



**LONG-TERM WATER CONSERVATION AND DEMAND
MANAGEMENT FOR UMGENI WATER IN KWA-ZULU NATAL**

**By
Vernon Nagan**

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DECLARATION

I, Vernon Nagan, hereby declare that this dissertation, except as indicated in the text, is my work and has not been submitted in part or whole at any other University or the University of Technology.

This research on the “Long term water conservation and demand management for the Umgeni Water in Kwa-Zulu Natal” and registered at the Durban University of Technology under the supervision of Dr. Mohammed Seyam and co-supervision of Dr. Taher Abunama.

Vernon Nagan.

APPROVED FOR FINAL SUBMISSION

DEDICATION

I wish to dedicate my thesis to my loving parents, who taught me to persevere and prepared me to face challenges with faith and humility. They have been a constant source of inspiration in my life, and their presence urges me to strive to achieve my goals in life.

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I want to thank my God, who gave me strength and guidance towards successfully completing my Master of Engineering Degree in Civil Engineering.

I want to thank and appreciate the following individuals and institutions that assisted me and drove me to complete the research successfully.

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I want to thank Mr. Ntuthuko Ngcamu from Umgeni Water, who assisted me immensely in obtaining relevant data and information. Thank you for your kind and good helping nature.

To my parent for bringing me up into the kind-hearted individual that I am today. Thank you so much. I am forever grateful to you.

ABSTRACT

South Africa is considered a water-scarce country and is anticipated to encounter extensive water deficits in almost all its water management areas by 2025. Due to water scarcity, adequate resource management and planning are required to sustain its water resources. From 2015-2019 the country faced severe water shortages, which forced many provinces to implement water restrictions as a water conservation and demand management strategy. South Africa faces several obstacles regarding water management, such as long periods of inadequate rainfall, population growth, and excessive water losses, to name a few. South Africa has developed most of its water resources with limited scope for further development. The study focuses mainly on the Mgeni system, which consists of Upper and Lower Mgeni systems managed by Umgeni Water, the main supplier of potable water to most of the Kwa-Zulu Natal province.

The Mgeni System is recognised as the main source of water supply in the Durban and Pietermaritzburg region situated in South Africa. The Durban-Pietermaritzburg region is the primary economic hub of Kwa-Zulu Natal, and this will bring about a high level of demographical pressure and water supply problems. The study's objective was to (i) analyse the study area to assess whether there will be sufficient supply to meet future demand with climate and demographic impacts, (ii) identify the quantity and causes of current water losses within the study area and to assess the Key Performance Indicators, and (iii) to evaluate efficient strategies, tools, and measures for water conservation and demand management which will reduce water losses in future years.

The study adopts both quantitative and qualitative analysis. The quantitative analysis investigates the water supply and demand situation in the Mgeni System catchment and evaluates the future supply and demand accounting based on Water Evaluation and Planning (WEAP) software. The WEAP model is used to analyse the study area from 2009 to 2050 to develop outcomes scenarios that visualise future water supply shortfalls with current data inputs. The assessment model is computed based on four scenarios such as varying population growth rates and impacts of extended dry climates. The qualitative analysis utilises questionnaires to investigate the current WC/DM strategies. The qualitative method involves data collection from structured questionnaires targeting Umgeni Water department with thorough water conservation and demand management knowledge. The study found that the Mgeni catchment is relatively sensitive to changes in population growth, which will

significantly alter water availability. Furthermore, an extended dry climate will cause a water supply deficit, thus exposing the study area to water scarcity problems. The study results also indicate that Umgeni Water currently has water conservation and demand management strategies and interventions in place, but it requires more investment from stakeholders to produce the required benefits.

In response to the future water demands, the only way one can overcome the unmet demand is by introducing water conservation and demand management strategies such as pressure management, active leak detection testing to reduce the water losses encountered, as well as education and awareness which forms an integral part of the initiative. By implementing these strategies, water losses can be reduced, preventing early water scarcity, and giving decision-makers time to provide further solutions to the water problems in the study area.

Keywords: Water, management, resources, population, climate change, water losses, WEAP, Scenarios, demand, supply, water conservation, precipitation, streamflow.

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LIST OF ABBREVIATIONS

AMR	Automated Meter Reading
ALC	Active Leakage Control
ALI	Apparent Leakage Index
BABE	Burst and Background Evaluation
CARL	Current Annual Real Losses
CAAL	Current Annual Apparent Losses
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
DWAF	Department of Water Affairs and Forestry
IoDSA	Institute of Directors in South Africa
ILI	Infrastructure Leakage Index
IMP	Infrastructure Master Plan
KPI	Key Performance Indicator
KZN	KwaZulu-Natal
RAAL	Real Apparent Annual Losses
NRW	Non-Revenue Water
NWA	National Water Act
NWRS	National Water Resource Strategy
MAP	Mean Annual Precipitation
MMTS	Mooi-Mgeni Transfer Scheme
SAWS	South African Weather Service
SEI	Stockholm Environment Institute
UW	Umgeni Water
UARL	Unavoidable Annual Real Losses
WDS	Water Distribution System
WC/DM	Water Conservation and Demand Management
WEAP	Water Evaluation and Planning
WMA	Water Management Area
WRC	Water Research Commission
WSA	Water Services Authority

LIST OF UNITS

l/s	:	Litres per second
m ³ /s	:	Cubic metres per second
million m ³ /year	:	Million cubic metres per year
Ml/day	:	Megalitres per day
Kl/month	:	Kilolitres per month
Km ²	:	Squared kilometres

CHAPTER 1 : INTRODUCTION

1.1. Background

Water in South Africa has a powerful link not only to all aspects of the physical environment but also to poverty reduction, sustainability, equity, and economic development (Knight, 2019). According to Rockström (2014), water plays a crucial role in all aspects of life and the environment, from health and sanitation to agriculture, food, and ecosystems.

Section 3 of the National Water Services Act (NWSA) 1997, states that water authorities are required to take reasonable measures to ensure that everyone has access to basic water supply and sanitation. According to the World Wildlife Fund (WWF), around 1.1 billion people lack access to clean water, and about 2.7 billion experience water scarcity at least one month a year (World Wildlife Fund, 2022).

South Africa is a semi-arid country characterised by spatial and temporal rainfall variability and is considered a water-stressed country (Department of Water Affairs and Forestry, 2010). The depletion of our water resources results from low average annual rainfall, climate change, population growth, rapid economic development, urbanisation, industrialisation, and inefficient irrigation activities. The world, especially semi-arid countries like South Africa, is facing severe and growing challenges in meeting the rapidly growing demand for water resources. This calls for encouragement for a more sustainable approach to water conservation and demand management in many areas in South Africa.

The average rainfall in South Africa ranges from 450mm to 500mm per annum, which is well below the world average of 860mm to 1000mm per annum. South Africa's water usage normally is comprised of 77% surface water, 9% groundwater, and 14% re-use of return flows. (Department Water and Sanitation, 2013). As shown in Figure 1.1, South Africa is one of the few countries that face water scarcity, with an estimated water availability of 843m³/person/year.

Although the Department of Water and Sanitation (DWS) implemented WC/DM strategies, the demand continues to increase. Instead of merely concentrating on expanding the supply of freshwater, South Africa must also pay attention to the need to minimize water use. South Africa needs to focus on the need to reduce water demand and not just on focusing on

increasing freshwater supply alone. Water supply options are becoming increasingly expensive and unfeasible, such as inter-basin transfers and seawater desalination or acid mine drainage treatment. The way forward to proper water resource management lies in effective demand management approaches to the resource (Jacobs-Mata et al., 2018).

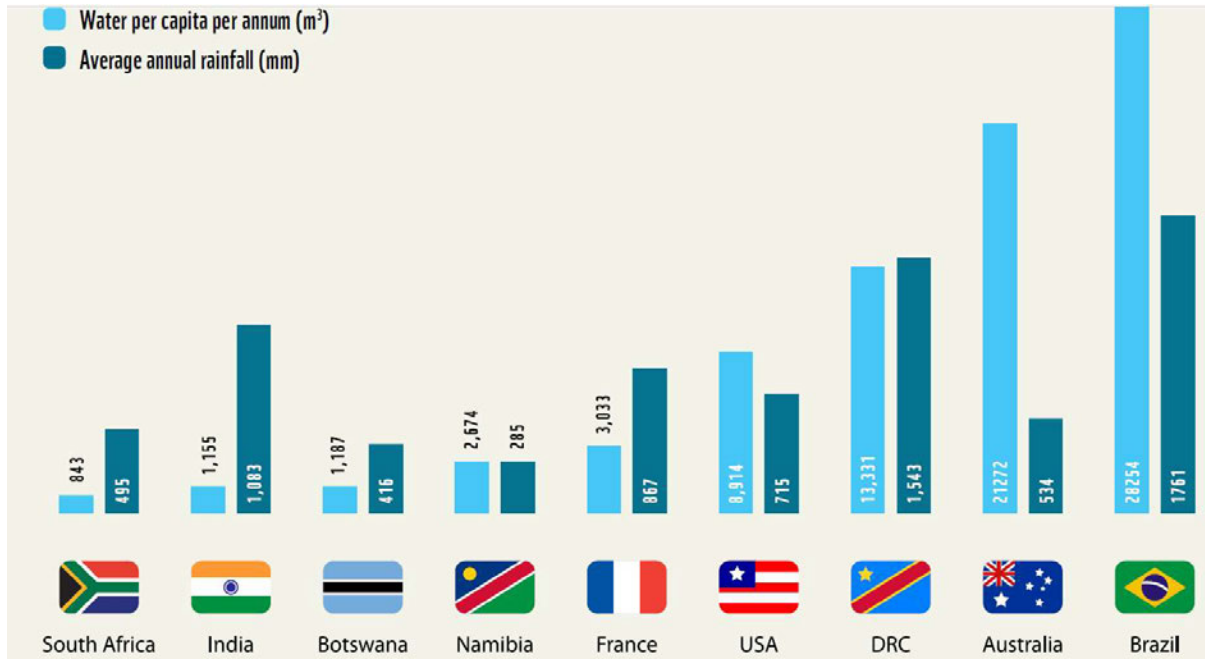


Figure 1.1: Water availability in certain countries (National Water Resource Strategy, 2013)

1.2. Research Problem

A study conducted by the Department of Water Affairs (DWA) estimated that by 2025, water demand is projected to exceed supply by 1.3% and that there will be water deficits of approximately 234 million m³ (Department of Water Affairs, 2004). Climate change and population growth are fundamental drivers of the water resource situation and determine how much water is available. The population growth rate of 1.1% had been determined whereby the study area comprised approximately 4,5 million people in 2009, increasing rapidly to 5,0 million in 2019, which put immense pressure on the country's limited natural resources and freshwater supply (Stats S.A, 2019).

Many Water Service Authorities (WSA) encounter excessive water losses, accounting for about 30% of the total supply volume (Umgeni Water, 2020). In comparison, the national average NRW for South Africa is about 35% while the international NRW ranges between 5%

to 15%. Some communities have NRW much higher than the national average. Typical examples include Mbombela Local Municipality (40-70%) and Emfuleni Local Municipality (49%) (Mutamba, 2014).

The research investigates the effectiveness of Water Conservation and Demand Management (WC/DM) in dealing with the water crisis in South Africa. The study area being the Mgeni system, which mainly services the Durban and Pietermaritzburg areas, has seen a rapid increase in population growth, putting severe strain on the water industry. Durban and Pietermaritzburg are regarded as the province's economic hub, which results in a vast increase in population within the area. As a result, the Water Service Authority must implement effective measures to conserve water and manage water supply and demand. This should be accomplished to ensure the security of water supply to residents, businesses, and agricultural industries, without depleting existing water resources. Furthermore, developing a policy framework that promotes public awareness is needed in South Africa to make people appreciate the economic value of water as a scarce resource.

1.3. Study Objectives

The research objective was achieved through the following specific objectives:

- i. Analysing the quantity of current and future water demand in the Mgeni System and evaluating if there will be sufficient supply to meet the demands.
- ii. Identify the quantity and causes of current water losses within the study area and assessing the Key Performance Indicators (KPI's).
- iii. To evaluate current Water Conservation and Demand Management (WC/DM) strategies, tools, and measures and to provide more efficient WC/DM solutions for water loss reduction.

It is important to understand the current measures and strategies being implemented to accomplish the study's objectives. Therefore, the emphasis is on developing a practical methodology to determine the effectiveness of WC/DM measures applicable to developing countries like South Africa. The study aim should therefore determine the effectiveness of WC/DM measures from the previous implementation such that the measures can be practically, feasibly, and realistically applied to future planning scenarios, as well as to develop a WC/DM model to evaluate the effectiveness of individual and combined actions to reduce water usage and waste.

1.4. Significance of the study

South Africa's water security depends on the sustained supply of our water resources. All our investments in the water sector are dependent on these natural resources. It is imperative that these are conserved, restored, maintained, monitored, and carefully managed (World Wildlife Fund, 2022).

The outcomes of this study are expected to provide more insight into water conservation and demand management in the Mgeni System. Results from the study will form a basis for planning for efficient water distribution, management, and conservation to sustain the scarce resource. By determining and evaluating the current Key Performance Indicators (KPI), the study will also promote strategies, tools, and measures to reduce the number of water losses within the region. This study will contribute to the information on the water shortage mitigation strategies implemented in Durban and Pietermaritzburg. It will also indicate the importance of consumer awareness of how to conserve water and use it wisely.

Planning for long-term water demand and supply is critical for the Mgeni system considering the increase in population due to economic development within the area. By developing reliable water use and allocating scenarios for the future, we can improve planning and management decisions, and it would significantly influence future decisions about water supply and allocation.

The key to identifying appropriate planning options for sustainable water supply in the study area is in both the water modelling approach and an understanding of current measures and how to improve the efficiency of those measures. The finding of this modelling study improves the information on the state of water resources of the Mgeni system and its current allocation priorities to the eThekweni, Msunduzi and uMgungundlovu districts.

The significance of this study is to assess if the study area has sufficient water supply to keep up with the various scenarios in population growth and possible climate change. Potable water is a human right and is a basic need, therefore studies such as this provides a researched background on the potential impacts and problems faced in the future.

1.5. Scope and Limitations of Study

This study was undertaken to identify long-term water conservation and demand management strategies for the Mgeni System situated in the Kwa-Zulu Natal province. Its purpose was to evaluate the current state of the water resource situation and determine the future water demand considering the impacts of demographical growth and climate changes.

In conducting the study, the researcher engaged with Umgeni Water department at various technical level to conduct questionnaires to gather information on current strategies and measures implemented with the aim of understanding the current state of WC/DM. Initially, questionnaires were sent electronically to participants, but due to the poor response, the researcher had to conduct in-person interviews to acquire information. The questionnaires were aimed at the Umgeni Water Planning Services and Water Demand Department, which consisted of twenty-one departmental members with background knowledge and work on water conservation and demand management implementations. The researcher determined the sample size of eighteen to provide information based on their perceptions and norms on water resource management and water supply and demand. This was focused on the Planning Services Department at Umgeni Water who deals with the water demand management for the study area.

1.6. Thesis Outline

This thesis comprises of five chapters presented to promote ease of understanding and reading of the research goals and scope and the methods employed to accomplish the research objectives. A brief description of each chapter is provided as follows. **Chapter One** provides information on the background of the research being conducted, describes the study area, and indicates the relevant data such as rainfall, and evaporation. A brief overview of the water resources situation in South Africa is provided in **Chapter Two** by examining various literature to provide a foundation of knowledge regarding the study. **Chapter Three** describes this study's research design and discusses the methodology. It explains how the data was analysed and how the model was constructed. **Chapter Four** presents the study results, discusses the results, and compares them to existing data. Finally, **Chapter Five** summarises and concludes the study, proposes solutions to the research problem, and offers research recommendations.

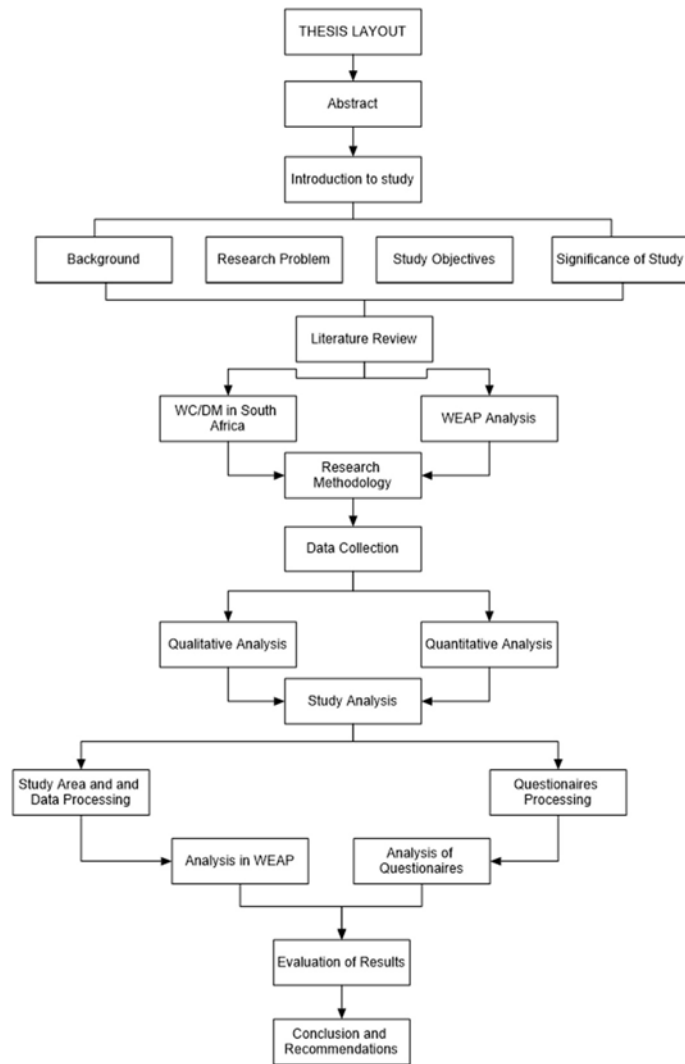


Figure 1.2: Thesis Flowchart

1.7. Summary

This chapter has provided the background and context to the research study. The pertinence of WC/DM as a solution to the water supply and demand problems for the Mgeni system has been introduced. This chapter emphasises the importance of conserving water (a scarce resource) and confirms that South Africa faces challenges because of water scarcity. The study objectives and significance of the study have also been explained in this chapter. Consequently, legislation and strategies relevant to WC/DM should be prioritised and put into place to ensure a sustainable water supply for future demands. Furthermore, the thesis outline describing the chapters and content are also elaborated in this chapter. Chapter 1 sets the foundation for the research, followed by Chapter 2, which will review the previous literature on WC/DM and the utilisation of WEAP to analyse the water supply and demand situations.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter presents an overview of the implementation of water demand management and policies in South Africa. Evidence of water shortages in the future is imminent in South Africa, and this will be explored together with literature related to the study of water conservation and demand management.

2.2 Water Resources

2.2.1 Background of Water Resources in South Africa

All the investments in the water sector are dependent on the sustainability of our water resources. The conservation, restoration, maintenance, monitoring, and careful management of these resources is essential to the security of our water resources. As shown in Figure 2.1, water usage for municipal/domestic purposes only accounts for 27% of the total water usage distribution, with the agriculture sector being the highest user at 61% of the total water usage, and power generation, mining and bulk industrial use, livestock and nature conservation summing up the balance of usage at 12% (Department of Water and Sanitation, 2018).

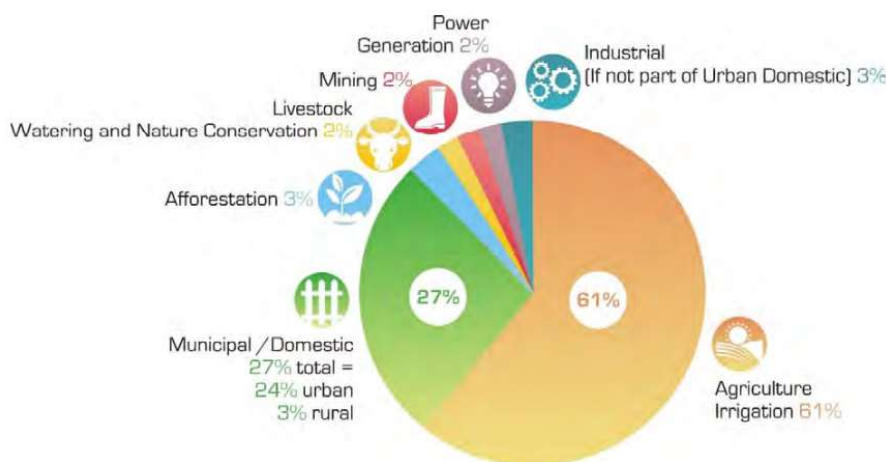


Figure 2.1: Water Usage per Sector in South Africa (Source: DWS, 2018)

2.2.2 Climate

Rainfall is the major component of the hydrologic cycle and is the primary source of runoff (Beven, 2011). Even though water is widely distributed and an abundant resource on earth, freshwater is still a scarce commodity, mainly due to climate change. Umgeni Water has obtained rainfall data for the four dams within the study area, and this is shown in Figure 2.2.

As shown below, the study area is a summer rainfall area which occurs from November to March. It has also been established that the study area receives convective rains whereby the high temperatures cause moist air to rise and cool down, where it then condensates and forms thunderstorms.

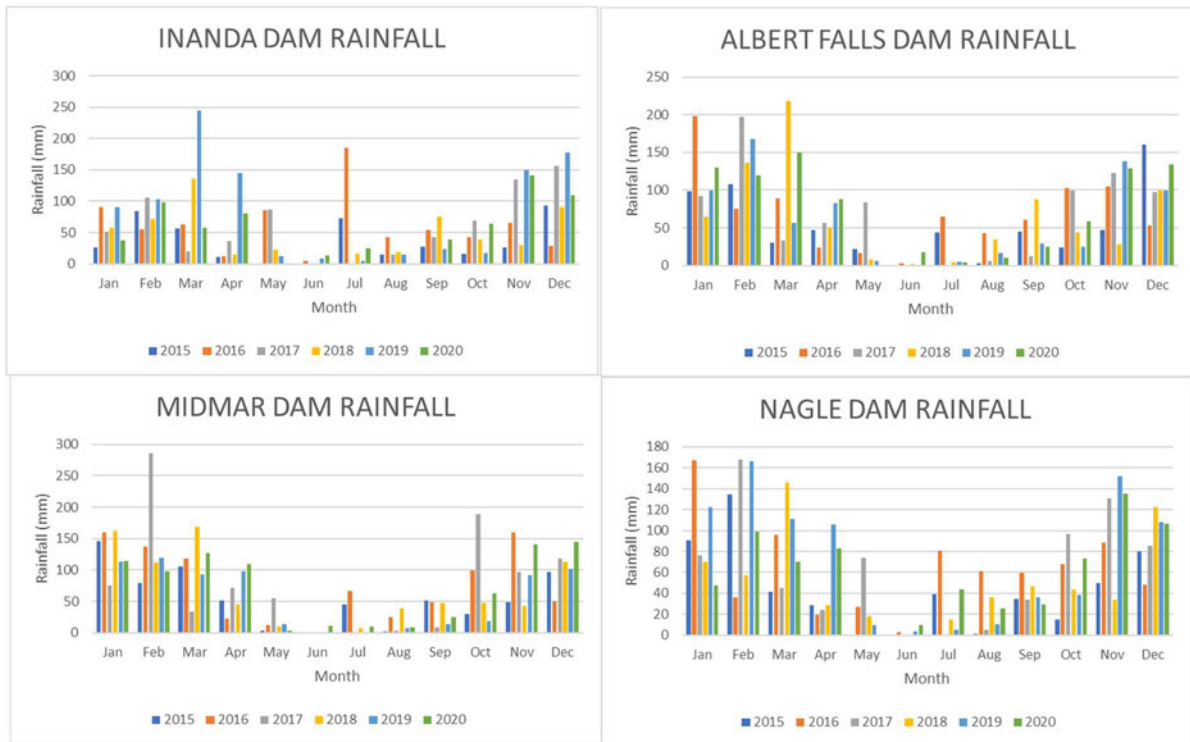


Figure 2.2: Rainfall Data (Source: SAWS, 2021)

The evaporation rate for South Africa is greater than 1400 mm per annum for most of the country (Van Dijk and Van Vuuren, 2008). Presently, over 2 000 mm³ is lost each year through evaporation from surface storage reservoirs (Smakhtin et al, 2001). As a result of South Africa being semi-arid country, evaporation within the catchment accounts for 8% which is loss of stored water resources and 6% is lost through various land use activities. Most water consumption can be attributed to drinking, irrigation, electricity, mining, and industrial processes (Oosthuizen et al., 2015). This evaporation data has a similar pattern to rainfall, where a relatively high evaporation rate is experienced in summer.

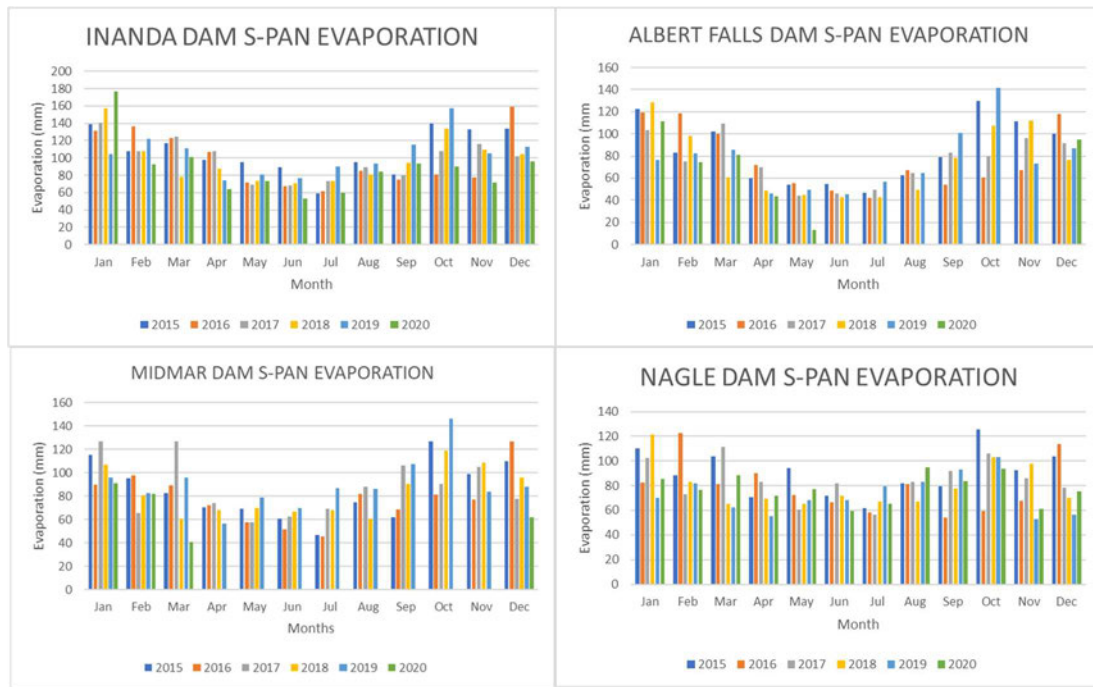


Figure 2.3: Evaporation (S-Pan) (Source: SAWS, 2020)

2.2.3 Raw Water Quality

According to numerous studies, the watercourses have shown a decline in quality due to pollution caused by mining, agriculture, urbanisation, and power generation. Due to the country's limited water resources and the population growth expected, it is unlikely that it will be able to maintain its current patterns regarding the use of water and the discharge of wastes (Bwapwa, 2018). The current state of water quality plays an integral part in the rate of water supply. Water quality differs from catchment to catchment, which poses a risk to the raw water quality being utilised to supply the community with potable water. Aspects such as eutrophication and organic contaminants affect the method used to treat the raw water and may result in high-cost implications. Table 2.1 indicates the raw water quality of the study area.

