of sectors including agriculture, power supply, forestry and fisheries. Climate change causes an increase in temperatures, which affects the amount of power needed for cooling processes in industrial applications as well as domestic cooling. Food security and agriculture remains a concern, both for large-scale commercial farmers, small-holder and subsistence farmers. Extreme events cause loss of homes during flooding and livestock losses during droughts deeply affecting marginal communities.

3. ADAPTATION RESPONSE OPTIONS

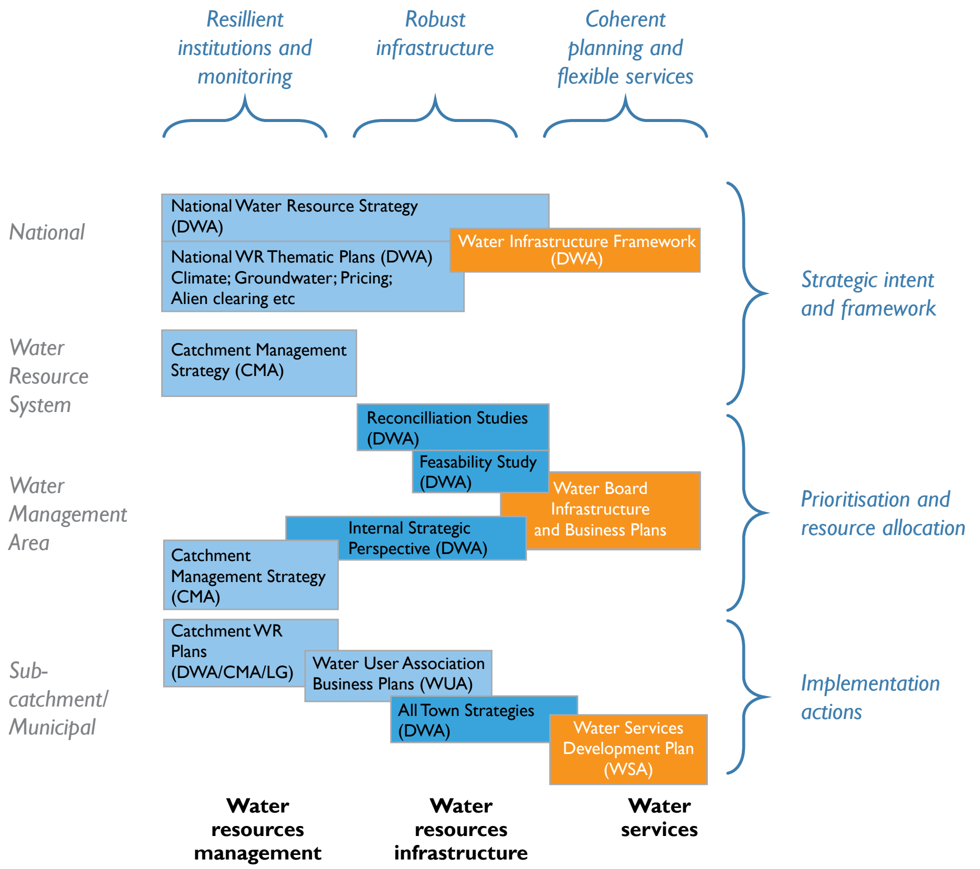

Figure 14. Climate adaptation interventions with reference to the water planning framework

3.1 Integrating adaptation into the water resources planning framework

South Africa has robust water planning procedures in place, which consider uncertainty due to historical climate variability. However, consideration needs to be given to planning under a range of climate futures which could encompass future changes in climate variability. At national level, broad economic processes such as the National Development Plan (NPC, 2011) and the National Infrastructure Plan (PICC, 2012) provide the framework for long term planning and infrastructure development in South Africa. Specifically in the water sector, national water planning includes the National Water Resource Strategy, which provides the guiding framework for water resource management. At local level the catchment management strategies are meant to build adaptive institutions, but still require protocols to build these adaptive institutions and create improved longer term strategies for catchment management incorporating climate change.

The water resources planning framework presented in Chapter 2 provides a useful lens against which to understand these climate adaptation responses for the water sector. A first distinction may be made between responses at the:

- *National* scale, which provides the strategic intent and enabling framework for adaptation to ensure consistency across the country
- *WMA or system* scale, where key institutions prioritise and allocate resources to adaptation interventions, reflecting the conditions in that area
- *Sub-catchment or municipal* scale, where local implementation actions are designed and adopted to respond to local challenges, resources and capacity.

Coherence and consistency is required between these three levels, but it is as important to recognise that the nature of climate adaptation differs between the three, namely that adaptive:

- *Water resources management* requires effective monitoring, flexible institutional rules and capacitated organisations in order to observe and respond to changing conditions; and requires the maintenance of healthy functioning ecological infrastructure
- *Water resources infrastructure* requires robust infrastructure that has operational flexibility to perform its purpose under different future climatic conditions
- *Water services* require coherent planning with other municipal services, with flexibility in water infrastructure and services under different climate futures.

This implies that specific interventions will be appropriate at each level for each focus area. These interventions should give effect to the following core aspects of building resilience (Pegram et al, 2013):

Make decisions that do not foreclose future options. Some planning decisions remove the flexibility and ability to change at a later stage. Three critical aspects of this are:

- *Maintaining healthy functioning ecosystems/ecological infrastructure as part of ecosystem based adaptation.* Freshwater ecosystems that are already degraded in terms of geomorphology, habitat, water quality or flow will have limited capacity to withstand future climate change impacts. Thus, protecting and rehabilitating aquatic systems so that they can provide flow attenuation, waste assimilation and ecosystems goods and services is critical to buffering these systems. Implementing appropriate adaptation interventions to maintain the reserve, such as catchment restoration and maintenance with local alien clearing initiatives, provides this opportunity.
- *Developing flexible infrastructure.* Infrastructure decisions are amongst the longest term of all basin planning decisions, with the least flexibility for change. Developing infrastructure that is robust to future changes requires system planning at catchment and system level, rather than at individual project level. This increases the ability of the system to respond flexibly to changing conditions. It may also suggest that some tributaries should be left free of infrastructure to increase the overall environmental resilience of the river basin. Particular individual pieces of hard infrastructure could be constructed to permit flexibility, such as multiple releases at multiple levels of a reservoir or the incorporation of redundancy into flood defence infrastructure planning to allow for future development if required. This should be supported by healthy functioning ecosystems or ecological infrastructure.
- *The ability to modify rules as conditions change.* Laws, policies and regulations should all be automatically subject to modification as conditions change. This may relate to changes in development planning guidance or zonation as flood risk changes, or flexibility in water allocation agreements and

plans in response to changes in runoff. Reservoir operating rules should allow flexibility in response to variable conditions, and be redesigned as conditions shift. The ability to change will apply not only to specific rules and agreements, but at policy and regulatory levels as well.

Develop the ability to respond to unforeseen events. This includes the establishment of clear drought and flood contingency planning, including the ability to manage and respond to events that lie outside the historic record. Unforeseen events can also occur over longer-term time horizons, such as the development of new industrial, urban or agricultural centres in unforeseen locations, or long-term declines in runoff. Being able to respond effectively requires:

- *Building specific organisational capacity.* The ability to manage under uncertainty implies the development of new organisational capabilities, built around adaptive management with effective monitoring and evaluation systems.
- *Develop sustainable financial management systems* that allow for access to resources at all spheres of government, including the catchment level, in order to maintain functioning catchments.

Monitor indicators so that changes can be observed. An effective and comprehensive system of monitoring is a crucial pre-requisite for the adaptive management that is at the core of responding to change. Monitoring needs to cover a suitable suite of hydrological, water quality, ecological and economic variables, and, importantly, be accompanied by sufficient resources to analyse and assess data to identify long-term changes and trends.

Change plans as conditions change. Water management, infrastructure and services plans need to be reviewed and updated in the context of changes. This requires a process and approach that is open and responsive to change.

Taking into account these core aspects and building the resilience of South Africa's water sector to climate change impacts will require the introduction of the following priority functions to be led by the DWA:

- Policy review that is able to ensure that the enabling frameworks remain flexible and that mandatory reviews of plans and objectives are maintained.
- Infrastructure planning that considers flexibility and robustness in project selection and design.
- Resource directed measures that ensure critical natural infrastructure is maintained in vulnerable systems.
- Institutional oversight that ensures that water management and water services institutions build adaptive management capacity.
- Information management that ensures that monitoring and evaluation systems are maintained appropriately to observe expected (and unforeseen) changes.
- Financial management that is sustainable and accessible at catchment and local levels.

This having been said, there is a distinction between:

i) ensuring that *current* water management processes consider climate change and build adaptive capacity for the future through short and medium term actions and initiatives (which is the role of the water sector climate change adaptation strategy); and

ii) taking a *longer term* perspective on the considerations and requirements to build an economy and society that are resilient to the impacts of climate change on water (which the LTAS can help provide).

The following figure distinguishes three types of resilience through the lens of water, namely:

- *Development resilience*: related to economic and social systems supporting equity and growth (the focus of integrated development planning at national, provincial and local government scales).
- *Water resilience*: which is built on integrated planning and based on water management that responds to hydrological variability, including through water planning at national, catchment and system scales.
- *Climate resilience:* which expands on water resilience, but ensures that water management will be robust under alternative climates – moving from water resilience to climate resilience has been the focus of much of the preceding discussion in this document and is captured in the water sector climate change adaptation strategy.

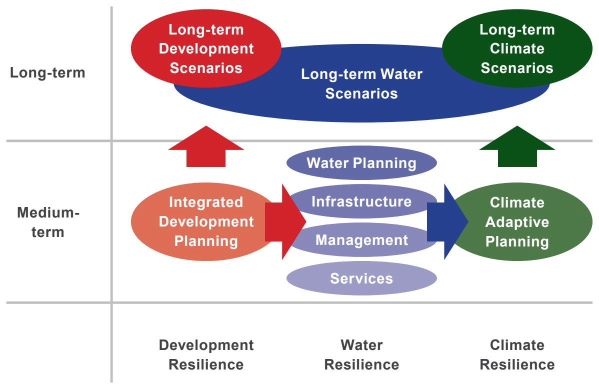

Figure 15. Distinction between medium term and long term planning for water, development and climate

The three medium-term perspectives on resilience project the current situation between 5 to 15 years into the future, in order to ensure current actions develop resilience and achieve broader social, economic and ecological imperatives. However, in the longer-term (40+ years), a somewhat different perspective may need to be taken into account to ensure long-term water resilience under different scenarios. It is important to consider that in five decades, both the structure of the South African economy and society and the nature of climate-water interactions may be qualitatively different. Therefore, mere projections of the current situation are not necessarily adequate.

Importantly, the water future of South Africa will be entirely governed by the development and climate futures. On the other hand, the development futures may be influenced by climate-water futures, either through opportunities and constraints that arise as a result of climate change impacts on the water sector. Furthermore, driving forces may change and decisions may need to be made in development planning, based on climate-water futures. Following this logic, South Africa (or parts of the country) may face a continuum in climate-water futures between two plausible extremes:

- A slightly wetter future, in which trade-offs in water allocation between sectors would be less dramatic. This future enables a continuation of urban-industrial economic growth while maintaining a vibrant agricultural sector with significant food self-sufficiency at a national scale – importing certain foods will always be necessary due to poor conditions for their domestic growth; or
- A drier future in which significant trade-offs, linked to the marginal costs of further augmentation, will need to be made to support continued development particularly in terms of the allocation between agricultural and urban-industrial water use. These constraints are most likely to be experienced in the central, northern and south-western parts of the country. This future has some significant social, economic and ecological consequences for national development planning, namely:
  - shifts in agriculture and its implications for food security
  - shifts in energy production linked to pressure to reduce carbon emissions
  - reconsidering a rural economy based largely on agriculture
  - greater pressures on water use efficiency and water conservation

- appropriate catchment level environmental allocations and maintaining functioning ecosystems in a changing climate
- considerations of regional integration and imports of food and energy
- managing trade in food and energy linked to the current trading account.

In both futures, flooding and drought extremes will need to be planned for as hydrological variability and temperature will certainly increase. It is relatively certain that water will be supplied to meet domestic urban and industrial demands. The key question, however, is how this will be done in the context of viable agriculture and energy production, noting that increasingly expensive water will have an impact on water supplies to economic and social users. A related question involves the stage at which it will be necessary to give clear planning direction to the trade-offs between water, energy and food production, versus trade, which in turn should increasingly frame the water, food and energy security debate.

The LTAS can play a leading role in understanding water as an opportunity and constraint linked to other sectors in South Africa and how this feeds back to economic planning. Additionally, the LTAS can provide guidance on the importance of cross-sectoral planning and coordination for future development. It is an important lens through which to view climate impacts on development.

3.2 Incorporating climate change adaptation into reconciliation studies

As described above, the reconciliation studies could usefully form a key pillar for future climate change adaptation responses in the water sector as they focus on ensuring that there is adequate infrastructure to meet the demand, and forecast when new water infrastructure should be developed. The focus in the reconciliation studies is on the economic and ecological needs of water. Climate change adds an additional layer of variability, but due to the uncertainty in the GCM models, this additional layer has largely been excluded from planning. In the instances where the reconciliation strategies do consider climate, it is in terms of timing, and the notion of resilience is not yet fully addressed

The reconciliation studies provide a short- to medium-term outlook focused on optimisation in the 10–15 year planning horizon and when new water infrastructure would be required to meet the anticipated demand. Demand projections are generally based on a statistical forecasting process, which has not, for the most part, yet considered climate change, and thus demand projections could also usefully be better informed by the impacts of climate change on, for example, irrigation needs. Protocols are thus required to examine the implications of different climate futures and to provide robust decision making in the short term. A further discussion on the appropriateness of infrastructure, which provides short term optimality but not long term robustness, needs to be reconsidered as this could lead to stranded assets, especially if there is a shift in the economy driven by climate change.

Climate change could modify the spatial dependence (cross-correlations for various annual lags) between sub-systems. This means that existing operating rules designed to incorporate spatial dependence in favour of optimising inter-sub-system support during droughts would not necessarily remain robust. However, for a specific bulk water resource system this aspect would need to be confirmed by detailed systems modelling with climate change-related stream flow modifications in place.

Six hydrological zones were developed as part of the Draft Water Sector Climate Adaptation Strategy process, reflecting institutional boundaries defined by WMAs in South Africa, grouped according to their climate and hydrological characteristics. Each of these zones is driven by distinct climate systems, ranging from the mid-latitude cyclones interacting with the south Atlantic high in the west, through the tropical temperate troughs interacting with the continental heat low in the central parts, to the south Indian high and tropical cyclones in the east. This results in the following 6 zones (Figure 16):

- **Zone 1:** the Limpopo, Olifants and Inkomati WMAs in the northern interior (Limpopo/Olifants and Inkomati).
- **Zone 2**: the Pongola-Umzimkulu WMA in KwaZulu-Natal in the east (Pongola-Umzimkulu).
- **Zone 3:** the Vaal WMA in the central interior (Vaal).
- **Zone 4:** the Orange WMA in the north west (Orange).
- **Zone 5:** the Mzimvubu-Tsitsikamma WMA in the south east (Mzimvubu-Tsitsikamma).
- **Zone 6:** the Breede-Gouritz and Berg Olifants WMAs in the south west (Breede-Gouritz/Berg).

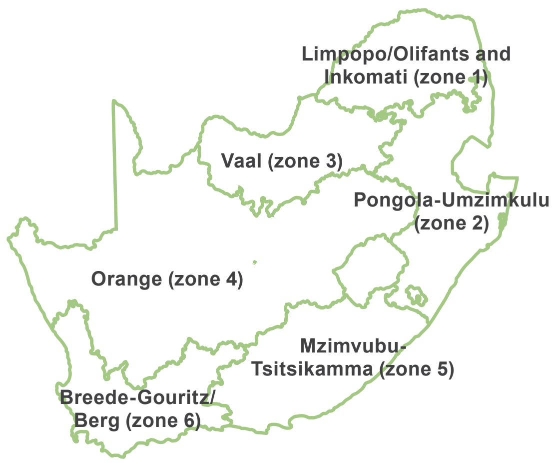

Figure 16. Climate change impacts across South Africa will be mediated through primary impacts on the water sector. Six hydrological zones have been developed as part of the National Water Adaptation Strategy process, reflecting boundaries defined by water management areas (WMAs) in South Africa; and grouped according to their climatic and hydrological characteristics. These zones can be appropriately modelled and analysed for direct impacts on the water sector, and related indirect effects on other sectors.

