URBAN GROUNDWATER DEVELOPMENT AND MANAGEMENT – BASEMENT WATER USE

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Certification

This dissertation has been assessed thoroughly and accepted by the supervisor, **Prof Kai Witthueser**, at the Institute for Groundwater Studies, Faculty of Natural and Agricultural Sciences, University of the Free State.

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Prof Kai Witthueser

Date: November 2019

Declaration

I, Thandilizwe Bengeza, declare that the master's degree research dissertation that I herewith submit for the master's degree qualification *Master of Science majoring in Geohydrology* at the University of the Free State is my independent work, and that I have not previously submitted it for a qualification at another institution of higher education.

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Thandilizwe Bengeza Date

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Abstract

South Africa is a water-scarce country and is among the 30 driest countries in the world. Urban areas have a high water demand due to population growth and increased urbanisation. Most of the urban areas of metropolitan municipalities use surface water, which is essentially fully allocated. There was an urgent need to investigate for alternative water sources to meet the rapid water demand in urban areas. It was, therefore, necessary to address the indirect use of groundwater and the lack of active management of groundwater because urban areas in South Africa have not currently been utilising groundwater to its full potential. The study identified high-level technical solutions, strategies, and tools as a decentralised approach that could address groundwater use and lack of management. This included water sensible designs, basement water use, the agency managing groundwater management and issuing licenses, and using numerical groundwater models in decision-making.

The main aim of this study was to determine the current groundwater use and groundwater protection measures in urban areas and compare the status quo of groundwater use and management with the international best practices and adopt the best practices that are suitable for South Africa. Furthermore, the aim of the case study was to promote the beneficial use of basement water and encourage more buildings to use the basement water rather than to discharge it with no beneficial use.

The overall results from the analysis of the status quo of metropolitan municipalities were that groundwater use and management were poorly integrated into the key statutory planning processes at metropolitan municipalities. No coherent plan for groundwater development and management was evident from metropolitan municipalities. Five case studies investigated the feasibility of the use of basement water for five buildings and the results revealed that each building has significant volumes of basement water ranging from 4.3 kl/d to 155 kl/d. The basement water is discharged into stormwater systems and none of the buildings are using the basement water beneficially. At the State Theatre building in the City of Tshwane, up to 75% of the water demand is used for the air conditioning system, and the feasibility of replacing this demand with basement water was investigated. The capital cost to implement the use of basement water for the cooling system was estimated to be around R1.5 million, which would be recovered over a three-year period. The results showed that the use of the basement water would be feasible and efficient for the South African Reserve Bank and Tshwane House. The investment would require R2.7 million and be recovered over a two-year period. Furthermore, Tshwane House would only require R500 000 to develop the basement water use system over a period of two years. A hydrocensus of the other buildings in the central business district of the City of Tshwane was conducted, leading to an estimated total basement water yield of 1.1 –2.3 Ml/d.

The study recommended that the basement water use innovation should be implemented across the City of Tshwane (on a regional scale) to alleviate some of the city’s water demands in a sustainable manner and reduce reliance on limited surface water resources. The study further recommended that all metropolitan municipalities should amend their by-laws to discourage the discharge of basement water to ensure beneficial use.

Key terms: Urban groundwater development; basement water, beneficial use, urban areas, secondary use, stormwater, capital cost, investment, metropolitan municipality

Dedication

To my beloved late grandmother, Novethanda Petheni, and sister Nonzukiso Bengeza, I wish you guys were here to see who I have become on this day, but I know you are watching over me from your spiritual home.

You were the inspiration of my life.
I live for you.
I'll love you forever.

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List of Elements and Units

EC	Electrical conductivity
Ga	Giga years
kl/d	Kilolitre per day
km	Kilometre
kWh	Kilowatt-hour
l/d	Litre per day
l/min	Litre per minute
l/s	Litre per second
m	Metre
m^2	Square metre
mamsl	Metres above mean sea level
mbgl	Metres below ground level
m^3/min	Cubic metre per minute
m^3/s	Cubic metre per second
mg/l	Milligram per litre
Ml/d	Million litre per day
mm	Millimetre
Mm^3/a	Million cubic metre per year
mS/m	Millisiemens per metre
S	Second
P	Power
$P_{(W)}$	Power in Watt
TDS	Total dissolved solids
$t_{(hr)}$	Time in hours
ug/l	Micrograms per litre
W	Watt

List of Abbreviations and Acronyms

CBD	Central business district
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EPD	Environmental Protection Department
FAO	Food and Agricultural Organization of the United Nations
F-BW	Fully treated basement water
HVAC	Heating, ventilating and air conditioning
IDP	Integrated development plan
M&E	Mechanical and electrical
NWA	National Water Act
NMBM	Nelson Mandela Bay Municipality
NPV	Nett present value
O&M	Operation and maintenance
P-BW	Partially treated basement water
SA	South Africa
SDF	Spatial development framework
SUDS	Sustainable urban drainage systems
SANS	South Africa National Standards
SARB	South African Reserve Bank
SAWQG	South African Water Quality Guidelines
U-BW	Untreated basement water
UNEP	United Nations Environment Programme
WC/WDM	Water Conservation/ Water Demand Management
WRC	Water Research Commission
WSD	Water sensitive design

Chapter 1
Overview

1.1 Introduction

Water is essential to life, a fundamental human need, and a basic right for human beings. South Africa is a water-scarce country and is among the 30 driest countries in the world (South Africa, Department of Water and Sanitation [SA DWS], 2015). Urban areas have high water demands due to population growth and increased urbanisation (United Nations Environment Programme [UNEP], 2003). Most of the urban areas or metropolitan municipalities in South Africa use surface water that is fully allocated (SA DWS, 2015). There is a need to investigate alternative water resources to meet the rapid water demand in urban areas (SA DWS, 2015). The reconciliation studies of the DWS (SA, 2014) have recommended the consideration of alternative water resources such as groundwater, rainfall harvest, reuse of wastewater and desalination. Furthermore, the increasing development in urban areas may have an impact on local water resources, as indicated by a decrease in the amount of water and the deterioration of water quality (Foster and Vairavamoorth, 2013). There is a challenge of a decrease in water quantity due to the impervious surface which has a negative impact on groundwater recharge (Singh et al., 2015).

The urban population is expected to increase, as many people are moving from rural to urban areas in search of job opportunities, better schools, higher educational institutions, and to improve their lifestyles (Food and Agricultural Organization of the United Nations [FAO], 2009). Water demand is directly proportional to population growth and urbanisation. Surface water is already fully allocated and the challenges of water shortages in urban areas will rise. Therefore, new water resources need to be explored to address this water challenge, as well as better management of water resources (SA DWS, 2015). In the reconciliation studies, groundwater is the priority augmentation of the water supply system.

Groundwater has not been exploited to its full potential in urban areas and it is a viable option to meet the water demand in urban areas. However, in some cases the deteriorating water quality is an issue due to anthropogenic activities (Foster et al., 1999; Morris et al., 2003). The treatment of groundwater will be much cheaper, compared to other options such as the construction and maintenance of dams and desalination, because in some cases groundwater will require little or no treatment before use (Foster et al., 1999).

Underground structures such as basement parking lots, deep foundations, and tunnels, which are present in urban areas, impact the groundwater flow direction by blocking and changing the direction of the flow. Thus, groundwater velocity tends to be affected by these structures (Trcek and Juren, 2006; Vàzquez-Suñé, 2003). These changes disturb the natural environment reflected by a decrease in base flow to rivers and wetlands.

Groundwater needs to be utilised effectively, efficiently, and sustainably because it can play a key role in adaptation strategies to climate change in many developing countries. For this reason, the large groundwater storage of many aquifers should be managed strategically, and in some cases used conjunctively with surface water to improve water supply. Therefore, this study sought to investigate and unravel reasons for lack of groundwater use and poor management of groundwater resources in South African urban areas. Subsequently, the results were compared with the best groundwater practice guidelines applied in developed countries such as the United Kingdom (London), Denmark, and Norway. This assisted in identifying gaps, developing a research strategy, innovative technical solutions, and policy requirements to protect groundwater resources in South Africa. This study aimed to provide high-level technical solutions, strategies, and tools that will contribute to the improvement of existing practices for enhanced groundwater use.

1.2 Problem statement

Water stresses are increasing across the world and this affects water quality, quantity, and availability (Foster and Vairavamoorth, 2013). There is a need to protect and not pollute valuable freshwater resources. The rising demand for water supply in a water-scarce country causes concerns about the water supply to meet future needs, especially in urban areas.

The main issue in urban areas is not using groundwater to its full potential, and not recognising groundwater as a vital water resource that can be managed and developed to meet water needs. In most cases, groundwater is available locally and can be developed cheaper compared to other water resources (Foster and Vairavamoorth, 2013). Groundwater in urban areas is generally of good quality, although it depends on contaminants and geology, while in most cases the groundwater is locally polluted (Foster and Vairavamoorth, 2013). Currently, five out of eight South African metropolitan municipalities do not include groundwater in their water resource plan, and only 2% of groundwater contributes to the total water supply in the remaining three metropolitan municipalities (Water Research Commission [WRC], 2016).

1.3 Aim and objectives

The main aim of this study was to determine the current groundwater use and groundwater protection measures in urban areas and compare the status quo of groundwater use and management with the international best practices and adopt best practices that are suitable for South Africa. Furthermore, the specific aim of this study was to investigate the optimal utilisation of inflows/seepage from groundwater into the basement structures of buildings in urban environments to reduce the utilisation of expensive potable municipal water supply for non-potable uses and/or off-grid from the municipal water supply. The study aim was achieved by conducting a systematic desktop study and field investigations.

The specific objectives for the case study entailed the following:

1. To identify the prevalence of inflows into the basement structures derived from groundwater.
2. To determine the volume of basement water.
3. To test the quality of basement water.
4. To determine whether the water is suitable for use, for example flushing of toilets in office blocks.
5. To put forward a proposal for alternative uses.
6. To propose or develop regulations for the usage of basement water.

1.4 Research methodology

1.4.1 Desktop study

The approach for this study was to conduct a survey on buildings that were affected by groundwater seepage around the City of Tshwane. This was done by conducting interviews and meetings with the building managers or technical team as well as municipal officials. This aided in understanding the problems that are related to groundwater leakage into basement structures around the city. Site visits were conducted to the buildings that were affected by groundwater seepage and managing the groundwater table by discharging basement water into the stormwater or sewerage system.

1.4.2 Hydrocensus

A detailed hydrocensus was conducted within the study area. The aim of the hydrocensus was to compile a complete inventory of the available groundwater level monitoring stations, groundwater abstraction points, and a comprehensive groundwater level survey of the entire study area. Also, to identify the buildings with the potential of basement water in their building. Initially, 15 buildings were under consideration for this study, but a decision was made to use only five buildings, based on the availability of high-water quantity and easy access.

1.4.3 Site assessment

1.4.3.1 Water quantity

Level loggers were used to determine the flow rate / sump yield from the sump pumps for each of the buildings. For buildings with one sump pump, measurements were conducted twice for quality assurance, and for those with more than one pump, two-level loggers were used in one pump. An hour meter was used to measure the time corresponding to sump yield and the energy required for pumping the water out.

1.4.3.2 Up scaling benefits for the City of Tshwane

A hydrocensus was conducted in 20 buildings around the City of Tshwane’s central business district (CBD), where 15 were found to have basements with groundwater seepage. Only five buildings were investigated in detail as discussed in the case studies. The results from these five buildings were used to extrapolate a rough estimate of the overall basement yield in the CBD. The CBD was divided into blocks, and each block was assigned a basement water yield value based on the most proximal site-measured volume.

1.4.3.3 Water quality

Water samples were analysed at the Waterlab (Pty) Ltd in Pretoria which is accredited to conduct water analyses (accreditation number 74507-A). Sterilised sampling containers were supplied by the Waterlab. Water samples were collected from sump pumps using a bailer and a bucket for the five buildings in the CBD. The collection of water samples was conducted on 15 May 2018 and submitted to the laboratory for analysis within 24 hours, following the instructions of the Waterlab. For each building, three sealed containers were submitted for major elements, trace elements, and bacterial analyses. pH and electrical conductivity (EC) were measured in situ, using a pH and EC meter to make a comparison with the results obtained from the laboratory analysis.

1.4.3.4 Anion-cation balance

The cation charge should equal the anion charge in a water sample. The anion–cation balance is the difference between the anion and cation charge and should be between −10% and 10%. Negative anion–cation values indicate either low cations or high anions in the analysis, and could reflect an analytical error, or an analyte that has not been included in the analysis.

1.4.3.5 Cost calculations

Furthermore, the quotation for the basement water system exploitation was provided, or calculated, to know the cost of extracting and using basement water. The Reserve Bank pre-feasibility study was undertaken and the cost-related matters determined. AQUAffection (Pty) Ltd (hereafter AQUAffection) helped with the quotations for the State Theatre and Tshwane House.

1.5 Limitations of the study

The limitations of the study were the following:

- Limited access to the buildings to conduct measurements.
- Limited time was given by building managers to take measurements.
- Funding was a limitation regarding the water quality analysis.
- The feasibility of the business case for the other buildings, except the State Theatre and Reserve Bank, was not done due to lack of access to the buildings.

1.6 Dissertation outline

The urban groundwater development and management study for five metropolitan municipalities and for the case study of five buildings around the City of Tshwane, are divided into the following tasks:

Chapter 1: Overview

This chapter gives a general background of urban groundwater development and management (basement water use case study) in the City of Tshwane, as well as describing the aim and objectives of the study.

Chapter 2: Literature review

In this chapter, the literature on the impacts of urbanisation on groundwater, the management of groundwater impact in urban areas, and legislation and regulatory framework is reviewed and a research gap is thus identified.

Chapter 3: Case study

This chapter describes the study area in terms of regional setting, location, topography and drainage, climate, soil and vegetation, land use, water use, the geology of the area and hydrogeology. It also describes the methodology used in the dissertation to be able to achieve the aim and objectives of the dissertation. Lastly, this chapter presents the results of the study, basement water use, and up scaling, and determines the cost of developing basement water use systems.

Chapter 4: Conclusion and recommendations

This last chapter provides the concluding remarks of the project and recommendations for future research endeavours. The implementation strategy for basement water use is also outlined.

Chapter 2

Literature Review

2.1 Introduction

This chapter reviews the available literature regarding urbanisation impacts on groundwater, management of groundwater impacts in urban areas, legislation and regulatory frameworks, and a case study of the legislative framework of basement water use. The status of groundwater use and management in metropolitan municipalities is discussed and the gaps are identified where the best practice and status of groundwater use and management are compared. This section chapter examines key concepts and problems to understand the challenge of urbanisation on the groundwater.

2.2 General impacts of urbanisation on groundwater

2.2.1 Flow directions and flow paths

Groundwater flows under the force of gravity from points of higher static groundwater elevation to lower static groundwater elevation (Fetter, 2014). Urbanisation has an impact on the flow direction of groundwater by local distortions of the water table near the underground structures. According to Marinos and Kavvadas (1997), alterations consist of a rise in groundwater levels located upstream of the barrier or impermeable elements; however, the groundwater level decreases occur downstream. Underground structures such as basement storage, parking lots, and tunnels act as barriers or impermeable layers, unless drained. The underground structures do not only have an impact on the flow direction but also involve changes in the flow path and velocity. Furthermore, the abstraction of groundwater during construction or dewatering in order to keep the environment dry, often alters the flow direction (Trcek and Juren, 2006).

- **Barrier effect**

The barrier effect is one of the interactions between groundwater and vertical urban infrastructure elements (Pujades et al., 2014). The obstruction or blockage of groundwater movement in the subsurface due to vertical underground structures is called a barrier effect.

The main impact of the barrier effect on groundwater is the change in the flow direction and fluctuation of groundwater levels (Boukhemacha et al., 2013). This may result in the reduction of base flow and wetlands (Jia et al., 2009).

❒ Drain effect

In some instances, urban underground structures could form drainage or subsurface dams that can alter the groundwater flow direction locally (Boukhemacha et al., 2013; Jia et al., 2009). The cone of depression is caused by abstraction or dewatering of groundwater as a result of drawdown in the aquifer (Marinos and Kavvadas, 1997). The cone of depression may cause changes in flow direction if a bulk amount of groundwater has been abstracted (Dassargues, 1997).

❒ Altered topography

Urban developments are mostly accompanied by the destruction of the natural landscapes into flat slopes for construction and roadway design (Marinos and Kavvadas, 1997). With time, the low-lying areas and elevated areas are levelled up. This may lead to changes in the flow direction as the shallow groundwater flow direction follows topography: from high to low elevation (Pujades et al., 2014).

❒ Altered vegetation

In urban areas, deforestation is a common practice as a result of developments, and impervious cover increases as a result of the reduction of evapotranspiration through the absence of native vegetation (Dassargues, 1997). Changes in the vegetation of an area can alter the groundwater flow directions and recharge (Dassargues, 1997). Alien plants would take more water from groundwater than indigenous plants. Alien plants were planted as a result of groundwater recharge was reduced and also the change in groundwater flow. The example case studies related to the impact of urbanisation on groundwater are discussed briefly:

The rise in water levels affects urban structures that were constructed when water levels were low, without acknowledging the possibility of changes in the water table resulting from increased recharge. Most European cities, for example Birmingham, London, Copenhagen, and Barcelona, have currently been experiencing fluctuations in water levels which, in turn, affect underground structures such as subway tunnels, underground parking lots, domestic cellars and entrenched parts of roads (Vàzquez-Suñé et al., 1997).

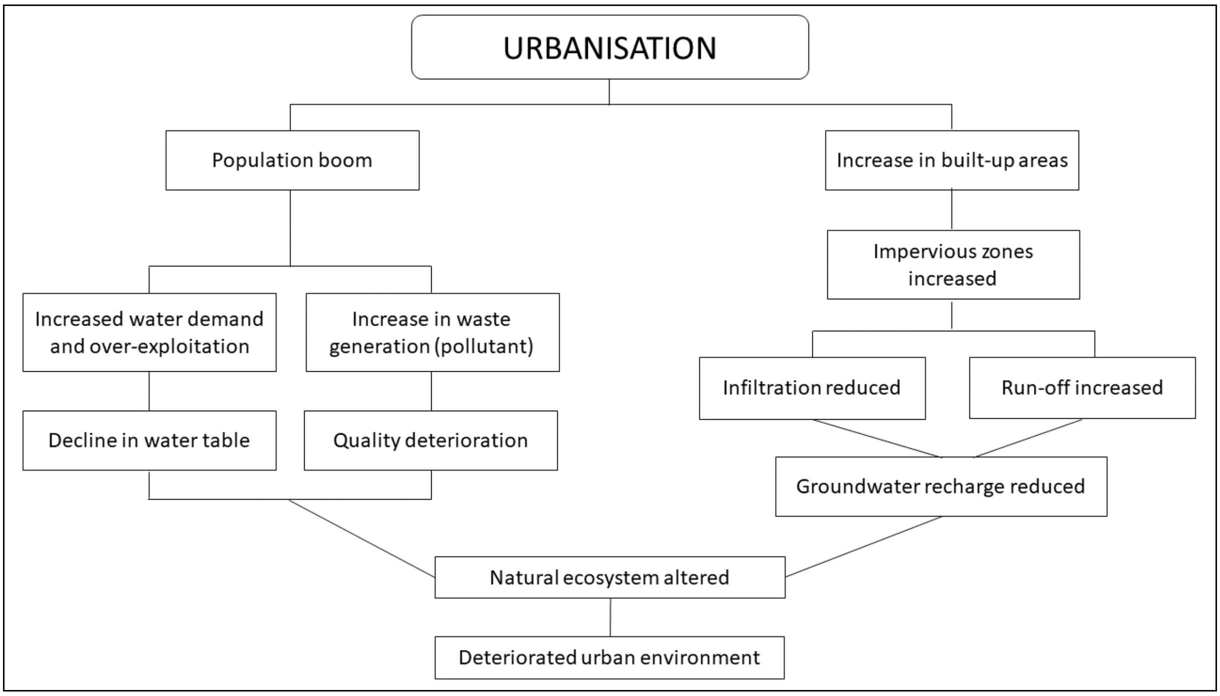
A tunnel in Barcelona, Spain, is frequently monitored to assess its impact on the groundwater table. Results showed that the tunnel is mainly impacted by the barrier effect, including both a local and regional barrier effect (Pujades et al., 2014). A *local barrier effect* is the maximum head rise (or drop) which occurs close to the barrier, whereas the *regional effect* is the impact observed at some distance from the barrier.

2.2.2 Groundwater storage

Groundwater storage is defined as the volume of water that are stored in the ground. Primary impacts on groundwater storage in urban areas are a decrease due to excessive abstraction from aquifer storage, or an increase due to leaks from sewerage and stormwater systems, seepage, and injection (Mudd et al., 2014). Recharge plays a significant role in groundwater storage and can be caused by both diffuse and discrete sources (Foster and Hirata, 1988). *Diffuse recharge* is defined as water added to the groundwater by direct vertical percolation of precipitation through the unsaturated zone. *Discrete recharge* is defined as water added to the groundwater by discrete sources such as leaking pipes. Both types of recharge contribute towards increasing the groundwater storage.

Urban development attracts more people from rural areas which results in significant population growth and therefore an increase in water demand (Lerner, 2002). Urbanisation has huge impacts on groundwater storage due to the large amounts of water that are being abstracted from aquifers to support urban development and the growing population (Lerner, 2002). Moreover, urban development plays a significant role in the reduction of the direct groundwater recharge (recharge from rain) due to an impervious surface such as roads and pavements (Singh et al., 2015). The above-mentioned points contribute to the reduction or increase of groundwater storage or quantity. Decreasing groundwater levels may produce local and large-scale land subsidence. This effect can be caused not only by direct pumping but also by the construction of underground structures that can act like drains or form barriers against the natural flow, thereby locally decreasing or increasing water levels (Lerner, 1986). Figure 2.1 illustrates the urbanisation impacts on groundwater storage and quality.

According to Lerner (1986), urbanisation also introduces new sources of water that increase groundwater recharge. These sources include irrigation of parks and lawns, leakage from water mains, sewers, and infiltration structures. Although these kinds of recharge have a negative impact on groundwater quality, they increase the storage. In addition, uncontrollable recharge from leaks causes groundwater levels to rise, which leads to flooding (Lerner, 1986).



Source: After Suresh (1999)

Figure 2.1: Conceptual model depicting the impact of urbanisation on the hydrological regime and urban environment quality

Urban underground structures disturb the natural parameters of the ground and alter its porosity and hydraulic conductivity (Lerner, 1986). Compacted materials from the construction in an urban area may reduce the porosity and hydraulic conductivity whereby groundwater storage is limited (Foster and Lawrence, 1996). Alterations of hydrogeological characteristics may cause changes in groundwater storage by either reducing or enhancing the storage.

A large amount of abstraction or dewatering of groundwater for urban development causes a cone of depression. This leads to a reduction of groundwater storage which makes it hard to recover over time. For example, continuous over-abstraction of groundwater in coastal areas may cause seawater intrusions, subsidence, or decline in groundwater-dependent ecosystems (Singh, 2015). Case studies considering the impact of urbanisation on groundwater are briefly discussed below:

❒ Case 1– Milan

In Milan, there was a decline of industries located in urban areas because of rising groundwater levels (Bonomi and Cavallin, 1997). A study conducted by Kim et al. (2001) described the recovery of the groundwater table due to reduced pumping, but these rises can also be exacerbated by an increase in recharge, resulting from losses in the water supply systems. Water level rises affect urban structures that were built in periods when water levels were low (Kim et al., 2001).

❒ Case 2–London

According to Fookes et al. (1985), decreasing water levels can impact buildings with wooden piles. The piles were initially constructed in the saturated zone, and a decrease in the water level can causes accelerated degradation, with subsequent building damage when in contact with air. Furthermore, the decreasing groundwater tables may advance seawater intrusions in coastal cities. As a result, saline water, rich in sulphate, often accelerates the corrosion of concrete and metallic foundations and buried structures (Fookes et al., 1985).

❒ Case 3 – New Zealand

Christchurch City in New Zealand uses groundwater for drinking and for industrial supplies (Van Toor, 1996). In this case, the challenge includes groundwater management and protection. Groundwater levels must be monitored and managed to prevent the over-exploitation of the aquifer.

❒ Case 4 – Middle East

In the Middle East, the major issue is the rise in the groundwater table because of recharge from the leaking of water mains, septic tank systems and over-irrigation of parks and gardens (Morris et al., 2003). UNEP (2002) reported that groundwater level increases are identified in most parts of the world.

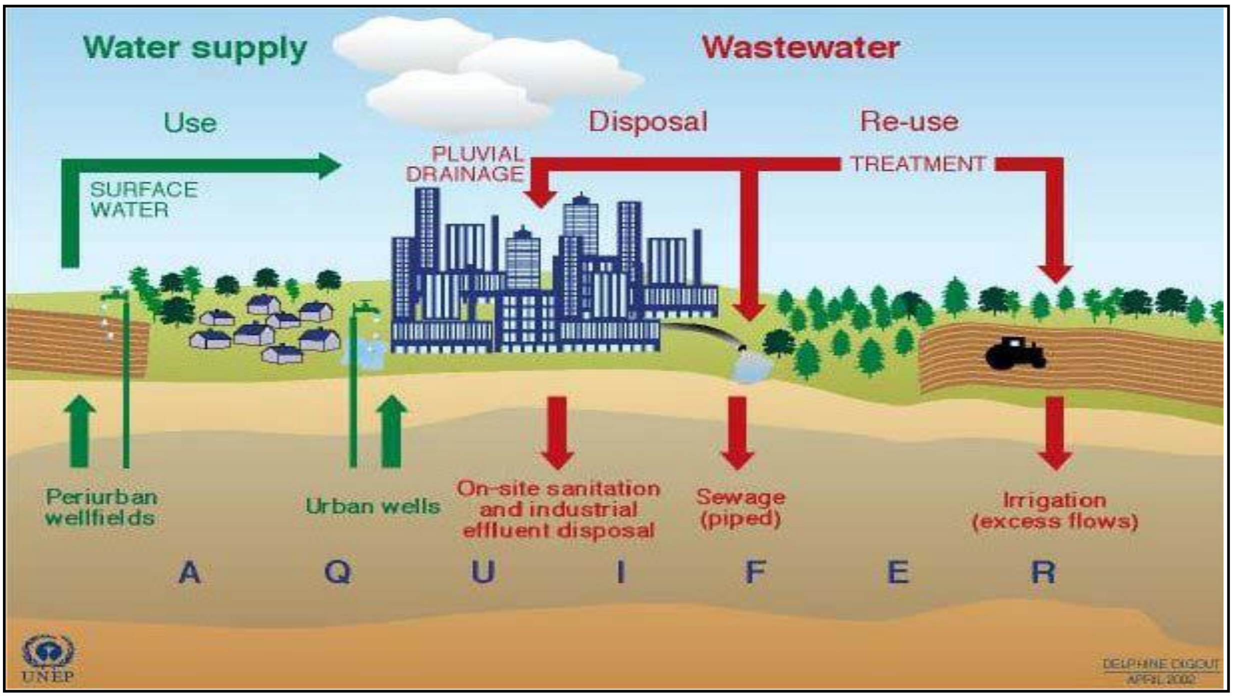
❒ Case 5 – Ireland

Cork is a coastal city in South Ireland that is subject to flooding during heavy rains. In addition, significant contributing factors include leakage from the water supply distribution system, sewerage, and stormwater drainage system (Allen, 2005). Water loss from the main water system is estimated to be around 40% volume per day in Cork (Mudd et al., 2014).

Groundwater contamination was also identified and linked to the failure of the municipal water infrastructure (Commander et al., 2002).

2.2.3 Groundwater quality

Water quality is a key issue in urban areas as shallow aquifers and surface water are subjected to pollution by human activities (Foster and Hirata, 1988). Sources of groundwater pollution include point and non-point sources (Navarro and Carbonell, 1992). The pollutants can be derived from industrial sources, sewer pipe leaks, stormwater pipe leaks, water supply system pipe leaks, impacts related to declining or rising water tables, land use and leaks from irrigation systems (Figure 2.2). These pollutants infiltrate into the groundwater as recharge (Navarro and Carbonell, 1992).



Source: UNEP (2002)

Figure 2.2: Groundwater within an urban water cycle

Recharge in urban areas is associated with contaminants which are the main reason why shallow aquifers are commonly polluted (UNEP, 2002). Leaks from sewer and water supply pipes are the main pollutants of groundwater in urban areas (Hirschberg, 1989). The common pollutants from sewers are organic pollutants and high concentrations of nutrients such as ammonium, nitrate, nitrogen, alkalinity, and biological oxygen demand (UNEP, 2002). Furthermore, pathogens and micro-pollutants are commonly encountered in urban areas from sewers such as bacteria, viruses, and protozoa. Most of the pipes are old and lack of maintenance leads to the leakages. Some materials of pipes are toxic to groundwater, and the underground structures can cause corrosion of excavation pillars or the foundations of buildings (Vazquez-Sune, 2003). Over-irrigation of sports fields, gardens or lawns can recharge groundwater, although pesticides or fertilisers may also pollute the aquifer (Morton et al., 1988). These leaks from irrigation systems have an impact on water quality (Flipse et al., 1984; Morton et al., 1988).

Several studies have confirmed that graveyards in urban areas contribute to the deterioration of groundwater quality if they are poorly placed or developed (Engelbrecht, 1998; Sililo et al., 2001). Since urban areas are hotter than the surrounding rural areas (Menberg et al., 2013), an increase in groundwater temperature has a negative impact on the water quality and groundwater-dependent ecosystems (Tinti et al., 2017). Furthermore, the over-abstraction of groundwater can cause groundwater levels to decline, which leads to seawater intrusion which negatively impacts on the water quality in coastal areas (Tinti et al., 2017). It is therefore essential to monitor and manage groundwater systems to prevent deterioration in the quality and quantity of this resource.