As a water provider, Umgeni Water has established resource quality targets for water resources used for abstraction and uses these target alert levels to assess and mitigate treatability risks, optimize raw water quality, and provide early warnings when adverse conditions arise. As part of water quality plans, water resource quality is monitored in order to determine raw water treatability, risks associated with deteriorating trends in eutrophication, chemical contamination, pathogens, and turbidity, and waste discharge quality from operational sites is monitored and improved (Umgeni, 2020).

Table 2.1: Raw Water Quality (Source Umgeni Water, 2016)

System	Catchment	Impoundment	Raw Water Quality Problem	Water Quality Status
Mgeni	Mooi, Mgeni	Mearns Weir, Midmar Dam	High algal counts are associated with high nutrient concentrations, and iron and manganese problems have been experienced occasionally.	Good
	Mgeni	Albert Falls Dam, Nagle Dam	High algal counts are associated with high nutrient concentrations and high turbidity/suspended solids.	Good
	Mgeni	Inanda Dam	Elevated algal counts are associated with high nutrient concentrations, chemical contamination and high suspended solids.	Moderate

2.3 Water Conservation and Demand Management

2.3.1 What is Water Conservation and Demand Management?

Water Conservation and Demand Management (WC/DM) refers to the minimisation of water loss through efficient control of water supply and demand (Department of Water Affairs, 2004). The principle encompasses two sets of water management strategies, namely strategies for curtailing growth in the amount of water used (water demand management “WDM”) and approaches to limit the loss or wastage of water and enhances the care and protection of water resources (water conservation “WC”). WC/DM approaches focus on improving water use efficiency and promoting sustainable development (Mutamba, 2014).

Water Conservation and Demand Management (WC/DM) can be broken into two sections, the first one is the conservation of water resources, and the second one is the demand management of water resources. Water conservation aims to preserve and manage water resources to develop the ecosystem and habitats. Water demand management aims to manage the water demand, minimising the amount of water losses and encouraging its efficient and effective use through education and awareness. To achieve future development, poverty alleviation, jobs creation, and addressing societal inequalities, an adequate and proper water management system is crucial. Water scarcity could be a limiting factor to growth and development. As a result of over-exploitation of freshwater resources, the National Development Plan 2030 may

be hindered from achieving its outcomes, as the plan emphasizes growth, transformation, and investment (Hedden and Cilliers, 2014).

Successful water demand management (WC/DM) entails comprehensive reforms and actions to optimise existing water supplies. The goal is to conserve water by controlling usage, influencing demand, and promoting efficient use over the long term (Kotzé, 2018).

2.3.2 Water Conservation and Demand Management in Umgeni

Umgeni Water implemented a Water Conservation Policy in 1999, and a Water Demand Strategy was implemented in 2013 (Umgeni Water, 2013). These two documents focus on the legislative requirements and aim to enable the supply to all reasonable demands without placing undue stress on exploitable water resources, postpone capital expenditure on expanding bulk water infrastructure, and minimise expenditure on developing new resources.

Due to the extensive water losses registered in the Umgeni Water footprint, Umgeni Water established a Water Demand Management (WDM) Unit in 2016, which aims to support water service authorities in curbing water losses in their respective water supply systems. This WDM Unit provides measurement and analytical support with technical recommendations where necessary. Four areas of framework support are strategic, tactical, financial, and regulatory.

Umgeni Water undertakes several WC/DM strategies to aid the promotion of water conservation and demand management. Some key water demand management strategies implemented by Umgeni Water are water balances, meter accuracy testing and calibration, monitoring and reduction of repair leaks and bursts, and education programs and awareness.

2.3.3 Principles of WC/DM

The principle of WC/DM is critical to ensuring adequate water supply and demand for future sustainability. In order to achieve success in WC/DM, it is important to incorporate principles and measures (Mineral Council South Africa, 2020). Water Conservation and Demand Management have still not been effectively utilised in South Africa, which can be seen in the past and current water resource situation. Implementing these principles plays a vital role in reaching the WC/DM goals and objectives set by Water Service Authorities. Some of the principles developed by the Department of Water Affairs are summarised below:

- i. Effective water conservation and water demand management interventions is critical to promote water resource planning in drought affected areas.
- ii. Development of water infrastructure is based on measures and strategies that can impact the water supply and demand with appropriate supplies, which can be developed together with policy maker and authorities.
- iii. Rainwater harvesting, borehole water reuse, seawater desalination, and water conservation and demand management interventions can be good components of South Africa's water resource Reconciliation Strategies.
- iv. In aligning with the Urban Development Framework in support of South Africa's cities and towns, water infrastructure planning meets the needs of a growing population for shelter, economic development, and environmental sustainability.
- v. Water infrastructure planning considers the multiple use needs of communities.
- vi. Cost-effective investments in water infrastructure produce sustainable value for money.
- vii. Infrastructure development, operation, and maintenance are used to generate jobs and to promote socioeconomic equity.
- viii. Considering the possible consequences of climate change in water resource development and water supply planning, construction, operation, maintenance, and management is key to effective management.

2.3.4 The Need and Benefits of WC/DM

South Africa has been struggling to manage water resources for several years. While the augmentation of water supply through new physical infrastructure relieves water scarcity, it is often limited to some extent. Therefore WC/DM is an urgent requirement and is needed to promote the efficient usage and management of the scarce commodity.

There are several benefits of implementing water conservation and demand management in South Africa. These benefits can be categorised from financial to ecological, or it can be categorised from different beneficiaries. The following benefits can be achieved through WC/DM:

- i. Consumers: WC/DM can make water affordable, especially for poor and vulnerable communities. Most water losses are laid on the consumer, and in turn, the consumer pays for these losses. Reducing losses through WC/DM can alleviate high bills to the consumer.

- ii. Water Service Authorities: WC/DM interventions can reduce Non-Revenue Water (NRW), reduce leakages, reduce meter reading errors, and ensure an adequately managed water supply system. NRW are regarded as financial losses to the WSA; therefore, WC/DM can save WSA revenue.
- iii. Communities: WC/DM can benefit communities by creating jobs such as plumbing, leak detection opportunities etc. The WC/DM also promotes education and awareness, which teaches the communities good practices for proper water usage, which is financially beneficial to them.
- iv. Environment: WC/DM should be implemented before the implementation of infrastructure projects which in turn protect the environment. Implementation of WC/DM also for possible reallocating of existing infrastructure projects and resources to people without services, enabling the enhancement of service delivery.

2.3.5 Challenges associated with Water Conservation and Demand Management

Water Conservation and Demand Management can positively impact the water situation faced. While WC/DM is seen as a strong strategy, implementing such is confined to many challenges. In order to achieve a successful WC/DM program, these challenges must be overcome. Some of the major challenges are:

- i. Education and Awareness: there is a lack of education among professionals in the water sector, especially in issues regarding WC/DM, as most professionals are oriented in the supply side approach. Water Conservation and Demand Management are neglected because decision makers are not fully informed and knowledgeable of the benefits. The consumers also lack education about the benefits of water conservation and water reuse. The lack of knowledge in WC/DM prevents WSAs and consumers from engaging in these WC/DM measures and strategies.
- ii. Institutions: institutions that deal with water-related issues and legislations operate on old philosophies. With technological improvements in the water industry, the institution still tends to focus on ancient methods. There is also the issue of multiple institutions with no collaboration and a lack of communication.
- iii. Legislation: the government must implement adequate policies and legislation to protect the environment and the consumers. It is also important to have regulations about the responsibilities in the water sector. These policies and legislations must provide a basic good, quality water supply to the communities, and it is the government's responsibility to ensure the water suppliers follow all laws and

regulations to ensure a society for the environment and consumers.

- iv. Funding: Water Conservation and Demand Management require adequate planning and implementation together with ongoing research to improve strategies and interventions. Funds are necessary to conduct proper research, planning of programs, and overall implementation of WC/DM. WC/DM are indeed financially beneficial in the long term, but there is still a financial implication at the beginning of the program.

2.3.6 Water Conservation and Demand Management Interventions

i. Rainwater Harvesting

Rainwater harvesting describes the small-scale concentration, collection, storage, and use of rainwater runoff for productive purposes. Domestic rainwater harvesting on rooftops, courtyards, and similar compacted or treated surfaces is one of the broad categories of rainwater harvesting. Water is collected, stored, and used mainly for irrigation of gardens and small-scale production activities. (Kahinda, Taigbenu and Boroto, 2007).

Rainwater harvesting has many advantages, such as it provides an alternative supply of water, it provides a cost-efficient solution to water supply, it provides good quality water provided that stormwater is caught directly from roof surfaces, and it improves the quality of groundwater through dilution when recharged and reduces soil erosion and flooding. Compared to other alternative water resources, rainwater harvesting is one of the most beneficial methods and can be adopted in any scenario and environment in South Africa. It can be seen that rainwater harvesting has been successfully implemented even with the lack of prior technical knowledge or external assistance but simply as a common-sense response to a lack of water (Houston and Still, 2002). The South African government and non-governmental organizations (NGOs) have promoted rainwater harvesting. South Africa has a high potential for rainwater harvesting; however, institutional, legal, and financial factors have prevented this from becoming a mainstream WC/DM measure (Kahinda, Taigbenu and Boroto, 2007). Rainwater can resolve both immediate water security issues as well as long-term water security issues if implemented correctly. Figure 2.4 illustrates the process of the immediate and long-term implementation of rainwater harvesting and a structured approach to tackling water resource problems in South Africa.

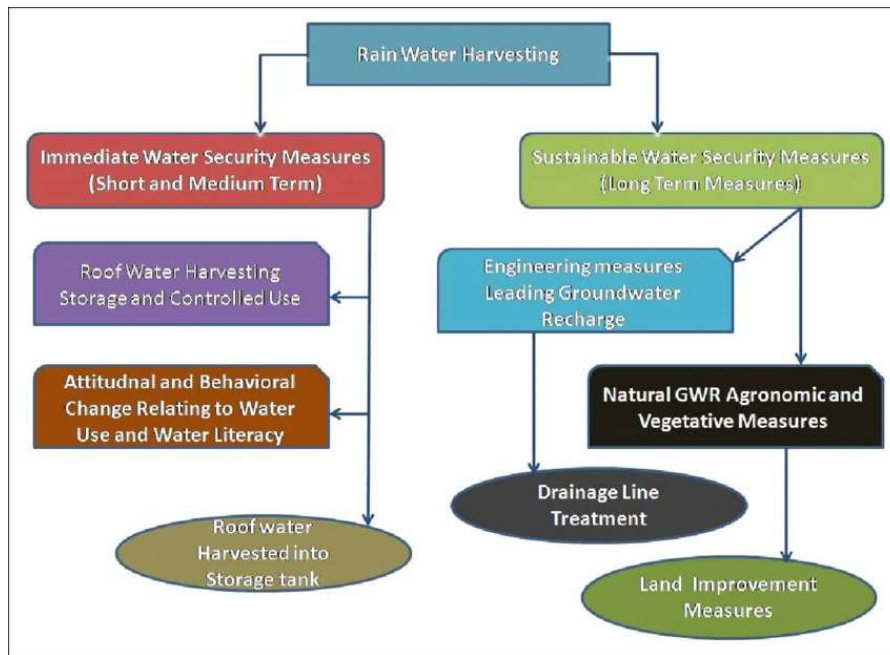


Figure 2.4: Flowchart for Rainwater Harvesting (Narender et al. 2018)

The amount of potential water savings is dependent on factors such location, rainfall patterns and the catchment size. For example, a 100m² roof can collect approximately 3,000 litres of water for every 30mm of rainfall. If you live in an area with 800mm of annual rainfall, you could collect up to 85,000 litres of water annually (Mattias, 2023).

Several case studies around South Africa demonstrate the synergistic relationship between rainwater exploitation and groundwater. Due to high levels of salinity in the groundwater, rainwater is used to provide the majority of potable drinking water in Xolo, KwaZulu Natal, and Garies, Northern Cape. In areas with little groundwater availability, rainwater harvesting has provided reliable, cheap, and high-quality drinking water alternatives to households. According to the Guidelines for Human Settlement, Planning and Design (CSIR, 2019), rainwater should be considered as a supplementary source of water for non-potable uses, since it may pose health risks as it is naturally slightly acidic but can be made very acidic by industrial pollution. In order to give this alternative water source political credibility, rainwater harvesting systems in South Africa need the government's official support. There are NGOs developing skills in the rainwater harvesting sector, but there are few and far between. In a 21st century where water is scarcer and finite, rainwater harvesting must be rediscovered and utilized (Houston and Still, 2002).

ii. Grey water Re-use

As stated in the National Water and Sanitation Master Plan, it had been predicted that South Africa would experience approximately 17% water supply deficit by 2030. In order to increase the availability of potable water, the Development Bank of South Africa (DBSA) had called for major investment in upgrading of the current water reuse technologies and interventions (Fluence Corporation, 2022).

Essentially, water reuse refers to recovering water from various sources to be treated and used for different purposes, including drinking and farming. In arid and semi-arid regions of the world, such as South Africa, recycling treated wastewater instead of water from catchments can reduce water usage and promotes sustainable water conservation. The use of recycled water is a sustainable source of drinking water, but it also creates a variety of issues, such as economic, technical, and institutional ones, and safety issues as well. A number of countries, such as Jordan, Kuwait, Israel, Spain, Australia, Namibia, Germany, the United Kingdom, and the United States, have adopted wastewater reuse as a key component of water demand management (Jimenez and Asano, 2008).

In light of the wide range of wastewater treatment technologies available and the successful implementation of wastewater reuse in many of these countries, it is imperative that wastewater reuse be evaluated as a viable alternative to overcome the current and future challenges of water shortages in South Africa (Adewumi, Ilemobade and Van Zyl, 2010). With adequate treatment, greywater can save approximately 70 litres of potable water per person per day in domestic households, therefore greywater re-use is one of a number of water solutions that we should look to in order to decrease our usage (Persaud, 2016).

The development of water reuse schemes in South Africa has generally been slow compared to some other developed countries. South Africa's water authorities have only recently begun to identify various water reuse and recycling schemes (Bakare, Mtsweni and Rathilal, 2017).

iii. Automatic Meter Reading (AMR)

Automatic Meter Reading (AMR) are new technological devices that automatically collect data such as consumption and billing on an ongoing system which is easily accessible. The

AMR system provides WSA with real-time data, which can analyse daily to estimate and locate leakages which also helps reduce the loss of water due to leakage, theft and irresponsible behaviour.

The AMR is controlled remotely from any location and broadcasts the readings using radio frequency bands. A computer program manipulates the readings so that the user is billed according to the correct tariff amount when the results are entered into the main database. Many benefits of using an AMR include eliminating human errors in meter reading, quicker billing of meter usage, accurate live term readings and the ability to deal with complex tariff structures accurately.

iv. Education and Awareness

Public education and awareness are important to a successful Water Conservation and Demand Management program. Communities that are educated and informed on the current problem and situation of water resources within the country are more likely to participate in the WC/DM practices. Education and awareness measures can produce large water savings by illustrating water conservation measures to the end users.

Umgeni currently has implemented WC/DM practices, including an education programme on water conservation and demand management. In order to promote conservation and awareness of scarce water resources, education and awareness programmes are aimed at educating and encouraging the community. Programs of public awareness could be used instead of other demand management measures such as raising water prices, purchasing water-saving devices and restricting water supply. Additionally, water demand patterns are often influenced by education or communication strategies. These can take various forms, such as educational materials distributed by water providers or water efficiency labelling. Education and awareness strategies are often incorporated into larger water demand reduction programs that can make evaluating their effectiveness difficult.

In spite of increased awareness of the global water crisis, there is still much that can be done to make sure future supplies are assured, especially in South Africa. The government's program for free water provision has existed for more than a decade, but its awareness has reached only 38%, while the bulk water service provider's initiative had an awareness of

almost 60%, having also run for more than a decade. In spite of a certain degree of awareness, respondents stated that it would like more information on how to use water responsibly and conserve it. It is this willingness to learn more that should be encouraged by those who are in a position to make a difference. In the future, research should focus on sustaining and expanding current awareness campaigns in an effective and cost-efficient manner (van der Vyver, 2015).

2.4 Water Balance – IWA Method

The International Water Association (IWA) Water Balance is used as a graphical tool worldwide to quantify volumes of water that enter the system and shows the amount of authorised consumption and water losses in the system. It also highlights the Non-Revenue Water and the Revenue water to illustrate the economics of the system. Table 2.2 shows the breakdown of the IWA Water Balance. The Water Balance of the study area has been calculated and shown in Appendix B. As illustrated in the three municipalities, namely eThekweni, uMgungundlovu and Msunduzi, it is shown that water losses are around 28% to 43% of the total System Input Volume (SIV). Furthermore, approximately 39% to 57% of the SIV is taken as Non-Revenue Water.

Water loss is an important indicator of how much water is currently being used within an area and utility. In spite of the best operation and maintenance, water losses cannot be eliminated completely. The characteristics of the water supply systems can be measured based on a variety of Key Performance Indicators (KPI) once the water balance has been determined. In order to improve efficiency and reduce commercial losses, physical losses, or NRW, the water utility needs to determine the water balance as well as KPIs. Identifying and quantifying the main sources of water loss contributes to identifying the most effective WC/WDM intervention to eliminate them. NRW comprises the following categories: unbilled metered, unbilled un-metered, illegal connections, inaccurate meters, mains leaks, reservoir overflows and service connection leaks (Wegelin, 2015).

Table 2.2: IWA Water Balance (Source: Seago & McKenzie, 2007)

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water		
			Billed Un-Metered Consumption			
		Unbilled Authorized Consumption	Unbilled Metered Consumption			
			Unbilled Un-metered Consumption			
	Water Losses	Apparent Losses (Commercial Losses)			Unauthorized Consumption	Non- Revenue Water (NRW)
					Customer Meter Inaccuracies and Data Handling Errors	
		Real Losses (Physical Losses)			Leakage in Transmission and Distribution Mains	
					Storage Leaks and Overflows from Water Storage Tanks	
					Service Connections Leaks up to the Meter	

2.5 Water Losses

It is imperative that all South Africans understand the importance of conserving the nation's water resources in order to ensure the effectiveness of water conservation and demand management programs. There are traditional stereotypes and mindsets that lead to high water usage, including beliefs that water comes from above and is free (Department of Water and Sanitation, 2018).

Water losses are grouped into two types of loss: real losses and Apparent losses. Whilst Real losses are an expense due to lost water; Apparent losses are not so much an expense to the water utility as it poses a loss of potential revenue.

In order to resolve the water losses within the system, one needs to completely understand the terminology of water losses and how it originates. The International Water Association defines water loss as:

$$\text{Water losses} = \text{Real losses} + \text{Apparent losses} \quad (\text{Eq. 1})$$

2.5.1 Real Losses

Real losses can be regarded as the water lost due to leakage and overflow at service reservoirs, leakages from distribution mains, transitional mains and service connections. There are generally four methods of managing Real Losses: Pipeline and Assets Management, Pressure Management, Speed and quality of repairs, and Active Leakage Control (A.O. Lambert et al.,

2002). To reduce Real Losses, one needs to address these four components:

- i. Leak detections need to be more efficient.
- ii. Response time for the leak repairs needs to be increased.
- iii. Improve maintenance of current infrastructure.
- iv. Implement adequate pressure management control.

2.5.2 Apparent Losses

Apparent losses relate to water that is being consumed but not being paid for. As a result, every cubic metre of water unbilled as the result of an apparent loss costs the water utility money. Apparent losses can be regarded as the water lost due to metering errors, water theft, and data handling errors. There are four methods of managing Apparent Losses: Reduction of Human Error, Reduction of Computer Error, Reduction of Water Theft, and Reduction of Metering Errors (Thornton and Rizzo, 2002). To reduce Apparent Losses, one needs to address these four components:

- i. The reduction of water losses as a result of measurement errors.
- ii. The reduction of water loss due to theft.
- iii. Reducing the loss of water due to computer errors.
- iv. The reduction of water losses due to human errors.

2.6 Leakage Management

Leak management aims to reduce water losses from a water supply system through pressure management and leak detection methods. To adequately manage leakages, the water system needs to be investigated and analysed to determine the cause and extent of the leakage.

Several types of water audit software can be used to track the water supply input volume and the water lost in a system. This software also allows for determining the approximate location of the leakages. Furthermore, new technology-driven tools such as acoustic leak detectors, correlation leak detectors, tracer gas leak detectors, noise loggers and thermal imagers tools can be utilised to manage and resolve leakages to prevent excessive losses within the system.

2.6.1 Leakage Detection, Control and Repairs

Good leakage detection and control require fast identification and quantification of present leakages regularly. This can be achieved by conducting acoustic leak detection surveys regularly. Leakage detection and control are crucial for cost-effective and efficient leakage

management and water loss reduction.

Good leakage repairs require prompt and proper repairs, which is crucial to the success of the leakage management strategy. The duration of the leakage affects the volume of the water losses; therefore, the repairs should be completed as soon as it is detected. The standard of the repair work is also critical and should fall within the South African guidelines.

There are four leakage control strategies that can be used to reduce water losses from water systems, and each has to be balanced in order to achieve the most cost-effective leakage control programme that reduces leakage economically, environmentally, and socially.

2.6.2 Pressure Management

Pressure management is one of the most important WC/DM interventions that should be considered when developing a comprehensive WC/DM strategy for an area. Although pressure management does not resolve every leakage and wastage problem, it is often considered one of the most cost-effective measures to reduce leakage and wastage. Pressure management is the most important WC/DM intervention in many parts of South Africa and is often the first WC/DM measure to be implemented (McKenzie and Wegelin, 2009).

If implemented correctly, pressure management can successfully reduce leakage from existing and new burst pipes and reduce the hidden and often overlooked background leakage (McKenzie and Wegelin, 2009). Decreasing the pressure in the system can be done in several ways, such as fixed outlet pressure control, time-modulated pressure control, flow-modulated pressure control etc.

Pressure management is the most effective way to solve the excessive NRW problem within South Africa. Pressure management decreases the water pressure in the system and reduces the stress levels in the infrastructure, which intimately prevents leakages and bursts within the water system. By implementing pressure management initiatives in areas with high amounts of water losses, the systems NRW will be decreased which will result in a decrease in total water demand. Furthermore, pressure management prevents damage to infrastructure which also leads to reduction in water losses and total water demand. In addition to reducing leakage of Non-Revenue Water (NRW), pressure management has been proven to improve energy efficiency and reduce operation and maintenance costs (Fantozzi, 2015).

2.6.3 Active Leakage Control

The purpose of Active Leakage Control (ALC) is to detect leakages within water networks that is not visible. ALC is important because it discovers leaking infrastructure, otherwise it would not come to the attention of the operating company through customer contact. Active leakage control involves leakage detection teams and units searching surroundings for leaks with the help of sounding techniques, latest technologies, or other approaches. (Williams, 2020). Active Leakage Control techniques discover areas leaking and burst pipes and allow for quick repairs of the leakages to prevent prolific water losses.

2.6.4 Infrastructure Management

As South Africa continues to develop, factors such as population growth, climate change, industrial development and ageing water infrastructure impact the availability of this scarce resource. It puts a strain on the existing water and wastewater infrastructure and technologies. A complex institutional system is at the core of the water infrastructure management which contains several stakeholders and interests with a high degree of interconnectedness more so than merely technical considerations (De Bruijn & Herder, 2009).

The South African water sector anticipates spending over R670 billion over the next ten years on infrastructure (McDonald, Gray and Taylor, 2015). Proper infrastructure management is crucial to the proper management of the water system and decreasing NRW.

2.6.5 Speed and Quality of Repairs

The speed and quality of repairs are critical for preventing extensive losses within a water system. Large bursts are usually visible and disruptive to network pressures, resulting in them being repaired quickly. The problem is that small connections bursts usually do not propagate and are not as disruptive to network pressure, traffic, or pedestrians as large ones, which makes them more difficult to repair (McKenzie, Mostert and De Jager, 2004).

The speed of the repairs is therefore more critical than the actual size of the leak. Figure 2.5 below indicates the impacts of the duration of a burst pipe. Illustration A illustrates a leak detection and repair within 1.1 days; it can be seen that the burst was a quickly reported leak due to its magnitude, and the losses equated to 75m³/day. This would produce approximately 80m³ of water loss. Illustration B, on the other hand, a leak over a 16-day period; it can be seen that the leak was a background/unreported leak with 25m³/day lost per day. The amount of

water lost until the repair was done equates to 400m^3 . Finally, the same leak as Illustration C, but this was not detected until 46 days. This would produce a loss of 1150m^3 .

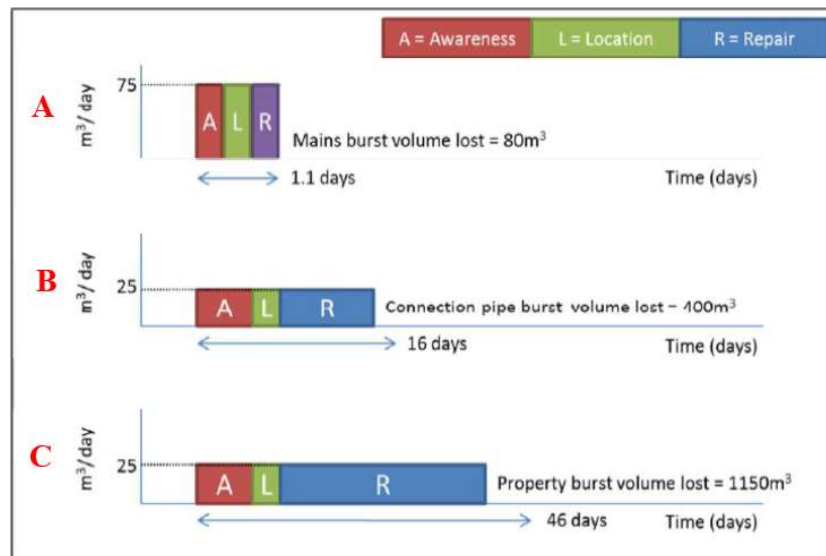


Figure 2.5: Effect of leak repair response times (McKenzie & Lambert, 2002)

Water loss reduction programmes must include the rapid and appropriate repair of leaks, which is also a legal requirement under Clause 12 of the Water Conservation Regulations (Department of Water Affairs and Forestry, 2001) which states that “a water services institution must repair any major, visible, or reported leak in its water services system within 48 hours of becoming aware thereof.”

