Adaptive Climate Change Technologies and Approaches for Local Governments: Water Sector Response

RA Dube, B Maphosa and OM Fayemiwo

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Report to the
Water Research Commission

by

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Executive summary

The earth's climate has always changed, moving through warming and cooling cycles. However, recent large-scale anthropogenic influences have led to dramatic changes within this cyclic system. As a result, the earth has entered into a warming cycle at an unprecedented speed in a period when it should be cooling. In this regard, observed changes in the climate system have shown that Global Mean Surface Temperature (GMST) has increased since the late 19th century with the last three decades being the warmest. Observations have also shown that the temperature increased by 0.89°C from 1901 to 2012 with most of the increase (approximately 0.72°C), taking place in the last fifty years. The observed records compare very well with the outputs from simulations on climate. The verified projections of observations are now being used to plan the climate change response in various sectors including water and wastewater service provision.

Past investigations and practices have reinforced the idea that adaptation is a local activity. It is for this reason that guidance on adaptation is based on data and information which are closely related to the distinct local area of interest. The adaptation compendium project addresses the issues surrounding adaptation within different settings, affecting local government institutions in water and wastewater services.

Currently, the water sector institutions in the country are overwhelmed with dealing with immediate challenges such as providing potable water of acceptable quality, and extending sanitation provision to unserved communities. However, issues surrounding climate change impacts that will become more pressing in the future are usually not accounted for in municipal plans. The Integrated Development Plans (IDPs) of most local municipalities and district municipalities do not mention climate change; although in both the Assessment Report Number 4 (AR4) and AR5, the Intergovernmental Panel on Climate Change (IPCC) advises that climate change impacts which have already started to affect service delivery will continue to cause negative impacts after 2100, even when the best possible mitigation scenarios are applied. As such, the water sector like any other sector that is affected by climate change has to adapt.

Local government institutions, and especially municipalities, are currently looking at how they can address the impacts of climate change as part of their business process. There is very little guidance however regarding how this can be achieved, and less so, guidance that is directly linked to their business, location, existing infrastructure, resources and other unique factors. In this research, a water sector adaptation guide was developed. The guide deals with the selection of relevant water sector adaptation technologies and approaches for specific climate change impacts over the short-, medium- and long-term. Specific objectives of the study include the following:

- To investigate if all or just some municipalities will need to adapt to climate change;
- To develop a set of criteria to classify adaptation technologies and approaches;
- To identify appropriate adaptation technologies and/or approaches to climate change at local government, community and/or household level;
- To map the adaptation technologies for near-, medium- and long-term planning, while taking into consideration the types of municipalities – rural, urban and metros;
- To ascertain the institutional capacity and requirements of a local government to roll out a climate change adaptation strategy;
- To define practical implementation steps and planning horizons that will be required, and
- To provide a review and way forward of current research that could provide future solutions and address the gaps in the sector to meet climate change needs.

This study approach relied on downscaled data and information from the Department of Environmental Affair (DEA)'s 2013 Long Term Adaptation Scenarios (LTAS) studies. In addition, the data on current practices and water services were secured through the use of three case studies – Tshwane Metropolitan Municipality, uMgungundlovu District Municipality and Vhembe District Municipality. The selected three case studies were representative of a wide range of characteristics for various municipal institutions in South Africa. Furthermore, the case studies selected are located in different hydroclimatic zones. The climate change projections for the different zones informed the decisions regarding proposed adaptation technologies and approaches in the compendium.

The climate projections for all the regions were translated to impacts related to the short-term, medium- and long-term climate timeframes. The project evaluated the nature of climate change impacts, including socio-economic and environmental implications across four time frames, namely: immediate- (approximately 5 years); short- (<2030); medium- (<2050) and long- (<2100) term. The 5-year time frame was included in this study to deal with the heightened vulnerability and service backlogs in certain regions where resolution of backlogs should be prioritised in ongoing plans such as the 5-year IDPs.

The development of the adaptation compendium aimed at dealing with the following:

- Climate change impacts;
- Vulnerability to climate change;

- Capacity to adapt; and
- Potential development opportunities.

- The team took advantage of the guidance provided the United Nations Environmental Programme (UNEP) where three generic options for adaptation were suggested. The three generic options were considered for this project to define three main activity routes as follows:
- Protect: defend vulnerable areas, especially population centres, economic activities and natural resources;
- Accommodate: continue to occupy vulnerable areas, but develop adaptation and improve preparedness to counter the impacts;
- Retreat (planned): provide conditions to abandon systems and structures when they are no longer viable due to the negative impacts.

- Vulnerability was determined to be a function of three main variables: exposure, sensitivity and adaptive capacity. The three variables were considered to be composed of indicators that could be evaluated on the basis of the information obtained from the field studies and literature. The decisions on preferred adaptation measures were reached on the basis of comparing the measure or degree of vulnerability, also called the vulnerability index in each case.
- The developed adaptation compendium comprises proposed technologies and approaches, which were prioritised on the basis of evaluated performance, in terms of the nature of impacts and the characteristics defined for each zone. These characteristics included institutional variables, geographical settings, and social dimensions, as well as the overall cost benefit assessment.
- During the course of the project, two workshops were held. The workshops were set to share the project progress and obtain inputs from stakeholders regarding important developments as well as other advice that could improve the project impact.

- This research resulted in the following findings:
- The impacts of climate change in all regions are significant enough to warranty adaptation response. Temperature is expected to continue to rise under non-mitigation scenarios, and even when high levels of mitigation are applied.
- Ideally, the selection of adaptation options should be based on several variables which define the specific local circumstances. The options to be selected should optimise prevailing and anticipated environmental, social, economic and cultural aspects. Options should also be associated with a favourable economic assessment after accounting for the social components for which monetary returns are not expected.

- The rural water institutions, especially those that are not served by large water boards have the worst adaptive capacity, making them more vulnerable to the additional stresses due to climate change impacts. The research established that the large water boards like Umgeni and Rand Water were associated with a higher level of service delivery, thus reducing vulnerability.
- Although, several water sector institutions have attempted to develop a climate change policy, researchers did not come across cases where the policies had been translated to clearly defined adaptation projects in the business plans. In some cases, even though there are active projects which can be classified as having an ability to contribute to climate change adaptation, these projects are still not classified under any adaptation initiative. The concept of adaptation has not yet been articulated into projects and programmes for which budgets are allocated.
- Blue- and green drop scores also point to the nature of vulnerability in water and wastewater services. A poor score also means that the institution and the service delivery process are highly vulnerable to the impacts of external factors such as climate change. As such these vulnerabilities have to be dealt with even before accounting for climate change.
- Water sector legal instruments have not been updated to reflect the threat of climate change to water service provision. As such, the plans for implementing climate change adaptation are still failing to make it onto the list of prioritised projects for the municipalities, even though several climate change strategies may have been developed.

Based on the study findings, the following recommendations are proposed:

- The relevance of climate change response strategies is affected by the fast pace of changes in the conceptualization, global simulations, and guidance at international level. During the course of this study, the IPCC Assessment Report Number 5 (AR5) replaced the AR4 as the international guiding framework for climate change. This change came with new data, new concepts in climate change targets, new sets of tools and generated new understanding. The pace of climate change research and the implementation of response mechanisms in the country have to match the international rate of progress on the subject. This way, climate change responses will generate the best possible returns.
- In the absence of the latest regionalised or localised CC projections, the authors of this adaptation guide advocate for the selection of 'no-regret', 'low-regret', 'win-win' and 'flexible' adaptation options. Development and implementation of these options are more viable as they tend to build on the understanding of the current state where other water service challenges are prevailing and have been planned for.

- No regret options are also achieved through the implementation of projects and practices that result in a greener and more sustainable water and wastewater services system.

Observations made during the course of the study showed that water service institutions stand to gain more if they prioritise adaptation through green solutions.

- The national guidance for responding to climate change is developing slowly. As such, important legislative tools such as the Water and Water Services Acts are falling short when it comes to guiding CC response in the water sector. The current environment, however, does not stop any institution or local government body from investigating and taking leadership on climate change response.
- Impacts on key chemical processes associated with water services will continue to change as the climate changes. In addition, the impacts of climate change from past greenhouse gas emissions will continue to rise until well after 2100. New designs and improvements to existing infrastructure should take into account climate change impacts and advance opportunities for adaptation.
- Consultations with the climate change directorate in the South African Local Government Association (SALGA) revealed that there is a general reluctance by most municipalities to incorporate climate change in the IDPs. In the absence of a system to enforce the uptake of climate change policies, DEA, Cooperative Governance and Traditional Affairs (COGTA), in collaboration with SALGA, could develop a formal incentivised monitoring programme that is similar to the DWS' Blue/Green drop certification programme to monitor and encourage the municipalities' response to climate change using a progressive scoring system.
- Community members also have a major role to play in water services adaptation. Knowledge on climate change has to be shared with communities to ensure that they are actively involved when the institutions such as the municipalities seek to drive climate change response strategies. The local municipalities need to embark on intensive climate change awareness campaigns with the aim of bringing understanding and knowledge to the local people as a forerunner to the introduction of adaptation strategies.
- Climate change research in the water sector has largely focused on water resources due to the easy link between water resources and primary climate change impacts. Future research in South Africa's water sector should increase the focus on potable water and wastewater services, which are increasingly being negatively impacted by secondary and tertiary climate change impacts.

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Acronyms

AR	Assessment Report
CC	Climate Change
CCAM	Conformed-Cubic Atmospheric Model
CMA	Catchment Management Agency
CSAG	Climate Systems Analysis Group
CSIR	Centre for scientific and Industrial Research
DCG	Department of Cooperative Governance
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
GCM	Global Climate Model
GHG	Greenhouse Gas
HFD	Hybrid Frequency Distribution
IDP	Integrated Development Plan
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
JGCRI	Joint Global Change Research Institute
L1S	Level one stabilization
LTAS	Long-term Adaptation Scenarios
LTMS	Long-term Mitigation Scenario
MIT	Massachusetts Institute of Technology
NCCRP	National Climate Change Response Policy
NCCRS	National Climate Change Response Strategy
NDP	National Development Plan
NEMA	National Environmental Management Act
NEMAQA	National Environment Management: Air Quality Act
NEMBA	National Environment Management: Biodiversity Act
NEMCMA	National Environment Management: Integrated Coastal
NEMPAA	National Environment Management: Protected Areas Act
NEMWA	National Environment Management: Waste Act
NEPA	Netherlands Environmental Protection Agency
NFA	National Forest Act
NIES	National Institute for Environmental Studies
NPC	National Planning Commission
NWA	National Water Act

SACS	South Africa Country Studies
SALGA	South Africa Local Government Association
SOMD	Self-Organizing Map-Based Downscaling
TAs	Technologies and Approaches
UCE	Unconstrained Emissions
UCT	University of Cape Town
UGEP	Utilisable Groundwater Exploitation Potential
UKZN	University of KwaZulu-Natal
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework convention on Climate Change
USA	United States of America
WMA	Water Management Area
WMO	World Meteorological Organization
WRC	Water Research Commission
WWTW	Wastewater treatment works

1 Introduction and background

1.1 Introduction to climate change and water services

Climate change is a key focus area of global environmental studies, and forms the basis for the development of new environmental policies and legislation (Janssen et al., 2006). Climate change is not a novel phenomenon; according to Houghton (2009), “the past million years have seen a succession of major ice ages interspersed with warmer periods, with the last of these ice ages ending about 20 000 years ago.” Currently, however, the earth is set on an unprecedented warming trend with no cooling cycle in sight (Levitus et al., 2001) due to carbon emissions and other gases that set the stage for climate change (Uppenbrink, 1996).

Climate change warnings were first issued by scientists during the early 1900s. The warnings stated that the release of ozone-depleting compounds, in addition to the utilization of fossil fuels and anthropogenic activities could result in a warming effect on the earth’s atmosphere, affecting human habitation, water and food availability, and resulting in extreme weather events (Callender, 1938; Nordhaus and Boyer, 2003; Denton, 2002). The vulnerability of different sectors to climate change, coupled with the projected ill effects, as described in successive studies produced by the Intergovernmental Panel on Climate Change (IPCC), has resulted in the need to better understand climate change as it affects different regions, and to propose adaptation technologies and approaches that are adequate and efficient (IPCC, 2001).

In developing regions like Africa, vulnerability is very high, while the ability to adapt remains weak (Challinor et al., 2007). The global increase in temperature as a result of climate change has resulted in extensive ill weather effects which will be greatly felt by the water sector, and subsequently other sectors (Bates et al., 2008). Based on projections from the IPCC, and downscaled information from local climate scientists, South Africa has adopted a pro-adaptation strategy to build resilience within communities.

Currently, in South Africa the water sector is under stress even without the ill effects of climate change (Estache and Kouassi, 2002; Turpie et al., 2008). In November 2015, the provinces of KwaZulu-Natal and the Free State were declared disaster zones due to extreme water shortage as a result of drought and lack of adequate water resources. The Western Cape

Province and Gauteng were identified as high risk zones for water shortage during this time. The current strain on South Africa's water sector is due mainly to backlogs in terms of infrastructure and poor or non-availability of skills in the field of water and wastewater services (Hemson, 2004). Climate change will further amplify the strain on the water sector in terms of water resources and water service systems (Hughes et al., 2014), highlighting the need to adopt climate change adaptation technologies and approaches into national government and municipal plans (Bryan et al., 2009).

Many of the climate change studies commissioned by the Water Research Commission (WRC) have focused on the water resources sub-sector, with water services receiving less attention. Studies such as Warburton and Schulze, (2005), Schulze, (2011), Siebrits and Winter, (2013), and Vogel et al. (2015) have aimed to understand how climate change will affect South Africa's water sources, and provided guidance regarding water resource management in the face of climate change. In terms of water services, very few studies (Piketh et al., 2013; Hay and Hay, 2014; Hughes et al., 2014) have been published. Based on the temperature and precipitation trends forecast for Southern Africa as a region, there is a need to understand the extrapolated effects as well as propose the necessary adaptation strategies for the water services sub-sector.

1.2 Aims and objectives of the study

Local government institutions, and especially municipalities, are currently looking at how they can address the impacts of climate change as part of their business process. There is very limited guidance, however, regarding how this can be achieved, and even less guidance that is directly linked to their business, location, existing infrastructure, resources and other unique characteristics. This project aimed at developing a water sector guide of the most relevant adaptation technologies and approaches to climate change over the short, medium and long term for local government institutions, especially municipalities in South Africa. Other objectives in the project were:

- To identify which local municipalities will need to consider adaptation technologies and approaches to climate change.
- To develop a set of criteria to classify adaptive technologies and approaches.
- To identify which water, distribution and wastewater options are appropriate as adaptive technologies or approaches to climate change at a local government, community and household level.
- To map these technologies for short-, medium- and long-term planning, and preparation for climate change for the different types of local municipalities (rural, urban and metros).
- To ascertain the institutional and capacity requirements of local government to roll out a climate change adaptation strategy.
- To define the practical implementation steps and planning horizons that will be required.
- To provide a review and way forward of current research that could provide future solutions and address the gaps in the sector to meet climate change needs.

1.3 Approach and methods

The adoption of climate change adaptation as part of business is a developing phenomenon that is still in its early stages. As such, the framework and guidance through which institutions can seek to respond to climate change is still not readily available and, when it is found, it is usually characterized by an inclination to be more directly useful to more developed countries in the Northern hemisphere, where the subject has developed to a greater extent. Adaptation has to take place at a local scale, and yet the climate change models which generate the impacts are best simulated at large global scales. These global and regional scales provide the environment at which new climates are manifest. The methodology generated in developing the adaptation guide was set up to provide the processes which learn from the global climate scales, and yet present adaptation solutions for much smaller local scales.

While several institutions are dealing with water services at local level, it was noted that the majority of water access and water services, as well as sanitation activities, are carried out at relatively small scales by municipalities. To allow for a better understanding of the processes and adaptation issues associated with municipalities, three municipal areas were selected for use as case studies in the development of the adaptation guide. The case studies also brought the potential for investigations to deal with targeted adaptation options involving specific communities. The interpretation of local or small scale adaptation as conceptualized for case study areas is not directly used in this guide, but rather the content of observations and deductions made. The content of the information derived from the case studies is used to determine the impacts and adaptation trends for similar cases across the country.

The investigations preceding the development of the guide were conducted using three case studies to understand the possible impacts of climate change in different regions. The resulting information was used to develop the adaptation guide for the water services sector. The case studies which were investigated as part of the process to understand the current state of affairs as well as plans for the future involved different municipalities, namely: Tshwane Metropolitan Municipality in Gauteng, Vhembe District Municipality located in Limpopo, and UMgungundlovu District Municipality in KwaZulu-Natal. The locations of the case study municipalities differ in terms of geographical features, population size, density, economic development and resource availability. The three case studies are located in different climatic zones in South Africa, and hence they are representative of a broad spectrum of the climatic trends in the country (Table 1).

Table 1: Characteristics of case study areas

	Tshwane Metropolitan Municipality (Gauteng)	UMgungundlovu District Municipality (KwaZulu-Natal)	Vhembe District Municipality (Limpopo)
Municipal code	TSH	DC 22	DC 34
Area in square kilometres	6 368	8 500	21 407
Sub-divisions	7 regions	7 local municipalities	4 local municipalities
Population (Stats SA, 2012; rounded off)	2 921 000	1 018 000	1 300 000
Population density	460 per sq. km	120 per sq. km	61 per sq. km
Population growth per annum (Stats SA, 2012)	3.1%	0.88%	0.78%
Official unemployment rate (Stats SA, 2012)	24%	30%	39%
Piped water inside dwelling (Stats SA, 2012)	64.2%	43%	15.4%
Flush toilet connected to mains sewerage (Stats SA, 2012)	76.6%	42%	13.9%
Blue Drop score (DWA, 2012)	95.76%	92.42%	74.85%
Green drop score 2011	63.8%	73.6%	14.2%
Water Authorities	Rand Water Magalies Water	Umgeni Water	None

The development of the adaptation guide relied on climate change impact projections from the Long Term Adaptation Scenarios Flagship Research Programme (LTAS), a DEA programme that was last updated in June 2013 (DEA, 2013a). In the case study investigations, the climate trends were obtained for the three case study areas. The reported trends and projected impacts of climate change in these three different municipalities formed the basis of the development of an adaptation guide. The vulnerability and adaptive capacity of the three case study areas were found to be directly related to differences in their location, risk to impacts, and access to resources and water governance structures, among other factors. Data and information from the LTAS for the whole country were then used to obtain the trends for other areas in the country. The impacts constituted some of the key inputs in determining potential adaptation options. Other important factors which were investigated and accounted for included geographical location, adaptation time frames, available resources, type and state of infrastructure, as well as the institutional and legislative framework available.

1.4 Report structure

This report consists of eight chapters.

Chapter one presents an introduction to climate change and water services, the research objectives, the study areas and the research methodology.

Chapter two describes the impacts of climate change globally, drawing on information published by key international climate change bodies such as the IPCC, the United Nations Framework Convention on Climate Change (UNFCCC), UNEP, etc. Climate change projections internationally and in South Africa, as well as the vulnerability of South Africa's water sector are discussed in this chapter.

Chapter three describes the local impacts of climate change and the state of adaptation in case study areas. This chapter also highlights progress in developing a climate change response strategy, the state of implementation and the way forward for water services institutions. The chapter also highlights the roles of key institutions in climate change adaptation.

Chapter four focuses on the selection criteria for adaptation options, and discusses in detail what users of the adaptation guide should consider before selection of adaptation. The factors discussed include, but are not limited to, geographical/socio-economic setting, time, and climate projections based on hydroclimatic zonal classifications. This chapter also highlights the various proposed adaptation technologies.

Chapters five and six provide the architecture of the compendium on adaptation, where the adaptation techniques and approaches are presented against the identified impacts. This section also provides information on the priorities attached to the different adaptation options.

In Chapter six descriptions of the adaptation approaches are also presented. This chapter highlights how the soft issues in climate change adaptation are handled to create the environment that is suitable for development and implementation of adaptation technologies.

Chapter seven highlights the processes that need to be followed for seamless adaptation implementation to take place.

Chapter eight focuses on the need to establish oversight structures as well as to understand the importance of monitoring and evaluation.

2 Climate change impacts and the water sector

Observation of changes in the climate system has shown beyond doubt that Global Mean Surface Temperature (GMST) has increased since the late 19th century, with the last three decades being the warmest (IPCC, 2013). These observations are based on direct physical and biogeochemical measurements, remote sensing from ground stations and satellites, as well as information derived from palaeo-climatology archives to provide long-term context. Observations have shown with certainty that the temperature increased by 0.89°C from 1901 to 2012 with most of the increase, 0.72°C, taking place in the last fifty years. Thus, the temperature increase is increasing at an increasing rate in a fashion that could be similar to the characteristic J-shaped graph which has now become known as the "hockey stick curve". This J-curve was used to describe past temperature changes by the IPCC in past climate change physical sciences reports (IPCC, 2007).

Recent climate projections have shown that temperatures could increase by up to 5°C in some regions of the world over the next hundred years (Engelbrecht *et al*., 2009; Solokov et al., 2009; Schulze, 2011). The IPCC (2013) reports temperature change predictions that are lower at up to 2°C for both the Coupled Model Inter-comparison Project Phase 3 and Phase 5 (CMIP3 and CMIP5) models. CMIP5 temperature patterns released in late 2013 are illustrated in Figure 1 below.

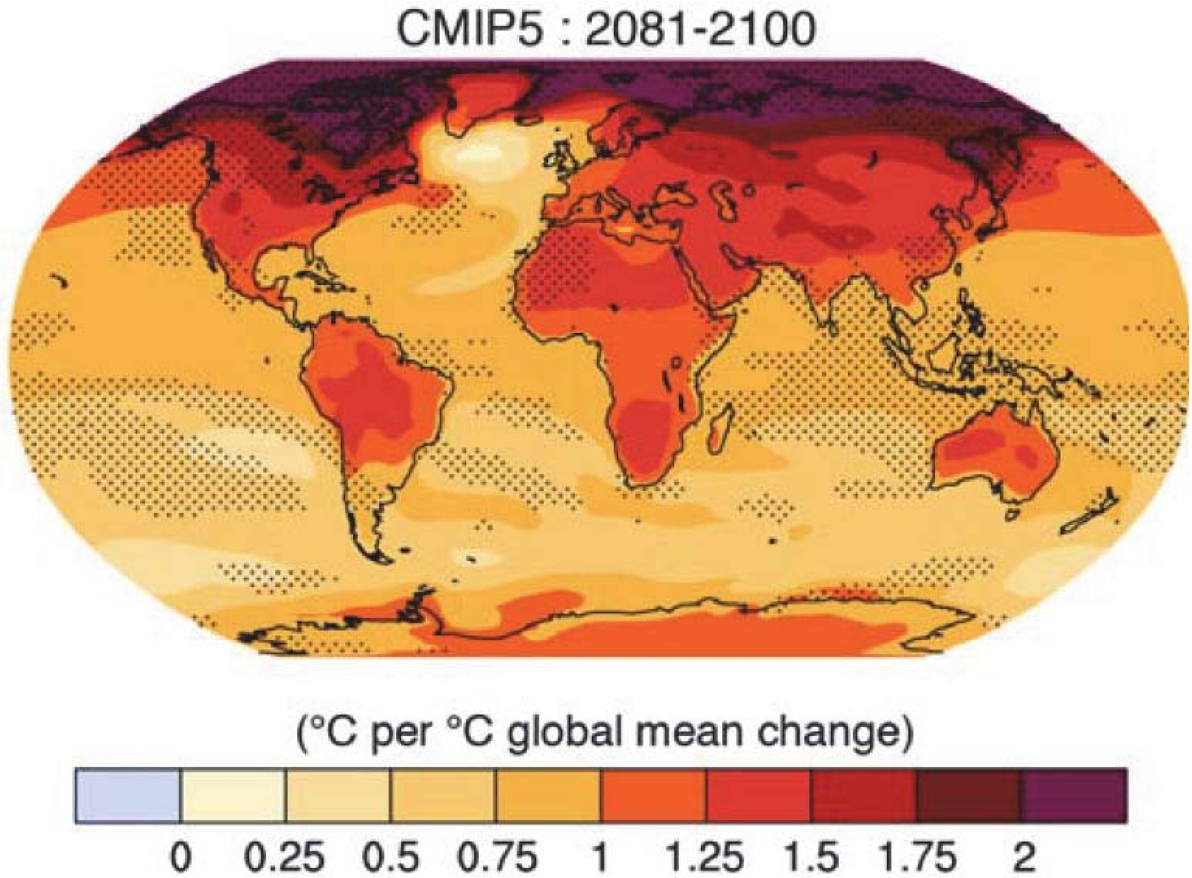

Figure 1: Average temperature from the period 2081-2100 is compared with the period 1986-2005 using averaged values from several CMIP5 models (IPCC, 2013)

In developing countries, the international community is focusing on preparing communities to adapt to the impacts of a changing climate. Participants at the international adaptation forum for water utilities in 2010 (AMWA, 2010), were advised that water service providers should first understand the range of impacts and implications of climate change, and then focus on preserving and developing adaptation options that enhance system resiliency, maintain management flexibility under a range of possible climate impacts while also considering the energy/water nexus. As part of the (UNFCCC) COP17/CMP17 held in Durban (COP17, 2011), the Durban Adaptation Charter (DAC) was approved by more than 100 mayors from 27 countries. These mayors represented their cities in pledging to strengthen local level adaptive capacity to climate change.

The charter committed local governments around the world to urgent and decisive climate adaptation action in the drive to address a climatically extreme and unpredictable future. This charter complements existing local government climate change initiatives which include earlier agreements by cities in COP16, the Mexico City Pact. The Durban Charter also translates into the development, adoption and use of adaptive technologies, thus transforming the world's cities and local governments and making them more 'climate smart' (COP17, 2011).

2.1 International context of climate change (observed and expected impacts)

The science of climate change is constantly changing. In previous assessment reports released by the IPCC, various climate models have been utilized based on various scenarios to paint a vivid picture of expected climate trends (Rogelj et al., 2012). Past observations of temperature and precipitation have been used to understand the present trends, and predict possible future occurrences in terms of weather conditions (Easterling et al., 2000). The temperature observations from 1901 to 2012, as well as the observed changes in annual precipitation over land from 1901 to 2010 and from 1951 to 2010 are presented in the IPCC (2014) report. These observations show clearly a temperature increase of up to 2.5°C in some regions within the considered historical period 1901 to 2010. Figure 2 below shows the observations of global changes in surface temperature for the period 1901 to 2012, according to the most recent assessment report by the IPCC (IPCC, 2014).

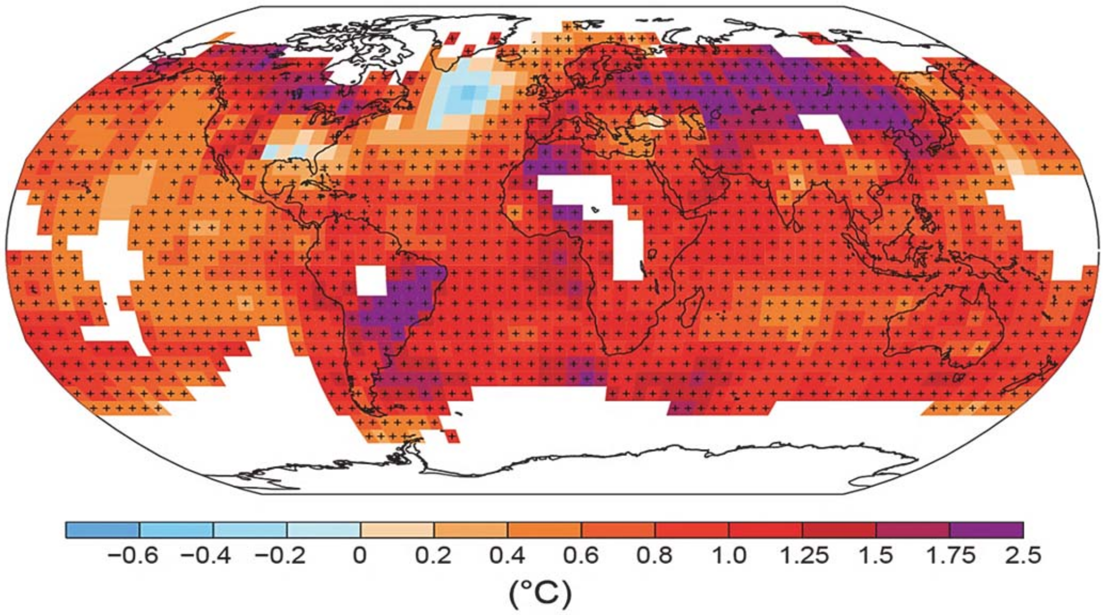

Figure 2: Observed changes in surface temperature 1901-2012 (IPCC 2014)

In terms of precipitation, there is no clear trend as different regions are likely to experience different impacts.

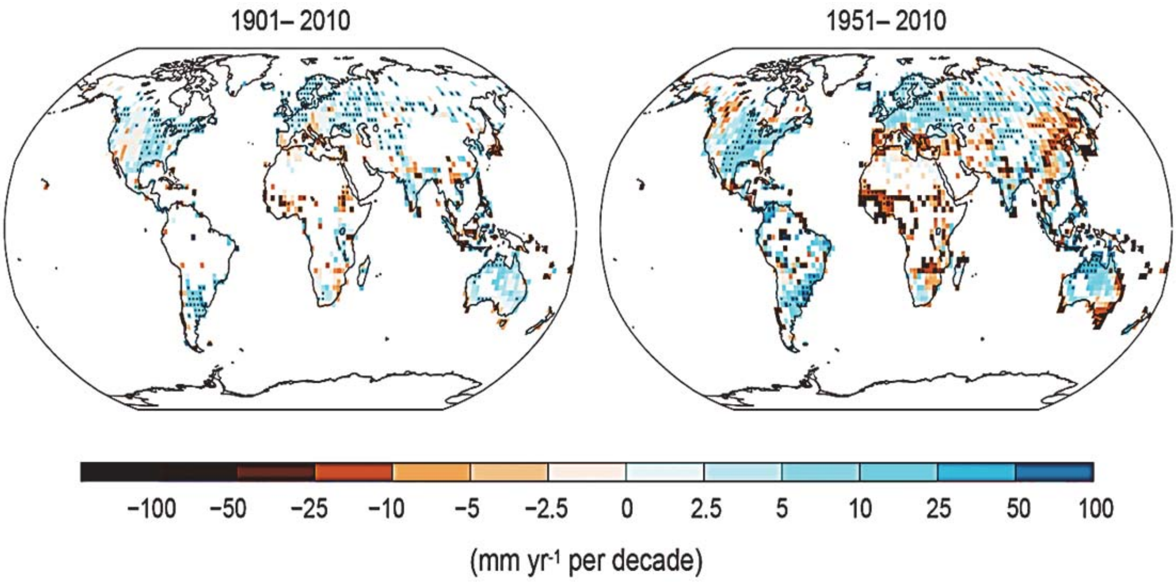

Figure 3: Observed changes in annual precipitation over land for the past century (IPCC 2014, WGI AR5 Presentation)

Rainfall over the observed period shows a general decrease across Africa; however, some parts of South Africa show steady precipitation while other parts show a reduction in precipitation (Figure 3).