Example case studies relating to groundwater monitoring and management are briefly discussed below:

❒ Case 1 – Germany

In Germany, an investigation was conducted to assess the urban groundwater issues related to leakages from water, sewerage, and stormwater systems. The results have shown that groundwater levels rise due to recharge from distribution pipe leakages which are also a contributing factor to groundwater contamination (Held et al., 2006). The recommended solution was to encourage the city to maintain or replace old pipes and monitor and manage groundwater and underground structures.

❒ Case 2 – Thailand

In the city of Bangkok in Thailand, the major groundwater issues were subsidence, saline intrusion and poor quality that were enhanced by groundwater abstraction (Ramnarong, 1996).

- ❒ **Case 3 – Nepal**

In the Kathmandu Valley in Nepal, an investigation of groundwater quality showed faecal contamination due to leaking sewers and septic tanks (Bauld, 1998). Seasonal effects of contamination were visible, with concentrations during and immediately after the wet period or season.

- ❒ **Case 4 – South Korea**

The degradation of groundwater quality was identified in Seoul, South Korea, and the causes of deterioration in water quality derived from point and diffuse sources (Kim et al., 2001). In this case study, groundwater pollution was not related to abstraction. It was concluded that the major source of impact on groundwater quality was exfiltration from sewers, mains, and stormwater.

- ❒ **Case 5 – Europe and Australia**

According to Burn et al. (2005), Europeans and Australians initiated a programme to assess and improve the sustainability of urban water resources and systems. The main aim was to assess the impact of leaking urban water systems on the underlying aquifer (groundwater). The leakage from water or sewerage systems was determined to be the contributing factor to groundwater pollution. The study proposed guidelines for sustainable development of urban water systems that would consider aquifer pollution and protection in the future (Burn et al., 2005).

2.3 International best practice examples

2.3.1 Birmingham in England

2.3.1.1 The use of groundwater, current management practices and challenges

Initially, the city of Birmingham was known as an industrialised area; however, many industries were shut down in 1940s because of rising groundwater levels. The rising of groundwater levels posed a serious threat to underground infrastructure and foundations (Darteh et al., 2010). The major challenges that Birmingham faced, included polluted groundwater, run-off and associated local flooding risks (Dutton, 2007; Darteh et al., 2010). Subsequently, management efforts were put in place to develop sustainable urban drainage systems (SUDS) and the use of an integrated approach to facilitate the optimal management of available water resources (Darteh et al., 2010).

2.3.1.2 Groundwater protection

The protection of groundwater includes the use of actions to avoid pollutants entering the groundwater system. Pollution can be controlled if landfills are sited properly, namely designed and constructed with appropriate containment barriers and linings, and monitored and managed well (Dutton, 2007). In the process, environment protection agencies should ensure that potential polluting agents and activities are not located on aquifers, by influencing local development plans, amending suitable conditions in waste management licenses, or refusing to issue them all together, where appropriate (Darteh et al., 2010).

Many farms have fuel storage tanks that may leak into the soil and pollute groundwater. Manure and slurry storage facilities, tractor and vehicle washing facilities and cattle yards may also contaminate run-off drainage (Darteh et al., 2010), which also contribute to groundwater pollution. These sources of pollution can be reduced by appropriate measures such as spill and leak containment or relocating tanks.

2.3.1.3 Innovative integrated solutions for urban water challenges

A SUDS was developed to include modified roofing systems such as green and brown roofs to reduce run-off during heavy rainfall events and to enhance biodiversity (Darteh et al., 2010). The advantages of using green roofs include reduction in run-off during heavy rainfalls, and biodiversity enhancement as a general environmental benefit.

An improved integrated model, named City Water Balance, has been developed for assessing the sustainability of the urban water system, with the potential to contribute to planning and decision making at various levels (Darteh et al., 2010). Furthermore, reuse of groundwater was adopted as a solution to the challenges that were facing the city of Birmingham, namely artificial recharge known as aquifer storage recovery. Raising awareness, changing attitudes and supportive behaviour were also used to combat the challenges of water resource in the city (Darteh et al., 2010).

2.3.1.4 Policy and governance approaches

It is essential to reduce the flood risk of new developments through location, layout, and design, including the application of sustainable urban drainage systems, sustainable defences, and increased flood storage.

The following policies are related to water resources:

Policy 1: Measures will be taken to prevent pollution of controlled water within the river catchment. Both groundwater and surface water should be prevented from pollution (Dutton, 2007).

Policy 2: The full potential for the use of SUDS will be reviewed in the initial stages of development and it must be demonstrated by the developer that the potential for the use of SUDS has been considered and, where appropriate, used in the surface water drainage strategy for the site **(**Dutton**,** 2007).

2.3.2 Denmark in Europe

2.3.2.1 The use of groundwater, current management practices and challenges

There is a shortage of surface water in Denmark and the country is entirely depended on groundwater as a source of water supply. The total land area (approximately 62%) of the country is under agricultural use. The Danish government has therefore declared the entire area as vulnerable to nitrate pollution which forces the groundwater monitoring programmes to cover the entire country (Danish Water Technology Group, 2015).

Denmark has experienced a drought in 1983 that led to a shortage of surface water resources. Pollution from farming is a further challenge to surface water supply. Over time, it has been a major challenge to change the location of the wellfields so that their influence on river flows could be stabilised or re-established (Danish Water Technology Group, 2015). The greatest challenge was to find new wellfields or deep-lying aquifers to comply with the country’s drinking water quality standards. Where possible, the wellfields were moved to pen landscapes, far away from the urban pollution sources (Danish Water Technology Group, 2015). To accomplish this, water suppliers used thorough hydrogeological mapping which was initiated in 1998. The implementation of planning for the protection of groundwater by the municipalities was a condition to avoid groundwater pollution (Environmental Protection Department [EPD], 2007).

The Danish government produced the following ten-point programme in 1994 with the aim of reducing and mitigating the pollution of water resources (Danish Water Technology Group, 2015):

- Pesticides injurious to health and dangerous for the environment shall be removed from the market.
- Pesticide tax – the consumption of pesticides shall be halved.
- Nitrate pollution shall be halved before 2000.
- Organic farming shall be encouraged.
- Protection of areas of special interest for drinking water.
- A new Soil Contamination Act – waste deposits shall be cleaned up.
- Increased afforestation and restoration of nature to protect groundwater.
- Strengthening of the European Union achievements.
- Increased control of groundwater and drinking water quality.
- Dialogue with farmers and their organisations.

2.3.2.2 Groundwater protection

As described by the EPD (2007) as well as Hasler et al. (2005), the Danish government produced groundwater protection measures which included the following:

- Detailed hydrogeological mapping as an important tool for the effective protection of capture zones of wellfields. Comprehensive mapping makes it more acceptable for landowners to accept restrictions on land use.
- Public participation was identified as an important initiative for implementing the action plan of groundwater protection.
- Groundwater monitoring as an important tool to document positive and negative developments in groundwater quality.
- Groundwater modelling as an important tool to calculate scenarios for water balance, abstraction, captures zones, and climate change.
- Remediation and preventive pumping at old waste disposal and polluted urban sites have reduced the number of point sources. Agreements with farmers have reduced pollution from pesticide spraying equipment cleaning sites.
- Regulation of pesticides has reduced pollution from farmland and urban areas.

- Afforestation is an effective way to achieve lasting protection of catchment areas. It is a Danish policy to double the Danish forest area within the coming 80 years.

2.3.2.3 Innovative integrated solutions for urban water challenges

Denmark has produced an integrated monitoring system of water resources, air and point sources, and this integration monitoring system was meant to obtain the necessary focus within a monitoring network for environmental pollution control such as water pollution control (EPD, 2007). The network design should be initiated by surveys to identify potential water quality problems and water uses and by inventories of pollution sources in order to identify major pollution loads. The following are examples of innovative integrated solutions for urban water issues.

Best practices were implemented by the EPD (2007) to eliminate agricultural pollution in Denmark:

- Sustainable land use in terms of forests, permanent grassland, and environmentally friendly farming.
- Areas for recreational at the countryside.
- Ban on new sources of pollution.
- Elimination of causes of pollution.

The changes in land use are based on a voluntary principle. Total nitrate contamination under the converted forest and grassy areas had been reduced significantly, together with the overall vulnerability of the reservoir (EPD, 2007). Water-saving initiatives of the EPD promoted the use of water-saving mechanisms, for example a washing machine that minimises the leakages from the distribution network. Artificial recharge using infiltration through soil or the unsaturated zone water would be purified and sediments or salts would be removed to improve the water quality (EPD, 2007).

2.3.2.4 Policy and governance approaches

The municipalities in Denmark were responsible for the administration of water abstraction permits and the protection of water resources against pollution (EPD, 2007) while using European Union regulations. The Water Plan is in accordance with the Water Framework Directive which requires that the use of groundwater and surface water be regulated through integrated planning, comprehensive assessment and protection of water resources, while concomitantly ensuring water supply needs and protection of nature and the environment (EPD, 2007).

According to the Danish Water Supply Act, all water supply data collected must be reported to the national groundwater database managed by the Geological Survey of Denmark and Greenland. An action plan for the Aquatic and Pesticide Action Plan was produced to prevent, manage, and control the water resources. Direct abstraction from surface water is prohibited and groundwater abstraction was regulated to secure a certain minimum flow in all rivers, mainly through moving the abstraction wells away from riverbanks and wetlands (EPD, 2007).

The following are the policy plans:

- Implementation of European Union Water Resources Directive Actions.
- Action plan for the Aquatic Environment III.
- The Water Fund seeks to introduce a public–private partnership and innovative financing to conserve watersheds and water resources.
- The designation of “particularly valuable water abstraction areas” specifies that all groundwater in Denmark must be divided into three categories: particularly valuable areas, valuable areas, and abstraction areas of limited value. To designate these areas, assessments in the following areas were carried out: amount, quality, and natural protection of the groundwater resources, water demand (current and future), point-pollution sources and effect on surface water bodies.

2.3.3 Zhengzhou in China

2.3.3.1 The use of groundwater, current management practices and challenges

The City of Zhengzhou uses about 60% of its available groundwater especially for irrigation purposes (Bassam, 2009). However, Zhengzhou is facing a problem of groundwater depletion and quality deterioration. Similarly, farmers cannot afford new water-saving technologies such as sprinklers and drip irrigation due to the high installation costs. On the other hand, no mechanisms have been implemented to maintain current water-saving technologies. Subsequently, most of these water-saving technologies are not fully functional (Howard, n.d.). According to Howard (n.d.), to cope with these challenges, the people of Zhengzhou have ensured coordinated groundwater management, as well as joint urban and rural groundwater management. Furthermore, the people have increased their water supply through rainwater harvesting, increased conjunctive management of surface water and groundwater as well as enhancing artificial groundwater recharge. Also, they have engaged in changing cropping and adapting water technologies reformed their water price policies and created public awareness.

2.3.3.2 Groundwater protection

To control groundwater, the Zhengzhou government developed policies such as a water abstraction licensing policy as well as the closure of private tube wells in urban areas (Howard, n.d.). The regulation stated that tube wells in areas of declining water levels and in seriously polluted areas should be backfilled or closed permanently without compensation (Andersen, 2013).

2.3.3.3 Innovative integrated solutions for urban water challenges

Their innovative approaches included the increase of water supply by rainwater harvesting, increased conjunctive management of surface water and groundwater as well as groundwater recharge with reclaimed water (Andersen, 2013).

2.3.3.4 Policy and governance approaches

There is no current legislation regulating and controlling the use of groundwater at national government level in China (Andersen, 2013). Although, at local level there are numerous policies and guidelines on how groundwater should be managed and used, these are not addressing the groundwater issues (Andersen, 2013). These policies are related to water pricing, the use of water-saving technologies, and the control of groundwater development.

In their policy measures and regulations, water-saving technologies such as low-flush toilets, showerheads, and car washing equipment are promoted so that water demand will be reduced (Howard, n.d.). The policies promote that the farmers must use micro-irrigation such as sprinklers and drip irrigation. The Zhengzhou government have developed policies to control groundwater which include the water abstraction licensing policy of the central government and the policy to close private tube wells in urban areas (Howard, n.d.).

2.3.4 City of Basel in Switzerland

2.3.4.1 The use of groundwater, current management practices and challenges

The construction of a tunnel highway was done in the north-western area of Basel (Bonsor et al., 2015), which led to extensive use of groundwater. The challenges encountered during the construction of the tunnel highway included the significant decline in groundwater levels, water quality deterioration, change of groundwater flow and velocities, as well as the groundwater budgets (BonsorMa et al., 2015).

Integrated and adaptive water management were identified as the best management approaches that needed to be developed and implemented to achieve sustainability in urban water resources and systems (Bonsor et al., 2015). These management approaches included groundwater monitoring and modelling.

2.3.4.2 Groundwater protection

To ensure the protection of groundwater, the city had to install supplementary injection and interception wells. This was also necessary to ensure a steady supply of groundwater for the industrial users, while simultaneously preventing the attraction of contaminated groundwater (Langa and Bachmann, 2004).

2.3.4.3 Innovative integrated solutions for urban water challenges

Groundwater modelling and scenario development were identified as an innovative tool for the City of Basel to address its urban water challenges (Langa and Bachmann, 2004). Systematic consideration of groundwater in urban development and the implementation of groundwater management systems served as a decision-making tool (Langa and Bachmann, 2004).

2.3.4.4 Policy and governance approaches

The management of water in Switzerland is under public law and is subjected to strict water quality and environmental requirements (Luís-Manso, 2005).

The Federal Law on Water Protection of 24 January 1991 and the respective Ordinance of 28 October 1998, remained the main legal framework for water resources management in Switzerland (Luís-Manso, 2005). The first Water Protection Law came into effect with important amendments in 1971 and 1991 and these regarded the provisions to improve water quality, for example development of a sewerage network and its connection to sewage treatment plants (Luís-Manso, 2005).

The Water Protection Law specifically stated the objectives of “maintaining the health of human beings” and of “guaranteeing the supply of safe drinking water for industrial and domestic uses” (Mauch and Reynard, 2002).

2.3.5 London in the United Kingdom

2.3.5.1 The use of groundwater, current management practices and challenges

The Chalk aquifer underneath London was increasingly exploited due to industrialisation as well as the associated developmental initiatives in groundwater sources (Environment Agency, 2013). Since the mid-1960s, industries in central London relocated or shut down and businesses turned more to commerce than that of a heavy industrial sector (Environment Agency, 2013). The subsequent reduction in groundwater abstraction resulted in a gradual rebound of the water table as groundwater levels recovered. The continuous rise of groundwater levels posed threats to structures in the London Basin, such as underground parking lots or basement and building foundations in London (Environment Agency, 2006).

In response, the General Aquifer Research Development and Investigation Team implemented a strategy to control water levels in 1992. Numerous large public water supply abstractions were licensed to Thames Water under this strategy, with the intention to slow the rising groundwater levels and eventually stabilise them (Environment Agency, 2013). The strategy of the General Aquifer Research Development and Investigation Team successfully resulted in significant additional abstraction volumes to assist with the management of groundwater levels (Environment Agency, 2013).

Proposals of the Artificial Recharge Scheme were treated as a special case as they involved the management of groundwater levels to provide an additional resource to the scheme operator (Environment Agency, 2017). The water table and geology map will continue to be used as the basis for the Licensing Strategy of the London Basin Chalk Aquifer. The strategy involves increased abstraction of groundwater from boreholes to control the rise of the levels with most of the water used for public supply (Environment Agency, 2013).

2.3.5.2 Groundwater protection

The Groundwater Daughter Directive restricts the discharge of hazardous substances into groundwater to protect aquifers and promotes the protection of groundwater by defining source protection zones (Lloyd and Foster, 2012).

2.3.5.3 Innovative integrated solutions for urban water challenges

Abstraction and artificial recharge are used as tools to manage groundwater tables that impose a threat to the foundation of buildings and underground structures or basements (Environment Agency, 2013).

2.3.5.4 Policy and governance approaches

The Water Framework Directive set out to protect and improve all aquatic ecosystems and associated wetlands within the European Union, by safeguarding them against future deterioration, while enhancing water quality (Environment Agency, 2013). The Water Framework Directive also aimed to promote sustainable use of water resources and to ensure a progressive reduction of groundwater pollution (Anderson, 2011).

The Groundwater Daughter Directive set out the basis for protecting European groundwater from pollution.

The Floods Directive requires all European Union member states to assess whether all watercourses are at risk of flooding, to map the extent of floods and assess the risk to assets and humans (Anderson, 2011). The member states also need to provide adequate and coordinated measures to reduce any anticipated flood risks (Anderson, 2011).

Section 85 of the Water Resource Act of 1991 of England and Wales makes it an offense to knowingly pollute controlled waters, which comprise all groundwater and surface water, including ponds, streams, and rivers (Anderson, 2011). This Act as well as the Amended Water Resource Act of England and Wales (Regulations 2009, Section 93) provide for the establishment of water protection zones. This is implemented under the Environment Agency’s policy and practice for the protection of groundwater through the definition of Source Protection Zones. Schedule 3 of the regulations encourages the use of sustainable drainage, especially the SUDS, as part of development and redevelopments. According to the Act, the local authorities are responsible for adopting and maintaining the SUDS (Anderson, 2011).

At the local level, Policy CS15 on Sustainable Development and Climate Change, requires developments to positively address water quality and flood risks, particularly in areas at risk of sewer flooding, as identified in the Strategic Flood Risk Assessment (Anderson, 2011). Policy CS18 on Flood Risk aims to ensure that the city remains at a low risk of flooding.

2.3.6 Libya, in North Africa

2.3.6.1 The use of groundwater, current management practices and challenges

Libya is considered as one of the countries which suffer from limited water resource availability because most parts of the country are either semi-arid or arid with average annual rainfall ranging from 10 mm to 500 mm (FAO, 2009). Just five percent of the entire area of Libya exceeds 100 mm of rainfall annually. Under such conditions, surface water development is not a sustainable option, thus putting immense pressures on groundwater resources (FAO, 2009). Groundwater monitoring is done throughout the major wellfields which have piezometers to monitor water levels and drawdown (FAO, 2009). Monitoring the amount of groundwater abstraction is well recognised as an essential part of groundwater management programmes (Bindra et al., 2013).

2.3.6.2 Groundwater protection

The protection of the aquifers against overexploitation and pollution is promoted and encouraged (FAO, 2009). There are no practical mechanisms or measures to protect the groundwater.

2.3.6.3 Innovative integrated solutions for urban water challenges

The Great Man-Made River project in Libya is totally dependent on the abstraction of groundwater basins to supply water, and most of this water was recharged between 38 000 and 14 000 years ago, though some pockets are only 7 000 years old. To deal with the problem of diminishing supplies of high quality water, Libya embarked on this enormous engineering project designed to exploit the vast underground water potential known to exist in south-eastern Libya (FAO, 2009). The groundwater mining is used as a tool or innovative integrated solution for water challenges in Libya.

2.3.6.4 Policy and governance approaches

An old water law exists but this was amended in 1982 to set out the boundaries of water utilisation. After promulgating the law, the General People's Congress issued the declaration, defining the regulations for the protection of the aquifers against overexploitation and pollution, which is the responsibility of the General Water Authority (FAO, 2009). However, there is little evidence in the Country Report on how well this law is being implemented (FAO, 2009). A Joint Commission for Studies and Development of this aquifer was set up by Libya and Egypt, then between Libya, Egypt, and Sudan (UNEP-MAP & UNESCO, 2015).

2.3.7 City of Palo Alto, California

2.3.7.1 Legislative framework for basement water use

Underground structures during the construction and operational phase are required to dewater and discharge water into stormwater system (City of Palo Alto, 2018). In recent years, people's concern about dewatering and discharging without beneficial use as the wastage of water. This water could be used for beneficial use (City of Palo Alto, 2018). In response to that, the City of Palo Alto developed new requirements in 2016, designed to minimise and standardise the process of pumping and discharge of groundwater from dewatering of below groundwater structures during construction (City of Palo Alto, 2018). Furthermore, the city must not allow more permanent drains around basement foundations for continuous pumping and removal of groundwater. Basements must be constructed to be waterproof and groundwater dewatering should be allowed only in the rain season.

The city should impose restrictions on basement depth based on the groundwater levels obtained from geohydrological studies to limit an abstraction of too much groundwater. There are requirements to be followed prior to commencement of any underground related work; the water must be tested for quality before it can be discharged into the stormwater system at stipulated intervals during the dewatering process.

To mitigate the impacts of the discharge of groundwater from basement dewatering, the following measures are required (City of Palo Alto, 2018):

- Buildings must have basement water use plans; basement water use can be used on-site or the water can be donated if the building does not need the basement water.

- New buildings must be “green” in order to save water and energy (green buildings refer to both a structure and the application of processes that are environmentally responsible and resource-efficient throughout a building’s life cycle).
- A hydrogeological study is required to determine any potential impacts within a 5 km radius of the property by determining the cone of depression.
- The dewatering permit must be obtained before the dewatering can begin. This can be issued after the above criteria have been met.
- The dewatering permit should be issued for a minimum of five years after which the authorities need to renew it.
- The quantity that is abstracted must be measured and reported to the city to help gather the data in order to manage the groundwater, and also be enabled to avoid the overflow of the stormwater system.

The new groundwater dewatering regulations include encouragement of a groundwater dewatering water use plan, monitoring actual groundwater elevation changes during the dewatering season, assessing impacts on nearby structures, clarifying reporting requirements, and enhancing the hydrogeological study.

The following is a list of the new groundwater dewatering regulations requirements (City of Palo Alto, 2018):

2.3.7.2 Storage requirements:

- Each building that has a basement and is abstracting groundwater must have a tank system.
- A flow meter should be installed.
- Water sampling must be done continuously for water quality purposes.
- The owner will be required to report on the measurements and requirements by means of a report that should be done twice per year.

2.3.7.3 Basement water use plans

A short basement water use plan must be prepared to illustrate how the basement water (groundwater) will be used to its maximum potential. It should be submitted with the dewatering permit application and should have the following minimum requirements:

- The owner should inform the public about the availability of basement water by posts. The people who can use the basement water can come and collect it.
- The owner must use basement water on-site, for instance for toilet flushing, garden irrigation, air conditioning systems, fountains, car wash, cleaning streets and use basement water for firefighting. During an emergency situation like a drought period, the basement water can be used for domestic purposes but it requires the proper purification of the water.
- The owner should also pipe water to any parks, sports fields, and schools nearby.
- The owner/city should use a truck to transport water one full day per week to irrigation sites that will be indicated by the city.
- The owner/city should use basement water on-site or next to construction sites for dust suppression and other construction needs.

2.3.7.4 Hydrogeological study

A hydrogeological study should be undertaken to investigate the groundwater levels and the proposed basement height of the building. In addition, the effects or impact of the basement dewatering need to be determined within a 5 km radius. A pumping test should be conducted before the dewatering to determine how much water can be pumped out.

The monitoring plan should also be implemented by measuring groundwater levels. The hydrogeological study should states whether dewatering will not cause subsidence or sinkholes around the area. The study should also state whether the dewatering will not reduce the amount of water for ecological water requirements and if it would not be affecting the rivers, trees, or vegetation.

The hydrogeological study should be conducted by a hydrogeologist/geohydrologist; otherwise, a permit should not be granted if such a study was not done.

The study should also clearly state the avoidance measures:

- The hydrogeological study must recommend the height of the basement based on the groundwater levels and geology of the area, dewatering methods, or construction methods.
- The hydrogeological study must be made available for public review.
- Dewatering must be granted if the above requirements are met by the applicant.
- Administrative penalties should be put in place.

2.3.8 Summary

The high demand for water, the deterioration of drinking water quality and the general hydrological problem of discrepancy in time and or space between need and availability of water, are common problems to most cities throughout the world. More efficient and sustainable use of water resources are seriously needed. Some issues were highlighted and discussed such as groundwater flow, storage, and quality in urban areas. Development in urban areas significantly changes the hydrogeological cycle which leads to social, economic, and environmental impacts. Urbanisation disrupts the natural groundwater flow and quantity, and also affects quality.

Groundwater contamination in urban environments is another major issue and is complicated by a large number of potential sources of contaminants that can be found in a city. As discussed above, some countries have groundwater protection measures or mechanisms in the urban set-up, which requires an integrated framework that involves the use of groundwater that could be understood by decision-makers. Furthermore, the management models are developed in order to help characterise and quantify the potential risk to aquifers and natural systems associated with them, as well as on urban structures. The countries discussed in this chapter encourage water managers or city managers to recognise groundwater as a key component in the city planning process. Increasing social pressure on the city managers to advance towards sustainability will help to promote the recognition of groundwater as an important resource in cities. South Africa could also learn from other countries such as Denmark, Norway, and the United Kingdom (London city) how they use groundwater and manage it in urban areas.

2.4 South African examples

2.4.1 Status quo assessment of urban groundwater development and management in metropolitan municipalities in South Africa

The plans and strategies of metropolitan municipalities in South Africa were reviewed regarding current and future bulk water supply. The integration of groundwater to municipal planning, protection and management was assessed by considering the following points as summarised in Table 2.1 and Table 2.2:

- The key urban impacts on groundwater in the metropolitan municipality.
- Whether Water Sensitive Design (WSD) is planned and/or embraced by the metropolitan municipality and the groundwater role is acknowledged and planned for.
- Whether groundwater is included in the Integrated Development Plan (IDP) or Spatial Development Framework (SDF).
- Whether the metropolitan municipality has any groundwater protection mechanisms, for example by-laws.

The following metropolitan municipalities were reviewed: Nelson Mandela Bay Municipality (NMBM), City of Cape Town, Buffalo City (domestic supply to coastal villages), City of Tshwane and Mangaung Metropolitan Municipality (domestic supply to rural Thaba Nchu) (Table 2.1 and Table 2.2). All of these municipalities use groundwater, even though it is a small percentage compared to the potential of the urban groundwater.

The City of Tshwane and City of Cape Town are the only two of the five metropolitan municipalities that are currently using groundwater as a source for bulk water supply (City of Cape Town, 2013; City of Tshwane, 2017). The other three municipalities do not use groundwater as a source for bulk supply, and groundwater makes up only an insignificant percentage of the supply (2%) in the remaining two metropolitan municipalities (WRC, 2016).

The City of Cape Town and the NMBM plan to initiate and expand groundwater resource developments as part of future reconciliation initiatives (City of Cape Town, 2018, NMBM, 2017). Groundwater is planned to make up 25% of the water resources for the City of Cape Town (2017). However, in the Mangaung Metropolitan Municipality and Buffalo City Metropolitan Municipality groundwater has received little attention since the groundwater for bulk supply is limited in these two municipalities. In most cases, other uses of groundwater as an alternative resource to decrease the demand on the potable water service supply are not acknowledged (Table 2.1). Groundwater can be used as an alternative to potable water use with regard to domestic activities that do not require good quality water, for example gardening, flushing of toilets and cleaning streets.

Table 2.1: Current and planned future for bulk supply to metropolitan municipalities

Metropolitan Municipality	Current water requirement	Future requirement	Current supply source(s) and yield	Future supply source(s)	Significant aquifers
Buffalo City Metropolitan Municipality	84 Mm^3/a in 2013	78 to 113 Mm^3/a (low and high scenario)	Surface water and groundwater (coastal villages)	Enhance existing surface water Water Conservation / Water Demand Management (WC/WDM) Water re-use	Fractured and intergranular aquifer
City of Cape Town	334.7 Mm^3/a in 2014/15 for the City of Cape Town only; 547.26 Mm^3/a in 2014/1 for the whole Western Cape Water Supply System (DWS, 2015a)	750 Mm^3/a (low growth scenario), 940 Mm^3/a (high growth scenario) in 2035; for the whole Western Cape Water Supply System (DWS, 2015a)	Surface water: 98% Groundwater:2% (Le Maitre et al., 2017)	• WC/WDM • Volvlei augmentation scheme • Reuse • Groundwater use • Aquifer storage and recovery • Desalination	Cape Flats Aquifer, Atlantis, Langebaan and Elandsfontein aquifer (primary) Table Mountain group aquifer, intergranular and fractured aquifer (secondary)
City of Tshwane	300 Mm^3/a in 2010		Rand Water and Magalies water supply (81%) and 19% from metropolitan municipality dams, boreholes, and springs	• Increase surface water • Increase groundwater • Harvesting • Re-use of water	Fountains, upper and lower springs. Rietvlei spring, the Grootfontein spring, dolomites aquifer group
Mangaung Metropolitan Municipality	83 Mm^3/a in 2009 and 79.5 Mm^3/a in 2011 (to the Mangaung Metropolitan Municipality only)	108 Mm^3/a (low growth scenario). 170 Mm^3/a (high growth scenario).	Surface water and groundwater (in Thaba Nchu domestic supply only)	• WC/WDM • Surface water interventions • Re-use • Groundwater (only small towns)	Highly weathered areas and contact zones
NMBM	149.7 Mm^3/a in 2011/12 for NMBM	188 Mm^3/a (low growth scenario) 241 Mm^3/a (high growth scenario)	Surface water and Uitenhage spring (2.3%)	• WC/WDM • Seawater • Groundwater • Water re-use • Improve the operations	Table Mountain Group aquifers

Table 2.2: Integration of groundwater to municipal planning, and projection in metropolitan municipalities

Metropolitan municipality	Urban groundwater impacts	Water sensitive (Development & spatial planning)	Groundwater protection
Buffalo City Metropolitan Municipality	Anthropogenic sources Sea level rise and coastal flooding	Groundwater is not considered as future water supply No groundwater management plans in place. Does not embrace the WSD	By-laws: • No discharge into groundwater(except a line with NWA) • Owners should report their boreholes • French drains may not contaminate boreholes
City of Cape Town	Industrial areas, leaking effluent infrastructure, cemeteries, waste sites, leakage of reticulation and sewage network, informal settlement, and agricultural area (particularly the Cape Flats)	Groundwater resources planned as part of the Western Cape Water Supply System reconciliation are reflected in the IDP and SDF Other uses of groundwater are recommended Embraces the WSD	Groundwater management and protection (in the by-laws): • Owner provides any information • A borehole may not impact any well or other borehole • Approval of the borehole is required • May request a geohydrology assessment prior drilling
City of Tshwane	The groundwater is sourced from dolomitic areas. There is a fear of creating structural instability in the subsurface. Tshwane is also under threat of acid mine drainage	Groundwater is incorporated into the Water Services Development Plan and acknowledges groundwater as a valuable resource that is currently used for bulk water supply and requires protection if it is to be available for future use	By-laws protecting the resource: • Sewage and other pollutants not to enter stormwater drains • Stormwater not to enter sewers • Permission to discharge industrial effluent • Metering and assessment of the volume and composition of industrial effluent
Mangaung Metropolitan Municipality	Very little discussion Possible sources: Anthropogenic activates	Groundwater is not considered as future water supply No groundwater management within SDF The WSD does not directly promote the IDP nor SDF	By-laws: • Metropolitan municipalities can request for all existing and planned boreholes • Owners obtain approval from metropolitan municipalities • Metropolitan municipalities may impose conditions
NMBM	Very little information Possible sources: Anthropogenic activates	Groundwater is part of the reconciliation strategy Groundwater is fully planned for the IDP No other uses of groundwater other than bulk supply Groundwater is not in the SDF It does not embrace WSD	By-laws: • Metropolitan municipalities can request for all existing and planned boreholes • Owners obtain approval from metropolitan municipalities • Metropolitan municipalities may impose conditions

For groundwater to be developed in cities, it needs to be reflected, planned, and budgeted for in the IDP (Table 2.1). With reference to the NMBM (2017), groundwater development was fully planned and budgeted for in the IDP (Table 2.1). The protection zone, mapped potential aquifers and recharge zones should be delineated in the SDF (NMBM, 2015). This will contribute towards emphasising proper protection measures to prevent any pollution threats to the potential aquifer. The City of Cape Town is the only city with aquifers delineated and included in the SDF (Table 2.2) (City of Cape Town, 2017). Green infrastructure is not fully incorporated in the documents like the SDF in all four metropolitan municipalities (Table 2.2) (City of Cape Town, 2017).