2.7 Water Evaluation and Planning Software

2.7.1 Water Evaluation and Planning (WEAP)

WEAP was developed by the Stockholm Environment Institute (SEI) in 1988. Using WEAP's water resources and planning software, the researcher can manage municipal, agricultural, or complex transboundary river basin systems based on basic water balance principles. It provides a comprehensive, flexible, user-friendly framework for planning and policy analysis. The WEAP software program is becoming increasingly popular among water professionals as an addition to their toolbox of models, databases, spreadsheets, and other applications. As a result of WEAP, a sequential mass balance is performed along a river system, taking into account abstractions and inflows. In order to simulate the system, the river is divided into reaches. The reach boundaries are determined by points in the river where there is a change in flow as a consequence of the confluence with a tributary, an abstraction or return flow, or where there is a dam or a flow gauging structure (Sieber and Purkey, 2011).

The WEAP model is applied by configuring the system to simulate a recent “baseline” year, for which the water availability and demands can be confidently determined. Using the model, alternative scenarios are simulated to assess how development and management options might impact the environment. A Linear Programming algorithm is used to optimize the water use in the catchment according to a set of user-defined priorities, which aims to maximize water delivery to demand sites. When water is limited, the algorithm is formulated to progressively restrict water allocation to those demand sites given the lowest priority (Sieber Purkey, 2011). It also allows for evaluating scenarios such as different population growth rates and climate change impacts. The scenario analysis evaluates a broad range of what-if questions, such as: What if population growth and economic development patterns change? What if ecosystem requirements are tightened? What if irrigation techniques and crop patterns are altered? What if various demand management strategies are implemented? (Lévite, Sally and Cour, 2003).

The WEAP system provides the following (U.S. Climate Resilience Toolkit, 2021): Integrated Approach: A unique approach for conducting integrated water resources planning assessments.

- i. Stakeholder Process: Through WEAP's transparent structure, diverse stakeholders can be engaged in a collaborative process.
- ii. Water Balance: A database maintains water demand and supply information for a link-node model of water balance.
- iii. Simulation-Based: A range of hydrological and policy scenarios are considered in the system, in order to calculate water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge, and instream water quality.
- iv. Policy Scenarios: The WEAP evaluates multiple and competing water systems and considers the full range of options for water development and management.
- v. User-Friendly Interface: A GIS-based graphical interface that allows users to drag-and-drop models and export output as maps, charts, and tables.
- vi. Model Integration: Includes dynamic links to other models and software, such as MODFLOW, PEST, Excel, and GAMS.

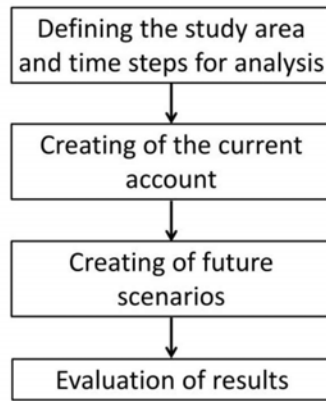


Figure 2.6: Modelling Process of WEAP

2.7.2 Previous Studies carried out using WEAP

Over the years, WEAP has become a popular software model used by many river basins and sub-basins worldwide. According to previous studies, most have been conducted in North America, Europe, and Asia, but a few have been conducted on the African continent. Figure 2.7 below indicates the location of previous studies that have been carried out, which will be reviewed hereunder.

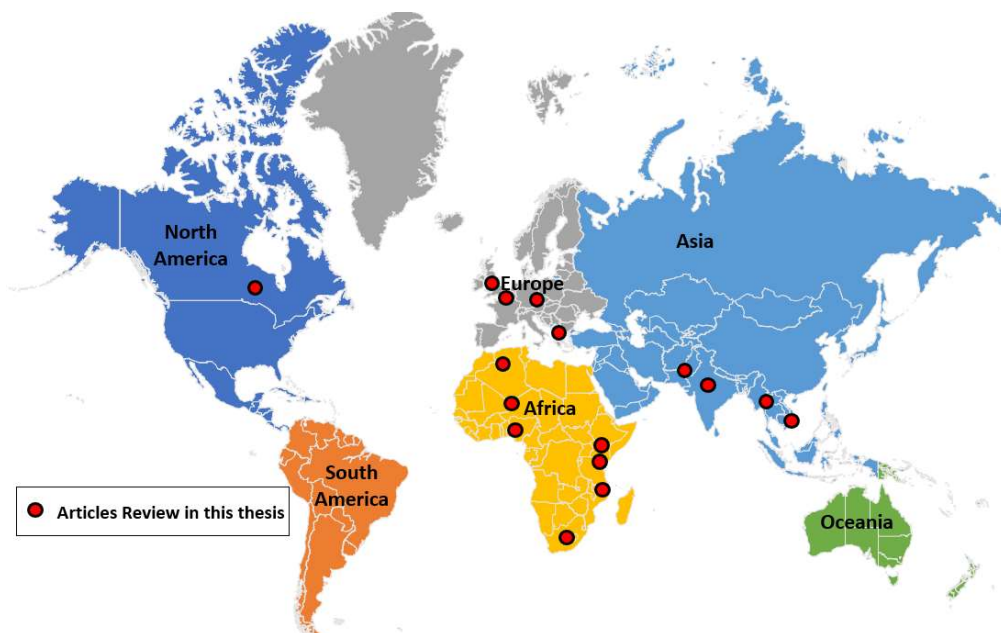


Figure 2.7: WEAP studies from different countries around the world

Many studies in Asia have utilised WEAP, for example, a study in a tributary basin of Tonle Sap Lake, Cambodia, that examined the supply and demand impacts of climate change through an integrated modelling approach. A water balance simulation model in WEAP was used to

estimate water supply and demand relations, including the effects of water infrastructure development and climate change on water resource allocation (Touch et al., 2020).

In another study conducted in south Asia in Pakistan, WEAP was used to calculate supply and demand requirements considering economic growth, urbanisation, and climate change, which place enormous demands on the water supply network and cause water scarcity. This study aimed at identifying an effective water management strategy and encouraging water resources managers to adopt that strategy in order to resolve water crises or meet unmet water demand, which was accomplished by performing a comparative analysis of the feasible options and identifying a policy that would ensure water security for the catchment (Amin et al., 2018). Furthermore, a study conducted in India concluded that WEAP could be used for the megacity of Chennai to predict and quantify water management strategies under several scenarios. The study also evaluated the impacts of certain strategies, such as water reuse, desalination plants etc., to aid the future water demands (Paul and Elango, 2018).

A study carried out in the upper Dong Nai River Basin situated in Vietnam aimed to assess climate change impacts on water availability using WEAP and SWAT modelling tools. The study's findings showed that a 7.0–30.1% reduction in water shortage could be expected from climate change compared with the baseline scenario. In the baseline scenario, there was a 7.0–30.1% water shortage in three dry-seasonal months from January to March. By incorporating the increasing demands for water due to population growth and agricultural expansion, water shortages would range from 18.6 to 6.0% in the future. The results can be used to develop effective water management strategies to minimise future water shortages. In general, the results suggest that adequately adapting to the challenges of climate change will be vital to meeting future water requirements for domestic, agricultural, and industrial uses. (Khoi et al, 2021).

Several European studies have employed WEAP to investigate water demand and supply situations within the relevant catchments. The Ali Efenti catchment in Greece is experiencing seasonal water shortages, resulting in a high gap between water supply and demand. The WEAP software had successfully been used to model the catchment, conduct analysis to simulate the water balance, and estimate future water availability and demand considering the population and climate change impacts considering environmental goals. According to the

study, future climate and socioeconomic changes are expected to have only a small influence on local water stress over the study period.

One of the studies was conducted by Brown, Mahat and Ramirez (2019) in the United States. The study assesses the projections of water demand and renewable water supply considering population growth and climate change. The article examines several adaptations to predicted shortages, including improved water withdrawal efficiency, reservoir storage enhancements, demand reductions, reductions in instream flows, and groundwater depletion. The study indicates that water managers must focus on options such as additional reservoir storage capacity, groundwater mining, instream flow reduction, and urban transfers with serious external costs.

Dallison, Patil and Williams (2021) conducted a study to assess the impacts of climate change on future water availability for hydropower and public water supply for the future population of Wales situated in the United Kingdom. The study used WEAP to project and analyse the water demand and supply requirements, which was successful as the study found that spring and autumn are the seasons most affected long-term by water availability, and winter and summer are more impacted in the medium-term. This is evidence that WEAP can be adequately used to analyse water requirements based on the period and climate conditions (Dallison, Patil and Williams, 2021).

In Slovakia, a study was conducted for the testing and application of integrated software, namely the Water Evaluation And Planning (WEAP) model, to address the issue of the redistribution of available water resources in space and over time in the physical and geographical conditions in the Hron River Basin. It has been acknowledged that the software tool had successfully used to analyse the study area and resulted in water balance simulation models being fully applied in practice, which had never been applied in previous years (Kandera et al., 2021).

WEAP has been used in the African continent for hydrological modelling, water use studies and effects of climate change and population growth impacts on water resources. WEAP was applied to evaluate the water supply and demand of the Yala Catchment in Kenya. It was allocated with three scenarios similar to this study. The model was developed to evaluate past trends and simulate current demand scenarios for the purposes of planning by authorities

regarding future use (Okungu, Adeyemo and Otieno 2017). Furthermore, WEAP was used in a study conducted in the Perkerra catchment in Kenya, whereby WEAP was utilised to perform hydrological and water management analysis of the catchment (Akivaga et al. 2010).

WEAP was used to develop and assess the future water demands in the Niger Republic. An application of the WEAP system was developed to study the impact of varying population growth and climate change on agricultural water management and the potential for adaptation in the Niger River Basin (Mounir, Ma and Amadou, 2011).

WEAP model was also used in Nigeria to analyse the hydrological and metrological data of the study area to ascertain the water allocation for different purposes. The model was applied to analyse the management of transboundary water resources in the Hadeja Jama'are River Basin, which is a very complex situation due to political conflicts in the region in the Tiga dam. The study provided a technical approach to resolve the conflict between the water allocation requirements of Kano city and the major irrigation projects. It also predicted sufficient water allocation for different demand requirements within the study area (Mohammed et al, 2020).

Furthermore, WEAP was used to make some baseline water supply and demand in the Great Ruaha Catchment Basin in Tanzania and project the future water supply and demand gap under socio-economic and climate change (Simkonda et al., 2020).

Research carried out in South Africa on the application of WEAP analysis for water demand management is limited. One of the studies carried out in South Africa was conducted in the Olifants River basin to assess the pros and cons of using the WEAP model for the application of the Steelpoort sub-basin (Lévite, Sally and Cour, 2003).

Studies were carried out in Algeria to assess the impact of additional water demand in the Guelma region in Middle Seybouse in the long-term using the Water Evaluation And Planning System (WEAP). The WEAP analysis was modelled with data obtained in the region, and the finding concludes that it is estimated that there is a significant amount of unmet water demand; available resources, such as the average rainfall and the incoming water collection and storage infrastructure, including natural groundwater reservoirs, are incapable of meeting current and upcoming needs. This shows that WEAP can be used for the exact same purpose as this study which investigates the long-term water demand (Boudjebieur et al., 2021).

Various WEAP-related research was conducted around the African continent, including South Africa. However, this is the first application of the WEAP analysis in the Kwa-Zulu Natal region, specifically on the Mgeni System. Table 2.3 below shows studies carried out within the African continent.

Table 2.3: Previous Study on Application of WEAP

Reference	Country	Article Topic
African Continent		
(Levite et al., 2003)	South Africa	Testing water demand management scenarios in a water-stressed basin in South Africa: application of the WEAP model
(Akivaga et al, 2010)	Kenya	Impact of introducing reserve flows on abstractive uses in water-stressed Catchment in Kenya: Application of WEAP21 model
(Mounir et al, 2011)	Niger	Application of Water Evaluation and Planning (WEAP): A Model to Assess Future Water Demands in the Niger River (In Niger Republic)
(Okungu et al, 2017)	Kenya	Scenario Analysis of Water Supply and Demand Using WEAP Model: A Case of Yala Catchment, Kenya
(Mohammed et al., 2020)	Nigeria	Application of the WEAP Model for Future Water Allocation from Tiga Dam
(Simkonda et al, 2020)	Tanzania	Integrated Water Resources Management under socio-economic and climate change of Great Ruaha catchment in Tanzania using the WEAP model
(Boudjebieur et al, 2021).	Algeria	Long-Term Water Demand Assessment Using WEAP 21: Case of the Guelma Region, Middle Seybouse (Northeast Algeria)
Asian Continent		
(Amin et al. 2018)	Pakistan	Analysis of Current and Future Water Demands in the Upper Indus Basin under IPCC Climate and Socio-Economic Scenarios Using a Hydro-Economic WEAP Model
(Paul, 2018)	India	Predicting future water supply-demand gap with a new reservoir, desalination plant and wastewater reuse by water evaluation and planning model for Chennai megacity, India
(Khoi et al, 2021)	Vietnam	Assessment of climate change impact on water availability in the upper Dong Nai River Basin, Vietnam

(Touch et al., 2020)	Cambodia	Integrated Modeling of Water Supply and Demand Under Climate Change Impacts and Management Options in Tributary Basin of Tonle Sap Lake, Cambodia
Europe and North America Continent		
(Psomas et al., 2017)	Greece	Assessing future water supply and demand in a water-stressed catchment after environmental restrictions on abstractions
(Brown et al., 2019)	United States	Adaptation to Future Water Shortages in the United States Caused by Population Growth and Climate Change
(Dallison et al., 2021)	Wales	Impacts of climate change on future water availability for hydropower and public water supply in Wales, UK
(Kandera et al., 2021)	Slovakia	Testing of Water Evaluation and Planning (WEAP) model for water resources management in the Hron River basin

The WEAP software was proficient in providing reliable analysis in locations with varying climate and demographical factors. From the review of the various applications of WEAP as described above, it was concluded that the WEAP model could be applied successfully for developing water conservation and demand management plans in countries where water is scarce. The objectives of the study are to examine the projections of the supply and demand for the Mgeni system catchment using Water Evaluation and Planning (WEAP) software. It will examine the water resources concerning various scenarios such as low population growth rate, high population growth rate, and climate change impacts. Solutions to water problems depend not only on freshwater availability but also on how the water is managed both by the water authority and the consumer's perspective. Development and management processes and practices, supply management, appropriateness, and implementation status of the existing legal frameworks are also key to adequate water conservation and management.

2.8 Summary

This chapter has examined and illustrated literature on water conservation and demand management. It discussed key theories and empirical studies relevant to the research and WEAP related to the problem statement discussed in chapter 1. The literature indicates that water conservation and water management can be considered sustainable concepts, and there are various methods by which they can be developed and implemented through strategies and measures. Chapter 2 sets the foundation for the research, which reviewed the previous

literature carried out in terms of WC/DM and the utilisation of WEAP to analyse the water supply and demand situations. This is followed by the research methodology in Chapter 3, describing the method used to evaluate the water situation in the study area.

CHAPTER 3 : RESEARCH METHODOLOGY

3.1 Introduction

The purpose of this chapter is to outline and explain with details various steps to be followed in this study in order to complete the study objectives. This chapter describes the method through which the information was gathered and utilised. The research design, research instruments used to collect data, data collection technique and data analysis, are discussed in this chapter. The research methodology followed in this work was both qualitative and quantitative.

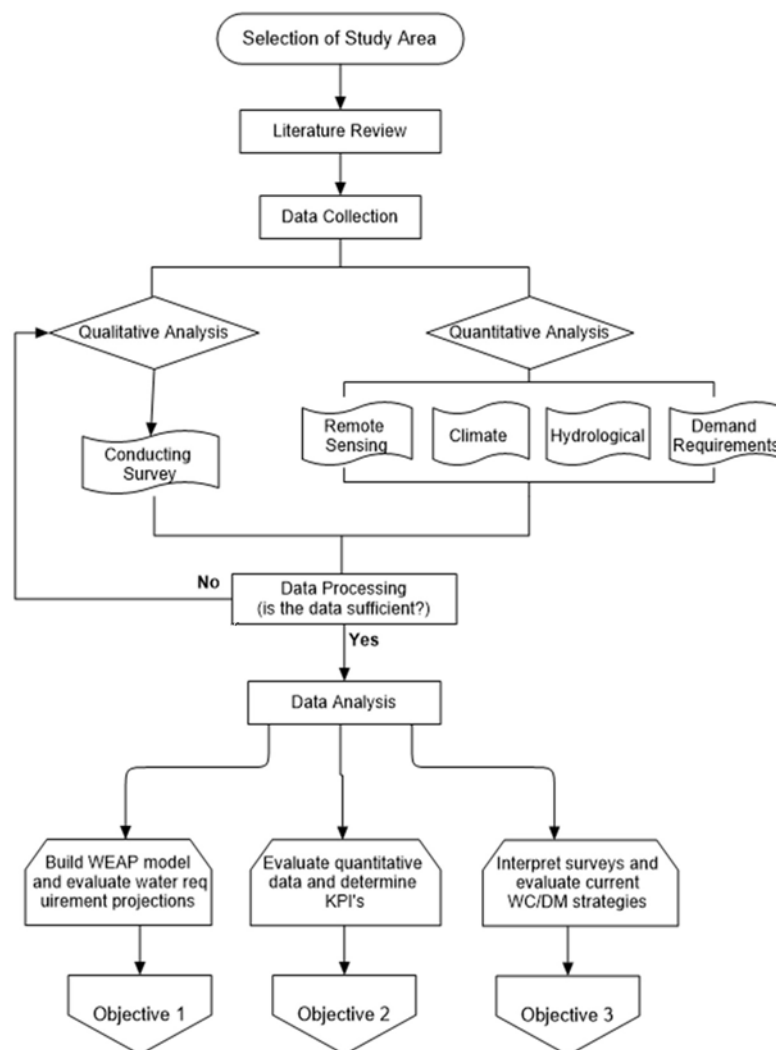


Figure 3.1: Overall Flowchart for Research Design

3.2 Research Design

The research design outlines how the study area information will be gathered, identifying the data collection method, the research instruments used, and the methods for organising and analysing the data. The study used a secondary data analysis type of a study that was both

qualitative and quantitative and took an exploratory approach. Quantitative research uses Water Evaluation and Planning software to analyse the data to investigate the water demand and supply for future years, while qualitative research uses questionnaires to extract and evaluate WC/DM practices currently used by authorities. The following methodology has been utilised to determine the specific objectives.

3.2.1 Specific Objective 1 – Determine the quantity of current and future water demand in the Mgeni System and determine if there will be sufficient supply to meet demands:

The main objective was to predict if the water supply was sufficient to cater for future population growth and climate change. A WEAP model was analysed to determine the future water demands, and the results illustrate the unmet demand for the varying scenarios. The following method has been taken to meet Objective 1:

- i. Compile data sets consisting of the current population, current water demands.
- ii. Obtain schematic data such as streamflow gauges, dam locality, demand sites, catchment boundaries.
- iii. Obtain hydrological data such as naturalised flow data, data system data, streamflow gauges data, demand site requirements.
- iv. Construct the WEAP model using data gathered and input all relevant parameters.
- v. Introduce the varying scenarios to the model.
- vi. Conduct the analysis and evaluate the results.

3.2.2 Specific Objective 2 – Identify the quantity of current water losses within the study area and determine the Key Performance Indicators (KPIs) and causes of the water losses.

In order to develop successful tools and strategies for WC/DM, it is essential to establish the quantity of water being lost, where it is being lost and why. To determine the quantity of water losses, the IWA Water Balance calculation method can be utilised. Input data required for the IWA Water Balance has been collected, and this will be utilised to determine the components, such as real losses and apparent losses.

To understand and deal with water losses, one needs to fully determine and understand the Key Performance Indicators (KPI's) such as Unavoidable Annual Real Losses

(UARL), Infrastructure Leakage Index (ILI), Current Annual Real Losses (CARL), Real Annual Apparent Losses (RAAL), Current Annual Apparent Losses (CAAL), and Apparent Losses Index (ALI). Water Losses can be reduced by determining the key KPIs. The CARL can then be compared to the UARL to determine how much of the water losses can be reduced by WC/DM strategies.

3.2.3 Specific Objective 3 – To determine efficient strategies, tools and measures for water demand management and water loss adequately for future use within the Mgeni Systems:

In order to investigate the effectiveness of current WC/DM strategies, one needs to understand the strategies utilised and to what extent it has been implemented. The questionnaires asked the respondents about the strategies used and how the strategies are used. It also asks what the respondents think would be successful strategies one can implement. Using the information from the questionnaires, the study can investigate the successful strategies and how to improve them for future implementation in WC/DM.

3.3 Data Collection and Analysis

This chapter systematically represents the captured data from the qualitative and quantitative research processes. These data are analysed, described, and interpreted systematically as the next step of the research process. As part of the administration and the documentation and analysis process, data was presented to be intelligible and interpretable and meet the research objectives.

The research results were first presented as an analysis of the qualitative data obtained from the interviews. The qualitative data analysis was followed by an analysis of the quantitative data obtained from various sources and referenced in Table 3.1. The data obtained for the analysis was of adequate quantity and quality to produce reliable conclusions. The data was discussed and analysed while considering the strengths and weaknesses of the data. Data have been analysed, and conclusions are shown in the report through graphs, charts, and tables.

3.3.1 Quantitative Data

The quantitative data used for this study were collected from relevant sources, as shown in Table 3.1 below. Data sets include meteorological and hydrological data such as rainfall and temperature, historical population data from Census reports, Remote Sensing data such as Geographic information system (GIS), and historic supply and demand data. Data were obtained from various sources and are described below.

Table 3.1: Description and sources of data used in analysis.

Data	Description	Source
Remote Sensing Data	Digital Elevation Model for catchment delineation, land cover	WEAP Data (ESA-CCI-LC, Princeton)
Climate Data (2009-2020)	Precipitation, Temperature	South African Weather Services (SAWS)
Hydrological Data (2009-2020)	Naturalised Rivers Flows Streamflow Gauges Flows	WRC2012 (waterresourceswr2012.co.za)
Demand / Supply Data	Population Dams Data Water consumption	CENSUS, 2016 Umgeni Water Reports (UWIMP_2020,C0209MASR0034)

The development of the WEAP model for this study follows the normal formality of any WEAP model, i.e., Study definition, Current accounts, Scenarios, and Evaluation. The steps in developing the WEAP model were as follows:

- **Study Definition:** The Study Definition consists of the study area and network configuration. In this step, GIS data can be inputted and used to configure the position of rivers, boundaries, gauges, and catchment areas. This study used GIS data from WRC2012.
- **Current Accounts:** This is a baseline representation of the system and includes the demand data, river naturalised flows, catchment characteristics.
- **Scenarios:** are used to evaluate different outcomes of the study. These scenarios can be demographic, water use patterns, water system infrastructure, hydrology.
- **Evaluation:** this involves the investigation of the different outcomes concerning scenarios inputted.

Various scenarios are used to evaluate the model. A “scenario” is derived from the current account in which all basic data will be inputted into the model. The scenario covers the period 2009–2050 and reflects a projection of current trends without major changes. Implementing various scenarios serves as a point of comparison in which some changes in the system data can be made.

The period 2009-2050 was chosen as a Reference Scenario for all information on the system, such as application consumption, abstraction volumes, rainfall, temperature etc. The other scenarios for the analysis involve parameters such as population, climate change and water usage.

- Scenario 1: Reference Scenario (1.1% growth rate)
- Scenario 2: Low Population Growth Rate (Growth Rate 0.75%)
- Scenario 3: Higher Population Growth Rate (Growth Rate 2.5%)
- Scenario 4: Extended Period of Dry Climate

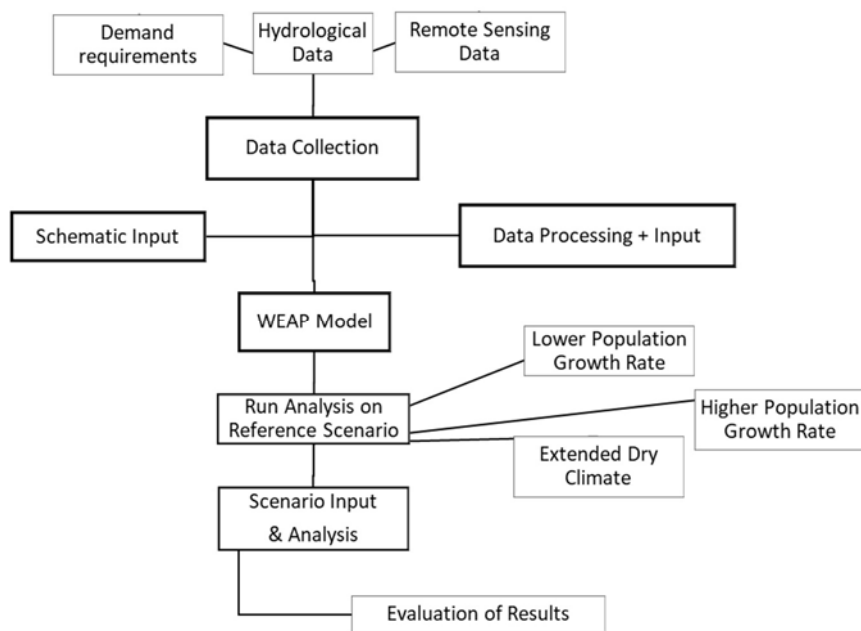


Figure 3.2: Flowchart for WEAP analysis

3.3.2 Qualitative Data

The qualitative data was collected from Umgeni Water members using the Likert scale questionnaire during the interviews. The respondents had to answer a set of questions to gauge the effectiveness of the current water conversation and the implementation of demand management strategies and interventions. Respondents were also allowed to provide additional comments to substantiate their answers and provide a more detailed description.

The target population consisted of twenty-one departmental members within the Planning Services Department (who deals with WC/DM). The sample size of eighteen was determined based on the sample size determination equation (Daniel and Cross 2018).

$$n = \frac{N \times X}{((N-1) \times E^2 + X)} \quad (\text{Eq. 2})$$

Where, n: sample size,

N: population size,

X: $Z^2 \times P \times (1-P)$, Z: 1.96 for the confidence level of 95%,

P: Maximum at $P = 0.5$

E: Maximum Error at $E = 0.09$

$$\begin{aligned} n &= \frac{N \times X}{((N-1) \times E^2 + X)} \\ &= \frac{N \times (Z^2 \times P \times (1-P))}{((N-1) \times E^2 + (Z^2 \times P \times (1-P)))} \\ &= \frac{21 \times (1.96^2 \times 0.5 \times (1-0.5))}{((21-1) \times 0.09^2 + (1.96^2 \times 0.5 \times (1-0.5)))} \\ &= \frac{21 \times 0.9604}{((21-1) \times 0.09^2 + 0.9604)} \\ &= 18 \end{aligned}$$

A comprehensive questionnaire comprising thirteen structured questions, broken into two sections, was utilised to collect data on current WC/WDM measures and tools. The questions were designed to be completed by the Umgeni Water personnel, who had good knowledge of the strategies currently practised within the study area. The goal of this questionnaire was to compile information regarding water demand management practices within the study area.