Climate change is not a consideration in existing reconciliation studies, and very few incorporated climate change considerations in forecasting either water supply or water demand. This section will flag the key climate-change related considerations in the reconciliation study areas and the key questions posed for long term adaptation strategies within each system. The focus will be on the following systems:

- Olifants
- Vaal
- Lower Orange
- Umgeni
- Algoa
- Western Cape

Figure 17. Key economic areas in relation to existing water supply system studies (RSS – reconciliation strategy study)

These six systems cover the various climatic zones in South Africa and provide insights into unique vulnerabilities in each of the systems and climate zones. What this brief analysis indicates is that the climate change assessment associated with the reconciliation studies should be tailored to address the issues and uncertainties that are most relevant for the particular climate zone. These vary from temperature driven water demand and system loss effects in the lower Orange River, through recharge and acid mine drainage (AMD) effects in the Highveld (Vaal), to shifting rainfall patterns in the Western Cape system. This provides the focus for these analyses, but further work is required to enable bottom-up analysis using the system analysis tools.

3.2.1 Olifants

The Olifants region has a range of economic activities, namely mining, agriculture, forestry and the Kruger National Park. The region can be characterised by three zones:

- Highveld
- Lowveld
- Escarpment.

The availability of water in this area is of great concern and the impact of variability in the three zones needs to be better understood, especially considering that this is an area for major investment. There is great uncertainty in the GCM climate projection, particularly for the lowveld and the escarpment.

3.2.1.1 Highveld

The mining region of the Highveld is coal driven and the mean annual runoff is an issue. This zone forms part of the mining belt and will be impacted by AMD as increased rainfall in the region will result in more ingress and more decant. It should be noted that whilst currently there are technically feasible solutions to mitigate the effects of AMD, there may be long term challenges. It becomes important to understand who will bear the responsibility 100 years down the line, when much of the infrastructure may not exist.

Increased temperatures in this area will give rise to high evapotranspiration rates for the natural vegetation and will increase the environmental demand. In addition, there may be greater demands for agriculture in this zone. Agricultural production in the Highveld, differs from that in the Lowveld, primarily consisting of cereal and grain production which is directly linked to the food security of the country.

3.2.1.2 Lowveld

This region is also actively mined for platinum, with water required for dust suppression of ash dumps. Studies have indicated greater demand for water in the Lowveld as compared to the Highveld, which may be related to the type of mining and the higher temperatures in the Lowveld. Agricultural production in the Lowveld focuses on high value export products. How the mean annual runoff in the area can be used to serve the Lowveld areas needs consideration should demand for water increase.

In the long term, a decision will need to be made regarding the hierarchy of agriculture and mining – which of these two sectors will be more important going forward?

3.2.1.3 Kruger National Park

Water flows in the Kruger National Park (KNP) will be impacted on by increases in temperature and variability, which may result in increased salinity in the region. This will be detrimental to the flora and fauna in the area. Ways to mitigate this need to be considered, whether in the form of changing the ecological reserve when the hydrological conditions change or finding alternative sources to curb demand.

Variability in rainfall and runoff needs to be considered. The real challenge will come when rainfall patterns vary and the timing of flood events changes. The question then will be whether to try and maintain the system as is or shift it to a new equilibrium with ecological processes being highly dependent on timing. This raises the concepts of implementing the ecological reserve for conservation and the resilience of the KNP. In trying to mitigate the varying effects, the baseflow, groundwater interaction, mean annual runoff (MAR) and decant need to be considered together with the variability.

3.2.1.4 Escarpment

Little mining takes place in the escarpment region. This zone is mainly dominated by forestry and driven by orographic rainfall. Increases in temperature will increase water extraction for forestry making it important to understand forest hydrology.

A Climatic Adaptive Reconciliation Study for the Olifants system needs to consider different climatic futures with shifts in agriculture, forestry and mining and to determine under which rainfall conditions the system will fail. The relationship between the demand requirements of mining and increased temperatures should be looked at. The impact of orographic rainfall on the yield system and forest hydrology needs to be considered. Finally, attention should be given to developing an understanding of how the ecological reserve relates to climate change characteristics, including the need for improved catchment management.

3.2.2 Vaal

The Vaal system is a highly interconnected system with links to the Inkomati, Tugela, Lesotho and Orange River. The economy of the Vaal system sits in the urban, mining and agricultural sectors.

Climate predictions show that precipitation in the area will either remain constant or increase. The mean annual temperature is expected to increase but no radical shifts are expected. The variability of the system has a great impact on the yield and it will be useful to understand the variability of rainfall and runoff in the area. There may be flooding events in some parts of the region and, once again, variability becomes important. Due to the interconnectedness of the Vaal system, it will be important to understand the impacts on the sub-systems that feed into the Vaal like the Lesotho and Inkomati sub-systems. Are the overall conditions experienced for the Vaal region the same as those experienced for its sub-systems?

In order to understand the system in more depth a cross correlation between the drivers of climate change needs to be understood.

3.2.2.1 Agriculture

Agriculture will be the sector most impacted on in this region and the sector's future is uncertain. Issues that need consideration include whether there will be continued irrigation on the Highveld in the next few decades and if so what measures are in place in the event of failure due to temperature rise in this region? The rising cost of water may also have implications for the sector. The selection of crops to grow in the region is also crucial as the crops currently produced are linked to the food security of South Africa. In the future, diversification in the location and type of crops grown may alleviate the impact of climate change on food security.

3.2.2.2 Mining

This zone forms part of the mining belt and will be impacted by AMD with increased rainfall in the region resulting in a potential increase in ingress and decant. It should be noted that whilst currently there are technically feasible solutions to mitigate the effects of AMD, there may be long-term challenges. It becomes important to understand who will bear the responsibility 100 years down the line, when much of the infrastructure may not exist.

3.2.2.3 Urban

The biggest impact in the Vaal region will be on the economy. Variables that affect economic growth and demand are taken into consideration in the existing reconciliation studies. Climate based demand is not huge in this sector, the behavioural patterns, quality of life and population growth rate may have some impact on the economy if actual growth rates are twice as high as the projected rates. However, the impact of possible increases in temperature on demand patterns related to gardens, pools etc are not considered.

A Climatic Adaptive Reconciliation Study for the Vaal region needs to consider the impact of temperature on demand (urban and agriculture), test the allocations for long term allocation versus the demand, and factor in the inter-connectedness of the Vaal with other sub-systems.

3.2.3 Lower Orange

The Lower Orange region is a highly interconnected region with various transfer schemes and international links. The economic activities of the region lie with the agricultural, mining and urban sectors.

This region is extremely vulnerable to temperature and projections show the mean annual temperature increasing twice as fast compared to the country as a whole. The rising temperature may have the following impacts:

- dry areas will experience further water losses
- irrigation demand will increase
- the accumulation of salts will increase resulting in higher salinity
- a greater allocation to the estuary will be needed to maintain a good environmental flow.

The higher temperatures may result in increased water losses from the lower Orange system. The water from the Vaal River and Lesotho that feeds into the Lower Orange is linked to mines and irrigation upstream. The water quality from the Vaal supply is of particular concern due to high salinity and its potential to impact negatively on the Lower Orange. Some of the water entering the system is diverted down the Fish River to the Algoa system while Namibia also shares water from the Orange adding further pressure to the demand on the system.

The availability of water for the agricultural sector needs to be highlighted for careful consideration in the light of overall demand in the region. The long term strategy will need to look at whether there will be continued growth in the production of high value crops for export if the water supply becomes deficient.

A Climatic Adaptive Reconciliation Study for the Lower Orange region needs to consider the scenarios around river losses under changing temperature conditions and the impact on the upstream catchment. In addition, scenarios around change in the irrigation demand should also be looked at in an attempt to climate-proof the system.

3.2.4 Umgeni

The Kwa-Zulu Natal region is in a unique position as the potential for climate change to limit water supply is not high in this region. The urban demand for this region is not driven by the climate and the irrigation requirements may be reduced as little growth in agriculture is expected and the climate predictions show a tendency towards greater wetting. It should be noted that with the increased wetting trends, the potential for flood events increases and this should be considered in the design and maintenance of infrastructure including ecological infrastructure such as wetlands. Furthermore, this is a coastal region where desalination is an option to meet the water demand should the supply be deficient.

Key Considerations for a Reconciliation Study: A Climatic Adaptive Reconciliation Study in the Umgeni region is not a high priority given that the projected impacts of climate change are not projected to severely limit water supply in this region and the existing reconciliation study is therefore robust as it stands.

3.2.5 Algoa

The water supply for the Algoa system is a combination of the local supply and the supply from the Upper Orange. Currently, there does not seem to be major vulnerability in the Upper Orange area, however, it must be seen in the context of the broader Orange System. There is some risk associated with the Upper Orange, but very little of it has to do with climate change.

The three drivers in the Algoa region are temperature, mean annual rainfall and variability, which will undoubtedly have an effect on the system. The climate change models indicate that the intermediate future will show lower mean annual rainfall and fewer runoff events, resulting in decreased soil moisture. Currently, Algoa, due to its unique location, has a bimodal rainfall pattern. Going forward, the local Algoa system is likely to get drier, but this is uncertain. There are measures that can be put in place to mitigate the uncertainty and close climatic monitoring needs to continue. Being a coastal region, desalination may play a role in meeting future water demand, but it should be noted that the bigger risk lies with the catchment from a yield perspective.

The reconciliation study explored phasing out the Orange River Project while simultaneously phasing in replacement transfers by trading irrigation allocations on the Fish River. By doing this, the system becomes more vulnerable to climate impacts, especially in the absence of desalination. It is crucial to test different climatic scenarios to observe what happens to the system, especially since the irrigation demand will increase with losses that will be experienced due to the hotter climate.

A Climatic Adaptive Reconciliation Study for the Algoa system needs to consider testing various climatic scenarios in the absence of desalination to get a clearer picture for the phasing in and out of schemes.

3.2.6 Western Cape

The Western Cape system is characterised by high commercial agricultural and domestic demand, with agriculture contributing 50% of the economy. Under climate change, this area, which receives winter frontal rainfall, is projected to become drier if frontal weather systems change track to the south. More orographic rainfall may fall on the mountains in the summer.

As temperature is projected to increase there may be an increase in evapotranspiration, which would increase water demand for irrigation.

Unlike some of the systems in the north, where systems are interconnected and transfers can be made between systems, the Western Cape system is isolated but resilient. This is due to the Berg, Breede, Palmiet and Theewaterskloof systems being linked. Being at the coast, desalination is an option for dealing with variability of supply allowing for assurance of supply as well as providing resilience.

A Climatic Adaptive Reconciliation Study for the Western Cape system needs to test the different assumptions on how the hydrology might change from less frontal to more orographic rainfall and the impact on yield. Good monitoring of the shifting rainfall patterns is needed and it is also necessary to test how soon to incorporate desalination under different climate drivers.

3.3 Adaptation priority measures in the Draft Climate Change Adaptation Strategy for the Water Sector

The South African Climate Adaptation Strategy for Water currently being developed has been based on the framework provided by the SADC climate change adaptation strategy for water, which was completed in November 2011 (SADC, 2011). As with the SADC strategy, the South African strategy prioritises adaptation in dealing with the effects of climate change, rather than mitigation. The strategy starts with the recognition that climate change has already resulted in changed intensity and frequency of extreme weather events, and increased vulnerability of poor countries and communities in particular. It is underpinned by work done as part of defining the status quo on climate change in South Africa. The focus of the South African strategy is to develop climate change resilience and to reduce vulnerability through integrated water management at a variety of scales, including regional, river basin and local levels. Integrated water resources management is seen as a critical tool in the management of climate change impacts.

The strategy focuses on the implementation of both "no regret" and "low-regret" measures and sets out a series of actions to be implemented within a defined time period, recognising that climate change adaptation is an issue of water governance, infrastructure development and water management.

The strategy promotes a multi-dimensional approach to adapting to climate change, based on different adaptation measures taking place at different levels, with different stages of adaptation, and different areas of intervention, as set out in the "SADC Water Adaptation Cube" in Figure 18 below. The strategic actions of the strategy are grouped into three sections: water governance, infrastructure development and water management.

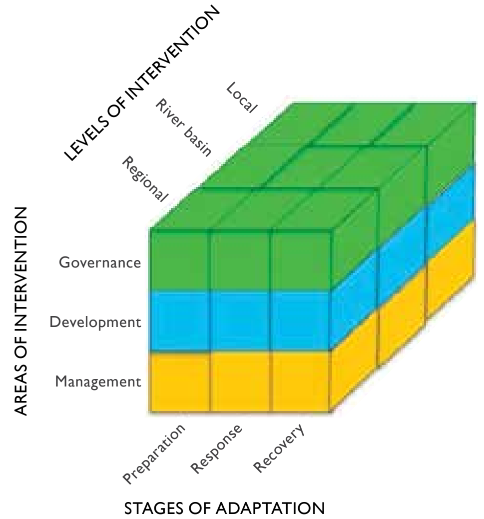

Figure 18. SADC Water Adaptation Cube

3.3.1 *Water governance*

One of the key elements of responding to climate change is ensuring that the institutions responsible for water management and governance are able to adapt timeously and effectively to changing climatic conditions. This requires that policy and legislation support adaptive approaches, and that management institutions are designed and operate as adaptive, learning institutions. There are a number of institutions and different levels of government that have important roles to play in water management in South Africa. These include the DWA, CMAs, water boards, water services authorities, water services providers, water user associations, the Trans-Caledon Tunnel Authority (TCTA) and the Water Research Commission (WRC). Effective alignment and good intergovernmental relations will be a critical part of ensuring effective adaptation to climate change across the water value chain.

In addition, relationships with related departments, such as the Department of Environmental Affairs (DEA) (biodiversity protection), national and provincial Departments of Agriculture (irrigation development and management), the Department of Economic Development, the Department of Land Reform and Rural Development, and the Department of Mineral Resources, will also be important to ensure alignment between the national programmes of these departments and issues of water availability under scenarios of climate change. To ensure good water governance it is critical that not only should all stakeholders have open channels of communication, but also climate adaptive financing needs to be part of the water investment framework to ensure adaptive measures are implemented.

Overview of the Defined Governance Actions

- Develop climate change guidelines for CMA's and adaptation manuals for municipalities and water user associations.
- Awareness and climate change training for all DWA members, transboundary basin bodies and other stakeholders.
- Ensure water sector representation at all climate change forums.
- Protect water allocations to poor and marginalised communities.
- Ensure adaptation responses are included in water investment framework.

3.3.2 *Infrastructure development, operation and maintenance*

South Africa has relatively robust water infrastructure due to the already high variability in climate. Climate change exacerbates this variability, and potentially increases the frequencies of extreme events thus reducing the natural recovery time between events. The safety and resilience of existing infrastructure needs to be ensured in the face of potential changes in rainfall intensity and flooding.

The planning horizon for infrastructure is long term, and requires more planning time than build time. For this, we need to ensure we have several options planned to deal with the high level of uncertainty on climate change.

There are a wide range of potential climate change impacts on water supply and sanitation. These include flood damage to infrastructure which may interrupt supply and result in contaminated water supply or water resources from flooded or damaged sanitation and waste water treatment systems. The vulnerability of different systems varies depending on the technology, management systems and human capacity in the system. Systems that provide water to large populations from a single water resource are extremely vulnerable to climate change, particularly in areas where the potential for significant droughts is likely to increase. Systems that provide water from multiple sources spread the risk and are more resilient as a result.

Overview of the Defined Development Actions

- Update design codes and criteria to incorporate climate change.
- Test DWA water resource infrastructure plans against no regrets/low regrets framework and against most recent climate change impact scenarios to ensure that the appropriate infrastructure decisions are being made.
- Ensure all national and municipal dams have written operating rules in place, including clear rules for drought conditions.
- Develop new groundwater sources and secure appropriate recharge including artificial recharge where appropriate.