The WSD measures can be promoted in the cities as a tool to protect and enhance groundwater use. For instance, by not avoiding the hardening of surfaces in the recharge area as a result of reducing run-off and promoting infiltration. The WSD is promoted in the City of Cape Town but focuses more on stormwater management (Table 2.2). The potential benefits of the WSD are not recognised. All metropolitan municipalities have by-laws that are used to protect and manage groundwater. Most metropolitan municipalities stated in their by-laws that the owner or occupier should notify them of the presence of boreholes on the property, and some metropolitan municipalities imposed conditions on the use of private boreholes, for example the Mangaung Metropolitan Municipality (2006/07) and the NMBM (2010) (Table 2.2).

Not even a single metropolitan municipality has met all the key statutory planning processes for groundwater. No single metropolitan municipality achieved a representation of groundwater in all relevant planning documents. No coherent plans for groundwater development and management were evident from the metropolitan municipalities and integrated across each of the necessary planning documents.

2.4.2 Review of legislative framework

2.4.2.1 Legislative framework of basement water use in South Africa

To control, manage and allocate the water resource in fairness, efficiency and in an effective manner, the following legislations are being followed: National Water Act (NWA), Act 36 of 1998; Water Services Act, Act 108 of 1997, and the water by-laws of each municipality. Basement water use will depend on the type of water use, which would require different methods to get a permit to use it. Table 2.3 highlights section 21 of the NWA (water use) and the discussion that follows is about legislations or regulations of water use in South Africa.

Table 2.3: General principles for water use in the National Water Act

Section 21(a)	Taking water from a water resource
Section 21(b)	Storing water
Section 21(c)	Impeding or diverting the flow of water in a watercourse
Section 21(d)	Engaging in a stream flow reduction activity as contemplated in section 36
Section 21(e)	Engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1)
Section 21(f)	Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduits
Section 21(g)	Disposing of waste in a manner which may detrimentally impact on a water resource
Section 21(h)	Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process
Section 21(i)	Altering the bed, banks, course, or characteristics of a watercourse
Section 21(j)	Removing, discharging, or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people
Section 21(k)	Using water for recreational purposes

Source: NWA, Section 21(1998)

The following types of authorisations need to be adhered to regarding the use of water resource in South Africa (NWA, 1998):

- Schedule 1:Permissible use of water
- Section 32 and 33: Existing lawful water use
- Section 39: General authorisations to use water
- Section 40 and 41: Water use license

❒ Schedule 1: Permissible use of water

Schedule 1 water use is defined as a reasonable domestic use in a person's household from any water resource, including a small garden but not for commercial purposes. There is no need for registration and application with the DWS (NWA, 1998).

☐ **Existing lawful water use**

Existing lawful use means the use of water authorised by or under any law that took place at any time for a period of two years before the NWA came into effect (30 September 1998), including court orders (NWA, 1998).

☐ **General authorisations to use water**

The General Authorisation is an authorisation to use water without a license, provided that the water use is within certain limits and complies with the condition as set out in the General Authorisation. The General Authorisation addresses the confirmation and registration of water use (NWA, 1998).

☐ **Application for water use license**

Any new water uses which are not permissible in terms of Schedule 1, do not qualify as an existing lawful use and fails to comply with the conditions of a general authorisation. A water use license includes the application and registration with the DWS (NWA, 1998).

☐ **City of Tshwane water by-laws (2015)**

> Use of water from sources other than the water supply system (58):
>
> (1) No person may use or permit the use of water obtained from a source other than the water supply system, except for a rainwater tank that is not connected to a water installation, provided that –
>
> > (a) The prior written consent of the engineer has been obtained for the use of water from a source other than the water supply system or rainwater tank, as the case may be; and
> > (b) The use of water is in accordance with the conditions that the municipality may impose for domestic, commercial, or industrial purposes.
>
> (2) Any person desiring the consent referred to in subsection (1)?
>
> (3) Must provide the engineer with evidence satisfactory to the engineer that – (a) the water referred to in subsection (1) complies, whether as a result of treatment or otherwise, with the requirements of South Africa National Standards (SANS) 241; or (b) the use of such water does not or will not constitute a danger to health.

(4) Any consent given in terms of subsection (1) may be withdrawn by the Engineer if, in the opinion of the engineer –

(a) A condition imposed in terms of subsection (1) is breached, or

(b) The water quality no longer conforms to the requirements referred to in subsection

(5) If water obtained from a borehole or other source of supply on any premises is used for a purpose which gives rise to the discharge of the water or some of the water into the Municipality's sewerage system, the Municipality may install a meter in the pipe leading from the borehole or other source of supply to the point or points where the water is used.

(6) The provisions of section 22 apply in so far as they may be applicable to the meter referred to in subsection (4).

2.4.2.2 Discussion of legislation related to basement water use

This section discusses the possibilities of using basement water within the legislative framework of South Africa.

Basement water is mostly abstracted from the groundwater; this is covered by Section 21.

Water use (21): Taking water from a water resource

The possible end-users of the water which the relevant property owners are considering

a) on-site use for non-potable purposes or potable supply; and
b) off-site use for non-potable purposes by way of sale or donation to other property owners.

The taking or diversions of the water or the envisaged end users require a water use license in terms of the Act.

Section 22 of the NWA – permissible water use – (1) A person may only use water:

a) without a license –

(i) if that water use is permissible under Schedule 1;
(ii) if that water use is permissible as a continuation of existing lawful use; or
(iii) if that water use is permissible in terms of a general authorisation issued under section 39.

b) if the water use is authorised by a license under this Act: or

c) if the responsible authority has dispensed with a license requirement under subsection (3).

The only permissible use of water listed in Schedule 1 that could be applicable would be the following:

- A person may, subject to this Act, (i) take water for use on land owned or occupied by that person, for domestic use and (ii) small gardening not for commercial purposes.

It can thus be concluded that basement water can lawfully be used for on-site non-commercial gardening purposes by the owner of a building.

Taking and use of water on-site is furthermore permitted in terms of the General Authorisation published in GN538 and GG40243 on 2 September 2016, to the extent that it does not exceed the limit of 2 000 m^3per year and an abstraction rate of one litre per second. The General Authorisation is an authorisation to use water without a license, provided that the water use is within certain limits and complies with the conditions set out in the General Authorisation.

2.4.2.3 Legislative framework governing the transfer of water to another property for use off-site, by way of sale or donation

Section 25 of the NWA– Transfer of water use authorisations – can be interpreted that if the owner of the property does not need the basement water, the water can be given to someone else. However, to do this legally, they should apply for a license which can be granted in terms of Section 24, according to which the owner will then act as a “water service provider”. According to Mr Tsunduka Khosa at the DWS head office, both parties should have an agreement before coming to the department and then the department will decide which type of authorisation would be suitable for that particular case, for instance through General Authorisation or a water use licence.

In terms of section 22 of this Act, a person wishing to act as a water services provider must obtain authority for this purpose from the water services authority under whose jurisdiction he/she/it falls. The City of Tshwane is the water services authority for this metropolitan area. There is a difference between General Authorisation and a water use licence which is yield abstracted only, and the General Authorisation limit is set per quaternary catchment.

Schedule 1 is not applicable if the water use is not only for domestic purposes and used by a business is not considered as domestic use. The General Authorisation or a water use licence is required to take water from the water resource. Water use licensing is any new water use that is not permissible in terms of Schedule 1 and does not qualify as an existing lawful use and fails to comply with the conditions of a general authorisation.

In Pretoria (quaternary catchment area A23D) the General Authorisation limits for section 21 (a) – taking water from a water resource – is 100 m^3 per day. If the buildings are planning to use the basement water at less than 100 m^3 per day, the water use will fall under the General Authorisation. However, basement water will be some mix of groundwater (where the basement is below the water table) and may contain shallow seepage water and run-off.

In communications with the DWS, according to Mr Tsunduka Khosa, basement water is considered by the DWS as groundwater or water source, and hence Section 21 (a) does apply to such extent, then Section 21(j) is more applicable. He emphasised his view by giving an example of a mine. An alternative legal classification of basement water is under section 21 (j) of the NWA –“removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people”. Water found underground is legally defined as “water that enters mine work, basements, tunnels, or other construction through seepage or run-off and does not refer to water found in an aquifer” (SA DWS, 2013:26).

According to Mrs Anet Muir, director of Compliance Monitoring and Enforcement at the Department of Water and Sanitation, basement water is a mixed water source of groundwater and rainfall, which is why section 21 (a) does not apply in this case. Removal, discharge, and disposal of water found underground is not listed under Schedule 1 and is not allowed without registration or license. Hence, any activity triggering section 21 (j) will require registration under the General Authorisation applicable to section 21 (j). Furthermore, Mr Fanus Fourie from the DWS shared a similar opinion about the use of basement water with Mrs Anet Muir. Mr Fourie stated that the DWS is supposed to require a license if the abstraction is directly on the water resource. For instance, when the mines have boreholes surrounding a mine pit or dam abstracting water directly from the water resource, then section 21 (a) applies. Furthermore, if the water is seeping into the mine pit, then there is no need for the authorisation section 21 (a) does not apply because abstraction is not directly from the water resource.

Furthermore, the General Authorisation's limit for section 21 (j) provided that the person removing water legally owns, or has legal access to the land on which section 21 (j) occurs, is the removal of "up to 100 cubic meters of water found underground on any given day if the removing of water:

- Does not impact on a water resource or on any other person's water use, property, or land;
- Is not detrimentally impact the stability or health of the surrounding ecological functioning of any hydrological lined water resources" (SA DWS, 2013:26).

The above discussion refers to the actual activity of removal of basement water to maintain dry conditions. The subsequent reuse of this water is permitted under the General Authorisation, which states that the removed water must be discharged to a water resource, or disposed of, or reused. The General Authorisation limits for 21 (j) of 100 m^3/d (1.15741 l/s) is likely to be enough for the removal of water from basements around the City of Tshwane. Furthermore, the General Authorisation states that the water user must meter the quantity of water removed and that the quality of raw water abstracted must also be monitored, but in accordance with the requirements for its use.

The Water Utilisation Directorate has advised that section 21 (j) is applicable to basement water and this usage of basement water basically falls under the General Authorisation unless the yield of abstraction does not comply with the General Authorisation limits. Therefore, a water use licence is required in case the General Authorisation is not applicable.

2.5 Gap analysis

The urban groundwater challenges in South Africa were discussed and the status quo was identified in South African metropolitan municipalities (section 2.4). Combining the challenges highlighted in the literature review, with insights from the status quo assessment, a comparison has been made between the current status of urban groundwater development and management in South Africa with best practice examples in other countries (section 2.3).

The overview summary of the results from international best practice guides and the status quo of groundwater development and management in urban areas indicated that urban groundwater is used for bulk supply in Denmark and London (section 2.3.2 and 2.3.5), while in South Africa, it is poorly developed and only makes up a small percentage of the total supply in urban areas. The groundwater management is also well implemented in other countries such as Denmark and Birmingham in England, while South Africa lacks groundwater management plans due to lack of monitoring, adaptive water management, decentralised approach, management, and licensing of groundwater. The groundwater recharge zones are well protected in other countries such as Denmark and the United Kingdom, especially London, while it lacks recognition in South Africa, as part of water sensible design measures. Additionally, the issue is also implementation of the existing management plans and policies in South Africa.

The beneficial use of inflows into the basement and tunnel structures derived from groundwater are well used and developed in countries such as the United Kingdom and Norway, while South Africa is not well aware of the innovative solution that urban groundwater can offer to tackle supply–demand challenges. In urban areas in some other parts of the country they have started using basement water, for instance in Cape Town, to counteract the effect of droughts. There is uncertainty over legislative requirements about the beneficial use of groundwater extracted from underground structures.

The aim is to address the misconception that groundwater cannot provide sufficient yields for it to be considered a meaningful water supply source in urban areas. This dissertation intended to address the challenge of poor groundwater and/or basement water use and management in urban areas by outlining the beneficial use of basement water as a case study and example. The case studies illustrated the beneficial use of basement water and the possible development of this resource for enhanced urban resilience.

2.6 Closing remarks

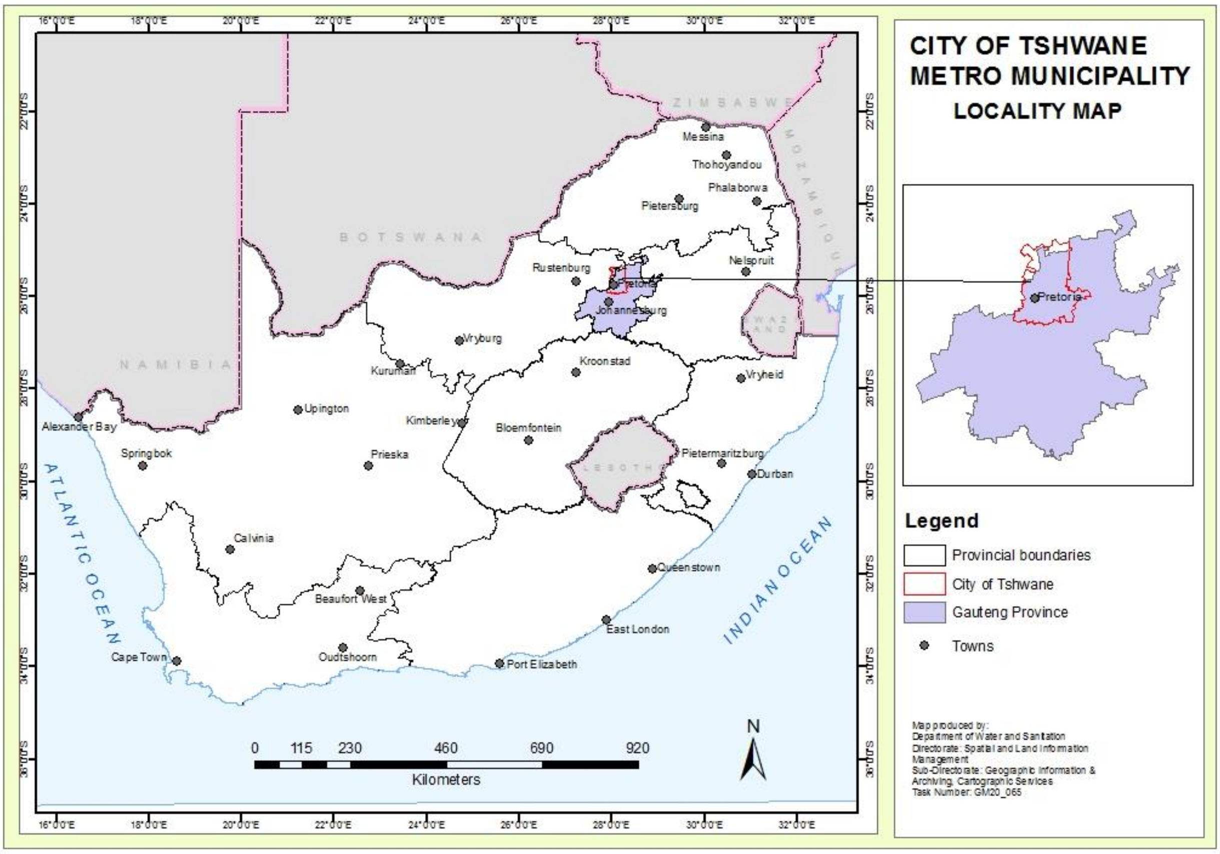
Based on the literature review, groundwater is used and protected in urban areas of other countries. In South Africa, groundwater is not fully used to its potential in the urban areas and management of the groundwater resource is lacking. There are gaps between the international best practices of groundwater use and management and that of South Africa. To address this gap of underutilised groundwater in the urban areas, the innovative technical solution which is inflow into the basement structures derived from groundwater (basement water) was investigated to determine if it would be feasible and reliable in the South African setting.

Chapter 3
Case Study

3.1 General setting

3.1.1 Location

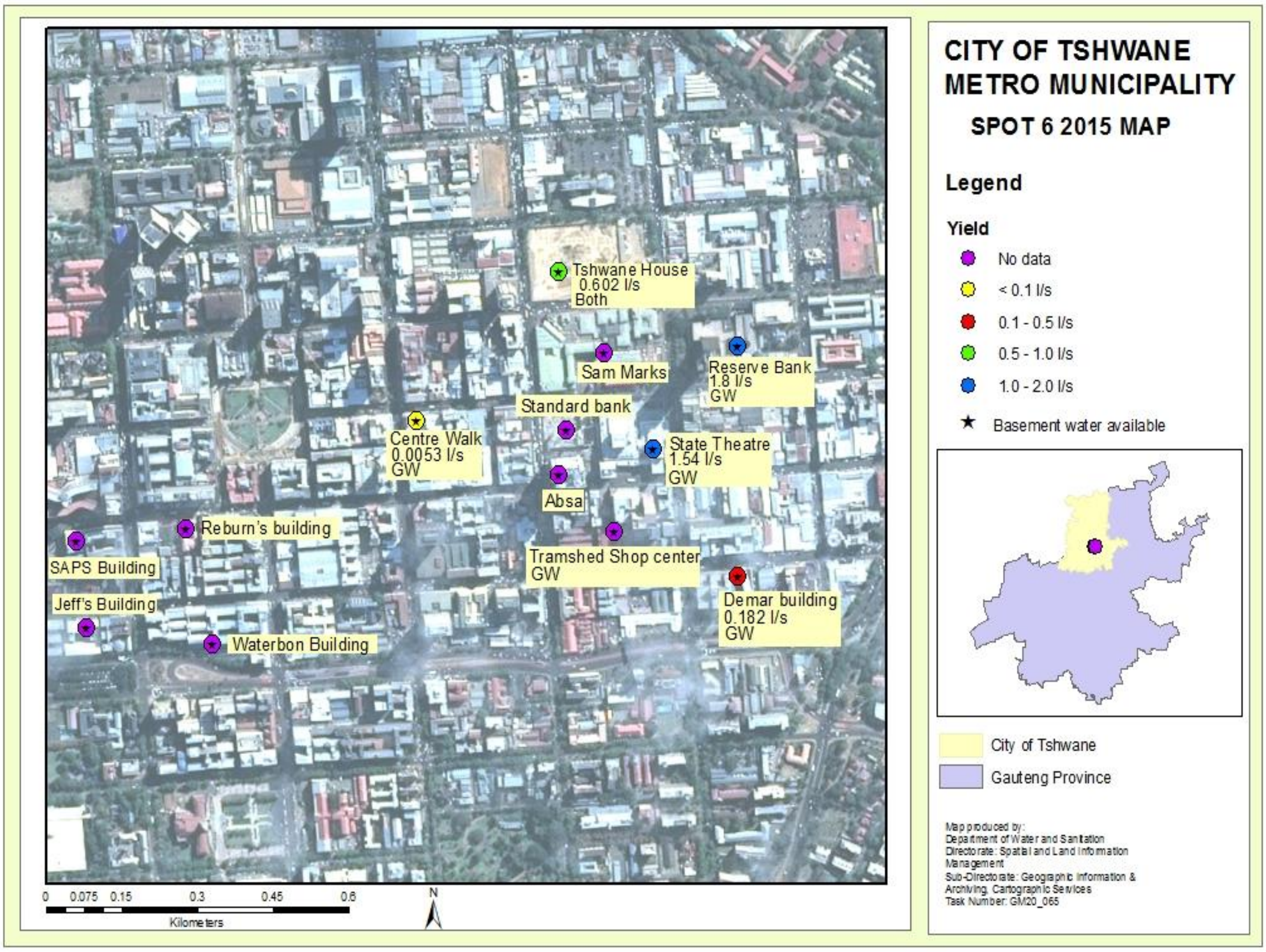
Pretoria is the capital of the City of Tshwane Metropolitan Municipality and is located approximately 50 km north of Johannesburg in the north-eastern side of South Africa (Figure 3.1).



Source: Esri South Africa (2019)

Figure 3.1: Map of South Africa showing the City of Tshwane

Five buildings were investigated in the City of Tshwane for groundwater use, quantity, and quality, namely the Reserve Bank, State Theatre, Tshwane House, Centre Walk, and Demar Building. The location of the study area is illustrated in Figure 3.2 where the fieldwork was conducted from 24 April 2018 to 03 June 2018. Figure 3.2 shows the building's locality, sump yields, and basement water status.

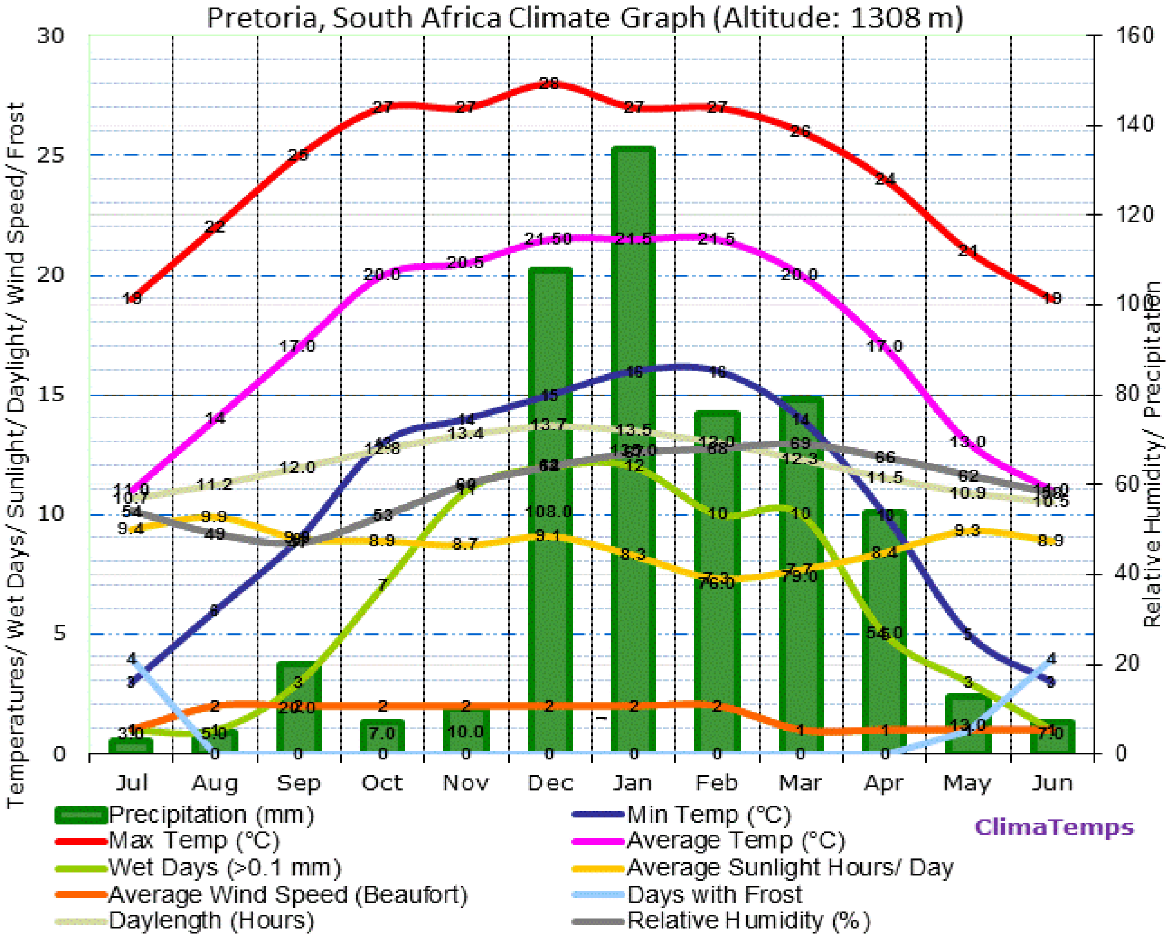


Source: Google map (2019)

Figure 3.2: Locality of the study area within the City of Tshwane

3.1.2 Climate and rainfall

The climate in the City of Tshwane is subtropical, with hot, wet summers and cool, dry winters. Most of the rainfall takes place as sudden thunderstorms caused by convection, and the average rainfall in the area is between 700 mm and 1 000 mm a year. The annual evapotranspiration in the City of Tshwane is approximately 1 600 mm. A closer look at the climate in the Pretoria area is illustrated in Figure 3.3. The bar graph shows the average monthly rainfall and evaporation. The mean annual precipitation in the area is approximately 705 mm, with the highest rainfall in January (124.41 mm) and the lowest rainfall in July (4.49 mm).



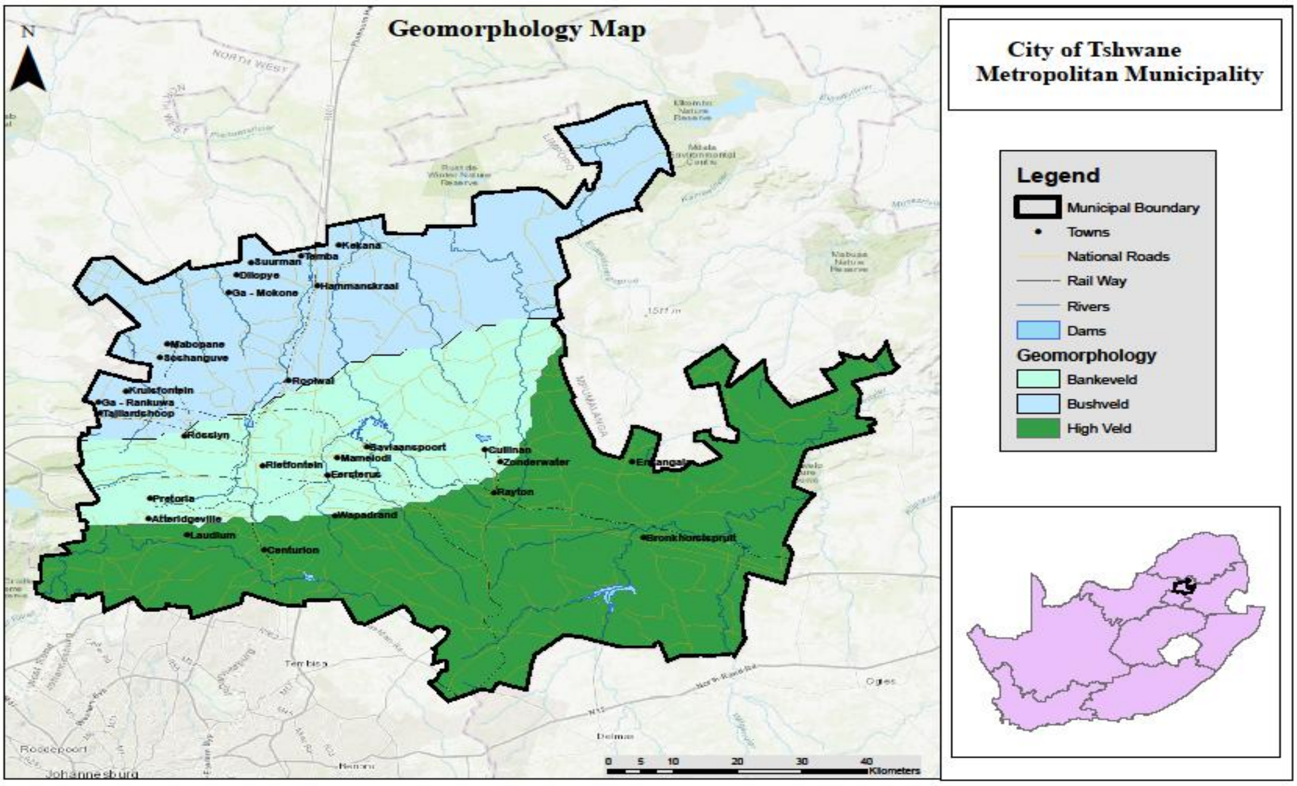
Weather SA (2018)

Figure 3.3: Bar graph illustrating climate and rainfall for the City of Tshwane

The warmest month of the year is January with an average temperature of 26.4 °C. In July, the average temperature is 23.6 °C. It lies in a transitional belt running between the plateau of the Highveld to the south and the lower-lying Bushveld to the north. Because of an altitude of about 1 350 mamsl, the city enjoys a warm climate surrounded by hills of the Magaliesberg range with a sheltered and fertile valley (SA DWS, 2010).