The IPCC (2014) further highlights different indicators of a changing climate such as changes in snow cover in the Northern Hemisphere, changes in sea ice content during the Arctic summer, global average sea level change, and change in heat content of the upper ocean globally.

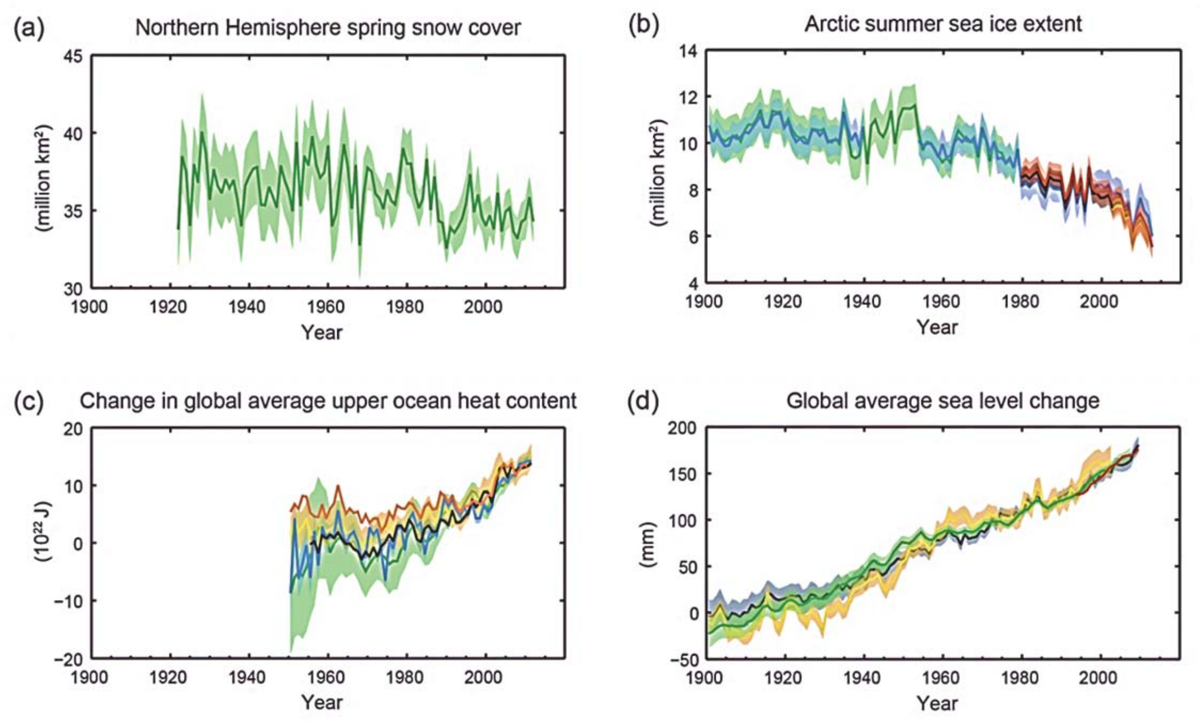

Figure 4: Multiple indicators that confirm the occurrence of climate change over the past century (IPCC, 2014)

The clear reduction in snow cover and sea ice extent in the Northern Hemisphere and the Arctic respectively, indicate melting of the ice shelves in these regions. In addition, the exponential increase in ocean heat content and global sea level rise indicate unwelcome impacts on aquatic life and low-lying coastal cities globally (Figure 4).

The climate models utilized by the IPCC (2014) are an improvement on previous models employed in former IPCC reports. Even the most recent models, however, still tend to focus on some regions more than others in a bid to achieve political correctness for regions deemed as important.

In the IPCC (2014) the data obtained from global climate models show that the "global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios presented except RCP 2.6". RCP 2.6 represents a scenario whereby a considerable amount of effort is put into mitigation measures in order to reduce the rate of climate change occurrence. Under this scenario, model graphs from the Coupled Model Inter-comparison Project (CIMP5) multi-model show a temperature increase of no less than 2°C. Scenario 8.5 indicates an absence of adaptation or mitigation, and the projected results show a temperature increase of no less than 4°C compared to pre-industrial levels.

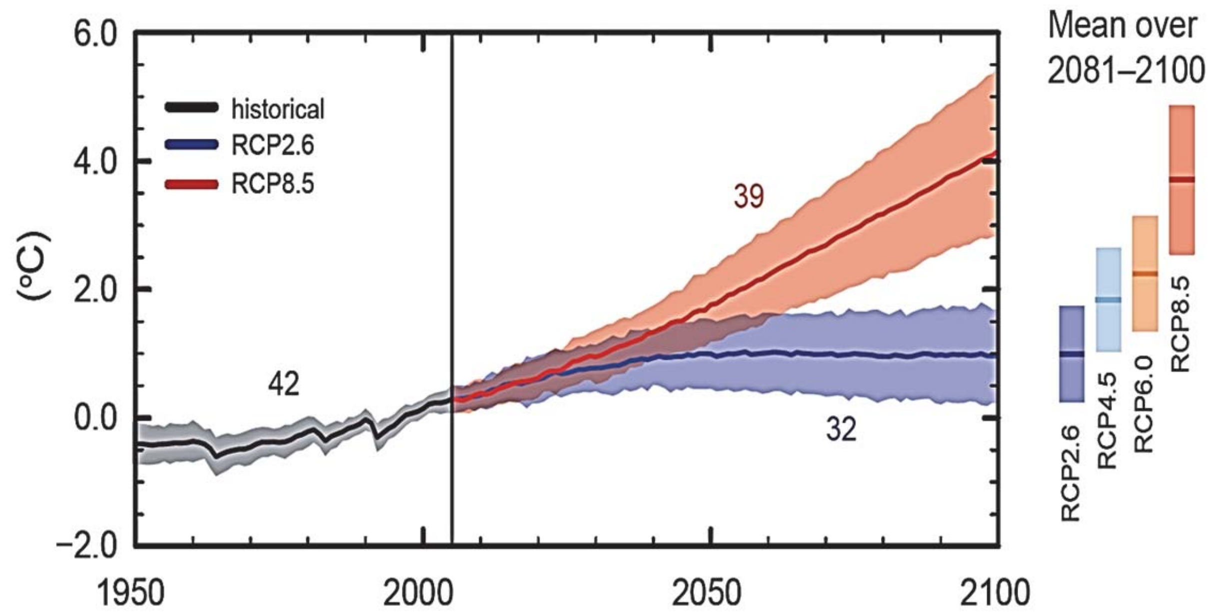

Figure 5: Global average surface temperature change (IPCC, 2014)

For RCP 6.0, temperature increase is likely to exceed 2°C, while for RCP 4.5 it is more likely than not to exceed 2°C (Figure 5).

It is important to note that the different scenarios used in model projections were developed independently in different regions. RCP 8.5 was developed at the International Institute for Applied Systems Analysis (IIASA) in Austria, and represents increasing GHG emissions over time with no adaptation or mitigation efforts (Riahi et al., 2007). RCP 6.0 was developed at the National Institute for Environmental Studies (NIES) in Japan, and represents an equilibrium scenario in which emissions are stabilized shortly after 2100 due to mitigation efforts (Mokhov and Eliseev, 2012). RCP 4.5 was developed at the Joint Global Change Research Institute (JGCRI) in the United States of America, and also represents an equilibrium state whereby emissions are stabilized without overshooting long-term emission goals (Thomson et al., 2011). RCP 2.6 was developed by the Netherlands Environmental

Protection Agency (NEPA). This scenario represents the effects of immediate mitigation, which will lead to an increase in temperature of no more than 2°C (Van Vuuren et al., 2011).

The key fact to note with regard to the development of scenarios and models is that none of the regions where the scenarios were developed is closely related to Africa in terms of present climate, topography, economic stability, vulnerability and capacity to adapt (Van Vuuren et al., 2011). This makes it rather difficult to translate the information obtained from these models to local data for a country like South Africa. Downscaling of data remains a big issue that should be addressed with future studies (Fowler et al., 2007; Wilby and Wigley, 1997). The need for locally developed models and scenarios has become imperative for Africa as a region, given its high propensity to be terribly affected by climate change impacts (Giorgi et al., 2009).

In addition to the efforts by the IPCC, the UNFCCC is constantly investigating the means by which national governments can fully understand the impacts of climate change in their countries, hence compelling them to research adaptation and mitigation options (Morgan and Waskow, 2014). The UNFCCC initiated the Kyoto protocol in 1997, to which 189 countries are signatories. The protocol set achievable limits on GHG emissions for all its signatories, causing member states to work collaboratively to reduce their contributions to factors that expedite global warming (UNFCCC, 2014). Significant changes to the commitments of UNFCCC countries came in 2015, when the Paris protocol was set in motion. The Paris protocol required signatory parties to set individual achievable limits.

Other international institutions which are big drivers of climate change research include the World Meteorological Organization (WMO) – a UN-based organization that facilitates cooperation between national weather agencies regarding weather-related projects. These projects are often focused on observations of weather stations to provide basic climate data of different regions (WMO, 2007). The United Nations Environment Programme (UNEP) is the administrative core of all the UN’s efforts regarding environmental issues. UNEP increases awareness on climate and other environmental issues by providing a commendable hub of published reports, and advertising upcoming events that address climate change (UNEP, 2006).

Currently, reports have it that the earth is set to breach the 1°C threshold increase in temperature in 2015 due to an unexpected increase in emissions. The pressure to not reach the 2°C ceiling has since increased, as projections show that a 2°C increase in temperature will lead to rising oceans and subsequent submergence of land currently occupied by 280 million people (BBC news report, 2015). The World Meteorological Organization (WMO) reported that the concentration of GHG gases in the atmosphere has exceeded 400 parts per million, reaching levels that have not been experienced on earth for more than 800 000 to a million years (WMO, 2015); this has been referred to as uncharted territory. The recent surge in temperature increase has caused necessary panic as the World Bank has highlighted that more than 100 million additional people will be impoverished by 2030 due to the ill effects of climate change (World Bank, 2015). There is an increased urgency to agree on limiting the acceptable increase to the maximum of 2°C and prevent the ripple effects of wars over dwindling resources like water.

Internationally, many regions are focusing on adaptation and mitigation approaches that can be implemented to curb climate change (Metz, 2001). Developed countries like the United States of America (USA) and Australia have implemented measures to mitigate GHG emissions in order to curb the ill effects of climate in their respective regions. Some of these mitigation efforts include an intense dedication to the implementation and utilization of renewable energy on a large scale, and strict emission reductions for car and machinery manufacturers (IPCC, 2011).

2.2 Instruments for climate change projection

The use of Global Climate Models (GCMs) to understand climate change impacts has been established by the IPCC. These models correlate past atmospheric data with the present, to predict the future based on different scenarios designed by climate scientists. GCMs take into consideration the heating effect of the sun, the flux of heat and moisture from oceans, and the effect of GHG emissions on the atmospheric temperature (Smith and Tirpak, 1989). GCMs are developed for use in different regions, and the approach so far has been to utilize the GCM that simulates projections for regions that are closely related to South Africa. This represents a model bias and cannot be relied on for precision, as different anomalies may occur even in regions with identical climates (Hagemann et al., 2011).

Although over the last decade, downscaling of data from GCMs has improved greatly, the process nevertheless makes obtained information imperfect. For users of GCMs dealing with regional issues such as water use, precipitation and water management, information from downscaled data is unreliable as the scales utilized in GCMs are often too far off course (Wilby and Wigley, 2000).

Currently, South Africa has not established any local models for location-specific data projections. Climate scientists in South Africa still rely heavily on international projections from the IPCC which are downscaled in order to gather information. The Self-organizing Map-based Downscaling (SOMD) has been developed at the University of Cape Town (UCT) to aid the empirical downscaling of information from the most recent GCMs (Landman et al., 2009).

2.3 Climate change predictions for South Africa

Africa is generally regarded as a low emission region relative to other developed regions (Hulme et al., 2001), hence many of the models and scenarios that have been developed to explain and understand climate change have not taken Africa into consideration (Liverman, 2007).

South Africa's water sector suffers momentously from backlogs in infrastructure and services, and a general lack of skills in many regions (Jonker, 2007). The aridity of the country as a whole increases the sensitivity and vulnerability of the water sector to climate change impacts (Van Jaarsveld, 2001; Rijsberman, 2006). Predictions for South Africa's precipitation suggest a decrease of about 20% for the South-Western Cape (Engelbrecht et al., 2009), while Hewitson and Crane (2006) predict an increase in summer rainfall over the central and eastern plateau, as well as the Drakensberg Mountains area, increasing the chances of flooding and reduced water quality in these areas. A rise in sea level is expected for coastal areas in South Africa, and observations in this regard have been reported by Cartwright et al. (2013), and Roberts and O'Donoghue (2013). The vulnerability of South Africa's water sector is at all stages of the water service cycle ranging from raw water source, through the purification and distribution processes, to the processing of effluent and subsequent wastewater treatment.

In South Africa, climate scientists at the CSIR, the University of Cape Town (UCT) and the University of KwaZulu-Natal (UKZN) are statistically downscaling climate projections from global models to paint a vivid picture for South Africa based on downscaled data and translated information from the IPCC. The Department of Environmental Affairs (DEA) has proposed four fundamental climate scenarios for the country as follows:

- Warmer and wetter (< 3°C above 1961-2000), with a greater frequency of extreme rainfall events;
- Warmer and drier (< 3°C above 1961-2000), with an increase in drought frequency and somewhat greater frequency of extreme rainfall events;
- Hotter and wetter (> 3°C above 1961-2000), with a substantially greater frequency of extreme weather events;
- Hotter and drier (> 3°C above 1961-2000), with a substantial increase in the frequency of drought events, and greater frequency of extreme rainfall events (DEA 2013b).

Furthermore, the DEA has investigated the possible temperature increases and changes in precipitation for different climatic zones in South Africa based on the recently-developed IPCC scenarios – RCP 8.5 and RCP 4.5. The information as it pertains to the three case study areas is presented in Table 2.

Table 2: Downscaled sub-regional projections for temperature changes for the period 1961-2100 relative to a baseline period of 1971-2005 (DEA, 2013b)

IPCC scenario	Limpopo	KwaZulu-Natal	Northern and Central Interior
RCP 8.5 High emissions scenario	Temperature increases of between 1-3°C to 2-5°C by 2040-2060; and 3-6°C by 2080-2100	Temperature increases of 1-3°C by 2040-2060. Increase of 3-5°C (4-6.5°C) by 2080-2100	Temperature increases of 1-3°C (2-5°C) by 2040-2060. Increase of 3-6.5°C (5-8°C) by 2080-2100
RCP 4.5 Emissions stabilization scenario	Temperature increase of 2-3°C by 2080-2100	Temperature increase of 1-3° by 2080-2100	Temperature increase of below 4°C by 2080-2100

The effects of climate change on South Africa's water sector are more likely to have negative impacts, even though some positive effects might occur. The current state of infrastructure, backlogs in service delivery, and the general lack of skills in the sector, however, might make it difficult to exploit climate change benefits unless adaptation is adopted.

2.4 Climate change vulnerability in South Africa's water sector

The definition of vulnerability to climate change remains subjective depending on the group of scientists; social scientists often refer to vulnerability as "the set of socio-economic factors that determine people's ability to cope with stress or change" (Allen, 2003), whereas climate scientists define vulnerability as "the likelihood of occurrence and impacts of climate-related events" (Klein and Nicholls, 1999). According to the IPCC, "vulnerability is a function of the character, magnitude, and rate of climate change, and variation to which a system is exposed, and the sensitivity and adaptive capacity of that system" (IPCC, 2007). Vulnerability assessments are necessary in order to select and implement adaptation options. Vulnerability to climate change is defined by three factors, namely: exposure, sensitivity, and adaptive capacity (IPCC, 2001). Exposure is defined as "the type of direct danger (i.e. the stressor), and the nature and extent of changes to a region's climate variables such as temperature, rainfall, and the likelihood of extreme events" (IPCC 2001). Sensitivity is defined by human or environmental conditions that can worsen the hazard, enhance the hazard or trigger an impact, while the adaptive capacity of a region is an indication of the potential to implement adaptation factors that build resilience (IPCC 2001). A flow chart for the determination of a region's vulnerability index was proposed by Dube et al., 2014 (Figure 6).

In South Africa's water sector, the differences in vulnerability for different regions is highly dependent on the topography of such regions, the structure of community settlements in terms of urbanization, which in turn dictates water use and demand patterns, availability and suitability of skills, the municipal structure of such regions and the presence or absence of an effective water board and catchment management agency (CMA). A relatively high level of vulnerability to climate change is experienced by different communities in the country due to the widespread existence of poorly functioning water and wastewater service systems that are aggravated by the failure to improve expertise, repair and maintain existing systems. Rural and small facilities also lack operators and sometimes they have to go without water purification chemicals, making the water situation precarious and worsening the state of vulnerability. In many rural municipalities, there are prefabricated modular structures put in place for water treatment, which are difficult to adjust in the face of climate change. In addition, the lack of financial resources of many municipalities makes them increasingly vulnerable.

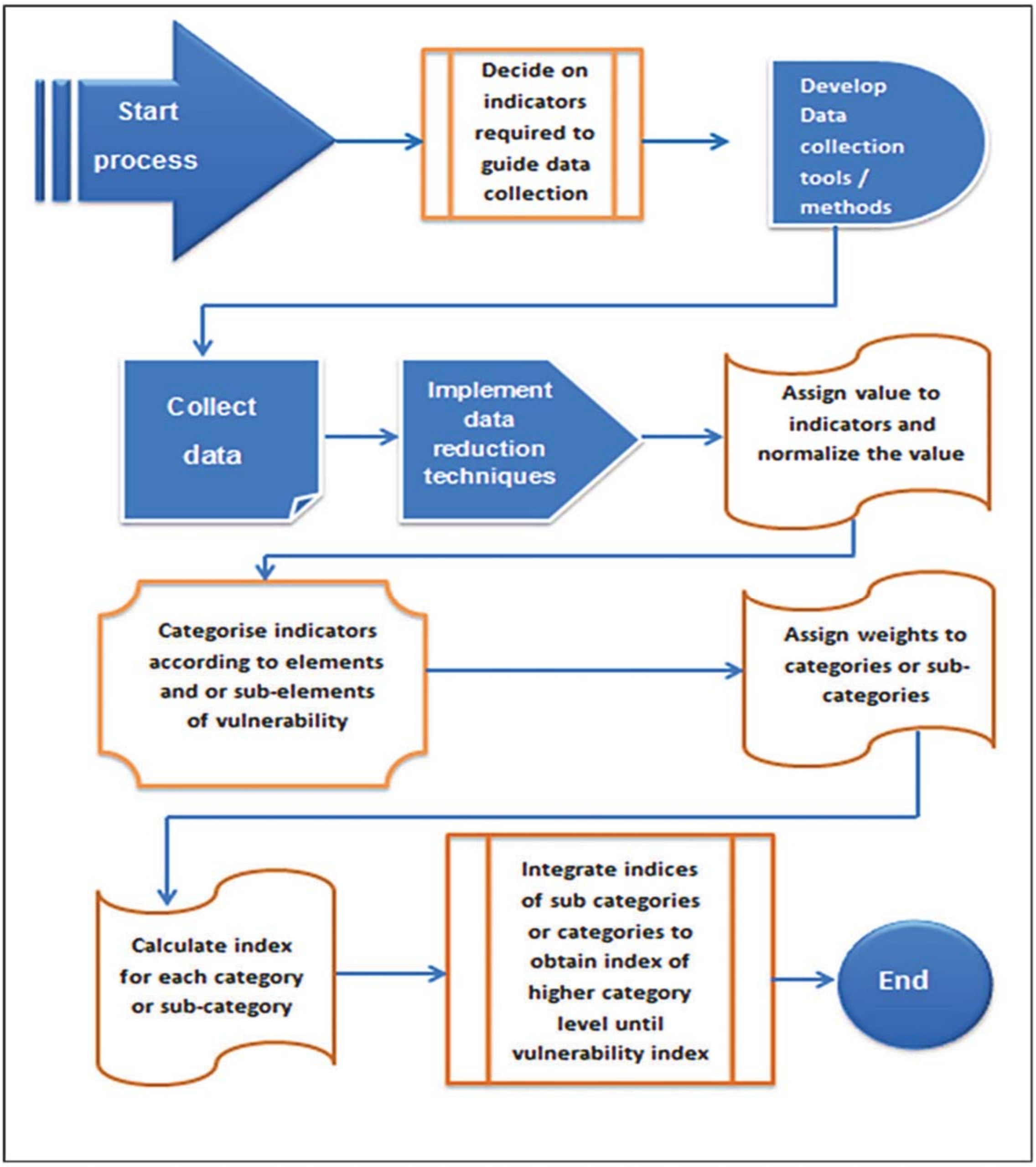

Figure 6: A comprehensive framework for precise assessment of the vulnerabilities of different regions and the selection of the right adaptation TAs

The vulnerability of water services can be identified at different points. South Africa is highly reliant on surface water bodies, including rivers and dams, for its water resources, and hence will be highly susceptible to ill effects (Meigh et al., 1999). The increased temperatures will inevitably result in an increase in evaporation of these surface water sources. This will in turn affect the abstraction of sufficient raw water, and may result in the need to develop different raw water abstraction technologies or explore new water resources. Increased run-off in mountainous regions will lead to the deposition of silts and unwanted dissolution of chemicals in water bodies, making it rather difficult to obtain good quality water for treatment.

Other points of vulnerability include the storage of water, distribution of water, treatment of wastewater, etc. The level of economic development of different regions in South Africa also indicates the level of vulnerability. Observation of the three case study areas chosen for the purpose of this study showed that well-developed and urbanized regions like Tshwane and Pietermaritzburg are less vulnerable to climate change. This is due to the fact that urbanization of a region attracts more skills from local and international sources. Regions like the Vhembe district in Limpopo are more vulnerable to climate change due to the evident lack of urbanization and socio-economic development.

A general lack of capacity, skills and expertise contribute to South Africa's vulnerability. An illustration of lack of capacity in the water sector can be found in studies of the condition of wastewater treatment works in the country conducted by the DWA in 2012 (Figure 7).

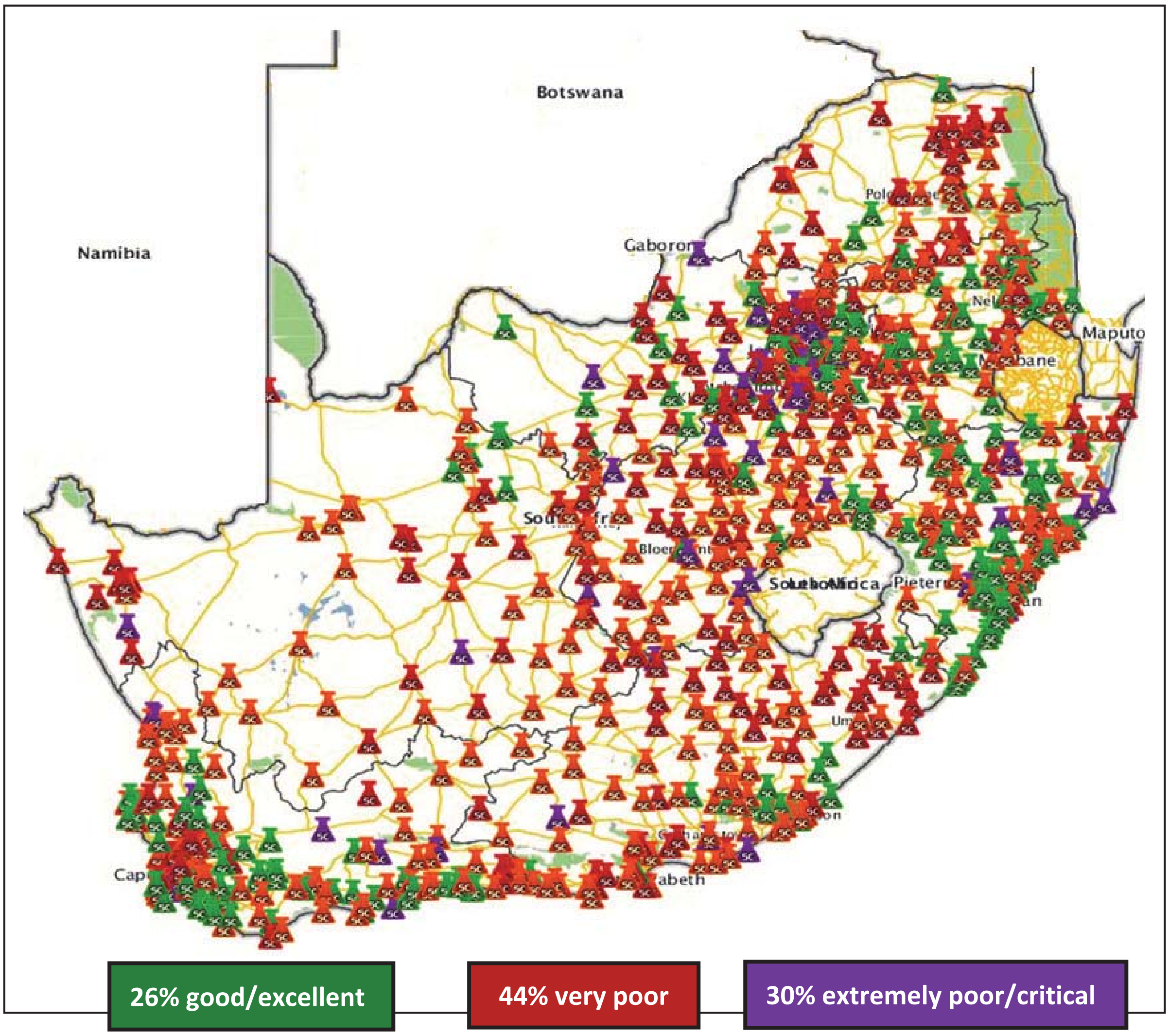

Figure 7: Performance rating of wastewater treatment works in South Africa based on extent of exceeding capacity, effluent compliance, skills deficit and delivery functionality (DWA, 2012)

According to the performance rating investigations, only 26% of South Africa's municipal WWTWs are in good condition, while the others are plagued by lack of adequate and appropriate infrastructure, inability to manage water and wastewater influx, lack of skills, and backlogs that heighten their vulnerability to climate change. In spite of perceived heightened vulnerability, many of these municipalities do not prioritize climate change as an area of focus. The concentration is often on trying to restore the municipality's functions to a state of excellence.

3 Local impacts and adaptation

3.1 General nature of impacts in the water sector

The water sector is one of the most vulnerable sectors to climate change globally. Extreme weather events such as floods, droughts, saline water intrusion, freshwater contamination, etc. are key concerns (Rosenzweig et al., 2001). There has been a lot of research focused on understanding the impacts of climate change on water resources. Without the impacts of climate change, scientists already predict that about 62.5% of the world's population will be faced with water stress by 2050 due to insufficient water resources (Arnell, 1999). Climate change will further increase the pressure on the water sector due to the frequent occurrence of water-related weather impacts.

In tropical regions like some parts of Africa and Asia, there is an expected increase in annual run-off which will by no means be beneficial to the water resources of such regions if adequate measures like dams are not put in place (Arnell 2004). In sub-tropical regions, reduced run-off will most likely result in the occurrence of droughts, and reduction in available water all year round. If adaptation TAs are not put in place, the impacts of climate change on the water sector will become destructive, hence the need for research into adaptation options.

The effects of climate change on the water sector can be split into primary, secondary and tertiary effects. The main primary effect of climate change is an increase in temperature and changes in rainfall patterns. This translates to various secondary effects such as an increase in surface water temperatures, reduced water quality due to higher dissolution of pollutant compounds, and reduction in available water due to longer dry periods in some areas (Evans et al., 2005). Other secondary effects include an increase in the evapotranspiration rate from surface water which will contribute to reduced water availability. Secondary effects which will be felt in the water services sector include the effect of temperature increase on the materials used for pipeline distribution channels, as well as the sedimentation of storage tanks and their consequent flooding (Delpla et al., 2009). The secondary effects of climate change will lead to inevitable tertiary effects as shown in Figure 8 (Douglas et al., 2008). These effects pose grave threats to human habitation and survival in many regions.

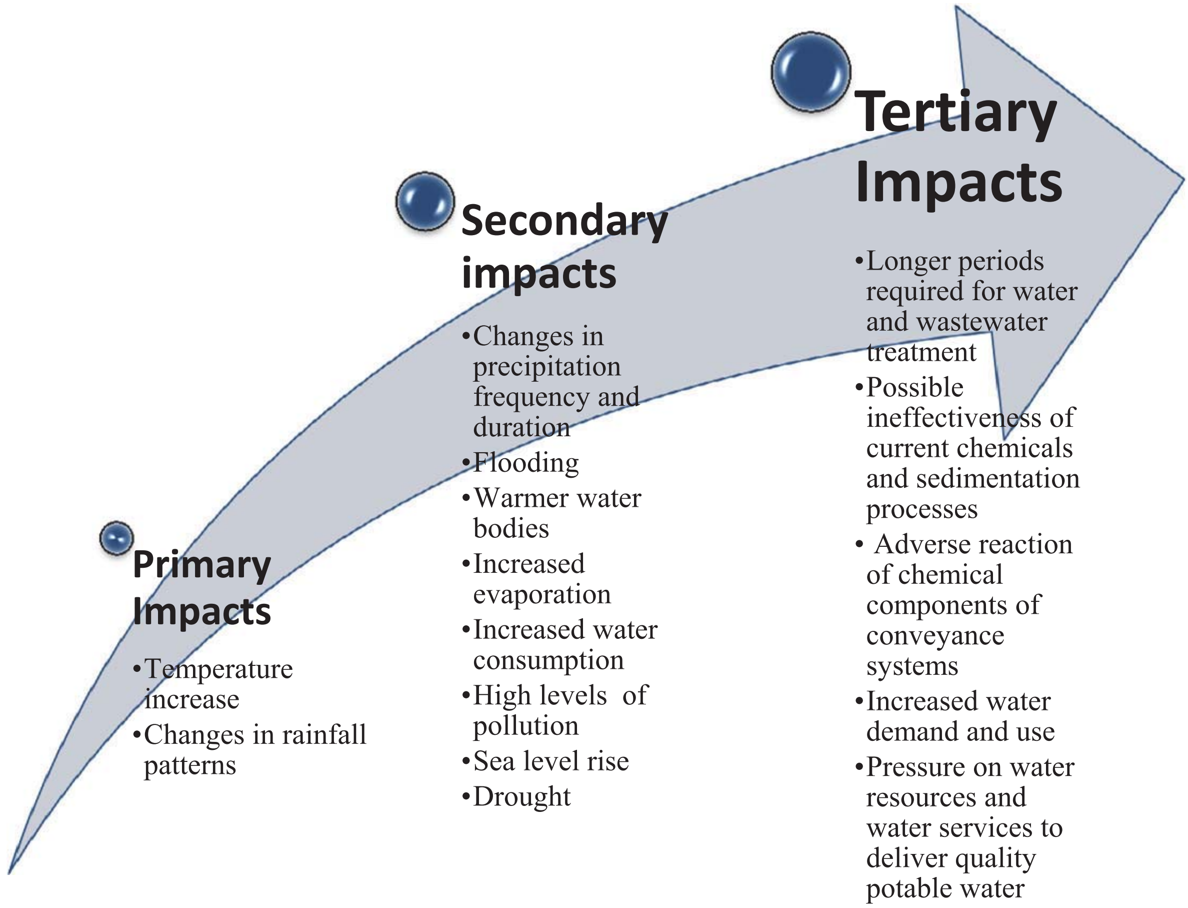

Figure 8: Schematic illustration of climate change impacts on the water sector, split into primary, secondary and tertiary impacts

3.2 The nature of climate change impacts on South Africa's water sector

Climate change impacts on the water sector will be felt greatly by municipal water services. According to the DEA (2013a), climate change impacts on the water sector will be felt in the following ways:

❖ **National run-off**: There is a possible increase in national run-off of between 20% and 60% under a high emissions scenario such as RCP 8.5. The most vulnerable areas to high level of run-off include the Eastern Cape, southern parts of Mpumalanga and KwaZulu-Natal (DEA, 2013a).