- Develop tools to measure the effect of climate change on groundwater.
- Monitor groundwater systems and ensure appropriate maintenance plans are in place
- Investigate the feasibility of desalination plants in coastal areas to augment municipal water supplies.
- Improve flood warning systems, evacuation plans and ensure that there is regional coordination of flood plans.
- Revise the National Water Act (Act 36 of 1998) with respect to floodlines and control development within floodlines.
- Ensure infrastructure planning considers the effects of climate change including appropriate reinforcement in high flood risk zones.
- Review monitoring network over 5 years – continue to look at rainfall, water levels, water temperature and information systems used across riparian states, especially Lesotho.
- Set climate change objectives for each national monitoring programme.
- Strengthen links between hydroclimatic monitoring systems and climate models to link observed data with modelled outputs and to support water management decision making.

3.3.3 Water management

Effective water management is a key element in the water strategy. South Africa has good water management practices; however, due to capacity constraints these may not always be implemented. The strategy aims to reinforce good water management which will make climate change adaptation easier. Water management links together a number of areas including:

- resource management and protection
- gathering, storing and reporting of data and information on water resources
- water planning
- water allocation and authorisation
- optimisation of dam and groundwater management and operation
- water conservation and demand management
- disaster management.

The climate change strategy for South Africa's water resources is currently in draft form. The draft strategy describes key issues pertaining to likely climate change impacts on water resources and water services in the country and identifies a number of actions that must be taken in order to enhance resilience to water-related climate change impacts and to reduce vulnerability. The strategy recognises that climate science is evolving and there is still a great deal of uncertainty about the future impacts of climate change, particularly in the context of southern Africa. In order to be able to adapt to the coming changes, it is important that we have the best information available. This requires further research and the development of appropriate adaptation strategies and mechanisms.

There is still much uncertainty in climate change modelling and scenarios. Climate science is a relatively new field and the modelling is being updated as climate models become more refined. There are critical issues around reliable, predictable, quality data for further research. There is a need to continue to model water parameters, to include monitoring of soil moisture, wind speed and water temperature, and to make this information freely available to research organisations and institutes.

Overview of the Defined Management Actions

- DWA to enhance its information system and ensure that data collection instruments are fully functional and feed data into a national data system, and that adaptation responses are included in the water investment framework.
- DWA to determine sectors and ecosystems which have the highest risk associated with climate change and provide vulnerability assessments.
- Adjust hydrological and stochastic models to incorporate climate change.
- Increase monitoring, especially rain gauge and flow monitoring.
- Account for long-term rainfall changes and the high levels of uncertainty in the understanding of these long term changes in all water resources planning.
- Compulsory licensing, water trading, and licence reviews are required for ensuring water allocation is sufficiently flexible to cope with climate change.
- Revise the water conservation and demand management strategy and set new targets for water savings in the municipal and agricultural sectors.
- Develop leak detection systems and ensure proper maintenance of infrastructure to reduce physical water loss to acceptable levels.
- Enhance the groundwater capacity in the DWA to provide support to water services and management institutions in the operation, maintenance and management of groundwater supply schemes, the evaluation of artificial recharge potential and conjunctive use schemes, and the assessment of groundwater potential.
- Ensure the implementation of existing strategies, regulations and guidelines on groundwater management such as the Artificial Recharge Strategy and others.
- Ensure Working for Water includes the monitoring and removal of new alien vegetation especially in aquatic zones.
- Maintain and restore the capacity of floodplains to absorb and release water under flood events.
- Ensure early warning systems are implemented in key catchments.
- The DWA to ensure that all water service providers have drought operating rules in place.

There is a research gap in groundwater recharge and how climate change will affect groundwater. Further research is needed in the area of water quality, and in examining the multi-layered effects climate change has on water resources. Engineers and planners have been using the same design codes and standards for years. Research is needed as to how climate change affects floodlines, and how design manuals should be updated to include the effects of climate change. In order for climate change to be mainstreamed, there needs to be an increase in the skills and capacity of climate change researchers involved in both modelling and adaptation. Furthermore, communication of the research outcomes needs to be repackaged to make it understandable for a wider audience.

Key stakeholders are being consulted on actions in the strategy, which will be revised taking into account their input. The final strategy should then be translated into an implementation plan with clear targets and timeframes, and with appropriate financing in place. Implementation must then be monitored and evaluated by the DWA so that corrective actions can be put in place to ensure effective implementation. Assessment of the implementation of the strategy will underpin the revision of the strategy every five years.

4. RESEARCH REQUIREMENTS

Based on the above information, the three main areas of required research are:

1. Supporting the development of tools, approaches and case studies of how water planning may consider long-term climate change through bottom-up stress testing of:
    a. Water management strategies, particularly at WMA and catchment scale, supported by appropriate institutional, organisational and physical interventions that increase long-term adaptive capacity.
    b. Water resources infrastructure projects that provide robust and operationally flexible supply augmentation as part of broader systems.
    c. Water services and infrastructure that are robust to alternative climate futures, while being flexible within a broader municipal services and infrastructure system.
2. Understanding the way in which climate driven changes in water resources availability or demand may constrain (limit) or enable (catalyse) different development pathways in different parts of South Africa, particularly in terms of agricultural production and energy generation:
    a. Trade-offs related to allocation between different sectors and their impacts on economic and rural development priorities.
    b. Opportunities and risks related to regional trade in food and energy in the Southern African Development Community (SADC). For example, research should focus on the implications of importing more water intensive (lower-value) products (i.e. with higher water footprint) on trade balance, food security and energy security.
3. Exploring the long-term non-stationary hydrological implications of climate change on the appropriate definition of the ecological reserve as well as on the implications for catchment management in different systems in order to maintain the reserve.

5. CONCLUSION

Climate change impacts on South Africa are likely to be felt primarily via effects on water resources. In both wetter and drier futures, a higher frequency of flooding and drought extremes is projected. It is relatively certain that water will continue to be supplied to meet domestic urban and industrial demands. **The key question**, however, is how this will be done in the context of viable agriculture and energy production, noting that increasingly expensive water will have an impact on water supplies to economic and social users. **A related question** involves the stage at which it will be necessary to give clear planning direction to the trade-offs between water, energy and food production, versus trade, which in turn should increasingly frame the water, food and energy security debate. **Under a drier future scenario**, significant trade-offs are likely to occur between developmental aspirations, particularly in terms of the allocation between agricultural and urban-industrial water use, linked to the marginal costs of enhancing water supply. These constraints are most likely to be experienced in central, northern and south-western parts of South Africa, with significant social, economic and ecological consequences through restricting the range of viable national development pathways. Under a **wetter future scenario**, trade-offs in water allocation between sectors are likely to be less restrictive, providing greater scope for urban-industrial economic growth and water provision for an intensive irrigated agricultural production model. There is a need to explore the socio-economic implications of a range of possible climate-water futures to inform key decisions in development and adaptation planning in South Africa in order to build climate resilience of vulnerable communities and groups.

ANNEX 1: REVIEW OF EXISTING RECONCILIATION STUDIES FOR SOUTH AFRICA

1.1 Stochastic systems analysis methodology

An overview of the reconciliation study method, the supporting concepts, and its focus areas is described here, as these studies could usefully form a central pillar of adaptation responses to climate variability and change.

The stochastic systems analysis methodology used in the reconciliation studies is presented together with an understanding of how climate data have been employed in the modelling processes used to analyse water resource systems or schemes. It is useful to understand this stochastic planning process, especially with regard to the length of the climate record used to develop it, as this would provide insights into the envelope of natural variability within which planning has occurred. This provides a platform for assessing the risk of future climate change introducing supply conditions that exceed this envelope.

1.1.1 Incorporating hydrological uncertainty

Intermittent long-duration droughts and consequent extended periods of deficient streamflows are inherent to the natural climatic and hydrological variability of South African catchments. Since the early 1990s, in South Africa, the uncertainties caused by such significant variations in surface water availability have been explicitly incorporated in probabilistic terms in decision-making processes related to the planning and operation of bulk surface water resources infrastructure.

The primary avenue for incorporating this uncertainty has been the application of a suite of system modelling software that enables the probabilistic analysis of the sequential behaviour of a particular water resource system or scheme when subjected to a particular scenario of water demands. The modelling requires long-term naturalised streamflow sequences as inputs at all relevant incremental main-stem or tributary sub-catchment points or as inflows to dams, as well as the superimposition of all water demands, abstractions and losses at relevant points in the system. The use of large samples of equally-likely long-term streamflow sequences as system model inputs, stochastically generated from the historical naturalised streamflow sequences, enables the development of a probabilistic understanding of the inherent long-term variability of water availability in such a system or scheme.

Uncertain climate change impacts on catchment hydrology would certainly add to the uncertainties related to significant and extended natural variations in water availability in bulk water resource systems. However, the existing well-established system-based approach to gaining a probabilistic understanding of such variability provides an appropriate framework for system-based probabilistic examination of climate change adaptation strategy options. The stochastic tools underlying this approach are based on sophisticated state space techniques linking spatial and temporal variability.

The rest of this section introduces certain primary concepts relevant to water resources analysis and management, followed by overviews of the aforementioned modelling processes and of their indispensable roles in water resources planning and operation in South Africa.

The concept of yield

The annual volume of water that can "reliably" be supplied from a bulk water resource system or scheme is universally represented by the concept of system yield, or scheme yield. In probabilistic terms, the yield is the maximum annual volume of water that can be consistently supplied over the long term at a specified "annual recurrence interval of failure". The "annual recurrence interval of failure" concept is interchangeable with the concept of the "annual assurance probability" of a specific annual volume of water supply from a particular system or scheme.

Yield analysis is conducted by modelling the sequential behaviour of a water resource system or scheme. In quantitative terms, the yield of a surface water resource is primarily determined by the total water availability during periods of severely deficient streamflow, i.e. "drought", in any long-term sequence of years. It follows that any modifications to deficient-flow patterns during droughts in surface water resource systems caused by climate change would manifest in changes to yield volumes and assurance of supply.

Determinants of yield

In South Africa, bulk water supplies are generally delivered from large, complex, multi-user, multi-scheme, multi-tributary river systems sometimes including inter-catchment transfers to large population and economic concentrations (metropolitan areas, large industries, power generation and large irrigation schemes). The primary determinants of usable yield in the context of such bulk surface water resource systems are summarised in Table 2. Variable distribution of climate change impacts across such bulk water resource systems would affect the relative importance of each of these determinants of yield in each system's unique context.

Table 2. Primary determinants of usable system yield in a surface water resource context (extract from DWA, 2013)

Determinant	Effect/importance
Long-duration deficient-flow characteristics of the main-stem river and primary tributaries of the system.	During prolonged deficient flow-periods, dam storages are continuously drawn down until failure of supply occurs, or until a series of floods during a subsequent wet period refills the dams. In dam storages that are small relative to their catchments' mean annual runoff – say, smaller than 75% of mean annual runoff (MAR) – the yield is quite dependent on the baseflow portion of the streamflow regime. For much larger dam storages – say, larger than 150% of MAR, the flood portion of the streamflow regime is a dominant determinant of yield. These sequential low- or high-flow characteristics are described by the concept of statistical persistence and are measured by the auto-/serial-correlation statistic for annual streamflows.
Prolonged wet period streamflow characteristics of the main-stem river and primary tributaries of the system.	
Total dam storage capacity in the system.	Large intra-year variability and multi-year droughts characterise South Africa's catchment hydrology; therefore, considerable storage capacity is required to ensure reliable water supply during seasonal and multi-year deficient-flow periods.

Table 2. Primary determinants of usable system yield in a surface water resource context (extract from DWA, 2013)

Determinant	Effect/importance
Net evaporation loss from all primary dams.	Net dam evaporation losses often reduce the potential system yield significantly. For example, in the Western Cape Water Supply System (WCWSS) net evaporation losses from Voëlvlei Dam exceed 22% of its 1:50 year recurrence interval yield.
Locations of dams and bulk abstraction sites.	Dams and abstraction schemes in series can be operated in unison to optimise their combined yield. Additionally, large upstream dam storages usually experience relatively low net evaporation loss, thereby benefitting the total system yield. For example, in the WCWSS the high-elevation Theewaterskloof Dam experiences net evaporation losses of only 5% of its 1:50 year recurrence interval yield, as opposed to the much higher loss value for the low-elevation Voëlvlei Dam mentioned above.
Existence of interconnected parallel sub-systems.	Long-duration deficient-flow periods or prolonged wet periods that occur out of phase in different parts of the system, or that occur at different intensities, could benefit the system yield (and vice versa) significantly if adequate hydraulic connectivity exists between different parts of the system. This is obviously the case from upstream to downstream along the main-stem river, but also applies to inter-basin transfer source catchments. This phasing/spatial dependence characteristic is described by the pair-wise cross-correlation statistic for annual streamflows.
Provision of the Reserve/ ecological water requirements (EWRs).	The Reserve/EWRs have a primary claim on water availability and, therefore, decrease the yield available for economic activities.
Operating rules of dams, abstraction schemes and sub-systems.	EWRs, water quality objectives and prioritisation of dam releases and river abstractions for particular uses are achieved through operating rules. Operating rules need to be optimised to maximise the total system yield.
Locations of primary demand centres in the system.	The remoteness of potential bulk water resources from primary demand centres is a limiting factor in the affordable use of the potential yield from such resources (and vice versa).
Conjunctive use of groundwater to support surface water systems during droughts.	Conjunctive use can boost system yield significantly, but due to a scarcity of large primary aquifers with advantageous locations, conjunctive groundwater-surface water use optimisation has so far not played a significant role in the operation of bulk water resource systems in South Africa. However, the need for more conjunctive use in various bulk systems will become more prominent in the foreseeable future.

Long-term historical naturalised streamflows

The long-term yield analysis of a particular bulk water resource system requires, on the one hand, naturalised long-term historical monthly streamflow sequences at all relevant inflow points to the system and, on the other, a particular scenario of multi-user monthly water demands at all relevant points across the system (e.g. current-day demands). The long-term historical naturalised monthly streamflow sequences for various points in the system are generated by a calibrated monthly catchment rainfall-runoff model, the Water Resources Simulation Model 2000 (WRSM2000), commonly known as the Pitman model. The quasi-physical parameters of this catchment rainfall-runoff model need to be calibrated against streamflow records that can be deemed as "reliable". To enable such calibration, a time-line of historical water use and land-cover/land-use changes upstream of the streamflow gauging station needs to be developed. Naturalised stream flows are generated by removing all human impacts from the catchment model and running it with the calibrated parameters. The parameters can be transferred to catchments that are ungauged.

The typical length of records is in the range of 40–50 years, with some as short as 20 years, but others going back 80 years and even longer. Long-term naturalised streamflow sequences 80–90 years in length are generated by extending the rainfall sequences used as inputs to the catchment model backwards to, say, the 1920s. In this process, specialised software, CLASSR and PATCHR, is used to infill (or "patch") periods of missing rainfall data in a particular record statistically from the data in other records. CLASSR identifies which rainfall records are statistically similar and PATCHR does the actual infilling by advanced regression.

Long-term stochastic naturalised streamflow sequences

A suite of specialised software is used to generate long-term streamflow sequences stochastically within a system context. The stochastic algorithms in the software are designed to preserve both the persistence characteristics (serial correlations) in individual streamflow sequences and the cross-correlations between the various sequences in the system. The stochastic parameters for this process are calculated from the matrix of all the long-term historical naturalised streamflow sequences in the system. For the Western Cape System, for example, given that the system model is configured with 61 inflow nodes and that the historical naturalised streamflow sequences are each 77 years long, the size of the matrix from which the stochastic parameters are calculated is 61x77 and the resulting stochastic model (an ARMA (n, p) model) has 61 individual terms.

1.1.2 System modelling approach

The following two closely-related water resources system models are being used to support water resources management in South Africa:

Water Resources Yield Model

Purpose: The Water Resources Yield Model (WRYM) is used to analyse the long-term or short-term system or scheme yield for a particular demand scenario, to derive suitable operating rules to optimise yield, and to develop stochastic yield-reliability characteristic curves applicable to that particular demand scenario by means of a large number of equally-likely stochastically-generated streamflow sequences. Such stochastically-based analyses enable derivation of the probabilistic assurance of any particular yield (risk of non-supply) of the water resource system as a whole, as well as of any of its sub-systems and dams.