3.1.3 Topography and drainage

The City of Tshwane is situated on the central Highveld plateau of South Africa at an average altitude of 1 500 mamsl (SA DWAF, 2008). The topography can be described as rolling hills with scattered rocky outcrops and quartzitic ridges, intersected by small streams and rivers (SA DWAF, 2008) (Figure 3.4).

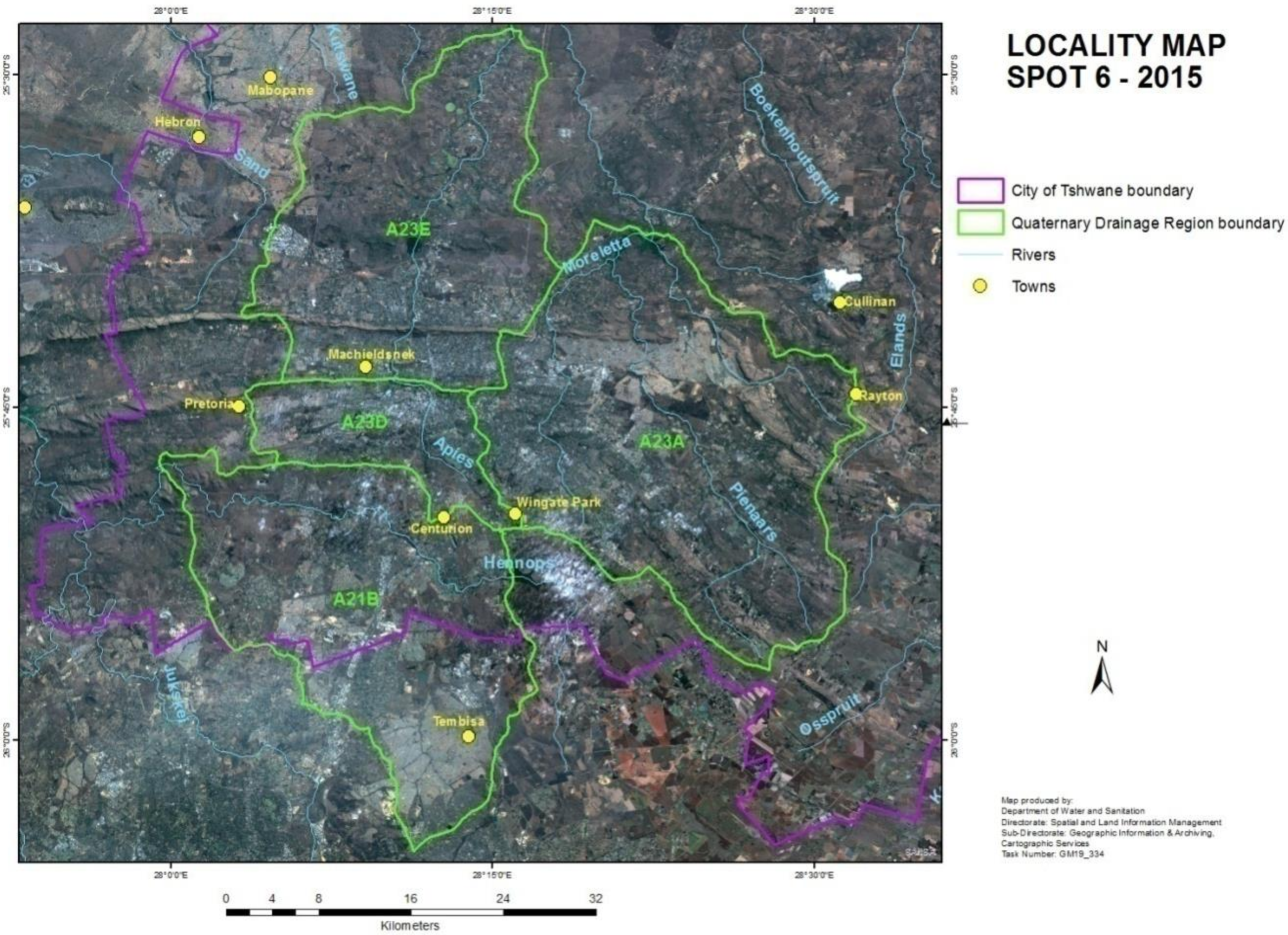


Source: Esri South Africa (2019)

Figure 3.4: Topography and drainage map for the City of Tshwane

On a regional scale, the City of Tshwane lies within a shallow valley that is framed by quartzitic ridges to the south and the Magaliesberg Mountains to the north. The topography of the valley is of special significance in that it has directly resulted in the development of a limited number of access routes leading from the north and south of the city (SA DWAF, 2008). The project site is situated directly north of Fountains Valley, which is a regional topographical low-lying area.

The historical Water Management Area 3 is divided into six tertiary drainage regions or sub-catchments. The City of Tshwane falls into two of these sub-catchments, namely the Upper Crocodile and the Apies–Pienaars sub-catchments. The sub-catchments are further divided into quaternary drainage regions (SA DWAF, 2008), these are A23A (Apies–Pienaars: Roodeplaat), A21B-H (Upper Crocodile: Hartebeespoort), A23D and A23E (Apies–Pienaars: Upstream of Klipvoor) (Figure 3.5).

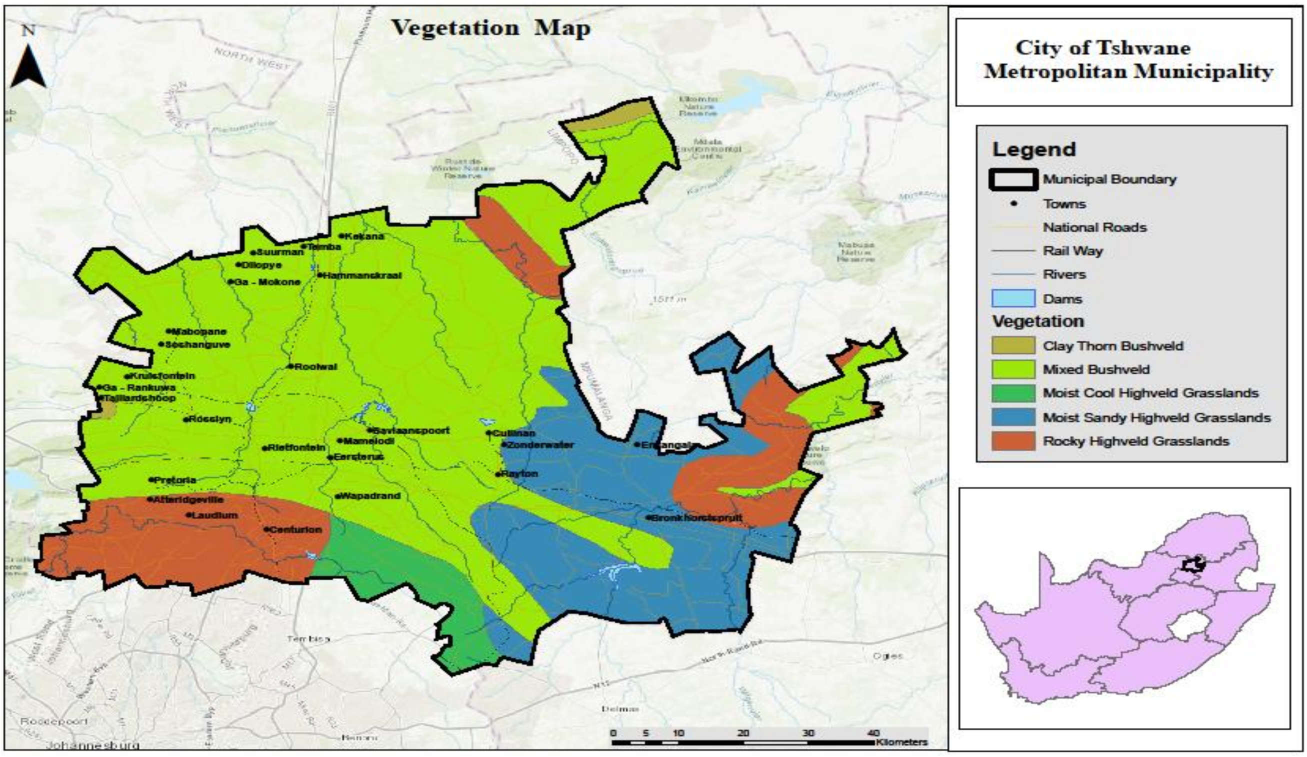


Source: Esri South Africa (2019)

Figure 3.5: Quaternary drainage regions within the City of Tshwane

3.1.4 Soil and vegetation

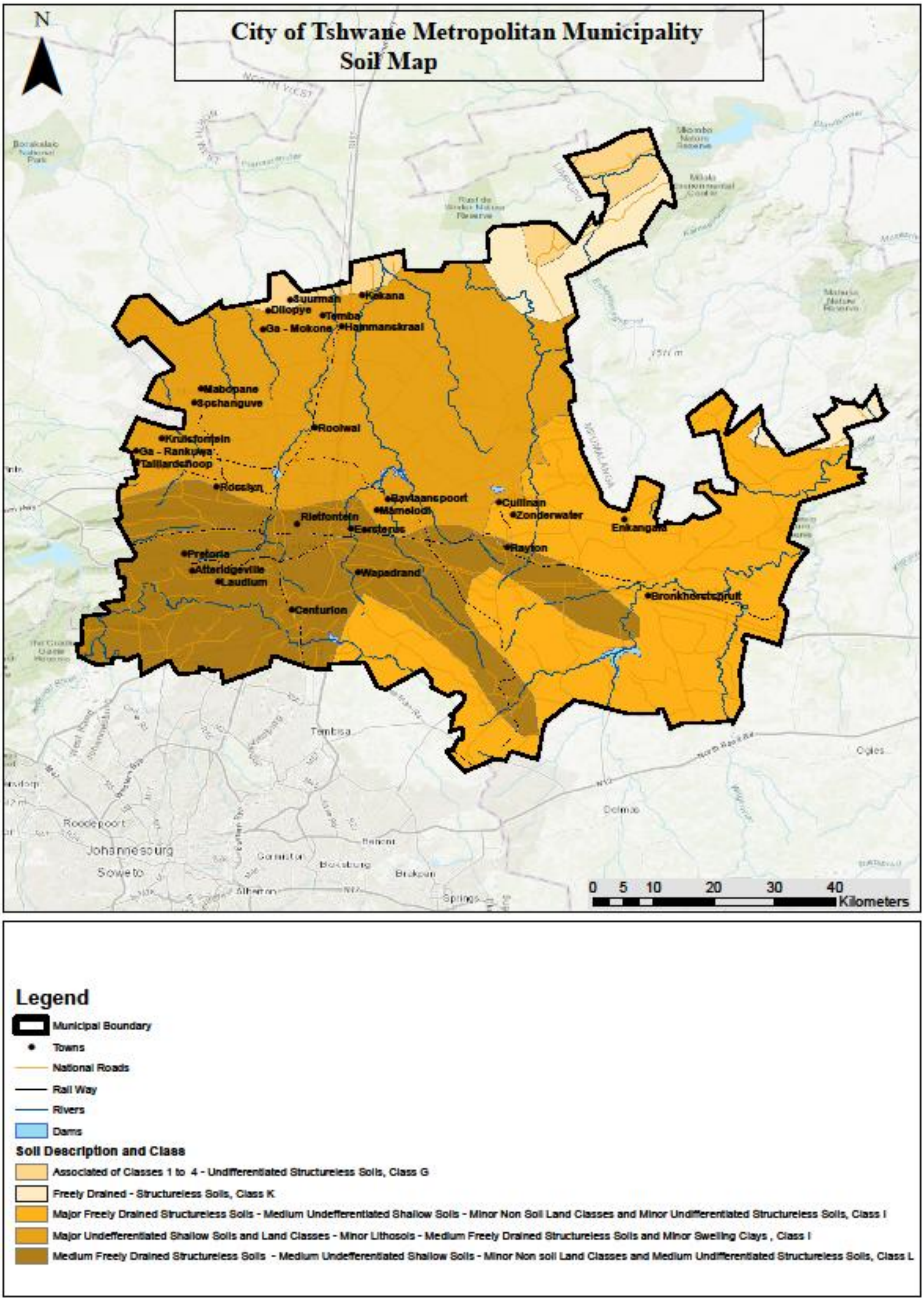
Grassland and sparse Bushveld shrubbery and trees are the main types of natural vegetation found throughout the area. The study area (Figure 3.6) is mainly dominated by the Bankenveld and sourish-mixed Bushveld (Rutherford and Westfall, 1986).



Source: Esri South Africa (2019

Figure 3.6: Vegetation map for the City of Tshwane

The soil classes encountered in the project area are shown in Figure 3.7. The majority of the soil type falls within areas characterised by freely drained, structureless soils, undifferentiated clays, and non-soil classes. Figure 3.7 shows that the other parts of Tshwane consist of undifferentiated shallow soil and land classes and undifferentiated structureless soil, and the study area consisting of lithosols.



Source: Esri South Africa (2019

Figure 3.7: Soil map for the City of Tshwane

3.1.5 Geology

3.1.5.1 Black Reef Formation

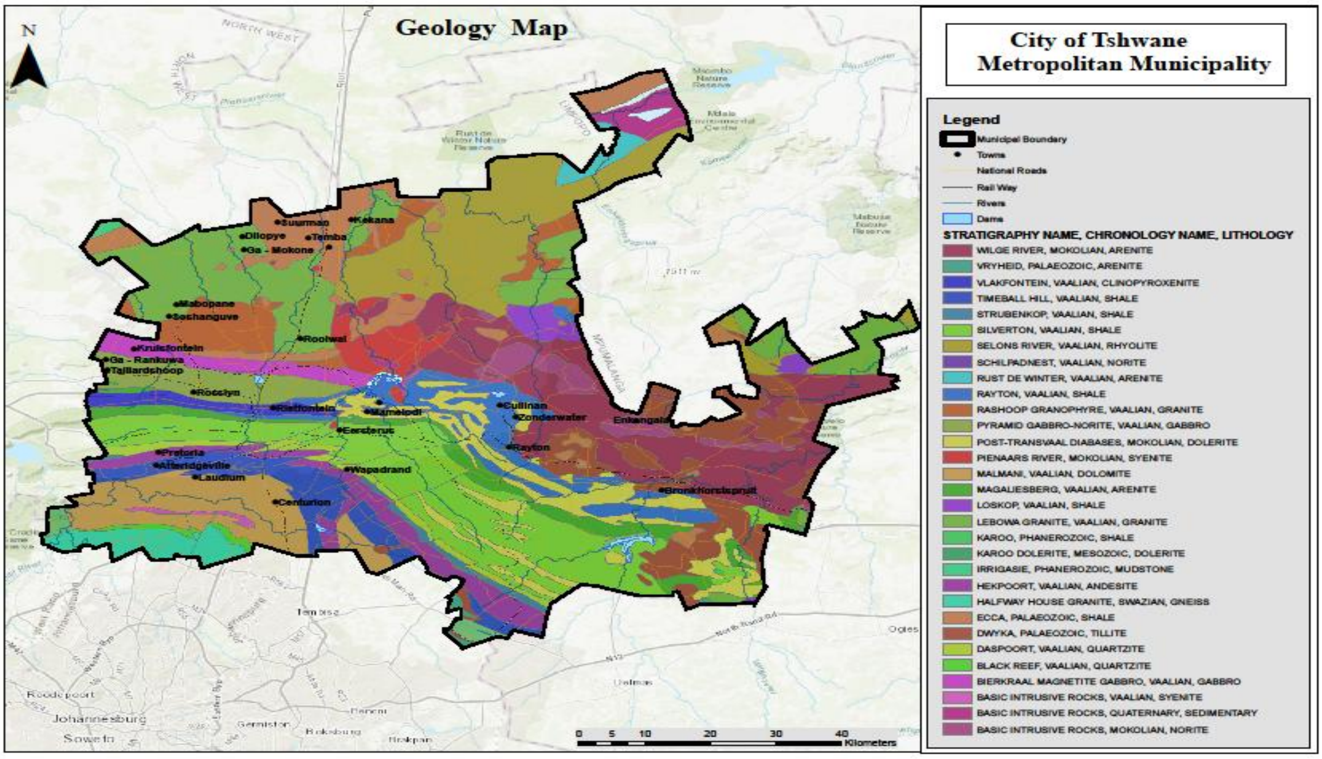
The Black Reef Formation forms the base of the sequence and is conformably overlain by the carbonates of the Malmani Subgroup (Table 3.1).

Table 3.1: The Lithostratigraphic subdivision applied in the study area

Supergroup	Group	Subgroup	Formation	Member	Lithology	Thickness (m)
Transvaal	Pretoria		Houtenbek Steenkampsberg Nederhorst Lakenvlei Vermont		Alluvial fan and shallow basins	
		Lower Pretoria Group	Mageliesberg Silverton Daspoort		Chert breccia with siliceous and ferruginous matrix	
			Strubenkoop Dwaalheuwel Hekpoort Boshoek	Pologround	Sandstone and interbedded siltstones	2.5–30
					Shales and interbedded siltstones	6.5–30
			Timeball Hill	Beverts	Chert conglomerate in a ferruginous matrix	0.5–4
			Rooihoogte		Shales and siltstones	11.5–30
	Chuniespoort	Malmani	Frisco		Chert-free dark brown dolomite	158
			Eccles	Leeuwenkloof	Silicified chert breccias	5–10
					Chert-rich light grey dolomite	477
			Lyttelton		Chert-free dark brown dolomite	224
			Monte Christo	Crocodile River	Chert-rich grey-brown dolomite	237
				Rietspruit	Chert-rich and colour-banded dolomite	312
				Moolplaats	Chert-rich light grey dolomite	185
				Rietfontein	Chert-free light grey dolomite	165
			Oaktree		Chert-free dark brown dolomite	190
			Black Reef		Interbedded quartzite and shale	11

Source: Catuneanu and Eriksson (1999)

Black Reef Formation consists of five lithofacies which are conglomerates, trough crossed-bedded quartzites, horizontally laminated quartzites, planar cross-bedded quartzite, and laminated siltstone and mudstone (Figure 3.8) (Catuneanu and Eriksson, 1999).



Source: Esri South Africa (2019)

Figure 3.8: Geology map of the City of Tshwane

Laminated siltstone or mudstone is a dark grey to black laminated silt, and mudstone unit is weathered to a brown colour. The texture is coarser-grained silt and finer-grained mud laminated (Eriksson et al., 2006). Horizontally laminated quartzite is a unit which consists of fine to medium-grained, well-sorted quartzite beds. Thickness of quartzite is in the range of 20 cm to 50 cm. Planar crossed-bedded quartzite is fine to medium grained and also well-sorted quartzite beds. The thickness is approximately 30 cm and also bounded by sharp upper and lower contacts, though cross-bedded quartzite is medium grained, and the thickness ranged from 5 cm to 30 cm. Massive conglomerates are dominant at the base of the Black Reef Formation and vary in thickness from 10 cm to 50 cm. The texture of the conglomerate consists of well-rounded quartzite pebbles (Eriksson et al., 2006).

3.1.5.2 Malmani Subgroup

The City of Tshwane is underlain by rocks of the Malmani Subgroup, which forms part of the Chuniespoort Group (Table 3.1). These dolomitic rocks accumulated in the Transvaal Basin during the Vaalian Era. The age of the Malmani Subgroup is estimated around 2.5 Ga to 2.6 Ga. The subgroup is divided into five formations and is up to 2 km thick (Eriksson et al., 2006).

The five formations in the Malmani sequence are the Oaktree Formation, Monte Christo Formation, Lyttelton Formation, Eccles Formation, and Frisco Formation (Table 3.1). The Oaktree Formation is between 10 m and 200 m thick and is a transition from siliciclastic sediments to platform carbonates. Oaktree is composed of carbonaceous shales, stromatolites, dolomites and some quartzites (Figure 3.8) (Eriksson and Warren, 1983). The tuff layer was formed in the Oaktree Formation at an age of 2.585 Ga.

The Monte Christo Formation is between 300 m and 500 m thick. The Monte Christo Formation moved from an erosive breccia at its base to stromatolitic and oolitic platform to dolomitic towards the top (Eriksson et al., 2006). The Lyttelton Formation is comprised of shales, quartzites and stromatolites and is between 100 m and 200m thick (Eriksson et al., 2006). The Eccles Formation overlies the Lyttelton Formation. The Eccles Formation is up to 600 m thick and is built up mostly of cherty dolomites and includes a series of erosion breccias. This erosion is made up of mineralised rock by the remobilisation fluids of the Bushveld Igneous Complex and is called auriferous (Eriksson et al., 1995).

The Frisco Formation is up to 400 m thick and is comprised of stromatolitic dolomites at the bottom and moved towards shale-rich dolomites towards the top. The shale-rich deposits represent the deepening deposition environment in the Transvaal Basin (Eriksson et al., 2006). The different compositions of dolomite in these formations influence the amount of karstification and also the yield of the aquifer. The Eccles Formation defined by the more chert-rich layers is considered to be a high-yielding aquifer (Catuneanu and Eriksson, 1999).

3.1.5.3 Pretoria Group

The dolomitic rocks of the Chuniespoort Group are bound to the north by the rocks of the Pretoria Group (Catuneanu and Eriksson, 1999). The Upper and Lower Fountain springs are situated near the boundary between the two lithologies. The Pretoria Group is composed of mudrocks and quartzitic sandstones (Figure 3.8). There are also major basaltic-andesitic lavas, minor conglomerates, and diamictites as well as carbonates (Catuneanu and Eriksson, 1999). All these rock types have undergone a low-grade metamorphism. Seven of the formations that make up the Pretoria Group can be found in the Pretoria area (Eriksson et al., 2006). The formations together are up to 6 km in thickness.

The Rooihoogte Formation forms the base of the Pretoria Group and overlies the paleo-karst topography of the Chuniespoort Group (Table 3.1). In the Pretoria area, the Rooihoogte Formation is comprised of well-developed chert breccias. The Timeball Hill Formation is the second oldest formation in the Pretoria Group (Table 3.1), made up of thick shales and minor sandstones. The formation originated from the fluvial-deltaic basin-fill sedimentation system (Eriksson et al., 2006).

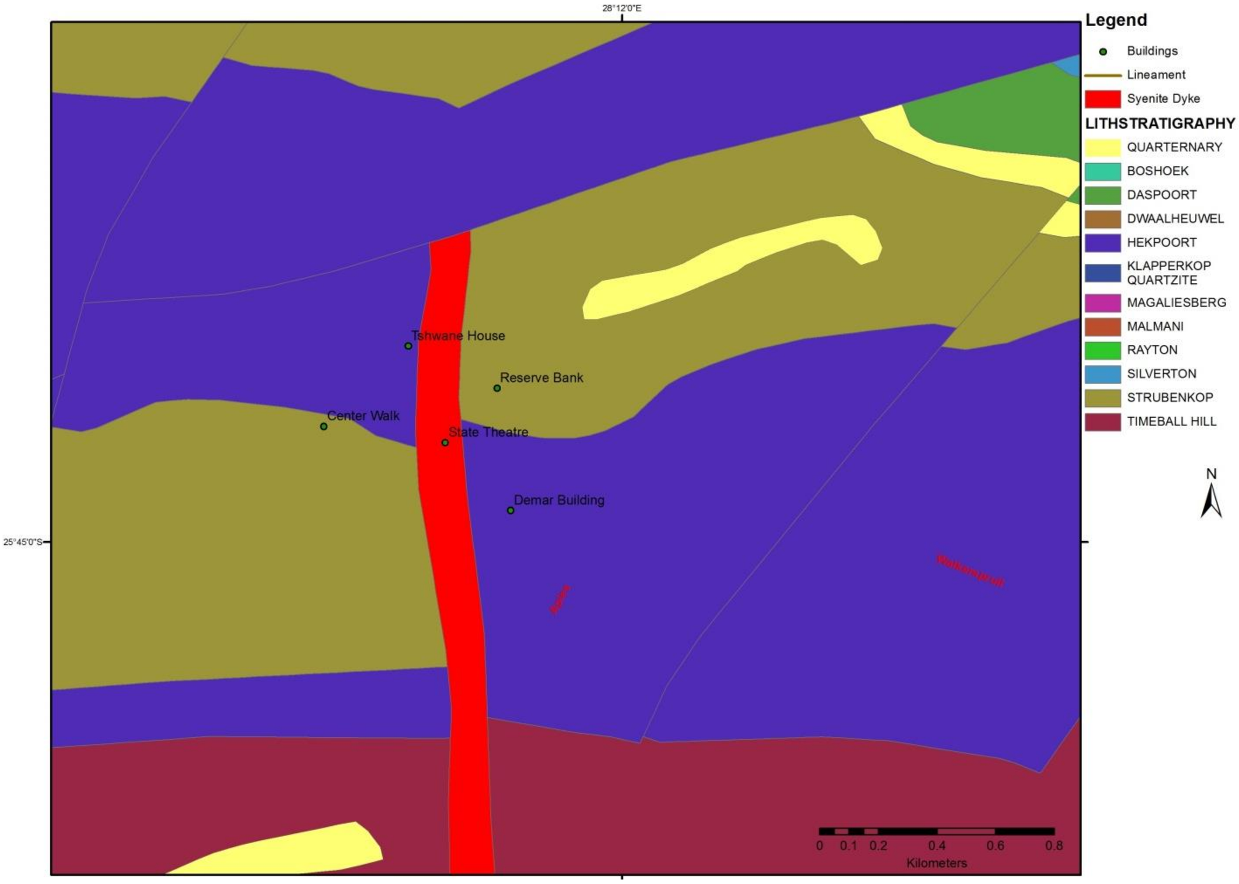
The black shales, pyroclastics, mudstones, fine-grained sandstones, quartzite, as well as diamictites and wackes, are found in the Pretoria area (Figure3.8). The Hekpoort Formation is the third formation (Table 3.1) and is made up of andesitic-basaltic lavas which were erupted subaerially predominantly as fissure eruptions (Eriksson et al., 2006). The Strubenkop Formation is the fourth formation of the Pretoria Group (Table 3.1). The Strubenkop Formation is comprised of mudstones and alternating siltstones as well as fine-grained sandstones (Eriksson et al., 1995). According to Eriksson et al. (2006), the Strubenkop Formation is generally coarsening upward and originated from lacustrine deposits.

The Daspoort Formation is the fifth formation of the Pretoria Group (Table 3.1). The Daspoort Formation overlies the Strubenkop Formation unconformably. The formation is comprised of immature sandstones, pebbly arenites, conglomerates, and mudrocks (Figure 3.8). The Daspoort Formation marks the transition between fluvial conditions and the beginning of the major marine transgression (Eriksson and Warren, 1983). The Silverton Formation is the sixth formation of the Pretoria Group.

Lastly, the Magaliesberg Formation overlies the Silverton Formation as the seventh formation of the Pretoria Group. The Magaliesberg Formation is comprised of immature sandstone, which was laid down in an environment with braided deltas and high energy tidal channels.

3.1.6 Structural geology

Many dykes, sills, and faults are present in the geology of the City of Tshwane. These geological structures are variable in size from small to large regional structures. They play an important role in the movement of groundwater within different lithologies. Figure 3.9 shows that some of the buildings are situated on top of or near a dyke. This may be the cause of high sump yields in these buildings.