Structured research questions were used to collect information that gave an overall indication of the progress and achievements of WC/DM strategies and measures currently utilised. The questionnaire, attached as Appendix A, were completed by professionals who have direct roles in water conservation and water demand management processes. A total of eighteen questionnaires were administered over a period of eight months, which gave the respondents sufficient time to apply their minds and respond to the questionnaires.

For the purpose of this research study, a “Likert scale evaluation” method has been used. A Likert scale is a five- or seven-point scale that allows the respondents to express how much the respondents agree or disagree with a particular statement. In this research study, the five-point Likert scale was used. This scale would consist of 5 answer options:

- 1) Strongly Agree: this means the respondents are in total agreement with the statement.
- 2) Agree: means the respondents agree with the statement for the most part.
- 3) Neutral: means the respondents prefer the neutral middle, meaning the respondents have neither a positive nor a negative response.
- 4) Disagree: this means the respondents disagree with the statement for the most part.
- 5) Strongly Disagree: means the respondents are in total disagreement with the statement.

The tactical purpose of the questionnaire was to determine if Umgeni Water implements water conservation and demand management strategies and measures within the study area. Respondents had to answer several questions focusing on the following statements. The questions comprised sections as follows:

Section A Water Resource Management

This section of the questionnaire was designed to gather participants' information on their water conservation and demand management practices. This section aimed to get a broader insight into the common WC/DM practices for the study area.

Question 1: Does Umgeni Water aid water resources management within the Umgeni Water supply area?

This question inquires if Umgeni Water had the necessary regulations and controls to ensure that water resources are adequately managed in a broader spectrum. The question aims to gain

insight into how the scarce resource has been managed and the tools used to manage the resources.

Question 2: Has Umgeni Water developed adequate Water Conservation and Water Demand Strategies?

This question aimed to find out if the organisation has strategies in place to implement WC/DM. This question also aims to gain background knowledge of the existing strategies and tools utilised.

Question 3: Umgeni has periodically implemented a full leak detection program for your distribution system.

Question 3 sets out to understand if the organisation carries out regular leak detection programs, the methods for the leak detection used, and if this strategy is beneficial. Fast detection and repair of leaks decrease the water losses, reducing the non-revenue water.

Question 4: Does Umgeni Water allocate a sufficient budget for WC/WDM strategies and measures?

Implementing water conservation and demand management strategies and measures requires budgetary provision by the organisation. It is important to assess whether the organisation allocates sufficient budget for water conservation and water demand management-related projects.

Question 5: Is the water pressure regulated at various times a day to promote leakage reduction?

Question 5 was asked to determine if the pressure of the water supply was regulated at specific times during the day to prevent excess water losses from unknown leakages. This also investigates the current methods taken by the WSA.

Question 6: Do you have a public education plan in place?

This question was asked to determine if the organisation implements sufficient educational programs and awareness campaigns to promote water saving. By understanding the current processes, it can be used to provide more effective methods of educating communities on water problems.

Question 7: Have water Conservation and Demand Management strategies decreased water losses?

Question 7 sets out to understand the current success of implementing WC/DM and if and how the outcomes of the WC/DM can be achieved. This will show the efficiency of the current WC/DM being implemented.

Question 8: Do you provide educational literature about the installation of water-saving devices and water conservation savings to the community?

Question 8 investigates if newer technology, such as water-saving devices, has been more commonly used in recent years. Water-saving devices can reduce apparent losses due to meter reading errors etc. It also allows consumers to monitor their water usage.

Section B Water Supply and Demand

This section was designed to gather information about water supply and demand. It investigates the ways to reduce losses with the introduction of new technology and investigates if the study area has a sufficient supply for the increase in population and climate change.

Question 9: Has Umgeni Water played a part in bridging the gap between water supply and demand in KwaZulu- Natal?

The study area has limited water supply for the existing demand; with the increase in population and climate change, the need to look at different options to improve supply security while investing in water WC and WDM solutions is a critical task. This question sets out to see if the organisation has been working on ways to meet future demands to cater for factors such as population growth and climate change.

Question 10: Will Automatic Meter Reading (AMR) systems decrease errors in meter reading and billing compared to the manual meter systems currently being used?

Question 10 investigates the utilisation of Automatic Meter Reading systems which could reduce the apparent losses in the system. It also investigates if AMR is currently used or if it is being implemented. It will also indicate the pros and cons of using the AMR system.

Question 11: Do Umgeni Water and municipalities have protocols in place to ensure the accuracy and consistency of the manual meter readings?

Manual meter reading brings its own form of errors and mistakes. These errors contribute to apparent losses within the system. By limiting these errors, WSA's can decrease water losses. This question gauges learning the processes taken by authorities to prevent errors and what is being done to avoid these errors.

Question 12: Do Umgeni Water liaise with building inspectors to ensure the plumbing codes are strictly applied in new and renovated buildings?

An alternate solution to reducing water loss would be to inspect buildings to ensure it falls within the legislation. This will allow all wet works and plumbing to be done in accordance with regulations and prevent future losses from loose water connections, burst pipes, etc. This question tries to investigate the current protocols to ensure all water infrastructure at the house/building level is per relevant standards to prevent excessive losses.

Question 13: Has Umgeni Water implemented any sort of new technology into the water supply and demand, for example, pressure sensors, controllers etc.?

Question 13 inquires if any new technology has been utilised in the water supply and demand system. This was to see if the study areas have been using up-to-date methods for WC/DM. It also looks into the benefits of current methods used and how this can be improved.

3.4 Study Area

3.4.1 Background to Umgeni Water

Umgeni Water provides potable water to seven Water Service Authorities (WSA) within the Kwa-Zulu Natal area, which equates to 447 million cubic meters of potable water per annum (1224 Ml/day). This study focuses mainly on the Mgeni system, which consists of Upper and Lower Mgeni systems. The Upper Mgeni System supplies potable water to the uMgungundlovu District Municipality, Msunduzi Municipality, and eThekweni Municipality's Outer West area, while the Lower Mgeni System supplies potable water to the coastal areas and hinterland of the eThekweni Municipality. The water resources of the Upper and Lower Mgeni system are located on the same river system and are highly interdependent (Umgeni, 2020).

The Mgeni System operating rule maximises the reliability of supply in the system through pumping from Spring Grove Dam, Mearns Weir (Mooi River) and Inanda Dam to reduce the risk of drought water restrictions as far as possible. The current operating rule for the Mgeni System, as shown in Figure 3.3 below, optimises the assurance of supply via all the pumping that is undertaken simply because the water requirements are now higher than the long-term yield. The potential risk of imposing regular restrictions on the system has increased significantly over recent years, which is why the operating rule had to be reviewed a few years ago (Umgeni Water, 2020).

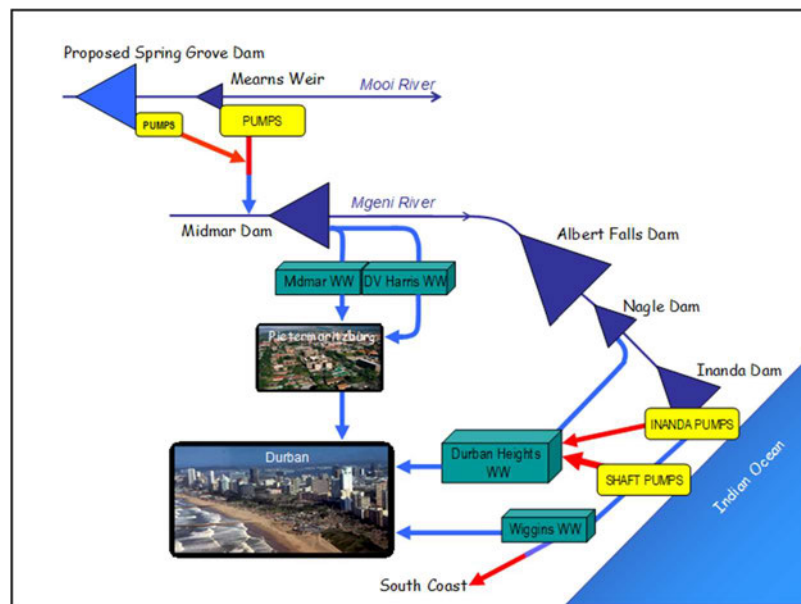


Figure 3.3: Mgeni System Infrastructure Configuration (Source: Umgeni Water, 2020)

3.4.2 The Mgeni System

The Mgeni System comprises four dams on the Mgeni River: Midmar Dam, Albert Falls Dam, Nagle Dam, and Inanda Dam, with Albert Falls Dam being utilised as a balancing dam. These dams are augmented by the Mooi-Mgeni Transfer Scheme (MMTS), which consists of the Mearns Weir on the Mooi River, the Mearns Pumping Station with a maximum transfer capacity of $3.2\text{m}^3/\text{s}$ and a raw water transfer pipeline that discharges into the Mpopana Stream, which flows into the Lions River and then into the Mgeni River upstream of Midmar Dam (Ramnath, 2018).

The Mgeni River is a major water source for the Pietermaritzburg and Durban regions. The demand from the Mgeni River first exceeded the system yield in 2004. A Mooi-Mgeni Transfer system was initially set up during the 1983 drought to provide additional water into the Mgeni

System. In 2002, the Mearns Weir was raised to 8m, increasing the storage to 4.9 million m³, and the Midmar Dam wall was raised an additional 3.5m. This was referred to as the Mooi-Mgeni Transfer Scheme 1 (MMTS-1) and was viewed as an interim solution whilst the feasibility of a dam on the Mooi was investigated (Department of Water Affairs, 2011).

The Mooi-Mgeni Transfer Scheme 2 (MMTS-2) involved the construction of a dam and bulk raw water infrastructure for inter-basin transfer. In addition, a new raw water pipeline from Spring Grove Dam to the Mgeni catchment has been completed, enabling a continuous transfer of water at a higher rate and increasing the yield of the greater Mgeni System by 164Mℓ/day. The Mooi and Mgeni catchments are now fully utilised, and no additional water use can be licensed (Umgeni Water 2015). The current yield of the Mgeni System is shown in Table 3.2 below. It can be seen that the supply yield of Midmar Dam is 501.4 Mℓ/day, Nagle Dam of 912.3 Mℓ/day and Inanda Dam 1189.0 Mℓ/day. This gives a total yield of 2602.7 Mℓ/day (950 million m³/year). This yield will be used to compare the projected water demand, and should the projected water demand exceed the yield, it would mean there is a shortage of water for the study area.

Table 3.2: Yield Information for the water resource (Umgeni Water, 2020)

Phase	Position in system	Historic Firm Yield	Stochastic Yield (1 in 50-year risk of failure)		Stochastic Yield (1 in 100-year risk of failure)	
			million m ³ /annum	Mℓ/day	million m ³ /annum	Mℓ/day
-	-	million m ³ /annum	million m ³ /annum	Mℓ/day	million m ³ /annum	Mℓ/day
MMTS	Midmar Dam	167	195	534.0	183	501.4
	Nagle Dam	277	348	953.4	333	912.3
	Inanda Dam	416	446	1,221	434	1,189

Umgeni Water sources water from three major water resource systems, namely, the Mgeni System, which abstracts water from the Mooi and Mgeni rivers, the North Coast System, which abstracts water from the Mdloti River); and the South Coast System, which abstracts water from by the Nungwane, Mzimayi and Mzinto rivers. This research will focus on the Mgeni System, which comprises the eThekwini, uMgungundlovu and Msunduzi regions.

3.4.3 Water Service Authorities

The three WSAs being studied are the eThekwini Municipality, Msunduzi Municipality, and uMgungundlovu District Municipality. These WSAs are described in detail below:

- i. eThekwini Municipality: is primarily supported by the Mooi-Mgeni transfer scheme.

Water in the eThekweni Municipality's northern areas is also secured from the Hazelmere Dam on the Mdloti River and from the Tongati River. The Nungwane Dam on the Nungwane River provides a small portion of the municipality's water requirements in its southern areas. Groundwater is also used to a limited extent. Water transfers from the uMkhomazi River, wastewater reuse, and seawater desalination are potential future water sources for this area. Water from the uThukela River could also be utilised to a limited extent (Umgeni Water 2016).

- ii. Msunduzi Municipality: is only supported by the Midmar Dam on the Mgeni River. Water transfers from the Mooi River are used to augment this resource. Groundwater is used to a limited extent (Umgeni Water 2016).
- iii. uMgungundlovu District Municipality: is primarily supported by the Midmar Dam on the Mgeni River, supported by the Mooi-Mgeni transfer scheme, which is the primary source of water for this municipality (Umgeni Water, 2016).

3.5 Catchment Area

The study area is Umgeni Water, situated 28,728006° N, 30,727232° E in Kwa-Zulu Natal, South Africa. Umgeni Water's current operational area is bounded by the uThukela River in the North, the Mtamvuna River in the South, the Indian Ocean in the East, and the Drakensberg Mountains in the West and it covers a total of 21,155 square kilometres and has a population of approximately 11-million people. (Umgeni Water, 2020).

The study area falls within the Pongola-Mtavuna water management area, consisting of the Thukela (V) and Mvoti-Umzinkuklu (U) primary catchment, as shown in Figure 3.4. The secondary catchments area, namely V20 and the U20. Secondary catchments V20 and U20 have a catchment area of approximately 4,444 km² and 2,872 km², respectively.

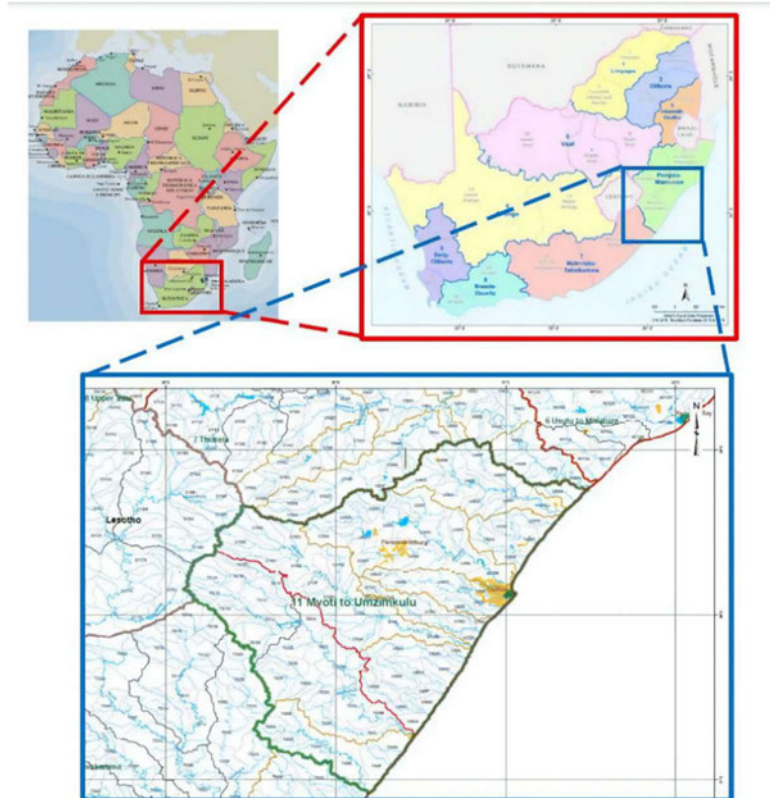


Figure 3.4: Location of Catchment Area

3.6 Supply and Resources

3.6.1 Streamflow

Streamflow measures the quantity of raw water flowing through a stream or river over a certain period. Streamflow data have been collected from the Water Research Commission (WRC) of South Africa. WRC has developed a resource centre where data can be readily available. The area has six (6) streamflow gauge stations identified for this study, shown in Figure 3.5 below.

Gauge ID	Co-ordinates	
	Latitude	Longitude
U2H014	-29.437080°	30.475420°
U2H052	-29.598750°	30.631250°
U2H055	-29.619580°	30.676250°
V2H002	-29.219580°	29.984580°
V2H004	-29.073750°	30.243750°
V2H005	-29.312920°	29.813750°

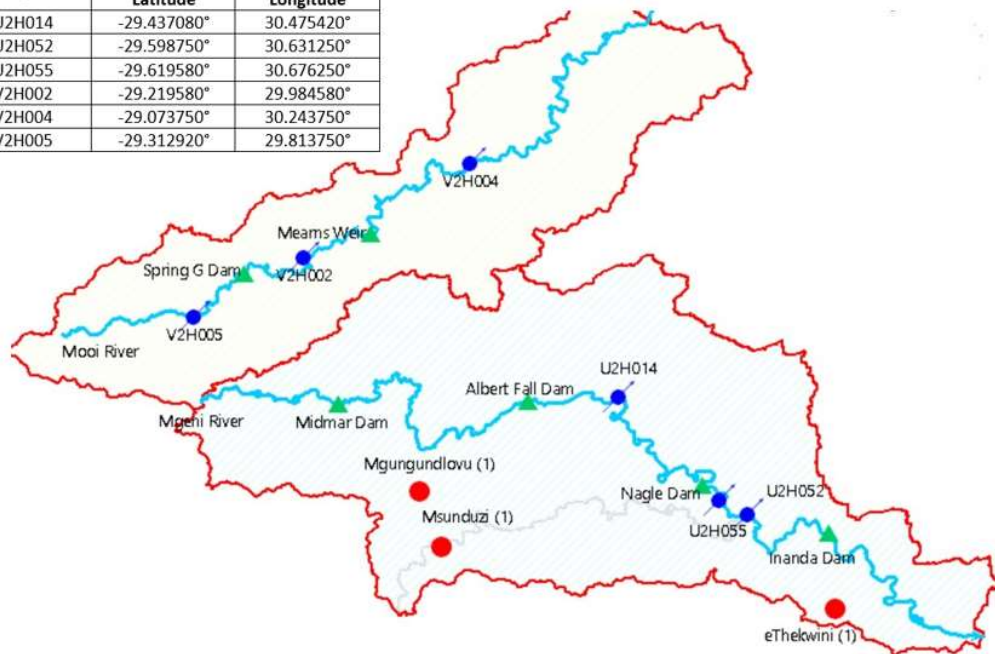


Figure 3.5: Location of Streamflow Gauges

3.6.2 Reservoirs and Dams

There are six (6) dams located within the study area. Two dams fall within the Mooi River catchment, which augments the Mgeni River supply. Four dams fall within the Mgeni River, shown in Figure 3.6 below.

Spring Grove Dam and Mearns Weir are located along the Mooi River and have a catchment area of 339 km² and 887 km², respectively. Spring Grove Dam was completed in 2013, and Mearns Weir was completed in 2003 for the purpose of water supply augmentation of the Mgeni System. Spring Grove Dam is concrete with an earth embankment dam with a spillway height of 26.4 m and a crest length of 231 m along the non-spillway section. Mearns Weir is a concrete weir with a spillway height of 6.89 m and a crest length of 165 m.

Midmar Dam, Albert Falls Dam, Nagel Dam, and Inanda Dam are located along the Mgeni River and have a catchment area of 926 km², 1654 km², 2539 km² and 4082 km², respectively. Midmar Dam was completed in 1963, Albert Falls Dam was completed in 1976, Nagel Dam was completed in 1948 and Inanda Dam was completed in 1989. Midmar Dam is concrete with an earth embankment dam with a spillway height of 26.4m and a crest length of 1283m along the non-spillway section. Albert Falls Dam is concrete with an earth embankment dam with a spillway height of 21.6 m and a crest length of 1930m along the non-spillway section. Nagel

Dam is concrete with an earth dam with a spillway height of 24.1m and a crest length of 272m along the non-spillway section. Inanda Dam is concrete with an earth embankment dam with a spillway height of 31.2m and a crest length of 468m along the non-spillway section.

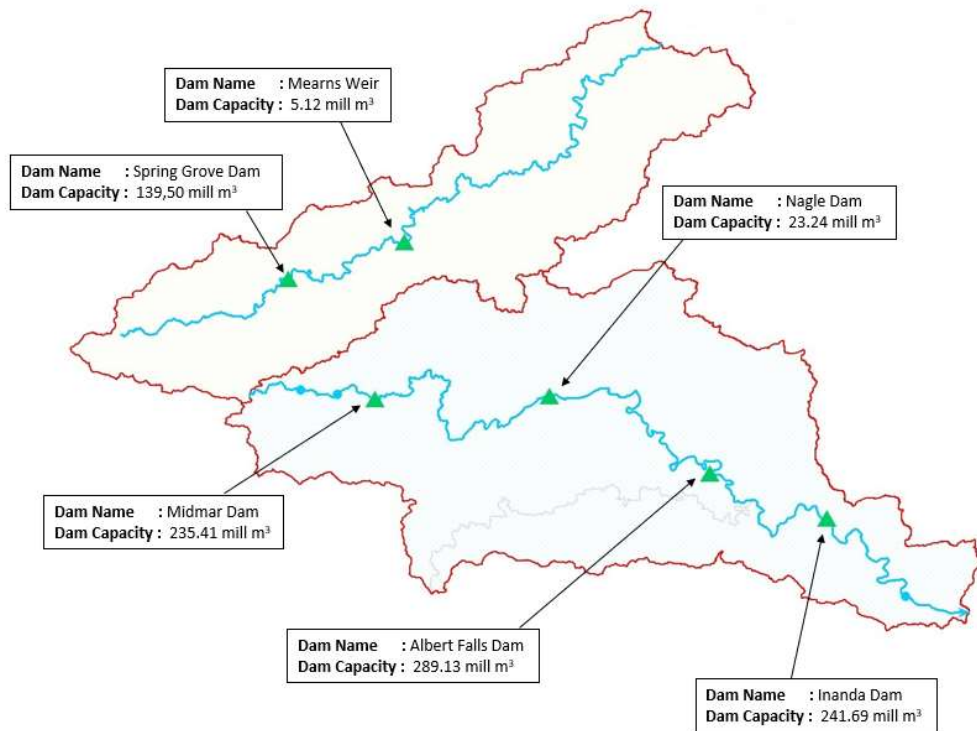


Figure 3.6: Dam Characteristics (Source: Umgeni, 2020)

3.6.3 Rainfall and Temperature

All data for rainfall and temperature were collected from the South African Weather Services (SAWS). The area has seven (7) rainfall and temperature stations identified and used in this study, shown in Figure 3.7 below.

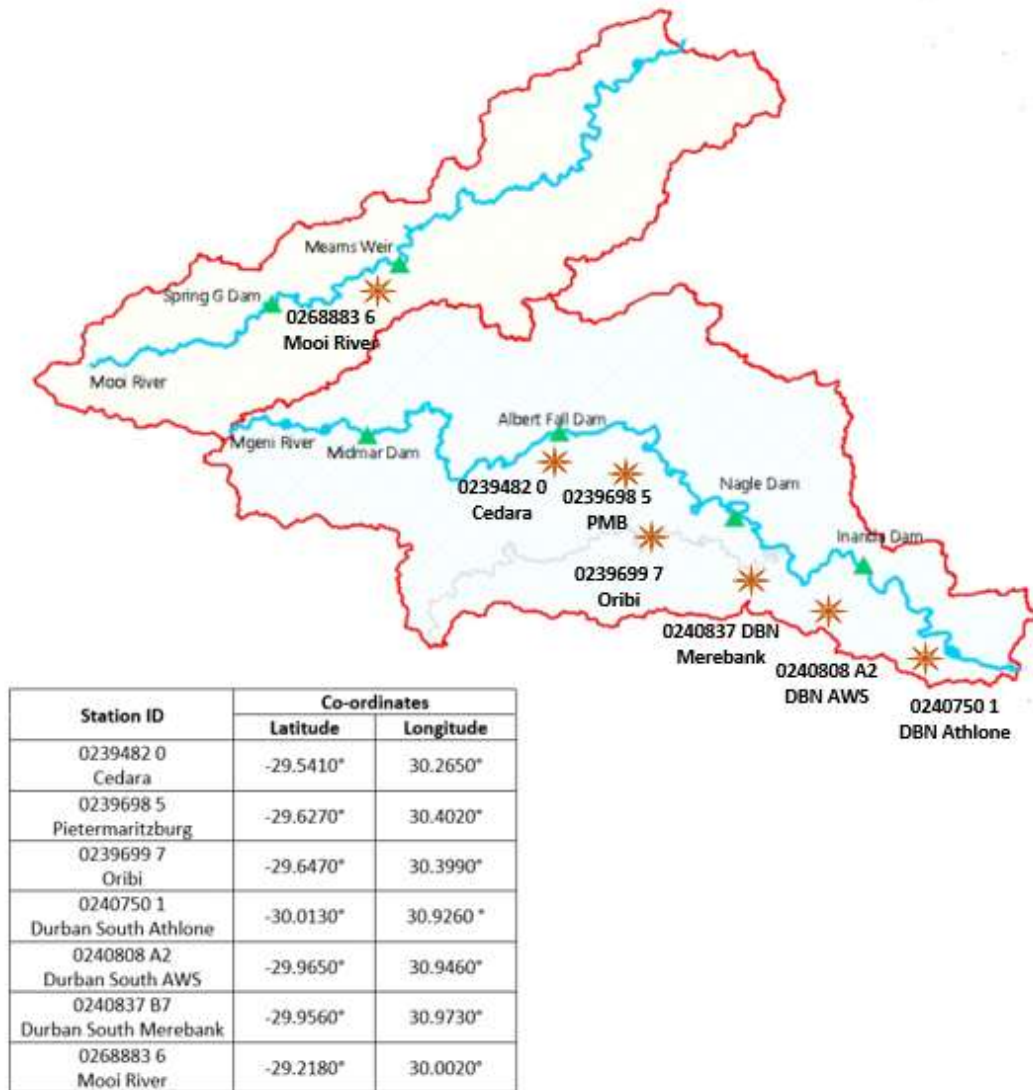


Figure 3.7: Location of Rain and Temperature Stations

3.6.4 Land Class Inflow and Outflow

The land class provides a detailed breakdown of inflows and outflows of the catchments, and their sub-land classes, including precipitation, surface runoff, irrigation, interflow, evapotranspiration, soil moisture, increase or decrease in surface storage, and base flow.

Monthly average Land class inflows and outflows, the reference scenarios show a marked precipitation inflow in November to February with approximately 612 to 733 million m³, respectively, which are long rain periods in the year in the catchment. The study area also registers the highest surface run-off periods and evapotranspiration rates, as shown in Figure 3.8.