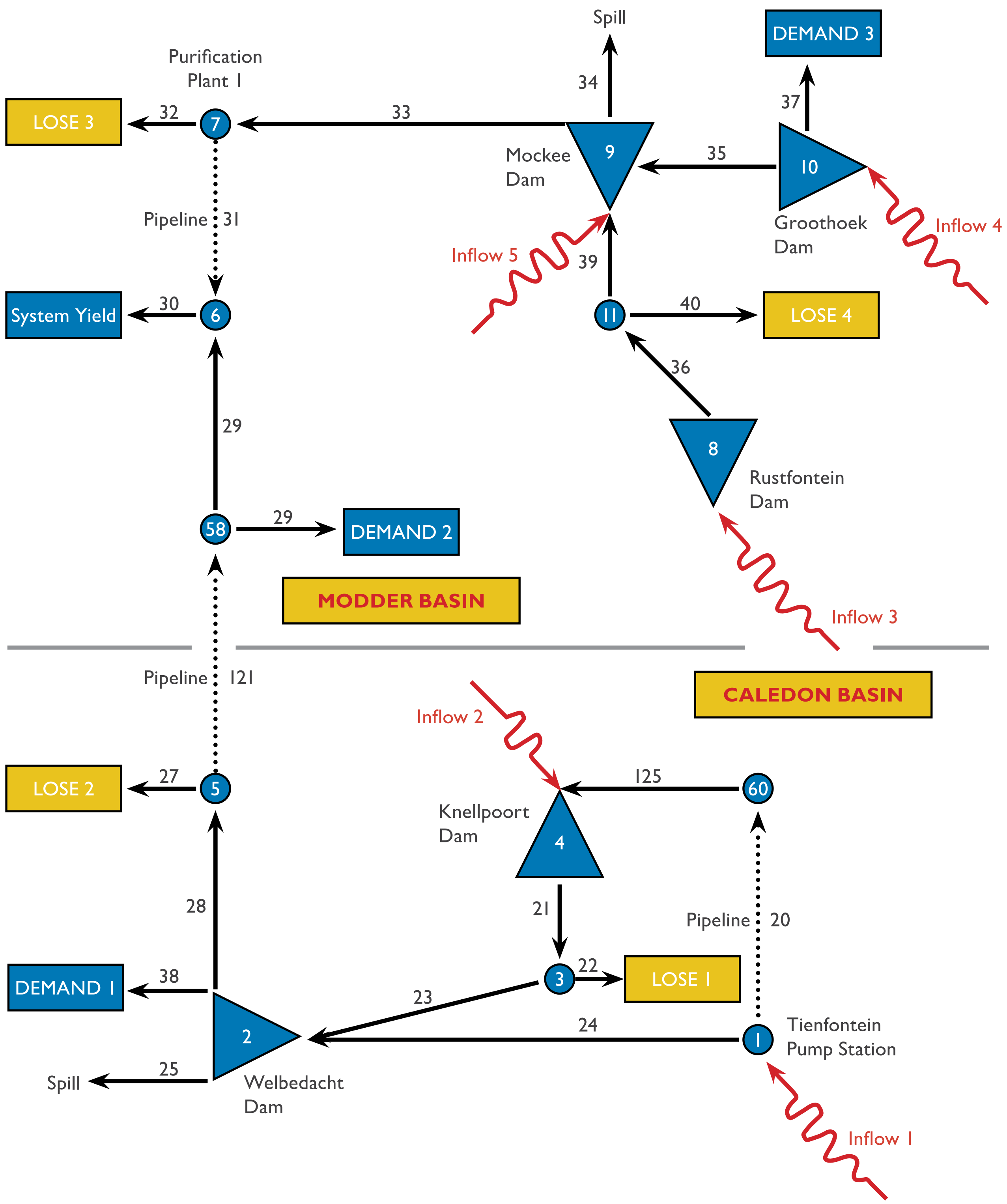

Figure 19. An example of a typical WRYM configuration (Caledon-Modder sub-system, part of the Vaal River catchment integrated system)

Description: WRYM is a monthly time-step network model that can be configured to represent all significant components of a particular bulk water resources system. The configuration may encompass any number of sub-catchment streamflow input points, dams, abstraction points and transmission losses. Naturalised streamflow series at all relevant points form inputs to the model, as do demand series at relevant points for specific catchment development or other future scenarios. Any number of parallel sub-systems can be combined to form an integrated overall system. Operating rules for any particular component or sub-system are determined by a set of penalties. The distribution and allocation of water throughout the system is mathematically optimised for each monthly time-step through the use of the penalties.

Figure 19 presents an example of a typical WRYM configuration, while Figure 20 depicts a typical set of yield-reliability characteristic curves derived with the WRYM.

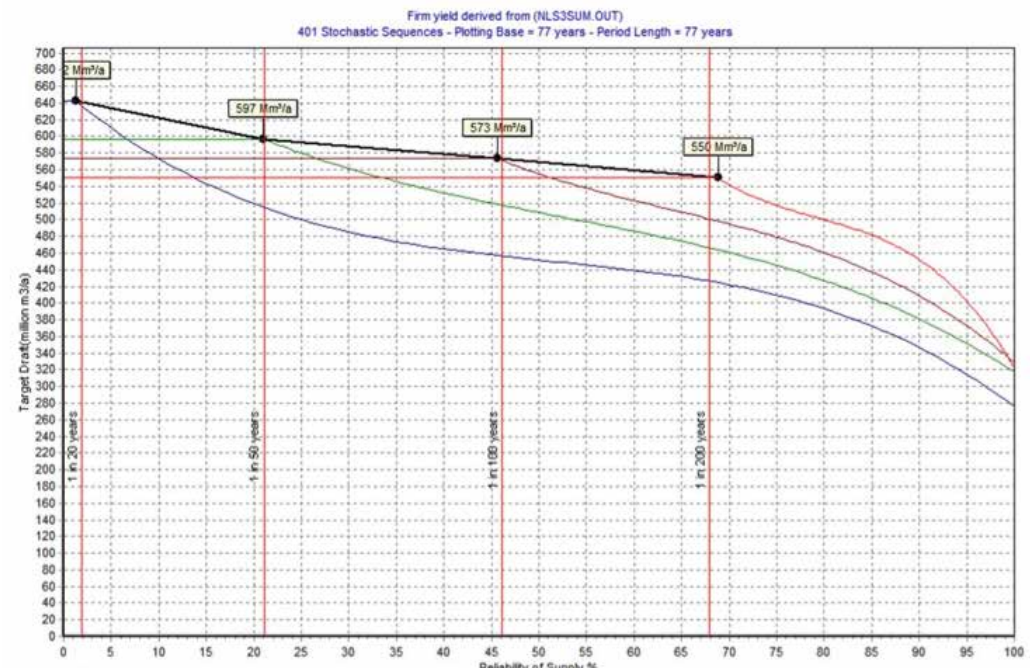

Figure 20. An example of a typical set of stochastic yield-reliability characteristic curves as outputs from WRYM (WCWSS)

Water Resources Planning Model

Purpose: The Water Resources Planning Model (WRPM) is used in two different modes:

- To inform long-term development planning decisions (for a target time horizon of, say, 10–20 years) under conditions of growing demand regarding the optimal timing of augmentations to bulk water resources infrastructure in a particular system.
- To optimise short-term operational decisions (for a target time-horizon of, say, 12 months) about balancing water availability across sub-systems, or about the introduction of water restrictions, given a particular starting storage state in the system or scheme.

Description: WRPM is a monthly time-step network model with the configuration based on a simplification of an existing WRYM configuration. For development planning decision-making, WRPM is run with a large number (e.g. 201) of stochastically-generated long-term (60–90 years) streamflow sequences and with demands that are steadily increasing up to the future target time horizon. The required reliability of supply requirements of different categories of users (e.g. domestic, industrial, agricultural, power generation) are part of the model inputs.

For each year into the future the model superimposes the set of increasing system demands linked to that particular year and then simulates the sequential behaviour of the total system for each individual set of stochastic streamflows. For each of these model runs, long-term stochastic yield-reliability characteristics – previously derived with WRYM – are used to try and maintain allocations to the different users that meet their respective reliability constraints. Failure to meet reliability constraints triggers the imposition of curtailment of supplies on a stepped increasing scale according to a pre-planned formula. The model keeps track of these curtailments and outputs a probabilistic box-whisker diagram of restriction levels for each year up to the target time horizon. This sequence of increasing risks of restrictions of demands into the future is used to determine an optimal target date for the introduction of an augmentation to the system's water supplies.

Figure 21 represents an example of a typical probabilistic box-whisker diagram output series of the risks of water restrictions in the longer-term future – in this case, for informing a decision about the optimal target date for operationalising the next augmentation of the WCWSS. The extent of curtailments is represented by a number on the vertical axis, e.g. a "level one" water restriction is currently associated with supplying 93% of the urban demand and 90% of the agricultural demand, which, if the relative supply to each consumer is taken into account, equates to 92% of the total demand. In the WCWSS it is deemed acceptable that this degree of curtailment occurs up to once in every 20 years. The horizontal bar of each whisker represents the restriction level that is exceeded in 5% of 201 long-term stochastic runs (i.e. a 1:20-year risk of water restrictions at or more severe than that level), while at the outer extreme, the solid line indicates the restriction level that is exceeded in 0.5% of the stochastic runs (i.e. a 1:200-year risk of water restrictions at or more severe than that level). The figure below shows that 2019 should be the target date for operationalising the next augmentation of the WCWSS, because that is the point at which the 5% (i.e. 1:20-year) risk of water restrictions rises above the "level one" line. This underlies one of the central questions for reconciliation studies, namely "by when must the next scheme be commissioned?" Alternative augmentation options can then be evaluated in terms of their ability to meet this increasing demand, within the timeframe required.

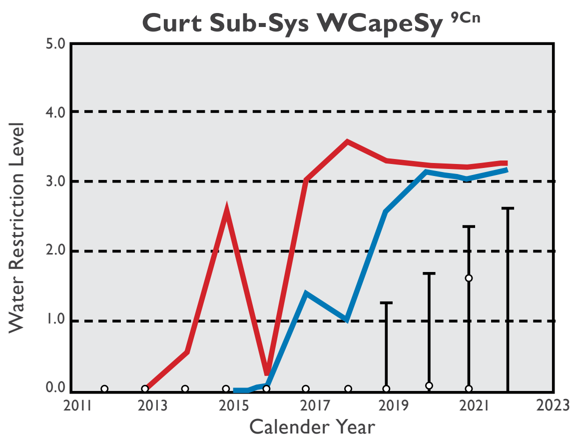

Figure 21. An example of a typical box-whisker diagram output series from a WRPM application (for the WCWSS to determine the optimal augmentation target date)

For annual operational decision-making about water allocations for the year ahead, WRPM is run with a large number (e.g. 401) of stochastically-generated short-term streamflow sequences (3 to 5 years) and with current-day demands. For each of these model runs, short-term stochastic yield-reliability characteristics – previously derived with WRYM – are used to try and maintain water allocations to the various users that meet their respective reliability constraints.

1.2 Algoa Reconciliation Study

Area of supply

The Algoa Water Supply System (AWSS) provides water for domestic use and for use by more than 373 industries in the Nelson Mandela Bay Municipality (NMBM), for several smaller towns within the Kouga Local Municipality and for irrigation of 7 420 ha to the Gamtoos Irrigation Board. Approximately 65% of the water use is for urban and industrial use and 35% for irrigation. Increases in water demand are occurring due to in-migration, increased service levels and industrial activity.

Hydrological record

As part of the Algoa System Annual Operating Analysis Study (2006–2009), hydrology data for the period 1927 to 1991 was applied. Whilst there is more recent (1930 to 1998) hydrology for the Kouga sub-system, the same time series had to be used for all areas which meant using data for the period from 1927 to 1991. There were large discrepancies between the period from 1927 to 1991 and more recent hydrology and the need for a detailed investigation, especially given the uncertainty relating to water use in the upper Kouga River catchment, was noted (DWA, 2012).

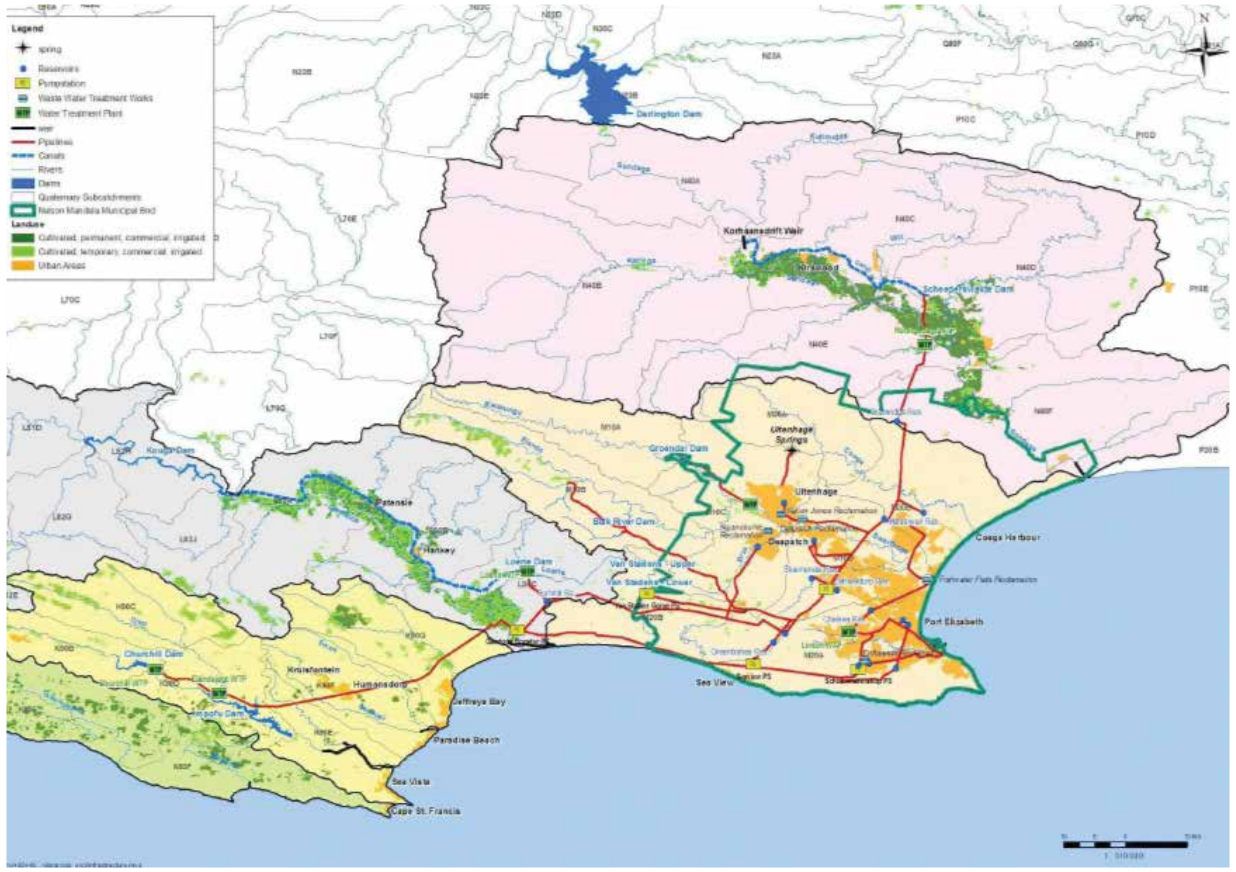

Figure 22. Algoa water supply area (DWA, 2011)

The historical water demand for the Algoa area is available from the period starting 1961.

Figure 23. Historical water demand for the Algoa area (DWA, 2011)

Current and future water requirements

Figure 24 shows the high and low growth water requirement scenarios.