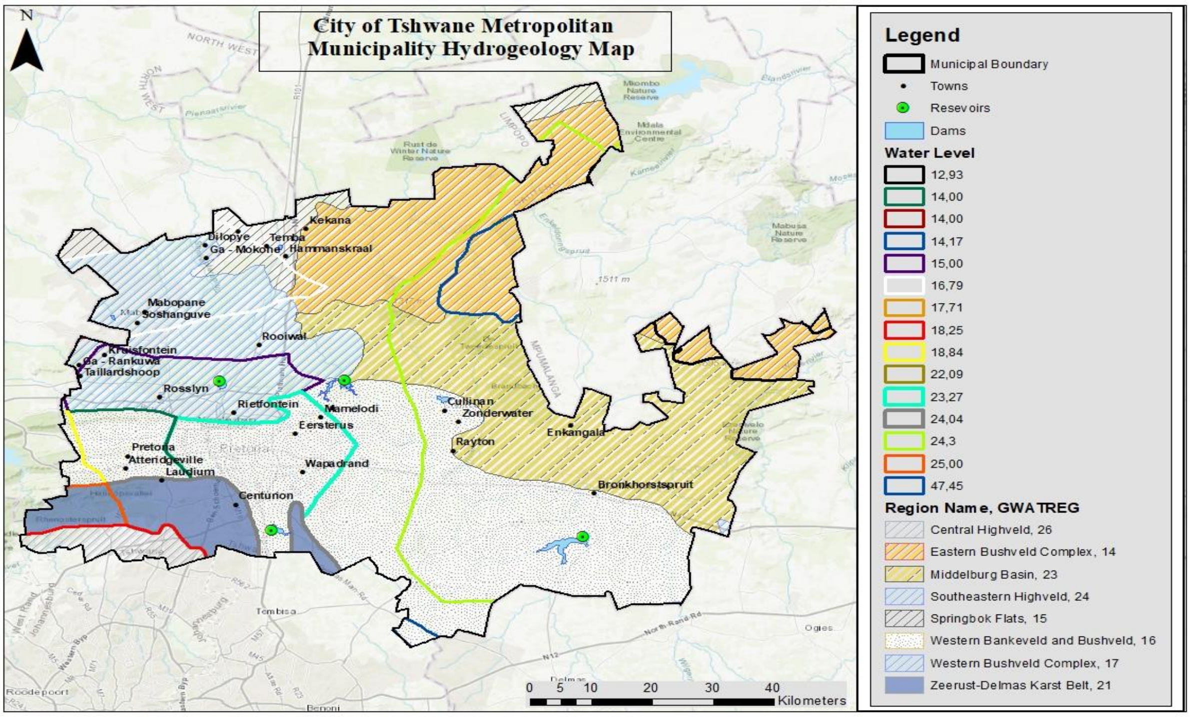


Source: Esri South Africa (2019)

Figure 3.9: Geological structures in the study area

3.1.7 Hydrogeology

In the study area, the main aquifer is the dolomitic aquifer of the Chuniespoort Group of the Transvaal Supergroup, and a dolomitic aquifer is the most important aquifer in South Africa (SA DWAF, 2006). Dolomite is a magnesium-rich calcium carbonate rock that can dissolve in the presence of water when combined with carbon dioxide (SA DWAF, 2006). It is formed as result of the weathering process that leads to cause the formation of the subsurface solution of cavities or cave systems and surface sinkholes (Vegter, 1995). This dissolution weathering can result in a dissolution landscape known as karstification (Vegter, 2001). Any local or regional geological structures such as a fault or fracture systems or fracturing brecciation adjacent to dolerite intrusions can enhance the dissolution and karst development (Figure 3.10). The dolomite has a relatively low primary permeability but due to karst, the high secondary permeability features along with a high rate groundwater flow are formed (Vegter, 2001). The continuity of the dissolution weathering can cause a karst terrain provided there is enough recharge. The dolomite aquifer yield within the study area is generally ranging from 0.1–0.5 l/s to 2.0–5.0 l/s (Figure 3.10).



Source: Esri South Africa (2019)

Figure 3.10: Hydrogeological map of the City of Tshwane

Wetlands, pans, springs, and sinkholes may be indicative of subsurface groundwater bearing solution cavities. The dolomite aquifer is generally confined or semi-confined, with compartmentalisation by dolerite dykes as a possible effect due to dykes acting as aquitards or barriers to groundwater flow (SA DWAF, 2006). The contact zones between the dolomite formation and dolerite dykes are commonly fractured, and along with other faults or fracturing zones result in the development of groundwater flow paths in the area (Vegter, 2001). This can be used as an indication for the siting or drilling of boreholes. High-yielding boreholes are likely to occur in these settings. The localised groundwater targets within the study area are the weathered and fractured zones or contact zones of intrusive dykes and high-yielding springs (Figure 3.10) (Vegter, 1995).

The geological and hydrogeological characteristics are responsible for good dolomite aquifers with high transmissivities and yields (SA DWAF, 2006). The dolomite aquifers are highly vulnerable to anthropogenic contamination. Water quality within the study area is generally good and groundwater from the Chuniespoort Group has a calcium-magnesium-bicarbonate nature, with an EC of <63 mS/m (Vegter, 1995). This suggests that the groundwater is acceptable for use, although several elements, particularly chloride, sulphate, and nitrates often show coefficients of variation greater than 200% (SA DWAF, 2006). This suggests the presence of contamination which calls for caution when the groundwater is considered for human consumption.

The quartzites/shale and sandstone are found to generally have low transmissivities, except if weathered and have formed extensive aquitards in outcrop areas (SA DWAF, 2006). The sandy soil horizon is expected to allow for rapid infiltration into the vadose zone during precipitation events to recharge. Streams that converge at right angles are common in jointed, folds or faulted quartzites. Folding leads to a high degree of fracturing and the shallow weathered aquifer is thought to have developed a high fracture density due to folds (SA DWAF, 2006). The main source of recharge into the shallow alluvial aquifer is rainfall that infiltrates the aquifer through the unsaturated zone (Calow et al. 2010). Vertical movement of water is faster than lateral movement in this system as water moves predominantly under the influence of gravity. Groundwater recharge was estimated to be an average of 10% of mean annual precipitation (SA DWAF, 2006). The commonly expected values of porosity and hydraulic conductivity are 0.05 and 0.1 m/day, respectively (Figure3.10).

At depth, Pretoria Group quartzites are generally competent rock and tend to develop good jointing systems (Figure 3.10). Primary porosity is virtually not visible and the presence of water is generally limited to secondary structures such as joints and fractures. Both the porosity and the hydraulic conductivity of these aquifers are known to be low (Calow et al., 2010). The commonly expected values of porosity and hydraulic conductivity are 0.035 and 0.01 m/day, respectively (SA DWAF, 2006). The Pretoria Group quartzites are low-yielding aquifers, with a low groundwater development potential at depths greater than 40 m below the surface.

3.1.8 Description of each building in the study

- ❒ **South African Reserve Bank (370 Helen Joseph, Tshwane CDB)**

The South African Reserve Bank (SARB) is the central bank of South Africa. The SARB building has 37 floors and four basement levels (at a depth of 11.4 m). Groundwater seepage is collected in two sumps; some of it is used for garden irrigation, while the rest is discharged into the municipal stormwater system. The SARB currently uses potable water from the municipal reticulation network for domestic use, mostly non-potable uses for carwash, fountains, toilet flushing and air conditioning systems; hence, the SARB could benefit financially from integrating basement water into its water systems. The water quantity that is being discharged from both pumps is estimated to be around 540 l/min (or 9 l/s). The water quality has not yet been determined.

❒ **State Theatre (320 Pretorius Street, Tshwane CDB)**

Located in the heart of the Tshwane city centre, the State Theatre consists of five arenas, a large public square, and a number of restaurants. There are three basement levels (at a depth of 13.4 m), and the groundwater ingress is managed by collecting the seepage in three sump pits and discharging for disposal into the municipal stormwater drainage system.

❒ **Tshwane House (320 Madiba Street, Tshwane CDB)**

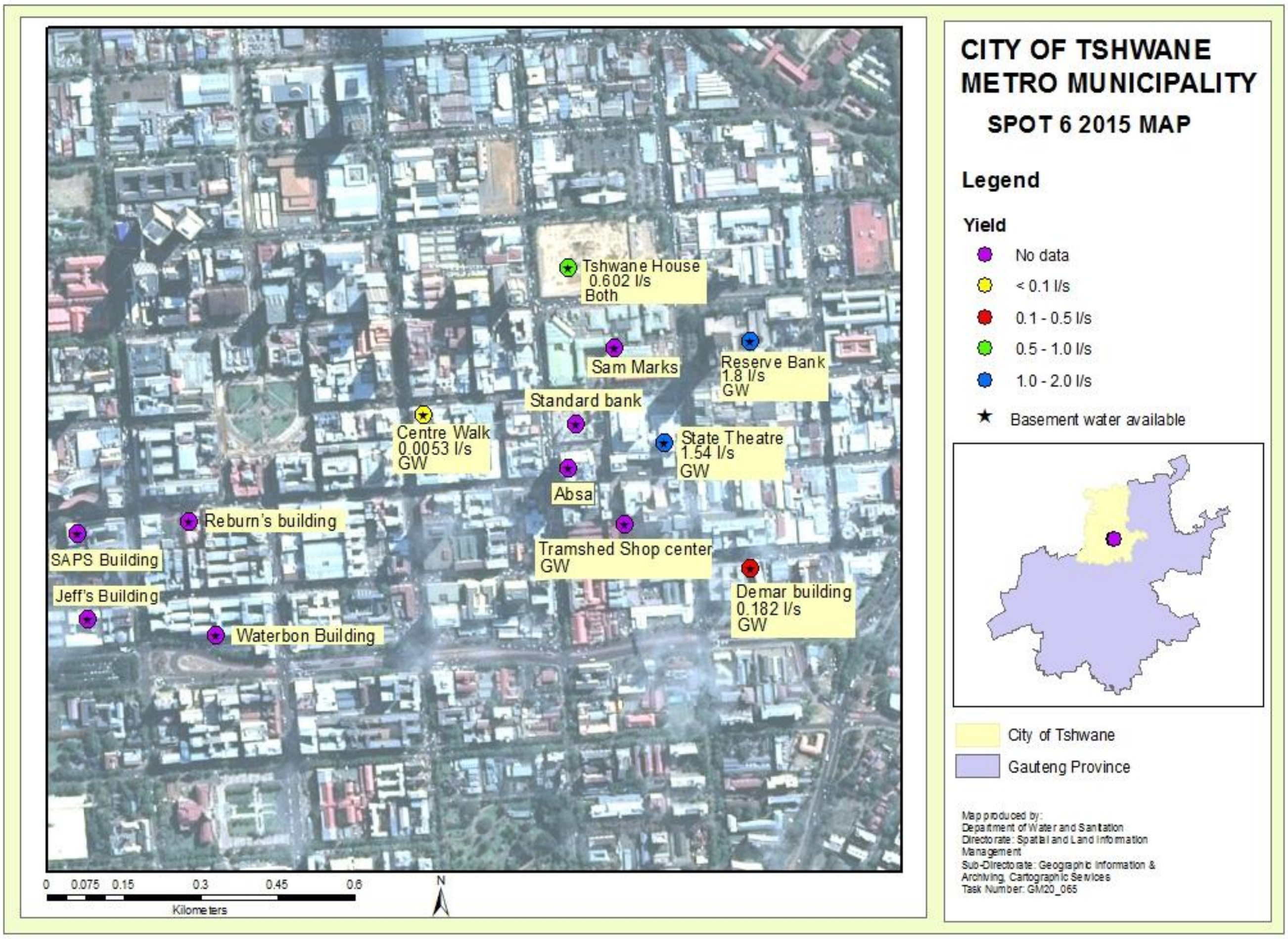
Tshwane House is the new headquarters for the City of Tshwane Metropolitan Municipality and was one of the first government buildings to target a 5-Star Green Star South Africa certification within a public–private partnership. The building has three basement levels (to a depth of 9 m) situated on Madiba Street, and two basement levels on Johannes Ramokhoase Street. The seepage groundwater is collected in two sumps and discharged into the municipal stormwater drainage system.

❒ **Centre Walk (267 Helen Joseph Street, Tshwane CBD)**

Centre Walk is a shopping centre with two basement levels (at a depth of 9 m). Basement water is collected into a single sump and discharged into the municipal stormwater drainage system. The building uses potable water for domestic use, for example drinking, cleaning, and toilet flushing, garden irrigation and the air conditioning system.

❒ **Demar Building (371 Francis Baard Street, Tshwane CDB)**

Demar building is a residential building with three basement levels (at a depth of 8.3 m). The basement water is collected into a single sump and discharged into the stormwater drainage system. The Demar Building currently uses potable water for domestic uses, for example drinking, cleaning, flushing toilets, garden irrigation and the air conditioning system.



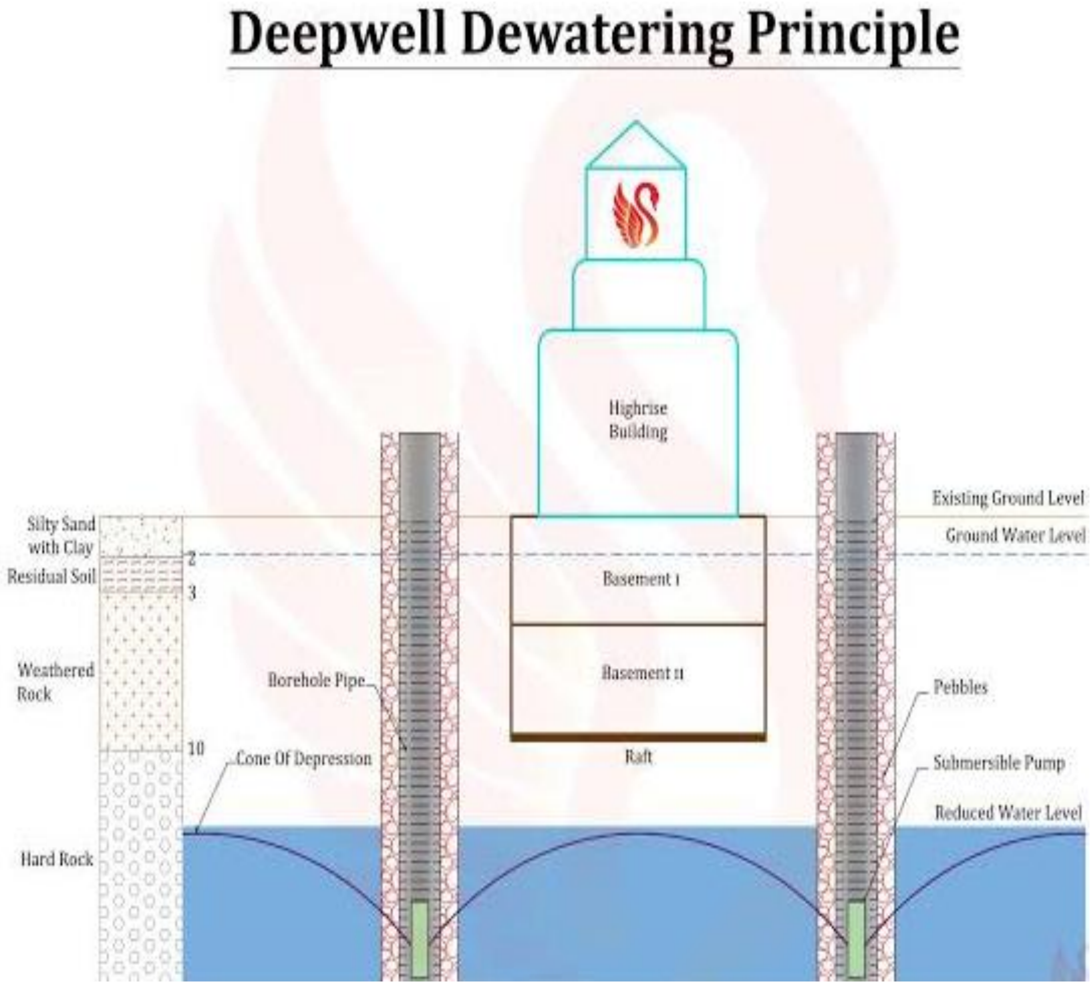
Source: Google map (2019)

Figure 3.11: Location of the buildings in the study

3.2 Basement water use (sump water)

3.2.1 Source of basement water

For shallow basements in areas with deep groundwater levels, the dewatering system may not be necessary and only drains to ensure that water does not accumulate. In some instances, where underground structures are deep enough to extend below groundwater level, they require dewatering systems or groundwater control measures to ensure dry conditions. The dewatering system diagram for a basement is shown in Figure 3.12.



Source: Swan Dewatering (2015)

Figure 3.12: Typical dewatering principle for basements

The design of the low permeability cut-off wall controls the movement of the diverted water. The water entering basements may include stormwater derived from surface run-off, for example the physical collection of rainfall on the roadway into an underground parking area. Above the water levels, water may accumulate in the unsaturated zone on less permeable layers, forming perched aquifers, and percolate into the basement. Even without the presence of perched aquifers, water moves within the unsaturated zones, and may seep towards the basements. The water entering the basements may be a mixture of groundwater in cases where the basement extends below groundwater levels, perched groundwater, stormwater, and shallow seepage water from the unsaturated zone. The use of basement water requires registration or licensing.

3.2.2 Water quantity of each case study

3.2.2.1 Reserve Bank building

The set-up of the basement exploitation drain in the Reserve Bank was designed to collect groundwater around the building into the sump pumps, but in this case, the pumps were not connected to each other. Each sump pump discharged into the stormwater channel. Each sump had two pumps, one running and one backup pump. The groundwater leakage occurs throughout the year, but mostly in the rainy season. Table 3.2 provides a summary of the sump pump information.

Table 3.2: Sump pump information

Sump name	Sump pump 1	Sump pump 2
Area (Sump dimensions)	54.4 m^2	25 m^2
Datum below groundwater level	11.1 m	
Sump depth	3.6 m	3.2 m
Equipment (specifications)	Head (from pump intake to discharge point) = 10 m	

- ❒ **Basement water use plans**

The SARB was considering using the basement water after the consultation it had with Mr Johan Riekert, technical manager. The SARB was considering the option of using the basement water for its supply. They were also looking into the use of a solar system to save energy.

- ❒ **Estimating sump yield (calculations) – Water level monitoring**

The data recorded is shown in Figure 3.13, where the calculations for sump yields are presented. These calculations show the estimated amount of water from each sump in the basement of the building. The first calculation estimated the sump yield using level logger data (Equation 1), and the second calculation was the estimation of the sump yield using an hour meter which measured the energy used by the pump to discharge water into the stormwater system (Equation 2 and 3). A water level logger was installed into the sump on 14 May 2018 at 17:00 and was removed at 16:30 on 23 May 2018. The measurements were taken for a week. The logger was installed at a depth of 2.4 m and was recorded at a 15-minute frequency. Figure 3.13 shows the inflow of water in the sump pump.

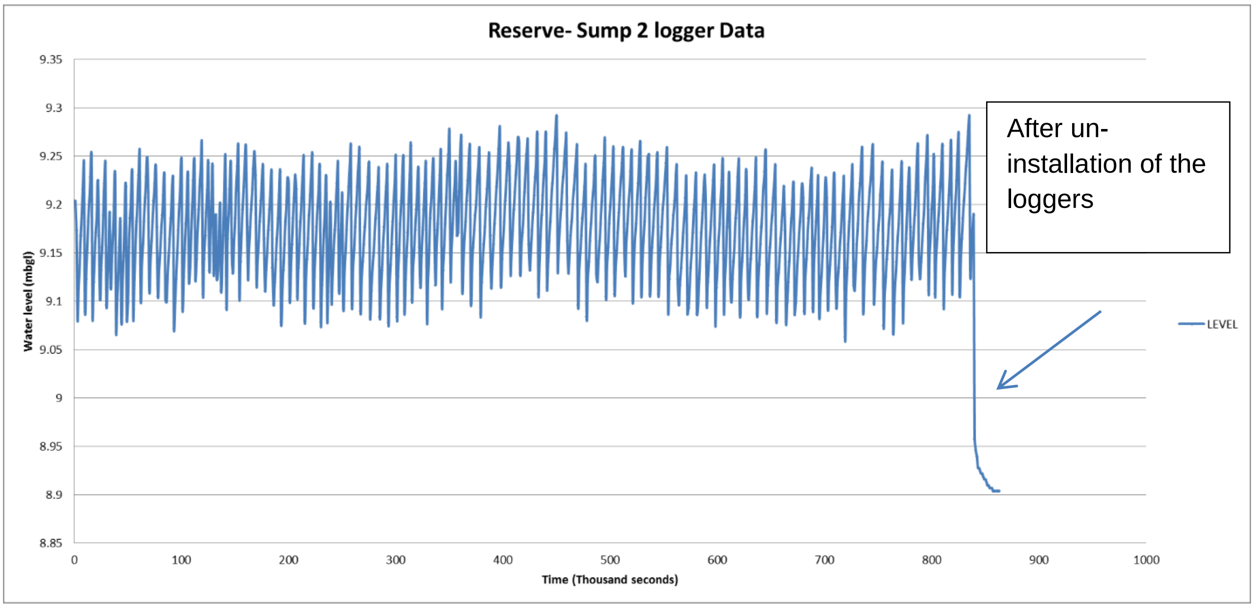


Figure 3.13: Sump logger data graph

❒ Sump 2

The total sump yield for the period of water level monitoring was determined by the following equation:

$$Sump\ yield = \frac{\text{(Total water level increase)}*\text{(Sump area) (cubic metre)}}{\text{Total period of monitoring (seconds)}} \qquad \text{(Equation 1)}$$

$= 0.00114185\ m^3/s$

$= 1.14185\ l/s$

Table 3.3: Estimating sump yield calculations to measure the power used to pump the water out (Sump 1)

Time	Date	Readings	Difference
10:00:00	14/05/2018	832 kWh	0
10:00:00	25/05/2018	846 kWh	14 kWh

Data: Head = 10 m, P = Power, Q = Flow rate, p = density of water, g = gravity acceleration, $P_{(w)}$ = Power, $t_{(hr)}$ = time, E = Energy

$$P_{(w)} = \frac{1\ 000 * \mathrm{E}\ (\mathrm{kWh})}{t(hr)} \qquad \text{(Equation 2)}$$

$$= \frac{1\ 000 * 14\ kWh}{215.5}$$

$$= 64.97\ \mathrm{W}$$

$$P = Q * p * H * G$$

$$Q = \frac{P}{p * H * g} \qquad \text{(Equation 3)}$$

$$= 6.6\mathrm{E}{-4}\ \mathrm{m}^3/\mathrm{s}$$

$$= \underline{0.66\ \mathrm{l/s}}$$

The total yield of these sumps was estimated at around 1.8 l/s (or 155 520 l/d). This total sump yield came from adding the value of the sump yield calculated by using the water level monitored over a period of time (Equation 1) and also the energy used to pump the water out (Equation 2 and 3).

The total water demand of the building was **75.85 kl/d**, which could be fully supplied by the estimated yield of the sumps (**155 kl/d**).The SARB can use the basement water for other services instead of using municipal water for all their water use. Water surplus could also be used for other beneficial options such as donating it to the neighbours or sports fields and parks for irrigation.

3.2.2.2 State Theatre building

The basement water of the State Theatre was constantly pumped throughout the year. Mr Barend Vorster, operations and maintenance manager at the State Theatre, mentioned in an interview that there was no need for a permit to discharge basement water or rainwater into the stormwater in which case no license was required to discharge the basement water into the stormwater system. There were no measurements prior to the discharge of the basement water into stormwater in terms of water quantity (how much has been discharged into stormwater) and quality (what kind of water quality).

The set-up of the basement exploitation drain in the State Theatre was designed to collect groundwater around the building into one point and from the focus point (sump pump) discharged into the stormwater system. There were three sump pumps in the basement, and two of them were in the parking area and the remaining one, inside the building. The two pits in the parking area discharged water into the stormwater system and also to the big one inside the building. Each sump pump (pit) had two pumps, one was pumping out water and the other one was there for backup in case the first pump stopped working. There was one pit for rainwater. The information of the sump pumps is presented in Table 3.4.

Table 3.4: Sump pump information

Sump name	Sump pump 1	Sump pump 2	Sump pump 3 (main)
Area (Sump dimensions)	9 m^2	25 m^2	42 m^2
Datum below groundwater level	13.41m (44 feet)		
Sump depth (mbd)	5 m	3 m	7 m
Equipment (specifications)	Head = 16 m, Submersible pump, Model KTZ 35.5, three-phase induction motor, Capacity max = 1.1 m^3/min (18.3 l/s)		

❒ Water use and demand

The State Theatre building used potable water for domestic use such as drinking, cleaning, and toilet flushing, garden irrigation and the air conditioning system. A huge portion of of potable water (65–75%) is used for an air conditioning system (Barend Vorster, interview). The State Theatre was spending around R170 000 per month on potable water. The use of basement water for the air conditioning system could save more than R1.2 million per year at R100 000 per month.

❒ Basement water use plans

The State Theatre was planning on doing a business proposal about the basement water use for the air conditioning system.

❒ Estimating sump yield (calculations) – water level monitoring

The data recorded is presented in Figure 3.14 (Sump 1) and Figure 3.15 (Sump 2), where the results of the sump yield are presented, and the calculations for sump yields are presented in Appendix B. The results showed the estimated amount of water from each sump in the basement of the building. A water level logger was installed into the sump at 17:00 on 7 May 2018 and was removed at 11:15 on 15 May 2018. The measurements were taken for a week. The logger was installed at a depth of 2.2 m and was recorded at a 15-minute frequency. The inflows in the sump pump are depicted in Figure 3.14 and 3.15. These inflows were showing when the water came in of the sump pump and when it went out of the sump.

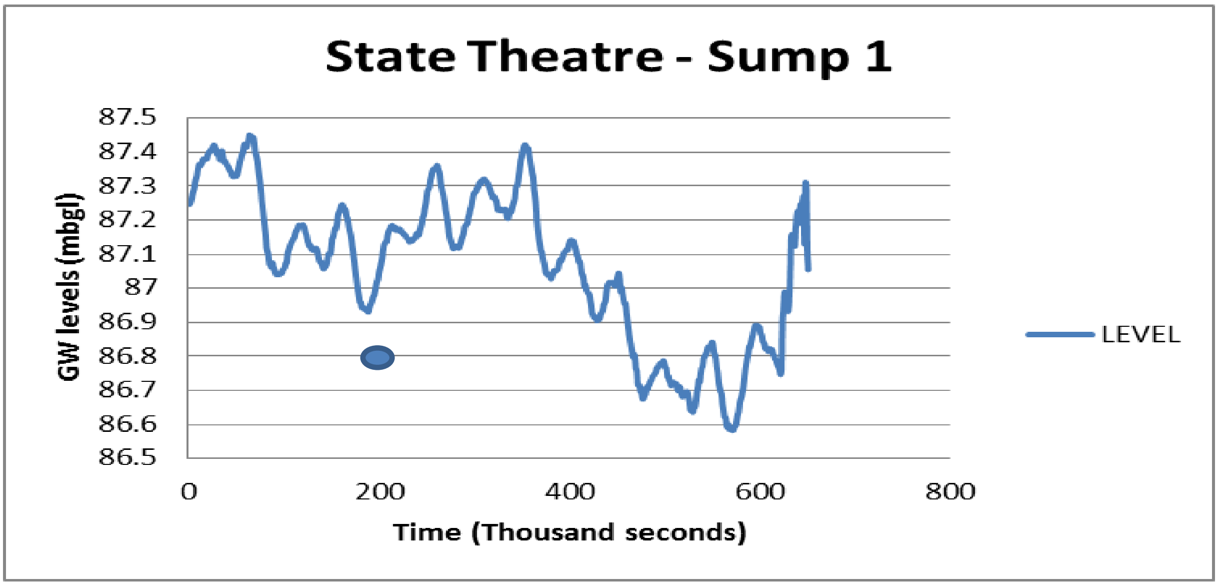


Figure 3.14: Sump 1 logger data graph

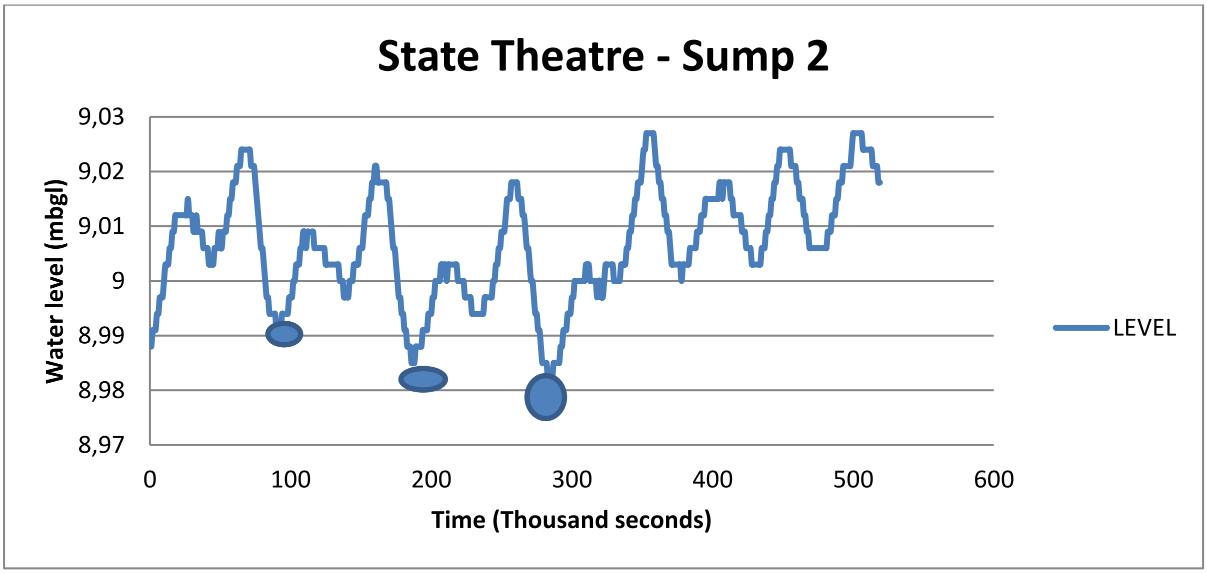


Figure 3.15: Sump 2 logger data graph

The total sump yield for the period of water level monitoring was determined by using the same equations and calculations indicated in the first example for the SARB, using the following equation:

$$Sump\ yield = \frac{(Total\ water\ level\ increase) * (Sump\ area)\ (cubic\ metre)}{Total\ period\ of\ monitoring\ (seconds)}$$

Table 3.5: Results for water demand and potential sump yield

Total sump yield	133 kl/d
Water demand	136 kl/d
Ratio	98%
Surplus	None

The total water demand of the State Theatre was 136 kl/d (Table 3.5), of which 65–75% was used for the air conditioning system. The yield of the sumps was estimated to be 133 kl/d, which could potentially cover almost 98% of the State Theatre's total water demand (see Appendix B). The possibility of supplementing the heating, ventilating and air conditioning system (HVAC) with groundwater to reduce water consumption from the council was investigated.

3.2.2.3 Tshwane House building

There were two sump pumps inside the parking area of the Tshwane House building situated in the eastern and western corners. The pumps were submersible. There was no need for a permit to discharge the basement water and rainwater into the stormwater system. There were no measurements prior to the discharge of the basement water into the stormwater system in terms of water quantity (how much has been discharged into stormwater) and quality (what kind of water quality).