- **Infrastructure**: Increased temperatures will affect existing water treatment infrastructure and conveyance systems. Storage tanks, flocculation chambers, and pipelines used for water distribution may be exposed to increased corrosion as a result of higher temperatures. The occurrence of extreme weather events such as floods will affect roads, rail lines, and other socio-economic structures.
- **Increase in water demand and use**: An increase in temperature will directly lead to an increase in water demand and use, and a decrease in available water at the source due to a higher rate of evapotranspiration. This will result in an increased concentration of pollutants in water resources, which will translate to an increase in cost of water treatment.

Water and wastewater infrastructure will be terribly affected by an increased flow of water in areas where there is a decrease in precipitation, especially for wastewater purification systems that also receive storm water (Clark et al., 2011). This will result in reduced quality of potable water being distributed, increased levels of pathogens as a result of partially treated wastewater, and increased concentration of organic matter.

3.3 Water and wastewater services adaptation concept

Adaptation can be defined as adjustments of a system to reduce vulnerability and increase the resilience of the system to change, in this case in the climate system (Adger et al., 2005; Christiansen et al., 2011). Adaptation occurs at a range of inter-linking scales, and can either occur in anticipation of change (anticipatory adaptation), or as a response to those changes (reactive adaptation) (Adger et al., 2005). Adaptation can involve building adaptive capacity, thereby increasing the ability of individuals, groups, or organisations to adapt to changes, and implementing adaptation decisions, i.e. transforming that capacity into action. Both dimensions of adaptation can be implemented in preparation for, or in response to impacts generated by a changing climate. Hence, adaptation is a continuous stream of activities, actions, decisions and attitudes that inform decisions about all aspects of life, and reflect existing social norms and processes (Adger et al., 2005).

Most methods of adaptation involve some form of technology which, in the broadest sense, includes not just materials or equipment but also diverse forms of knowledge. Unlike those for climate change mitigation, the forms of technology for adaptation are often fairly familiar. Indeed, many have been tried and tested over generations – for example, coping with reduced access to water through various rainwater harvesting techniques, water transfer between catchment areas using Roman times aqueducts and locks. Other forms are much more recent, involving advanced materials science, and in some cases, some of the latest sciences such as desalination using reverse osmosis, pressure-retarded osmosis and even shock electro dialysis where desalination can be achieved without the use of hydraulic force.

These methods range from complex models to assess climate change impacts to guidelines on the steps to take for identifying, designing, implementing and evaluating adaptation measures. In all these technologies, one of the main challenges is to ensure that they serve those in greatest need – the most vulnerable communities, particularly those who live and work in close contact with the natural environment and stand to lose most when ecological resources are under threat. Adaptation planning involves the full spectrum of activities from identifying and assessing to implementing adaptation measures, and is informed by the assessment of impacts and vulnerability.

Adaptation options are not limited to the improvement of current water service infrastructure, or the installation of novel technologies. Water reuse is increasingly becoming an important option to consider, and is a technique that could aid water conservation where fresh water resources are limited. A report by the Department of Water and Sanitation (DWA, 2011) highlighted the strategic importance of reuse in large corporations and public firms. The DWA (2011) study involved an assessment of the Olifants River catchment and the benefits of encouraging water reuse in the area. The companies that reuse their industrial water, as well as opportunities for reuse outside of just the municipalities, were investigated to determine the potential benefits of reuse. By encouraging water reuse in many regions, strains on water resources will be greatly reduced. As a result increased water demands due to climate change could be met.

The concept for adaptation as articulated in this guide is to provide solutions that can be applied across various geographical settings and municipal capabilities, thus setting the basis for adaptation to be planned and applied where and when required, especially in the most vulnerable regions and within suitable timeframes. An illustration of the impacts, processes experiencing the impacts and where adaptation is applied is shown in Figure 9 below.

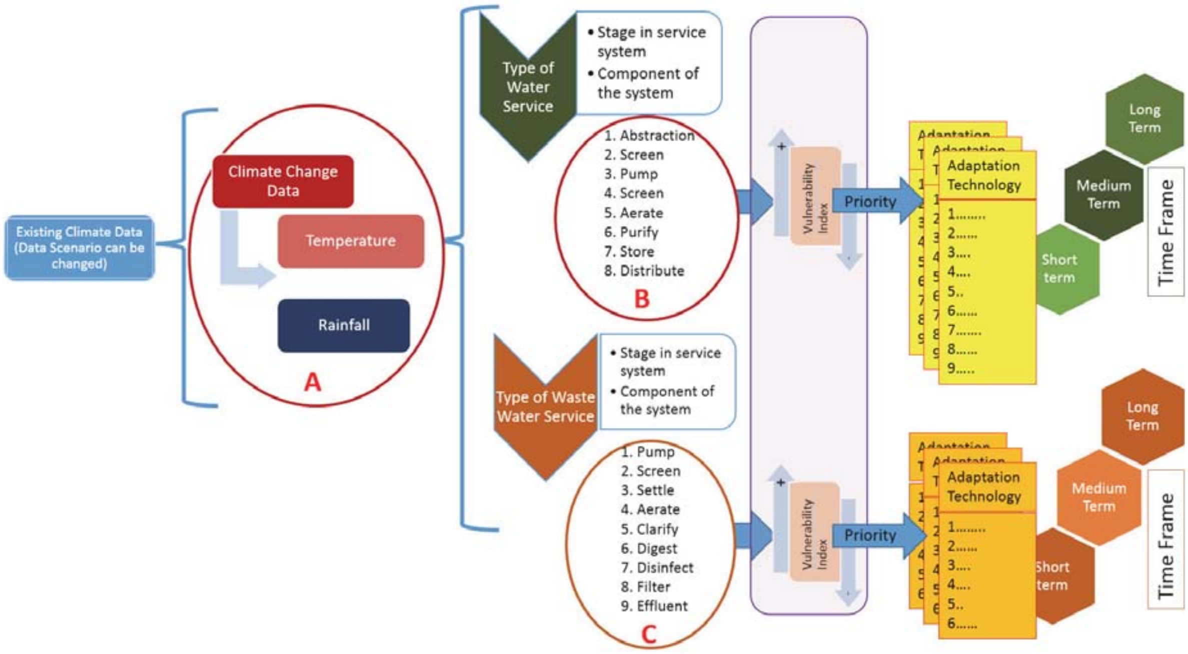

Figure 9: Schematic illustration of the adaptation guide highlighting climate change impacts and the adaptation process

3.4 Climate change response strategy for the water sector

3.4.1 Background to development of climate change strategies

In August 1997, South Africa ratified the UNFCCC (Holgate, 2007). In order to successfully achieve its mitigation objectives, the UNFCCC adopted the Kyoto Protocol in 1997. The Kyoto Protocol required member signatories to conduct country studies, as well as submit GHG inventories. This was to determine the contribution of member countries to GHG concentration in the atmosphere, which was inevitably expected to lead to the development of a response strategy (Dodman, 2009).

In 2002, South Africa acceded to the Kyoto Protocol and hence a national climate change response strategy document became imperative (DEAT, 2004). Detailed country studies for South Africa regarding the possible effects of climate change in different sectors of the country aided the development of the strategy document which was submitted to the UNFCCC in 2004 (DEAT, 2004). According to the South African Country Studies (SACS) Programme, the sectors of highest vulnerability in the country include the health sector, maize production, plant and animal biodiversity, rangelands, and water resources (DEAT, 2004). These sectors require adaptation on a large scale, as mitigation efforts might not be sufficient to dampen the ill effects of climate change.

The National Climate Change Response Strategy (NCCRS) document highlights the importance of climate change adaptation as a key focus for South Africa. According to the NCCRS, "global climate change is a threat to sustainable development, especially in developing countries, and could undermine global poverty alleviation efforts, while having severe implications for food security, clean water, energy supply, environmental health and human settlements" (DEAT, 2004). Assessment of vulnerability was highlighted as a key focus in the document. Although South Africa is a signatory to the Kyoto Protocol, as a non-annex I country, there is no compulsion to reduce GHG emissions. The need for a sustainable energy programme, however, is paramount, since South Africa has been identified as one of the energy-intensive countries in the region (DEAT, 2004).

Based on the highlighted key focus areas in the NCCRS, various institutions in South Africa have developed response strategies to address the effects of climate change in different sectors, in order to achieve sustainability and resilience in the face of climate change.

3.4.2 Translation of national strategy for other institutions

The development of a national strategy simply serves as a guideline for provincial and local governments, as well as sectoral government institutions. Therefore, the translation of the NCCRS by other institutions must follow the required guidelines of vulnerability assessment, climate change adaptation, clean energy processes, and sustainable development.

In line with the NCCRS, the DWS has developed a methodology for assessing the impacts of climate change on the water sector, and the vulnerability of different regions in order to ensure informed decisions are made regarding response options. Figure 10 is a schematic illustration of the DWA's approach to understanding climate change impacts on the water sector.

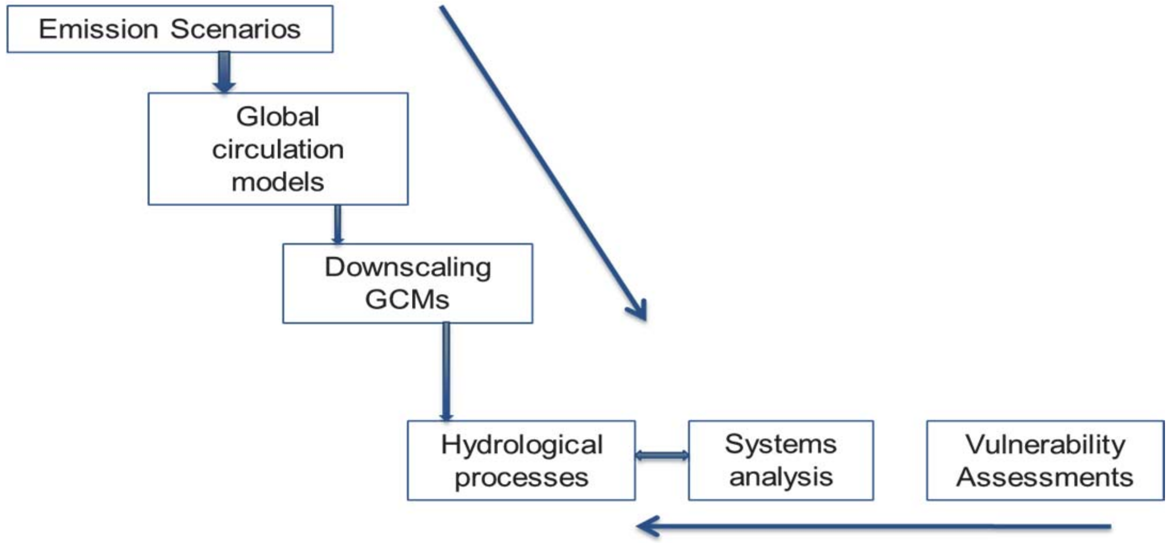

Figure 10: Methodology for understanding climate change impacts on water sector (DWA, 2012)

The DWA's response strategy for climate change aims to address the following:

- ❖ Identification of possible responses in the broader sector of sustainable development for the water sector.
- ❖ Understanding of infrastructural, institutional, developmental and regulatory processes.
- ❖ Examination of possible synergy between adaptation and mitigation.
- ❖ Institutional analyses on capacity and capability of institutions to implement strategies, and determine resource requirements for implementation.
- ❖ Identification of policy and legislative amendments required for strategy implementation.
- ❖ Practicality and affordability of response strategies with existing capacity of the nation (Adapted from DWA, 2012).

In addition to the DWA's efforts, the Water Research Commission (WRC) has dedicated its resources to understanding the ill effects of climate change on raw water, abstraction techniques, treatment procedure and infrastructure, conveyance and reticulation. Many of the commissioned studies, however, have focused on understanding the impacts of climate change on water resources, and not necessarily on water services (Green, 2008). In light of this, the WRC has identified the need to highlight climate change as one of the lighthouses for its Key Strategic Areas (KSAs) (WRC, 2015). Research on climate change vulnerability of rural regions and the need to create awareness and implement adaptation strategies remains one of the key focus points of the WRC.

Local government institutions like SALGA have indicated the need for municipalities to incorporate climate change adaptation in their Integrated Development Plans (IDPs). Municipalities are tasked with the delivery of water, amongst other services, to their wards, and hence it is highly important that any developed strategies designed to respond to climate change for the water sector should involve the direct input of municipal offices. In 2012, SALGA, in collaboration with the DEA, and the Department of Cooperative Governance and Traditional Affairs (CoGTA) developed a toolkit to guide the integration of climate change risk assessment and adaptation into municipal planning. An abridged version of the steps outlined in the toolkit is schematically illustrated in Figure 11.

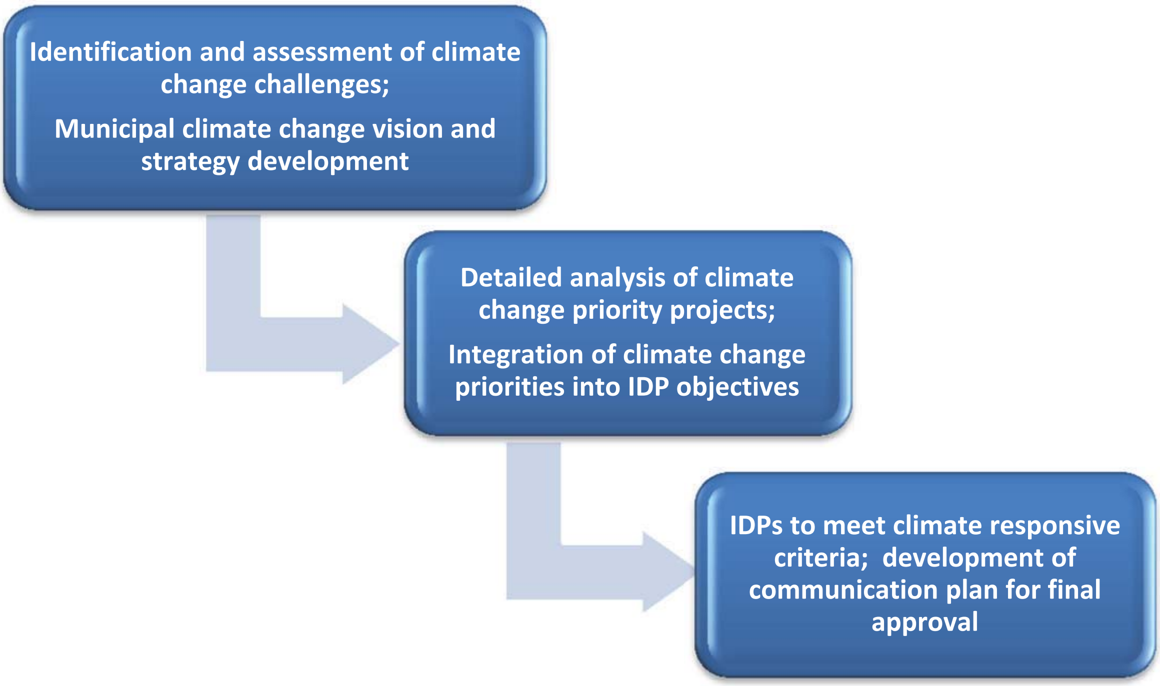

Figure 11: Schematic illustration of SALGA's strategy for integration of climate change into municipal planning (SALGA, 2012)

3.4.2.1 What next after strategy development?

Strategy development has to be accompanied by research into adaptation options and their prioritization. Through these processes, climate change vulnerabilities are interpreted into suitable adaptation options. Selected and planned adaptation options should be followed by the allocation of suitable budgets for implementation, and implementation of options suitable for the different regions. Adaptation options vary from technical adaptations to various non-technical approaches. Adaptation implementation should be followed by monitoring and evaluation of implemented options to ensure that the adaptation processes are indeed effective and provide the required benefits in the long term.

However, even if water sector institutions have completed climate change risk and vulnerability assessments as well as the strategy development, climate change vulnerabilities in the water sector are rarely mentioned in the business plans, such as the IDPs for municipalities where adaptation can be mainstreamed into other development priorities. In the case of the municipalities, all activities that are to be undertaken by a municipality must be supported by a budget in the IDP; therefore if climate change adaptation technologies are not listed within IDP planning activities, they cannot be executed. The lack of climate change adaptation interventions identified with IDP planning is alarming given that it was a requirement of the National Climate Change Response Policy that climate change is mainstreamed in local government planning by 2014.

3.5 Regional and institutional roles and boundaries in adaptation

3.5.1 Adaptation roles in national institutions

The Department of Environmental Affairs (DEA) is the national institution that is expected to lead climate change response for South Africa. In 2011, the DEA published the climate change response white paper which outlines the specific target areas for climate change response, and provides a guideline for other institutions to address climate change in their respective sectors (DEA, 2011a). The DEA's focus is on the environmental sector as a whole, and encompasses different sectors such as biodiversity, the green economy, sustainable energy development, waste management, and water. Hence, the DEA simply provides climate change response guidelines for other national institutions (DEAT, 2004). Other national institutions are therefore tasked with addressing specific climate change impacts in their various sectors, while also seeking to align the response initiatives to the guidance provided by the DEA.

The DEA has conducted extensive studies to understand the impacts of climate change, and has developed fundamental scenarios to aid South Africa's adaptation research and implementation. The DEA studies, especially the Long-Term Adaptation Scenarios (LTAS) flagship research programme, has set clear guidance on climate change impacts on the basis of several climate model data using simulations which were done for the period ending in 2012. In the studies, climate trends for the various regions of South Africa are discussed and impacts of climate change on the water sector were also captured (DEA, 2013a).

The Department of Water and Sanitation (DWS), the guardian of South African water resources, is committed to understanding the impacts of climate change, mostly on water resources. The DEA's LTAS studies provide important information regarding the water sector, and possible adaptation options that are available for the water sector. The assessment of water resource tools and assessment of water use and future requirements have been extensively analysed by the DEA in these studies (DEA, 2013a).

3.5.2 National government, local government, and municipal adaptation boundaries

South Africa has a three-tier government system: national government, provincial government and local government (Ndegwa, 2002). The adoption of approaches and technologies for climate change adaptation, as well as the development of strategy response programmes have been traditionally viewed as the duty of national government (Roberts, 2008). Decisions taken on provincial and local levels have to be in line with the vision of the national government. This creates a barrier for climate change adaptation uptake in South Africa, as national government cannot necessarily perceive or address location-specific local needs (Roberts, 2008). With an increasing awareness that adaptation has to take place at a local level, it is clear that climate change adaptation in the water sector falls on the shoulders of municipal structures across different regions. The state of a municipality can either aid adaptation to climate change or become an impediment. A state of local government report published in 2009 (CoGTA, 2009) demonstrated the differences in municipal challenges based on the categories of municipalities.

Table 3: Classification of municipalities in South Africa (SALGA, 2010)

Class	**Description**
A	Metropolitan: large urban complexes with populations of over 1 million; accounts for approximately 56% of municipal expenditure in South Africa.
B1	Local municipalities with large budgets; contain secondary cities.
B2	Local municipalities with large towns as an urban core.
B3	Local municipalities with small towns, relatively small populations, a significant proportion of urban population, but no large town as urban core.
B4	Local municipalities with mainly rural communities and at most one or two small towns in the area. Has no urban core.
C1	District municipality which is not a water service authority.
C2	District municipality which is a water service authority.

While classes A, B1 and B2 municipalities are often financially capable of conducting climate change research and exploring available adaptation options, classes B3 and B4 municipalities are often not sufficiently well-equipped in terms of financial resources and skills (Table 3). Metropolitan municipalities, as well as the B1 and B2 class municipalities are well-established, well-resourced and have well-grounded administrative capacities. On the other hand, the B3 and B4 municipalities struggle with the generation of revenue from their wards and are in economically depressed regions of the country. Due to their weak financial abilities, these municipalities are unable to retain highly skilled individuals, making it challenging for them to achieve their basic set of responsibilities (CoGTA, 2009). The addition of climate change adaptation to the list of obligations is therefore an additional burden to B3 and B4 municipalities as their main focus remains the clearing of backlogs in their facilities and improving existing administrative and technical infrastructure (CoGTA, 2009). There is an undeniable link between urbanization, economic development, access to resources and institutional capacity.

Although urban municipalities are better equipped to handle climate change, they face major challenges in terms of population growth within their wards. The pressure to deliver quality potable water to an ever-increasing population, based on limited water resources which will inevitably be affected by climate change, remains a major challenge for class A, B1 and B2 municipalities. Rural municipalities, on the other hand, face conveyance challenges as the communities in their wards are often dispersed and distant from one another. Due to their inability to deliver water successfully to their wards, and many clients being unable to pay for services, revenue generation is low. Poverty and unemployment also contribute to the lack of revenue in these areas.

It is imperative that climate change obligations be decentralized from the national government to local municipalities. Each municipality understands the wards and the region within its location, hence research that focuses on the specific needs of the region can be orchestrated, as opposed to implementing suggestions from the national government that may not address the climate issues faced by specific municipalities in different regions. This is currently SALGA's vision with its capacity-building '*Let's respond'* toolkit (DEA, 2013b).

3.5.3 The municipalities' role in climate change adaptation

South Africa's national response to climate change is framed by its commitments to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. As a signatory to this convention, the national government of South Africa has committed to a goal of achieving a 34% reduction in greenhouse gas (GHG) emissions, against a business-as-usual trajectory, by the year 2020. Further, the South African government has committed to reducing GHG emissions by 42% by the year 2025 against a business-as-usual trajectory (DEA, 2011b). These commitments were announced by the Presidency in 2009 at the 15th Conference of the Parties (COP 15) held in Copenhagen, Denmark (ibid). These commitments are, however, subject to technical, financial and capacity development assistance from the more developed nations. The national commitments are subject to future changes since the Paris protocol is currently under consideration.

In line with these commitments, the DEA has published the National Climate Change Response Policy (NCCRP) (DEA, 2011b) which quotes the means by which these commitments will be achieved. The NCCRP deals with both climate change mitigation and climate change adaptation. In order to fulfil the obligations of the NCCRP, South Africa embarked on the Long Term Mitigation Scenarios (LTMS) (DEAT, 2007) research process to inform the long term mitigation policy in the country. The LTMS focused on understanding the rationale behind reducing GHG emissions, the options for climate change mitigation and the costs of climate change mitigation. Similarly, the LTAS research process aimed at producing a series of reports which documented a consensus on the climate change trends, projections and key impacts for key sectors in South Africa, including water.

The NCCRP White Paper has recognized local government as an important site of climate change mitigation and adaptation delivery. In particular, Section 10.2.6 identifies the key Constitutional mandates of local government that are critical in developing the South African national climate response (DEA, 2011b). These include: planning and urban development; municipal infrastructure and services; water, energy and waste demand management, and local disaster response.

3.5.4 Adaptation roles in other public institutions

Climate change adaptation must involve the three different tiers of government. Generally, provincial governments seem to be excluded from climate change response, leaving most of the strategy development to national institutions and local government institutions like SALGA. SALGA aims to direct municipalities across the country to respond to climate change through its ‘Let’s Respond’ toolkit. Presently, many municipalities across South Africa are unable to include climate change response in their municipal IDPs. Some municipalities include climate change response but do not take any action regarding it. It is SALGA’s role to ensure that municipalities adhere to the climate change mandate in line with the national government’s vision, as well as the municipality’s unique challenges. It is also important for SALGA to nurture cooperative relationships between municipalities that fall into the same climate change projection zone. By fostering such relationships, climate change response becomes a shared burden, available skills will be increased, and knowledge can be shared between the municipal offices. This will make adaptation planning, selection and implementation seamless, especially in municipalities where resources are limited.

Water boards also play an important role in supporting adaptation for the regions which they serve. In the large metros, it would seem as though the water boards are the front line for the water service delivery and are therefore expected to lead the strategy for adaptation, especially in the provision of potable water. The over-reliance on water boards on issues of climate change tends to be a source of risk to some municipalities that have no alternatives or plans to establish competent additional water service adaptation mechanisms, especially in the realm of bulk water service delivery. The examples of high risk bulk water provision for Gauteng was noted in the study. It was observed that, while Rand Water is providing the best service on bulk water provision, the water board relies on a system where all the service provision risk lies on just one water purification facility powered by one power station in Vereeniging. In the face of climate change, the risk of using one facility to provide water for such a large population, now exceeding 13 million people, increases as well.

The water boards are also expected to lead the way in improving the processes of water provision on behalf of the municipalities. They have to provide knowledge through research on new water and wastewater provision processes and systems, attract the right kinds of resources, especially financial and skilled resources, and be in a position to test new technology for the improvement of service delivery.

The public sector also benefits from the services of science councils and research institutions in dealing with adaptation. Public research institutions, including universities, are expected to aim at improving available knowledge on climate change by focusing on increased generation of local data, researching novel technologies that can be adopted to improve water services, and ensuring that researchers are more involved in applicable research that could be of benefit to South Africa.

3.5.5 Municipal water sector climate change adaptation challenges in South Africa

According to Ziervogel et al. (2014), the significant gaps remaining in climate change adaptation practice detrimentally affect the effectiveness of a causal chain from the biophysical impacts of climate change to adaptation responses. Ziervogel et al. (2014) further point out that these knowledge gaps are due to a lack of climate scenario products, complicated and contradictory climate information, incomplete impacts modelling approaches, inadequate process understanding, poor traceability between impacts assessments and the climate scenarios, inadequate socioeconomic and vulnerability assessments, and lack of cross-sectoral integration. Further, a consistent 'best practice' approach is lacking. In addition, South Africa lacks a robust national system of spatially extensive climate data. Up-to-date data in hydrology, in particular, is becoming increasingly expensive and difficult to obtain. Yet another major stumbling block for climate change adaptation is the lack of cost estimates and suitable finance mechanisms.

Implementation of climate change adaptation, specifically at the municipal level, is constrained by an overall lack of integrated assessment. Integrated assessments combine information from multiple sources on climate change impacts, vulnerabilities, and priorities for adaptation. In this way, integrated assessments help to explore the linkages between service sectors and regional vulnerabilities, and also incorporate climate change impacts into broader development concerns.

A further impediment to climate change adaptation implementation is the inability to upscale adaptation findings from the local or case level, across sectors and to the national level. This impediment exists mainly because of a lack of capacity, a high turnover of staff in government departments, limited understanding in tackling climate-related issues, the positioning of climate change as an environmental issue rather than as a development issue, conservative financial management practices, and poor communication between different government departments and spheres of government. Further, since climate change is a complex problem, a collaborative approach to adaptation between multiple stakeholder groups is missing.

Financing climate change adaptation at the local level remains a challenge. There is no evidence, however, to suggest that local governments are integrating climate change adaptation plans into their planning and practice. The idea of adopting climate change response strategies and including them in the business plan is not aligned to the current business vision of the municipalities which were investigated in developing this adaptation guide. Using the limited resources of municipalities to address climate change adaptation is tantamount to fruitless expenditure if done in the current environment, where the national drive for adaptation is not clearly defined and supported. It is clear that municipalities are in need of further direction and will be in a better position to deal with adaptation issues if national climate change policy is translated into the performance measures for municipalities. Municipal managers face strong criticism for perceived misdemeanors which include fruitless expenditure, misuse of funds, poor prioritization of available resources and failing to break even or even become profitable. A municipality that has to deal with service delivery backlog and has little revenue to collect is frowned upon. In such an environment, it is clear that the municipality will simply develop a climate change policy rather than take it into programmes, for which costs would be incurred. Climate change policies at national level, should therefore be translated into national and municipal goals.

A further challenge for climate change adaptation implementation at the local level is the lack of authority that environmental departments hold to address the impacts of climate change. Climate change at the local level is regularly referred to as an "unfunded mandate" (Ziervogel et al., 2014). While recent national climate change policy suggests that climate change is indeed a mandate, this feature is not reflected in municipal finance allocations. A lack of funding at the local level goes hand-in-hand with the silo approach of government towards finding solutions to challenges. Climate change adaptation requires an integrated approach with cross-sectorial problem-solving. Effective climate change adaptation therefore requires a transformation of political and bureaucratic infrastructure.

3.5.6 Adaptation boundaries in water boards and other water institutions

The presence or absence of water boards in municipalities plays a noticeable role in the vulnerability and sensitivity of different municipalities to climate change. Of the three case study areas, Tshwane Metropolitan Municipality and the UMgungundlovu District Municipality are clients of the Rand Water Board and Umgeni Water Board respectively. The

Vhembe District Municipality is not assisted by a water board or any other form of water governing body; hence it was ranked to be the most vulnerable and most sensitive municipality during the course of the study. The presence of a water board improves the skill, capacity, and partnerships of a municipality. This translates to higher research quality outputs, improvement of treatment infrastructure and conveyance systems, attraction of highly skilled and knowledgeable personnel, as well as the ability to focus on, and address matters arising such as climate change. The presence of Rand Water and Umgeni Water in the Tshwane metropolitan area and the UMgungundlovu district respectively increases the resilience of these two regions to climate change.

The adaptive capacity of a region depends greatly on well-managed and operational institutions (Staber and Sydow, 2002). Some municipalities, in spite of the presence of water boards, are still highly vulnerable to climate change. This is mostly due to mismanagement of funds as a result of municipal debt, and lack of skilled management personnel (DWA, 2013).