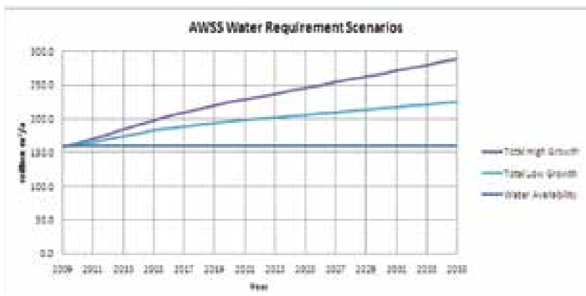

Figure 24. Algoa water requirement scenarios

Assumptions made for the study

The following assumptions were made for the study:

- A constant irrigation requirement of 50 million m^3/a
- 2.5% linear growth for urban/industrial water requirements
- Unit reference value (URV) system yield was taken as 159.4 million m^3/a
- The ecological water requirement was kept constant at 2 million m^3/a
- A saving of 10% (over 5 years) on water demand by using WC/WD management.

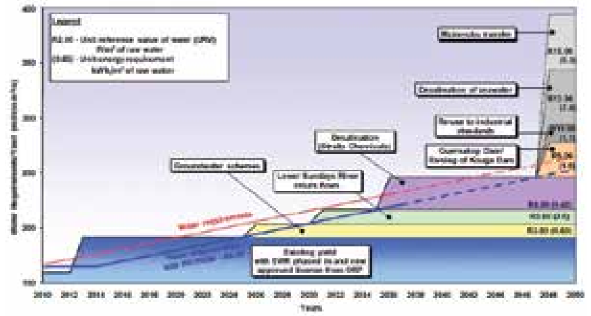

Figure 25. Water availability and requirements for Algoa

Figure 25 above presents the water availability and requirements for the Algoa system for the period up to 2050.

Water resource planning

The reconciliation study made the following recommendation's to ensure the future supply of water based on anticipated growth:

- Nooitgedagt Low-Level Scheme (which is currently being implemented)
- Groundwater development – Coega Kop aquifer and Churchill Dam area
- Re-use of water treated to industrial standards – Fish Water Flats Wastewater Treatment Works (FWF WWTW)
- Implementation of small groundwater developments

Beyond the 2030 timeframe, additional measures may need to be implemented to ensure the water supply to the area. Potential measures include:

- Re-use of effluent
- Desalination of seawater
- Development of further groundwater resources
- Construction of a new dam or raising an existing dam.

Climate change considerations

Global climate change models indicate that in the intermediate future (2046–2065) the Kromme and Kouga river catchments may experience slightly lower mean annual rainfall and fewer runoff events of 20 mm or more. Lower mean annual rainfall will result in lower soil moisture content and, together with reduced incidence of rainfall in excess of 20 mm per day, in reduced runoff (DWA, 2011). Models also indicated that the catchment of the Orange River may experience slightly higher mean annual precipitation as well as slightly increased frequency of rainfall in excess of 20 mm, which together would increase runoff from the catchment of the Orange River that serves the AWSS. Although there is considerable uncertainty concerning the possible effects of climate change on runoff into the existing and potential future dams of the AWSS, the formulation of a climate change scenario has been based on the conservative assumption that the runoff from all existing local water schemes serving the AWSS (but not the supply from the Orange River) will reduce linearly by 10% (13 million m^3/a) over the period 2011 to 2023 and that there will be no further reductions in yields thereafter. The dramatic dip shown in the figure below is a result of the phasing out of the Orange River Project over a five year period starting from 2030, with the simultaneous phasing in of replacement transfers from the trading of irrigation allocations on the Fish River, also over 5 years.

The study highlighted the need to monitor the impacts of climate change and conduct an impact assessment study to determine the expected regional impact of climate change on the AWSS water balance. Figure 26 shows the "worst case" scenario taking into account the following assumptions:

- Ecological reserves for these schemes would be implemented over 3 years commencing in 2015,
- Climate change would reduce the yields of existing local sources by 10%.
- The potential effect of climate change together with the implementation of the ecological reserve would necessitate the earlier implementation of the schemes presented. The Sundays River desalination scheme and an additional augmentation scheme would also be required.

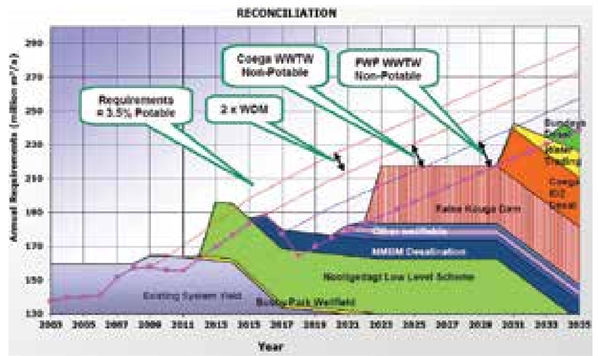

Figure 26. Worst case scenario study for the Algoa system

1.3 Amatole Reconciliation Study (DWA, 2008a)

Area of supply

The Amatole Bulk Water Supply System (ABWSS) supplies water to the Buffalo City Municipality, the Amathole District Municipality (ADM) and to irrigators along the Buffalo, Gubu, Kubusi and Nahoon rivers.

The Amatole to Kei Internal Strategic Perspective (ISP) study was conducted in 2004 and predicted water shortages for the area as early as 2012, this was subsequently expanded into a full reconciliation study. This study emphasises current and future urban, rural and agricultural water requirements; the availability of water; existing and future infrastructure; the ecological water requirement (EWR) for alternative categories, as well as both institutional and water pricing concerns. Water requirements in the ABWSS arise from domestic (urban and rural), industrial and agricultural uses, with the bulk of the requirements being for domestic use.

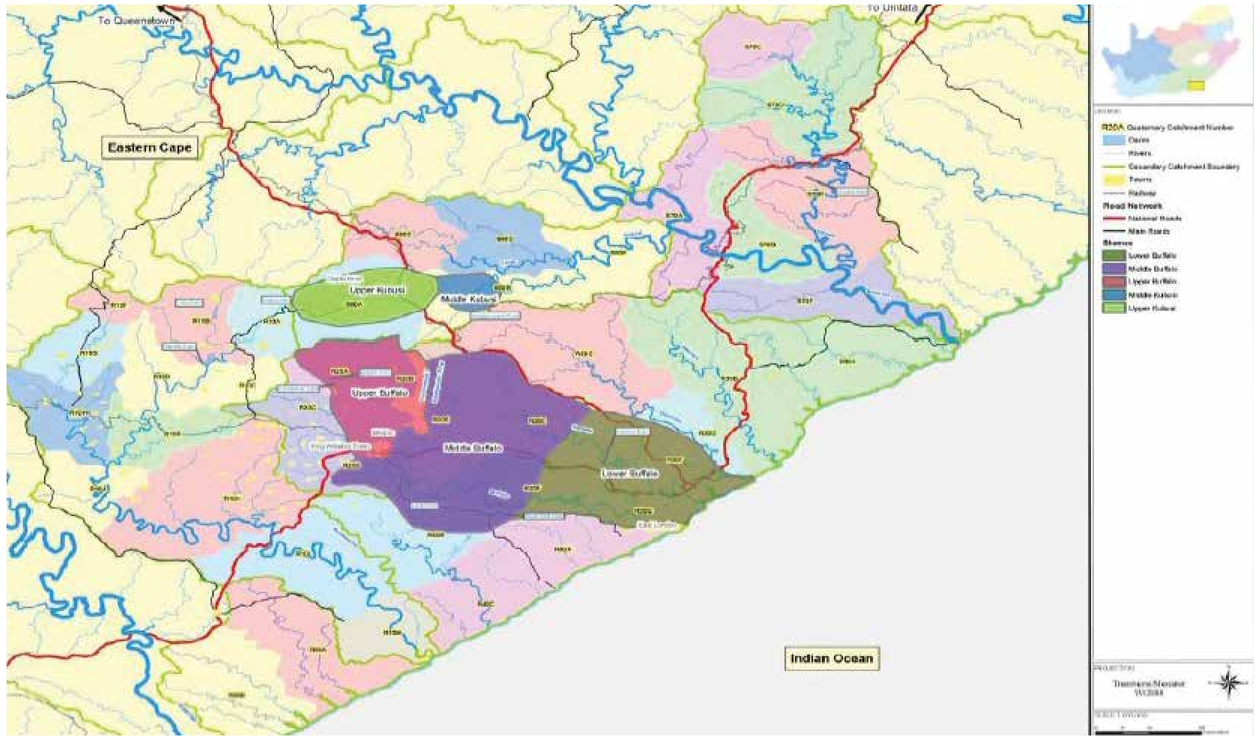

Figure 27. Amatole water supply area

Hydrological record

The hydrological record used in the study was extended from 1920–1996, (the period used in the previous hydrological analysis) to 1920–2003, (the latest data available at the time the review was done) by using the WRSM2000. Updated information was used to determine the yields in the dams for the ABWSS using the WRYM. The time series required for the WRYM were incremental streamflow, catchment irrigation, afforestation use and catchment rainfall.

The EWR for the rivers was an agreed value with the DWA; however, some provisions were made for lower ecological categories (ECs). In order to ascertain the impact of the EWRs on the yield of each dam and on the ABWSS as a whole (the system yield) various yield scenarios were prepared for each dam in the ABWSS.

There was a five year overlap in the natural flow time series, this was examined and discrepancies were found. Therefore, an independent review was undertaken i.e. to use WRSM2000 natural flow and land-use for the entire record period. The rainfall analysis was carried out using the DWAF Rainfall Information Management System (IMS) to extend the data to the 2003 hydrological year. Land-use data was obtained from the Water Situation Assessment Model (WSAM) database and the appendices to the Surface Water Resources of South Africa 1990 (WR90) study (DWA, 2008a).

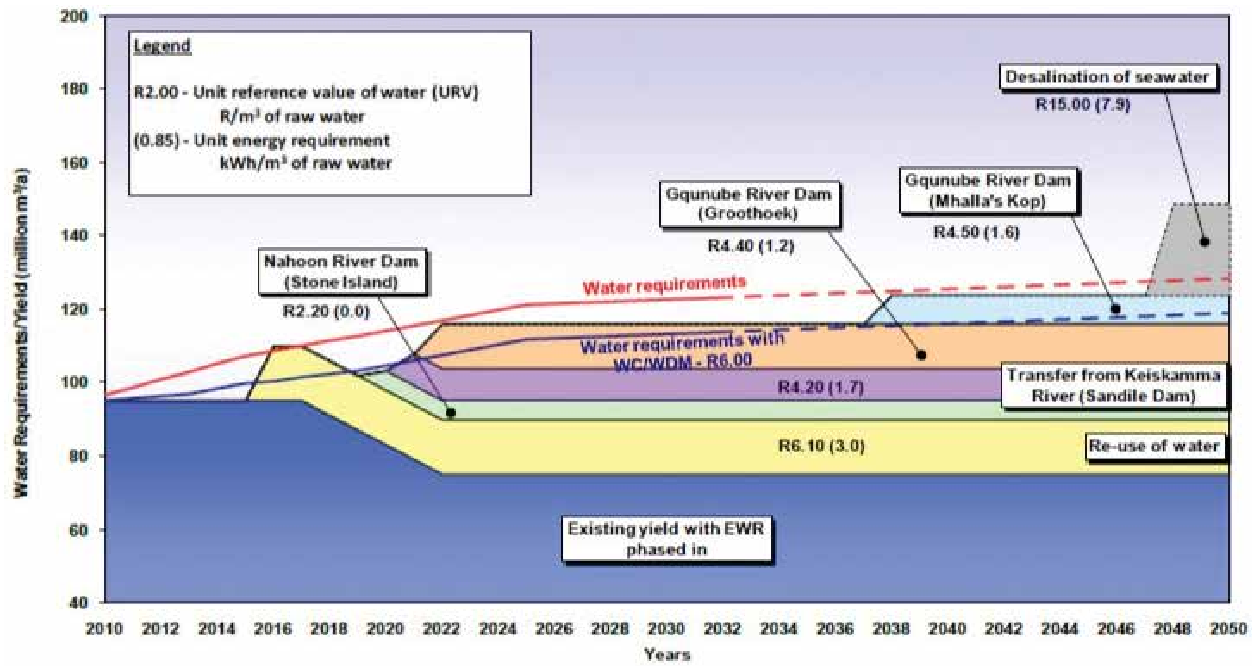

Figure 28. Amatole water availability and requirements (DWA, 2010a)

Assumptions for the study

The following were included as part of the study:

- Two different consensus data sets gave rise to different population growth rates
- Impact of HIV/AIDS formed the basis for the high/low growth scenarios
- Two different flow regimes for the EWR; with and without full flood release
- Two levels of WC/WDM were used
- Reduction in the water requirement of 9.5 million m^3/a.

Current and future water requirements

The water requirement scenarios are influenced not only by population growth scenarios, but also by factors such as the domestic, industrial and irrigation uses, levels of service, as well as water use efficiency, all of which are determined in terms of volume and timing. The basis for the domestic water requirement scenarios is population change, linked to the nature of household demands for water. Industrial water requirement scenarios are based on the current use together with the water requirements for the industrial development zone (IDZ).

Irrigation water requirement scenarios focus mainly on compensation water from the dams in the ABWSS. Invasive alien plants and afforestation have not been analysed as part of water requirement scenarios since these water uses were regarded rather as streamflow reduction activities affecting the yields of the water resources.

Water resource planning

The following are potential options to achieve the water requirements for the area:

- Build a new dam on the Nahoon River
- Transfer surplus yield from the Keiskamma River
- Build two dams on the Qunube River
- Re-use water from urban effluent
- Desalination.

Climate change considerations

In an addendum to the Amatole Reconciliation Strategy, issues around climate change were highlighted. Predictions show increased rainfall in the region during summer as well as increases in storm intensity. The winter periods however, will experience little rainfall and extended periods of drought. It was recognised that due to these variabilities arising from climate change, both infrastructural and management changes are required.

The assumption around demand for the winter months in the Amatole region was that there would be no increase in the demand for water in the winter months as compared to the summer months. There is increased evapotranspiration in the summer months, leading to high water demand. Water required for garden use was not included in the system and this will be affected by the lower rainfall in winter. In order to combat this, storage dams should be increased.

Based on the above information, the following measures regarding the supply of bulk water to the Amatole were proposed:

- Building additional dams, tunnels and pumps
- Increasing the size of some existing dams
- Increasing the size of storage dams

It was also recognised that education and awareness building were needed for success. The study also recognised that should the climate change predictions be incorrect, there will be a cost implication for funding the additional infrastructure as well as for additional maintenance of oversized dams. There is a direct relationship between the size of a dam and its efficiency. Generally speaking, a larger dam will have a greater rate of evapotranspiration. Irrespective of climate change, the following will be beneficial:

- Improved governance and management
- Increased community participation
- Improved communication to stakeholders

1.4 Bloemfontein Reconciliation Study (DWA, 2010b)

Area of supply

The Greater Bloemfontein Supply System provides most of the water required by the towns located within the Mangaung Metro Municipality, namely Bloemfontein, Thaba Nchu, Botshabelo, Dewetsdorp, Reddersburg, Wepener, Edenburg and Excelsior.

Hydrological record

The area uses surface water from the Rustfontein, Mockes, Welbedacht and Knellpoort dams. The historical firm yield calculated for the Welbedacht and Knellpoort dams takes into account the estimated environmental water requirements downstream of Welbedacht Dam and existing and proposed agricultural water requirements, which includes the water requirements for resource poor farmers. When all the resources supplying the greater Bloemfontein area are operated as a system, the yield of the system is greater than the sum of the yields of the individual resources. The river losses between the Welbedacht and Knellpoort Dams and Mockes Dam is large and estimated to be in the order of 11 million m^3/a.

Groundwater is currently not used to supply potable water, but is being used to irrigate gardens in residential areas, for agricultural purposes, by small industries for bottling water and for micro-irrigation of vegetables and nurseries.