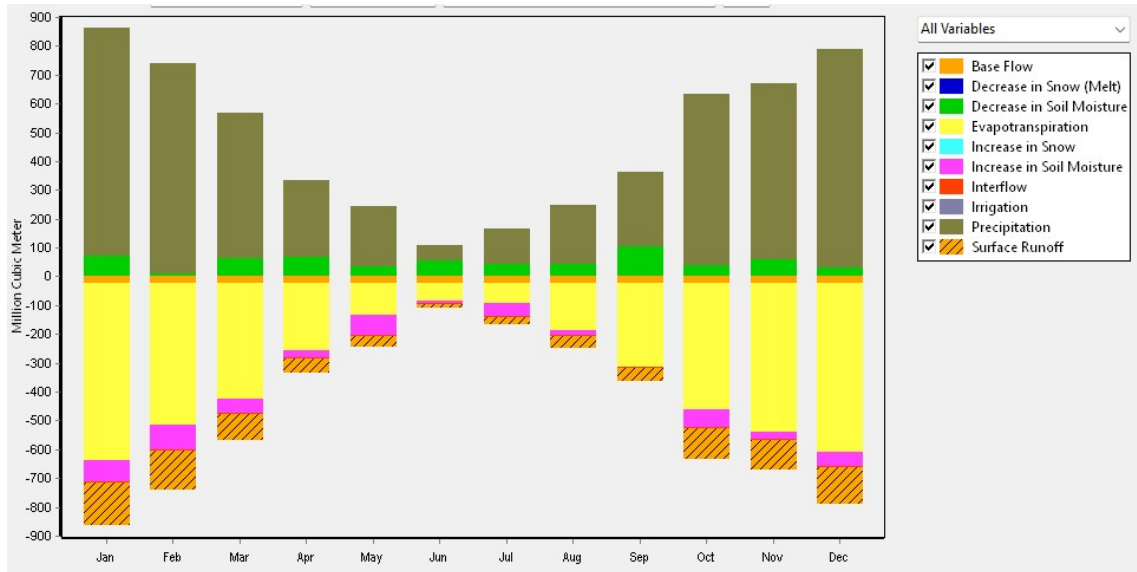


Figure 3.8: Land Class Inflows and Outflows

3.6.5 Connecting Demand with Supply

To ensure demand for the study area is satisfied in the WEAP model, the demand sites need to be connected to the supply system. The transmission link is used to connect the supply to the demand. These can be accomplished in the schematic view where the transmission link is added. The link is routed from the river/reservoir to the demand node. The study model comprises six (6) transmission links described in Figure 3.9 below.

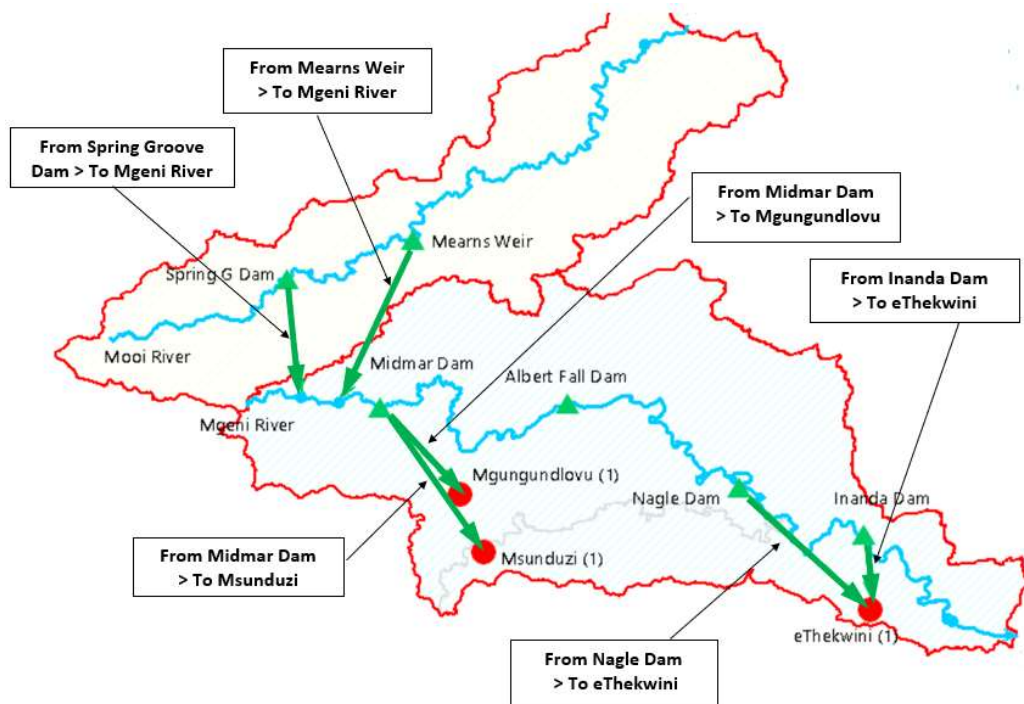


Figure 3.9: Transmission Links – Connecting Supply to Demand

3.7 Demand Sites

Demand sites are sites where water consumption is taking place. Accordingly, three distinct demand sites were identified in the study area: eThekwini, uMgungundlovu and Msunduzi. The current water demand for the demand sites is shown in Table 3.3 below. The Water Demand Volume, Annual Activity Level and Annual Water Usage form the base for the analysis in WEAP.

Table 3.3: Water Demand Volume (Source: Umgeni, 2020, NRW Report, 2021)

	2009	2015	2016	2018	2019
eThekwini (m³)	206,524,200	326,182,553	306,374,750	342,431,489	362,156,030
uMgungundlovu (m³)	15,960,243	19,741,987	20,741,808	22,297,283	25,270,080
Msunduzi (m³)	42,482,160	70,025,603	62,508,982	71,425,786	74,032,140

Over the last decade, from 2009 to 2020, the population growth rate of the study area has been increasing at 1.1 % per annum. The major site contributes to the increase in eThekwini, where the population increased from 3,442,070 to 3,825,754 from 2009 to 2019, respectively. Table 3.4 and Table 3.5 shows the Annual Activity Level (Population) and Annual Water Use Rate used in developing the model, respectively.

Table 3.4: Annual Activity Level (Source: Umgeni, 2020)

	Annual Activity Level (person)			
	2009	2016	2018	2019
eThekwini	3,442,070	3,702,231	3,784,128	3,825,754
uMgungundlovu	409,237	416,826	426,047	430,733
Msunduzi	606,888	679,039	694,060	701,695

Table 3.5: Annual Water Usage (Source: Umgeni, 2020)

	Annual Water Usage			
	2009	2016	2018	2019
eThekwini	60.0	82.8	90.5	94.7
uMgungundlovu	39.0	49.8	52.3	58.7
Msunduzi	65.0	92.1	102.9	105.5

3.8 Summary

This chapter discussed the research methodology and paradigm in detail, where quantitative and qualitative research approaches have been used in this study.

The quantitative approach follows technical design using modelling software, namely Water Evaluation and Planning (WEAP) software. Quantitative data was collected from sources, processed to functional formats, and modelled into WEAP to evaluate projected water demand and supply requirements. Qualitative data collected from the structured questionnaires generated two main sections: water resource management and water supply and demand.

The target audience for the qualitative analysis is the Umgeni Water Planning Services and Water Demand Department, which has a thorough knowledge of the current WC/DM strategies implemented and ways to improve the water resources situation within the country. From a sample size determination, eighteen questionnaires were required. The next chapter outlines the results and discussions of this study.

CHAPTER 4 : RESULTS AND DISCUSSION

4.1 Introduction

The purpose of this chapter is to analyse and interpret data collected during the research. The results are presented and discussed hereunder. This chapter presents analysis and results based on both qualitative and quantitative techniques. The analysis was done based on study objectives. The quantitative analysis data was conducted using the WEAP software. The qualitative analysis has been obtained from questionnaires. This chapter further discusses the study variables and their implication for water conservation and demand management.

4.2 Quantitative Analysis and Results

The WEAP model was developed by computing the entire model in Current Accounts for the base period of 2009 and the Reference Scenario information for 2010 to 2050. The comparative scenarios had been set in the model, and the model was generated to produce results.

4.2.1 Scenario 1: Reference Scenario (1.1% growth rate)

The Reference Scenario is the base scenario and is regarded as the scenario in which all the real-time data is inputted to help understand the best estimates about the studied period. The objective of the reference scenario was to help discern the likely occurrences of the current trend continuity and to understand the real situation as it is. It sought to identify knowledge gaps in analysing likely trends and where more information is required (Sieber and Purkey, 2011).

In the study model, the Reference Scenario is based on the Current Accounts with a Population Growth of 1.1%. The population growth rate was 1.1% during the study reference period. The WEAP model calculated the projected population using an exponential function. The population is shown in Table 4.1 below.

i. Projected Annual Activity Level

Comprehensive water demand and distribution begins with evaluating the area's historical population trends and projected growth patterns. The WEAP analysis tool determines the population growth rate for the study period. The population for each demand site is shown below in Table 4.1.

Table 4.1: Annual Activity Level at 1.1%. (Source: Umgeni Water, 2020)

	1.1% Population Growth (person)					
	2025	2030	2035	2040	2045	2050
eThekwini	4,100,513	4,331,058	4,574,565	4,831,762	5,103,420	5,390,351
uMgungundlovu	487,521	514,461	543,883	574,461	606,760	640,873
Msunduzi	722,982	763,630	806,564	851,911	899,809	950,399
Total	5,311,016	5,609,149	5,925,012	6,258,134	6,609,989	6,981,623

ii. Projected Water Demand and Unmet Demand

Projected future water demand is affected by several demographic and climatic factors. Results of future demand are shown in Figure 4.1 below to depict the temporal projection of demands as determined by the WEAP model. This is shown for all 3 demand sites under the reference scenarios of a 1.1% population growth rate.

The water demand for 2050 is 2,105 million m³/year for eThekwini, 470 million m³/year for Msunduzi, and 115 million m³/year for uMgungundlovu (Appendix C illustrates the total water demand in detail). In the period leading up to 2050, the total water demand is shown below. The analysis indicates that the demand increases approximately 5.6% per year. The largest share of this demand is expected to be consumed by eThekwini, which consumes about 75% of the total water demand. At this point, it is assumed that the extensive demand requirement is due to the population growth within the demand site and the extensive degree of water losses experienced in this demand site which will be shown in the “water losses section”.

The current system yield, referred to as Mooi-Mgeni Transfer Scheme (MMTS), is approximately 950 million m³/year. From an evaluation of Figure 4.1, it is illustrated that the demand will exceed the yield of 950 million m³/year by the year 2032.

The model registers total unmet demand starting in the year 2025 at 9 million m³/year and increasing significantly over the period up to 2050 with 1,915 million m³/year. Although in Figure 4.1, the demand exceeding the yield in 2032. The unmet demand illustrated indicates the quantity of the unmet demand considering factors such as rainfall, evaporation etc., of the study area, which is analysed in the WEAP model. Therefore, one can say that under current circumstances, with a population growth of 1.1%, the study area will experience a water shortfall within the study area in the year 2025. The unmet water demand for 2050 is 1,537 million m³ for eThekweni, 375 million m³ for Msunduzi, and 0 million m³ for uMgungundlovu. The evaluation of the Reference Scenario shows that with constant growth in the population of 1.1% within the study area, it is indicated that the water availability under the Reference Scenario is relatively sufficient until 2025 for Msunduzi and 2027 for eThekweni. (Appendix D illustrates the total unmet demand in detail).

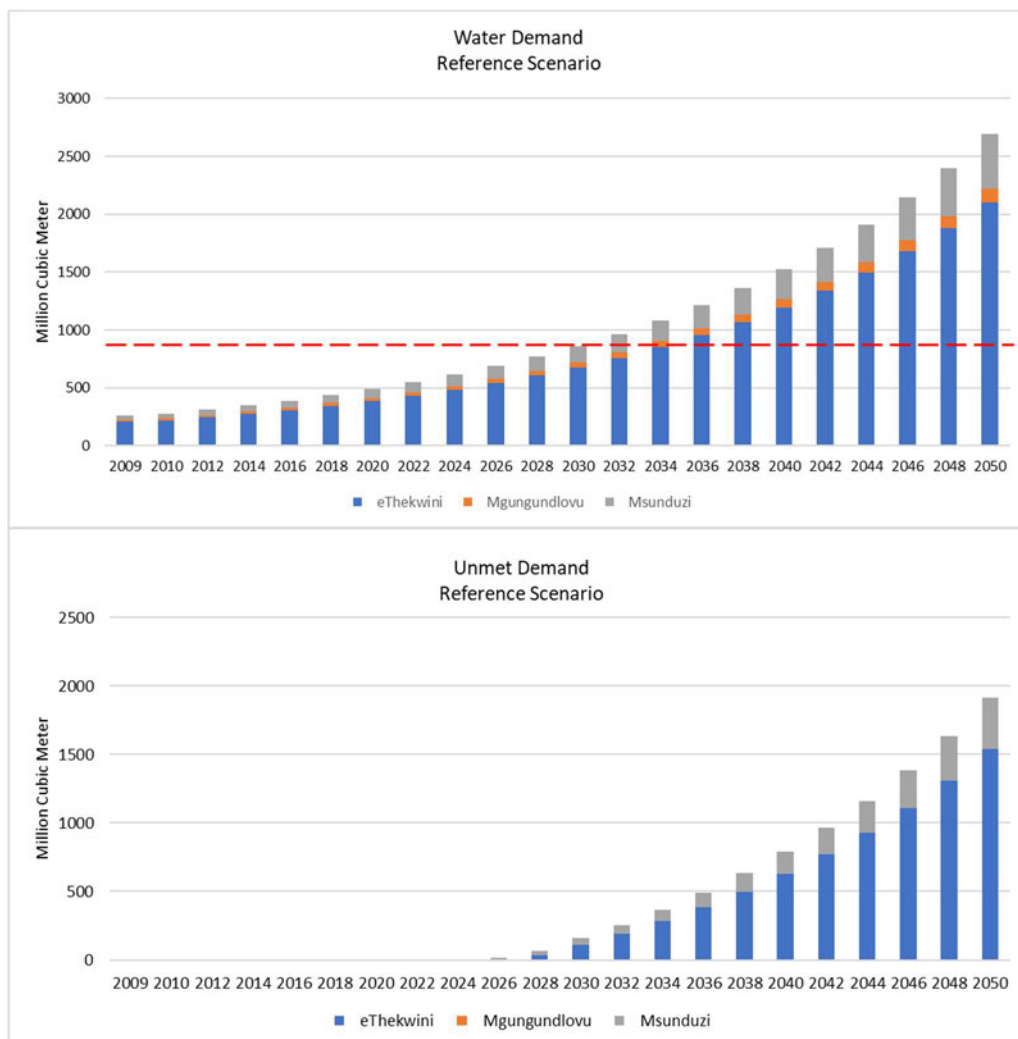


Figure 4.1: Water Demand and Unmet Demand under Reference Scenario

4.2.2 Scenario 2: Low Population Growth (Growth Rate 0.75%)

This scenario was developed to examine the possibility of a Lower Population Growth Rate. According to a study of the anticipated population growth for future years produced by “World Population Review” (worldpopulationreview.com), it is noted that population growth is expected to continue, but it will gradually decrease to below 1% by 2026. Therefore, for this study, the researcher will use a population growth rate of 0.75% to determine the impacts of a smaller growth rate compared to the growth rate of 1.1% and 2.5%. A new scenario was created with modified population growth to evaluate the impacts of a possible state of the WEAP model for a 0.75% population growth.

i. Projected Annual Activity Level

The projected population at a 0.75% growth rate generated in the WEAP model for each demand site is shown below in Table 4.2.

Table 4.2: Population for Reference Scenario at 0.75%.

0.75% Population Growth (person)						
	2009	2010	2020	2030	2040	2050
eThekwini	3,442,070	3,467,886	3,736,933	4,026,854	4,339,267	4,675,918
Msunduzi	606,888	611,440	658,877	709,994	765,077	824,434
uMgungundlovu	409,237	412,306	444,294	478,764	515,907	555,933
Yearly Total	4,458,195	4,491,632	4,840,104	5,215,612	5,620,251	6,056,285

ii. Projected Water Demand and Unmet Demand

Compared to the reference scenario, the water demand projections at all demand sites show a remarkable decrease as the population decreases from 1.1% to 0.75%. The major demand site for the water utilised from the analysis was eThekwini same as the reference scenario. Under the Lower Population Growth Scenario of 0.75%, the model projects water demand for the period of 2050 to be 1,826 million m³ for eThekwini, 408 million m³ for Msunduzi, and 100 million m³ for uMgungundlovu.

It is noted that the results for the water demand for Scenario 2 produce approximately 10% less water demand compared to the Reference Scenario. Furthermore, as shown in Figure 4.2, the current system yield will overcome the water demand by 2034. This is two years later than the current reference scenario of 2032.

However, with the analysis of historical climate data in the model, it can be envisaged that there will be a water shortfall in 2025 with approximately 4 million m³/year of unmet demands. Figure 4.2 below shows the unmet water demand for the period of 2050 to be 1,258 million m³ for eThekweni, 314 million m³ for Msunduzi, and 0 million m³ for uMgungundlovu.

The evaluation of Scenario 2 shows that with constant growth in the population of 0.75%, it is indicated that the water availability under Scenario 2 is relatively sufficient until 2025 for Msunduzi and 2030 for eThekweni.

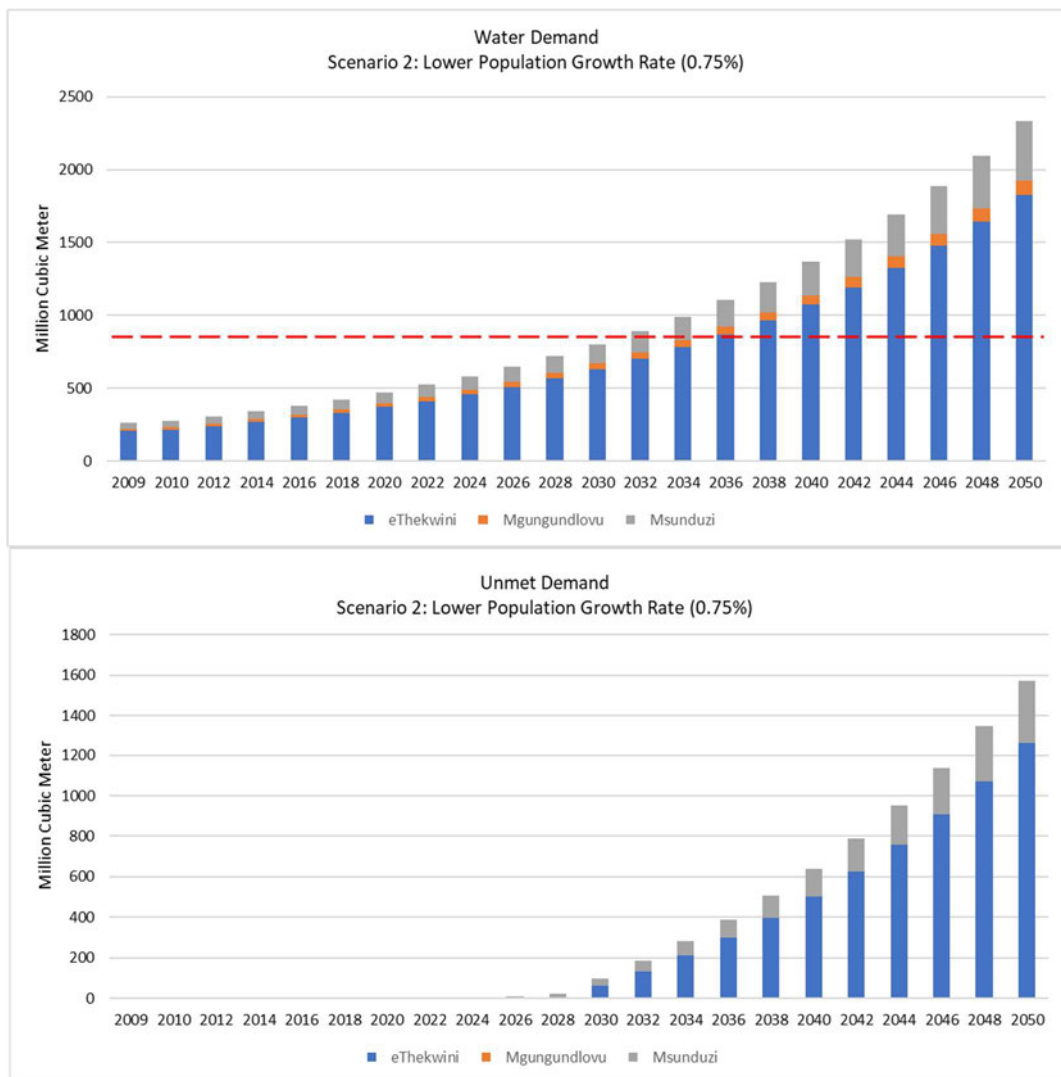


Figure 4.2: Water Demand and Unmet Demand under Scenario 2

4.2.3 Scenario 3: High Population Growth (Growth Rate 2.5%)

This scenario was developed to examine the possibility of a Higher Population Growth Rate. As explained above, the current population growth rate is 1.1%; however, envisioning a higher growth rate of 2.5%, this scenario caters for an unexpected rise in population. It was thus assumed that an increased population leads to increased water use.

In order to evaluate the impacts of a possible state of the WEAP model, a new scenario is created with modified population growth. Scenario 3 evaluates the impact of a population growth rate for the Mgeni system, where the population growth increased from the reference 1.1% to 2.5% from 2009 to 2050.

i. Projected Annual Activity Level

The projected population at a 2.5% growth rate generated in the WEAP model for each demand site is shown below in Table 4.3.

Table 4.3: Population for Scenario 3 at 2.5%

2.5% Population Growth (person)						
	2009	2010	2020	2030	2040	2050
eThekwini	3,442,670	3,528,122	4,516,294	5,781,238	7,400,474	9,473,232
Msunduzi	606,888	622,060	796,290	1,019,318	1,304,813	1,670,271
uMgungundlovu	409,237	419,468	536,954	687,347	879,862	1,126,298
Total	4,458,195	4,569,650	5,849,538	7,487,903	9,585,149	12,269,892

ii. Projected Water Demand and Unmet Demand

For the WEAP model to analyse the new population growth rate, a new scenario is added to the model using the Manage Scenario function in WEAP and is given the alias “Population Growth 2.5%”. Figure 4.3 shows the results projection of water demand based on Scenarios 3: Population growth 2.5%” for the study area. It is noted that the results for the water demand for Scenario 3 produce approximately 50% more water demand compared to the Reference Scenario.

Figure 4.3 shows the Unmet Demand results for Scenario 3: Population Growth of 2.5% for the study area. The evaluation of Scenario 3 indicates that the water availability is relatively sufficient until 2023 for Msunduzi and 2025 for eThekweni. The total unmet water demand for the period of 2050 is 3,131 million m³ for eThekweni, 731 million m³ for Msunduzi, and 45 million m³ for uMgungundlovu. The evaluation of Scenario 3 shows that with constant growth in the population of 2.5%, it is indicated that the water availability under Scenario 3 is relatively sufficient until 2023 for Msunduzi and 2025 for eThekweni.

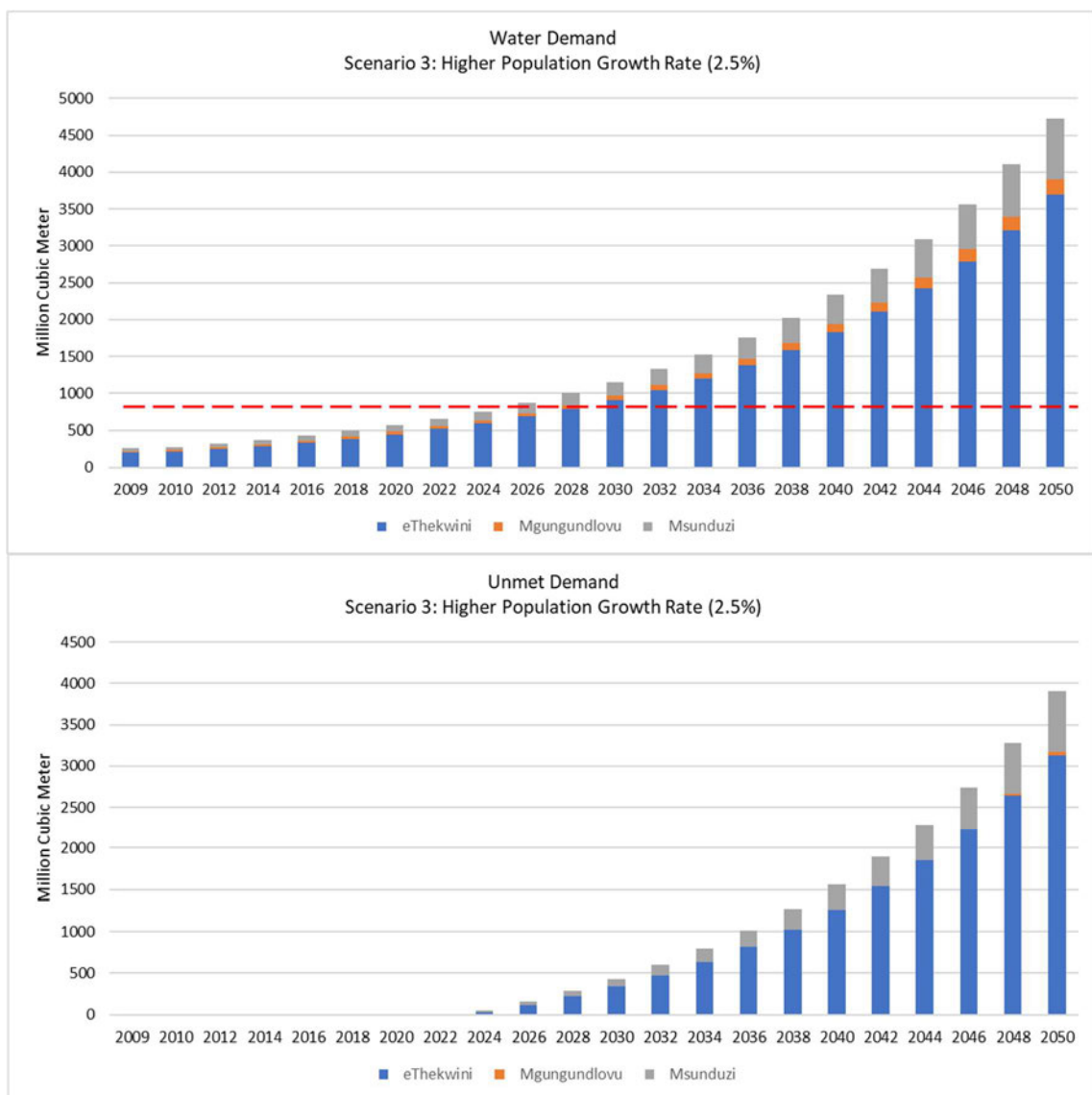


Figure 4.3: Water Demand and Unmet Demand under Scenario 3

4.2.4 Scenario 4: Extended Dry Climate Sequence

Climate change is already a measurable reality posing significant global social, economic, and environmental risks and challenges. Like many other developing countries, South Africa is especially vulnerable to the impacts of climate change (Kreft, 2017). Scenario 4 is developed to understand how climate change, specifically extended periods of dry climates, will affect the water supply for the study area.

i. Sequence of Climate

A new scenario with the alias “Extended Dry Climate” is created from the Reference Scenario, and the climate variation is modified to evaluate the impact of the water supply. For Scenario 4: Extended Dry Climate Sequence, the following sequence is assigned as shown in Table 4.4 below. This scenario analyses the study area to evaluate how the area will be affected by the effects of dry climates for a long period.