4 Selection criteria for adaptation options

4.1 Introduction to selection criteria in adaptation

The selection of adaptation options depends on a variety of factors which include geographical setting, availability of financial and human resources, availability and state of existing infrastructure, as well as the predicted climate change impacts. The selection of adaptation options should be aimed at addressing primary, secondary and tertiary impacts of climate change. The following factors have been defined as necessities for the selection of appropriate adaptation TAs**:**

- The aspect of climate change impacts to be addressed. These include changes in temperature, flooding, water quality degradation, extreme weather events, etc.
- Alignment of adaptation options with national goals and development priorities (e.g. the 2030 NDP vision for South Africa
- Alignment of adaptation options with the water sector goals and policies, such as the decentralization of decision-making, equity of access to water, etc.
- Alignment with water sector approaches such as integrated water resource management
- Responsiveness to international climate change adaptation principles, including contribution to sustainable development pathways
- Appropriateness of adaptation options to different regions in terms of location, geography, climate and climate change impacts
- Appropriateness to municipalities in terms of initial capital outlay, the ongoing costs of operations and maintenance, as well as the sophistication of technology, with its implications for management and maintenance.

For the selection of adaptation TAs for specific regions, the following considerations should be made:

Level 1 Assessment: Climate change and impacts

- The nature of climate change impacts in that specific area
- Sensitivity, vulnerability and adaptive capacity
- Resilience of solution to further changes.

Level 2 Assessment: Suitability and compliance

- Compliance to set standards
- Compliance to legislation and policies
- Maturity of technology and readiness to be applied
- State of existing water infrastructure
- Source of water
- Complexity of technology.

Level 3 Assessment: Stakeholder concerns

- Acceptance at all levels (policy and decision-makers, institutions and communities)
- Institutional capacity to implement
- Community size
- Socio-economic conditions
- Existing knowledge and expertise
- Prevailing cultural trends.

Level 4 Assessment: Fitness to institutional objectives and programmes

- Alignment to institutional business plan
- Within the institutional policies and provisions
- Availability of institutional capacity to implement
- Availability of other required resources and tools
- Approved by lead organizations e.g. Treasury

Level 5 Assessment: Cost Benefit Analysis

- Within available budget
- Cost-benefit analysis of selected adaptation option
- Cost-effectiveness analysis
- Sustainability to business framework
- Performance evaluations of the specific adaptation options.

A number of the considerations listed above can be applied in cases where detailed investigations are required. In this adaptation guide, the focus is also on the nature of climate change impacts, nature of services provided, geographical characteristics as well as compliance to prevailing legal and policy framework. The cost benefit analysis, which is always important on issues involving financial spending, should be carried out by suitably qualified internal or external specialists to ensure that the options for adaptation do not become a liability to the service institution.

4.2 Resources and capacity in adaptation options

The vulnerability and sensitivity of any region is heavily dependent on the available resources and the capacity to deal with climate change effects. Generally, urban regions are more resilient to climate change impacts due to the presence of highly-skilled personnel, better finances and functional water systems. On the other hand, rural and semi-urban regions are often characterized by inadequate skills, lack of functional infrastructure, poor financial resources and large service provision backlogs. It is also noted that many skilled personnel allocated to work in rural regions tend to struggle with other challenges, especially of a political nature, resulting in frustrations and even relocations. Hence, it is common for such individuals not to reside permanently in those regions. This exposes the water service delivery in such regions to failure. Climate change adaptation is complex to understand and address as one of the requirements for service delivery, and as such, requires competently trained and committed personnel. The competency can also be achieved by training the personnel already working in the relevant sections rather than bringing in one climate change 'champion' and assigning him/her all the climate change responsibilities.

In the selection of adaptation options, it is important for a user of the guide to identify the availability of suitable skills for implementing the selected or proposed adaptation options. Developing the suitable skills base could be one of the first stages of dealing with the key resources required in addressing climate change.

In this respect, financial resources also play an important role in climate change adaptation. In many local service institutions, there are challenges in terms of allocating the existing financial resources to address the present backlogs. It is also commonly known, however, that, once the finances have been made available, the same institutions fail to use these resources because they do not have suitable human resources to make decisions, and to provide the technical inputs that will result in the work being done and the allocated funding being used correctly. A user of this guide should aim at evaluating the level of finances in the region as well as the human resources that can be made available in order to determine the adaptation options which will be suitable and can be successfully implemented. In some regions, adaptation measures that address behaviours and beliefs can make a huge difference in addressing water-related challenges at a low cost while building the base for future wide-scale adaptation programmes.

4.3 Consideration of time in adaptation

The climate projections used in this study are based on the Long Term Adaptation Scenarios (LTAS) research programme conducted by the DEA (DEA, 2013a). The LTAS research programme provided national and regional scenarios for South Africa. The project evaluated the socio-economic and environmental implications of potential impacts of anticipated climate change for South Africa across three time frames, namely short (<2030), medium (<2050) and long (<2100) terms. In this guide, there is an additional time frame that was added to deal with adaptation initiatives for immediate implementation. This is to account for the shorter time frames used in local government and municipal planning. To account for this shorter period, the time frames were devised as follows: immediate (<2020), short (<2030, medium (<2050) and long (<2100). The immediate time frame is set to help municipalities plan for high priority adaptation projects by including them in their revised municipal IDPs, where the longest time horizon considered is usually five years. The NCCR white paper (DEA, 2011a) also emphasizes the need to consider shorter time scales for local programmes as opposed to the longer international time definitions with regard to climate change response.

The selection and successful implementation of adaptation options is dependent on suitability for the impact and implementation at the correct time. In order to successfully adapt water services to climate change, the responsible institution can define and adopt a customized generic time scale for the area served. This time frame should be advised by the sensitivity and vulnerability of the region. Figure 12 highlights the concept of time consideration in the selection of adaptation options.

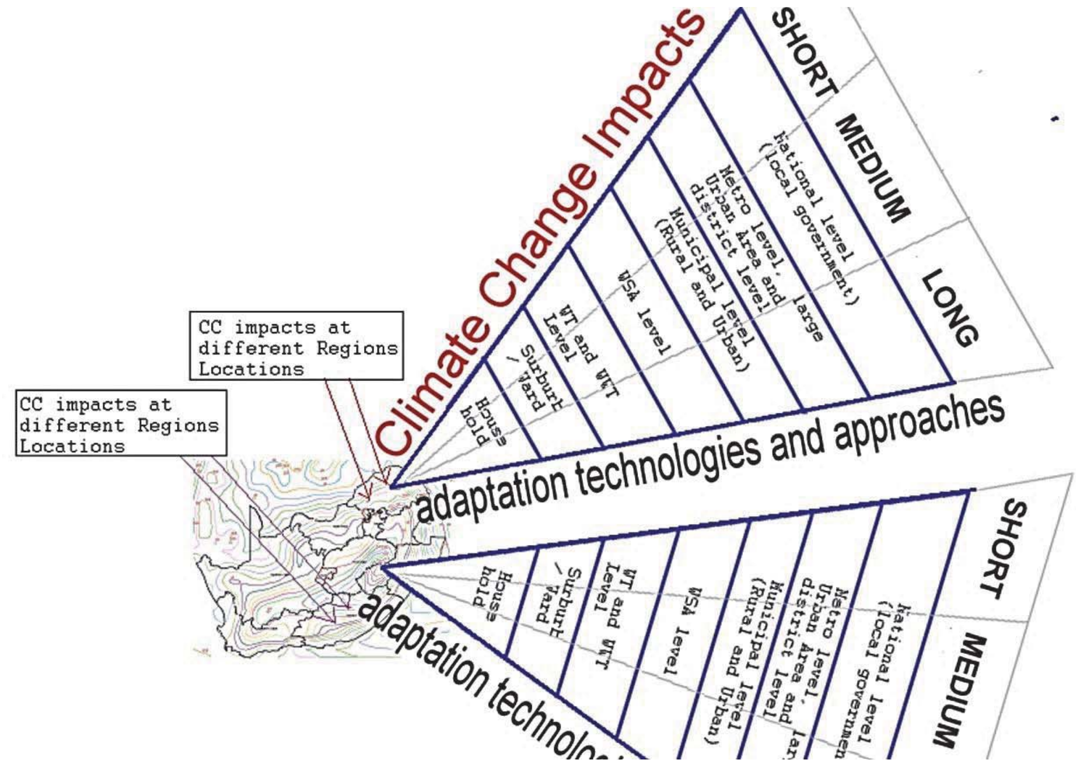

Figure 12: Climate change adaptation is defined in terms of time, based on expected impacts and vulnerability of the region

In developing countries, including South Africa, the urgency to respond to climate change has to be considered in the light of other urgent needs to address other service delivery backlogs. If climate change adaptation is not considered when a great deal of service delivery development is taking place, then it will be more costly to implement adaptation options after all the developments on service delivery have been concluded.

Another factor that is important to consider with regard to time is the level of development of certain adaptation technologies. Although one option could seem to be the most suitable for implementation, it is noted that in some cases certain adaptation techniques will require further research and development before use. An example of such technology for the South African cases is desalination. Desalination in South Africa cannot be implemented on a large scale as yet because feasibility studies and local development of the technology are yet to be completed. Investigations have also shown several such facilities that have been abandoned in countries such as Australia. Although studies of Australia's progress in this field have been extensively conducted, assessments regarding the technology's suitability for South Africa are currently under way and have still to be concluded (Bosman, 2014).

The development of legislation, adjustment of policies, and implementation of response strategies are also elements of time that may speed up or hamper the process of adaptation. Currently many national institutions have developed response strategies which they wish to implement in line with the NCCR white paper, and municipalities have been tasked by SALGA to develop their own unique response strategies based on research and projected trends of future climate change. The use of strategic adaptation options in the municipal business processes, however, remains unimpressive in most local water services institutions, due to the need to focus on water services backlogs, as well as the general lack of resources to implement rolling programmes.

In addition to resource constraints, the levels of technology development, as well as the poor state of existing infrastructure, are obstacles in the pursuit of implementing comprehensive and integrated approaches where climate change adaptation is central to ensure service delivery sustainability. There are existing technologies, however, that can be implemented with relative ease. The successful selection and implementation of adaptation TAs will also depend largely on the geographical setting and location of the different areas where adaptation is being considered.

4.4 Geographical setting and regional climate

Adaptation is not just a response to climate change, but has to be developed holistically in the light of other vulnerabilities which result in the unique impacts that are experienced at specific stages of water and wastewater services provision. These impacts are also unique for each particular geographical location. It is important to note that climate change trends and projections for the water sector are not similar across South Africa. Therefore the use of the adaptation guide is greatly dependent on the region in which a user is located, the level of development of that region, and the climate projections for that region.

4.4.1 Level of geographical development

There are two main classifications of South Africa in respect of the level of development – rural and urban areas. Observations of the case studies have shown that the level of development of a region affects the availability of skills, services, infrastructure, and resource capacity.

In many rural areas across South Africa, water service provision is highly limited. Residents often rely on nearby surface water or boreholes for their basic water needs. It is also common for residents of rural communities to depend on rainwater harvesting during the rainy season, while some areas lack access to an adequate potable water supply. Generally, there is a lack of sophisticated water treatment infrastructure, and water distribution channels in these areas are inadequate due to the communities being highly dispersed. The major challenge with rural communities is the lack of skilled personnel in water services, which in turn results in sub-optimal water service delivery systems. Furthermore, in rural communities, residents hardly pay for water services as they cannot afford them, making it difficult for municipalities in these areas to successfully address backlogs as they are financially incapable of doing so. In the face of climate change, rural communities stand a risk of increased water stress, and possible loss of homes due to flooding as a result of increased intensity and duration of rainfall. In other instances, the communities suffer from a lack of water due to drought after long periods of extremely low rainfall.

Urban areas face a set of different challenges. Increased migration from rural regions to urban areas will increase the stress on urban water services, and possibly reduce the efficiency of designated water service providers. Increased water demand due to an increased temperature will have to be met with quicker water processing times, and technologies that moderate water use. Most urban municipalities have the advantage of water boards. Water boards are often able to conduct extensive research, test new technologies, and implement necessary measures to address any existing backlogs in infrastructure, water use management, water resource management, etc. Furthermore, the presence of water boards attracts the right skills, and urban residents improve the financial standing of their municipalities due to their ability to pay for water services.

Another geographical setting to consider is coastal cities. Whether urban or rural, coastal cities face additional challenges in terms of extreme events that may possibly occur as a result of climate change. Sea surges, loss of homes and infrastructure located along coastal lines remain issues of concern locally and internationally.

Based on the level of geographical development and access to water, decision-makers and users of the adaptation guide can assess their geographical settings based on the classifications they fall into in Table 4.

Table 4: Geographical classification of South Africa based on level of development, water access, and coastal proximity

Geographical setting	Depiction	Description
Rural 1	R1	Rural areas with little to no water access
Rural 2	R2	Rural areas with access to developed surface water
Rural 3	R3	Rural areas with boreholes and/or access to limited surface water
Urban 1	U1	Urban and semi-urban areas with developed surface and/or groundwater, but failing or non-existent water boards
Urban 2	U2	Semi-urban and urban areas with well-developed service systems and/or large fully functional water boards
Coastal	C	Coastal cities and towns (This is a further classification for coastal cities and towns)

The level of infrastructure development in the different geographical regions should also play a role in the selection of adaptation technologies and approaches. In rural areas where water service systems are non-functional, adaptation to climate change is an opportunity to install appropriate infrastructure that can address the challenges specific to such regions, and at the same time deal with service sustainability issues which often affect such communities. The issue of skills, community commitment and infrastructure vandalism are usually associated with rural services facilities. Water service provision solutions in such rural areas could focus on the installation of automated, high security water service infrastructure. This is set to address the lack of skills, unwillingness of available skilled individuals to relocate to work in such areas as well as the propensity for vandalism. The selection of options for rural areas should also be simple, affordable and easy to operate should there be need for the infrastructures to have an operator.

In many urban regions, adequate and functional infrastructure already exist; the increased pressure on water services as a result of climate change however may result in the need to optimize existing infrastructure and processes, to ensure that the end user's needs are adequately met. It is therefore imperative during the selection of adaptation options in urban areas that improvement and optimization technologies and approaches be seriously considered, as opposed to the construction of completely novel structures, unless they are absolutely necessary. The selection of options for urban areas should focus more on improving the current existing processes rather than seeking novel infrastructure. The observations made in the case studies during the development of this guide showed that the three large water purification facilities in urban areas visited had ozonation facilities which were built in the recent past but were not being utilized, resulting in unnecessary wastage of resources.

4.4.2 Climate projections and hydroclimatic regions

The past, present and future climate trends are important in the selection of adaptation options. Emphasis, however, has to be placed on the future climate for the different time horizons. The local variations in climate trends are complicated by regional and global effects such as the El Nino Phenomenon and other unpredictable variations of sea surface temperatures, as well as internal convergence of currents such as the Inter-tropical Convergence Zone (lTCZ) over southern Africa. In addition, the permanent changes due to global warming have a developing effect that is still building momentum. Adaptation involves responding to the permanent changes. Given the high cost of adaptation, it is important that climate trends are more accurately mapped before extensive adaptation plans are implemented.

In order to easily understand the climate trends and projections for South Africa, the DEA LTAS studies adopted six hydroclimatic zones that are based on the water management areas. The LTAS climate scenario technical work analysed recent trends in climate, and synthesized a range of potential future climate conditions that plausibly could occur in South Africa over the defined time frames, that is 2015-2030 (short term), 2040-2060 (Medium Term) and 2080-2100 (Long Term). To reduce the complexity of the multitude of simulations performed in CC projections, the DEA opted to focus on two main groups of scenarios, namely unmitigated (unconstrained) and mitigated (constrained) future energy pathways. Observed climate trends for South Africa from 1960 to 2010 were analysed and constituted the baseline.

The LTAS process covers the six hydroclimatic zones at sub-national level (Figure 13). These zones are based on Water Management Areas (WMAs) and grouped according to their climatic and hydrological characteristics. They can thus be appropriately modeled and analysed for impacts on the water sector, and related indirect effects on other sectors (DEA, 2013a).

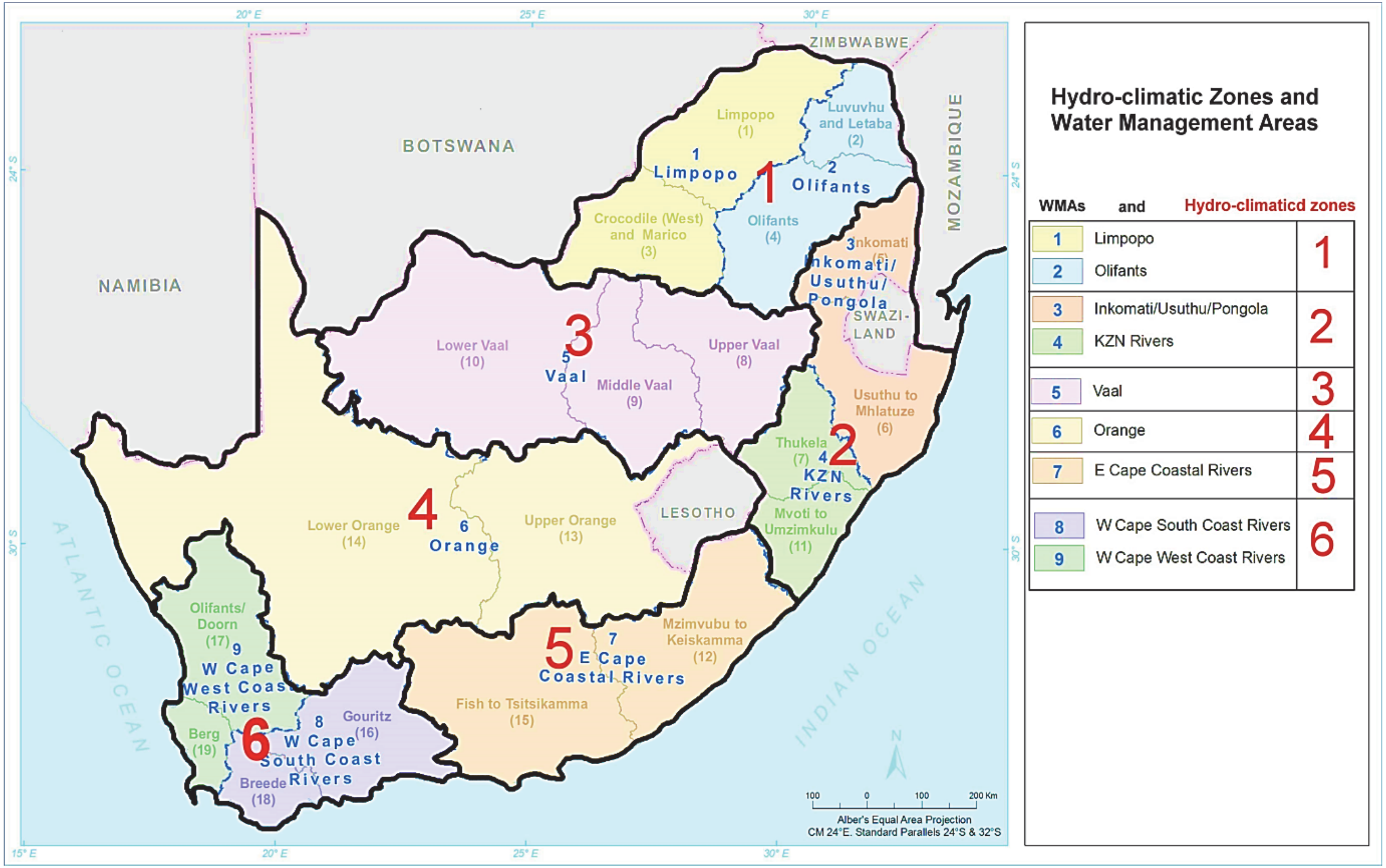

Figure 13: Six hydroclimatic zones of South Africa reflecting boundaries defined by Water Management Areas (WMAs). (Map was developed from DWA, 2013 and DEA, 2013a)

4.4.3 Climate change projections used in the adaptation guide

In the LTAS, the researchers suggest that they were futuristic in their approach which utilized improved 2013 simulations from the investigations on climate conducted by the SA Treasury and National Planning Commission. These simulations applied hybrid frequency distribution (HFD) of all possible climate futures resulting from the current set of global General Circulation Models (GCM) during that period. HFDs were generated using a two-dimensional atmospheric model of the MIT Integrated Global System Model. It is noted that the projections used over 6 000 possible climate scenarios which were produced and analysed for two possible scenarios: Unconstrained Emissions (UCE) and Level 1 Stabilization (L1S) (Treasury and National Planning Commission, 2013). In the LTAs the outputs from the HFDs were compared with downscaled models for South Africa produced by LTAS Phase 1. The result was the need to correct the wetter conditions generated in the HFDs.

To improve the understanding of projections from global circulation models, trends from available records over multiple decades are also presented as captured in the LTAS programme. These are based on records for the period 1960 to 2012. The information was derived from a number of recent studies, both global and regional in scope, which quantified how rainfall and temperature have varied in South Africa over the last century (Table 5, below).

Table 5: Observed temperature and rainfall trends (1960-2012)

Zone 1	Extreme changes in very hot days and very intense rainfall events. Fewer rain days.
Zone 2	Rainfall days are increasing, and the events are more intense. Temperature extremes increasing with more extremely cold days.
Zone 3	Region is characterized by opposing trends. In general extreme temperatures are on the rise. Extremely cold nights are also on the rise.
Zone 4	The region is characterized by a large climatic gradient such that regional mean values are not realistic. Extreme temperatures are rising for all seasons. Rainfall trends show that little changes are taking place.
Zone 5	Significant increase in rain days across whole region. Minimum and maximum temperatures are becoming more extreme.
Zone 6	Rain days are decreasing along the south and increasing along the west coastal areas. Extreme temperatures are also increasing.

In this guide, the Long-term Adaptation Scenarios Flagship Research Programme (LTAS) projections were interpreted to provide average trends per climatic region and used as part of the selection criteria for adaptation options (Table 6). Historical run-off changes (Figure 14) were also used to point to trends that are associated with rainfall change.

Table 6: Future climate projections based on the six hydroclimatic zones of South Africa (DEA, 2013a)

Zones	**Climate Projections in terms of temperature and water**	**Projected run-off changes (median UCE)** x100%	**Projected Temperature changes (2040-2050) (°C)**	
			HFD UCE (median)	**HFD L1S (median)**
1	High level of uncertainty regarding future precipitation and temperature. Water availability remains a key area of concern. High variability in precipitation predictions.	-0.1 / +0.15	1.75	1
2	Potential for increased precipitation; highly unlikely that climate change will affect water supply; increased potential for floods due to increased wetting.	+0.05 / +2.0	1.60	1
3	Precipitation will either remain constant or increase. Mean annual temperature will increase but no radical shifts are expected. Possibility of flooding in some parts.	-1.0 / +0.25	2	1
4	Extremely vulnerable to temperature increases. Mean annual temperature likely to increase twice as fast as the entire country. Rapid increase in temperature will result in increased water losses and irrigation demand in dry areas; accumulation of salts in water bodies causing higher salinity.	-1.0 / +0.15	1.75	0.75
5	Intermediate future shows lower mean annual rainfall which will result in reduced run-off, and decreased soil moisture. Region is likely to get drier, although this remains uncertain. Coastal region, hence threatened by ill effects of climate change on coastal bodies.	-0.05 / +2.0	1.75	0.75
6	Potential increase in rainfall and evapotranspiration due to increased temperature. Region is likely to become drier, however sea level rise remains a threat to coastal cities.	-0.1 / +0.05	1.5	0.6

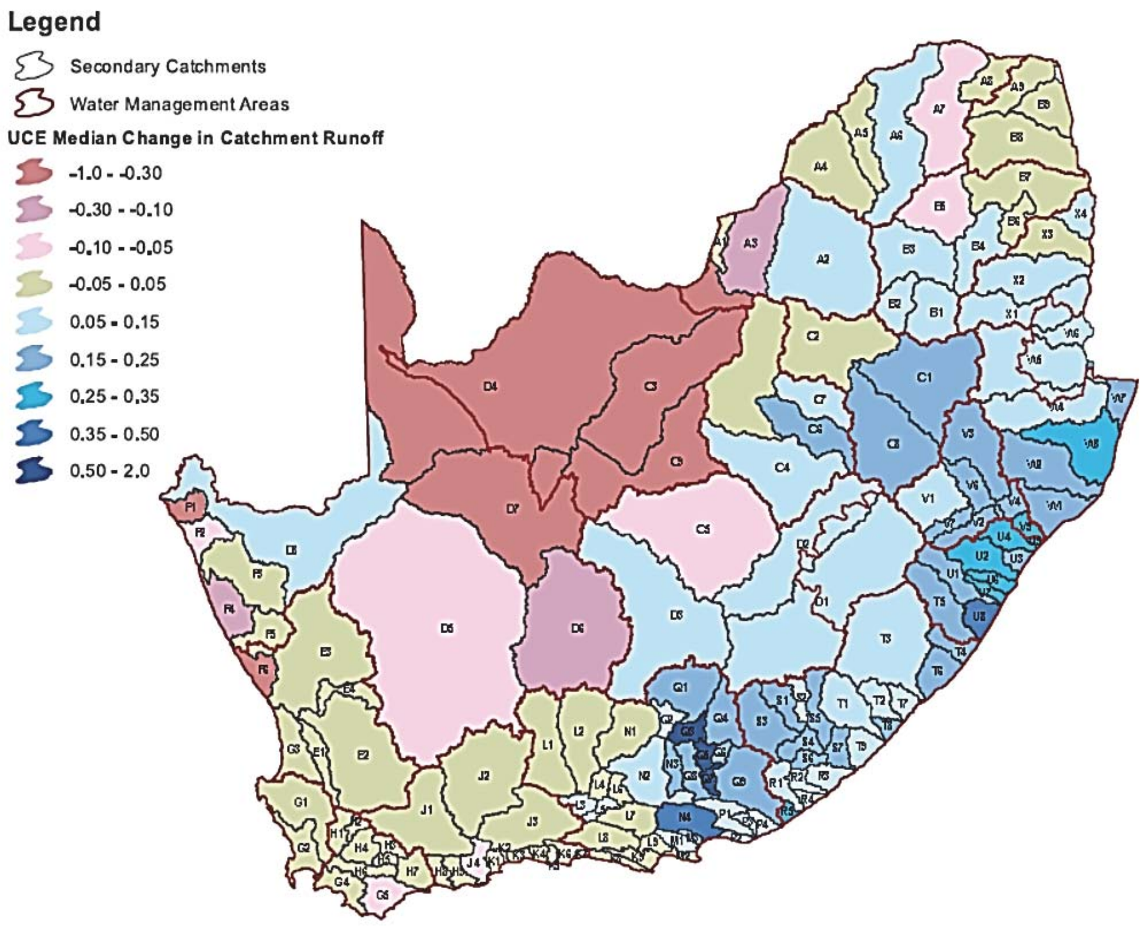

Figure 14: Projection of impact of climate change on run-off for the period 2040-2050 when compared to the base scenario of 1990-2000 (6 000+ scenarios were used for the unconstrained emission scenario) (DEA, 2013a)

Rainfall projections for the different zones were also simulated (DEA, 2013a). These projections are based on the DEA's scenarios which constitute four climate possibilities (Table 7). The warmer/wetter and warmer/drier scenarios indicate scenarios with high level of mitigation, while the hotter/wetter and hotter/drier scenarios indicate unconstrained climate scenarios. In spite of rainfall remaining the same or slightly decreasing in some areas, Figure 14 shows that there are areas where run-off is reduced by 100% (-1.0). The high evaporation in the country, which averages 1 400-3 000 mm/year, with projected increases, will result in the total loss of run-off in these areas.

Table 7: Rainfall projections for the six hydroclimatic zones under the DEA's four scenarios

SCENARIOS	HYDROCLIMATIC ZONES					
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**
Warmer and wetter	Increased in spring and summer	Increased in spring	Increased in spring and summer	Increased in all seasons	Reduced in autumn, increased in winter and spring	Reduced in autumn, increased in winter and spring
Warmer and drier	Reduced in summer, spring, and autumn	Reduced in spring, and strongly reduced in summer and autumn	Reduced in summer and spring, strongly reduced in autumn	Reduced in summer, autumn and spring	Reduced in all seasons, strongly reduced in summer and autumn	Reduced all seasons, strongly in the west
Hotter and wetter	Strongly increased in summer and spring	Strongly increased in spring	Increased in spring and summer	Increased in all seasons	Strongly increased in all seasons	Reduced in autumn, increased in winter and spring
Hotter and drier	Strongly reduced in summer, spring and autumn	Reduced in spring, and strongly reduced in summer and autumn	Reduced in summer and spring, strongly reduced in autumn	Reduced in summer, autumn and spring	Reduced all seasons, strongly in summer and autumn	Reduced in all seasons, strongly in the west

4.4.4 Other factors affecting selection based on geographical setting

In selecting adaptation options, there are other factors related to the location that need to be considered besides climate projections. Projected water demands for various regions have been mapped. Figure 15 gives an indication of the level of demand that can be expected in the face of climate change. Furthermore, the utilization of groundwater as a supplementary water resource is an option that is strongly under consideration. Figure 16 shows the zones in which groundwater is present. These two factors were taken into consideration in the adaptation selection process.