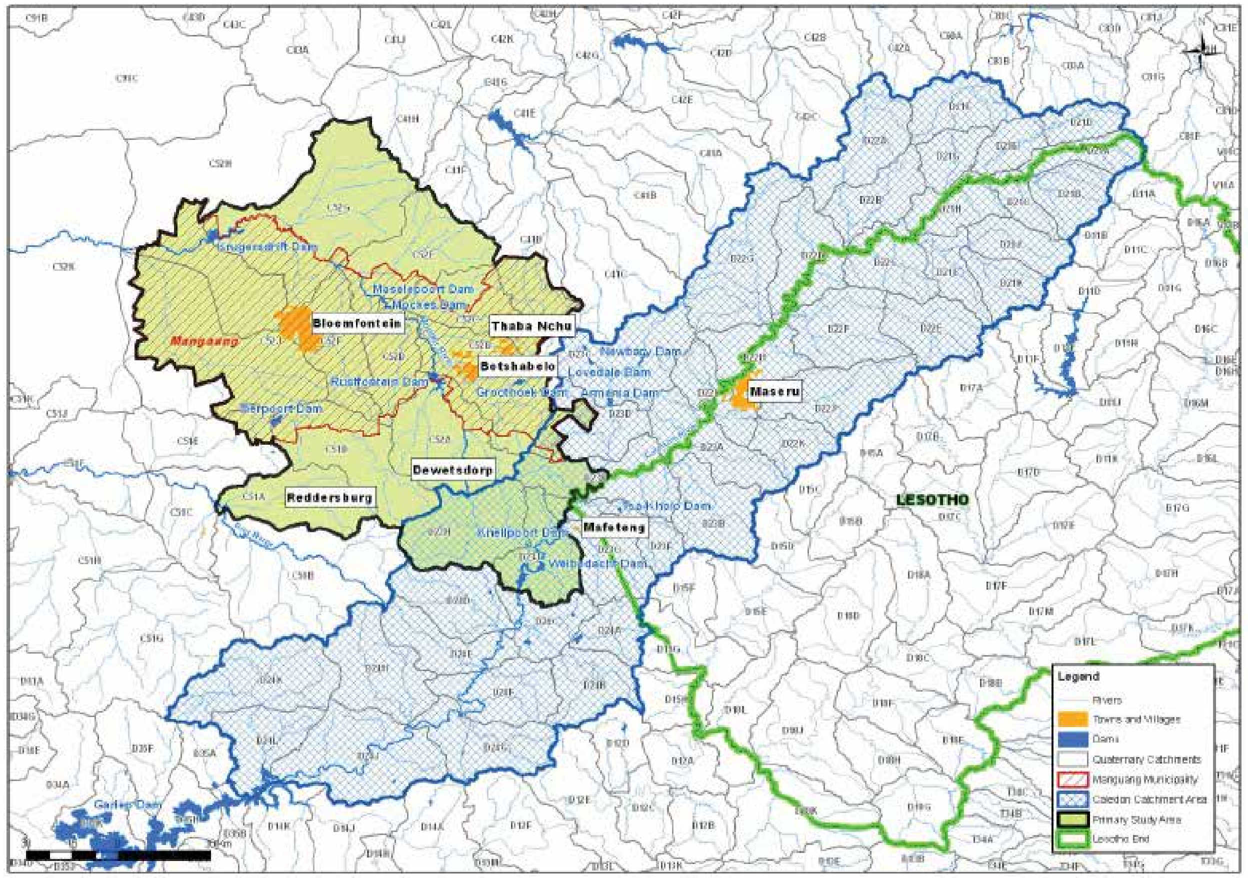

Figure 29. Bloemfontein water supply area (primary)

Current and future water requirement

The graph below shows the historical water demand for Bloemfontein and its surroundings.

The future water requirements for the Bloemfontein area were based on more than population growth and local economic growth. Other factors that were included were:

- Changes in the level of service with improvements in water services, sanitation, and health awareness
- Impact of HIV/AIDS, with the highest occurrence in the rural areas.

Three population growth scenarios, low, medium and high, were used and these are summarised below:

Low-growth scenario:

- Low anticipated growth in existing population mainly attributed to a higher mortality rate as a result of HIV/Aids.
- A lack of urbanisation in the smaller towns, and a decline of development within Bloemfontein.
- Higher emigration rates from the rural areas due to a stagnant and declining local economy, and a low immigration rate for Bloemfontein.

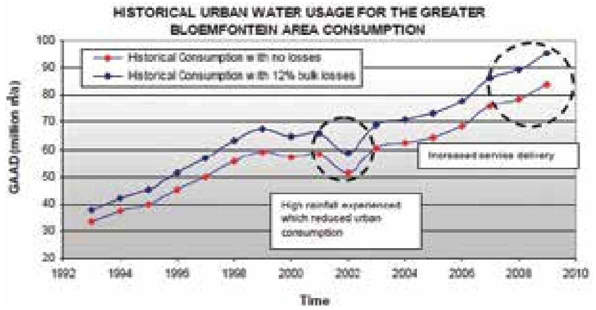

Figure 30. Historical urban water use

Medium-growth scenario:

- Medium anticipated growth in existing population, more or less in line with the average between the low and high growth scenarios.
- A lack of urbanisation in the smaller towns, but more positive growth for development within Bloemfontein.
- Higher emigration rates from the rural areas due to a declining local economy, with the assumption that these residents will migrate to Bloemfontein and Botshabelo in seek of employment opportunities.

High-growth scenario:

- High anticipated growth in existing population attributed to a lower mortality rate and a longer life expectancy as a result of a successful HIV/Aids treatment programme (supported by improved health services).
- An increase in urbanisation in the smaller towns, and further development within Bloemfontein. Emigration rates from the rural areas will decline, specifically to other provinces like Gauteng.
- A more positive immigration rate to Bloemfontein, specifically from other provinces such as the Northern Cape and Kwazulu-Natal.

Figure 31 below presents the water requirement scenarios for the Bloemfontein area based on the population growth scenarios.

Figure 31. Water requirement scenarios for Bloemfontein

Water resource planning

Figure 32 below shows the water requirements for the Bloemfontein area based on the population growth scenarios.

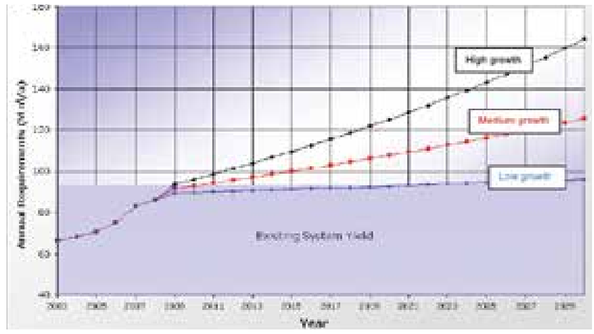

Figure 32. Water availability and requirements for Bloemfontein

The intervention envisaged in the strategy is to increase the capacity of the pumps at the Novo Pump Station and the Tienfontein Pump Station. Large-scale groundwater development was not considered as an option due to the impact of farmers in the area. Water re-use is an option and is being investigated.

Climate change considerations

The study stated that climate change would be considered, however, this was not evident.

1.5 Crocodile West Reconciliation Study (DWA, 2008b)

Area of supply

The Crocodile West Water Supply System Reconciliation Strategy covers the northern areas of Gauteng, the platinum mines, other developments around Rustenburg and Brits and further north to Thabazimbi, and large-scale energy-related developments that are planned for the Waterberg coalfields in the vicinity of Lephalale.

Figure 33. Crocodile West water supply area

Hydrological record

The simulated flow data, for the Crocodile (West) River catchment, covers the hydrological years 1920 to 2003. A large quantity of return flow from urban and mining developments reaches the Crocodile catchment from effluent discharges originating in the Vaal, which significantly impacts on the water quality of receiving streams and impoundments.

Current and future water requirements

Most of the water used in the catchment is for urban and industrial purposes (representing 50% of the total), followed by irrigation (33%) and mining (8%). The strongest growth in requirements is experienced in the urban/industrial and mining sectors.

The strong growth in the urban/industrial sectors is expected to continue in and around the existing metropolitan areas located in the upper parts of the catchment (and contributing to return flows downstream). New mining developments will be mainly in the middle and lower parts of the catchment, whilst a strong need also exists to abstract water in the lower part of the Crocodile River catchment for transfer to large new developments in the Lephalale area, which is located in the Mokolo River catchment.

Population growth will take place via two avenues: childbirth and migration. Economic growth is expected to continue at a rate above the national average. Socio-economic changes and improvements in service delivery also play a role in the water demand for the area and should be monitored. The combination of the three scenarios of population (high, base and low) and the three scenarios of demand management (no, high efficiency and low efficiency) results in nine scenarios which were evaluated and water balances were determined for them.

Irrigation areas, and irrigation water requirements, are accepted to remain constant between 2005 and 2030. Distribution losses associated with water supply to irrigation areas in the study area are in some areas accepted to be as high as 50%.

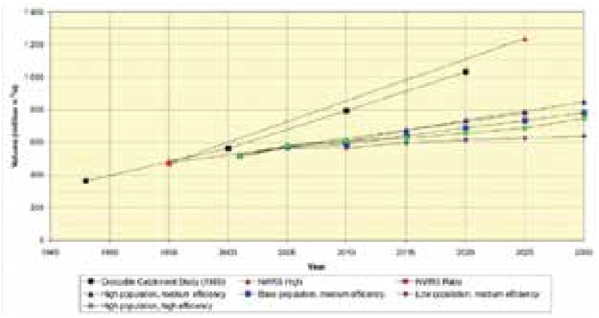

Figure 34. Water demand for the urban areas in the Crocodile West area

The water requirements of the mining industry, both the historical data and future projections, were very difficult to obtain. The total mining water requirement from a feasibility study was used as the water requirement for the reconciliation study. The data used was incomplete and further investigations are required.

Water resource planning

Scenarios with respect to population growth, economic growth, socio-economic changes and possible transfers of water are presented in the report. It is anticipated that the current development trends will continue for the foreseeable future with strong growth in the urban/industrial/mining sectors. Large new developments related to mining, power and petro-chemical industries are also being planned in the neighbouring Mokolo River catchment, with the expectation that water could be supplied from or via the Crocodile River.

The interventions of the strategy are to:

- Implement WC/WDM for all user sectors and fully utilise the local water resources, including ground water.
- Regulate return flows
- Re-use effluent below Hartbeespoort Dam
- Transfer water to the Lephalale area
- Raise the Mokolo Dam
- Free up water through improvements to irrigation distribution systems
- Re-allocate (purchase) water from irrigation in the Crocodile/Mokolo catchment.

The area relies heavily on return flows from the Vaal; however, this would become insufficient should there be increased demand in the area.

Climate change considerations

Climate change considerations were not found in the report.

1.6 KwaZulu-Natal Coastal Metropolitan Reconciliation Study

Area of supply

The study area comprises the water resources of the KwaZulu-Natal Coastal Metropolitan Area from Pietermaritzburg to Durban from west to east and from Kwadukuza (Stanger) in the north to Amanzimtoti in the south. It includes the eThekwini Metropolitan and the Msunduzi and iLembe municipalities. The main bulk water resources comprise the Mgeni, Mdloti, and Mvoti river systems supported by a transfer scheme sourcing water from the Mooi River. There are several large storage dams regulating the flow in the rivers: the Midmar, Albert Falls, Nagle and Inanda dams on the Mgeni River and the Hazelmere Dam on the Mdloti River.

This area is the third largest contributor to the national economy and has the second largest population concentration in the country. The area is experiencing rapid growth in water demand because of the influx of people from the rural areas, economic growth, and development initiatives. The study looked at water requirements up to the year 2030.

Water resource planning

The water requirement scenarios were based on the anticipated demographic dynamics driven by the socio-economic conditions and urban development planning in the area. The scenarios incorporate the provision of improved water supply services and also accommodate proposed housing development plans. The water requirement projections for the Ethekwini and Msunduzi municipal areas were determined with the Water Requirement and Return Flow database model, which was developed for the Department of Water Affairs as part of the Crocodile (West) River Return Flow Assessment Study. Various scenarios of future requirements were developed and the "high" scenario was used in the planning. The other scenarios were applied mainly to check the impact on the timing of the measures, as well as to ensure that the recommendations are stable and provide a flexible solution.

A diverse set of measures were identified covering both demand management initiatives and infrastructural water resource augmentation projects. The study was completed in 2010 and the following options were considered:

- WC/WD management
- Drought management
- Rainwater harvesting
- Re-use of water
- Desalination
- Dam construction and transfers.

Climate change considerations

The report states that the effects of climate change could not be accurately determined at the time of the study. Current models show no indication of a reduction in rainfall in the area but it may be more variable. The effects of climate change will be closely monitored.

1.7 Luvuvhu and Letaba Reconciliation Study

Area of supply

The area under investigation is the entire Luvuvhu and Letaba WMA and parts of the adjacent WMAs. Most of the development in this water management area is agriculture based, with strong contributions by irrigated agriculture and afforestation. Areas under natural vegetation are mostly used for livestock farming, with severe overgrazing experienced over large parts of the water management area. There are a few mining developments in the area as well.

Approximately 80–90% of the population can be described as rural. A large proportion of the population depends on subsistence farming and this makes availability of water a vital subject for consideration. The Kruger National Park lies along the eastern boundary and occupies approximately 35% of the WMA.

Water resource planning

The Letaba River currently exceeds its yield capability. The construction of Nandoni Dam is aimed at alleviating the water shortage problem. A better understanding of the resource is needed and other alternatives need to be investigated in order to bring the system back into balance.

Potential interventions may include:

- Implementation of water restrictions
- Implementing WC/WDM for all user sectors
- Full utilisation of groundwater and all other local water resources
- Eliminating unlawful water use
- Removal of invasive alien plants.

Climate change considerations

Work is currently underway and it is unknown whether climate change has been considered in the studies thus far. All indications are that it has not been explicitly addressed.

1.8 Mbombela Municipal Area Reconciliation Study

Area of supply

The Mbombela Reconciliation Study covers the municipal area which straddles the Sabie and Crocodile River catchments. Water use within the Mbombela Local Municipality (MLM) has increased rapidly over the last few years and hence both catchments are currently fully or over-allocated.

Water resource planning

The strategy will focus on increasing water availability primarily for domestic and industrial use. Increased irrigation and forestry has not been included in the future planning, however, should a scheme be implemented, conjunctive use will be considered.

Climate change considerations

The study is still in progress; however, there are no indications that climate change has been considered as part of the study.

1.9 Mhlathuze Reconciliation Study (Richards Bay)

Area of supply

Richards Bay is the economic centre of the Mhlatuze Local Municipality, comprising Empangeni, Ngwelezana, Nseleni, Esikhaweni and a number of rural villages. It is one of the strategic economic hubs of the country and has been designated an Area of National Economic Significance. Richards Bay has the largest coal export terminal in the world, the second largest port in South Africa and is the site of several large, strategic, export-oriented industries.

Current and future water requirements

Currently, a small surplus exists in the Mhlatuze system. The current water requirements for the Mhlatuze system are 266 million m^3/a, with the availability of water sitting at 258 million m^3/a, once the environmental water reserve (EWR) comes into effect. There is no growth projection for the area and irrigation requirements sit at 100 million m^3/a.

At the moment, the resource is sufficient, but there is a potential for new industries to start developing in the area and this should be monitored.

Figure 35. Mhlatuze water supply area

Assumptions made for the study

It should be noted that the system is still under development; therefore, no concrete assumptions have been made as yet.

Water resource planning

A small deficit is expected once the EWR comes into effect. This will have a small impact on the allocation of irrigation water, which is currently not fully utilised. The dominant contributors to the economy in this area are the port and large industries.

Due to stagnation in the area, no projected demands for water have been taken into account.

However, should there be additional water requirements, the following may become necessary:

- Transfer of water from the Lower Thukela River, should water be available at the time
- Development on the Mfolozi River
- Re-use of municipal or domestic effluent
- Desalination of sea water
- Use of groundwater
- WC/WD management
- Water trading.

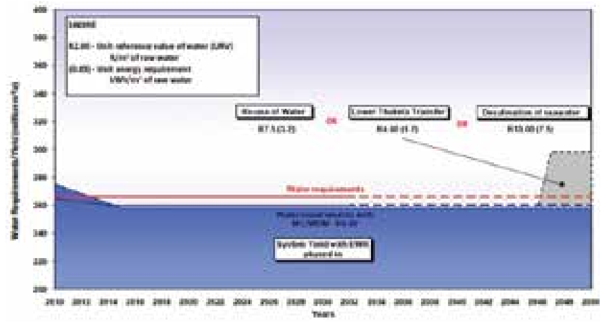

Figure 36. Water availability and requirements for Mhlatuze

Presented above is the water availability and requirements for the Mhlatuze System for the period up to 2050.