Table 4.4: Climate Categories for Scenario 4

Year Period	Sequence of Climate Variation
2009	Normal
2010 - 2014	Very Dry
2015 - 2020	Dry
2021 - 2024	Normal
2025 - 2028	Dry
2029 - 2034	Very Dry
2035 - 2039	Wet
2039 - 2045	Dry
2046 - 2050	Very Dry

ii. Projected Water Demand and Unmet Demand

The climatic variation for Scenario 4: Extended Dry Climate Sequence is assigned to the Reference Scenario to determine the impacts on water demand and supply.

Figure 4.4 below shows the Unmet Demands under Scenario 4: Extended Dry Climate conditions are illustrated, and a comparison can be made with the Reference Scenario. It is

found that with an extended dry period of climate, the unmet demand is of significant value and varies following the climate. This indicates that water demand and supply are highly dependent on climate conditions.

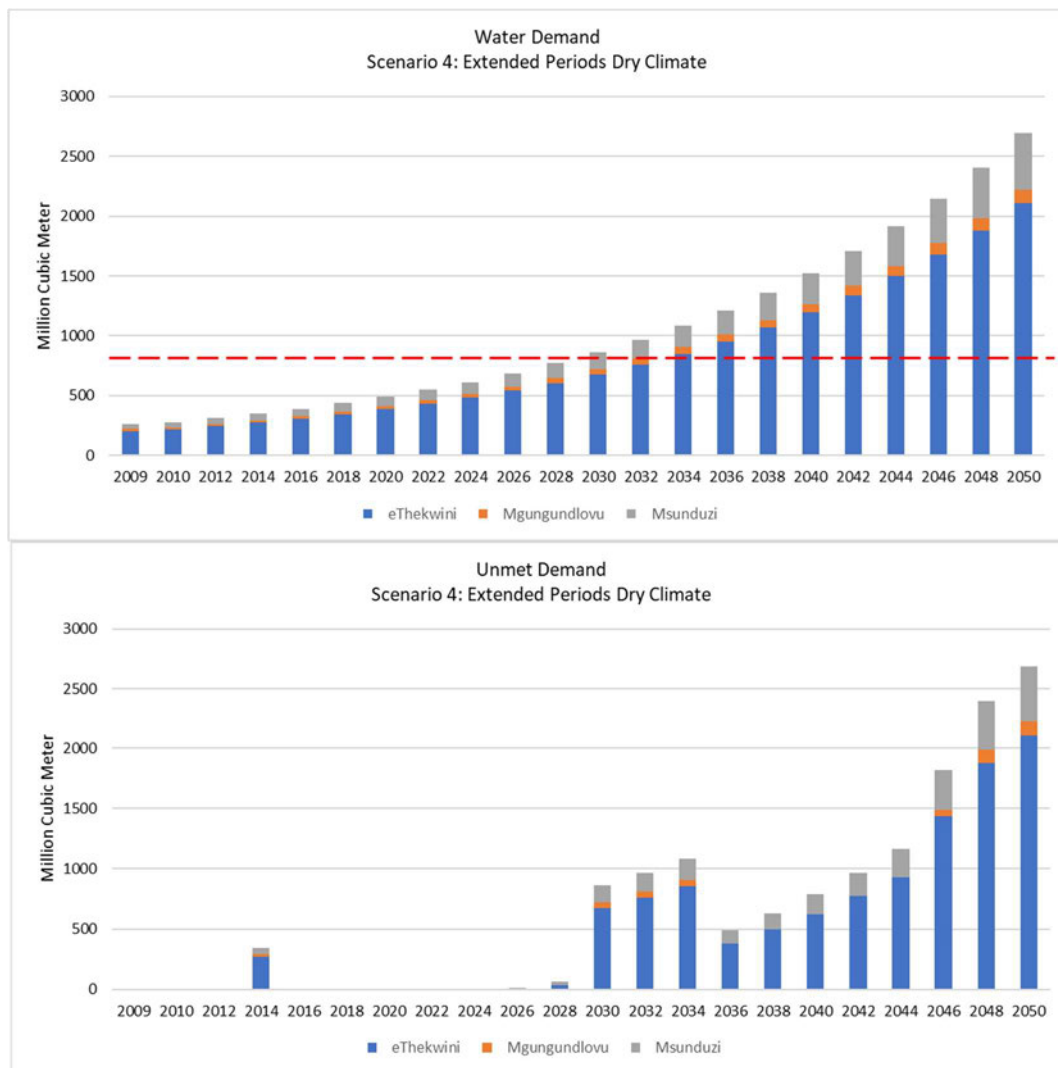


Figure 4.4: Water Demand and Unmet Demand under Scenario 4

4.3 Water Losses

Although the target for reducing our water losses has been set, there is still no clear indication of the actual water losses and how it has been split between Physical Leakage (Real Losses) and Commercial Losses (Apparent Losses).

The need for monitoring and measuring water supplied by Water Services Authorities is therefore crucial to gain a better understanding of the nature and extent of the challenges faced by the water sector (Mckenzie, 2012).

4.3.1 Real Losses

Real losses occur due to leakage or overflow at service reservoirs, from transmission mains, distribution mains, and distribution mains, etc. Several WSAs and municipalities are battling to contain the excessive losses of potable water. As shown below in Table 4.5, eThekwini is one of the highest water loss areas in South Africa, registering approximately 91.2 to 138.4 million m³/year. The objective of WC/DM is to reduce these losses in the future.

Table 4.5: Real Losses (Source: Moodley, T, 2021)

Real Losses (million m³)					
	2016-17	2017-18	2018-19	2019-20	2020-21
eThekwini	91.2	87.7	105.4	162.9	138.4
Msunduzi	13.1	16.6	15.2	17.9	17.4
uMgungundlovu	5.8	6.3	7.8	9.2	7.0
Total	110.1	110.6	128.4	190.0	162.8

It is almost impossible to remove all real losses from a system due to leakages that are small and cannot be detected. Unavoidable Annual Real Losses (UARL) is the amount of water losses that is “unavoidable” in the system.

To succeed in WC/DM, one needs to determine these UARL and compare them to the Current Annual Real Losses (CARL). An estimate of UARL can help to evaluate the feasibility of real loss minimisation, which provides a better understanding of real loss components (Sharma 2008).

The UARL can be calculated based on the Background and Burst Estimates (BABE). Leakages can be categorised in 3 ways, as indicated in Figure 4.5. Firstly, “background leakages” cannot be seen from the surface, which are not reported or detected by the eye. These leaks are caused when pressure is very low in a system or if the pipe infrastructure damage is small. Secondly, “unreported leakages” are leakages that also cannot be seen on the surface but can be detected using acoustic equipment to detect leakages. Finally, “reported leakages” are leakages that are big enough to surface and are visible to the public.

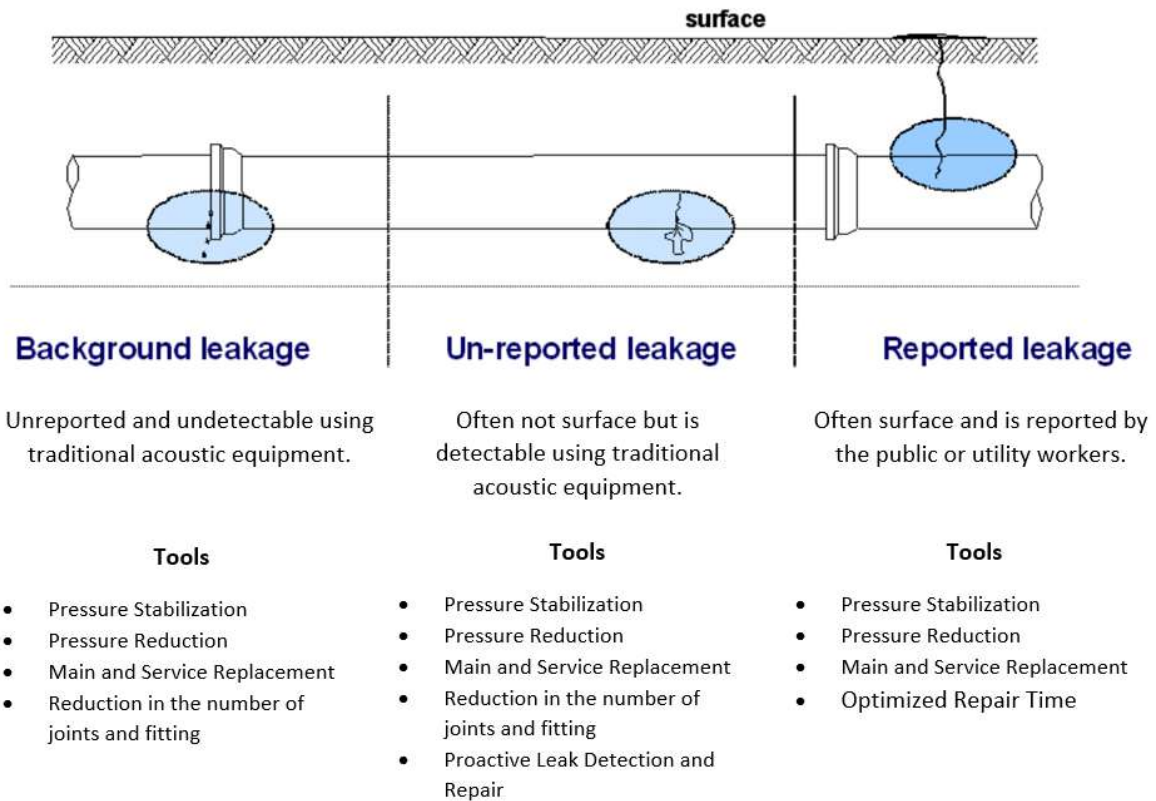


Figure 4.5: Background and Burst Estimates (BABE) Concept (Lambert, 2009)

$$\text{UARL (l/day)} = (18 L_m + 0.80 N_c + 25 L_p) \times P \quad (\text{Eq. 3})$$

Where,

- L_m = Length of mains in km,
- N_c = Number of service connections,
- L_p = Total length in km of underground connection pipes (between the edge of the street and customer meters), and
- P = Average operating pressure in m.

Table 4.6 below indicates the parameter used to determine the KPIs of the study area. The UARL and ILI can be calculated using the following factors.

Table 4.6: Factors for UARL Determination (Source: Moodley, T, 2021)

Length of Mains (km)					
	2016-17	2017-18	2018-19	2019-20	2020-21
eThekwini	12,360	12,360	12,605	12,686	12,746
Msunduzi	2,037	2,037	2,037	2,041	2,041
uMgungundlovu	2,381	2,381	2,381	2,381	2,381
Total	16,778	16,778	17,023	17,108	17,168
Number of Connections					
	2016-17	2017-18	2018-19	2019-20	2020-21
eThekwini	512,417	517,469	520,607	524,755	528,988
Msunduzi	183,472	183,472	183,472	183,472	183,472
uMgungundlovu	111,376	111,966	111,966	111,966	111,966
Total	294,848	812,907	816,045	820,193	824,426
% Time Pressure					
	2016-17	2017-18	2018-19	2019-20	2020-21
eThekwini	100%	100%	93%	93%	93%
Msunduzi	97%	97%	97%	97%	97%
uMgungundlovu	94%	86%	86%	86%	86%
Average Total	97%	94%	92%	92%	92%
Average Pressure in System (P)					
	2016-17	2017-18	2018-19	2019-20	2020-21
eThekwini	54	54	54	54	54
Msunduzi	65	65	65	65	65
uMgungundlovu	50	50	50	50	50
Average Total	56	56	56	56	56
Length of Connection (assuming 1.0km per conn)					
	2016-17	2017-18	2018-19	2019-20	2020-21
eThekwini	0.2	0.2	0.2	0.2	0.2
Msunduzi	0.2	0.2	0.2	0.2	0.2
uMgungundlovu	0.2	0.2	0.2	0.2	0.2
Average Total	0.2	0.2	0.2	0.2	0.2

Using the above UARL formula, the researcher can determine the number of water losses that is unavoidable and avoidable. Table 4.7 below shows the calculation for the UARL and CARL.

Table 4.7: UARL, CARL and ILI Calculations

UARL, CARL and ILI					
	2016-17	2017-18	2018-19	2019-20	2020-21
18 x Lm	2,030	1,974	5,796	5,825	5,846
0.8 x Nc	12,881	12,614	12,350	12,412	12,467
25 x Lp	0.01	0.01	0.01	0.01	0.01
UARL (l/day)	14,910	14,588	18,146	18,238	12,476
UARL (mill m³/year)	51	49	66	66	66
CARL (mill m³/year)	385	395	469	690	588
Avoidable Losses	334	346	403	624	522
ILI	7.6	8.0	7.2	10.5	9.0
Category	C	C	C	C	C

As shown in the table above, the Current Annual Real Losses (CARL) has been obtained from relevant reports, and therefore it can be used to determine the infrastructure leakage Index (ILI). The ILI can be determined as follows:

$$\text{Infrastructure Losses Index "ILI"} = \frac{\text{CARL}}{\text{UARL}} \quad (\text{Eq. 4})$$

Table 4.8 below indicates the ILI and the Technical Performance Category of the study area. The Technical Performance Category indicated the current WC/DM implemented and the nature of the current infrastructure.

- Category A: Further loss reduction may be uneconomic unless there are shortages, the careful analysis needed to identify cost-effective improvement,
- Category B: Potential for marked improvements consider pressure management, better active leakage control practices and better network maintenance,
- Category C: Poor leakage record, tolerable only if water is plentiful and cheap; even then, analyse level and nature of leakage and intensify leakage reduction efforts,
- Category D: Highly inefficient, leakage reduction programs are imperative and have high priority (Liemberger, 2005).

Table 4.8: ILI Comparison (Liemberger, 2005)

Technical Performance Category		ILI	Litres/connection/day				
			10m	20m	30m	40m	50m
DEVELOPED COUNTRIES	A	1-2		<50	<75	<100	<125
	B	2-4		50-100	75-150	100-200	125-250
	C	4-8		100-200	150-300	200-400	250-500
	D	>8		>200	>300	>400	>500
DEVELOPING COUNTRIES	A	1-4	<50	<100	<150	<200	<250
	B	4-8	50-100	100-200	150-300	200-400	250-500
	C	8-16	100-200	200-400	300-600	400-800	500-1000
	D	>16	>200	>400	>600	>800	>1000

As shown in Table 4.8, the study area falls within a Category C. As stated by Liemberger, Category C indicates poor leakage control and record, tolerable only if water is plentiful and cheap, even then, analyse level and nature of leakage and intensify leakage reduction efforts.

4.3.2 Apparent Losses

Apparent losses are losses that occur due to unauthorised consumption such as theft or illegal usage, inaccurate meter reading etc. As shown in Table 4.9 below, eThekweni is one of the highest water loss areas in South Africa, registering approximately 8.9 to 18.2 million m³/year.

Table 4.9: Apparent Losses (NRW Moodley, T, 2021)

Apparent Losses (million m ³ /year)					
	2016-17	2017-18	2018-19	2019-20	2020-21
eThekwini	8.9	14.3	17.2	18.1	18.2
Msunduzi	4.5	5.8	5.3	4.2	4.1
uMgungundlovu	1.3	1.4	1.7	2.0	1.5
Total	14.7	21.5	24.2	24.3	23.8

The Apparent Losses Index (ALI) has been recommended by the IWA task force to investigate current apparent losses and categorise them in similar nature to the ILI. The concepts for Apparent Losses are similar to those already defined for Real Losses, whereby the Current

Annual Apparent Loss (CAAL) is similar to Current Annual Real Loss (CARL), and the Apparent Loss Index (ALI) is similar to Infrastructure Leakage Index (ILI) (Vermersch et al, 2016).

The ALI can be determined by:

$$\text{Apparent Losses Index "ALI"} = \frac{\text{CAAL}}{\text{RAAL}} \quad (\text{Eq. 5})$$

Where RAAL = 5% x Water Supplied, excluding Water Exported

Table 4.10: CAAL, RAAL and ALI Calculations

CAAL, RAAL and ALI					
	2016-17	2017-18	2018-19	2019-20	2020-21
CAAL (mill m³/year)	14.7	21.5	24.2	24.3	23.8
Total Sales (mill m³/year)	389	410	436	461	487
RAAL (mill m³/year)	19.5	20.5	21.8	23.0	24.4
ALI	0.75	1.05	1.11	1.06	0.98

In countries with poor management of water resources, it was determined that the ALI is extremely high, i.e., higher than 5. In countries with ALI lower than 1, it is regarded as a good factor in which the management is under control, and proper techniques are followed. In cases where ALI is lower than 1.0, it is important to check that the default values used are valid and supported by appropriate field and lab surveys. ALI lower than 1.0 in the same way that an ILI lower than 1.0 can occur in some circumstances (Lambert et al, 2014), an ALI lower than 1.0 can also occur and be accepted if (Vermersch et al, 2016):

- Validation of the volume components of RAAL has been sufficient to justify the calculation of ALI or,
- It has been recently validated that the use of defaults lower than a RAAL of 5% of Billed Metered Consumption is justified.
- New metering techniques are used.
- However, if only a limited or cursory check on RAAL components has been done, further control and monitoring are required, especially if no measures were previously put in place to reduce this value to less than unity.

4.4 Evaluation of Future Demand with Avoidable Losses

From the analysis of the UARL, it is determined that the UARL for the 2020-21 financial year is estimated at approximately 66 million m³/year, with the CARL estimated at approximately 588 million m³/year. Therefore, the Avoidable Real Losses estimate at approximately 522 million m³/year. The CAAL is determined to be 23.8 million m³/year and RAAL 24.4 million m³/year. Therefore, the Avoidable Apparent Losses estimate at approximately 1 million m³/year. Hence, the total Avoidable Losses equate to 523 million m³/year.

If the study area achieves a 50% and 100% reduction in water losses, the unmet demand will be shown in Tables 4.11 and 4.12 below.

Table 4.11: Unmet Demand Evaluation with 50% Reduction in Losses

	UNMET DEMAND (million m ³)									
	2009	2015	2021	2024	2025	2030	2035	2040	2050	
50% Reduction in Losses	Scenario 1(with losses)	0	0	0	3	9	157	428	788	1,913
	Scenario 1(without losses)	0	0	0	0	0	0	166	526	1,651
	Scenario 2(with losses)	0	0	0	0	4	99	334	640	1,571
	Scenario 2(without losses)	0	0	0	0	0	0	72	378	1,309
	Scenario 3(with losses)	0	0	2	50	104	431	897	1,560	3,908
	Scenario 3(without losses)	0	0	0	0	0	169	635	1,298	3,646
	Scenario 4(with losses)	0	0	0	3	9	863	428	788	2,690
	Scenario 4(without losses)	0	0	0	0	0	601	461	794	2,428

Table 4.12: Unmet Demand Evaluation with 100% Reduction in Losses

	UNMET DEMAND (million m ³)									
	2009	2015	2021	2024	2025	2030	2035	2040	2050	
100% Reduction in Losses	Scenario 1(with losses)	0	0	0	3	9	157	428	788	1,913
	Scenario 1(without losses)	0	0	0	0	0	0	266	1,391	
	Scenario 2(with losses)	0	0	0	0	4	99	334	640	1,571
	Scenario 2(without losses)	0	0	0	0	0	0	118	1,049	
	Scenario 3(with losses)	0	0	2	50	104	431	897	1,560	3,908
	Scenario 3(without losses)	0	0	0	0	0	0	375	1,038	3,386
	Scenario 4(with losses)	0	0	0	3	9	863	428	788	2,690
	Scenario 4(without losses)	0	0	0	0	0	341	0	266	2,168

From the table above, it is determined that for Scenario 1 and Scenario 2, the study area, will only encounter water problems in 2035 for a 50% water losses reduction and 2040 for a 100% water losses reduction. In Scenario 3, the study area will encounter water problems in 2030 for a 50% water loss reduction and 2035 for a 100% water loss reduction. Finally, in Scenario 4, the study area will only encounter water problems in 2030 for a 50% and 100% water loss reduction with varying unmet demand due to the varying dry climates.

In summary, the unmet demand and experiences of water problems can be preserved in the face of difficulty by eliminating the water losses encountered in the study area. By introducing WC/DM, the study area would delay the water scarcity problems by a few years, which can be used to develop future solutions to the water problems in the study area. Water losses can be reduced by WC/DM strategies such as pressure management, active leak detection testing etc.

4.5 Non-Revenue Water, Revenue Water and Economics

One of the major challenges facing water utilities is the high level of water loss in distribution networks. If a large proportion of water supplied is lost, meeting consumer demands is much more difficult. Since this water yields no revenue, heavy losses also make it harder to keep water tariffs at a reasonable and affordable level (Rudolf, 2010).

In order to achieve WC/DM objectives, Non-Revenue Water needs to be drastically reduced. Umgeni Water, DWS, and CoGTA assess the state of the Non-Revenue Water across KZN to find cost-effective measures to reduce the amount of Non-Revenue Water. As shown in Figure 4.6 below, the NRW lost during the 2018-2019 financial year was approximately 41% of the total water supplied.

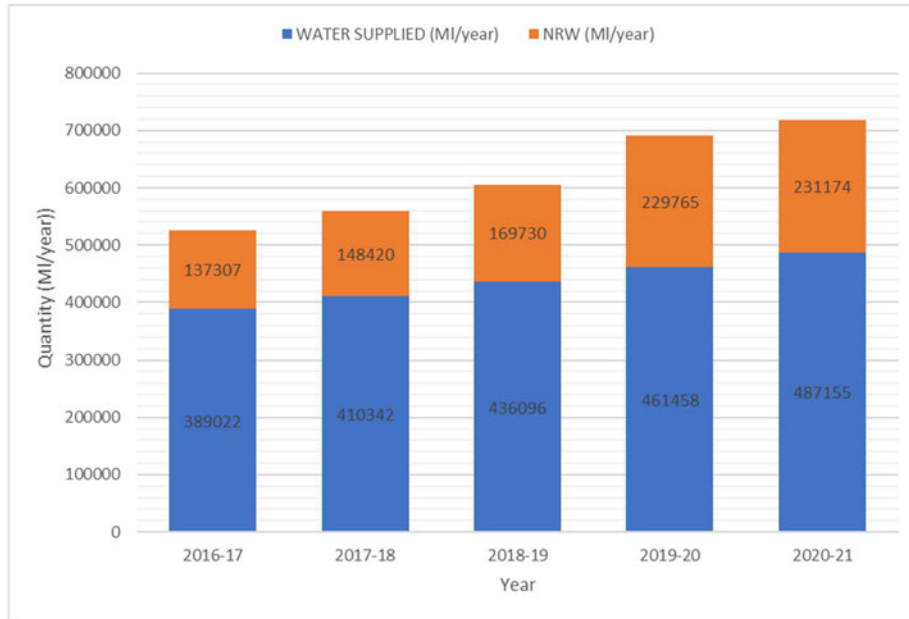


Figure 4.6: Water Supplied and NRW Volumes

Table 4.13 below shows the current Unit Cost of Potable Water. Using this unit cost, the researcher can determine the total cost of total water supplied as well as the expenditure of the non-revenue water, as shown in Figure 4.7.

Table 4.13: Unit Cost of Water (Moodley, T, 2021)

AREA	Unit Cost of Water per kl (excluding VAT)				
	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
eThekwini	R 5.31	R 6.35	R 7.82	R 11.56 *	R 11.56 *
uMgungundlovu	R 5.31	R 6.35	R 7.82	R 11.56 *	R 11.56 *
Msunduzi	R 5.31	R 6.35	R 7.82	R 11.56 *	R 11.56 *
TOTAL	R 5.31	R 6.35	R 7.82	R 11.56 *	R 11.56 *

* Calculated average cost from eThekwini, Msunduzi and uMgungundlovu

Figure 4.7 above illustrates that the NRW equals 35% to 47% from 2016-17 to 2020-21 financial years, respectively. In the 2020-21 financial year, approximately R 5,6 billion was lost due to water losses. By decreasing the NRW in the system, WSA can utilise this finance to aid WC/DM projects such as education campaigns, water harvesting, infrastructure replacements.

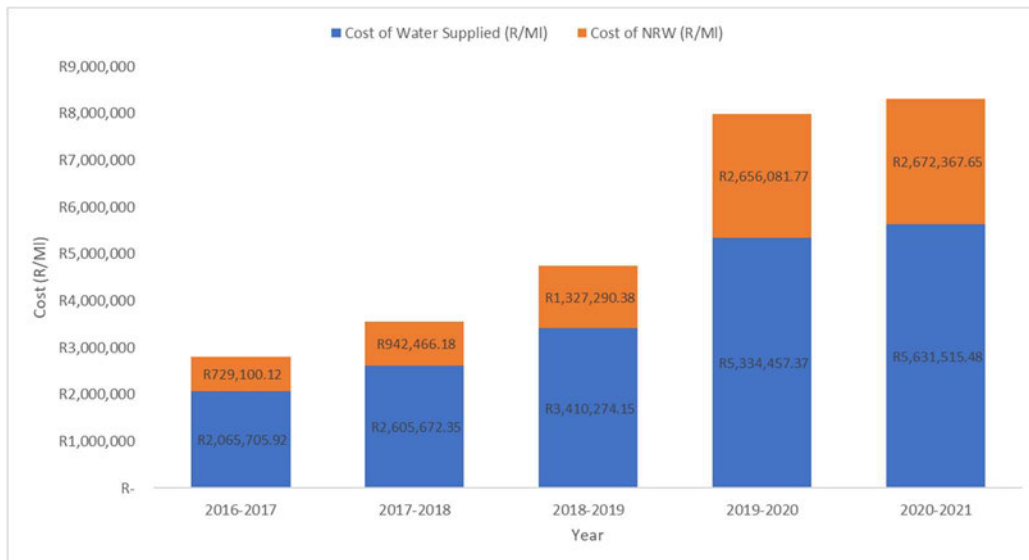


Figure 4.7: Cost of Water Supplied and NRW

4.6 Qualitative Analysis and Results

This section aims to analyse and interpret the qualitative data collected during questionnaires. The questionnaires were conducted for members at Umgeni Water. The respondents had to respond based on statements rated as either strongly agree, agree, neutral, disagree or strongly disagree (Appendix A). The research results are presented and discussed hereunder.

The research was conducted within Umgeni Water, and eighteen questionnaires were received. The questionnaires were drafted in such a way that respondents were allowed to add their comments on each statement. The responses are summarised and discussed below.