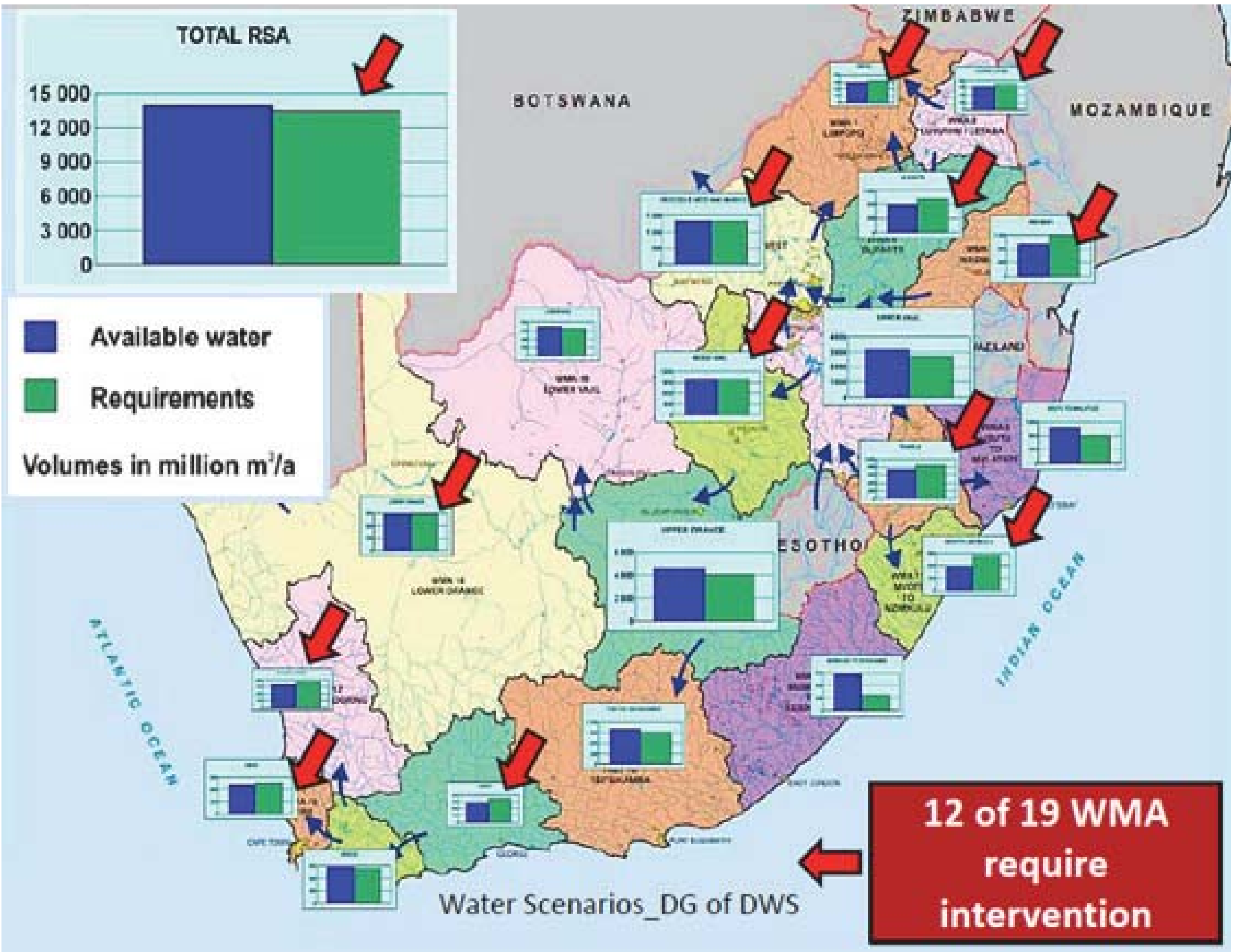

Figure 15: Projected water demand and availability in WMAs for 2025 (DWS, 2014)

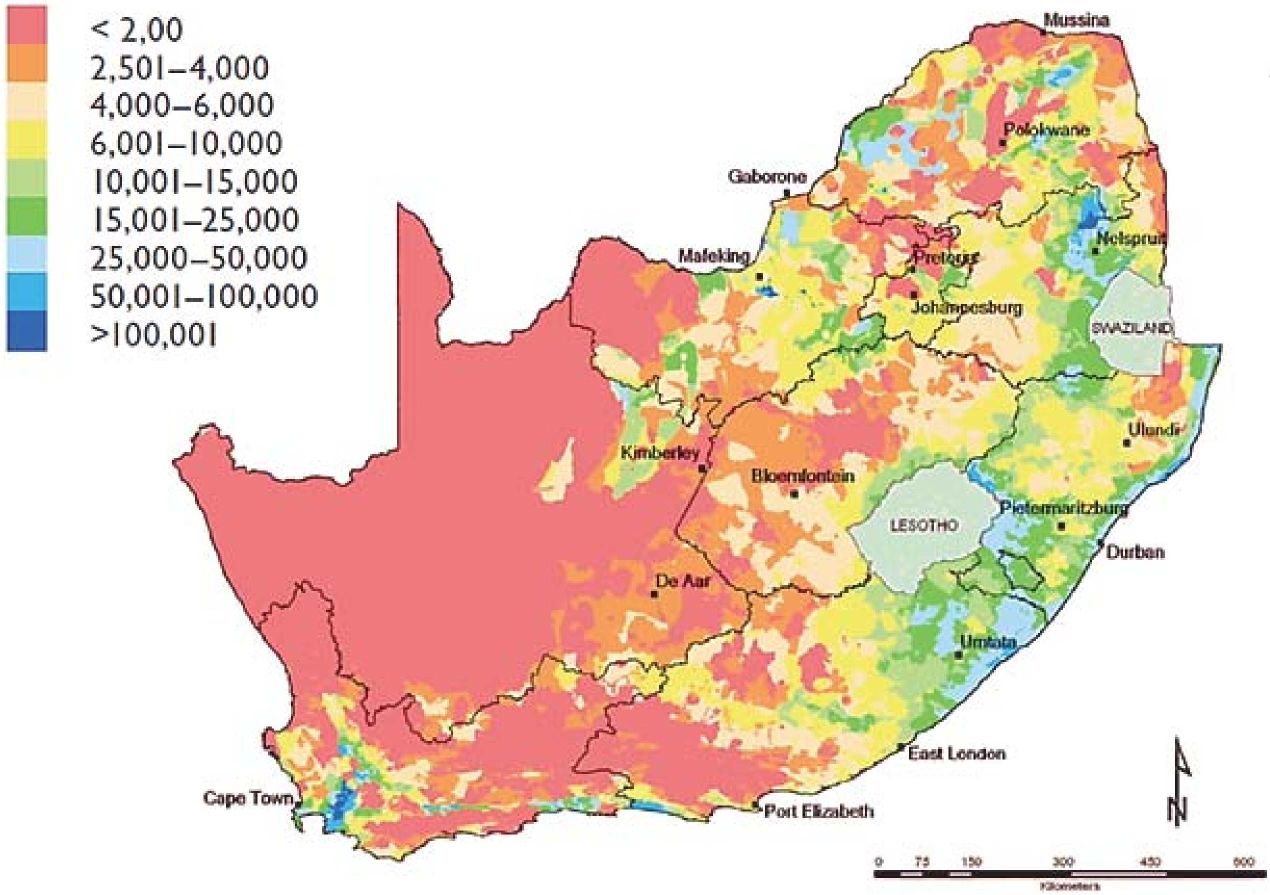

Figure 16: Utilizable groundwater exploitation potential in m^3km^2/a (DWA, 2010)

5 Adaptation compendium

5.1 Adaptation technologies and approaches at municipal level

Limited resources and lack of information are often cited as the major constraints in the uptake of adaptation options in municipal planning. The lack of information translates into uncertainty, which makes it difficult for local government institutions to direct resources to adaptation programmes with confidence. In the short term, the approach for implementing adaptation should be directed towards those processes which have already been identified as challenges in the prevailing environment. In South Africa one of the main challenges in water services is flooding. Climate change projections are also indicating that there will be increased incidences of flooding and increased intensity of extreme flooding incidences throughout the country. Observations at both potable water purification plants and wastewater processing facilities showed that the facilities face the greatest service provision challenge during flood events.

To ensure the best use is made of the available resources, the municipal planner or water services manager has to identify and list all the planned projects associated with water services. Processes that are at risk of climate change can then be identified. It is important that the nature of impacts and risk are quantified. The following section deals with quantification of impacts and vulnerability, which has to be done before committing resources to adaptation options.

5.2 Quantification of impacts and vulnerability in water and wastewater services

Ideally, consideration of adaptation should start with understanding the impacts and quantifying them to identify the cases requiring prioritization. Quantification of impacts involves impact assessments where the values associated with the extent of impacts are presented in comparable measures. Quantification of impacts of climate change is the first step in developing climate change adaptation strategies. One method for quantification of impacts and vulnerability entails the use of quantified indicators. Dannevig et al. (2012) developed a four-step indicator for measuring the degree of implementation of adaptation that involves:

(1) Assessment of the need to adapt in different sectors which requires the municipality to assess its vulnerability to climate change.

(2) Qualitative vulnerability assessment such as climate scenarios are carried out and corresponding adaptation measures are identified in municipality plans.

(3) Quantitative vulnerability assessments such as flood risks and sea level rise are done and corresponding adaptation measures identified in plans.

(4) Benefits of identified options are analysed as part of the whole business planning process. Alternative options are also compared.

5.3 Water and wastewater processes for adaptation

In the South African context, municipalities offer a range of water-related services whose various significant components can be vulnerable to impacts of climate change. It is in these areas that intervention through adaptation technologies and approaches is imperative and will thus need to be applied to alleviate the range of impacts and implications of expected climate change.

In theory all municipalities supply a range of services associated with the provision of treated water and the treatment of wastewater. These services constitute elaborate systems with an infrastructure and many different processes and components, all of which can be vulnerable to different degrees of negative impact due to climate change. It is necessary to dissect each system into its vital components, and examine the impacts and implications of climate change on them. The following make up the most significant components of the water and wastewater services delivery system of most local authorities.

Water supply:

Water supply can be a complex undertaking depending on the size of the communities served, their settlement pattern, the proximity of raw water sources and the available resources. The institution providing this service has to be well versed with the socio-economic development of the area to be supplied. The nature of available services has to be clearly understood. This includes the nature and specifications of different sources of water, large raw water storage facilities, treatment plants, and local storage and distribution networks/systems for the purified water.

The water sources could be groundwater or surface water (e.g. a river or dam), recycled or desalinated water, or water transferred from another system (catchment area). A schematic of a typical water treatment process is given in Figure 17. The distribution system comprises a network of pipes that usually starts with a main distribution line from reservoirs which then branches into smaller reservoirs and towers that feed reticulation pipes serving individual properties. These stages of water provision are analysed for opportunities to adapt and ensure service provision sustainability into the future.

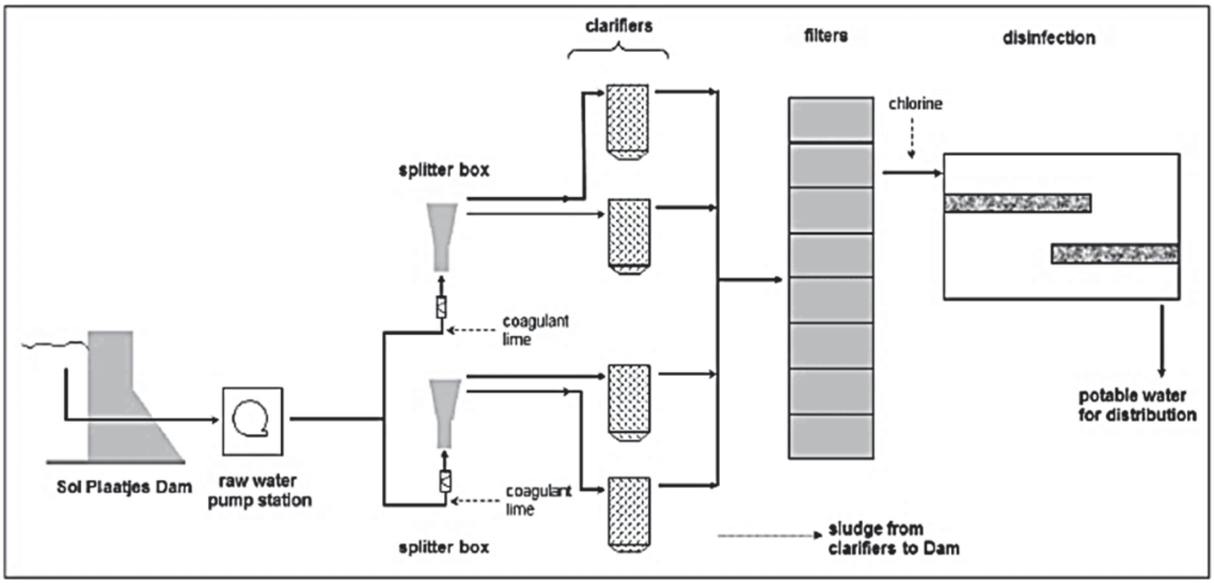

Figure 17: The schematic of a typical water treatment works for a municipality in South Africa. (Source: Budhram et al., 2013)

Wastewater (sewage) treatment system:

The service provider intending to adapt the wastewater system has to look at the various stages for possible adaptation (Figure 18). In general wastewater facilities have three main stages where adaptation can be applied – the primary, secondary and tertiary treatment.

- ***Primary treatment*** consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment.
- ***Secondary treatment*** involves the removal of dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. These micro-organisms are already being affected by CC, thus exposing the processes to adaptation. Most adaptation in secondary treatment is set to take advantage of the increasing temperature. Increased flooding, also due to CC, however, means that the design of these facilities needs to be reconsidered and possibly modified.
- ***Tertiary treatment****,* as the process applied beyond primary and secondary treatment, is usually set to be updated or adapted to ensure that the effluent from the facility does not threaten the environment, and where possible, is re-used. Treated water is sometimes disinfected chemically or physically (for example, by lagoons and microfiltration) prior to discharge into a stream, river, or wetland. The chemicals used, as well as the other chemicals and processes that are being developed now, can be selected for application to enhance the effectiveness of the wastewater purification service.

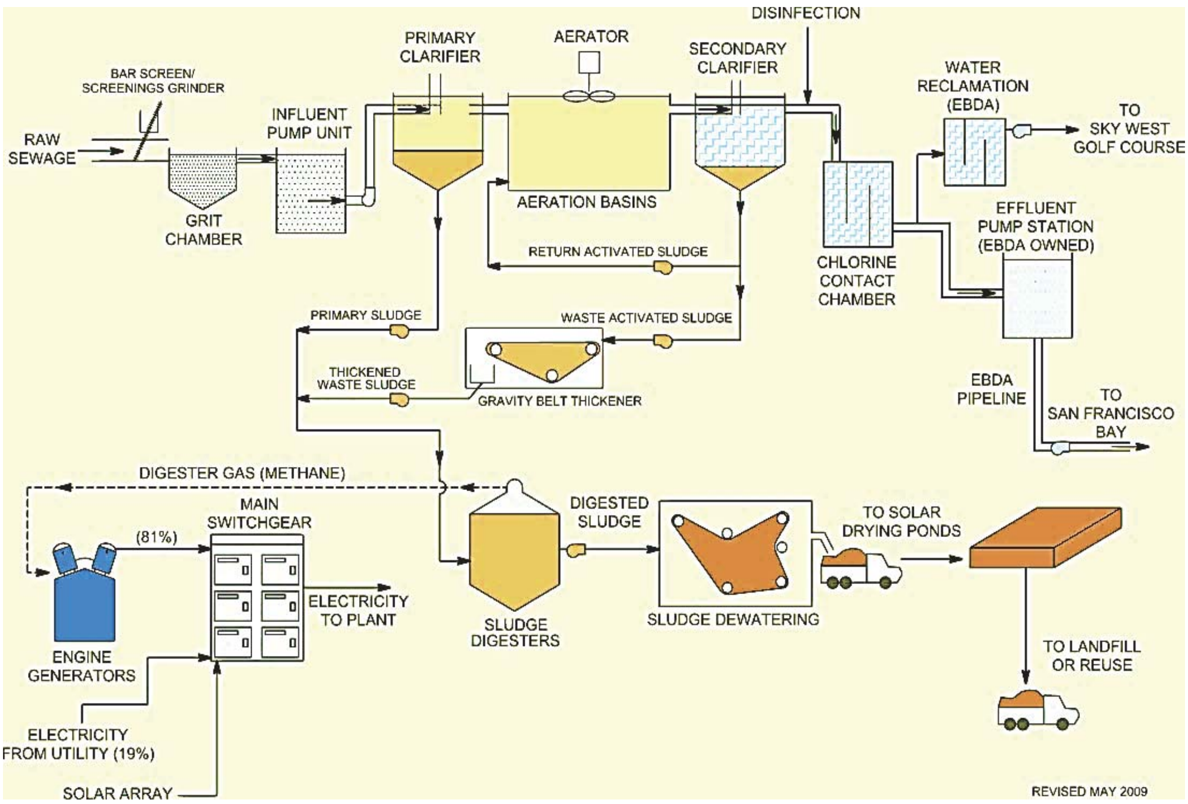

Figure 18: A schematic of the components and process of a wastewater treatment system

Infrastructure and processes related to wastewater services are exposed to the impacts and implications of climate change in different ways. It is through design and adoption of adaptation technologies and approaches, mainstreaming climate resilience into process efficiency, infrastructure investment, building regulations, and disaster preparedness that municipalities can hope to adequately counter the adverse effects of climate change in the water and wastewater services sector. The proposed technologies are grouped according to different points in the service delivery process for easier reference when relating to different scenarios where services will be considered for adaptation.

In wastewater services, the role of storm water in acerbating the impacts of climate change is often left out, resulting in poorly developed solutions. Storm water tends to be a process that falls between potable water provision and wastewater systems and yet it is managed by different units in most municipal settings. On the potable water side, storm water brings with it higher levels of pollution as a result of increased rainfall peaks and duration due to climate change. With regard to wastewater services, increased rainfall peaks and duration of flows with and without the impact of climate change affect the volume of water reaching the wastewater purification plant. At the wastewater purification plant, the storage facilities provided when the inflows are too high for the processing rate are usually not adequate for accommodating storm water during the peak of the rainfall season. The situation is deteriorating in areas where Climate Change impacts are increasing rainfall peaks. Most of the wastewater purification plants are also designed with a by-pass route where floodwater mixed with greywater is released directly into the river, causing degradation to the natural water sources. It is therefore important that storm water management is included in adaptation plans to ensure that the adaptation solutions are more robust even during peak storm inflows and floods.

5.4 Technologies in potable water process

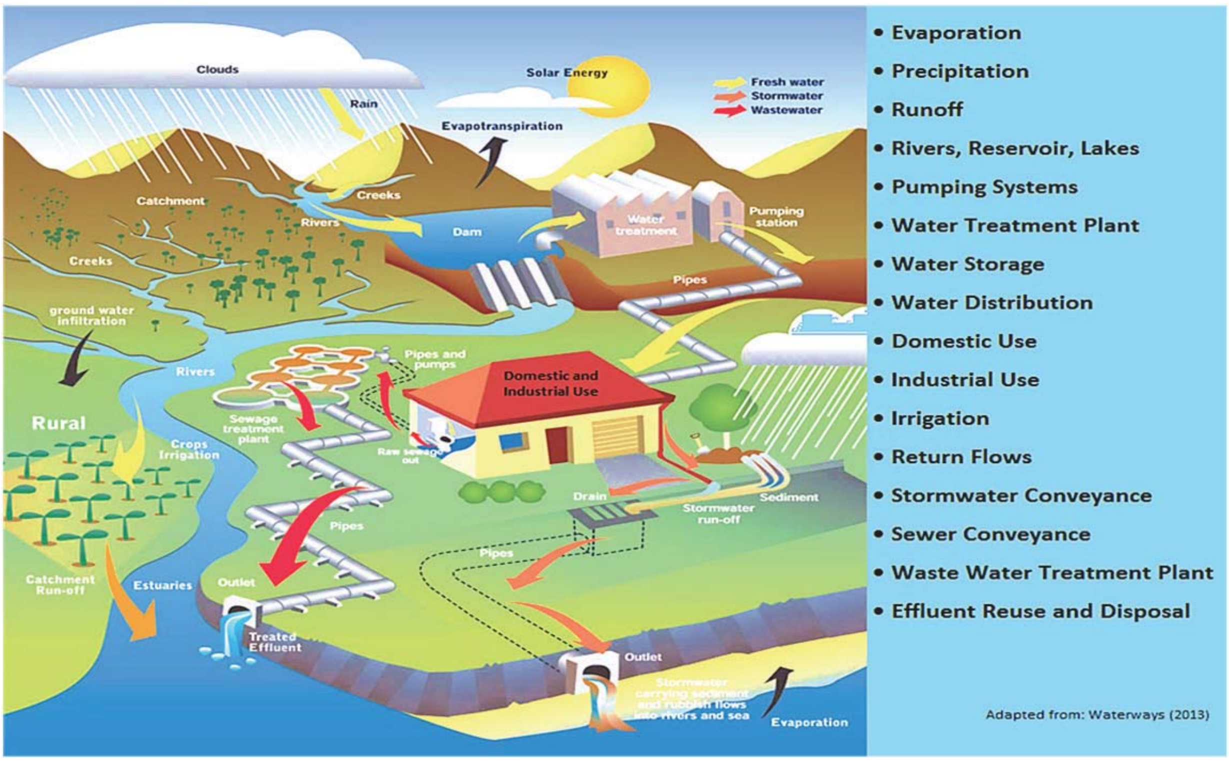

Figure 19: Urban water cycle showing the different water services points that are at risk from climate change

The illustration in Figure 19 shows the different points in the water and wastewater service provision where climate change impacts have to be addressed through adaptation. Given the variety of points for implementation of adaptation, it is important that priorities are set to avoid cases where the solutions are not addressing the most critical impacts. The selection of adaptation options is based on several factors. In this section, however, the priorities are discussed in terms of hydroclimatic characteristics, geographical settings and implementation time frames. The following prioritization indicators are applied in the guide (Table 8):

Table 8: Definition of priority terms as used in the compendium

Priority	Depiction	Description
Very high	**P0**	Should be considered for immediate implementation including retrofitting into ongoing projects and programmes (Section 3 defines the time frames involved)
High	**P1**	Should be considered for short-term implementation. The situation is urgent due to the nature of risk posed.
Medium	**P2**	Should be considered for mid-term implementation. Possibly, needs further investigation and funding to implement.
Low	**P3**	Can be considered in later stages if necessary. In this case, the risk due to impacts could be low, the nature of solution required could be beyond the budget or there could be more cost-effective and accepted options to implement before this. Options where further research is required fall into this category.

The priority settings in Table 8 above are based on the nature of risk, vulnerability and urgency (time factor) for implementation of adaptation options. While this guide provides an assessment of the priority level, the user of the guide has to evaluate the priority further on the basis of the other processes applied within his/her institution. In Chapter 4, the consideration to be made to decide on adaptation priorities is presented. The priorities and other adaptation considerations are aligned to the zones as articulated in the assignment of climate change impacts in the LTAs programme. The zones used are shown in Table 9 below.

Table 9: Definition of hydroclimatic zones as used in the adaptation guide

Zones	Depiction	Descriptions
1	Z1	The Limpopo, Olifants, and Inkomati WMAs in the Northern Interior
2	Z2	The Pongola-Umzinkulu WMA in KZN in the east
3	Z3	The Vaal WMA in the central interior
4	Z4	The Orange WMA in the North-West
5	Z5	The Mzimvubu-Tsitsikamma WMA in the South-East
6	Z6	The Breed-Gouritz and Berg Olifants WMAs in the South West

Tables 10 to 15 present the process of selecting adaptation options for the identified primary, secondary and tertiary impacts of climate change. The symbols used in the tables are explained in the earlier sections of this chapter.

5.5 Adaptation at point of water abstraction from rivers, lakes, and reservoirs

Table 10: Proposed adaptation technologies for the raw water abstraction and water source

Impacts	Technology	Description	Applicable Zones/ Implementation Priority	Geographical Setting
Increased water demand; Reduced surface water; Need for supplementary water sources	Wider use of boreholes as additional source of water and emergency backup supplies in time of drought	Construction of boreholes in strategic regions where groundwater is present will increase the assurance of water supply. Requires extensive investment in borehole prospecting and drilling.	Z1 / P0 Z2 / P1 Z3 / P0 Z4 / P1	All Settings
	Use of groundwater as a supplementary water resource	Increasing temperatures will affect the availability of sufficient surface water. In areas where there will be less rainfall, surface waters may not be easily replenished, and hence it is advisable to consider groundwater recharge of aquifers.	Z1 / P0 Z2 / P1 Z3 / P1 Z4 / P1 (Little potential in Zones 5 and 6; It is not the best option for Zone 4). See Figure 6.	R1 R2 R3 U1 U2

	Desalination of sea water and sea water recharge	Use of sea water as a water resource through desalination. Use of new improved desalination techniques with little environmental footprint should be preferred. Reduce salinity increase at the source by avoiding the disposal of removed salts into the ocean.	Z2 / P3 Z5 / P3 Z6 / P3	C
	Desalination of acid mine drainage and other saline water from the ground	By removing salts and harmful metal pollutants, water from mines can be used for irrigation, in industrial processes, or for other household uses that do not require ingestion of water. For water treated to a higher quality level, the water is supplied for potable uses.	Z1 / P1 Z3 / P0 Z4 / P1	All Settings
	Extension of exiting basin water transfer schemes and development of new transfer networks.	Water is currently transferred between a few basins. This can be extended to include more basins. New transfer methods could also be applied to accommodate smaller and distant basins.	All Zones / P1	All Settings

Accounting for water resources	Efficient water accounting tools	Groundwater is often not adequately incorporated into available water resources. Efficient accounting processes for surface and groundwater to ensure water service providers are aware of the amount of water actually available for use.	All Zones / P1	All Settings
Pollution affecting different levels in the source	Modification of abstraction levels using suitable abstraction equipment	Several levels of abstraction can be established for water that is extracted from dams and reservoirs. This will increase the chances of obtaining good quality and sufficient water for treatment.	All Zones / P1	R2 U1 U2 C
	First level pollutant reduction at abstraction point	Establishment and use of mechanical screens or strainers and flotation process to remove weeds, floating debris and algae. Stabilization of water to reduce chemical needs in later processes (lime or nano-remediation could be applied).	Z2 / P0 Z3 / P0	R2 U1 U2

Water loss due to evaporation and contamination	Secure raw water for safe storage from evaporation and contamination	Secure storage of raw water is becoming a necessity in the face of climate change due to the continued water quality degradation. Storage facilities should be deeper rather than wider to reduce surface area and thus limit evaporation; storage coverage can include the use of solar panels which can in turn be used to power the pumps. Store water in aquifers through recharge techniques.	All Zones / P1	R1 R2 U1 U2 C

5.6 Adaptation at water treatment processes and storage facilities

Table 11: Proposed adaptation technologies for water treatment and potable water storage

Impacts	Technology	Description	Applicable zones/ Implementation Priority	Geographical Setting
Increased temperature affecting flocculation and coagulation process	**Flocculation chambers**	Temperature increases will affect the flocculation process, and may cause it to be efficient only at night when temperatures are cooler. This might result in straining of the water treatment process as there will also be an increase in water demand due to the same higher temperatures. It is advisable to consider the use of cooling tubes around the flocculation tanks to ensure temperatures remain constant even if external temperatures increase, and flocculation process is unhindered, and perhaps even faster. This will require extensive knowledge of the flocculation process in order to	Z1 / P1 Z2 / P2 Z3 / P2 Z4 / P1 Z5 / P2 Z6 / P3	R2 U1 U2 C

		determine optimum temperature. Insulated flocculation chambers are also an option. These include those insulated by being constructed underground.		
	Use of coagulants	The dosage of highly effective coagulants with a wider range of operating temperatures is required in the face of increasing temperatures. This has to be prioritized for cases where flocculation chambers cannot be cooled otherwise application in all cases to improve potable water production is advisable.	Z1 / P2 Z2 / P2 Z3 / P1 Z4 / P1 Z5 / P2 Z6 / P3	R1 R2 U1 U2 C
High temperatures, flooding and other extreme events will result in low water quality	**Sufficient exposure of water to purification chemicals**	Need to develop improved water mixing processes, including use of powered mixing chambers and rotating mixers that increase the exposure of water to treatment chemicals within a shorter period of time in order to meet increasing water demand and deal with higher pollutant loads.	All Zones / P0	R1 R2 U1 U2 C
	Nano-remediation	The use of nanoscale zero-valent iron	All Zones / P1	R1

		particles in groundwater treatment has been investigated and reported in a number of studies, and recommendations suggest that these particles can be used in water treatment. Investigation and application of nanoscale particles in the degradation of pollutants in raw water should be considered when other solutions are not readily available.		R2 R3 U1 U2
	Non-clogging filtration membranes	Development and use of materials or membranes that are non-clogging, and are tailor-made for different pollutants. In this way, removal of harmful pollutants from water can be easily achieved.	All Zones / P3	R1 R2 R3 U1 U2 C
	Ozonation	Oxidation using ozone is a suitable additional disinfectant especially when raw water contains toxic algae. The method is more costly, however, and requires special expertise to use the very volatile and complex ozone. Large facilities could have the	Z1 / P3 Z2 / P2 Z3 / P3 Z4 / P1	U1 U2 C

		ozonation facilities on stand-by for use in cases of flood-induced algal blooms.	Z5 / P2 Z6 / P3	
	UV disinfection	UV treatment is very feasible in the local climate especially in an environment of global warming. It will reduce reliance on chlorine as a disinfectant, and take advantage of naturally existing UV radiation for water treatment. UV radiation can also be used in conjunction with titanium oxide nanoparticles to improve the treatment of water. The method replaces use of chlorine, or can be used together with chlorine.	Z1 / P1 Z2 / P2 Z3 / P2 Z4 / P1 Z5 / P2 Z6 / P2	R1 R2 U1 U2 C

Increased spread of pathogens through water as a result of high temperatures; Increased water demand	**Colloidal silver**	The use of anti-bacterial properties of colloidal silver for disinfection of water and the removal of pathogens in small water systems. The technique can be used to replace chlorine and traditional disinfectants for individual purification systems. Further investigation for use in different water processes including large-scale facilities is required.	All Zones / P3	R1 R2 R3 U1 U2 C
	Individual water resource and filtration systems	Creation of small-scale filtration/ treatment systems that can be operated without highly skilled support. These can be home-sized filters or community-based systems that can be operated without skilled personnel or support.	Z1 / P2 Z2 / P2 Z3 / P1 Z4 / P1 Z5 / P2 Z6 / P2	R1 R2 U1

	Automated multi-stage filtration and other high pressure systems	Development of self-cleaning filtration systems, non-clogging filtration membranes and automated addition of chemical additives in water treatment could be of use in areas where skilled support is lacking.	All Zones / P1, P2	R2 R3 U1 U2 C

5.7 Adaptation at water distribution and use by domestic, industrial and agricultural outlets

Table 12: Proposed adaptation technologies for water use and conveyance

Objectives	Technology	Description	Applicable zones/ Implementation Priority	Geographical Setting
Address low water quality at end user	**Chlorination during conveyance**	Water distributed to end users does not usually contain the optimum concentration of chlorine as it goes through the conveyance channels. To use technology for automated chlorine dosing at various locations and without personnel. Adding a specified amount of chlorine at various points of a conveyance system. The chlorination addition systems could be integrated into existing conveyance systems.	All Zones / P0	All Settings
	Use of colloidal silver during conveyance	Removal of pathogens in areas with increased temperatures will be of great necessity as pathogens are expected to increase with climate change.	All Zones / P2	R2, R3, U1, U2, C