Climate change considerations

The study is still underway; however, there are no climate change considerations thus far.

1.10 Olifants Reconciliation Study

Area of supply

This study covers the entire Olifants Water Management Area and the adjacent areas of Polokwane and Mogalakwena, which are supplied from the Olifants.

Figure 37. Olifants water supply area

Hydrological record

Groundwater is available throughout the Olifants WMA, although varying in quantities depending upon the hydrogeological characteristics of the underlying formations. The overall results of the groundwater yield model indicated that there is a surplus of groundwater in the order of 70 million m^3/a.

There are several large water transfers from the Upper Komati, Usuthu and Vaal systems to supply the power stations of Eskom located in the upper Olifants catchment. These transfers are estimated at 228 million m^3/a. Decant from acid mine drainage (AMD) from the coal mines can be regarded as yield additional, amounting to approximately 22 million m^3/a in total which will become available over a period of 20 years. It should be noted that the Olifants River does not have the assimilative capacity to dilute the AMD and this poses a huge threat to the resource.

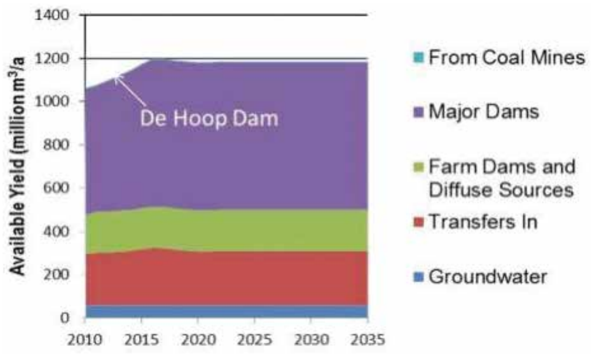

Figure 38. Projected future yield for the Olifants area

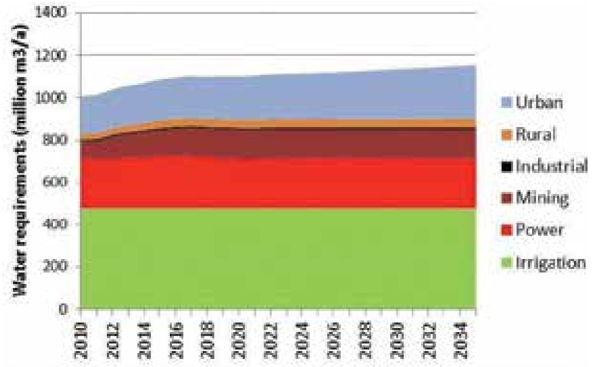

Figure 39. Water requirements for high growth scenario (DWA, 2010a)

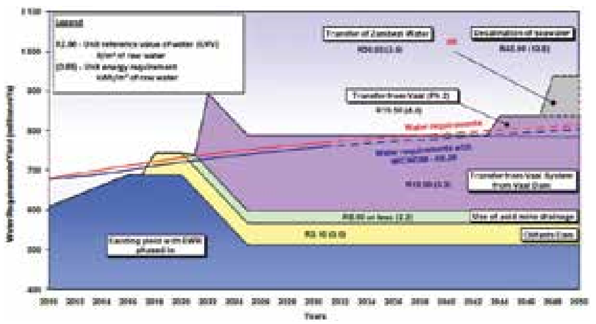

Figure 40. Water availability and requirements for the Olifants

Assumptions for the study

The following assumptions were made for the study:

- An increase in the water deficit for the area of 87 million m³/a between 2000 and 2025.
- Water requirements for mining development range from 94 million m³/a to 119 million m³/a between 2000 and 2025.
- No further growth in mining after 2025.
- 10% reduction in the urban water requirement achieved over five years.
- Future water requirement for power stations located in the Olifants area, but supplied by the Vaal, were excluded.
- Water requirement for irrigation was determined to be 557 million m³/a, and assumed constant for future projections.

Current and future water requirements

The graph below shows the future water requirements based on a high growth scenario.

Water resource planning

AMD is a huge factor for the Olifants WMA and, as such, was included in the reconciliation study. The projected total high and low growth water requirements have been used for the reconciliation scenarios for a period up to 2030.

The strategic interventions are to:

- Implement WC/WDM for all user sectors
- Full use of groundwater and all other local water resources
- Eliminate unlawful water use through compulsory licensing
- Treat AMD water to an acceptable standard
- Remove invasive alien plants.

- Re-use of return flows from Polokwane and Mokopane by the urban or mining sectors.

Water required to supply the current and future social and economic activities in the Olifants catchment will have to come from the catchment's local resources, except for the power stations within the catchment.

Climate change considerations

No climate change considerations have been made. However, it should be noted that there exists a direct link between climate change and AMD.

1.11 Orange Reconciliation Study

Area of Supply

This study focuses on the Upper and Lower Orange River water management areas (WMAs), while also considering all the tributary rivers and transfers affecting the water balance of the system. The core area forms part of the Orange-Senqu River Basin, which straddles four International Basin States with the Senqu River originating in the highlands of Lesotho, Botswana in the north-eastern part of the basin, the Fish River in Namibia and the largest area situated in South Africa.

Water resource planning

The area supports a large agricultural sector as well as various industries, mines, towns and communities. The area is supported by water coming in from the first Phase of the Lesotho Highlands Water Project (LHWP) and is looking to Phase II of the LHWP for additional water resources.

Climate change considerations

The Orange River Reconciliation Strategy is highly complex and needs to look at the international and institutional boundaries. Work is still underway; however, unfortunately, there are no preliminary indications that climate change has been incorporated into the study.

1.12 Vaal Reconciliation Study

Area of supply

The Vaal River System supplies water to about 60% of the economy and 45% of the population – the mines and industries on the Mpumalanga Highveld, the bulk of Eskom's coal fired power stations, the urban areas of Gauteng, the North West and Free State goldfields, iron and manganese mines in the Northern Cape, Kimberley, several small towns along the main course of the river as well as large irrigation schemes. The system will soon be extended to supply the Waterberg coalfield near Lephalale. In addition, this system overlaps with the Crocodile West River System and has been taken into account in that study.

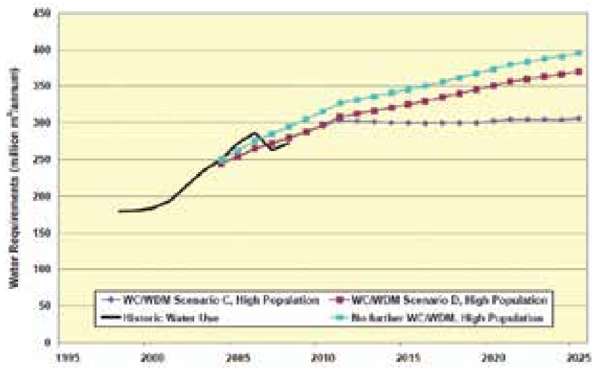

Figure 42. Future water requirements for the Vaal

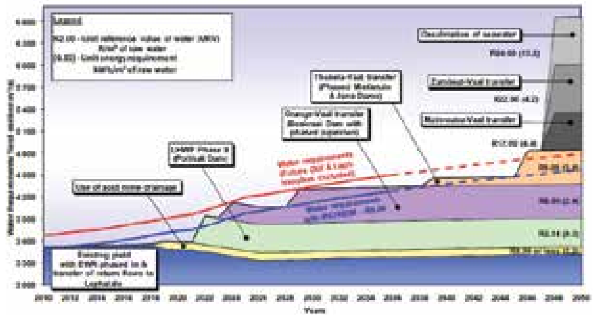

Figure 43. Water availability and requirements for the Vaal

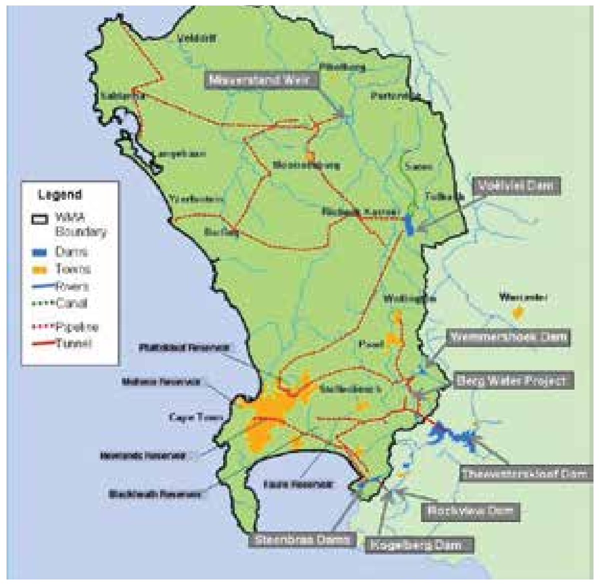

Figure 44. Map of Western Cape Water Supply System

Figure 41. Vaal water supply area

Hydrological record

The assessment of the irrigation water requirements showed that the estimated water use in 2005 for this system was 970 million m³/a, 204 million m³/annum higher than was applied in the previous investigation, indicating that up to 174 million m³/a of the water used for irrigation was unlawful. With increased activity in the area, efforts to curb unlawful water use have been unsuccessful.

Assumptions for the study

The following assumptions were made for the study:

- The future water requirements for power stations in the Olifants catchment that draw water from the Vaal were included.
- Future water requirements for the power stations in the Lephalale area were excluded.
- The irrigation water requirement was decreased by 200 million m³/a assuming that the unlawful irrigation use would be eliminated.
- The yield was reduced due to the expected transfer of return flow from the Vaal to the Crocodile West catchment.
- Municipalities in the Vaal region would reduce demand by 15% through WC/WDM.
- There would be a reduction of 130 million m³/a due to the introduction of the EWR.

Current and future water requirements

Urban water requirement scenarios were developed by applying the Water Requirement and Return Flow Model for the planning period up to 2030. Updated information was used to allow for population growth in the model. The base scenario remained constant. The Water Requirement and Return Flow Model was configured for 47 sewage drainage areas (SDAs) and calibrated for the year 2001 (year for which census data was available). The calibration involved changing model parameters to match both the water use and return flows observed for each SDA for the year 2001. Water requirement and return flow scenarios were compiled based on the high, base and low scenarios.

Water resource planning

The reconciliation study predicted increased growth in the population and suggested two scenarios for the area; with and without implementation measures for WC/WD management. Five core actions were identified to ensure water supply until the year 2035:

- Eradicate unlawful water use.
- Implement WC/WD management.
- Re-use of water from the gold mines (AMD treatment).
- Implement the Vaal River Integrated Water Quality Management Strategy.
- Implement Phase II of the Lesotho Highlands Water Project (LHWP).

The strategy predicts a deficit after 2035, and suggests water resource developments in the Thukela and Orange River systems.

Climate change considerations

No climate change considerations were made in the study; however, increased rainfall could exacerbate the phenomenon of AMD and considerations around this need to be made.

1.13 Western Cape Reconciliation Study (DWAF, 2007)

Area of supply

The Western Cape Water Supply System (WCWSS) serves more than 3 million people and provides water to the communities residing in the City of Cape Town and in certain Overberg, Boland, West Coast and Swartland towns, as well as to irrigators along the Berg, Eerste and Riviersonderend rivers and to rural and stock-watering schemes in the West Coast, Swartland and Overberg areas. This area is the second largest contributor to the national economy and houses the third largest population concentration in the country. It is the economic hub of the Western Cape with agricultural exports a significant component. Seventy per cent of the water in the area is for primary use, with 30% going to agriculture.

Hydrological record

Long-term streamflow, rainfall, water quality and climate records are available for 80 years. The system yield has increased to 579 million m³/a (2009) from 556 million m³/a in 1995. The mean annual rainfall for the area is approximately 2000 mm with 70% of the water requirements needed for the summer period.

In 2000, the area experienced low rainfall and water restrictions were introduced to meet water supply demands. Drought periods were also experienced in 2003 and 2004. The completion of the Berg Water Project ensured that there would be no water restrictions for the next few years, assuming average runoff.

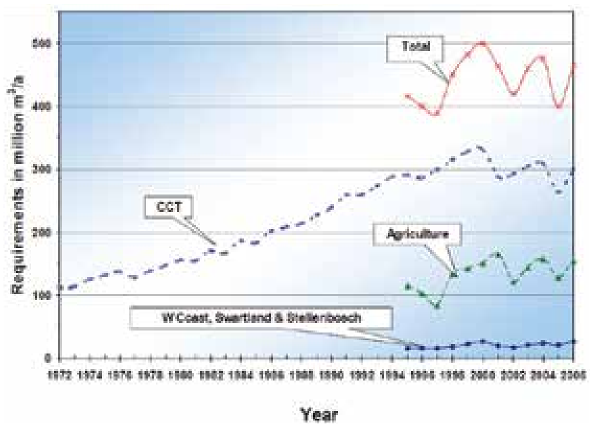

Figure 45. Historical water use

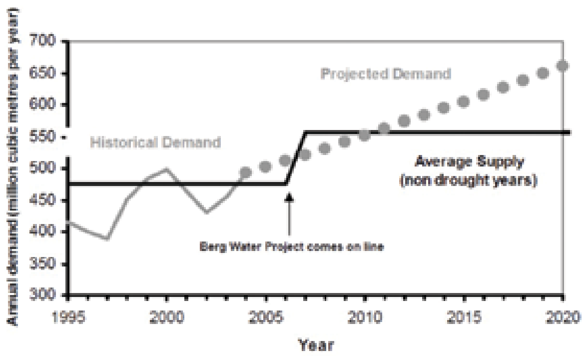

Figure 46. Historical and projected water demand for WCWSS

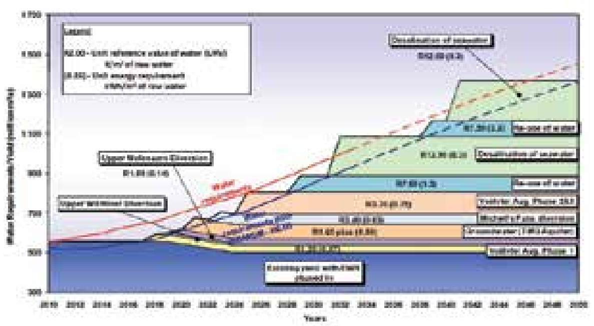
Figure 47. WCWSS reconciliation and supply requirement (http://www.dwa.gov.za/Projects/RS_WC_WSS/)

Data for historical water use goes as far back as 1972 for the City of Cape Town (CCT). Unfortunately, data for agricultural use, and the West Coast, Swartland and Stellenbosch only goes as far back as 1996.

The strategy was developed from 2005 to 2008. The system is modelled using monthly information from 61 input nodes and 77 years of naturalised inflows generated by calibrated sub-catchment runoff models. The stochastic inflow sequences were generated by a 61-D ARMA (n, p) model that preserves serial cross-correlations.

Current and future water requirements

Historical water use for the area has shown that during periods of drought, water restrictions are implemented to curb the use of water. The water requirements for the area were calculated using a forecast model. To predict future growth in bulk water an Excel-base model was developed based on historical trends for population growth, water demand, economic growth and the base year for the projected growth.

The reconciliation study showed that the agricultural sector has not yet reached full use of its allocation, and therefore has some room to grow. The forecast model assumed a 2% increase in the demand for irrigation. The economic growth rates ranged from 4% to 4.5% and the population growth rates were based on Dorrington's growth rate scenarios and assumed a growth rate of 6%. For the base years, 2003 was used for the high growth scenario and 2006 for the low growth scenario.

The future residential water requirement was calculated by taking the number of water connections and multiplying it by the water requirement for that connection, taking into account the population growth. The non-residential water requirement was calculated by escalating the present water usage by either the economic or population growth rate.

GROWTH SCENARIO	AVERAGE GROWTH IN WATER DEMAND (%)	POPULATION GROWTH RATE (%)			ECONOMIC GROWTH RATE (%)	
	2006–2030	2006–2011	2011–2016	2016–2030	2006–2010	2010–2030
High	3.09	1.12	1.38	1.74	4.5	6
Low	1.43	0.16	0.36	0.70	4	4

Table 3. Average growth in water demand as a function of population and economic growth models

It can take up to 10 years for a large supply study to be implemented, therefore it is crucial to identify future sources of supply so that they can be incorporated timeously.