4.6.1 Section A Water Resource Management

Following are the responses collected from the questionnaire regarding water resource management. Furthermore, this research explains the reason and proposes possible solutions to the survey's outcome.

Question 1: Does Umgeni Water aid water resources management within the Umgeni Water supply area?

A total of thirteen respondents (72%) answered the question by strongly agreeing, with the remaining five respondents (28%) answered the question by agreeing that Umgeni Water implements adequate water resource management within the study area. The response indicates that Umgeni Water has three departments supporting water resource management: Planning

Services, Water Quality and Environmental Services, and Catchment Management Department.

The Planning Services manages the water resources planning and water demand management, the Water Quality and Environmental Services focus on water quality management and environmental management, and the Catchment Management Department focuses on the water resource protection, conservation, restoration, water use efficiency and ecological infrastructure management. Evidently, Umgeni has taken major steps in protecting water resources with management interventions and measures. However, considering the current water losses, more needs to be done, and more measures such as awareness and education, rainwater harvesting, greywater re-use etc are required.

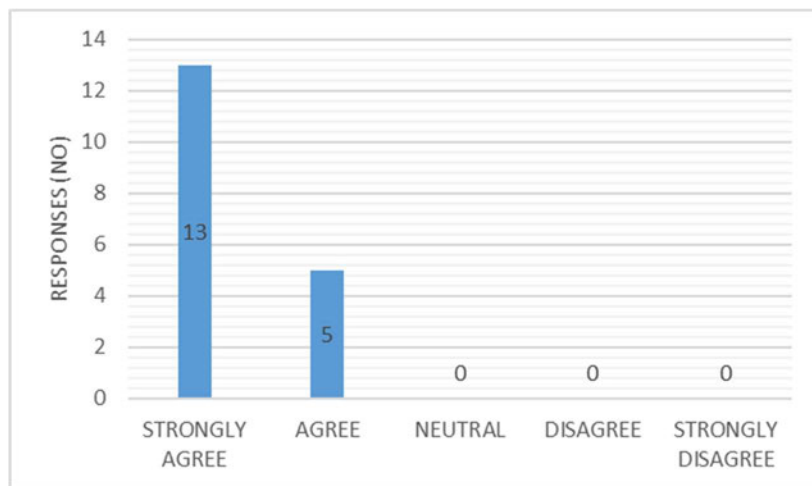


Figure 4.8: Questionnaire Response for Question 1

Question 2: Has Umgeni Water developed adequate Water Conservation and Water Demand Strategies?

A total of seven respondents (39%) answered the question by strongly agreeing that Umgeni Water has developed and adequately implemented WC/DM strategies. However, a total of eleven respondents (61%) agreed with the question. The results show agreement that WC/DM strategies have been implemented to some extent.

It has been acknowledged that WC/DM strategies form part of the organisational scorecard. This is a good method to ensure that WC/DM has been adequately implemented. Some respondents highlighted that WC/DM unit is relatively new, but it has already significantly

impacted identifying, monitoring, and fixing water leakages. Furthermore, the conservation component of the unit still needs to be strengthened through collaboration with the water education and awareness and the catchment management units. Finally, it can be concluded that the organisation has come a long way with WC/DM; a few years ago, the term WC/DM was vague, but now it has been highly implemented in most of the organisation's service areas. There has been a major shift in the department to focus more on the WC/DM which has filled the gap in knowledge. It is evident in the decrease in real and apparent losses for the 2020-21 financial year, as shown in Tables 4.5 and 4.9.

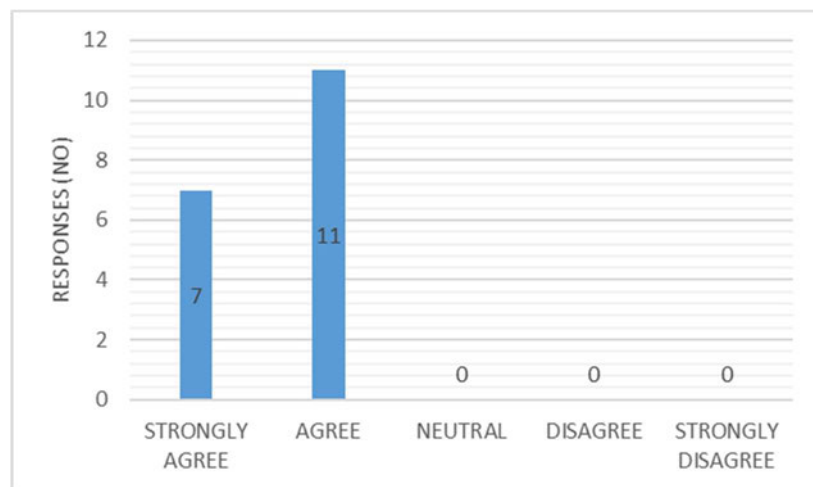


Figure 4.9: Questionnaire Response for Question 2

Question 3: Has Umgeni periodically implemented a full leak detection program for your distribution system (how often)?

Regarding the above question, a total of two respondents (11%) answered the question by strongly agreeing, and a total of twelve respondents (67%) agreed with the question that Umgeni had implemented a full leak detection program at regular intervals. However, a total of three respondents (13%) neither agreed nor disagreed, and one respondent (6%) disagreed with the statement. Responses indicated a lack of information about the leak detection program. The information gained from the questionnaires states that Umgeni Water monitors the water balance to check the quantity of the losses. Leak detection equipment is used to detect leakages scheduled to occur twice a year, but teams are constantly doing servitude inspections within the study area. This states that only the pipe as far as servitudes are checked and inspected. More initiatives are needed for pipes at buildings/houses as this also contributes to water losses that go unnoticed for long periods.

This shows that leak detection is applied in the water networks, but more can be done to implement the leak detection program properly. Most of the water losses are due to background leakages, and these programmes will eliminate these losses.

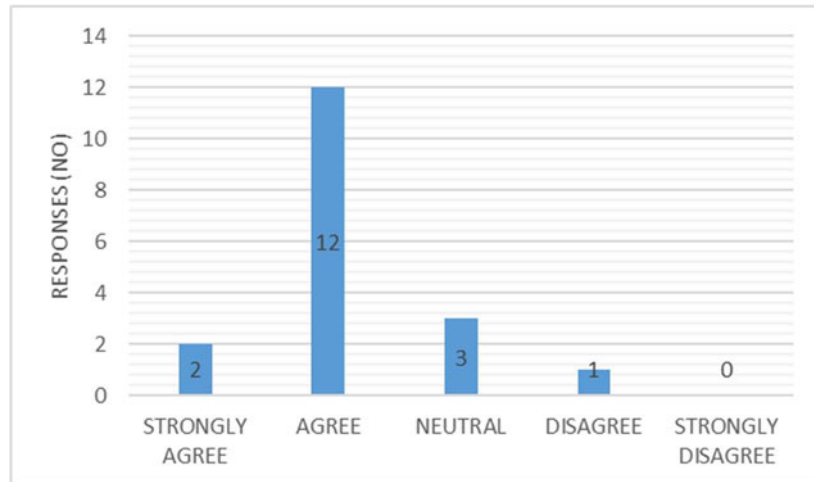


Figure 4.10: Questionnaire Response for Question 3

Question 4: Does Umgeni Water allocate a sufficient budget for WC/WDM strategies and measures?

On this question, a total of twelve respondents (67%) answered the question by agreeing that a sufficient budget is allocated in each financial year for the implementation of WC/DM projects such as pipe replacement, pressure management, water-sensitive urban design, leaks monitoring and repair. It has been highlighted that R4 million had been allocated for WC/DM to the current year (2019-20), which might go up to R10 million in the next financial year.

Conversely, six respondents (33%) answered with a neutral with the question stating that “more could be done”. The response indicated a degree of uncertainty regarding the budgeting processes and allocation of resources for implementing WC/DM projects.

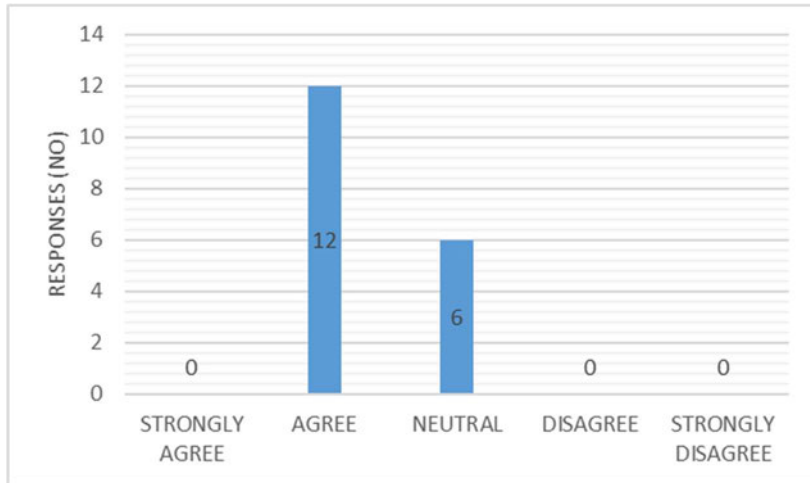


Figure 4.11: Questionnaire Response for Question 4

Question 5: Is the water pressure regulated at various times of the day to promote leakage reduction?

Analysis of the above figure showed that a total of six respondents (33%) answered the question by strongly agreeing, whereas two respondents (11%) agreed, one respondent (6%) respondent was neutral, a total of seven respondents (39%) disagreed, and two respondents (11%) strongly disagreed. The responses indicated a degree of uncertainty regarding pressure reduction within the system.

With most of the responses disagreeing with this statement, it shows evidence of minimal intervention in implementing effective and efficient water pressure regulation. The results indicate that pressure management is still vague within the organisation. It is also evident from the current state of water losses that pressure management is not applied in the Mgeni system. It is indicated in past research studies that pressure management has a significant impact and is one of the most important strategies for WC/DM implementation. For the study area to be successful, it will need to understand and implement pressure management quickly.

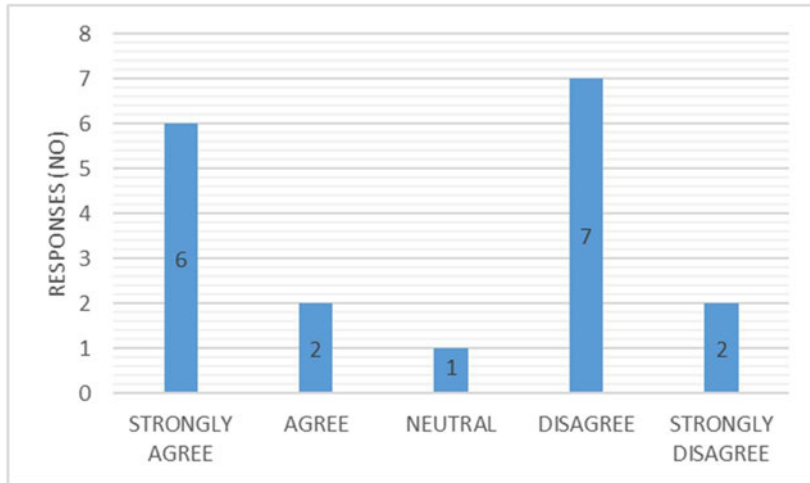


Figure 4.12: Questionnaire Response for Question 5

Question 6: Do you have a public education plan in place? (Please explain)

Regarding this question, only six respondents (33%) answered the question by strongly agreeing, with six respondents (33%) agreeing. The remaining five respondents (28%) answers were neutral, and one respondent (6%) disagreed with the question.

The majority of the respondents agree with the statement that there are measures in place to educate the public about the current state of the water resources; however, the 34% of respondents that was neutral and disagreeing stated that the organisation does not have a sufficient public education plan in place. It can be seen from the response that more can be done to educate the public on the importance of water conservation and the current state of water resources. Education is also crucial to WC/DM as this teaches communities how to use water sparingly and keep them up to date with the latest water trends and saving techniques.

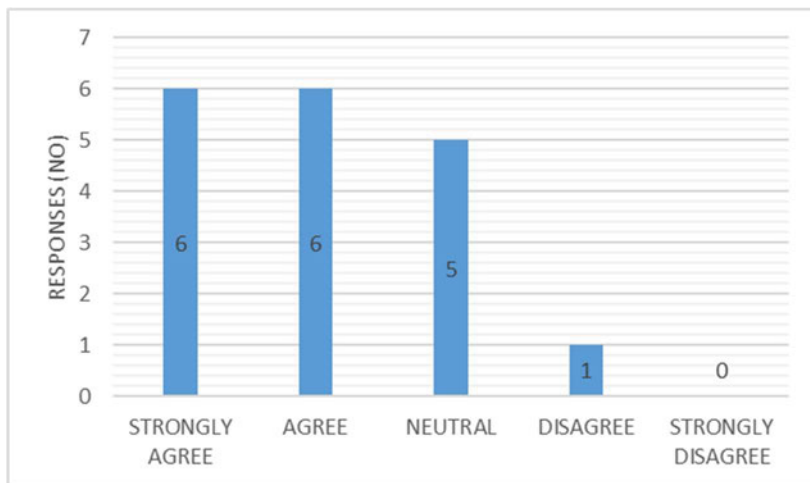


Figure 4.13: Questionnaire Response for Question 6

Question 7: Have water Conservation and Demand Management strategies brought about a decrease in water losses?

Analysis of the above figure showed that a total of two respondents (11%) answered the question by strongly agreeing, eight respondents (44%) agreed, whereas seven respondents (39%) was neutral, and one respondent (6%) disagreed. A total of eight respondents were neutral and disagreed with the question, showing that the respondent was not familiar with the water losses strategy.

It has been noted that the implementation of WC/DM has decreased water losses, and many other initiatives have been planned for implementation with the communities in areas where water losses are a major problem. One of the biggest challenges with implementation with the communities is the procurement process which currently does not effectively or adequately cater for projects of that nature. On the other hand, it was also noted that the water losses decreased when WC/DM was put in place, but the problem is so big that the small wins (decrease in water losses) are outweighed by the additional losses (bursts).

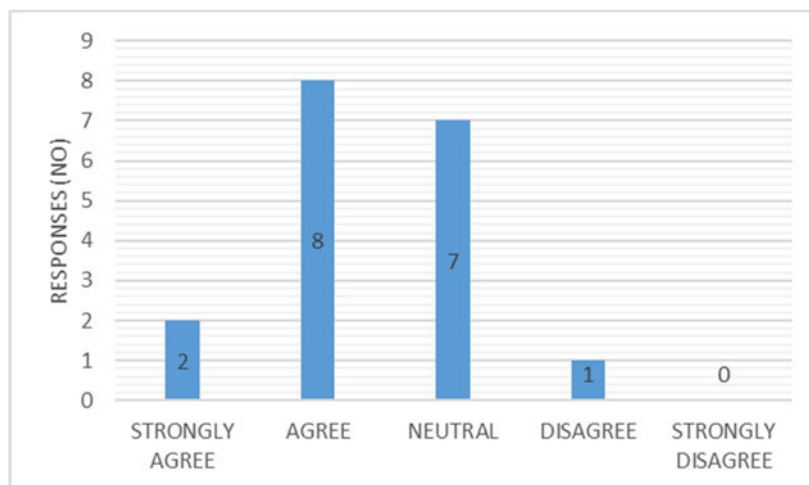


Figure 4.14: Questionnaire Response for Question 7

Question 8: Do you provide educational literature about the installation of water-saving devices and water conservation savings to the community?

A total of two respondents (11%) answered the question by strongly agreeing, with nine respondents (50%) agreeing and a total of seven respondents (39%) neutral. Respondents who agreed with this question stated that the organisation distributed literature and information to WSA and also put-up information on billboards whenever there was a need, e.g., during the drought of 2016 - 2018.

However, respondents who were neutral with this question stated that the information is unknown, but it is something that the organisation should consider and form part of the scorecard in promoting water conservation and demand management. Educating the public forms an integral part of WC/DM strategies and should be the first step in any WC/DM initiative.

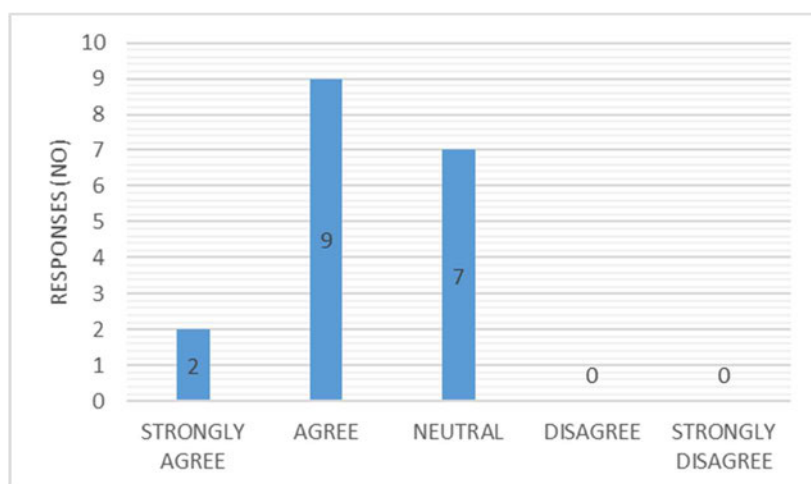


Figure 4.15: Questionnaire Response for Question 8

4.6.2 Section B Water Supply and Demand

According to the questionnaires, the following responses regarding water supply and demand have been given. The answer to the question is reviewed here, and further consideration is made as to the reason and possible solution for the problem.

Question 9: Has Umgeni Water played a part in bridging the gap between water supply and demand in KwaZulu- Natal? Please elaborate.

A total of ten respondents (56%) answered the question by strongly agreeing, with a total of six respondents (33%) agreeing, and two respondents (11%) were neutral with the question. Analysis of the above figure showed that there is sufficient measure in place to bridge the gap between supply and demand.

The summary of the answers highlights that Umgeni Water has a special department that conducts water demand projections and water resource availability as part of its infrastructure master planning for the entire province. Umgeni Water also assists WSA's with implementing WC/DM handbooks, regulation requirements, and NRW reduction master plans. Financial

constraints also play a vital role in the act the balance the supply and demand. It is acknowledged that there is not enough budget to sort supply-demand problems, which is also impacted by politics within the industry.

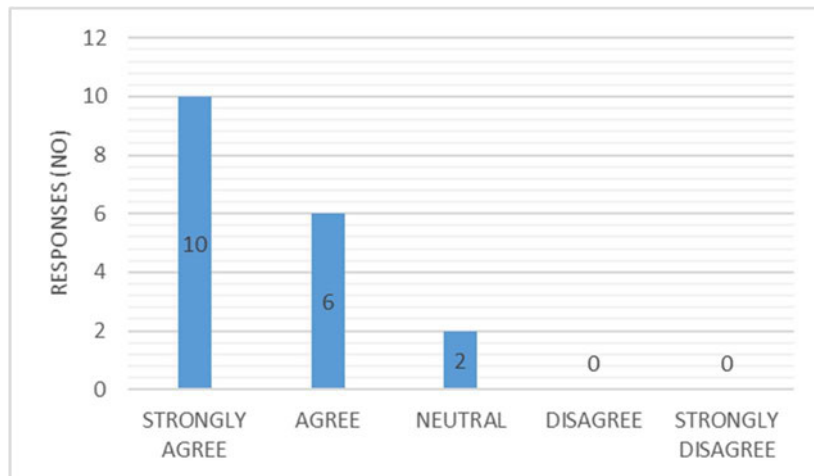


Figure 4.16: Questionnaire Response for Question 9

Question 10: Will Automatic Meter Reading (AMR) systems decrease errors in meter reading and billing compared to the manual meter systems currently being used?

A total of eight respondents (44%) answered the question by strongly agreeing, with a total of nine respondents (50%) agreeing with the question. However, one respondent (6%) was neutral showing unfamiliarity with AMR systems.

It has been ascertained that AMR would quickly pick up leakages within the system and also decrease human errors in recording meter readings. The AMR will also allow for remote access to data and readings. With the proper software, the inspector quickly picks up errors and possible leakages, theft, etc.

On the other hand, the AMR meter will also need to be adequately maintained and calibrated to avoid errors and inaccuracies. The inspector controlling the data would also have to conduct random checks as there can be anomalies in automated systems due to issues with the software, hardware etc. This gives a good idea of the pros and cons when implementing AMR as a full-scale measure.

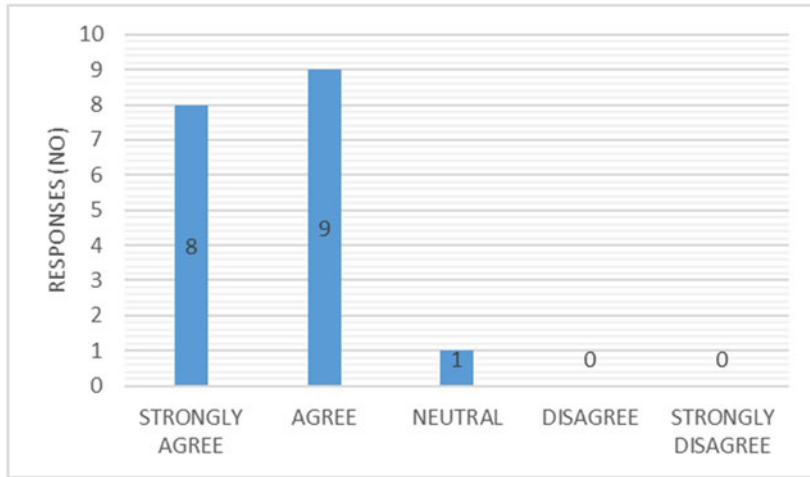


Figure 4.17: Questionnaire Response for Question 10

Question 11: Do Umgeni Water and municipalities have protocols to ensure the accuracy and consistency of the manual meter readings?

A total of four respondents (22%) answered the question by strongly agreeing, with seven respondents (39%) answered the question by agreeing. However, six respondents (33%) were neutral, and one respondent (6%) disagreed.

It has been ascertained that the manual meters are tested and checked regularly as well, and managers evaluate the data at regular intervals to pick up any errors. With manual meter readings, there is always room for error, which at a large scale can induce huge errors in the water balance and system. It is noted that with Automated Meter Reading (AMR), a leak would be picked-up and registered within a day, but the manual meter reading means that someone only notices an increase in demand one month after the last reading.

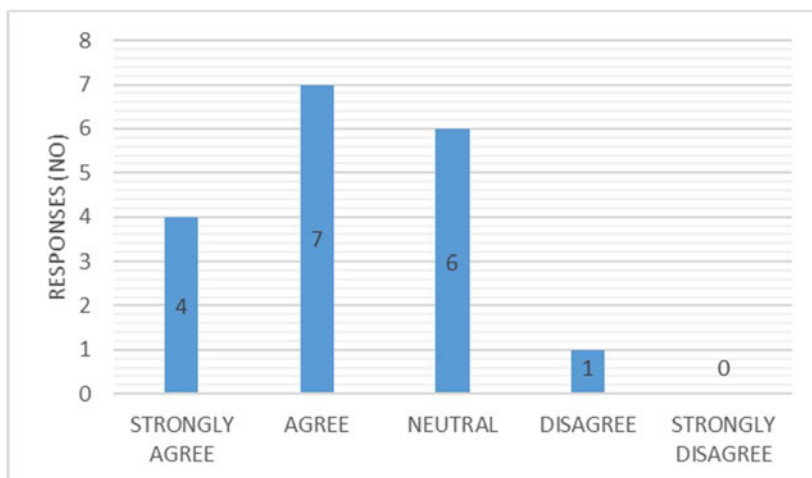


Figure 4.18: Questionnaire Response for Question 11

Question 12: Do Umgeni Water liaise with building inspectors to ensure the plumbing codes are strictly applied in new and renovated buildings?

A total of three respondents (17%) answered the question by strongly agreeing, and a total of five respondents (28%) agreeing. On the other hand, five respondents (28%) were neutral, two respondents (10%) disagreed, and three respondents (17%) strongly disagreed.

From the responses, it can be concluded that the organisation does indeed communicate with builders and plumbers to ensure that all works are done per regulations. However, there is a need for continuous monitoring required. Umgeni Water also conducts internal inspections to approve all projects. Although Umgeni Water liaises and communicates with plumbers, there is a limitation to testing and repairs as this fall within the consumer's responsibility to fix leaks.

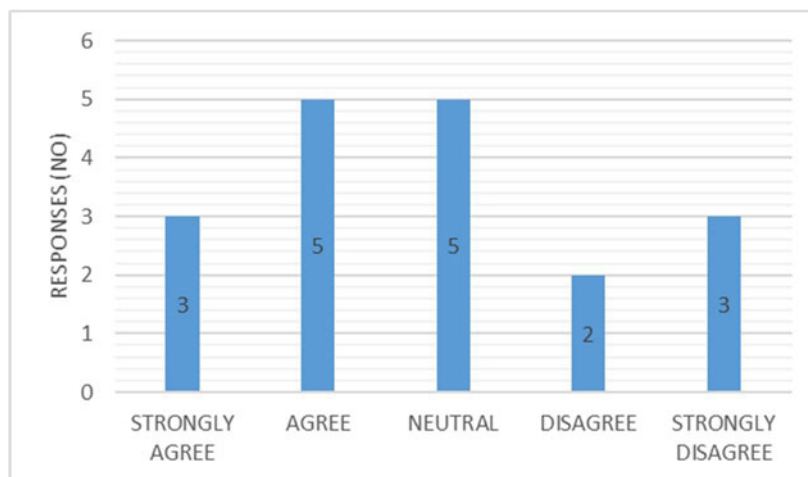


Figure 4.19: Questionnaire Response for Question 12

Question 13: Has Umgeni Water implemented any sort of new technology into the water supply and demand, for example, pressure sensors, controllers? Please list equipment.

A total of six respondents (33%) answered the question by strongly agreeing, with a total of four respondents (22%) agreeing. However, five respondents (28%) were neutral, and three respondents (17%) disagreed that Umgeni Water implements new technology for improving supply and demand practices.

It has been found that Umgeni Water tends to utilise the latest technology for water resources and water demand management. It has been acknowledged that the WaterNet Advisor software is widely used. It has also been acknowledged that pressure sensors are installed in the bulk pipeline infrastructure. Drone technology has also been used to detect leaks over large surface

areas. Umgeni Water also has a committee investigating new technologies to be piloted in the whole value chain.