The set-up of the basement exploitation drain in the Tshwane House was designed to collect groundwater around the building into one point and from the focus point (sump pump) discharged into stormwater. Tshwane House was using rainwater for toilet flushing, and water from shower was used for a garden. There was a filtration system for the purification of rainwater and shower water. The two sump pumps were not connected to each other. Information on the pumps is presented in Table 3.6.

Table 3.6: Sump pumps information

Sump name	Sump pump 1 (eastern corner)	Sump pump 2 (western corner)
Area	9 m^2	30 m^2
Datum below groundwater level	9 m	
Sump depth	3.6 m	3 m

❒ Water use and demand

The building used potable water for domestic use such as for drinking water and cleaning, fountains, and air conditioning system.

❒ Basement water use plans

Tshwane House had no plans for basement water use, but after engaging with Mr Hein Lotter, they were planning to use this water for flushing toilets and for the fountains. Tshwane House could also use their basement water for the air-conditioning system and fountains.

❒ Estimating sump yield (calculations) – Water level monitoring

The data recorded is presented in Figure 3.16. The results are presented in Table 3.7 and the calculations for illustration are presented in Appendix B. The results show the total estimated amount of water from the basement of the building. A water level logger was installed into the sump at 15:00 on 30 April 2018 and was removed at 13:30 on 07 May 2018. The measurements were taken for a week. The logger was installed at a depth of 3.6 m and was recorded at a 15-minute frequency. In graph in Figure 3.16 shows the inflow of water levels in the sump pump. These cycles in the water level shows the behaviour of the inflows of basement water at the sump pump.

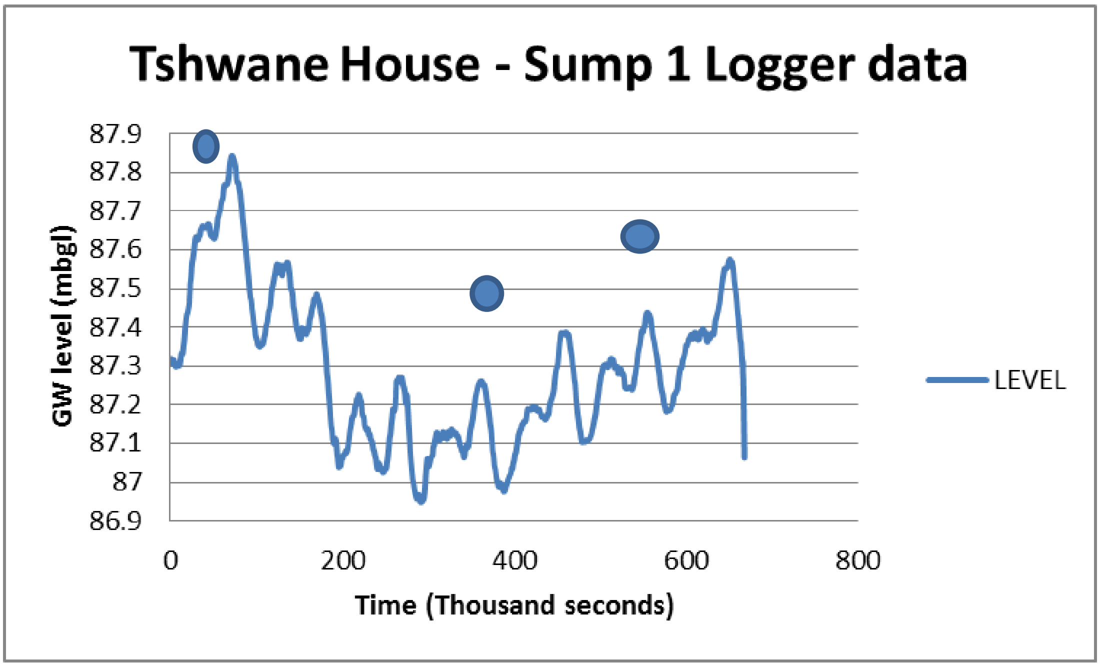


Figure 3.16: Sump logger data graph

The total sump yield for the period of water level monitoring was determined by using the same equation that was used in the section for the SARB calculations (Equation 1) and the results are shown in Table 3.7. The total yield of these sumps was estimated at around 0.602 l/s (**52 012.8 l/d**). The total water demand is approximately **45 kl/d**, which could be met by the estimated sump yield of 52 kl/d.

Table 3.7: Results for water demand and potential sump yield

Water demand	45 kl/d
Sump yield potential	52 kl/d
Ratio	116%
Surplus	7 kl/d

3.2.2.4 Centre Walk building

The Centre Walk building was experiencing groundwater leakages during rainy seasons. There was no need for a permit to discharge basement water and rainwater into the stormwater system. There were also no measurements prior to the discharge of the basement water into stormwater in terms of water quantity (how much has been discharged into stormwater) and quality (what kind of water quality).

The set-up of the basement exploitation drain in the Centre Walk building was designed to collect groundwater around the building into one point and from the focus point (sump pump) discharged into the stormwater system. The information on the pumps is presented in Table 3.8.

Table 3.8: Sump pumps information

Sump name	Sump pump 1
Sump area	9 m^2
Datum below groundwater level	9 m
Sump depth	1.4 m

❒ Water use and demand

The building used potable water for domestic use such as drinking water, cleaning, and toilet flushing, garden irrigation, and for the air conditioning system.

❒ Basement water use plans

The Centre Walk building was planning to use basement water for garden irrigation and cleaning of streets.

❒ Estimating sump yield (calculations) – Water level monitoring

The data recorded is presented in Figure 3.17 and the results are presented in Table 3.9. A water level logger was installed into the sump at 17:00 on 24 April 2018 and was removed at 11:00 on 30 April 2018. The measurements were taken for a week. The logger was installed at a depth of 1.4 m and was recorded at a 15-minute frequency. The graph in Figure 3.17 shows the inflow of water levels in the sump pump.

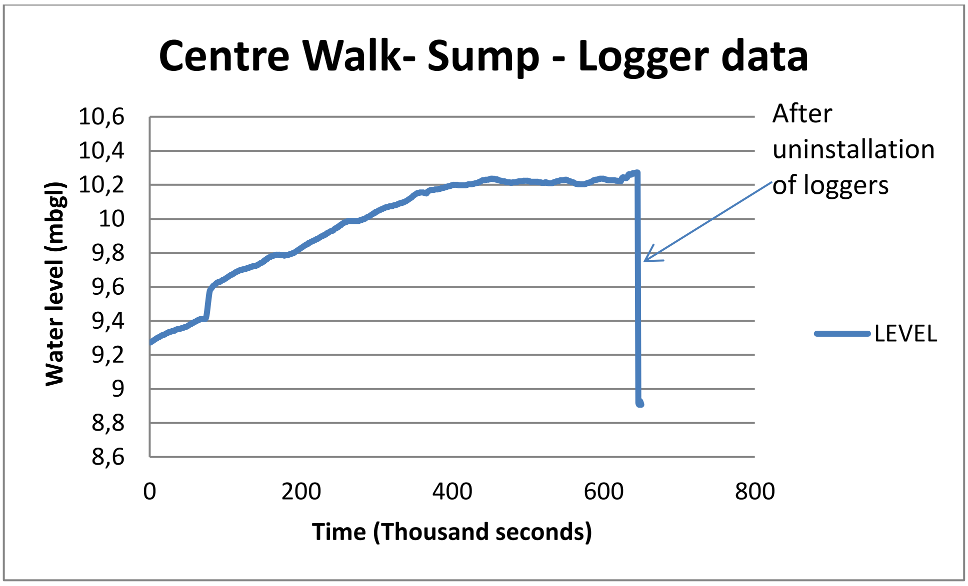


Figure 3.17: Sump logger data graph

The total sump yield for the period of water level monitoring was determined by the same equation that was used in the section for the SARB calculations (Equation 1).

Table 3.9: Results for water demand and potential sump yield

Water demand	14 kl/d
Sump yield potential	4.3 kl/d
Ratio	31%
Surplus	None

From the results presented in Table 3.9 it is clear that the total water demand of the building was 14 kl/d, which can be partially met by basement water (approximately 4.3 kl/d).

3.2.2.5 Demar building

The building has three basement levels, and the basement water is discharged into the storm water. The height of the basement is 8.3 m deep. The building has one sump pump that discharges the water into the storm water.

❒ Water use and demand

The building used potable water for domestic use such as drinking water, cleaning, and toilet flushing, garden irrigation and the air conditioning system.

❒ Basement water use plans

The Demar Building was planning to use basement water for garden irrigation and cleaning streets.

❒ Estimating sump yield (calculations) – Water level monitoring

The data recorded is shown in Figure 3.18 and the calculations are presented in Table 3.10. A water level logger was installed into the sump at 13:00 on 26 May 2018 and was removed at 11:15 on 2 June 2018. The measurements were taken for a week. The logger was installed at a depth of 2.9 m and was recorded at a 15-minute frequency. The graph in Figure 3.18 shows the inflow of water levels in the sump pump.

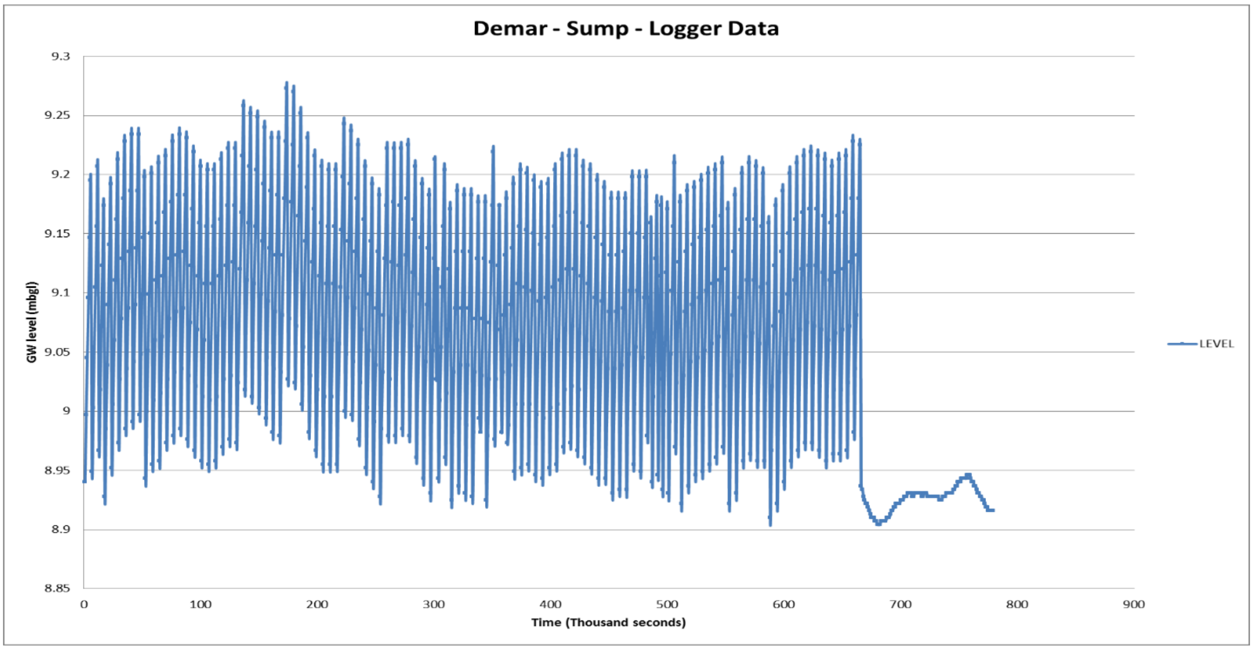


Figure 3.18: Sump logger data graph

The total sump yield for the period of water level monitoring is determined by the same equation that was used in the section of Reserve Bank calculations. Table 3.10 presents the results:

Table 3.10: Results for water demand and potential sump yield

Water demand	45 kl/d
Sump yield potential	15 kl/d
Ratio	33%
Surplus	None

Table 3.10 shows that the water demand of the building was 45 kl/d, while the total yield of the sumps was estimated to be 15 kl/d. Since basement water cannot meet the entire water demand, it can be used to augment the water supply, though some filtering and bacterial treatment would be required.

3.2.3 Case study discussion

3.2.3.1 Quantity

The average groundwater levels in the City of Tshwane were estimated to be around 3.63 mbgl (SA DWAF, 2006). The groundwater levels in the area were not homogenous; some areas were far deeper at approximately 50 mbgl. The depth of the basements of each building was below the average groundwater levels. The SARB and State Theatre had basements plus excavations which were estimated at around 11.1 m and 13.4 m, respectively, and these were below groundwater levels. Both of these buildings were pumping water continuously throughout the year. The total sump yield of each building (Reserve Bank and State Theatre) was 1.8 l/s (155 kl/d) and 1.54 l/s (133 kl/d), respectively. Considering the geological structures (Figure3.8) these two buildings are seated on a dyke or not far away from it. This can be the reason these buildings were pumping such a massive amount of water out of their buildings.

The water discharged into the stormwater system can be used for non-potable purposes in these buildings and any surplus water can be shared among non-potable water users such as for nearby parks, car wash and sports fields. Utilising the basement water can save a lot of potable water from the municipality’s water supply system. The shortage of water issues in an urban area could be solved by utilising basement water for the short term.

It was evident that these basements were below the groundwater levels as suggested by the measurements which were done in the winter where the rainfall was relatively low, and interflows were also low. However, a massive amount of water had been pumped from the subjects' basements. These buildings had the opportunity to start using the basement water to ensure that the potable water demand from the municipality would decrease, thus reducing the stress on the municipality's water supply system.

The sump yield of Tshwane House was 0.602 l/s which may also be used for the fountain ornaments and garden irrigation. The Demar building showed a high basement water yield with a sump yield of 0.182 l/s. The water may be used for other suitable uses. The sump yield of Centre Walk was 0.005 l/s and was low compared to the yields of the other buildings. The reason for this low sump yield may be due to other buildings such as Sterland Mall and Mediclinic Heart Hospital around Demar building that were dewatering the groundwater levels in their basements to keep the basements dry.

3.2.3.2 Up scaling benefits for the city

The result of the total yield was estimated at approximately 2.3 Ml/d (Appendix B: Up-scaling calculations). In comparison, the average basement yield (72 kl/d) calculated from the five case studies were applied to the 15 sites with basement seepage, the result would be an estimated minimum yield of 1.1 Ml/d (Appendix B: Up-scaling calculations).

These potential yields across the city were highly uncertain but these values showed the total potential water surplus available to the City of Tshwane from diverting basement water for beneficial use. This type of quantification was difficult without a complete audit. The average range between 1.1 Ml/d and 2.3 Ml/d of potential basement water surplus can be beneficially used in the Tshwane's CBD. Therefore, if implemented on a regional scale across the Tshwane Metropolitan Municipality area, the basement water use could alleviate some of the water demands in the City of Tshwane in a sustainable manner and reduce the reliance on the surface water. Nevertheless, this range of 1.1–2.3 Ml/d indicated that basement water comprises a non-negligible fraction of the total annual water demand of the City of Tshwane (up to 0.74%), which is comparable in the order of magnitude to 12.6% of the annual yield of the Rietvlei Dam located in Pretoria, Gauteng.

3.2.3.3 Legal permit for basement water use

In the City of Tshwane, the water supply by-laws of 2003 prohibit the use of water from other sources either than the water supply system, except for a rainwater tank not connected to a water installation, for either potable or non-potable use without the written consent of a city-appointed engineer and adherence to the imposed regulations regarding the water use. To gain permission, the water use must provide satisfactory evidence that the water (with or without treatment) complies with the requirements of SANS 241, or that the use of the water will not pose a danger to health.

Furthermore, according to the by-law, a borehole is “a hole sunk into the earth for the purpose of locating, abstracting or using subterranean water” (City of Tshwane, 2003:5), which indicates that basement water, that is water collected using abstraction in sump pits, should meet the requirements to comply with all by-laws applicable to boreholes. Metropolitan municipalities may request notification of planned and existing boreholes, require owners or occupiers to conduct an environmental impact assessment and obtain permission (and comply with its conditions) from the metropolitan municipalities to use the borehole for potable supply, as well as if the water is discharged into the city’s sewerage system, provide and maintain a meter measuring the total quantity of water discharged.

However, it appears that currently in the City of Tshwane the use of basement water was not regulated or enforced. From the five investigated sites, none had a permit (or claimed a need for one) to discharge basement water into the stormwater system and none were taking measurements of the quantity and quality of the discharged water. Considering the high discharge rates from some of them, for example the SARB with 155 kl/d and the State Theatre with 133 kl/d, and the high risk of urban groundwater contamination, the lack of compliance with the regulation of abstraction and discharging water may lead to a shortcoming in the city’s ability to manage the groundwater and stormwater systems, and create a health hazard. It is not allowed without registration or license. Furthermore, the General Authorisation states that water users must meter the quality of raw water abstracted and the quantity of water removed. The buildings should start metering their water abstracted from their basements. The metering water abstracted will assist in aquifer management as it will give an accurate picture of current groundwater use.

3.3 Groundwater quality analysis

The water analysis was done by the Waterlab in Pretoria for the chemical, trace elements, and microbiological parameters. The groundwater sources could be polluted by chemical and microbiological pollutants originating from natural sources, human activities, and sewage waste (Kelly, 1997). The major problem in urban groundwater is pollution. Hydro-geochemical processes in groundwater are largely controlled by the physical and chemical interactions that occur between the recharging water and the aquifer material. Table 3.11 shows the water analysis results, including both chemical and microbiological results.

Table 3.11: Water quality analysis results

Chemical constituents	SAWQG target water quality ranges: Irrigation (1996)	SANS 241: 2015 Standard limit (health)	Centre Walk building_01	Tshwane House building_02	State Theatre building_03	Reserve Bank building_04	Demar Building_05	Pretoria fountains lower (Spring)	Borehole Groenkloof	Borehole Lyttelton Manor (1183)
			14May 2018	14 May 2018	14 May 2018	14 May 2018	14 May 2018	April 2015	April 2015	April 2015
pH	6.5–8.4	5–9.7	7.7	7.3	7.5	8.9	7.8	8.076	8.08	7.7
EC (mS/m	≤90	≤170	26.9	55.8	51.6	67.6	44.2	49	42.9	34.5
Macro-chemistry (in mg/l)										
Total dissolved solids (TDS)	≤585	≤1 200	162	380	378	474	280	377.588	298	254
Turbidity in Nephelometric Turbidity Units	–	0–1	0.8	2.6	1.3	0.9	0.5	–	–	–
Free residual chlorine as Cl_2	–	–	<0.1	<0.1	<0.1	<0.1	<0.1	–	21	
Total alkalinity as $CaCO_3$	–	–	116	216	140	332	192	196.689	128.5	153.8
Chloride as Cl	≤100	≤300	6	33	48	26	17	22.439	0.11	1.5
Sulphate as SO_4	–	≤500	24	32	48	23	16	12.109	4.27	8.9
Flouride as F	≤2	≤1.5	<0.2	<0.2	<0.2	<0.2	<0.2	0.104	0.02	0.12
Nitrate as N	≤5	≤11	0.3	4.5	2.1	4.5	2.7	3.413	0.008	0.46
Nitrite as N	≤5	≤0.9	<0.05	<0.05	0.2	<0.05	<0.05	0.11		
Orthophosphate as P	–	–	0.2	<0.1	<0.1	0.5	<0.1	0.014		
Faecal coliform bacteria /(100 ml)	–	0	1	23	0	0	10	–		
Free and saline ammonia as N	–	–	<0.1	<0.1	0.4	<0.1	<0.1	–		
Sodium as Na	≤70	≤200	6	20	17	27	10	10.974	8.8	4.6
Potassium as K	–	≤50	2.8	0.6	3.6	1.8	3.8	0.853	0.15	0.62

Chemical constituents	SAWQG target water quality ranges: Irrigation (1996)	SANS 241: 2015 Standard limit (health)	Centre Walk building_01	Tshwane House building_02	State Theatre building_03	Reserve Bank building_04	Demar Building_05	Pretoria fountains lower (Spring)	Borehole Groenkloof	Borehole Lyttelton Manor (1183)
			14May 2018	14 May 2018	14 May 2018	14 May 2018	14 May 2018	April 2015	April 2015	April 2015
Calcium as Ca	–	≤150	39	52	52	77	45	48.629	38.1	27.3
Magnesium as Mg	–	≤70	5	30	22	47	23	27.372	25.2	28.4
Dissolved Metals (in ug/l)										
Aluminium as Al	≤5 000	≤300	<0.100	<0.100	<0.100	<0.100	<0.100			
Arsenic as As	≤100	≤10	0.001	<0.001	<0.001	<0.001	<0.001			
Cadmium as Cd	≤10	≤3	<0.003	<0.003	<0.003	<0.003	<0.003			
Total chromium as Cr	≤100	≤50	<0.025	<0.025	<0.025	<0.025	<0.025			
Cobalt as Co	≤50	≤500	<0.025	<0.025	<0.025	<0.025	<0.025			
Copper as Cu	≤200	≤2000	<0.010	<0.010	0.018	<0.010	<0.010			
Iron as Fe	≤5000	≤2000	<0.025	<0.025	<0.025	<0.025	<0.025			
Lead as Pb	≤200	≤10	<0.010	<0.010	<0.010	<0.010	<0.010			
Manganese as Mn	≤20	≤200	<0.025	<0.025	0.158	<0.025	<0.025			
Nickel as Ni	≤200	≤70	<0.025	<0.025	<0.025	<0.025	<0.025			
Zinc as Zn	≤1000	≤5000	<0.025	<0.025	0.150	0.489	0.189			
%Balancing			94.2	97.6	99.5	95.9	98.2			

3.3.1 Quality assurance

❒ Field vs laboratory data

pH and EC were measured in the field during groundwater sampling, using calibrated pH and EC meter equipment. For quality assurance, these measurements were repeated in the laboratory.

There was a good agreement between field and laboratory data for EC, with a correlation coefficient of 1.0. A good correlation existed between field pH measurements and the laboratory recorded pH (correlation coefficient of 0.88) (Figure 3.19). Small differences might have occurred due to degassing of samples and calibration.

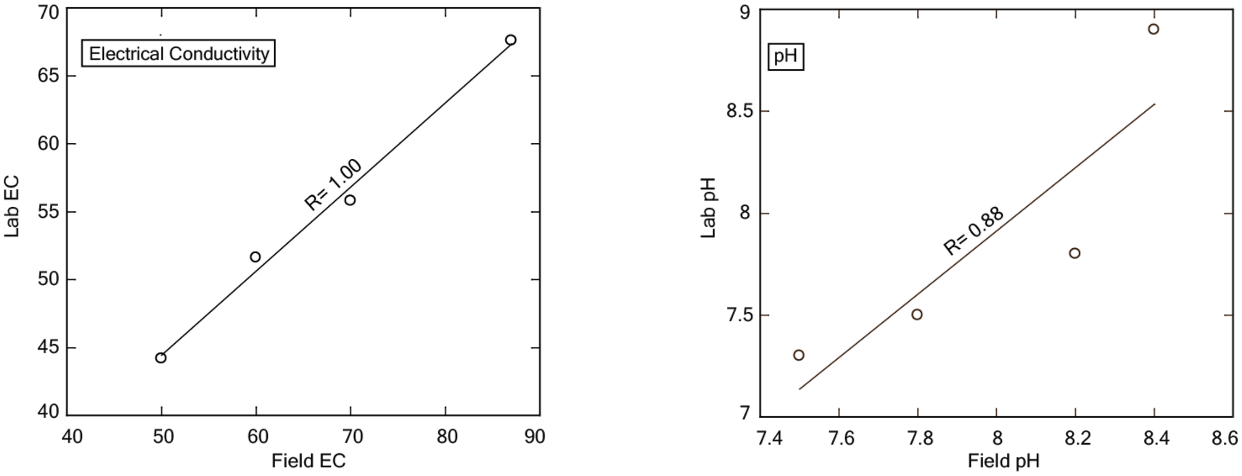


Figure 3.19: Field vs lab electrical conductivity and field vs lab pH

3.3.2 Groundwater classification

The water quality results indicated that the water quality generally satisfies the drinking water standards of the country, compared to the SANS 241 standards for domestic use and the South African Water Quality Guidelines (SAWQG) irrigation targets. The water can be used for human consumption and irrigation purposes. For the Reserve Bank, the pH was slightly elevated but only exceeded the standard limits for irrigation purposes (Table 3.11). The irrigation pH standard ranges from pH=6.5–8.4, while for the Reserve Bank building the pH was 8.9, with a difference of 0.5 for the required target. There is a need for verification of the water quality before any use would be implemented in these cases because the water quality in the urban area varied over a short period of time.

The faecal coliform concentration for the Reserve Bank and State Theatre was zero, which satisfies the targeted water quality. The Central Walk, Tshwane House, and Demar buildings exceeded the target water quality range for faecal coliforms (Table 3.11). Domestic wastewater and industrial effluent disposal were considered to be the major sources. The Central Walk, Reserve Bank, and Demar buildings satisfied the target water quality range of turbidity which was 0–1. Turbidity for the Tshwane House and State Theatre ranged from 1–5; meaning there was no visible turbidity and a slight chance of advanced aesthetic and infectious disease. Table 3.12 shows the coding where illustrate the water quality according to classes. On the water quality result, there are two classes (class 0 and class I) which are ideal and good water quality (Table 3.12).

Table 3.12: Coding

Ideal	Good	Bad	Extremely bad
Class 0	Class I	Class II	Class III
White	Orange	Darker Orange	Red

Source: SANS 241 (2015)

3.3.3 Piper diagram

The Piper diagram is one of the most commonly used graphical methods for interpreting hydro-chemical data. According to the analytical results, the Piper diagram of the hydrogeochemical composition of all water samples in the study area is shown in Figure 3.20. The results indicated that the water type for the basements, the boreholes at Groenkloof and Littleton Manor (1183) and the springs (Pretoria Fountains Lower) in the study area had a magnesium-calcium-bicarbonate (Mg-$CaCO_3$) composition, clearly indicating that the basement, spring, and groundwater had a similar water type. Groundwater quality had its natural variations. Almost all the samples were clustered in the magnesium-calcium-bicarbonate facies of the Piper diagram. That reflected the chemistry of the dolomite, indicating that the dissolution of dolomite was the dominant process controlling the chemistry of the groundwater or weathering of silicate minerals. As expected, groundwater from the dolomitic aquifers was of magnesium-calcium-bicarbonate nature due to the dolomite composition.

Sampling results for the basement, springs and borehole waters were taken from the National Groundwater Archive which were taken in 2015 by Department of Water and Sanitation to compare with the sampling analysis of the current study. The location of the boreholes and springs were within the A23D catchment quaternary in a 10 km radius related to the buildings. The samples for the current study were all exhibiting the same hydrogeochemical characteristics as those recorded in the National Groundwater Archive database, suggesting groundwater discharge into surface water systems via springs, with the primary source for basement water being groundwater discharge. The State Theatre was the only the outlier in the Piper diagram (Figure 3.20).

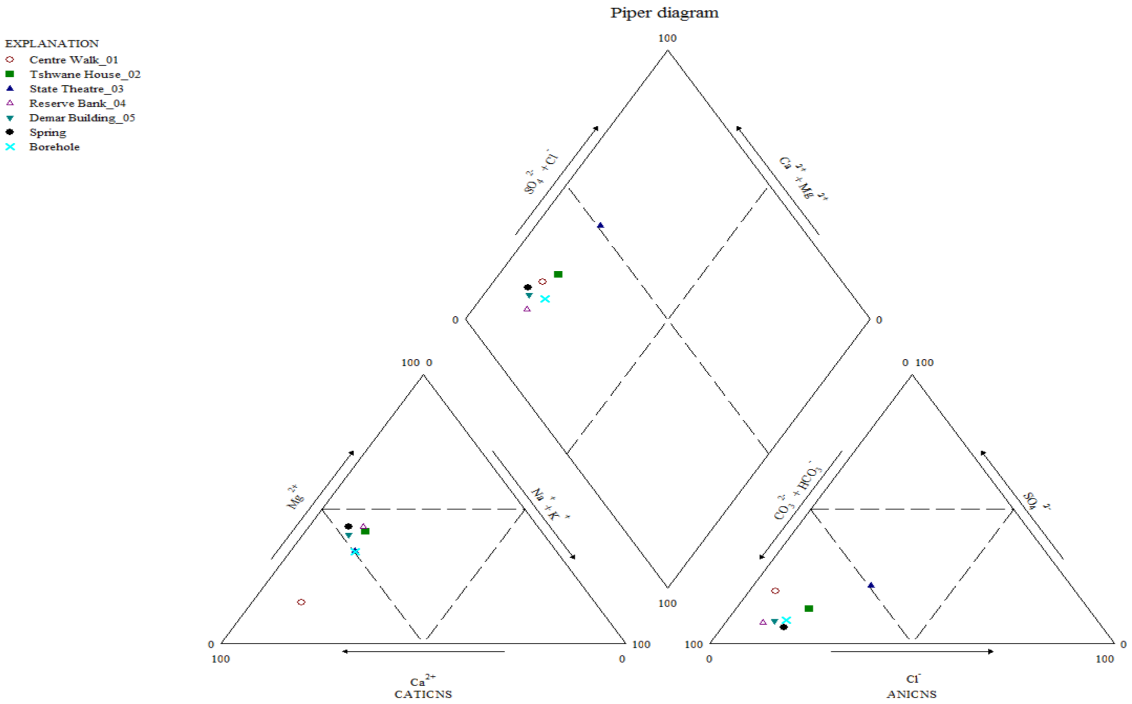


Figure 3.20: Piper diagram

3.3.4 Sodium adsorption ratio diagram

In the study area, the result showed that all of the samples were clustered into the C2S1 class (Figure 3.21). These are expressed as excellent and good waters, suitable for irrigation purposes.