	Protection of conveyance systems from corrosion	In the face of increasing temperatures, corrosion and other degradations of pipelines are aggravated. Investigation and use of cathodic protection as a corrosion prevention technique can be utilized to ensure conveyed water is not contaminated by corrosive products. Use of suitably lined pipes.	All Zones / P1	All Settings
Address increase in water demand	**Use of recycled water**	Wide-scale development and use of recycled potable water and greywater. Many industrial establishments do not need the potable water, and the access to greywater has to be developed for these. Develop reticulation for greywater. Recycled greywater collection and treatment systems can be developed within homes, public buildings and facilities.	All Zones / P0	All Settings
	Efficient water use	Use of the same amount of water to cover larger areas by using more efficient distribution systems. Avoid communal water points but	All Zones / P0	All Settings

		install individually metered points. Install prepaid meters. Apply incentives for large-scale water saving at major water users such as factories, office blocks and other businesses.		
	Demand management of water used by households and industries	Municipality or service provider can use steep water tariff plans to restrict use. Cutting on losses through pressure management. Revamping the water plumbing at user level (DWS has a suitable initiative where thousands of plumbers are being used to addresses shortcomings at the point of use.) Implement modern water use accounting and revenue collection tools.	All Zones / P0	All Settings

5.8 Adaptation technologies in wastewater process

5.8.1 Storm water and sewer conveyance

Table 13: Proposed adaptation technologies for storm water and sewer conveyance

Impacts	Technology	Description	Applicable zones/ Implementation Priority	Geographical Setting
Increased flooding and extreme rainfall events	**Do away with bypasses at WWTW**	Storm water often mixes with sewer water due to erroneous water connections, or bypasses created at WWTW facilities. Rather than creating bypasses, adequate separate storage systems should be created for storm water and greywater.	All Zones / P0	R1 R2 R3 U1 U2
	Flow management of storm water and sewers	Poorly constructed conveyance systems often result in erratic flow of storm water and sewer water. Well-connected conveyance systems necessary for flow management. Do away with wrong connections at domestic, municipal and industrial outlets.	All Zones / P1	All Settings

	Efficient sewer and storm water drainage	Plumbing at houses to separate greywater and storm water with no chance of mixing. Penalize households, business or other facilities where storm water is connected to the greywater and also where greywater is connected to the storm water. Modernize urban storm water and sewer water conveyance to account for system performance, capacity, losses and bottlenecks	All Zones / P0	All Settings
	Effective stormwater drainage using public infrastructure	Stormwater can be collected through the use of porous pavements, and the design of drainage pathways at public for storage. This will reduce the effect of water resource degradation through pollutants carried in stormwater. The water collected can be conveyed for treatment or used at public buildings for non-potable uses	All zones/P2	All settings

Increased temperature and extreme temperature events	**Prevention of conveyance system degradation**	Increase in temperature may facilitate the reaction of certain components of conveyance systems with effluent components. Can prevent degradation by utilizing protection technologies.	All Zones / P1	R1 R2 R3 U1 U2 C
Increased solid matter in flooded sewer systems	**Screening at wastewater plant inlets**	The use of screens at wastewater treatment inlets will reduce the amount of debris that flow into the treatment plant, hence reducing their negative impact on the treatment process. This improves operation efficiency and potential capacity of facility.	All Zones / P0	R1 R2 R3 U1 U2

5.8.2 Adaptation in wastewater treatment and effluent reuse

Table 14: Proposed adaptation technologies for wastewater treatment processes and effluent reuse

Impacts	Technology	Description of Adaptation	Applicable Zones/ Implementation Priority	Geographical Settings
Increase in Temperature and UV light concentration	**Anaerobic and aerobic digesters**	Digesters should be redesigned to fully exploit increase in temperature for improving the rate of anaerobic digestion process. Digestion tank materials should be heat-absorbing to enable the speed-up of the process.	All Zones / P1	All Settings
	Reduction of contact time in digesters	By taking advantage of the increased temperatures, contact time can be reduced for the anaerobic digestion process. Thus increasing output of wastewater treatment systems.	All Zones / P1	All Settings
	Photo-catalysis in tubular solar reactors	Use of light to break down substrate compounds and increase ease of access to compounds by digesters. This could also	All Zones / P2	All Settings

		be used in conjunction with nanoparticles to increase degradation of pollutants.		
	Advanced oxidation	Take advantage of increased UV concentration, or ozone, hydrogen peroxide, hydroxyl radicals to treat wastewater.	Z3 / P3 Z2 / P3 Z5 / P3 Z6 / P3	R2 U1 U2
Increased pollutants and pathogens due to flooding and high temperatures	**Use of membrane filtration for the removal of pollutants**	Membrane filtration has been well-developed in South Africa; however, implementation has not been enforced. The use of membrane filtration could aid wastewater treatment because membranes developed according to pore sizes can remove a range of unwanted substances, especially suspended solids.	All Zones / P3	All Settings
	Ultrafiltration and nano-filtration in local municipalities	This can be used to remove small colloidal particles, a.k.a. suspended solids, which are often present in high concentrations in wastewater. For local municipalities, it will be important to consider non-clogging filtration materials.	All Zones / P2, P3	R1 R2 R3 U1

	Reverse osmosis	Reverse osmosis will reduce duration of water in settling tanks; hence will reduce risk of pathogens and loss of water through evapotranspiration. It is also applied for desalination but uses significantly high energy levels.	Z3 / P3 Z4 / P2 Z6 / P2	R1 R2 R3 U1 U2 C
Seawater rise resulting in seawater intrusion	**Use of sea water intrusion sensors and barriers.**	Use electrical resistivity tomography to determine water intrusion statistics and apply automatic pumping systems to balance abstraction with non-saline water inflows thus avoiding sea water intrusion. Install sea water intrusion barriers	Z2 / P2 Z4 / P3 Z5 / P3 Z6 / P2	U1 U2
Increased water demand	**Create more solid sludge**	Ensure all of the water in sludge is extracted to avoid water wastage through sludge disposal.	All Zones / P2, P3	All Settings
	Treat wastewater to tertiary level	Wastewater can be treated to tertiary level where it can then be used to serve as potable water to communities, and help address increased water demand in the face of increasing temperatures.	All Zones / P2,P3	All Settings

	Water reuse	Greywater can be used again for certain uses. For certain uses, water quality does not have to be as high as potable water. Certain industrial uses, construction and irrigation of urban lawns and gardens (not for vegetables and crops).	All Zones / P1	All Settings
	Use of other marginal water	Identifying unaccounted-for water, leaking water and other wasted water, and tapping into this water for use.	All Zones / P1	All Settings
	Screening and removal of priority pollutants in industrial effluents	Some industrial effluents contain high grade pollutants that are easily dissolved and are not detected by current municipal water systems. Screening methods for such pollutants and removal techniques need to be developed	All zones/ P1	All settings

5.9 Technical adaptation in other associated technical and non-technical areas (Indirect Adaptation TAs)

Table 15: Proposed adaptation technologies for associated technical and non-technical areas

Impacts/ Objectives	Technology	Description	Applicable Zones/ Implementation Priority	Geographical Settings
Flooding/ Address high energy consumption and loss of energy	**Rainwater harvesting**	Encourage and provide for rainwater harvesting at households and other facilities. This addresses issues associated with flooding while also preventing loss of energy. By harvesting rainwater directly instead of letting it flow to the rivers, less energy is consumed in sourcing the water. Reduction in power use also reduces water consumed during power generation as less power will be required.	All Zones / P1, P2	R1 R2 R3 U1 C

	Creation of flood attenuation systems including dams	The creation of drainage dams to collect floodwater that can be stored for use during dry seasons will be highly beneficial. Storage of run-off underground including in storage facilities under car ports in urban areas.	All Zones / P2	R2 R3 U1 U2 C
	Reduction of power consumption at the abstraction point and during water purification	Development of energy-efficient processes. These reduce water consumption in the power production process. Use of water's energy in water conveyance to generate electricity. Less electricity translates to less water use for the types of power production in South Africa (e.g. coal power stations).	All Zones / P1, P2	R2 R3 U1 U2
	Gravity-powered distribution channels	Use of gravity-fed systems to transport water to end users and reduce energy consumed and cost of the process.	All Zones / P2	All settings

	Methane capture at wastewater plants	Take advantage of high methane concentrations released from anaerobic processes. Methane capture in anaerobic digesters can be used to generate the power required to drive treatment processes and hence reduce water consumption. Methane could be used to directly produce heat energy and also to generate electricity.	All Zones / P2	U1 U2 C
General CC impacts causing poor performance in existing system	Expert Tools and Live Online Controls of processes	Changes in temperature and rainfall patterns create new complexities in water and wastewater service provision. The new challenges will require an update to the operations, including software used in the case of large facilities. Large facilities were observed to be running with several disjointed software tools. These tools need to be integrated and updated to take advantage of other recent technological improvements, especially in the area of live data and immediate communication. Technological solutions of this nature are to be accompanied by appropriate skills and knowledge.	All Zones / P1	U1 U2 C

	Small scale individual water resource and filtration systems	Development of compacts and other small scale water treatment systems that can be operated by households to help people take control of their water treatment, hence reducing reliance and burden on municipal water providers. This reduces the risk to CC impacts in the whole system.	All Zones / P1	R1 R2 R3 U1
	Increasing water storage capacity in water services systems	Storage facilities are improved by construction of dams, construction of artificial wetlands, increasing dam storage capacity in areas prone to increased precipitation, and reservoirs for winter rain in areas that experience winter rainfall. Water storage is also extended through reduction of evaporation. Implementing covered water storage facilities extends the availability of water.	All Zones / P1	All Settings

Address water use and demand management	Introduce desert type gardens and other forms of landscaping where lawns and greens are not required	It is estimated that gardens in the former white areas with large yards contribute to high rates of water use. On average up to 35 k*l* of water are used in such houses every month, which translate to more than a thousand litres of water each day. Green gardens contribute to the high use. Municipalities can put in place by-laws to direct house owners to have less green and more desert plants.	All Zones / P0	All Settings
	Implement projects to upgrade water reticulation in townships	Several former black townships experience high levels of un-accounted-for water (as high as 70% is common). The reticulation system was disturbed over the years with many illegal connections being installed. These installations are not designed and are usually installed using rudimentary fittings which leak and even cause water pollution. The additional connections are outside the design provision, which results in water shortages, loss of pressure and diseases. Such reticulation systems have to be over- hauled.	All Zones / P1	All Settings

	Low pressure distribution systems	Low pressure systems will reduce water losses and control availability of water at the users' side. Currently, distribution systems utilize high pressure, which encourages unnecessary water loss and wastage.	All Zones / P1	R3 U1 U2
	Dry sanitation	The use of dry sanitation within communities should be encouraged to reduce water demand.	All Zones / P2	R1 R2 R3
	Development of cheap and compact solutions	Use of ceramic materials for filtration. Use of modular water provision systems for small communities. Use of charcoal for filtration, and removal of colour and odour can be investigated. Mass production of low cost filter bottles.	All Zones / P2	R1 R2 R3 U1

	Effluent reuse by industries before release into the natural systems	Investigate and implement the reuse of effluents for chemical and industrial processes to reduce pressure on municipal treatment systems. Make the facilities efficient by aiming to use water several times before it is released.	All Zones / P2	U1 U2
	Development and planting of low-water consumption crops in agriculture	Some agricultural practices use potable water, especially in urban areas. The utilization of biotechnology to aid the development of modified crops that require less water will be of great advantage to the water services sector, as this will help to conserve water used during irrigation processes.	All Zones / P1	All Settings

6 Water and wastewater adaptation approaches

Apart from adaptation technologies, water sector stakeholders have to articulate and implement relevant approaches for adaptation. Adaptation approaches include all the soft issues on adaptation, which range from creating awareness in communities to the high level approaches where legislation and policies are developed to guide adaptation responses.

Adaptation has to be planned at different scales (EPA, 2012; UNFCCC, 2006). The DEA (2013a) identifies three main governance levels: national, system scale and municipal scale. This guide is focused primarily on the municipal scale – water service authorities and water service providers at district or local municipality level. The DEA (2013a) has developed an approach to support the integration of climate change responsiveness into municipal development planning tools. The approach involves five steps:

Preparation – setting up a municipal lead department to drive the process and creating a municipal interdepartmental climate change response committee;

Analysis – identification of climate change challenges;

Strategy – development of a municipal wide vision and strategy;

Projects – development of specific, priority projects and operational plans within each sector;

Integration implementation – the plans are integrated into the municipality's planning tools.

This section also looks at the different adaptation approaches that are required at various levels of water and wastewater services. It is imperative that all institutions concerned with water services adopt these approaches as far as is practical.

6.1 Policies

Policies are compositions of papers, strategies and plans and are not legally enforceable. At this stage most municipalities are in the process of developing climate change policies. These policies are set to be aligned to the National CC policies in the DEA as well as the DWS. The policies are set to provide guidelines for decision-making and implementation of programmes for service delivery. They are also the basis for the development of strategies and the business plans for the different institutions. Water service institutions have to test the CC adaptation responses against the policy provisions locally and at national level, if a local policy is not available. Further guidance could be provided through the National Development Plan (NDP) vision for 2030, which highlights the need for adaptation strategies as part of the national development strategies as well as the NCCR white paper which was released in 2011 (DEA, 2011a) to guide climate change response for the country.

Climate change policies guide the climate change response efforts of water sector institutions and municipalities. Important guidance issues include the following:

- Management of CC impacts through interventions that build and sustain SA's social, economic and environmental resilience
- Transition to a lower carbon and climate resilient society
- A focus on programmes that are developmental, transformational, and participatory
- Need for programmes that are needs-driven and customized to address South Africa's specific challenges
- Allocation of fairly equal amounts of effort, costs and benefits to address the disproportionality in vulnerability and sensitivity of different regions
- Ensuring policies and measures address the needs of the poor and the vulnerable with urgency (DEA, 2013a).

Apart from targeted CC policies, there are other policies which are available to guide other processes and activities in water and wastewater service provision. The NDP vision 2030 highlights the need for policy alignment at all levels and this requires the integration of adaptation objectives in the plans of all national and local government departments. It also highlights the need to ensure that adaptation plans in terms of policy development are flexible in order to guarantee a wide range of future climate scenarios can be responded to. Some policies that have been developed outside the water sector may assist South Africa's adaptation to climate change. These policies include, amongst others: the white paper on environmental management policy for South Africa (RSA, 1997), the white paper on integrated pollution waste management for South Africa (RSA, 2000), and the white paper on the promotion of renewable energy and clean energy development (RSA, 2002).

6.2 Legislation

The development of new legislation is dependent on available policies. Historically, there were no policies that addressed climate change, hence no historical legislature is available to directly tackle CC response issues. There are pieces of legislation, however, that were not directly developed for CC but nevertheless remain useful to the CC responses by water sector institutions. While policies simply provide guidelines, legislature is more binding, and requires that all concerned institutions adhere to set laws.

Some adaptation technologies will require adjustments to be more aligned to existing legislation and make their implementation easy. These include water re-use, the implementation of wastewater discharge charges, desalination of seawater in coastal cities, etc. Without adequate legislature that supports adaptation plans, implementation will be difficult.

Legislation in other areas outside the water sector, such as biodiversity, land use, waste disposal, pollution control, etc. enable the implementation of adaptation in some instances. This legislation, according to the DEA (2016), includes:

- The National Environmental Management Act (NEMA)
- National Environment Management: Biodiversity Act (NEMBA)
- National Environment Management: Air Quality Act (NEMAQA)
- National Environment Management: Protected Areas Act (NEMPAA)
- National Environment Management: Integrated Coastal Management Act (NEMCMA)
- National Environment Management: Waste Act (NEMWA)
- National Water Act (NWA)
- National Forest Act (NFA).

These laws do not address climate change directly; however, they have sections that deal with specific issues which can now be linked to response measures for climate change as adaptation options. The water sector stakeholder has to familiarize himself/herself with these pieces of legislation before embarking on adaptation options to ensure that the responses adhere to the legal requirements.

6.3 By-laws and regulations

By-laws and regulations take legislation into practical measures in order to ensure accountability. Legislation is enforceable and legally binding, and is often promulgated by parliament with the guidance of national institutions. This creates a necessity for local government institutions to create by-laws that are in line with promulgated legislature.

In terms of regulations, the DEA is the national leader on climate change issues and provides guidance to municipal offices and other water sector institutions on the development of by-laws regarding climate change.

In communities where water stresses and financial issues are prominent, the development of appropriate by-laws in line with adaptation plans can improve the state of water services, prevent water wastage, and in the process, protect water resources. The development of appropriate regulations could have a positive impact on the behaviours of community members, water boards, municipal ratings, and water service providers. Regulations will also address current pitfalls and shortcomings in water and wastewater services. Some of these shortcomings include storm water ingress, disposal of low quality effluents into water resources, etc.

Current legislature highlights the right of every individual to have access to potable water, which in essence translates to water access even if the communities in question cannot afford to pay for water. With the development of appropriate by-laws, water use is regulated by limiting the amount of water available to households and communities, and enforcing payment if limits are exceeded.

6.4 Education and awareness

Climate change is becoming a crucial factor in everyday decision-making by individuals and communities due to its complex interactions with ecological, socio-economic and political systems (Anable et al., 2006). The level of climate change awareness and understanding by institutions should reflect this complexity and, therefore, be multidisciplinary and holistic in its adaptation approach. It is noted that 'improving awareness and preparedness' is a cross-cutting measure that is relevant to varying degrees to any adaptation technologies that may be considered in an area/region. The education of individuals and communities is important if adaptation is to be successful.

Although there have been awareness programmes implemented in various communities, enough information has not been provided. Most of the awareness created tends to highlight the negatives of climate change by painting grim pictures of drought, flooding, and all kinds of water stresses. By providing the right kind of information, municipal offices in different regions can sensitize their residents, and cause them to not only be aware of the negative effects of climate change, but also prepare them to take advantage of the positives.

In light of this, informative programmes need to be tailor-made for different regions in line with projected climate impacts. In regions where an increase in rainfall duration and intensity is expected residents can be sensitized and trained to take advantage of the excess rainfall through rainwater harvesting techniques. Communities can be taught to reinforce their homes against adverse climate effects, and be sensitized to change inappropriate water use practices.

Currently, there are television campaigns aimed at sensitizing water users to change water use behaviours and reduce water demand. These campaigns, however, seem to be directed more at educated urban residents. Addressing climate change issues in languages that can be understood by both urban and rural residents will heighten their adaptive behaviours, and enable the development of climate-resilient communities. Furthermore, the benefits of adaptation technologies and approaches that can be implemented in homes also need to be publicized to further encourage efficiency in water use.

6.5 Strategies

Response strategies have been developed by various national institutions and local government bodies to guide municipalities. Although the development of national response strategies provide guidelines for adaptation, they are usually too generic in nature to address local needs for specific impacts. This does not help vulnerable communities as they find it difficult to directly translate the developed strategies into programmes that can be implemented.

In order for response strategies to be effective, it is important for local institutions and the served community to become more involved in climate change response, and its associated strategy development. It is also important for provincial and local governments to form partnerships based on their zonal classification in the hydroclimatic zones. This will lead to the development of effective and specific strategies to ensure adaptation is in line with expected projections. Water service providers that are not municipalities also need to combine their efforts with the governing institutions in their various regions to develop effective strategies for water services in the face of climate change.

Currently, there is a gap in strategy development and implementation between the three tiers of government due to the lack of high level involvement of the provincial government. Decentralization of strategy development will aid rapid response to climate change, as each province faces unique water challenges. This does not eliminate the role of the national government in response strategies. It simply highlights the need for the national government to provide a guideline for strategy development, while the provincial and local government bodies develop and implement the necessary response strategies based on the specific challenges faced in their water services sectors. In this regard, it is of the utmost importance that current challenges be integrated into strategic plans that address future climate change.

6.6 Business plans and programmes

Once the right strategies have been developed, they should be translated into businesses plans and practical programmes for the benefit of the concerned service area. The development of adaptation programmes aids the implementation of the vision of municipal offices, water service providers and other local government institutions. One of such programmes may be the development of incentives for communities that encourage water-efficient processes and behaviours. The developed programmes could also highlight specific projects that can be implemented within a set timeframe in order to allow for effective adaptation.

The articulation of climate change response strategies into business plans has to take place in an approach where the other services or sectors are also considered. This is because CC impacts and solutions are not necessarily specific to water, transportation or power generation, but are rather cross-cutting and require integration. An integrated perspective will enable easier implementation of adaptation programmes while generating the benefits of multi-use and achieving a more effective cost spread. As such, at the business planning stage the different units and sectors have to share information and seek connectivity in how they incorporate or develop adaptation programmes and projects into their business.

6.7 Proposed adaptation approaches in water services

Adaptation approaches have to do with the environment in which climate change responses are set to prevail, that is in addition to being direct adaptation response mechanisms. As such, the success of adaptation technologies which are applied for purposes of adapting to certain impacts, is dependent on adaptation approaches such as establishing or having a well-conceived operating environment where legislation and regulations are enabling, the presence of relevant and well equipped institutions, presence of stakeholders who have the will to embrace adaptation and that those who are beneficiaries to adaptation welcome the adaptation solutions. Adaptation approaches work hand-in-hand with adaptation technologies. Adaptation approaches are either directly or indirectly related to the adaptation technologies. In the adaptation compendium, adaptation technology recommendations are considered in tandem with the adaptation approaches. This provides the necessary environment for successful adaptation which will also be sustainable.

Table 16: Adaptation approaches for potable water services

Impacts/ Objectives	Approach	Description	Applicable Zones/ Implementation Priority	Geographical Settings
Increased water demand; high temperatures and reduced water availability	**Policies to encourage sustainable use**	Policies set the stage for the development of legislature. Proposing policies which promote sustainable water use and implementing these will create the environment for legislation and business strategies which direct sustainability through measures such as reduced use, demand management and putting a stop to wasteful processes. Policies set to encourage efficient water services including reuse and stopping unnecessary pollution, are also essential at national, municipal and institutional levels. Institutional policies to guide the response to CC especially adaptation will directly guide the local measures for adaptation.	All Zones / P0	All settings
	Legislation clauses to curtail demand	Legislative measures that are accompanied by relevant regulations and enforceable penalties are required to ensure that the best use of the water available is made and that water demand is driven by efficient practices. Legally binding legislative tools will be applied to all forms of water use. In the cases of domestic, agricultural and industrial uses, suitable tools such as water accounting meters have to be in place and they have to be consistently used to account for all water usage	All Zones / P0, P1	All Settings

		and determine any losses as these also form part of demand.		
	Water use charges, penalties and other forms of enforcement to handle usage and deal with misuse, wastage and even theft	Both normal use and abnormal water movement in the water services balance should be dealt with through established processes. Tariffs have to be applied for use and revenue collected without fail. The use of estimates or electricity use to determine water use such as in farms should be avoided as these only result in inaccuracies and usually reduced revenue for the fiscus. Illegal connections within municipal areas have to be penalized. Water use monitoring facilities must have equipment to determine irregular water use, theft and losses. The municipality must have the structure and personnel to penalize illegal water use activities, encourage good practices and apply penalties for irregular cases. Illegal connections make the whole water provision system more vulnerable through the damage caused to the infrastructure. The vandalized infrastructure is prone to high rates of water losses and reduced system performance due to head losses. These cases of water infrastructure vandalism have to be stamped out.	All zones / P0, P1	R2 R3 U1 U2 C
	Encourage use of alternative water sources including	Past municipal by-laws in some cities discouraged rainwater harvesting. Water collected though rainwater harvesting, however tends to reduce the burden of water services on the water service	All Zones / P0	All settings

	rainwater harvesting	provider. Rainwater harvesting also means that energy is conserved as some water does not have to flow all the way to the dam, collecting pollutants along the way, only to be purified and pumped back to the houses where it could have been collected in the first place. Water service institutions have to be in partnership with the building regulators and municipal planners to ensure that the guidance provided on rainwater harvesting addresses all relevant issues and that it is implementable.		
	Use restricting water tariff structures	Water tariff structures have to be efficient in curtailing unnecessary water use. Since the legislation has a free water component, further water use above the basic free water can be controlled by stringent water tariffs. Tariffs have to be analysed annually to ensure that they continue to give the best benefit in terms of improving the way water is used and keeping the demand to a minimum.	All Zones / P0, P1	R2 R3 U1 U2 C
	Water rationing and restriction of supplies	Application of water rationing by-laws, reduced pressure in conveyance systems as well as controlling the number of water collection or connection points will reduce water usage. Use of pre-paid water systems as well as applying controlled water cuts will reduce water supplies. Application of methods, however, which negatively affect members of the community or	All Zones / P3	R2 R3 U1 U2 C

		take away their right to water have to be applied as provided for by the constitution and legislation of the country. The rights of consumers still have to be upheld in such a way that water cuts should only be allowed when there is a declared water disaster.		
	Control of procurement to encourage water-saving technology and efficient water provision systems	The water services providers have to work with other units of the municipality to encourage the procurement of water saving technology. Such technology includes facilities at water use points in households, industry and agriculture. The water purification and conveyance system also contributes to poor water system performance if poor procurement procedures are applied. Typical examples where cases of inefficient procurement practices will affect water provision include many situations where components of the water distribution and plumbing systems are not tested in the country and have no certification from the South African Standards Bureau. The problem is escalated in the case of domestic buyers for purposes of household plumbing. Education and awareness is required to support communities to make the right decisions when building or repairing their plumbing systems.	All Zones / P0	R2 R3 U1 U2 C
	Encourage efficient agricultural irrigation as well as use of greywater	Agriculture that is practiced in urban areas tends to use portable water. In the case of the large municipalities such as Tshwane Johannesburg, eThekwini and Cape Town, this potable water is also provided at very low rates. The tariffs applied to agricultural water use should also be structured	All Zones / P1	R1 R2 R3

	where practical	to encourage more efficient practices while meeting other municipal goals for local agriculture. As far as possible, greywater reticulation should be provided for farming communities in urban areas		U2
	Water Trading	Water trading between different users allows for water to be utilized more efficiently thereby reducing potential wastage as users will compare the potential losses to the revenue that will be secured when they temporarily sell their water rights to those who have an immediate use for the water. The municipality has a role to establish an environment that promotes water trading and control the practice for the benefit of all.	All Zones / P1	R2 R3 U1 U2 C
	Virtual water	The provisions for virtual water are usually not left to the water service provider as they deal with cases where decisions involve scenarios where the local population is set to benefit from water use in another area, rather than use their meagre resources for certain practices such as agriculture. The institutions or municipality or even the national government planners could decide that there is no need for a certain community to develop agricultural facilities which use a lot of water. Then another area or zone will be tasked with, for example generating crops and vegetables to supply those areas where water supplies are	All zones / P1, P2	R3 U1 U2 C

		lower or poor. Decisions can also be made and by-laws enacted at municipal level to stop any agricultural practices or other activities that use excessive water quantities or cause pollution to water resources, thus reducing available water. Use of alternative products which use less water in their production could also be encouraged.		
	Integrate groundwater use into surface water provision strategy	Most water provision systems in South Africa hardly integrate surface water and ground water through the water management and the water service practices. As such ground water is hardly used, which results in unnecessarily high vulnerability in water service provision. Groundwater has to be accounted for in an institution's water service strategy and business processes in order to ensure that the water provision system has alternative water sources and also benefits from sources where available water quantities are less variable.	Zones 1, 2, 3, 5 and 6 have higher ground water potential Zone 4 has poor groundwater potential but in some areas of this zone groundwater is the main source / P0, P1	R2 R3 U1 U2 C
	Education and awareness campaigns using community leaders, the media and schools	Community members are usually keen to support good practices in water use but are often not adequately advised and empowered to play their part. Awareness programmes have to be developed and rolled out. Municipal institutions and other role-players in the water sector do not necessarily have to start from nowhere to establish good awareness practices, but rather use existing developments for several metros. All the metros have awareness	All zones / P0, P1	All Settings

		programmes and media material; which is not, however, spread adequately. Water services and wastewater practices have to be built into the education curriculum to improve knowledge and awareness, especially for the young generation, who can take this into the future.		
	Education, awareness and adequate training of personnel in water services on the possible impacts in their region and the right course of action	Although climate change strategies are discussed in some municipal IDPs, there is a lack of depth of subject knowledge amongst personnel. The impacts of climate change are not fully understood; hence the need to take action is usually underestimated resulting in a general lack of climate change response. Education and training of water sector personnel will build climate change response actions in institutions as well as in their communities. Water personnel also form part of the community structure where they will have influential influence in building community education and awareness. Once trained, the water sector personnel will become influential in developing the relevant response activities such as sustainable water use, household water use efficiencies, discouraging illegal water connections and preventing disposal of waste and other pollutants into water resources.	All settings / P0	All zones

Increased pollution due to higher flow peaks and extreme floods	**Penalties for improper waste disposal**	Illegal waste disposal usually affects water systems. All the waste that is left exposed in the catchment area could easily end up in the water source if it is not collected. The damage to the water source is worsened by climate change induced higher temperatures and extreme flooding events. Improper disposal of household wastes and sewage should be penalized.	All Zones / P0	R1 R2 R3 U1 U2 C
	Improve sanitation, especially in crowded and informal settlements	Improve sanitation facilities in all informal settlements to avoid unacceptable sewage disposal and runoff into surface waters during incidents of high flooding.	All zones / P0	R3 U1 U2 C
	Improve waste collection	Improvement of household waste collection in all areas will reduce pollutants being carried in runoff to surface water resources as well as ground water sources.	All zones / P0	All settings
Energy management	**Legislative measures to ensure green processes at water facilities**	Green processes that require less energy for operations must be enforced through legislation and ultimately lead to water sector institutional restructuring. By reducing energy demand, less water is used in power generation processes, thus reducing overall water usage and wastage. Some green processes to pursue include the use of gravity fed systems that require less power as opposed to systems that are heavily dependent on	All zones / P1	All settings

		pumping. In addition, the use of alternative energy sources which involve less water in the process as well as in the production of energy is also a long term adaptation measure.		
	Incentives to encourage green processes at industrial outlets	Incentives for industries that make use of green processes and sustainable water practices can aid the adoption of these processes. By relying less on energy-intensive methods and practices, the demand for energy is reduced. An incentive scheme to attract reductions in energy use could be applied. This system could be one system whereby rate of use and efficiency in overall energy demand is rated and the industries or organizations concerned can receive ratings. Ratings can become a source of image boost and could be used in organizational procurement advantage or for tax rebates. This however needs to work hand-in-hand with the education and awareness of the public in order to ensure collaborative effort and success.	All zones / P1	All settings

6.8 Proposed adaptation approaches in wastewater services

Table 17: Adaptation approaches for wastewater services and stormwater

Impacts/ Objectives	Approach	Description	Applicable Zones/ Implementation Priority	Geographical Settings
Increased temperature; Increased pollution	**Set up new standards for wastewater purification**	Increased temperatures will encourage processes in anaerobic digesters to work faster if the environment is appropriately established. Encouraging the redesigning of facilities to take advantage of the increasing temperature will add value. Higher treatment rates have to be enabled to take into account the effect of increased temperature, and also help meet any increase in water demand	All zones / P1	R2 R3 U1 U2 C
	Establish strategies and business processes to procure the equipment that works better in the new climatic environment	The strategies and business of wastewater services should seek to balance the benefits and negative implications of high temperatures. Certain facilities that are functioning well could end up compromised under higher temperatures due to the increased rate of endothermic processes which can deplete the oxygen and cause system malfunction. Existing plants have to be evaluated and decisions made on retrofitting equipment or establish additional	All zones / P0, P1	R2 R3 U1 U2 C

		units depending on findings.		
	Legislation and by-laws to promote industrial and mining effluent purification as well as reuse	The temperature increase will result in increased dissolution of solids in wastewater, escalation in algae formation and increased complexity in isolating pollutants. Industrial outlets, mines, feedlots and chicken farms will assist service provision if they have established wastewater purification plants at their premises. The purification processes achieved have to at least meet the acceptable standards for the receiving water. Responsible authorities should also encourage the reuse of treated effluent water at the facilities from where it came. This reuse is achieved by making sure that there is less benefit in obtaining fresh water if reuse is possible.	All Zones / P0, P1	R2 R3 U1 U2 C
	Define set of priority industrial pollutants that must be effectively removed from effluents prior to disposal	Many industrial outlets get away with disposing chemical pollutants in water resources. By defining a set of priority pollutants that MUST NOT be disposed in unremediated effluents in legislature, bylaws and regulations, water resources will be protected, and pressure on municipal water systems will effectively be reduced	All zones / P0, P1	All settings
	Encourage greywater use by domestic and industrial outlets for	Greywater can be used for gardening purposes, maintenance of vegetation scenery or lawns, and for sanitation. Many domestic irrigation systems can be connected to Greywater collected within the household and used for the	All zones / P0	All settings

	non-drinking purposes	maintenance of lawns and gardens. Industrial or public buildings can be encouraged to use greywater where applicable. By encouraging the use of greywater for these purposes, water demand can be effectively managed, and water demand will be reduced effectively by industries and households		
Extreme floods and sea water level rise	**Encourage storm-water collection by industries and households**	In the case of flooding events, collection of stormwater for non-potable uses can be encouraged to reduce runoff within home boundaries. Collection points could be underground reservoirs under car parks or suitably constructed sections of the landscape. To develop an enabling environment for storm water collection the water and sanitation departments have to collaborate with those sections dealing with the built environment and urban planning.	All Zones / P1	R3 U1 U2 C
	Improved stormwater management	Storm-water is a major source of additional load at wastewater purification plants. Storm-water management practices should encourage the construction of drainage pathways to define storm-water conveyance systems which are separate from wastewater will ensure that wastewater services do not become more vulnerable as the climatic conditions change. Developers or community members who end	All Zones / P1	R3 U1 U2 C

		up with infrastructure that cause storm water to flow into the greywater should be penalized. The use of permeable road pavements can also aid stormwater collection, preventing loss and flooding simultaneously.		
	Integration of stormwater in water and wastewater service plans	The units which are responsible for storm water, potable water, and wastewater have to have a point of integrated planning. This way the potential of stormwater as a benefit is enhanced while the negative impacts are eradicated. Municipalities have to eliminate the tendency to separate these service units to avoid the continued limitation in services provision which come with this approach.	All Zones / P0, P1	R3 U1 U2 C
	Legislature and by-laws to encourage industrial establishments to make use of storm water	Many manufacturing industries can afford to use and reuse storm water for their processes. By including this in legislature, storm water collection and use by industries can be encouraged and even enforced	All Zones / P1	All settings

	Promote practices which address impacts of sea level rise at wastewater facilities	Increase in sea level will result in raised groundwater level, affecting some wastewater conveyance systems and even plants with their location in the lowest areas. Development of new wastewater facilities including the retrofitting of existing facilities should be guided by revised specifications where solutions for sea water level rise are provided for.	Z2/ P2 Z5/ P2 Z6/ P2	C

7 Implementation of adaptation options

Once the appropriate adaptation options for a specific region have been selected, the implementation of such selections must be strategically conducted. In this report, we have identified four steps for successful implementation of selected adaptation options. These include incorporation of options into institutional strategies, prioritization in the business plan and resource allocation, establishment of institutional and community buy-in, and mobilization of community participation. These are further explained in detail in the sections that follow.