The availability of water from the WCWSS has been based on hydrology data from the late 1980s to early 1990s and does not take climate change into account. The WRYM and WRPM models were used to plan restrictions in order to minimise the risk of excessive drawdown from the reservoir during drought periods.

Water resource planning

The findings showed that the following should be taken into consideration:

- Use of groundwater
- Re-use of water
- Desalination
- Climate change monitoring.

Figure 47 shows the water demand management and water supply options for the WCWSS. The numbers presented in Table 4 correspond with the map shown in Figure 48, WS refers to widespread implementation and OMA indicates outside map area.


Figure 48. Preliminary water demand management and water supply options for the WCWSS

Table 4. Preliminary water demand management and water supply options for the WCWSS.

WATER SUPPLY OPTIONS Surface water schemes	WATER DEMAND MANAGEMENT Agricultural water demand management
Dams:	**River Release Management:**
1 Twenty-Four Rivers	23 Riviersonderend
2 Waterfall River	24 Berg River
3 Lower Wit River	25 Voëlvlei/Misverstand
4 Upper Wit River	**Irrigation Practices:**
5 Upper Campanula Scheme Diversions:	WS Canal and Farm Dam Losses
6 Lourens River	WS Crop-Deficit Irrigation
7 Eerste River	WS Drip/Microjet/Sprinkler irrigation
8 Olifants River (Keerom)	**Trading of Existing Allocations:**
9 Upper Wit River	26 Eikenhof Dam
10 Upper Molenaars Rivers	27 Loer Berg River
11 Michells Pass	28 Greater Ceres Dam (Koekedouw Scheme)
12 Voëlvlei Augmentation Phase 1	Removal of Invasive Alien Plants
Dam Raisings:	WS Within Catchments
13 Misverstand	WS Riparian Zones
14 Lower Steenbras	**Urban Water-demand Management:**
15 Theewaterskloof	WS Leak detection and repair
16 Voëlvlei Augmentation Phase 2 and 3	WS Pressure management
17 Brandvlei to Theewaterskloof transfer	WS Use of water-efficient fittings
Ground Water Schemes:	WS Metering and plumbing repairs in low income areas
18 Table Mountain Group Aquifer	WS Use of well points and boreholes
19 Cape Flats Aquifer	WS Metering Tariffs and surcharges/credit control
20 West Coast Aquifers including recharge	WS Water User education
21 Newlands Aquifer	WS Rainwater tanks
Desalination:	**Water re-use:**
22 Desalination alone/with co-generation of energy	WS Exchange reclaimed wastewater for commercial
Other Schemes	WS Industrial re-use
OMA Congo River Options	WS Reclamation to potable water standards
OMA Tanker/Inflatable Bladders	WS Urban irrigation
OMA Orange River (Sea/Surface Pipeline)	WS New housing (dual reticulation)
OMA Towing of Icebergs	WS Aquifer recharge

Climate change considerations

The authors of the reconciliation study recognised that the strategy needed to include adaptive management and needed to be a living document updated constantly with the relevant information. Consequently, the hydrology for the study was updated and a 15% reduction (DWA, 2010a) in the yield was assumed over a 25 year period to account for climate change. The results are shown in the figure below. It should be noted that this assumption was made to determine the timing for the next scheme and not to account for climate change and the robustness of the system.

The study indicated that there would be continued monitoring of the effects of climate change and that the study would be updated at the end of 2013. Specifically, on-going rainfall patterns and spatial distribution, river flows, spring flows and abstractions should be recorded for extending flow records and identifying trends. Climate change projections for the Western Cape include the following:

- Weakening winter rainfall
- Drying trend from west to east
- Potential increases in summer rainfall
- Rise in overall temperatures.

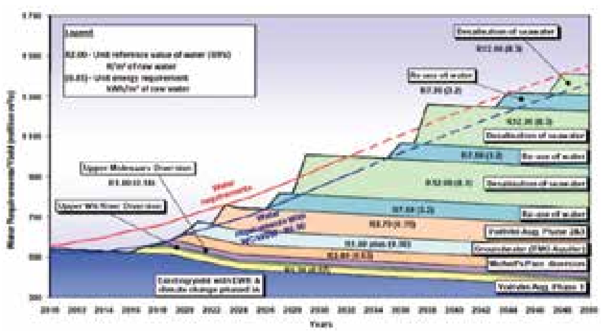

Figure 49. WCWSS augmentation options taking into account a 15% reduction in yield (DWA, 2010a)

In light of the above, the reconciliation studies need to be revised and need to take a holistic approach to combating the actual effects of climate change in order to make them more robust.

ANNEX 2: CLIMATE CHANGE IMPACTS ON WATER RESOURCE SYSTEM YIELDS (CASE STUDY)

2.1 System yield-reliability characteristics under climate change

System yield-reliability characteristics under climate change are likely to be notably different to present-day equivalents. If modification of streamflows should happen to be more extreme in a particular sub-system that dominates individual sub-system contributions to total system yield, then that degree of modification might be expected to translate through to total system yield.

Generically, potential climate change impacts on system yield might need to be assessed according to the various determinants of system yield outlined, but prime among these would be the changing streamflow hydrology caused by climate change. These hydrology changes are likely to pertain to changes at sub-catchment scale in mean annual runoff (MAR), inter-annual streamflow variability, frequency of zero- or low-flow days and frequency of intense storm-flow days. However, such localised streamflow changes cannot be directly linked to system yield changes in a complex, distributed bulk water resource system. Therefore, these localised hydrological changes require translation, by system modelling, into impacts on sequential bulk water resource system behaviour over many years, before their effects on system yield may be interpreted.

2.1.1 Stress testing of bulk water resource systems

In modelling terms, for each downscaled GCM scenario, the distribution of impacts would be unique to every bulk water resource system in the country and would need to be systematically assessed, scenario by scenario, before adaptation strategies might be optimised. Although this would be an achievable task, it would be onerous and costly, given the wide range of downscaled GCM scenarios currently in circulation. Equally important, the need to do such assessments in stochastic terms to capture the overlaying of climate change-related uncertainties on inherent uncertainties associated with natural hydrological variabilities and the long-term persistence dynamics of multi-storage systems significantly steepens the challenge of such a task.

A considerably more pragmatic approach would be to systematically "stress-test", in a stochastic systems modelling context, the component-, sub-system- and total system yield responses to heuristic interpretations of climate change impacts that are, respectively, "severely" or "moderately" conservative, against a backdrop of increasing water demands that represent, alternatively, moderate or strong economic growth. An ensemble of adaptive strategies may then be derived, based on the outcomes of these systematic and conservative heuristic interpretations that mimic potential climate change impacts.

It should be noted that deriving an appropriate methodology for such a stress-testing undertaking would require relatively fresh research in the South African context.

2.1.2 Pilot study in the Berg

Box 4 below outlines a pilot study examination of the characteristics of such impacts on system yield, for which the WCWSS was selected as a typical example of a complex, distributed bulk water resource system.

Box 4. Western Cape climate change pilot analysis

Agricultural Catchments Research Unit (ACRU) modelled monthly streamflows for five selected downscaled GCM outputs were extracted from the climate change impact study by Schulze (2011) for the intermediate future and used to modify the 61 naturalised monthly streamflow sequences (each 77 years long) of the existing configuration of the WCWSS integrated system model. Other GCMs and downscaling approaches are being evaluated in further work under the LTAS. The integrated system model was then run in stochastic mode with current-day demands and operating rules, resulting in the following stochastic yield-reliability characteristics for the five GCM scenarios:

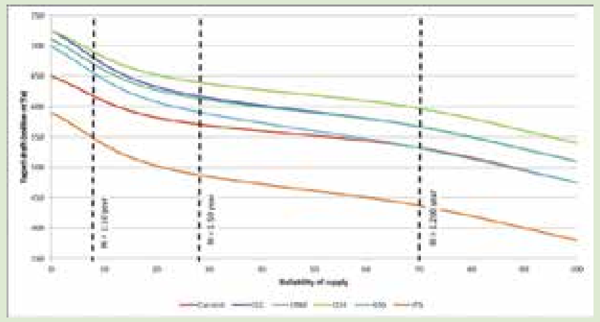

Figure 50: Stochastic yield-reliability characteristics for the five GCM scenarios.

The WCWSS yield appears fairly sensitive to potential climate change – e.g. four of the five yield-reliability characteristics differ markedly from the current-day case. For the five GCM-related scenarios the commonly-used planning benchmark of the 1:50 year yield shows changes of +12%, +9%, +9%, +4% and -14%, respectively. This change quantum is roughly equivalent to three to five years of accumulated demand growth in the WCWSS. The equivalent MAR changes are +32%, +17%, +3%, -15% and -15%, respectively. For the lower RIs the scenario yield-reliability curves tend to be steeper than for the current-day case, indicating intensive modifications to the scenario streamflows during the more frequent but less extensive low-flow periods.

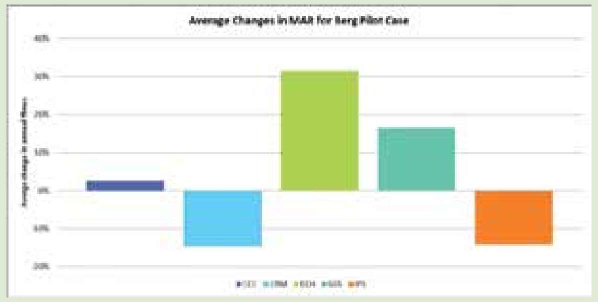

Figure 51: Average changes in MAR for the Berg pilot study.

Despite only examining a single bulk water resource system, this detailed pilot assessment does signal the following generic potential system yield impacts by climate change for the intermediate future, given that the WCWSS's complex and distributed structure, as well as its gradients of climate change-related response modifications, would in various ways be typical of the equivalent responses of various other bulk water resource systems in South Africa:

- Yield-reliability characteristics of systems under climate change are likely to be notably different to the present-day equivalents – this applies both to yields determined for historically "extreme drought" streamflow sequences, as well as to stochastically-derived yields for a range of RIs of failure of supply.
- Climate-modified stochastic yield-reliability characteristics might track systematically and markedly higher or lower than those for the present-day case, or even track diagonally across the latter.
- If modification of streamflows should happen to be more extreme in a particular sub-system that happened to contribute a major part of total system yield, then that local modification might be expected to translate through to total system yield.
- Climate-related modifications to the 1:50 year system/scheme yield, which is commonly-used as a long-term planning benchmark, could be expected to be only indirectly related to changes in the MAR and the annual variance. In general, future climate-driven changes to the 1:50 year yields of complex, distributed bulk water resource systems could be expected to vary over a much smaller range than that of the associated MARs.
- Higher-frequency deficient-flow periods (e.g. those producing the 1:10 year yield) might be most markedly affected by climate change – either negatively or positively.
- Climate change could significantly modify the statistical persistence behaviour of annual streamflows of particular sub-system rivers, which, as outlined in Table 2 (pg 49), could be one of the primary determinants of total system yield.

REFERENCES

Department of Water Affairs and Forestry (DWA) (2004). National Water Resource Strategy, First Edition (NWRS). Department of Water Affairs, Pretoria.

Downing TE, Butterfield RE, Edmonds B., Knox JW, Moss S, Piper, BS and Weatherhead EK (and the CCDeW project team) (2003). Climate Change and the Demand for Water, Research Report, Stockholm Environment Institute Oxford Office, Oxford.

DWA (2008a) Development of a Reconciliation Strategy for the Amatole Bulk Water Supply System, Final Report, Volume 1 of 2, March 2008. Report No. P WMA 12/R00/00/2608. Department of Water Affairs, Pretoria.

DWA (2008b) Development of a Reconciliation Strategy for the Crocodile West Water Supply System, Water Resource Reconciliation Strategy, July 2008, Version 1. Department of Water Affairs, Pretoria.

DWA (2009) Vaal River System: Large Bulk water supply reconciliation strategy. Department of Water Affairs and Forestry, Pretoria.

DWA (2009b). Water for growth and development framework: version 7 (WGDF). Available at: http://www.dwaf.gov.za.

DWA (2010a) Assessment of the ultimate potential and future marginal cost of water resources in South Africa. Department of Water Affairs, Pretoria.

DWA (2010c) Groundwater Strategy. Department of Water Affairs, Pretoria.

DWA (2011) Reconciliation Strategy for the Algoa Water Supply Area, Algoa Reconciliation Strategy, April 2011, Report No.: WMA 15/M00/00/1409/04. Department of Water Affairs, Pretoria.

DWA (2012). Water reconciliation strategy for the Algoa water supply area. Status Report 2. Department of Water Affairs, Pretoria. Available at: http://www.dwa.gov.za/Projects/Algoa/Documents/Status%20Reports/Algoa%20SSC%20Status%20Report_2%20Sep12%20.pdf

DWA (2013). Status Quo Analysis: Climate Change Impacts on Water Resources, Draft Report by Pegasys Strategy and Development (Pty) Ltd to Department of Water Affairs, DWA Report No P RSA 000/00/17912/4. Department of Water Affairs, Pretoria.

DWA (2013). National Water Resource Strategy, Second Edition (NWRS2). Pretoria: Department of Water Affairs, June 2013. Department of Water Affairs, Pretoria.

DWA, 2010b, Water Reconciliation Strategy for the large bulk water supply system, Greater Bloemfontein Area, June 2010, Report No.: P WMA 14/C520/00/0910/02. Department of Water Affairs, Pretoria.

DWAF (2007) Western Cape water supply system: Reconciliation strategy study. Department of Water Affairs and Forestry, Pretoria.

DWAF (2009). Water reconciliation strategy study for the Kwazulu Natal coastal metropolitan areas. Department of Water Affairs and Forestry, Pretoria.

Le Maitre DC, Forsyth GG and O'Farrell PJ (2012). Development of generic species- and area based prioritisation models for use by Working for Water in prioritising invasive alien plant control operations in South Africa. CSIR Natural Resources and the Environment, Report number: CSIR/NRE/ECO/ER/2012/ 0028/B, Pretoria.

Midgley, D.C., Pitman, W.V. and Middleton, B.J. 1994a to f. Surface Water Resources of South Africa, 1990, Water Research Commission, Pretoria, South Africa.

Mote PW, Canning DJ, Fluharty DL, Francis RC, Franklin JF, Hamlet AF, Hershman M, Holmberg M, Ideker KN, Keeton WS, Lettenmaier DP, Leung LR, Mantua NJ, Miles EL, Noble B, Parandvash H, Peterson DW, Snover AK, and Willard SR (1999). Impacts of climate variability and change, Pacific northwest. National Atmospheric and Oceanic Administration, Office of Global Programs, and JISAO/SMA Climate Impacts Group, Seattle, WA. 110 pp.

National Planning Commission (NPC) (2011). National Development Plan. The Presidency, Pretoria.

National Spatial Development Perspective (NSDP) (2006) Spatial Guidelines for Infrastructure Investment and Development. The Office of the Presidency, Republic of South Africa.

Pegram G, Li Y, Le Quesne T, Speed R, Li J, and Shen F. 2013. River basin planning: principles, procedures and approaches for strategic basin planning. Paris, UNESCO.

Pegram G, Yuanyuan L, Le Quesne T, Speed R, Jianqiang L and Fuxin S (2013) *River basin planning: Principles, procedures and approaches for strategic basin planning.* Paris, UNESCO.

Presidential Infrastructure Coordinating Commission (PICC) (2012). A Summary of the South African National Infrastructure Plan. Presidential Infrastructure Coordinating Commission, Pretoria.

Protopapas L, Katchamart S and Platonova A (2000). Weather effects on daily water use in New York City. *Journal of Hydrologic Engineering*, 5: 332–338.

Schulze RE (2011). A 2011 Perspective on Climate Change and the South African Water Sector. Water Research Commission, Pretoria, RSA, WRC Report 1843/2/11

Southern African Development Community (SADC) (2011). Climate Change Adaptation in SADC: a strategy for the water sector. SADC Secretariat, Gaborone.

Treasury and National Planning Commission (NPC) (2013). Biophysical modelling in support of systematic analysis of climate resilient economic development of the Republic of South Africa. 109009/01. The Presidency, Pretoria.

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