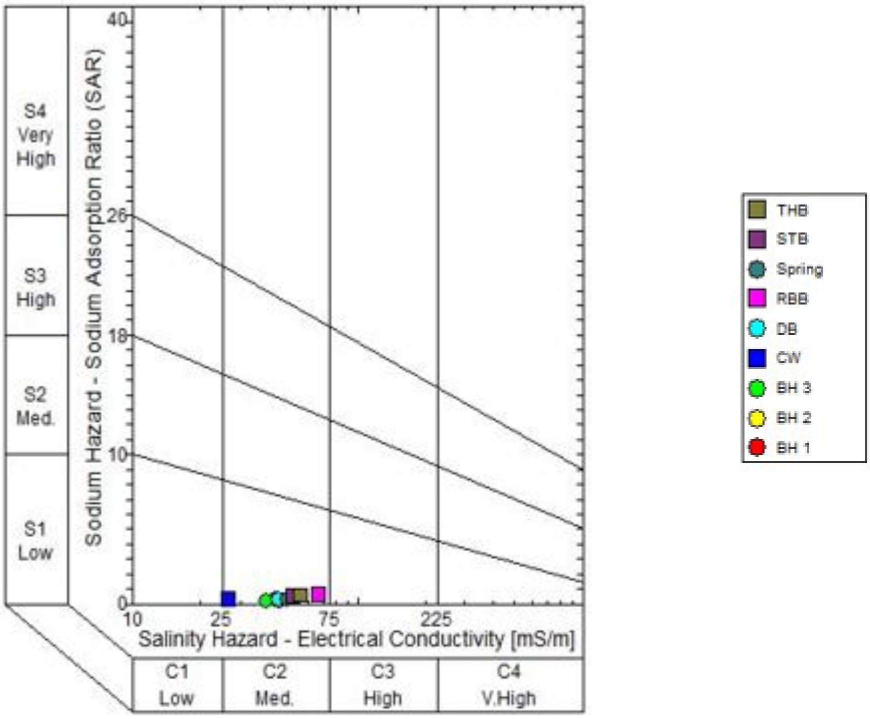


Figure 3.21: Sodium adsorption ratio diagram

3.3.5 Total dissolved solids

The TDS in water consists of inorganic salts and some small amounts of organic matter that are dissolved in water. Based on TDS levels from the World Health Organization (2017), Table 3.13 and Figure 3.22 show the groundwater quality classification for the study area.

Table 3.13: Groundwater quality classification of the site based on total dissolved solids

Total dissolved solids (mg/l)	Quality	Number of the samples
<300	Excellent	2
300– 600	Good	3
600 – 900	Fair	0
900 – 1 200	Poor	0
>1 200	Unacceptable	0

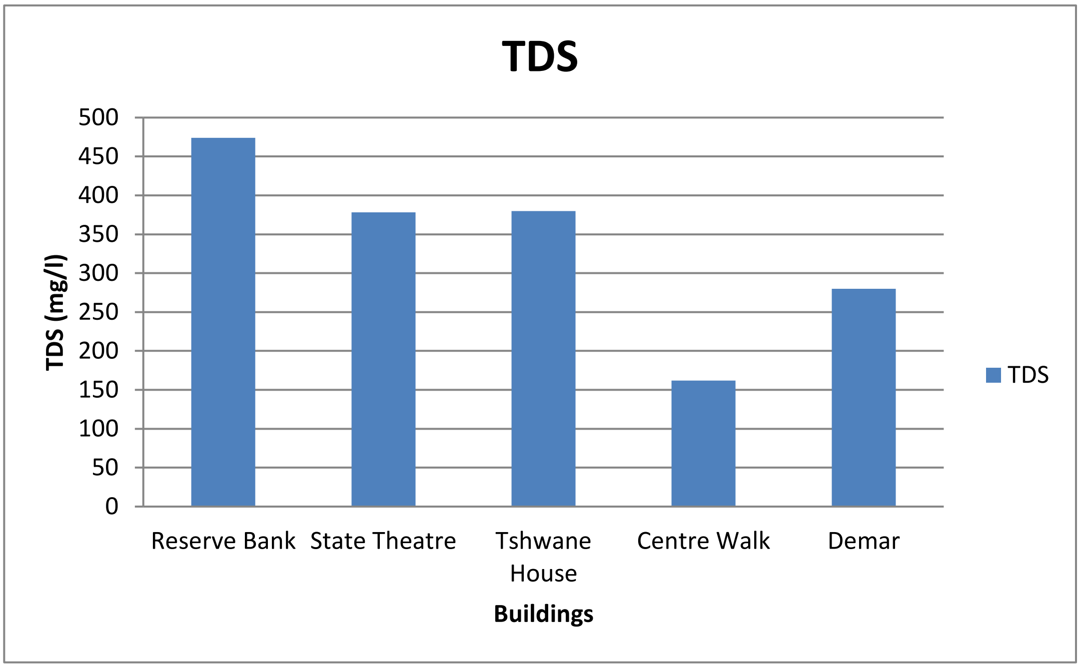


Figure 3.22: Variation of the total dissolved solids in the study area

The basement water at two sites (Centre Walk and Demar building) had TDS concentrations of less than 300 mg/l and can therefore be classified as excellent drinking quality. The remaining three sites (Reserve Bank, State Theatre and Tshwane House) had TDS values ranging between 300 mg/land 600 mg/l and can therefore be classified as good quality drinking water. According to the groundwater classification, the water is good for human consumption and other uses.

3.3.6 Hardness

Hardness in water is caused by the presence of a high level of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. These ions combine with carbonate (CO_3) when dissolved in water to produce scale which is composed of insoluble carbonates ($CaCO_3$ and $MgCO_3$). Table 3.14 and Figure 3.23 show the hardness classification (and respective variation) for the groundwater that was calculated based on the index (groundwater hardness classification).

Table 3.14: Groundwater hardness classification

Total hardness as $CaCO_3$ (mg/l)	Hardness class	Number of samples
<60	Soft	4
60 – 120	Moderately hard	1
120 – 180	Hard	0
>180	Very hard	0

Source: McGowan (2000)

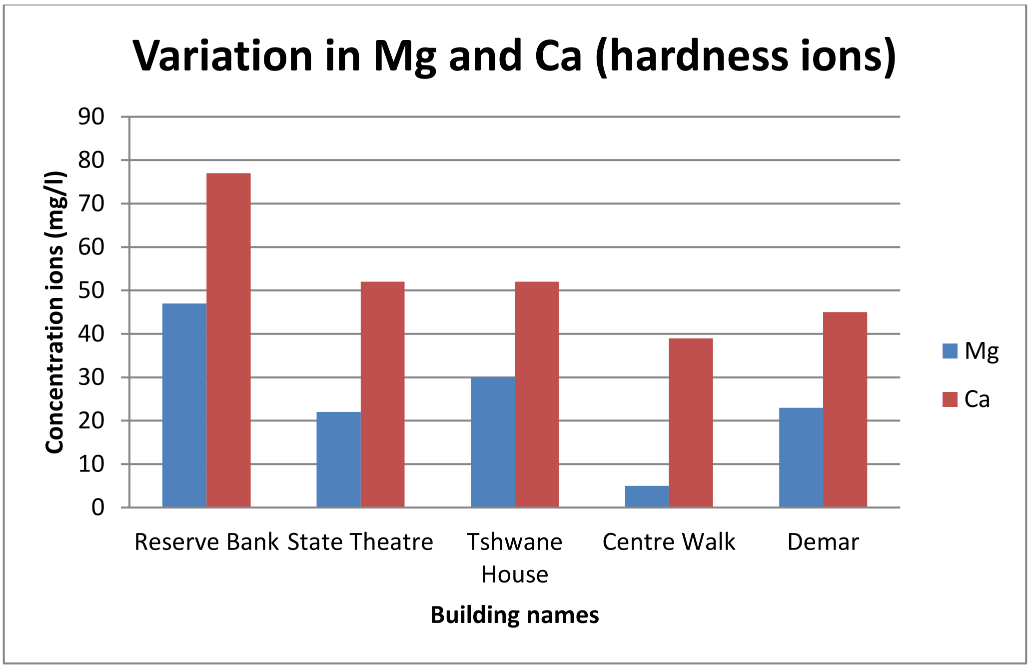


Figure 3.23: Variation in Mg and Ca concentrations for basement water at various sites

The results showed that 80% of the water samples collected in the basement sump had characteristics of soft class conditions (total hardness as $CaCO_3$ less than 60%) and 20% was classified as of a moderately hardness class. The hardness results showed that the majority of the basement sump samples can be characterized by a soft class of hardness which is mainly driven by the release of Mg^{2+} and Ca^{2+} ions. If the hardness level is less than 150 mg/l it is not problematic in terms of scaling issues or corrosion of the pipe works.

3.4 Cost–benefit analysis

The focus of this section is on proposals to use basement water to augment, supplement or replace municipal water supply and to build a business case to use basement water for various purposes per site, instead of using potable municipal water. The following options were evaluated, with life cycle costs and cost–benefit analysis:

- Use of basement water for air-conditioning systems.
- Using of basement water for all water demands in the building.

3.4.1 Business Case 1: State Theatre

3.4.1.1 Overview

A site inspection was conducted on 13 August 2018 at the State Theatre in the City of Tshwane for a financial feasibility study with Mr F. Snyman and Mr T. Molibeli from AQUAffection. A quotation was requested for the development of basement water. In line with the case study project to initiate or encourage the use of basement water, the company requested solutions to use basement water to augment or supplement the municipal supply, and by doing so, reducing the monthly cost of potable water and in cases of drought or emergency, the basement water use could be augmented to supply the whole building.

3.4.1.2 Description: AQUAffection business case proposal, 2018

The cost of the use of basement water for air conditioning was done by AQUAffection for the integrated basement water and municipal water system tank storage for supplying the HVAC system at the State Theatre. The proposed integrated system will be between groundwater harvested from the sump pits and the incoming municipal water supplied to the building. The groundwater will be pumped and stored in a combined municipal and groundwater storage tank. The groundwater will be pre-filtered before mixing with council water in the combined storage tank to mitigate the build-up of sediment and particles in the water storage tank.

A water treatment system will also be installed before water supply to the chillers to provide for effective efficiency, which in turn will conserve water and maintain the HVAC equipment and components. The treatment will lead to an economical operation cost of the HVAC system and also maintain the assets of the theatre. The water treatment will protect the equipment from scaling and other defects that may possibly cause damage to the HVAC system components. The proposed HVAC operating system will also serve as a water backup system; hence, the storage tanks need to be able to cater for periods of potential municipal water shedding.

The proposed integrated HVAC system installation will consist of a water storage tank for combined resources, a water storage tank for potable water, a pre-filtration unit, a filtration unit, a chemical dosing system, including water level management, pumps, and groundwater transportation pipelines and fittings.

3.4.1.3 Financial summary

Estimates of capital costs for the implementation of the groundwater (basement water) harvesting for HVAC and as backup of the potable municipal water when it stops is indicated in Appendix D. The costs summary is provided in Table 3.15 and Table 3.16 (based on the current design).

Table 3.15: Summary of proposed installation costs for the integrated heating, ventilating and air-conditioning system

The proposed integrated HVAC system installation will consist of the following:	**Quantity**	**Cost**	**Grand Total (including VAT)**
Water storage tank (combined resources), water storage tank (potable water), pre-filtration unit, chemical dosing system, water level management, pumps, and groundwater transportation pipelines and fittings	1 each	R1 500 000.00 (total excluding VAT)	R1 725 000.00

Source: AQUAffection (2018)

Table 3.16: Price summary for operation and maintenance

Description	**Cost (excluding VAT)**
Operation and maintenance of water treatment plant (O&M)	R144 000 per year

Source: AQUAffection (2018)

Table 3.17: Cost analysis summary

Year	**Cost of potable water**	**Cost of basement water developing**	**Maintenance And operations**	**Total cost to State Theatre**	**Balance on budget**
Year 0	R900 000	R1.5 M		R 2.4M	R1.5M
Year 1	R360 000 – R225 000		R144 000	R504 000 – R369 000	R1.104M – R0.969M
Year 2	R360 000 – R225 000		R144 000	R504 000 – R369 000	R0.708M – R0.438M
Year 3	R360 000 – R225 000		R144 000	R504 000 – R369 000	R0.312M – R0.093M
Year 4	R360 000 – R225 000		R144 000	R504 000 – R369 000	R0.084M – R0.624M

Source: AQUAffection (2018)

3.4.1.4 Cost–benefit analysis

- Cost of the potable water ±R900 000 (annually) with a total demand of 49 640 m^3/annum (1.6 l/s).
- The potential basement water can cover almost 98% of their water demand.

- The State Theatre was using 60–75% of its potable water for the air conditioning system.
- The cost is for developing the basement water use system for the air conditioning system.
- The total cost of the basement water use was estimated at ±R 1.5 M (excluding VAT).
- Maintenance and operation ±R144 000 per year.
- The capital would be recovered in a three-year period.
- The State Theatre could save R396 000 to R531 000 per year.
- Water could be saved from the municipal water supply system: 29 784 m^{3}to 37 230 m^{3}per annum or 81 kl/d to 102 kl/d.

The use of basement water for the air conditioning system would be economically wise for the State Theatre because, after three years, the capital investment could be recovered. This investment or proposal can be regarded as feasible and efficient.

The State Theatre will only use between 81 kl/day and 102 kl/day from the available basement water of 133 kl/day that will result in the State Theatre still having a surplus between 52 kl/day and 31 kl/day to that of the stormwater system that provides a further option to develop or donate the surplus water for neighbouring buildings or used for sports fields and parks in the vicinity.

3.4.2 Business Case 2: Reserve Bank building

3.4.2.1 Objective of the Reserve Bank building business case

The main objective of the Reserve Bank building business case (hereafter referred to as Business Case 2) was to investigate the feasibility of utilising the groundwater that is abstracted from the basement of the SARB building in the Pretoria CBD. The following key aspects were considered:

- Capital costs.
- Operation and maintenance (O&M) costs.
- Cost of the current municipal water supply.
- Life cycle cost analysis of the afore-mentioned costs over a period of twenty years.

- Cost–benefit ratios based on the nett present values (NPVs), which were derived from the life cycle cost analysis.

3.4.2.2 Scope of Business Case 2

The SARB is the central bank of South Africa. The SARB building has 37 floors, which include the basement levels. Each story is approximately 4 m high, and therefore the total height of the building is approximately 148 m, including the basement levels. The SARB building currently receives its water from the City of Tshwane's municipal system for domestic use as well as for the associated, mostly non-potable uses, for example carwash, the fountains, toilet flushing and the air conditioning system. The SARB could use basement water for only garden irrigation and the air conditioning system; however, saving costs should they treat and integrate the basement water that is currently abstracted from the building's basement into the building's water supply system.

The building's sump pump collection and discharge systems were designed to collect ingress groundwater around the building into a sump, which is then pumped up to the surface. There were two separate pump sets for both the sumps inside and outside of the building. Each pump set consisted of two pumps, with one pump running and the other pump always being on standby. A small percentage (10%) of the groundwater has been utilised for the gardens. The remaining water (90%) was, however, discharged into the City of Tshwane's municipal storm water system, which drains towards the Apies River. The groundwater ingress occurs throughout the year, but it increases during the rainy season. The details of the two respective groundwater sumps are given in Table 3.18.

Table 3.18: Details of the groundwater sumps

Description	Sump 1 – Outside	Sump 2 – Inside
Surface area (m^2)	54.4	25.0
Depth of top below ground level (m)	11.1	11.1
Sump depth (m)	3.6	3.2
Sump volume (m^3)	195.84	80.00

The investigation for this business case was a pre-feasibility level of detail investigation to establish whether this business case could be taken forward to the feasibility level of detailed investigation, which would also include a preliminary design. The scope of this investigation was therefore limited to the following:

- Site visits and fieldwork.
- Investigating the status quo in terms of the groundwater and the municipal water supply.
- Assessment of the water requirements.
- Assessment of the groundwater availability and quality.
- To propose and investigate the option for groundwater utilisation in and around the building (treatment and connection to the building's existing water supply system).
- Cost of the proposed groundwater utilisation option.
- Life cycle cost analysis and the cost–benefit ratios.

❒ Site visits and fieldwork

Two site visits were undertaken to the building during May 2018 and November 2019, respectively, which are discussed below:

❒ Site visit of 14 May 2018

The first site visit to the building was undertaken on 14 May 2018 and the main purpose thereof was to undertake the necessary fieldwork, which included the following:

- A meeting with the engineering services manager (Mr Gerhard Anker).
- Installation of data loggers for quantifying the discharged volumes.
- Water sampling of the groundwater.
- Measuring the sizes of the two groundwater sumps (Table 3.18).

❒ Site visit of 11 November 2019

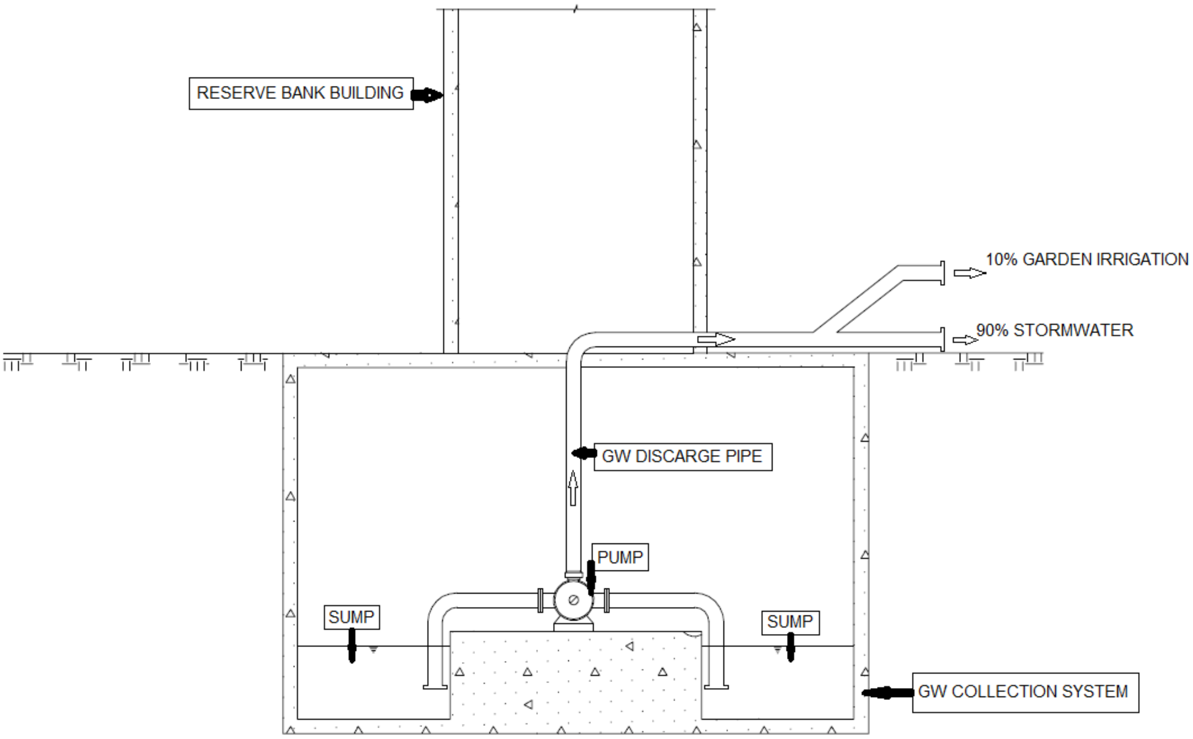
The second site visit to the SARB was undertaken on 11 November 2019 and the main purpose thereof was site inspections of the building's main water supply system and groundwater abstraction system. An experienced civil engineer from the DWS, Mr Johann Enslin, who was the chief engineer for DWS options analysis (northern areas), was also present in order to guide and mentor the researcher on the various engineering aspects associated with this business case.

Prior to the aforesaid site inspections, a meeting was held on the same day with the building's engineering services manager, Mr Gerhard Anker, with regard to the purpose and objective of this particular site visit. After the aforesaid meeting, Mr Anker led the site inspections from the first basement story right up to the top floor, which is the 33rd story above ground level.

During the meeting, Mr Anker explained both systems, namely the domestic supply system and the groundwater abstraction system. Furthermore, Mr Anker also answered all the technical questions that the researcher asked. The information sourced during this site visit informed the costing, the life cycle cost analysis and cost–benefit ratio calculations for the proposed groundwater utilisation option for the building as discussed below.

3.4.2.3 Status quo of the groundwater abstraction at, and municipal water supply to, the Reserve Bank building

As already stated under subsection 3.4.2.2 above, only about 10% of the groundwater is used to water the building's gardens, while all the remaining groundwater was discharged into the City of Tshwane's storm water system. Figure 3.24 provides a schematic presentation of the current groundwater abstraction from the basement for discharging into the City of Tshwane's storm water system and for irrigation:

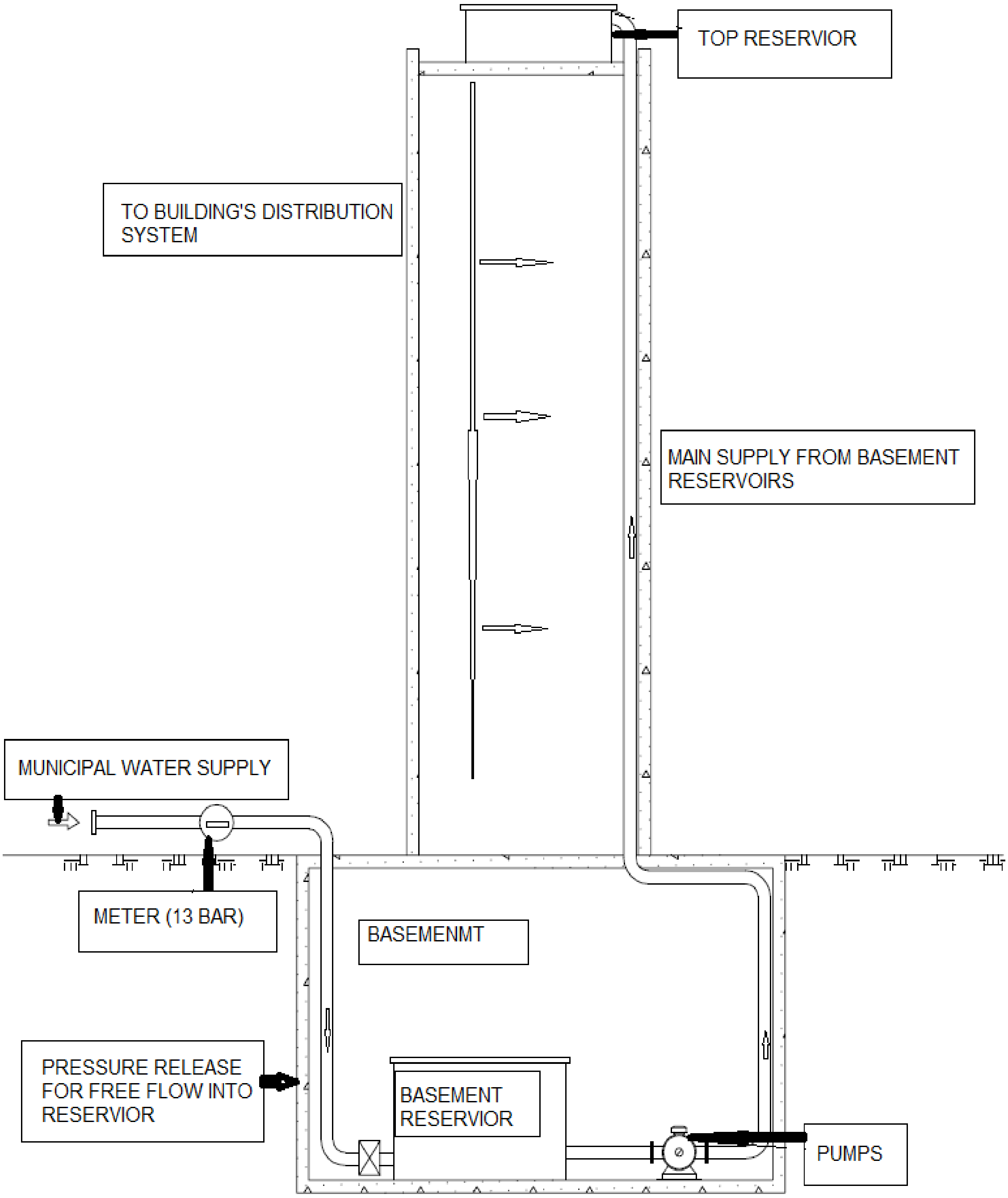


Source: AutoCAD (2019)

Figure 3.24: Current basement water abstraction from the building's basement for discharging into the City of Tshwane's storm water system and for irrigation

The building currently obtains its domestic (potable) water supply from the City of Tshwane's municipal water supply system. There is a 150 mm diameter supply pipe from the City of Tshwane's municipal water supply system in which the pressure is about 13 bar

(132.6 m). Pressure reduction valves within the supply pipe, however, reduce the aforesaid pressure significantly in order for the water to flow freely into the building's storage tanks in the basement. The water is pumped from the basement storage tanks right up to, and into, the building's storage tanks on the top floor from where the water is then distributed under gravity throughout the building. Figure 3.25 gives a schematic presentation of the building's current water distribution system from the municipal water supply system:



Source: AutoCAD (2019)

Figure 3.25: Current water distribution system from the municipal water supply system at the Reserve Bank building

3.4.2.4 Water requirements

The estimated average daily water requirement for the building is about 75.85 kl/d, which is based on water meter readings from April 2018 to May 2019 as listed in Table 1D of Appendix D. Furthermore, the available groundwater is about 155.50 kl/d, and therefore it can fully supply the average daily water requirement. The SARB could, therefore, utilise the ingress groundwater, which is abstracted and currently mostly discarded, conjunctively with the municipal supply. Furthermore, the SARB could also utilise the excess groundwater for further beneficial uses, for example by donating this water to neighbouring buildings and/or the nearby sports field for irrigation.

3.4.2.5 Groundwater availability, quality, and treatment

The estimated groundwater ingress is approximately 1.8 l/s, which equated to about 155.52 Ml/d. The water quality assessment results indicated that the groundwater quality generally satisfies the SANS 241 (2015) requirements. The water quality results were compared to SANS 241 for domestic use (2015) and the SAWQG (SA DWS, 2015). Therefore, the groundwater from the basement of the SARB building can be utilised for human consumption, with the minimal treatment thereof, as well as for irrigation purposes. The pH of the groundwater was good, however, slightly elevated, although only exceeding the Standard Limits for Irrigation Purposes (SANS 241). The irrigation pH standard ranged from 6.5 to 8.4, while the groundwater from the building’s pH was 8.9. The groundwater quality should, however, be regularly monitored and verified since the groundwater quality within urban areas varies over short periods of time due to the urbanisation activities that have a negative impact on groundwater. Furthermore, the hardness levels are/ more than 150 mg/l, which could be problematic in terms of scaling issues or corrosion of water pipes. Therefore, some treatment of the groundwater from the building’s basement would be required as a precautionary measure. The groundwater quality test results and comparisons are contained in Appendix C.

For the groundwater treatment, a fully automated containerised package water treatment plant (WTP) is proposed. The WTP will be required to have a maximum treatment capacity of about 80 kl/d in order to supply treated (potable) water for the building. The proposed WTP will consist of the following key components:

- An in-let strainer to remove debris from the supply sumps and an accumulative flow meter to measure water abstraction from the sumps. This flow meter can also be utilised to measure daily water flows and consumption for record-keeping purposes.
- A polyethylene tank of 5 000 l to store the inlet water, to be equipped with electronic level control and to be accommodated inside a modified 6 m shipping container.
- A process water feed pump set, which will consist of one duty pump and one standby sump, to supply the groundwater to a hydrochemical activation module.
- A hydrochemical activation module for the destruction of all harmful bacteria and pathogens as well as toxins that may exist in the water.
- A contact tank to optimise the flocculation process is to be incorporated into the package WTP container, followed by a manual flow control in order to achieve optimum flow rates within the filtration unit.
- A dual-media sand filtration unit into which the pre-treated water enters, comprising of hydra anthracite and silica sand. Dual-media filtration uses two layers, a top one of anthracite and a bottom one of sand, to remove the residual biological flow contained in settled, secondary treated wastewater effluents and residual chemical-biological floe after alum, iron, or lime precipitation in potable water treatment plants.
- A granular activated carbon filter bed through which the filtered water will pass directly into the 100 kl panel tank for potable water storage.

All the above-mentioned filters will be fully automated and will back-wash automatically as programmed. The panel tank, which will be fitted with an electronic level control for the automation of the plant, will be situated next to the WTP container. The package WTP treatment process is depicted in Figure 3.26.