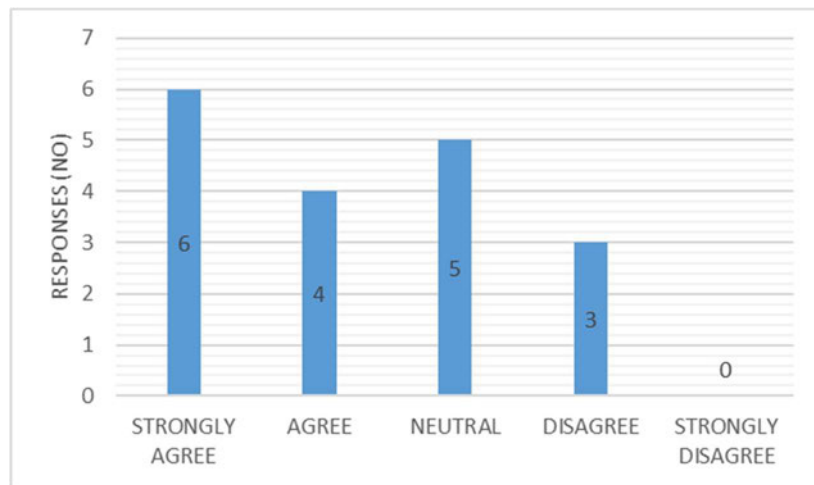


Figure 4.20: Questionnaire Response for Question 13

In summary, a total of twenty-four questionnaires were issued to the departmental members within the Planning Services Department at Umgeni Water. Eighteen questionnaires were completed and returned. The balance of the respondents seemed unwilling and busy with duties to complete the questionnaire. The overall picture of how the respondents answered the question is summarised below.

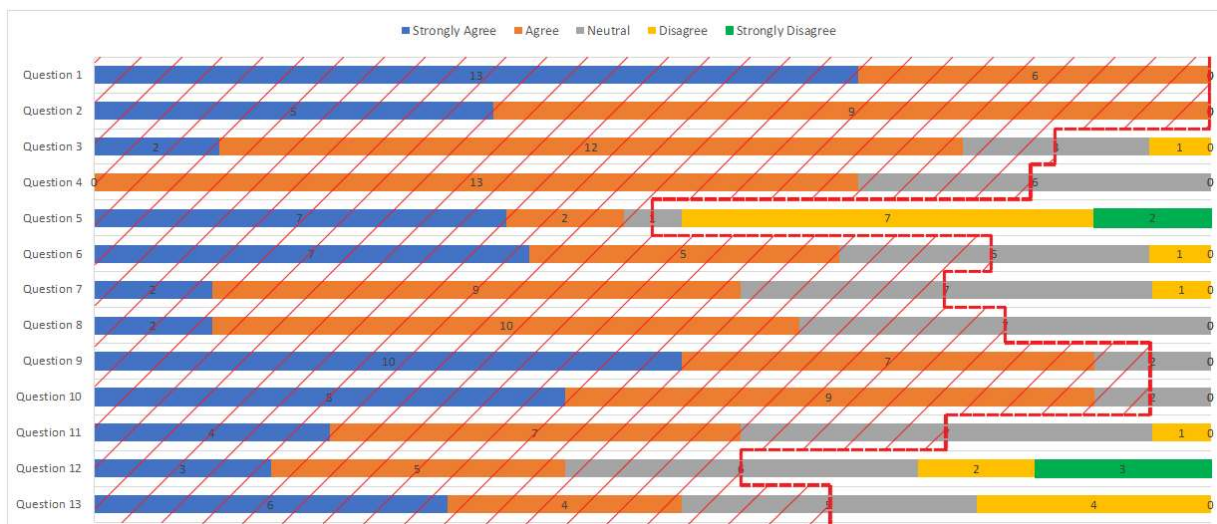


Figure 4.21: Overall Respondents to Qualitative Analysis

Figure 4.21 illustrates a summary of how the eighteen respondents answered the questions related to water conservation and water demand management within the study area. The consolidated picture is as follows: strongly agreed 32 (31%), agreed 44 (42%), neutral 19 (18%), disagreed 5 (5%) and strongly disagreed 4 (4%).

The red indicator line shows that the responses to the questions provided the majority of positive feedback. As shown in the figure, the right side of the indicator line shows 73% of the responses, which noted that the current situation within the organisation promotes WC/DM and that WC/DM has started to be introduced and implemented adequately, while the remaining 18% were neutral, and 9% showed a negative approach to the current situation of WC/DM within the organisation (as shown to the left of the indicator line).

Based on these findings, it was proven that although WC/DM have been implemented, there was still room for improvement by the water provider, considering the number of respondents who were neutral, disagreed, and strongly disagreed. Although WC/DM has been implemented within the organisation, it is evident that it remains a new phenomenon, and it would take some time to effectively implement WC/DM measures to a level of sustainable efficiency.

Some of the positives taken from the responses were that there is sufficient workforce and financial support for WD/DM strategies and implementation, which is increased every financial year. This plays a significant role in promoting WC/DM.

4.7 Summary

The current chapter presented various analyses and findings of the study, aimed at achieving the study's specific objectives as indicated in chapter 1. The researcher has contextualized the empirical analysis results into the broader framework of the study and presented them within the context within which has been conducted. A variety of statistical methods were employed in the analysis to determine the descriptive and inferential results.

The results were graphically illustrated in tabular and statistical formats and have identified a significant relationship between water demand, population growth, and climate change. The quantitative analysis and interpretation of data have indicated that high levels of population growth and climate change are the main influencing factor to water availability for the future decades. Furthermore, the results obtained from the analysis and interpretation of qualitative data have assisted in identifying key challenges within the WC/DM implementation. These challenges include poor pressure management, inadequate education, and awareness, limited financial resources to develop WC/DM initiatives.

As a result of these challenges, Umgeni Water has obliged to employ more water conservation and demand management techniques to develop measures to reduce losses and wastage. The next chapter deals with conclusions and recommendations derived from the findings.

CHAPTER 5 : CONCLUSION & RECOMMENDATION

5.1 Introduction

The purpose of this chapter is to interpret and discuss data collected and analysed during the research. Both qualitative and quantitative analysis was used in the research. For the qualitative analysis, a questionnaire was drawn up for members at Umgeni Water pertaining to WC/DM. The respondents had to respond to questions based on water resource management and water supply and demand, as shown in Appendix A. Statistical data were used to determine future water resource parameters for the quantitative analysis. As shown in Annexures C and D, a WEAP model was developed to analyse the water demands and unmet demand for the study area.

5.2 Conclusions per Objectives

The specific objectives, as defined in section 1.3, clearly illustrate the study's aims, which have been successfully analysed using quantitative and qualitative methods. The overall conclusion the objectives are explained below:

Specific Objectives 1 - Determine the quantity of current and future water demand in the Mgeni System and determine if sufficient supply will be met.

The study was conducted to evaluate the water availability in the Mgeni System catchment using Water Evaluation and Planning (WEAP) on the reference data for the year 2009. It was developed to produce four scenario models and examine the various scenarios. The period of the analysis in WEAP was taken from 2009– 2050, with the naturalised flow data readily available for the base period.

The results of Scenario 1: Reference Scenario with population growth at 1.1 % indicates that the water resources are adequately available up to 2025 for Msunduzi; and up to 2027 for eThekwini. However, the results of Scenario 2: Low Population Growth of 0.75% results indicated that the water supply can accommodate up to the year 2025 for Msunduzi; and up to 2030 for eThekwini. Scenario 3: Higher Population Growth at 2.5%, it is noted that the unmet demand is encountered in the year 2023 for Msunduzi and 2025 for eThekwini. Finally, the climatic variation for Scenario 4: Extended Period of Dry Climate was assigned to the Reference Scenario to investigate the impacts on the water supply. These results show that water shortages are experienced severely and at a high rate with a dry climate, and unmet

demand begins in the year 2025.

The Avoidable losses were determined to be 523 million m³ per year for the 2020-21 financial year, and with current trends, it is foreseen that the water demand will exceed the yield in about 2027. However, should the water losses be removed from the system, the water demand will continue to supply the demand sites for few more years which allows more time to execute and implement WC/DM strategies.

In conclusion, the results indicate that water scarcity is a real challenge. The impacts of climate change and population growth indicate various water shortages in certain years. The water resources situation in Kwa-Zulu Natal calls for solutions and interventions from decision-makers, consumers, and all stakeholders. The water shortage problems can be solved by the implementation of Water Conservation and Demand Management. Solutions to water problems depend not only on freshwater availability but also on how the water is managed both by the water authority and the consumers' perspective. Development and management processes and practices, supply management, appropriateness, and implementation status of the existing legal frameworks are also key to adequate water conservation and management.

Stakeholders such as water service authorities, water users, professional organisations, academic sectors, government institutions and members of parliament have the power to regulate and action strategies that can conserve and manage the water supply to cater for future demands. The implementation and regularisation of WC/DM strategies such as rainwater harvesting, greywater reuse, education and awareness, pressure management and active leakages control will be highly beneficial in combating future unmet demands.

Specific Objectives 2 - Identify the quantity and causes of current water losses within the study area and determine the Key Performance Indicators (KPIs).

Water losses were discovered to be excessively high for the study area, approximately 33% of the System Input Volume for the 2020-21 financial year. The major contributor to the water losses within the study area is the eThekwinini region consisting of about 85% of the total water losses.

The historic trend of the yearly ILI values for the Mgeni system has been determined, which illustrates a definite increase in the level of real losses within the system from 2016-17;

however, the most recent yearly record shows a decline in the losses which is a positive indication of current WC/DM interventions. The study area was found to have a CARL of approximately 163 million m³. The UARL were determined to be approximately 66 million m³, with Avoidable Losses of 522 million m³. Furthermore, it is illustrated that the study area ILI fluctuates between the factor of 8.0 and 16.0, which fall within Category C. This meant that the study area produces excessive leakage within its system. It can be concluded that the main causes of the high level of water losses is due to poor leak detection and repair programmes.

In many countries around the world, the ALI is very high because the management of the meter fleet is poor, and the number of unregistered consumptions is high. ALIs higher than 5 frequently occur in poorly managed environments. However, when the management of the meters and customers is under control, the ALI may be lower than 1.0 (Vermersch M et al. 2016). It was discovered that the Current Annual Apparent Losses (CAAL) within the study area was 24 million m³ for the 2020-21 financial year. The Apparent Losses Index (ALI) was calculated to be 0.98, indicating good organisation management.

In conclusion, the causes for water losses were discovered to be old infrastructure, illegal water consumption, shallow and exposed pipelines that would burst easily, abused authorised water consumption by the community, meter reading errors and estimated readings that gave incorrect data. The KPIs indicate room for improvement within the study area regarding leak detection, repairs, and maintenance.

Specific Objectives 3 - To determine and evaluate current Water Conservation and Demand Management (WC/DM) strategies, tools, and measures and to develop more efficient WC/DM solutions for water loss reduction.

The main purpose of this study was to review and assess the WC/DM strategy of the Mgeni system concerning development and implementation, as well as to identify any opportunities and constraints encountered in implementing it. From the evaluation of the responses from the questionnaire, it was identified that the study area had achieved some progress regarding WC/DM, but work is still needed to establish the effective implementation of the WC/DM strategies.

The questionnaires further noted that the concept of WC/DM was still relatively new, but it has already significantly impacted identifying, monitoring, and fixing water leakages. The key

strategies which are found to be beneficial are as follows:

- Cross over from manual meter reading to Automated Meter Reading (AMR)
- Using leak detection equipment to improve our leak detection program.
- Pressure management is to control the pressure in the system and decrease water losses.
- Implementation of education and awareness programmes, especially for poor communities.
- Introducing incentives for water saving within communities.
- Surveying existing water infrastructures and repairing old fragile pipe networks.

It is clear that water wastage can be reduced by education and awareness, legislation, retrofitting and tariff setting. Apparent losses can be reduced by proper meter reading (introduction of AMR), preventing theft and vandalism, and data analysis of water balance. Finally, the real losses can be reduced by pressure management, active leak detection and control, and infrastructure repairs.

5.3 Recommendations

The following recommendations, based on the study's outcomes, are therefore, proposed for the future reliability of the conservation and management of water resources in the Mgeni system. These recommendations target decision makers such as the government, Water Resources Management Authority, policymakers, and consumers. Based on the results and findings of the research, the following recommendation was suggested:

- i. The WC/DM unit for Umgeni Water must be responsible for adopting and implementing water awareness and education and training programs for enhancing water use in Kwa-Zulu Natal.
- ii. Education and awareness programmes should target poor communities, schools, and the youth.
- iii. In order to adequately implement WC/DM strategies, there needs to be sufficient professional cooperation between government officials, water institutions, educational institutions, consumers and., to ensure the success of future water conservation and demand management programmes.
- iv. Further research on improving the current processes of water management is crucial. With the current technological advancements, water usage and management can be improved to remove errors and losses in the system.
- v. Full-scale implementation of AMR in the entire country will remove all metering errors

and, in the long run, decrease NRW.

- vi. Water incentives should be implemented for consumers who do not exceed a certain water limit to encourage them to follow WDM measures, and water taxing should be introduced for consumers who exceed the specific water usage limit.
- vii. The government should implement WC/DM and develop more legislation to back these measures for water suppliers and users.

5.4 Proposed Further Research

A major finding of the study indicates that Umgeni Water is just getting started with water conservation and water management and that the scope of those ideas is vague. Therefore, it is advised that more detailed research of other WC/DM aspects in the Mgeni system should be explored. Further research on water losses is also highly recommended as the study area experienced extreme water losses, which had been mainly caused by leakages, poor infrastructure and water theft. With the world entering the fourth industrial revolution and technology gaining momentum, there will soon be advanced technologies that can aid the reduction and control of water losses and on a huge scale. Therefore, future research into water-saving techniques will always be proposed.

5.5 Summary

This chapter provided the final conclusion of the study, and it presented concluding remarks on the specific objectives. Furthermore, this chapter provided recommendations for the study to improve the current state of the WC/DM within the Mgeni system.

LIST OF PUBLICATIONS

- **Technical**

V. Nagan., M. Seyam., T. Abunama, 2023. Assessment of Long-Term Water Demand for Mgeni System using Water Evaluation and Planning (WEAP) Considering Demographic and Extended Dry Climate Periods. Water SA.

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APPENDIX A – QUESTIONNAIRE

Structured interview for members of Umgeni Water. Please tick the appropriate answer and give an explanation if required.

Name :
Position :
Date :

Section A: Water resources management

1. Does Umgeni Water aid water resources management within Umgeni Water? Please explain.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

2. Umgeni Water has developed adequate Water Conservation and Water Demand Strategies?

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

3. Umgeni has implemented full leak detection program for your distribution system periodically (how often)?

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

4. Does Umgeni Water allocate sufficient budget for WC/WDM strategies and measures?

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

5. Is the water pressure regulated at various times of the day to promote leakage reduction?

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

6. Do you have a public education plan in place? (If Yes, please explain)

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

7. Have Water Conservation and Demand Management strategies brought about decrease in water losses?

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

8. Do you provide educational literature about installation of water-saving devices and water conservation savings to the community?

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Section B: Water supply and demand

9. Has Umgeni Water played a part in bridging the gap between water supply and demand KwaZulu- Natal? Please elaborate.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

10. Will Automatic Meter Reading (AMR) systems decrease errors in meter reading and billing compared to the manual meter systems currently being used?

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

11. Umgeni Water and municipalities have protocols in place to ensure the accuracy and consistency of the manual meter readings? If so, please explain the protocols used

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

12. Do Umgeni Water liaise with building inspectors, to ensure the plumbing codes are strictly applied in new and renovated buildings?

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

13. Has Umgeni Water implemented any sort of new technology into the water supply and demand, for example pressure sensors, controllers. Please list the equipment used

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Section C : Recommendation (Optional)

1. What recommendation will you offer to residents during water shortage?

2. What recommendations will you give to improve water resources management in KwaZulu- Natal?

3. How can water supply be improved in KwaZulu-Natal, what alternative methods is being looked at?

4. What strategies do you find most effective for water conservation and demand management?

5. What public outreach and education efforts have you found most effective and why?

6. What challenges does Umgeni Water have as regards to supplying KwaZulu-Natal with water?

7. What future plan does Umgeni Water have for expansion of water supplies in areas of KwaZulu-Natal?

APPENDIX B- IWA WATER BALANCE

eThekwini District – Period 2018-19

Total System Input Volume 342,431,489 KL/annum	Authorised Consumption 210,119,696 KL/annum Percentage of SIW = 61.4%	Billed Authorised Consumption 206,537,017 KL/annum Percentage of SIW = 60.3%	Billed Metered Consumption-Domestic 20,653,701 KL/annum Percentage of SIW = 6.0%	Revenue Water 206,537,017 KL/annum Percentage of SIW = 60.3%
			Billed Metered Consumption-Commercial - KL/annum Percentage of SIW = 0.0%	
			Export Volume - KL/annum Percentage of SIW = 0.0%	
			Billed Unmetered Consumption - KL/annum Percentage of SIW = 0.0%	
	Water Losses 132,311,793 KL/annum Percentage of SIW = 38.6%	Unbilled Authorised Consumption 3,582,679 KL/annum Percentage of SIW = 1.0%	Unbilled Metered Consumption 159,264 KL/annum Percentage of SIW = 0.0%	Non-Revenue Water 135,894,472 KL/annum Percentage of SIW = 39.7%
			Unbilled Unmetered Consumption 3,423,415 KL/annum Percentage of SIW = 1.0%	
Apparent Losses 18,523,651 KL/annum Percentage of SIW = 5.4%		Unauthorised Consumption 12,322,763 KL/annum Percentage of SIW = 3.6%		
		Metering Inaccuracies 6,200,888 KL/annum Percentage of SIW = 1.8%		
Real Losses 113,788,142 KL/annum Percentage of SIW = 33%	Mains and Distribution Leaks - KL/annum Percentage of SIW = 0.0%			
	Reservoir Overflows - KL/annum Percentage of SIW = 0.0%			
	Service Connection Leaks - KL/annum Percentage of SIW = 0.0%			

uMgungundlovu District- Period 2018-19

Total System Input Volume 22,297,283 KL/annum	Authorised Consumption 12,672,574 KL/annum Percentage of SIW = 56.8%	Billed Authorised Consumption 9,572,267 KL/annum Percentage of SIW = 42.9%	Billed Metered Consumption-Domestic 8,541,483 KL/annum Percentage of SIW = 38.3%	Revenue Water 9,572,267 KL/annum Percentage of SIW = 42.9%
			Billed Metered Consumption-Commercial - KL/annum Percentage of SIW = 0.0%	
			Export Volume - KL/annum Percentage of SIW = 0.0%	
			Billed Unmetered Consumption 1,030,784 KL/annum Percentage of SIW = 4.6%	
	Water Losses 9,624,710 KL/annum Percentage of SIW = 43.2%	Unbilled Authorised Consumption 3,100,307 KL/annum Percentage of SIW = 13.9%	Unbilled Metered Consumption - KL/annum Percentage of SIW = 0.0%	Non-Revenue Water 12,725,016 KL/annum Percentage of SIW = 57.1%
			Unbilled Unmetered Consumption 3,100,307 KL/annum Percentage of SIW = 13.9%	
Apparent Losses 1,732,448 KL/annum Percentage of SIW = 7.8%		Unauthorised Consumption 1,390,789 KL/annum Percentage of SIW = 6.2%		
		Metering Inaccuracies 341,659 KL/annum Percentage of SIW = 1.5%		
Real Losses 7,892,262 KL/annum Percentage of SIW = 35%	Mains and Distribution Leaks - KL/annum Percentage of SIW = 0.0%			
	Reservoir Overflows - KL/annum Percentage of SIW = 0.0%			
	Service Connection Leaks - KL/annum Percentage of SIW = 0.0%			

Msunduzi District- Period 2018-19

<p>Total System Input Volume 71,425,786 Kl/annum</p>	<p>Authorised Consumption 50,828,232 Kl/annum Percentage of SIV = 71.2%</p>	<p>Billed Authorised Consumption 40,552,246 Kl/annum Percentage of SIV = 56.8%</p>	<p>Billed Metered Consumption-Domestic 40,552,246 Kl/annum Percentage of SIV = 56.8%</p>	<p>Revenue Water 40,552,246 Kl/annum Percentage of SIV = 56.8%</p>	
			<p>Billed Metered Consumption-Commercial - Kl/annum Percentage of SIV = 0.0%</p>		
			<p>Export Volume - Kl/annum Percentage of SIV = 0.0%</p>		
			<p>Billed Unmetered Consumption - Kl/annum Percentage of SIV = 0.0%</p>		
	<p>Water Losses 20,597,554 Kl/annum Percentage of SIV = 28.8%</p>	<p>Unbilled Authorised Consumption 10,275,986 Kl/annum Percentage of SIV = 14.4%</p>	<p>Unbilled Metered Consumption - Kl/annum Percentage of SIV = 0.0%</p>	<p>Unbilled Unmetered Consumption 10,275,986 Kl/annum Percentage of SIV = 14.4%</p>	<p>Non-Revenue Water 30,873,540 Kl/annum Percentage of SIV = 43.2%</p>
				<p>Apparent Losses 5,355,364 Kl/annum Percentage of SIV = 7.5%</p>	
		<p>Real Losses 15,242,190 Kl/annum Percentage of SIV = 21%</p>	<p>Metering Inaccuracies 1,216,567 Kl/annum Percentage of SIV = 1.7%</p>		
			<p>Mains and Distribution Leaks - Kl/annum Percentage of SIV = 0.0%</p>		
			<p>Reservoir Overflows - Kl/annum Percentage of SIV = 0.0%</p>		
				<p>Service Connection Leaks - Kl/annum Percentage of SIV = 0.0%</p>	

APPENDIX C- WATER DEMANDS

Water Demand – Reference Scenario (1.1% Population Growth Rate) m³

	2009	2010	2015	2020	2025	2030	2035	2040	2045	2050
eThekwini	206 524 200	218 664 605	290 204 834	385 150 774	511 160 076	678 395 648	900 345 472	1 194 910 368	1 585 847 688	2 104 687 440
uMgungundlovu	15 960 243	16 635 477	21 193 341	26 999 988	34 397 568	43 821 972	55 828 516	71 124 666	90 611 726	115 437 939
Msunduzi	39 447 720	41 966 205	56 765 300	76 783 194	103 860 266	140 485 874	190 027 257	257 039 064	347 682 138	470 289 884
Sum	261 932 163	277 266 287	368 163 475	488 933 956	649 417 910	862 703 494	1 146 201 244	1 523 074 098	2 024 141 552	2 690 415 263

Water Demand – Scenario 2 (0.75% Population Growth Rate) m³

	2009	2010	2015	2020	2025	2030	2035	2040	2045	2050
eThekwini	206 524 200	217 907 610	284 228 768	370 735 068	483 569 948	630 746 616	822 717 176	1 073 114 832	1 399 722 152	1 825 733 936
uMgungundlovu	15 960 243	16 577 886	20 756 916	25 989 412	32 540 942	407 44 012	51 014 949	63 875 028	79 976 939	100 137 890
Msunduzi	39 447 720	41 820 922	55 596 358	73 909 296	98 254 356	130 618 456	173 643 005	230 839 440	306 875 892	407 958 048
Sum	261 932 163	276 306 419	360 582 041	470 633 776	614 365 246	802 109 084	1 047 375 130	1 367 829 300	1 786 574 983	2 333 829 874

Water Demand – Scenario 3 (2.5% Population Growth Rate) m³

	2009	2010	2015	2020	2025	2030	2035	2040	2045	2050
eThekwini	206 524 200	221 692 598	315 167 114	448 054 224	636 971 908	905 544 848	1 287 358 936	1 830 161 168	2 601 830 576	369 8866 848
uMgungundlovu	15 960 243	16 865 839	23 016 309	31 409 672	42 863 842	58 495 011	79 826 397	108 936 709	148 662 675	202 875 526
Msunduzi	39 447 720	42 547 341	61 648 030	89 323 552	129 423 394	187 525 170	271 710 452	393 688 886	570 426 808	826 507 336
Sum	261 932 163	281 105 778	399 831 453	568 787 447	809 259 144	1 151 565 029	1 638 895 785	2 332 786 763	3 320 920 059	4 728 249 710

Water Demand – Scenario 4 (Extended Period of Dry Climate) m³

	2009	2010	2015	2020	2025	2030	2035	2040	2045	2050
eThekwini	206 524 200	218 664 605	290 204 834	385 150 774	511 160 076	678 395 648	900 345 472	1 194 910 368	1 585 847 688	2 104 687 440
uMgungundlovu	15 960 243	16 635 477	21 193 341	26 999 988	34 397 568	43 821 972	55 828 516	71 124 666	90 611 726	115 437 939
Msunduzi	39 447 720	41 966 205	56 765 300	76 783 194	103 860 266	140 485 874	190 027 257	257 039 064	347 682 138	470 289 884
Sum	261 932 163	277 266 287	368 163 475	488 933 956	649 417 910	862 703 494	1 146 201 244	1 523 074 098	2 024 141 552	2 690 415 263

APPENDIX D- UNMET DEMANDS

Unmet Demand – Reference Scenario (1.1% Population Growth Rate) m³

	2009	2010	2015	2020	2025	2030	2035	2040	2045	2050
eThekwini	0	0	0	0	0	110 748 242	332 698 076	625 707 772	1 018 200 288	1 537 040 064
uMgungundlovu	0	0	0	0	0	0	0	0	0	0
Msunduzi	0	0	0	0	9 257 324	45 885 782	95 424 470	162 190 888	253 090 260	375 695 586
Sum	0	0	0	0	9 257 324	156 634 024	428 122 546	787 898 660	1 271 290 548	1 912 735 650

Unmet Demand – Scenario 2 (0.75% Population Growth Rate) m³

	2009	2010	2015	2020	2025	2030	2035	2040	2045	2050
eThekwini	0	0	0	0	0	63 099 227	255 069 782	503 912 252	832 074 756	1 258 086 472
uMgungundlovu	0	0	0	0	0	0	0	0	0	0
Msunduzi	0	0	0	0	3 652 550	36 016 372	79 052 616	135 988 281	212 279 982	313 368 194
Sum	0	0	0	0	3 652 550	99 115 599	334 122 399	639 900 533	1 044 354 738	1 571 454 666

Unmet Demand – Scenario 3 (2.5% Population Growth Rate) m³

	2009	2010	2015	2020	2025	2030	2035	2040	2045	2050
eThekwini	0	0	0	0	69 324 490	337 897 438	719 711 520	1 260 958 536	2 034 183 200	3 131 244 608
uMgungundlovu	0	0	0	0	0	0	0	0	0	45 206 188
Msunduzi	0	0	0	0	34 826 034	92 933 544	177 113 188	298 833 198	475 831 912	731 922 660
Sum	0	0	0	0	104 150 524	430 830 982	896 824 708	1 559 791 734	2 510 015 112	3 908 373 456

Unmet Demand – Scenario 4 (Extended Period of Dry Climate) m³

	2009	2010	2015	2020	2025	2030	2035	2040	2045	2050
eThekwini	0	0	0	0	0	678 395 648	332 698 876	625 709 172	1 018 201 688	2 104 687 440
uMgungundlovu	0	0	0	0	0	43 821 972	0	0	0	115 437 939
Msunduzi	0	0	0	0	9 260 301	140 485 874	95 427 500	162 205 927	253 112 598	470 289 884
Sum	0	0	0	0	9 260 301	862 703 494	428 126 376	78 7915 099	1 271 314 286	2 690 415 263