7.1 Incorporation of selected adaptation options into institutional strategies

The incorporation of adaptation into institutional strategies is greatly dependent on the type of adaptation being considered. For the water sector, and other associated sectors, the first step is to ensure that climate change response is captured in the institution's vision. This will ensure that immediate and futuristic plans are made in line with climate change response.

For some local municipalities in South Africa, this is a challenge that is yet to be addressed as the focus is often on addressing existing backlogs. For example, the Msunduzi Local Municipality is yet to incorporate climate change into its institutional vision, hence climate change is hardly considered when IDPs are being developed. This makes it difficult for adaptation options to be considered, selected or implemented in such a municipality. It also makes resource allocation to climate change response rather difficult, as IDPs form the basis for programmes and projects that are undertaken and sponsored by the institution. There are many municipalities like Msunduzi, especially local municipalities, which currently do not have any strategies that respond to climate change. Although SALGA provides guidance regarding strategy development for municipalities, backlogs in services take priority over relatively new issues like climate change. The backlogs are not limited to water services, as municipalities are tasked with other services such as road maintenance, electricity, infrastructure development, etc. This sometimes makes it difficult to address all the current issues, while trying to incorporate new issues like climate change. By creating an umbrella strategy for climate change in the institution's vision, however, selection and implementation of adaptation options will become a lot easier. Municipal offices are not the only institutions responsible for the development of climate change strategies, or incorporation of climate change response into the institution's vision. Other institutions such as water service providers, environmental institutions and water-associated institutions should also aim to incorporate their adaptation options in such a way that the resulting programmes and projects can be efficiently carried out.

Once climate change has been incorporated into the institutional vision, the next step would be to incorporate it into the institution's objectives. This creates a platform for the institution to realign its focus regarding its state of water services, and the solutions being proffered. Some key questions to answer in this realignment would be: how can existing problems be addressed in line with our climate change response vision and objectives? How can we develop programmes from our climate change response strategy, and ensure that they are effectively translated into projects? Which projects should fall into the immediate, mid-term, and long-term time frames? Which units or directorates should be in charge of certain programmes and projects? Can we cooperate with other institutions that are non-technical to aid the implementation of programmes and projects that fall outside our available expertise?

Currently, most of the national institutions in South Africa have developed strategies to respond to climate. The DEA is at the forefront of strategy development on behalf of the national government, and other institutions such as the DWS and the DST have developed their specific policies to address issues faced regarding their services. For example, the DWS deals specifically with water and sanitation, and has developed a strategy that focuses on these areas to ensure that vulnerable regions nationwide have access to safe drinking water and basic sanitation services; on the other hand, the DST focuses on the development of adequate technologies for climate change, to ensure that mitigation and adaptation technologies are mature enough for implementation. In this regard, the DST has developed a response strategy that addresses issues across the board.

The state of development of institutional strategies varies based on the region being discussed and the class of municipality. This was evident in the various municipalities studied during the course of this research – the Vhembe District Municipality, uMgungundlovu Municipality and the City of Tshwane Municipality.

The Vhembe District Municipality, which is a water service authority that supplies water to the local municipalities within its jurisdiction, has yet to capture climate change in its IDPs. Although some of the priorities of the district such as water resource development and demand management, disaster risk management, and the development of a green economy appear to be in line with issues that may arise as a result of climate change, there is no defined strategy or organizational vision that addresses climate change. It is therefore of the utmost importance that institutions like the Vhembe District Municipality creates an institutional strategy that aligns its priorities to climate change in order to ensure that implementation of solutions to existing backlogs in the area are in line with the national vision regarding climate change.

The uMgungundlovu District Municipality has successfully captured climate change as an area of priority, and highlighted the need to build resilience, especially in the most vulnerable communities in the area. Adaptation options such as the development of early warning systems, climate change-proof settlements, and climate-smart agriculture have been identified as some of the available options that could aid the adaptation of the region to climate change. This is impressive, as the understanding of climate change and response has gone beyond literature and has identified the possible programmes and projects that can be implemented. This indicates that the institution understands the need for climate change response, has invested in research and even identified some adaptation options. The developed strategy can still be updated with adaptation technologies and approaches from the adaptation guide to ensure a wholesome response approach. Furthermore, the identification of the directorates responsible for the different adaptation TAs selected is necessary to ensure that the responsibilities of the different units are duly defined in the subsequent business plan of the institution.

The City of Tshwane is also heavily vested in addressing climate change response. Various initiatives have been identified as key areas of prioritization to aid the adaptation to climate change. Some of these initiatives include the development of green buildings such as the new developments east of Pretoria, the use of solar heaters in Olievenhoutbosch and Winterveldt, and the retrofitting of municipal buildings with energy-efficient and renewable energy technology. These responses are not based on water services; however, they assist the city of Tshwane's accession to the climate change response vision of the national government. These climate change responses have been dutifully captured in the city of Tshwane's IDP and vision, although specific adaptation responses for the water sector have not been indicated, nor have the units responsible for certain programmes and projects been identified.

There are other institutions like the City of Tshwane which have already developed response strategies to climate change; however, the strategies do not address specific areas for adaptation nor do they identify specific adaptation options for the water sector. Technical adaptation options such as the improvement of water quality in the face of climate change, the modification of treatment systems, and the establishment of novel systems where necessary still remain missing in institutional strategies. In such cases, an update is highly necessary, or institutions may consider developing an altogether novel strategy. The development of response strategies without identifying specific options that can be implemented makes it difficult for implementation to be infallible.

Furthermore, although some institutions may have developed response strategies, based on the continuous change in climate change science and the continuous development of adaptation options, their response strategies may already be outdated. In the case of such institutions, there is a need to develop new response strategies based on current and local information. The DEA LTAS studies have provided extensive information in this regard and hence information obtained should be used as guidelines to select the appropriate adaptation options for the region in which they are located, and aid the development of implementation strategies.

The successful development of strategies will result in the development of a business plan. The business plan should be designed to highlight programmes and projects that will be undertaken to aid the implementation of adaptation options. Adaptation options can be classified as soft options (which include legislation, interpretation of national policies, education and awareness, etc.), and hard options which are the technical adaptations involved in the potable water process, wastewater treatment, and other associated technical areas. This means that the programmes developed to highlight adaptation projects will need to successfully identify the units responsible for the different projects within the institution.

7.2 Cost-benefit analysis of adaptation options

Decisions reached on using a specific adaptation option involve a variety of considerations. As such, the consideration of each option should involve multi-criteria analysis. An important component of this analysis is the cost-benefit analysis (CBA). This should take place prior to the implementation of selected adaptation options. The selected adaptation options have cost-benefit implications which need to be determined and presented as part of the option selection process.

The best approach should attempt to use all the CBA ratios and considerations as currently applied for water and wastewater service projects. Ideally the criteria for evaluating the state of cost-benefit which will result from the implementation and long-term use of an adaptation option for a water or wastewater services project should include the following three:

(i) Net Present Values (NPV)

For a project to be accepted the net present value criterion must be positive; that is, the funds will be allocated to the project only if the analysis produces a positive net present value. The NPV entails obtaining the PVs of all the relevant cost and benefit flows after expressing these in monetary units and applying the selected discount rate. In cases where the consideration involves mutually exclusive projects, the option with the highest NPV should receive the green light. This is the option where the benefits to the community are highest. In considering NPV, it has to be noted that the positive NPV means that the project is profitable. In water and wastewater services, in the South African setting, options with negative NPVs can also be selected after consideration of the social and political component as explained in DBSA (2012), which is discussed at the end of this section.

In the case of adaptation options which involve infrastructure or installation of options that involve financial costs, the appraisal of the NPV should be done for the full life of the adaptation solution as a minimum. The year when the solution is to be implemented should be used as the base year. Annual time steps have to be applied in the evaluation. An important parameter in the NPV criterion is the discount rate to be used. Many water utilities around the world use a discount rate equal to the interest rate or the current cost of capital. At any one point this discount rate can be obtained from the national treasury.

(ii) The internal rate of return (IRR)

In the case of the use of the internal rate of return, the selected project should be one where the value obtained for the IRR exceeds the social discount rate.

(iii) The discounted benefit-cost ratio (BCR)

The preferred option should be the one where the benefit-cost ratio is greater than one.

The above considerations tend to be distorted by the need to consider the contribution of government grants in the assessment. Ideally, government contributions may be provided to address certain national goals such as equity, addressing historical imbalances and, in many cases, where provision of suitable wastewater or sanitation projects is set to restore human dignity. In the absence of these grants, such projects are usually economically unviable. The DBSA (2012) advised that economic evaluation should exclude the government grants, which are provided as a social component. This component is best described as a social and political component since in some cases it is observed that these grants are also set to address political interests. According to DBSA (2012), the costs of developing infrastructure in municipalities are composed of the social component, which is funded from the fiscus, and the economic component, where the municipality has to fund using its revenue or using loans or external sources where funding is secured at market conditions.

The DBSA also recommends that funding for water projects should be considered where full costs are to be recovered by levying water tariffs in accordance with the Water Pricing Strategy. In water infrastructure, the DBSA (DBSA, 2012) explained that the Water Pricing Strategy should allow for the recovery of operation and maintenance cost as well as depreciation on the investment. According to the European Commission (2011), the selected option should combine the best features to develop environmental, social, economic and cultural concepts.

7.3 Prioritization in institutional business plan

Once the appropriate adaptation options have been selected and incorporated into the institutional vision and response strategy, the development of required programmes and a business plan are of great importance to successful implementation.

It is imperative that institutions break down developed strategies so that they can be translated into programmes and projects. This strategy breakdown will require the prioritization of adaptation options, as well as identifying the various units within an organization which are responsible for the successful implementation of these options. In prioritizing, it is important that the most vulnerable aspects of water services are addressed with immediate effect, or on a short-term time scale, while other aspects can be delayed for mid-term or long-term adaptation implementation. In identifying responsible units, institutions will first need to understand that adaptation options are not all technical, hence the need to split selected options into hard and soft options. These options must be aligned to different programmes and/or projects which are aligned to the mission statement of the business plan, which is in turn aligned to the institution's strategy.

Soft options are mostly adaptation approaches such as interpretation of legislature, and strategy development, education and awareness campaigns, and instigating behavioural changes of individuals to water use. Soft options therefore do not require technical expertise, and units responsible may not be found within the water institution itself, depending on how versatile the institution's services are. It is therefore important to ensure that the units responsible for executing such projects are available within the institution, or can be collaborated with in partnerships to ensure infallible adaptation implementation. Hard options are the more technical options, and are dependent on the expertise of technical staff, extensive research and the state of maturity of the particular technology selected.

The prioritization of adaptation in business plans should also include action plans as to how adaptation implementation will be achieved. As stated earlier, this requires the input of units or institutions responsible for certain adaptation options. Specific steps that will be taken to ensure implementation must be highlighted in the institution's business plan. The inclusion of adaptation in an institution's business plan will require the need to re-engineer the institution's vision and mission. By highlighting successful climate change adaptation and implementation as a key priority in the business plan, institutions can successfully target adaptation implementation (Figure 20).

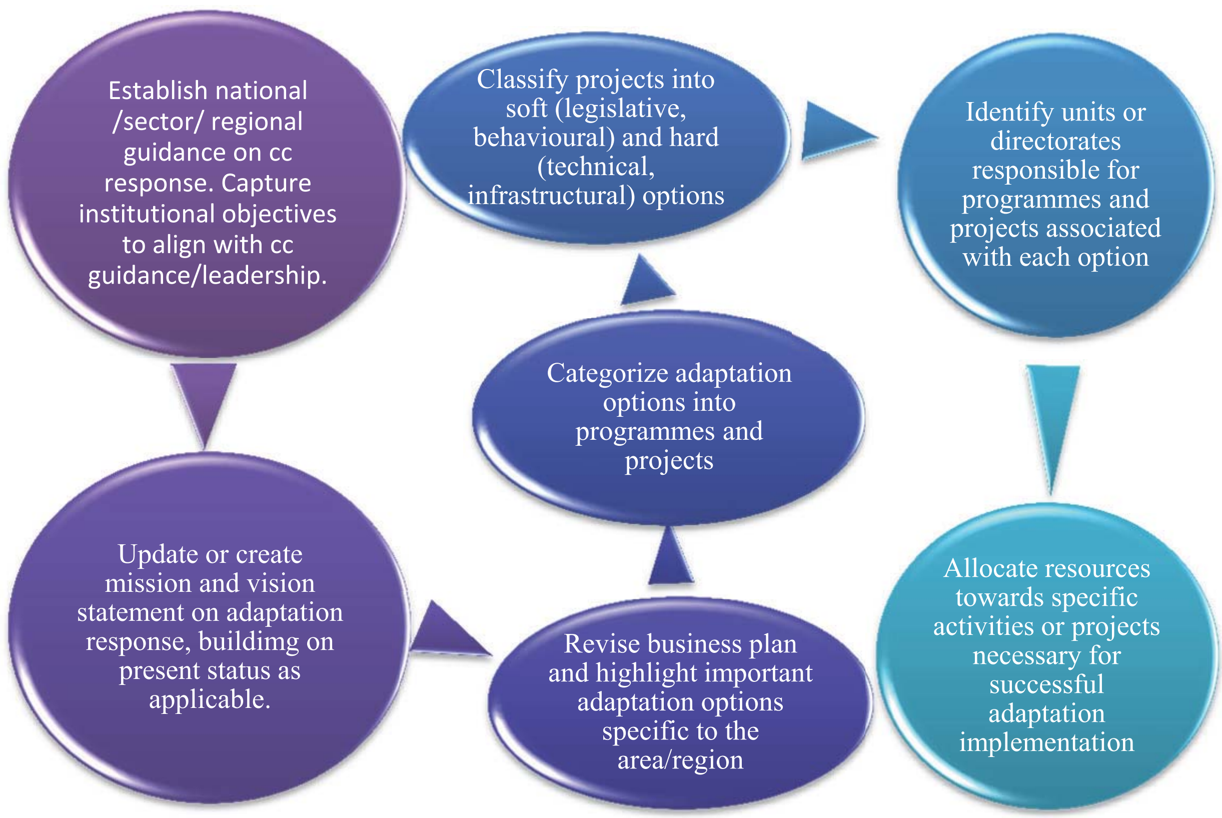

Figure 20: Illustrative description of steps required for prioritization of adaptation in business planning which incorporates successful adaptation planning and implementation

Once the prioritization of adaptation has been successfully achieved, and the various units responsible for selected options have been identified, resource allocation and, in some areas, resource acquisition is necessary.

7.4 Resource allocation for adaptation implementation

Resource allocation is an important aspect of adaptation planning and implementation. Without sufficient resources, adaptation planning cannot be successfully achieved, and implementation will be impossible. In identifying the adaptation programmes and projects required, it is important that institutions are able to attract the right resources to fuel the progress of these programmes. Existing resources can be redistributed to ensure better effectiveness, and motivation for extra resources can be submitted to the right institutions based on the prioritization in the business plan.

There are four key resources that every institution must possess in order to successfully plan for adaptation and implement selected options. These include finances, humans and materials, as well as capital and relevant assets.

7.4.1 Human resources

Different regions attract different levels of skills. In South Africa, the urban areas attract the most sophisticated skills, while rural regions attract semi-skilled or unskilled individuals. With rural areas being highly vulnerable, the right kinds of skills are necessary to ensure seamless adaptation. Urban areas, though able to attract the right kinds of skills still face challenges in terms of human resources. In urban areas, many technically-skilled individuals opt for other industries outside the water sector due to more attractive remuneration packages.

During the course of adaptation selection, planning and implementation, it is important that institutions consider the skills they currently have available, and the kinds of skills they can attract based on their financial resources. The allocation of existing skilled employees to certain projects and programmes could be the best way to handle human resources; in areas where there are no skilled individuals, however, skill acquisition programmes can be implemented. Interested residents of rural communities and semi-urban areas where skills are lacking can be trained to operate small-scale treatment and distribution facilities. This can help to increase the climate resilience in these communities, as well as improve the socio-economic standing of the residents. In regions where residents cannot be trained, unmanned facilities may be the best adaptation option, although the feasibility of this route remains debatable.

In some regions, there are no individuals skilled enough to develop strategies and business plans, not to mention to prioritize the available options. Such regions may never make progress in terms of adaptation selection, and hence human resource acquisition is of utmost importance, especially in rural and other highly vulnerable regions.

It is also important that the acquisition of human resources is in line with the kind of adaptation a particular region is opting for. For example, in areas where desalination may be adopted as an adaptation technology, qualified individuals in the field of desalination need to be acquired, not individuals who are skilled in demand management. This makes it easier to streamline skill acquisition, and also assist financial management of the institution by avoiding wage expenditure that may not now be necessary for that particular region.

7.4.2 Material resources

Adaptation implementation will depend on available materials and infrastructure in each region. In some regions, existing infrastructure is sophisticated and only requires small-scale modifications to aid climate change adaptation. In other regions, existing infrastructure is non-functional and may require a complete overhaul of the system. The successful selection, planning and implementation of adaptation options are therefore dependent on an in-depth understanding of existing infrastructure and its functionality.

For some regions, the current state of infrastructural and material resources can either aid or disrupt adaptation uptake. In municipal areas with sophisticated water infrastructure, adaptation may be easier because large scale implementations or modifications may not be required because existing infrastructure and materials are already functional. In more vulnerable regions with poor infrastructure, adaptation may be more difficult as it may involve the installation of novel systems, the overhaul of existing non-functional systems and large scale modifications.

7.4.3 Capital and relevant assets

The availability of capital and relevant assets cuts across all three factors of human resources, financial resources and material resources. The competition for these three resources among various institutions will be rather high, and hence it is important that institutions have sufficient resources to kick off programmes and projects, while working towards the acquisition of more assets, be they in the form of human or material assets. Institutional capital should be assessed to ensure short-term projects can be completed on available assets, while motivation for further acquisition can be made regarding mid-term or long-term programmes and projects.

The current sources for financial capital for municipalities include government grants, revenue collection (taxes, water bills, properties, fines on penalties and violations), collaborations with overseas institutions, and sale of assets. Based on the possible inflow of funds from these different avenues, municipalities are able to choose adaptation options that are well-suited to their revenue. Some of the metropolitan municipalities are able to attract more capital while some of the most vulnerable regions and the rural areas struggle to collect fines on penalties, water bills, or even establish international collaborations. This should be thoroughly considered during the selection of adaptation options to ensure suitable and appropriate selection.

7.5 Establish buy-in

Adaptation to climate change will require institutional and communal behavioural reforms. For these to be successfully achieved by water-governing bodies, it is important to establish buy-in from institutions and surrounding communities.

7.5.1 Establish institutional buy-in

Currently, there are many institutions that are not concerned with climate change issues. Some institutions fail to understand how their activities and climate change response can positively or negatively impact adaptation implementation. Many institutions in various regions are aware of climate change but see no reason to prioritize it in their business plans. This is evident in municipal IDPs which are designated to run for a period of five years. In many local municipalities, IDPs do not include climate change response in any of the units. These municipalities tend to focus more on their existing backlogs, and fail to incorporate what they regard as a futuristic event. This makes it difficult for adaptation implementation to occur, as designated funds are often spent on addressing backlogs and improving performance ratings.

In order to establish institutional buy-in, it is important to first ensure that the national response strategy and subsequent legislature on climate change are translated into local strategies that institutions can easily relate to, which are based on the climate events of their region. Generic projections and adaptation suggestions that appear to be too sophisticated may cause some institutions to lose interest in adaptation, as they find it difficult to relate. Localized liaisons with corporate service institutions can help extend institutional awareness, and the use of external bodies with a better understanding of climate change adaptation can help establish buy-in.

It is also important that institutions and water-governing bodies in different regions are made to understand that existing backlogs can be addressed while incorporating climate change adaptation options. By doing this, institutions are made to understand that climate change adaptation does not necessarily have to involve novel projects; rather it can simply be a modification of current practices. Institutional buy-in is highly necessary to ensure that the water service providers and other institutions in various regions are onboard. This can help ensure that adaptation implementation does not encounter barriers, and improves the resilience of regions in a timely manner.

7.5.2 Establish community buy-in

The role of community members cannot be under-estimated in the implementation of adaptation options. It is important to ensure community buy-in is established prior to extensive implementation of adaptation. This is because lack of information on the part of community members can cause them to rebel against implemented options, resulting in protests that may destroy modifications or novel implementations.

It is of utmost importance that community members are well informed regarding climate change issues, how their water use behaviours affect the water sector, and the adaptation options available. The dire consequences of climate change on the water sector should be clearly stated in order to ensure community members fully understand the purpose of adaptation, and the benefits that will result from climate change should be highlighted to ensure community members fully understand there are some benefits they can take advantage of. Without the understanding of communities, adaptation options are likely to be ignored or destroyed.

In order to establish community buy-in, extensive awareness programmes, which are specific to the regions in which institutions are located, are important to ensure that residents of such communities understand the information being conveyed. Institutions can make use of the media to convey information to more audiences. This can be done in the form of television adverts; it has been observed, however, that most of the awareness campaigns run on media outlets seem to target only the more educated individuals, as the messages are conveyed in English. South Africa is a nation with eleven national languages, and it may be helpful to convey the information not only in English, but also in other languages, to ensure the target audiences understand.

The use of posters in communities may be another suitable avenue for establishing community buy-in, especially if the posters are in local languages. Awareness can be created by making use of free newspapers, magazines and information leaflets that can be distributed within communities. Dialogue facilitation regarding the implementation of adaptation options can be achieved by taking advantage of established forums and gatherings such as church assemblies, traditional meetings, and political gatherings. This will increase the involvement of community members, causing them to view implementation as a collaborative effort between them and the decision-makers in the community. Residents of communities can also be informed about the various adaptation options available, and asked to vote for the options they believe they can adhere to, and effectively sustain. This will again give a sense of ownership to community residents, and will most likely increase their cooperation with decision-makers. This could be most helpful in rural communities where small community gatherings are popular.

Furthermore, international gatherings such as COP meetings can be used to create even more awareness amongst community residents by highlighting key outputs of such meetings and translating them into information that can be understood by the relevant communities. Many people in South Africa are unaware of what the national government accedes to at these meetings, hence they cannot modify their water-use behaviours in cooperation. The outcome of COP meetings and any conditions acceded to by the national government should be broadcast via news channels, and translated into local awareness programmes to help establish community buy-in. The extensive education of community residents and their sensitization to adverse water use behaviours will make adaptation a necessity for residents, and will result in appreciable changes that will benefit the water sector greatly. With community buy-in, adaptation implementation will be easier, will last longer, and will change the way community members view water as a resource.

It is also important to target areas of misunderstanding in communities. The understanding of climate change science is very fuzzy within communities, and is often confused with seasonal climate variability. Some communities believe climate change is a farce, or a conspiracy theory used by the government and decision-makers in their communities to prevent them from utilizing resources to their satisfaction. By increasing community awareness and establishing community buy-in, such theories can be negated. By helping communities understand that climate change has more dire long-term effects, implementation of adaptation options can be justified and more easily receive the required cooperation of community members. As stated earlier, residents can be made aware of the benefits of climate change, and educated as to how they can take advantage of these benefits. This will help erase the concept of climate change being a governmental conspiracy theory.

7.6 Mobilization of community participation

It is possible to establish general community buy-in, yet not receive the necessary participation from community residents. As stated earlier, establishing buy-in from community residents will aid the implementation process, and can give community residents a sense of ownership when it comes to the adaptation options. However, this is not sufficient. Awareness campaigns via media outlets might sensitize community residents, but may not be enough to result in behavioural changes and full acceptance of adaptation options.

In order to mobilize community participation, community groupings such as political groups and religious groups can be utilized to engage community residents. This will be most effective in rural and semi-urban areas where such groupings carry a lot of weight. Political group leaders can be encouraged to share climate change adaptation messages with their group members in ways that highlight progress for the group, and for the community. In regions where religion plays a big role in the daily lives of the residents, religious services can be used to advance the message of climate change adaptation in high-spirited ways that the community residents can relate to.

Furthermore, the use of modern-day technology can be utilized successfully. Most people in urban, rural, or semi-urban communities rely on the use of mobile applications for information and communication. The development of a mobile app that utilizes the GPS location of individuals to provide them with location-specific information on climate change can help increase participation in adaptation. An app like this is a supplement to awareness campaigns, and should provide local information regarding expected climate change projections for specific regions. The app can also highlight what can be done by individuals in their own little ways to improve the climate resilience of their communities, and can be used as a disaster warning outlet for highly vulnerable regions. The development of such an app, with the backing of national government institutions and SALGA, can be the information hub anyone can access anywhere to check climate vulnerability, and help improve climate resilience.

8 Climate change adaptation benefits and oversights

8.1 Monitoring and evaluation of adaptation options and their applications

Generally, the implementation cycle for adaptation to climate change can be schematically illustrated as shown in Figure 21.

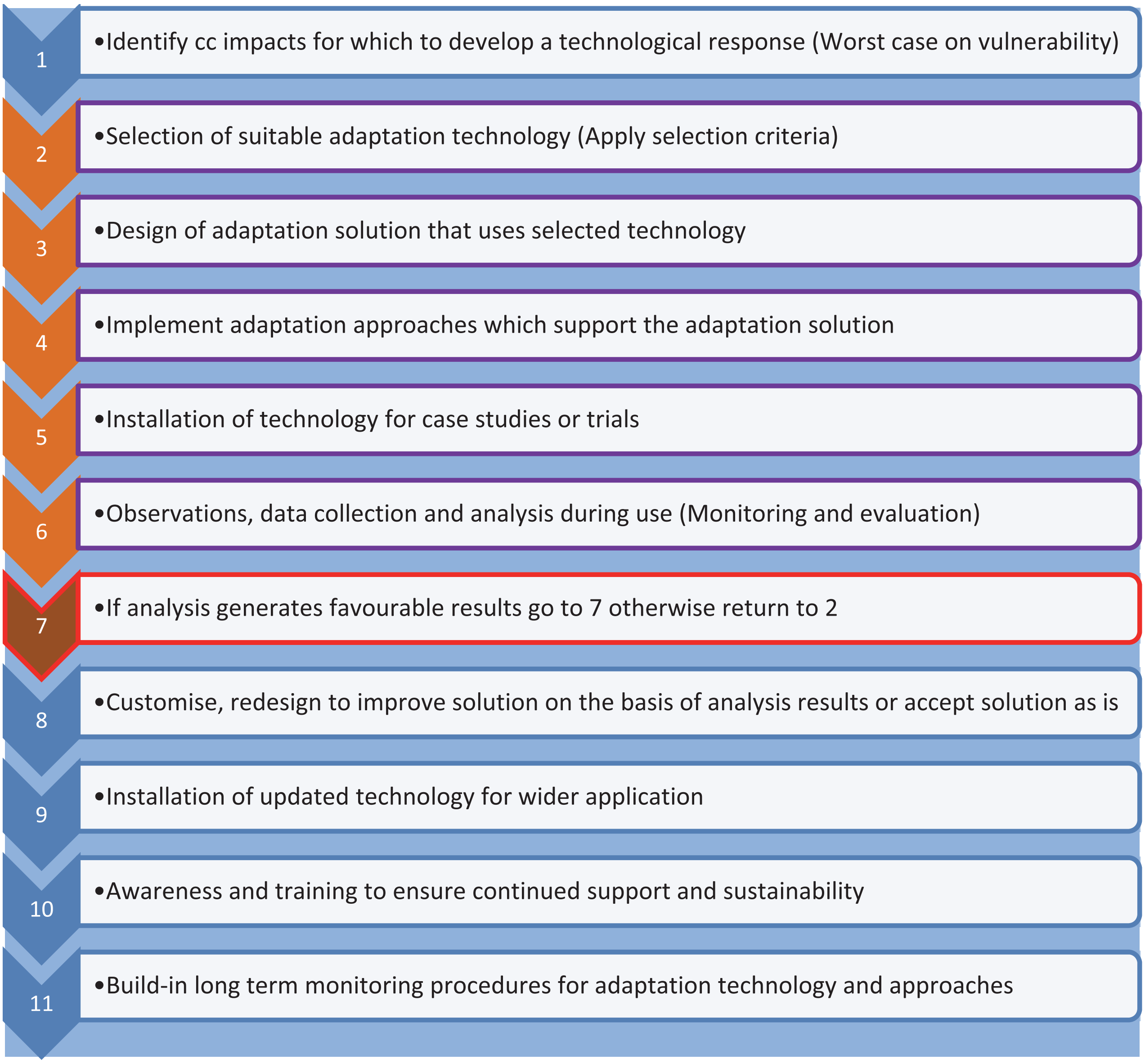

Figure 21: Implementation cycle for adaptation technologies and approaches

After implementation, assessment of selected options is necessary. This is to either re-engineer selected option for maximum effectiveness, or to select alternative adaptation option in cases where the first selected option fails to achieve the required results. It is important to note that adequate time should be allowed before alternative options are considered. This is to ensure that selected options are indeed inadequate before moving to different options.

The functionality of implemented options can be addressed through the use of a feedback mechanism whereby community residents are able to provide feedback regarding the implemented options. This should provide an avenue for implemented options to be re-engineered after evaluation to ensure that maximum benefits are obtained from them.

8.2 Oversight arrangements and structures

For successful assessment, every institution will need to develop a unit/directorate that is in charge of the measurement of effectiveness of adaptation options. This unit or directorate can also be appointed by the local or provincial government to ensure that objectivity in assessment is maintained.

When the selection of adaptation options is being made, many options may seem viable at the time of selection. Once implemented, however, they fail to meet the desired expectations. This can result in unnecessary expenses, as some of these options will need to be replaced with alternative options. The ideal thing to do with regard to oversight arrangements would be to investigate and assess the effectiveness of adaptation options by other institutions locally and internationally. This can help provide useful information regarding the effectiveness of certain options, and hence poor options can be removed from the list of selected options and replaced with suitable alternatives. It is important, therefore, that prior to implementation, extensive research is conducted regarding options selected to ensure cost-effectiveness and to save time.

It is also important that institutions develop an oversight framework for adaptation options. This framework should provide guidelines to the units in charge of adaptation effectiveness measurement, to help them understand steps that need to be followed if a particular adaptation option falls below the required expectation. Furthermore, there are currently existing arrangements and structures that can be realigned to ensure that implemented adaptation options are producing maximum benefits. Examples of such structures include the use of the green drop and the blue drop score. (The green drop score is a municipal score that indicates the state of wastewater services of the municipality).

The different criteria used to award the green drop score include the efficiency of the wastewater quality monitoring programme, the credibility of drinking water sample analysis, wastewater treatment works capacity, etc. (DWAF, 2009). The blue drop score, on the other hand, is based on drinking water quality reticulated by municipalities, indicating the level of performance of the water treatment and distribution works. These scores could be realigned to ensure that institutions are indeed adapting to climate change by measuring the performance of water and wastewater treatment works in correlation with the implemented adaptation options. This will enforce adaptation across all regions as municipalities aim to achieve maximum scores on the blue drop and green drop scales. Currently, some municipalities, especially metropolitan municipalities like Tshwane tend to score high on the blue drop and green drop scales, although their actual performance is sub-optimal. In terms of the green drop scale, the municipalities do not address burst pipes, and leakage of storm water, yet come across with high green drop scores that suggest they adequately and effectively treat wastewater. This is an oversight that can be addressed in line with the assessment of adaptation options.

8.3 Monitoring process

The monitoring process should be conducted by the appointed oversight directorate. Every institution responding to climate change adaptation will require a monitoring process for its selected adaptation options. This should ideally occur after adaptation options by other institutions have been assessed, poor options have been taken off the list, and suitable options have been put in their place. In spite of their projected suitability, the new options will have to be monitored after implementation to ensure that they are performing maximally. The key questions to ask during the course of the monitoring process include: 'What are the benefits of the implemented adaptation option?' and 'What are the shortcomings of the implemented adaptation option?'

In answering these questions, performance ratings of the institution can provide useful clues. Adaptation options, once implemented, should improve the performance of any water service institution. This can be determined by assessing performance scores like the blue drop or green drop. The rate of water distribution, storm water conveyance, wastewater treatment works, etc. can all provide the necessary information.

In order to ensure that institutions are truly invested in adaptation, and are not simply doing a shoddy job to get the oversight unit off their backs, a points score for adaptation can be used during the monitoring process to indicate which adaptation options are working effectively, which adaptation options need to be improved, and which adaptation options are simply non-functional. By creating such a system and linking it to institutional performance ratings, adaptation implementation can be rendered successful across the board.

8.4 Alignment to future climate change and changing international obligations

Climate change research and response in South Africa is driven mainly by the international community. International protocols and obligations determine the nature of response adopted by the South African national government, which in turn needs to be translated to local strategies, programmes and projects to ensure successful implementation. South Africa's accession to the Kyoto Protocol required that the country must meet up with international obligations in a collaborative effort with other signatory parties to ensure that climate change adaptation and mitigation strategies had the desired effect. While the Kyoto Protocol highlighted the need to reduce GHG emissions, the IPCC is constantly working to ensure the science of climate change is well understood. Based on the variations of models and scenarios used to explain climate change science, the available information is always changing, and often becomes outdated when new information is published. This subsequently affects the set obligations of international institutions.

Currently, the Kyoto protocol has been dismissed as ineffective, and a new protocol (the Paris protocol) has emerged. Although the Kyoto protocol set standards which ought to be met by signatory parties, it was proven ineffective as recent measurements of carbon emissions seem to have exceeded set thresholds. The Paris protocol, which was developed in December 2015, is the first legally-binding protocol that requires all signatory parties to meet the stated requirements by 2020 when the agreement comes into force. The main focus points of the 2015 Paris agreements include mitigation, adaptation, and loss and damage. In terms of mitigation, the agreement aims for signatory parties to collaborate so as to ensure that temperature increase is limited to 1.5°C. This requires extensive mitigation measures. In terms of adaptation, the signatory parties are tasked with the mission of strengthening the ability of societies to deal with climate change impacts. The agreement also highlights the importance of minimizing and averting loss and damage associated with climate change impacts by fostering cooperation amongst signatory parties to enhance emergency preparedness.

The Paris agreement also highlights the need for a global stock-take whereby signatory parties set their personal obligations according to the state of their economy, resources and abilities every five years in a bid to ensure effective mitigation. This means that every five years, South Africa will set different obligations to meet with the conditions of the Paris agreement, and hence some modifications might be required to ensure implemented adaptation options meet these requirements. This means that implemented adaptation options should be flexible to allow for modifications when necessary.

Adaptation technologies should aim to meet international obligations as they are during the time of implementation. The science and trends that lead to adaptation selection, however, must be well-considered and precise, based on local information. This will not hamper South Africa's accession to international obligations, as adaptation technologies are specific to South Africa's vulnerability and sensitivity to climate change.

8.5 Re-engineering to enhance adaptation benefits

The rapid changes in climate change information will require continuous re-engineering of selected and implemented adaptation options to enhance the benefits obtained, and ensure that the adaptation options are in line with rapidly-changing international obligations, as well as local evaluation standards.

8.5.1 Re-engineering to align adaptation to international developments

International developments that may affect climate change response are not limited to developed protocols and obligations. The science of climate change is constantly changing, and new scenarios are being developed by the IPCC to obtain more precise information regarding temperature increase, and possible climate change impacts in different regions of the world.

Given that South Africa relies heavily on the IPCC for data which is downscaled to provide local information, it is evident that when the next IPCC report is published, projections for Africa might have changed considerably. This might affect adaptation planning, and might even require the redefinition of time for South Africa. Past IPCC reports have highlighted that Africa is one of the most vulnerable regions, and with the recent surge in global temperatures, projections might have worsened.

It is therefore important that adaptation options can be improved after implementation to handle the changing projections, without any extensive cost implications. The focus should be mainly on improving the state of water services through adaptation, and averting loss and damage as they occur. In highly vulnerable regions, modular structures that can be easily modified should be utilized. Win-win adaptation technologies can also be utilized. These are technologies and approaches that are effective irrespective of the kind of climate change impact that occurs. Some of these technologies include the adoption of green processes.

8.5.2 Re-engineering to respond to the outputs of local monitoring and evaluation of adaptation initiatives

South Africa is a developing economy; hence there are other competing needs that must be addressed. Service delivery backlogs and the need for socio-economic development take precedence over emerging issues. It is important that climate change response is in line with these two factors, hence limiting the costs assigned to climate change response. In other words, the funds assigned to each institution can be used to address service delivery backlogs and improve the economic standing of the region in such a way that it builds the climate resilience of societies. This requires excellent decision-making when selecting improvement options for the water services sector of any region, and will reduce adaptation costs and planning. The improvement options can be monitored and evaluated for benefits and shortcomings. Where there are shortcomings, addressing them can be included in the next round of improvement plans to limit the associated costs.

It is important for institutions to look out for feedback sources; this could be the community in which certain adaptation technologies have been implemented, or early adopters in a separate yet similar region. Early adopters can report back on the performance of a certain adaptation technology or approaches, thereby helping skeptical institutions make decisions on implementation and improvement of the selected technology. Information from early adopters should not be limited to local adopters only. The performance of a certain adaptation option internationally can be used for monitoring and evaluation prior to implementation. By obtaining monitoring and evaluation information prior to adaptation implementation, local institutions can avoid expending money on options that may end up unsuitable.

In some areas, monitoring and evaluation only occur after implementation. Feedback from performance assessors and community members should be dutifully used to improve the state of the technology, or modify the process and its parameters in order to ensure desired results are obtained.

Climate change adaptation is cash- and skill-intensive, and hence it cannot be treated with levity. Technology uptake tends to be an expensive process which has a high element of financial risk. In many cases the decision-maker is faced with the risk of potential losses in the event that a chosen technology fails. Lack of a necessary enabling environment affects the uptake of adaptation technology and approaches. This environment is characterized by a high level of institutional support, available positive budget catering for research and development, and the possibility of implementing the technology to address issues across the different sectors in order to spread costs.

The decision-makers are expected to test the selected options against the unique nature of the service provided, how it is provided, where it is provided, when an option could be implemented, as well as ensuring that the prioritization done in the selection process has provided a positive net benefit. The options selected should be such that they enhance the prevailing business objectives. Observations indicate that adaptation initiatives are embedded within the broader context of development goals and planning of a municipality or other local government entity and are thus seldom undertaken in response to climate change alone.

Based on the lessons learnt from cases involving adaptation, implementation of adaptation should start with adequate knowledge of the baseline, which is clearly defined with measurable indicators that can be monitored for change during the life of the adaptation project or programme. It is prudent to point out that monitoring of adaptation technologies, or approaches during the initial period of adaptation, is an important component of adaptation implementation. The process of implementing the adaptation option is only part of the process, and there is need for continued monitoring in order to facilitate adaptive management and learning-by-doing.

After the implementation phase, further uptake costs will continue to be incurred as communities adjust to the new technology or approach (Birkmann, 2011). There should be a budget available to ensure that the adaptation technology is supported through its early life. The lessons that are drawn during implementation and monitoring will prepare municipalities for wider application of adaptation elsewhere.

References

AMWA (2010). 2010 annual report. Association of Metropolitan Water Agencies. Accessed on the internet on 12 April 2015 at http://www.amwa.net/galleries/default-file/AMWA 2010 Annual Report.pdf

Adger, N., Arnella, N. W. and Tompkins, E. (2005). Successful adaptation to Climate Change across Scales. Global Environmental Change 15, 77-86.

Allen, K. (2003). Vulnerability reduction and the community-based approach. Natural disasters and development in a globalizing world, 170.

Anable, J., Lane, B. and Kelay, T. (2006). An evidence base review of public attitudes to climate change and transport behaviour. Department for Transport, London, 228pp.

Arnell, N. W. (1999). Climate change and global water resources. Global environmental change, 9, S31-S49.

Arnell, N. W. (2004). Climate change and global water resources: SRES emissions and socio-economic scenarios. Global Environmental Change, 14(1), 31-52.

BBC news report (2015). Accessed online on 9 April 2015 at http://www.bbc.com/news/science-environment-34763036

Bates, B., Kundzewicz, Z. W., Wu, S. and Palutikof, J. (2008). Climate change and Water: Technical Paper vi. Intergovernmental Panel on Climate Change (IPCC)

Birkmann, J. (2011). First- and second-order adaptation to natural hazards and extreme events in the context of climate change. Nat Hazards (2011) 58:811-840 DOI 10.1007/s11069-011-9806-8.

Bosman, D. (2014). Large-scale desalination: what can we learn from Australia? Desalination. Water Wheel, 13(3), 22-25.

Bryan, E., Deressa, T. T., Gbetibouo, G. A. and Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. Environmental Science and Policy, 12(4), 413-426.

Budhram, S., Nyuswa, M., Rajagopaul, R. and Thompson, P. (2013). Operational and design considerations for high rate clarifiers in the South African water treatment industry. Pretoria. WRC Report No. 1942/1/13. Water Research Commission.

COP17. (2011). Durban Climate Change Adaptation Charter for Local Governments: A Local Government Response to Climate Change. Durban Accessed online on 13 January 2014 at http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/Projects/Documents/DAC_Pamphlet.pdf

Callendar, G. S. (1938). The artificial production of carbon dioxide and its influence on temperature. Quarterly Journal of the Royal Meteorological Society, 64(275), 223-240.

Cartwright, A., Blignaut, J., De Wit, M., Goldberg, K., Mander, M., O'Donoghue, S. and Roberts, D. (2013). Economics of climate change adaptation at the local scale under conditions of uncertainty and resource constraints: the case of Durban, South Africa. Environment and Urbanization, International Institute for Environment and Development (IIED). Vol 25(1): 1-18.

Challinor, A., Wheeler, T., Garforth, C., Craufurd, P. and Kassam, A. (2007). Assessing the vulnerability of food crop systems in Africa to climate change. Climatic change, 83(3), 381-399.

Christiansen, L., Ohlhoff, A and Traerup, S. (eds). (2011). Technologies for Adaptation: Perspectives and Practical Experiences. Roskilde, Denmark. United Nations Environment Programme Risø Centre on Energy, Climate and Sustainable Development Accessed online on 12 May 2015 at http://www.unep.org/pdf/TechnologiesAdaptation_PerspectivesExperiences.pdf

Clark R. M., LI Z., Buchberger S. G. (2011). Adapting water treatment design and operations to the impacts of global climate change. Front. Earth Sci., 5(4): 363-370 DOI: 10.1007/s11707-011-0197-7.

CoGTA (2009). State of Local Government in South Africa – Cooperative Governance and Traditional Affairs: Overview Report, Pretoria.

DBSA (2012). The State of South Africa's Economic Infrastructure: Opportunities and challenges. Development Bank of Southern Africa Limited.

DEA (2011a). National climate change response white paper. Department of Environmental Affairs, Republic of South Africa.

DEA (2011b). Climate Change Awareness Campaign. Department of Environmental Affairs. Accessed on the internet on 11 January 2015 at: www.climateaction.org.za/cop17-cmp7/sa-government-position-on-climate-change

DEA (2013a). Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa No. 1 of 6. Climate Trends and Scenarios for South Africa. Pretoria, South Africa.

DEA (2013b). Let's Respond Toolkit. Department of Environmental Affairs "Let's Respond Toolkit". Accessed online on 14 December 2014 at: www.environment.gov.za/sites/default/files/docs/lets_respond_toolkit_nccrp_workshop.pdf

DEA (2016). Acts and regulations. Department of Environmental Affairs. Pretoria, South Africa.

DEAT (2004). A national climate change response strategy for South Africa. Department of Environmental Affairs and Tourism, Pretoria

DEAT (2007). Long Term Mitigation Scenarios. Department of Environmental Affairs and Tourism. Accessed on the internet on 6 January 2015 at: www.erc.uct.ac.za/Research/publications/07Scenario_team-LTMS_Scenarios.pdf

DWA (2010). National Groundwater Strategy. Department of Water Affairs. Republic of South Africa.

DWA (2011). National Water Resource Strategy (NWRS): National Strategy for Water re-use. Department of Water Affairs, Pretoria, Republic of South Africa.

DWA (2012). Catchment Management Agencies. Accessed on the internet on 21 February 2014 at: https://www.dwa.gov.za/Communications/PressReleases/2012/Media%20release%20Catchment%20Management%20Agencies%20March%20%2030%202012.pdf

DWA (2013). National Water Resource Strategy. 2nd Edition. Department of Water Affairs, Pretoria, Republic South Africa.

DWAF (2009). Green Drop Report 2009_ Version 1South African Wastewater Quality Management Performance.

DWS (2014). Climate Change Implications for Water: Department of Water and Sanitation briefing. Parliamentary monitoring group, 03 September 2014.

Dannevig, H., Rauken, T and Hovelsrud, G. (2012). Implementing adaptation to climate change at the local level, Local Environment: The International Journal of Justice and Sustainability, 17:6-7, 597-611, DOI: 10.1080/13549839.2012.678317.

Delpla, I., Jung, A. V., Baures, E., Clement, M. and Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. Environment International, 35(8), 1225-1233.

Denton, F. (2002). Climate change vulnerability, impacts, and adaptation: why does gender matter? Gender and Development, 10(2), 10-20.

Dodman, D. (2009). Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories. Environment and Urbanization, 21(1), 185-201.

Douglas, I., Alam, K., Maghenda, M., Mcdonnell, Y., McLean, L. and Campbell, J. (2008). Unjust waters: climate change, flooding and the urban poor in Africa. Environment and Urbanization, 20(1), 187-205.

Dube, R., Maphosa, B. and Scott-Goldman, J. (2014). The role of local community institutions in the adaptation of rural and urban communities to the impacts of climate change on water access and use. WRC Report No. 1963/1/14.

EPA (2012). Climate Ready Water Utilities. Adaptation Strategies Guide for Water Utilities. Environmental Protection Agency of the USA. Accessed on the internet on 10 September, 2013 at: www.epa.gov/safewater/watersecurity/climate/toolbox.html?

Easterling, D. R., Evans, J. L., Groisman, P. Y., Karl, T. R., Kunkel, K. E. and Ambenje, P. (2000). Observed variability and trends in extreme climate events: a brief review. Bulletin of the American Meteorological Society, 81(3), 417-425.

Engelbrecht, F. A., McGregor, J. L. and Engelbrecht, C. J. (2009). Dynamics of the conformal-cubic atmospheric model projected climate-change signal over southern Africa. International Journal of Climatology 29, 1013-1033.

Estache, A. and Kouassi, E. (2002). Sector organization, governance, and the inefficiency of African water utilities. World Bank Policy Research Working Paper, (2890).

European Commission (2011). 6th Commission Summary on the Implementation of the Urban Waste Water Treatment Directive. SEC (2011) 1561 Final, Brussels.

Evans, C. D., Monteith, D. T. and Cooper, D. M. (2005). Long-term increases in surface water dissolved organic carbon: observations, possible causes and environmental impacts. Environmental Pollution, 137(1), 55-71.

Fowler, H. J., Blenkinsop, S. and Tebaldi, C. (2007). Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling. International journal of climatology, 27(12), 1547-1578.

Giorgi, F., Jones, C. and Asrar, G. R. (2009). Addressing climate information needs at the regional level: the CORDEX framework. World Meteorological Organization (WMO) Bulletin, 58(3), 175.

Green, G. C. (2008). Towards Defining the WRC Research Portfolio on Climate Change for 2008-2013. Water Research Commission.

Hagemann, S., Chen, C., Haerter, J. O., Heinke, J., Gerten, D. and Piani, C. (2011). Impact of a statistical bias correction on the projected hydrological changes obtained from three GCMs and two hydrology models. Journal of Hydrometeorology, 12(4), 556-578.

Hay, R. and Hay, P. (2014). Capacity building for climate change adaptation and disaster risk reduction in rural communities: Tsengiwe, Eastern Cape. WRC Report No. 2126/1/14.

Hemson, D. (2004). Beating the backlog: Meeting targets and providing free basic services. Human Sciences Research Council, Pretoria, Republic of South Africa.

Hewitson, B. C. and Crane, R. G. (2006). Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. International Journal of Climatology, 26(10), 1315-1338.

Holgate, C. (2007). Factors and actors in climate change mitigation: A tale of two South African cities. Local Environment, 12(5), 471-484.

Houghton, J. (2009). Global warming: the complete briefing. Cambridge University Press.

Hughes, D.A., Mantel, S.K., Slaughter, A.R. (2014). Informing the responses of water service delivery institutions to climate and development changes: a case study in the Amatole region, Eastern Cape. WRC Report No. 2018/1/14.

Hulme, M., Doherty, R., Ngara, T., New, M. and Lister, D. (2001). African climate change: 1900-2100. Climate research, 17(2), 145-168.

IPCC (2001). Climate Change 2001: Impacts, adaptation vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: UNEP/WMO.

IPCC (2007). Climate Change 2007: The Physical Science basis, contributions of working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, IPPC Secretariat, Geneva.

IPCC (2011). IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp.

IPCC (2013). Climate change 2013: The physical science basis – Summary for policymakers. Working Group I contributions of working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. WMO/UNEP

IPCC (2014). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S. and Seyboth, K. Cambridge University Press.

Janssen, M. A., Schoon, M. L., Ke, W. and Börner, K. (2006). Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. Global Environmental Change, 16(3), 240-252.

Jonker, L. (2007). Integrated water resources management: The theory-praxis-nexus, a South African perspective. Physics and Chemistry of the Earth, Parts A/B/C, 32(15), 1257-1263.

Klein, R. J. and Nicholls, R. J. (1999). Assessment of coastal vulnerability to climate change. Ambio, 182-187.

Landman, W. A., Kgatuke, M. J., Mbedzi, M., Beraki, A., Bartman, A. and Piesanie, A. D. (2009). Performance comparison of some dynamical and empirical downscaling methods for South Africa from a seasonal climate modelling perspective. International Journal of Climatology, 29(11), 1535-1549.

Lenntech (2015). http://www.lenntech.com/desalination.htm

Levitus, S., Antonov, J. I., Wang, J., Delworth, T. L., Dixon, K. W. and Broccoli, A. J. (2001). Anthropogenic warming of Earth's climate system. Science, 292 (5515), 267-270.

Liverman, D. (2007). From uncertain to unequivocal. Environment: Science and policy for sustainable development, 49(8), 28-32.

Meigh, J. R., McKenzie, A. A. and Sene, K. J. (1999). A grid-based approach to water scarcity estimates for eastern and southern Africa. Water Resources Management, 13(2), 85-115.

Metz, B. (2001). Climate change 2001: mitigation: contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Climate Change (Vol. 3). Cambridge University Press.

Mokhov, I. I. and Eliseev, A. V. (2012). Modeling of global climate variations in the 20th-23rd centuries with new RCP scenarios of anthropogenic forcing. In Doklady Earth Sciences (Vol. 443, No. 2, pp. 532-536). MAIK Nauka/Interperiodica.

Morgan, J. and Waskow, D. (2014). A new look at climate equity in the UNFCCC Climate Policy, 14(1), 17-22.

NRC (2008). Desalination: A National Perspective. National Research Council of the National Academies. Washington DC www.nap.edu

Ndegwa, S. N. (2002). Decentralisation in Africa: a stocktaking survey, Africa Region Working Paper Series 40, World Bank.

Nordhaus, W. D. and Boyer, J. (2003). Warming the world: economic models of global warming. MIT press.

Piketh, S.J., Fatti, C., Akoon, I., Dunsmore, S., Engelbrecht, F., Van Wyk, F. (2013). The impact of climate change on water services delivery – a case study of Ekurhuleni metropolitan municipality. WRC Report No. 1953/1/12.

RSA (1997). White Paper on Environmental Management Policy. Department of Environmental Affairs and Tourism, Republic of South Africa.

RSA (2000). White Paper on the promotion of renewable energy and clean energy development. Department of Minerals and Energy. Pretoria, Republic of South Africa.

RSA (2002). White Paper on the promotion of renewable energy and clean energy development. Department of Minerals and Energy. Pretoria, Republic of South Africa.

Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic N. and Rafaj, P. (2011). RCP 8.5. A scenario of comparatively high greenhouse gas emissions. Climatic Change, 109(1-2), 33-57.

Rijsberman, F. R. (2006). Water scarcity: Fact or fiction? Agricultural water management, 80(1), 5-22.

Roberts, D. (2008). Thinking globally, acting locally—institutionalizing climate change at the local government level in Durban, South Africa. Environment and Urbanization, 20(2), 521-537.

Roberts, D. and O'Donoghue, S. (2013). Urban environmental challenges and climate change action in Durban, South Africa, Environment and Urbanization, Vol 25, No 2.

Rogelj, J., Meinshausen, M. and Knutti, R. (2012). Global warming under old and new scenarios using IPCC climate sensitivity range estimates. Nature Climate Change, 2(4), 248-253.

Rosenzweig, C., Iglesias, A., Yang, X. B., Epstein, P. R. and Chivian, E. (2001). Climate change and extreme weather events; implications for food production, plant diseases, and pests. Global change and human health, 2(2), 90-104.

SALGA (2010). National analysis of local government finances. South African Local Government Association (SALGA).

SALGA (2012). SALGA 5 Year strategic plan 2012-2017. South African Local Government Association.

Schulze, R.E. (2011). Adaptive management strategies and options for water resources sectors in the context of climate change. Conference proceedings, WRC 40 year celebration conference.

Siebrits, R. and Winter, K. (2013). Identifying and prioritizing water research questions for South Africa. WRC Report Number 2170/1/13.

Smith, J. B. and Tirpak, D. A. (1989). The potential effects of global climate change on the United States (Vol. 1). Office of Policy, Planning and Evaluation, US Environmental Protection Agency.

Sokolov A. P., Stone, P. H., Forest, C. E., Prinn, R. G., Sarofim, M. C., Webster, M., Paltsev, S., Schlosser, C. A., Kicklighter, D., Dutkiewicz, S., Reilly, J., Wang, C., Felzer, B., Melillo, J and Jacoby, H. D. (2009). Probabilistic Forecast for 21st Century Climate Based on Uncertainties in Emissions (without Policy) and Climate Parameters, Journal of Climate, 22(19): 5175-5204 [Erratum], 2009

Staber, U. and Sydow, J. (2002). Organizational adaptive capacity a structuration perspective. Journal of management inquiry, 11(4), 408-424.

Thomson, A. M., Calvin, K. V., Smith, S. J., Kyle, G. P., Volke, A., Patel, P., Delgado-Arias, S. and Edmonds, J. A. (2011). RCP4. 5: a pathway for stabilization of radiative forcing by 2100. Climatic Change, 109(1-2), 77-94.

Treasury and National Planning Commission (2013). Biophysical Modelling in Support of Systematic Analysis of Climate Resilient Economic Development of the Republic of South Africa. 109009/01.

Turpie, J. K., Marais, C. and Blignaut, J. N. (2008). The working for water programme: Evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. Ecological Economics, 65(4), 788-798.

UNEP (2006). UNEP Annual report. Accessed on the internet on 16 June 2014 at: http://www.unep.org/pdf/annualreport/UNEP_AR_2006_English.pdf

UNFCCC (2006). Technologies for adaptation to climate change. UNFCCC. Bonn: Germany. UNFCCC (2014). FOCUS: Adaptation. Accessed on the internet on 13 July 2014 at: http://unfccc.int/focus/adaptation/items/6999.php

UNFCCC (2014). Annual report of the Executive Board of the clean development mechanism to the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol. Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol Tenth session Lima, 1-12 December 2014.

Uppenbrink, J. (1996). Arrhenius and global warming. Science, 272(5265), 1122-1122.

Van Jaarsveld, A. S. and Chown, S. L. (2001). Climate change and its impacts in South Africa. Trends in ecology and evolution, 16(1), 13-14.

Van Vuuren, D. P., Stehfest, E., den Elzen, M. G., Kram, T., van Vliet, J., Deetman, S., Isaac, M. and van Ruijven, B. (2011). RCP2. 6: exploring the possibility to keep global mean temperature increase below 2^0C. Climatic Change, 109(1-2), 95-116.

Vogel, C., Colvin, J., Scharfetter, B. (2015). Adaptation to climate change – what it may mean for the water resources sector. WRC Report No. TT630/15.

WMO (2007). WMO's role in global climate change issues with a focus on development and science-based decision-making. Position paper. Accessed on the internet on 6 March 2014 at: https://www.wmo.int/pages/themes/documents/FINALPositionpaperrevised19-09-07.pdf

WMO (2015). Greenhouse gas concentrations hit yet another record. Press release No. 11. Geneva. Accessed on the internet on 6 December 2015 at http://public.wmo.int/en/media/press-release/greenhouse-gas-concentrations-hit-yet-another-record

WRC. (2015). WRC Overview KSA's. Pretoria. Accessed on the internet on 11 November 2015 at: http://www.wrc.org.za/pages/Research_Overview.aspx

Warburton, M. and Schulze, R. E. (2005). Historical precipitation trends over Southern Africa: a hydrology perspective. In: Schulze R E (ed.) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. WRC Report No. 1430/1/05. Chapter 19, 326-338.

Wilby, R. L. and Wigley, T. M. L. (1997). Downscaling general circulation model output: a review of methods and limitations. Progress in Physical Geography, 21(4), 530-548.

Wilby, R. L. and Wigley, T. M. L. (2000). Precipitation predictors for downscaling: observed and general circulation model relationships. International Journal of Climatology, 20(6), 641-661.

World Bank (2015). Immediate push on climate-smart development can keep more than 100 million people out of poverty. Press release, November 8, 2015.

Ziervogel, G., New, M., Archer, E., van Garderen, E., Midgley, M., Taylor, A., Hamann, R., Stuart-Hill, S., Myer, J. and Warburton, M. (2014). Climate change impacts and adaptation in South Africa 5 (5) 605-620. DOI: 10.1002/wcc.295.

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