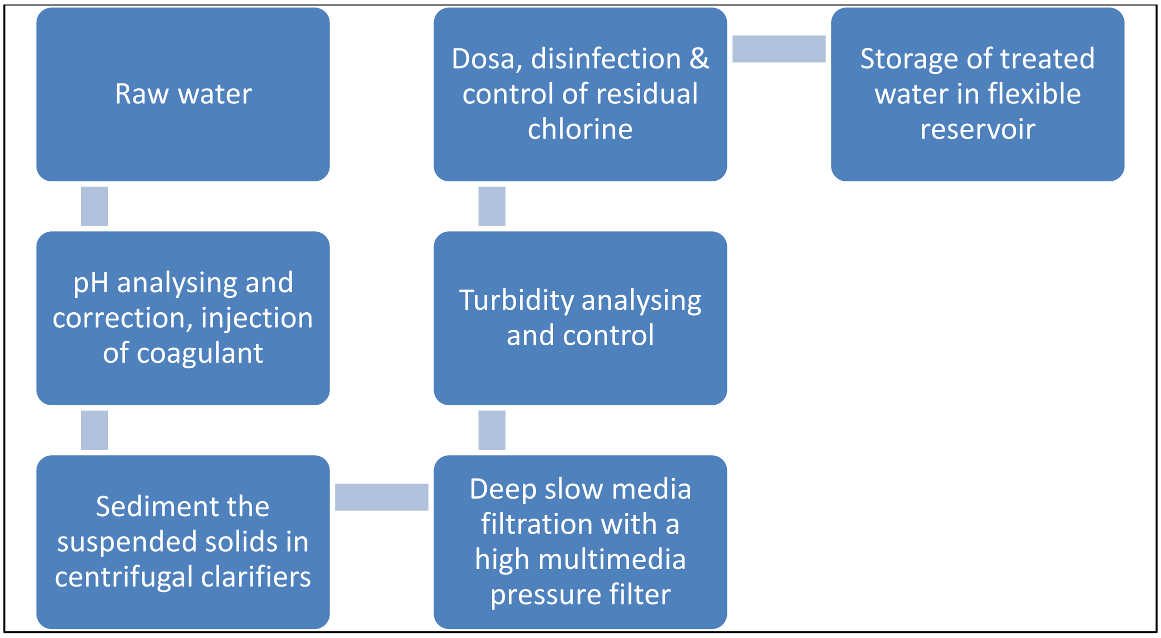


Figure 3.26: The treatment process of the package water treatment plant

3.4.2.6 Proposed option investigated for groundwater utilisation in and around the Reserve Bank building

For the proposed option for groundwater utilisation in and around the building (hereafter referred to as the proposed option) there is no need for any changes to the building. Basically, the treated groundwater from the basement needs to be piped and connected to the building's existing water supply system. The proposed option is to treat and utilise the groundwater from the building's basement for domestic use inside the building (after treatment) and for the gardens on the outside. Figure 3.28 is a schematic presentation of the proposed option.

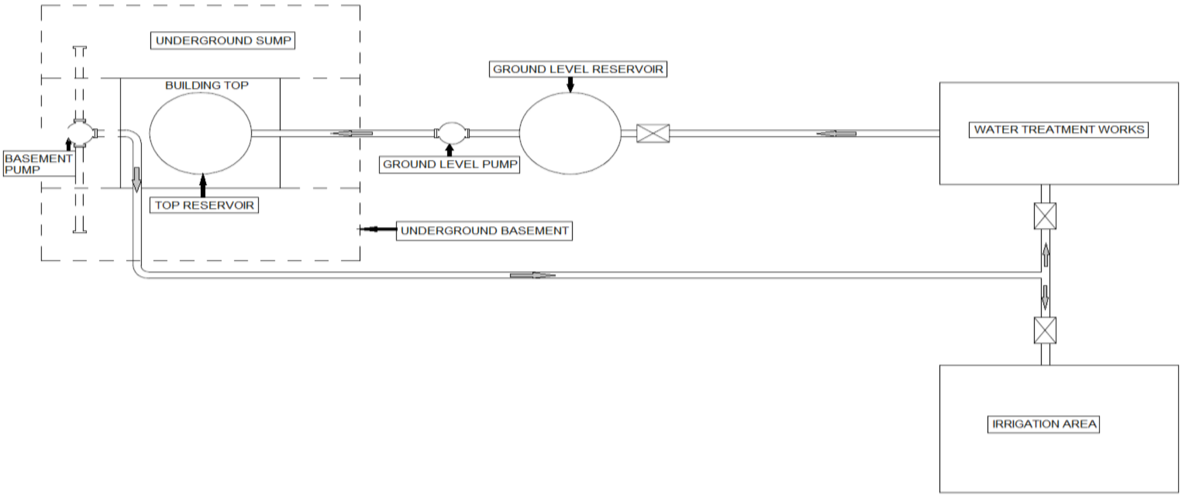


Figure 3.27: Top view of the proposed option

3.4.2.7 Cost of the proposed option for groundwater utilisation

The base date for all the rates for the purposes of the cost estimates is December 2019. The rates per metre for the supply and delivery of 150 mm diameter steel pipes that were obtained from three steel pipe suppliers, are summarised in Table 3.19. The average assumed rate was therefore taken as R1 667 per metre for the purposes of this investigation.

Table 3.19: Rates for the supply and delivery of 150 mm diameter steel pipes at December 2019 prices

Supplier	Rate per meter for supply and delivery
Envirowater (Pty) Ltd	R1 500
Aquamat SA (Pty)	R1 500
Murray & Roberts company	R2 000
Average assumed rate for supply and delivery	**R1 667**

All the costs pertaining to the package WTP, which are contained in Table 3.20, were obtained from the proposed supplier, namely Envirowater:

Table 3.20: Costs associated with the package water treatment plant

Description	Rate	Quantity	Total cost	Cost per annum
Supply and delivery of the package WTP	R800 000	1	R800 000	–
Energy cost	R4.78/kl	76 kl/d over 365 days	–	R132 597
Treatment	R1.47/kl	76 kl/d over 365 days	–	R40 778

The capital costs, O&M costs as well as the life cycle costing were based on the cost model for pipelines, which is contained in the Vaal Augmentation Planning Study Guidelines for the preliminary sizing, costing and engineering economic evaluation of planning options (SA DWAF 1996). A summary of the estimated capital cost, as well as O&M costs for the proposed option, are given in Table 3.21. The cost model, as well as all the calculations pertaining to the O&M costs, as well as the life cycle cost analysis, are contained in Appendix 2D and 3D, respectively.

Table 3.21: Summary of the estimated capital as well as operation and maintenance costs for the proposed option

Description	Amount
Total estimated capital cost for civil works (including VAT)	R114 343
Total estimated capital cost for mechanical and electrical (M&E) works, including the package WTP (including VAT)	R1 689 458
Total estimated capital cost	**R1 803 801**
Estimated O&M cost for the civil works per annum (0.25% of the total estimated capital cost for the civil works)	R286 per annum
Estimated O&M cost for the M&E works per annum (2.5% of the total estimated capital cost for the M&E works)	R42 23 per annum
Total estimated O&M cost per annum	**R42 522 per annum**
Estimated refurbishment cost for the M&E works after 20 years (50% of the total estimated capital cost for the M&E works)	**R844 729**

3.4.2.8 Life cycle cost analysis and cost–benefit ratios

The life cycle costs analysis for the proposed option was undertaken for a period of 20 years from 2020 until 2040, which is based on the following estimated costs:

- Capital cost.
- Annual O&M cost.
- Annual water treatment cost in terms of energy and chemicals.
- Refurbishment cost of the M&E works after 20 years.

The life cycle cost analysis for the municipal supply was only based on the municipal water tariff and what the SARB paid annually for their water to the City of Tshwane. The results of the life cycle cost analysis were the so-called NPVs for the proposed option and for the municipal supply from the City of Tshwane at discount rates of 6%, 8% and 10% per annum, respectively. The cost and benefits are the following:

- The NPV for the proposed option is the cost.
- The NPV for the municipal water supply is the benefit, meaning that the SARB would not need to pay for municipal water if they would utilise the groundwater from the building’s basement.

The annual cost of municipal water supply of R682 650 per annum was based on the City of Tshwane’s water tariffs for an average supply of about 27 700 kl per annum, at 2019 tariffs. The water tariffs were sourced from the City of Tshwane’s website. Both the life cycle cost analysis and cost–benefit ratio calculations are contained in Appendix 4Dand a summary of the calculated NPVs and cost–benefit ratios are contained in Table 3.22.

Table 3.22: Summary of the calculated nett present values and cost–benefit ratios

Description	Discount rates per annum (%)		
	6%	8%	10%
Calculated NPV for the proposed option (cost)	R4 759 417	R4 320 648	R3 983 320
Calculated NPV for the municipal supply (benefit)	R8 512 592	R7 385 008	R6 494 434
Calculated cost–benefit ratios	**0.56**	**0.59**	**0.61**

3.4.2.9 Conclusion and recommendation

The cost–benefit ratios for all the discount rates (refer to Table 3.22) were significantly less than one, and therefore the proposed option is economically viable and a feasible option for the SARB to implement. The capital cost can also be recovered within about 32 months since the SARB will not really need to purchase any municipal water, except in the case of an emergency and for maintaining the municipal water supply pipe from time to time. It is therefore recommended that the SARB commission a feasibility study for the proposed option, which should also include a preliminary design and a more detailed costing of the proposed option.

3.4.3 Business Case 3: Tshwane House

The potential sump yield can supply the entire building’s water demand which is 52 kl/d and 45 kl/d, at Tshwane House. The basement water design comprised of the water treatment plant, storage, and distribution pipes. The cost breakdown is indicated in Table 3.23. It is recommended that basement water development should take place at Tshwane House and off-grid from the municipal water supply system.

Table 3.23: Cost of the items

Description	Cost*
Pre-filtration, ultrafiltration system, ultrafiltration system specifications, submersible pump, tanks, piping and inline equipment and membrane replacement	R508 314
Operation and maintenance	R12 530 per month
Total (excluding VAT)	R508 314 (excluding O&M)

*All pipework, travel, and installation included. Source: AQUAffection (2018)

3.4.3.1 Cost–benefit analysis

- The cost of potable water for Tshwane House was ±R405 000.00 per year.
- The potential basement water could cover all their water demand.
- The total cost of the basement water use was estimated at ±R508 314.
- Maintenance and operation ±R150 360 per year.
- The capital out lay could be recovered in a two-year period.
- Tshwane House could save R254 640 every year.
- Water could be saved from the municipal water supply system at 45 kl/d.

The use of basement water for the whole building would be economically wise for Tshwane House because after two years the capital investment could be recovered. This would be feasible and efficient.

Chapter 4
Conclusion, Recommendations and Strategy Implementation

4.1 Summary

The specific aim of the study was to investigate the optimal utilisation of inflows/seepage from groundwater into the basement structures of the building in urban environments to reduce the utilisation of expensive potable municipal water supply for non-potable uses and/or of-grid from the municipal water supply, and also to investigate whether the basement water would be suitable for use with little or no treatment. Lastly, whether the basement water would be economically wise to use.

The study found that the basement water can be used to reduce the utilisation of potable municipal water and for non-potable uses the basement water could be used with little or no treatment. Therefore, the study confirmed that the main aim and objectives of the study were achieved. The summary of the results provided the findings of the study, based on the initial objectives.

4.1.1 Water quantity

The basement water of the Reserve Bank, Tshwane House, and the State Theatre could cover its own water demands. Basement water could cover 30% and 10% of water demands for Demar Building and Centre Walk, respectively.

There is a great opportunity to explore these alternative water sources in the City of Tshwane in order to avoid the uncertainty in the future reliability of traditional water supply sources due to climate change impacts and the growing demand from increasing urban populations. The role of alternative local water sources is to reduce the water demand for imported potable water and reducing the environmental impact of urban developments. The assessment of groundwater leakage into basements provided a more suitable source due to the constant supply of such water when compared to rainfall because of being independent on rainfall events. Even though there was no rainfall during the measurements of water quantity and quality, the Reserve Bank, State Theatre and Tshwane House buildings were consistently pumping out massive amounts of water from their basements, which indicated groundwater inflow.

4.1.2 Water quality

The quality of basement water was found to be suitable for secondary uses, without prior treatment or little required treatment, for instance for toilet flushing, garden irrigation, and for the air conditioning systems. However, the basement water can be classified as moderately hard, for instance at the Reserve Bank, which may lead to potential problems with corrosion and scaling in metallic pipes. It is advised that the hardness levels are addressed through a conventional two-stage lime-soda ash softening process.

This may limit the potential application of untreated groundwater at these buildings and indicates that groundwater quality testing would need to be the first step in considering its potential use in commercial buildings. The hardness of the groundwater could be managed through the use of non-metallic pipes, or the installation of a water softener system. While there was no evidence of contamination of the groundwater inflow into the basement structures, the fact that the intended use was only for non-potable water uses means the risk exposure would be low. The objectives of the study were therefore achieved.

4.1.3 Business case (Cost–benefit analysis)

The technical feasibility of basement water use for other non-potable water sources were assessed in terms of their ability to provide cost-effective solutions that can save water in the State Theatre building. The capital investment for developing the basement water that could be used in the air conditioning system will be covered in three years' time, while minimising adverse environmental impacts. It provides a relatively good quality non-potable water source with no additional treatments required, namely no energy requirements because the buildings were already pumping out this basement water. The capital investment of the SARB for developing the basement water for the entire building could be recovered in five years' time, while Tshwane House could be recovered in two years' time. The total amount of water saved after the complete installation of the basement water systems at the three buildings, would be 212.35 kl/d.

Figure 4.1 indicates the cost against level of treatment: basement water that requires no treatment prior use (called untreated basement water [U-BW]) could be used for dust control, garden irrigation and street cleaning, while the basement water that needs partial treatment before use should mostly be used for secondary water uses, for instance air conditioning systems. Furthermore, basement water for human consumption requires full treatment. The level of basement water treatment will play a role on determining the cost of developing basement water, for instance U-BW, will cost less than the partially treated basement water (P-BW) and fully treated basement water (F-BW), while F-BW will cost more than P-BW due to the cost of the full treatment of water.

The following are examples of water treatment based on the water use:

- U-BW: Dust control, garden irrigation and street cleaning.
- P-BW: Air conditioning water system supply.
- F-BW: Drinking water.

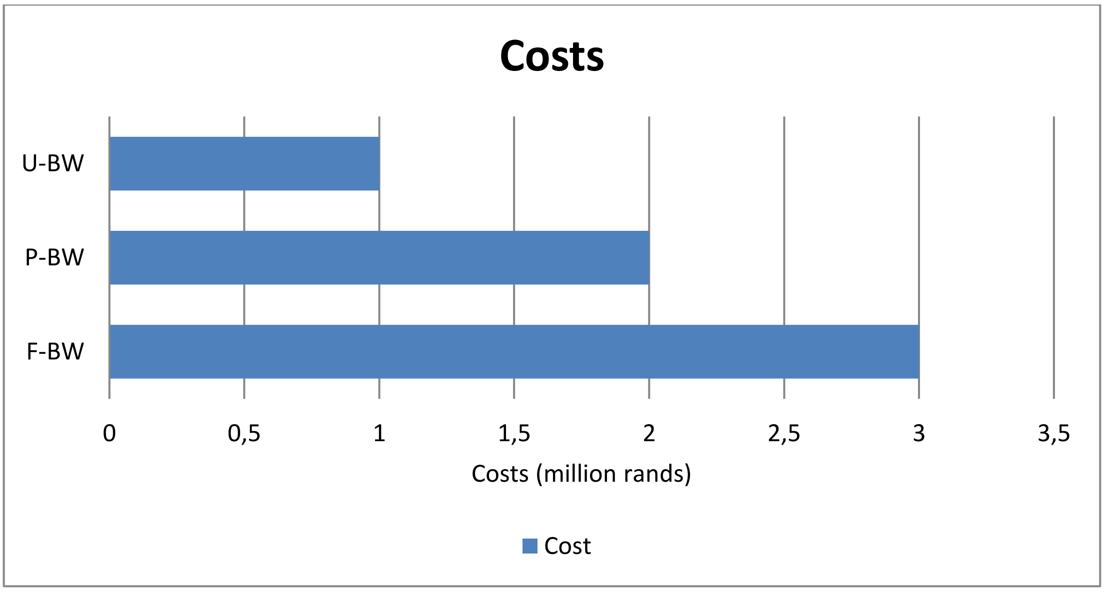


Figure 4.1: Cost comparison graph based on the three business cases

The SARB will supply the entire building with water from the basement and the cost of developing the basement water requires ±R2.7 million, while the State Theatre will use only basement water for the air conditioning system and would cost the State Theatre an estimated ±R1.5 million for their building. Furthermore, Tshwane House requires ±R0.5 million to supply the whole building because of their potential sump yield (basement water) that can meet the entire building's water demand. The potable water standard requirement means that the full level of water treatment would be needed for drinking water, which will increase the cost, compared to when the basement water will only be for secondary uses such as garden irrigation and the air conditioning system.

4.2 Generic approach to basement water use

A generic approach to basement water use is presented in Figure 4.2. This approach can be applied across urban areas in South Africa to decide if the basement water would be feasible for use and whether it would be worth to invest in it.

The initial step is to determine basement water availability, followed by how much water is available (Figure 4.2).

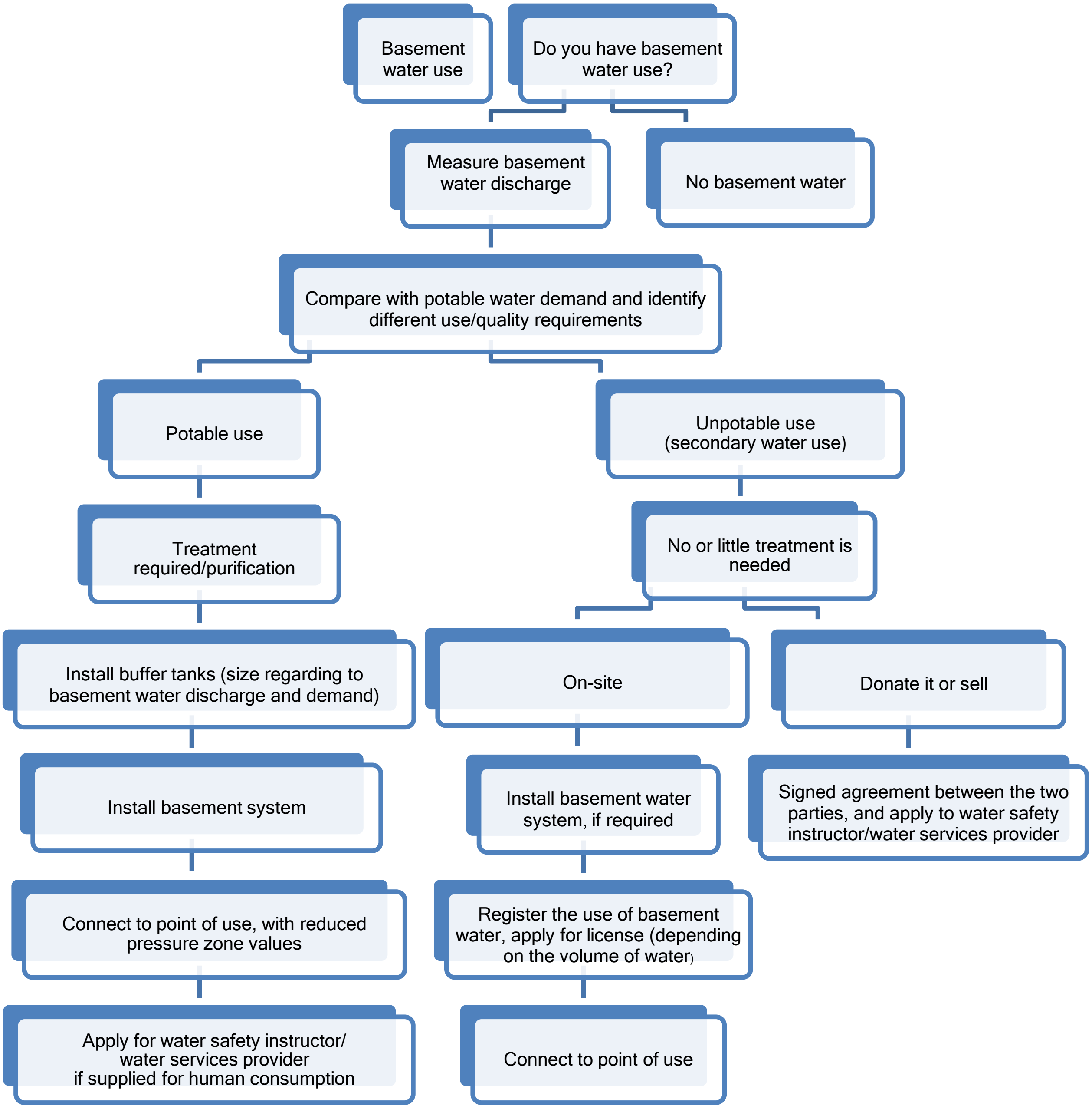


Figure 4.2: Generic approach to basement water use

The basement water that is available will enable to cover the entire building's water demand and the water quality, whether it will be used for potable or secondary uses. If the building decided to use basement water for potable purposes then the full water treatment is needed, with the installation of a basement water use system (Figure 4.2). After all these processes are followed, the building should apply for a water service intermediary or water service provider. On the other hand, if the building decides to use the basement water on-site then it would be necessary to install the system and register it for use. If the building does not need to use the basement water, they could donate it or sell it. There should, however, be an agreement between the two parties and the need to apply for a water services intermediary or water service provider (Figure 4.2).

4.3 Conclusion

The concluding remarks are summarised below:

- The status quo assessment results of groundwater use and management in the metropolitan municipalities showed that no single metropolitan municipality achieved the ideal representation of groundwater in all relevant planning documents. The results from the analysis were that the use and management of groundwater are poorly integrated into the key statutory planning processes of the metropolitan municipalities. No coherent plan for groundwater development and management could be found in each of the metropolitan municipalities in the study.
- The results from the case studies indicated that there is potential water available to be used in the City of Tshwane by diverting basement water for beneficial use. The potential volume or yield of basement water was estimated at 4.3 kl/d to 155 kl/d.
- The implementation of the basement water use innovation across the City of Tshwane (on a regional scale) could alleviate some of the city's water demands in a sustainable manner and reduce reliance on surface water.
- Based on the high discharge rates shown by some of the sites, for example the SARB with 155 kl/d and the State Theatre with 133 kl/d, it can be concluded that to use basement water, the Reserve Bank and State Theatre will need a water use license because they exceeded the General Authorisation permit limits of less than100 m^3 per year).

- The chemical analysis results indicated that the water quality of the buildings generally satisfied the water drinking standards of the country, namely SANS 241(2015) for domestic use, and the SAWQG irrigation targets, but some treatment would be needed for safety precautions so the treatment of the basement water is recommended.
- The results showed that the groundwater type is magnesium-calcium-bicarbonate that is controlled by dolomite dissolution and ion exchange hydrogeochemical processes. The hydrogeochemical investigation and analysis showed similarities between the chemistry of the boreholes, springs, and basement waters. Therefore, this suggested that the source of basement water came from the groundwater.
- The use or discharge of basement water should be addressed through by-laws and an agreement between the municipality and the basement water users needs to be in place.
- Based on the hydrocensus results obtained from the Tshwane CBD, there is an estimated total basement water yield of 1.1–1.2 Ml/d.
- The business cases indicated that there is a great opportunity to divert basement water for beneficial use rather than disposing of it. For the State Theatre building, the feasibility study of using basement water for the air conditioning system showed that up to 75% of the water was used for air conditioning systems. The investment would require R1.5 million, which could be recovered in a three-year period. The use of basement water would be feasible and efficient for the Reserve Bank and Tshwane House. The investment for both buildings would require R2.7 million, which could be recovered in a two-year period. Furthermore, Tshwane House would only require R0.5 million to develop the basement water use and recovery could be expected over two-year period.
- The basement water could contribute 0.74% to the total water supply of the City of Tshwane. This is significant because it could contribute similar amount of volume to the water supply system compared to other water sources such as the Rietvlei boreholes (0.6%).

The practical implications of this study would be important for developers and sustainability professionals who are decision-makers, particularly in the early stages of development projects who have the power to suggest the implementation or incorporation of basement water use in buildings. This study has shown that groundwater and basement water use has the potential to reduce pressure on the municipal water supply grid, thus reducing or encumbering the costs related to water use.

4.4 Recommendations

The following recommendations are made:

- All metropolitan municipalities should amend their by-laws to discourage the discharge of basement water to ensure the beneficial use thereof. The by-laws should be amended to encourage the use of alternative sources of water.
- Legally, these buildings must have a license to abstract and discharge the water, or a General Authorisation, and they must monitor the groundwater quantity and quality as well as per use.
- Green building regulations should be amended to promote the beneficial use of basement water.

4.5 Strategy implementation plan

The implementation strategy should address how basement water use should be encouraged and executed. The way forward will have to be tackled strategically by all the stakeholders and affected partners to be involved to achieve water security in the country by diversifying the water sources such as using basement water. The Department of Science and Innovation, as the department responsible for scientific research, as well as the WRC and the DWS, should champion this innovation in order to be executed across the country, where it is feasible. Table 4.1outlines the actions and organisations that should take part in this initiation.

At the awareness level, the media should play a primary role to raise awareness about basement water use and the existing platforms should encourage the basement water use at conferences, workshops, and schools. The awareness should be implemented starting now and onwards and this process should be prioritised because awareness is important (Table 4.1). The responsible organisations are the DWS, WRC and metropolitan municipalities (Table 4.1).

On the level of strategic planning, all the documents – including the IDPs, SDFs, master plans, all town studies, reconciliation studies, and the Water Services Development Plan – should incorporate the basement water use in their water plans (Table 4.1). The DWS and municipalities should play a major role to be enabled to achieve that (Table 4.1). The by-laws should be amended to encourage the basement water use in the municipalities where the use of basement water is feasible. The operational level should be led by property developers, building managers and owners to encourage the basement water use in their buildings (Table 4.1).

This action at operational level should be highly prioritised and should be encouraged to be implemented immediately. Research institutions should encourage researchers to do more research on the feasibility and cost of basement water use in different urban areas. The local implementation is about the measuring the volume of potential sump yields, water quality and the cost–benefit analysis of the buildings. The buildings' technical managers and managers should lead this process and encourage the use of basement water (Table 4.1).

Table 4.1: Proposed strategy implementation for basement water use

Themes	**Alignment with other programmes**	**Responsibility**	**Time-frame**	**Priority**
Awareness level				
• Basement water use should be raised, and the media should also play a role • Department of Science and Innovation, the WRC and DWS should champion this basement water use innovation • Local awareness at the building organisations • Workshop for buildings' technical managers • Use of symposiums, conferences, schools, etc. • Existing DWS stakeholder platforms e.g. CMF's, National Water Resource Strategy workshops, Sustainable Development Goals task teams, etc. • WRC Indaba	• Water Institute of Southern Africa conference • Engineering conference • IWISA • Curriculum at Universities • Water sensitive urban design programmes	WRC, DWS & metropolitan municipalities	0–2 years	1

Strategic planning level				
• Basement water use must be promoted in government documents	• IDP • Spatial Development Framework • All town studies • Reconciliation strategy studies • Catchment management strategies • Water Services Development Plan	Metropolitan municipalities and DWS	2–5 years	2
Regulatory level				
Amend by-laws to encourage the use of basement water.	• NWA (section 21 water use) • By-laws	DWS and metropolitan municipalities	0–5 years	1
Operational level • Buildings	• Green Building Council of South Africa • Save water and energy programmes • Probably need the involvement of water services to engage with municipalities • Engage with National Home Builders Registration Council	Building owners, and technical managers Property developers (buildings)	0–5 years	1
Research level				
• Estimation of the basement water potential across the metropolitan municipalities • More detailed basement water assessment in place	• Research papers • Articles	University institutions, WRC, DWS and metropolitan municipalities	2–5 years	2
Local implementation level				
• Measuring the volumes of basement water and determine the water quality • Site inspection • Cost benefit analysis	• Need to be incorporated in new buildings by the municipality • And existing buildings by owner	House builders, technical managers, etc.	0–5 years	1

*Priority = 1, Not priority = 2

Achieving the above actions would be a major step forward to reduce the strains or stress on the water supply system.

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Appendix A

Measurements taken at Sump Pumps

Figure 1A: Sump pump (Centre Walk)

These are the sump pumps, where the measurements were conducted the measuring of the water quantity and quality. From A1 to B2, in the Reserve Bank were not allowed to take photos. The size of the sump was also measured for each sump pumps, and also the depth of the sump.

Figure 2A: Sump pump (Tshwane House)

Figure 3A: Sump pump (State Theatre)

Figure 4A: Main sump pump or pit in the State Theatre

Figure 5A: Basement parking lots in the State Theatre

Figure 6A: Sump pump

Measurements and connecting

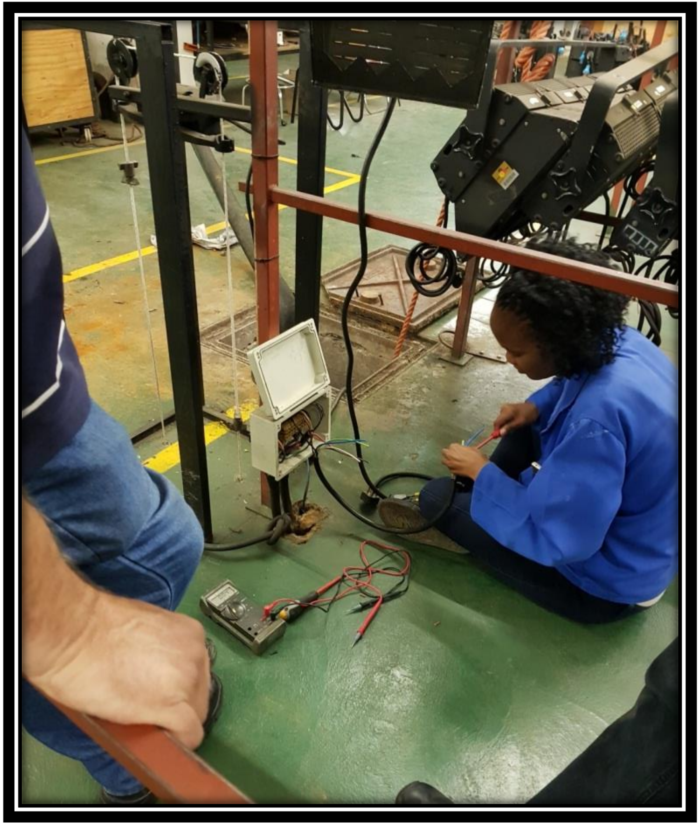


Figure 7A: Connecting the Hour meter at State Theatre

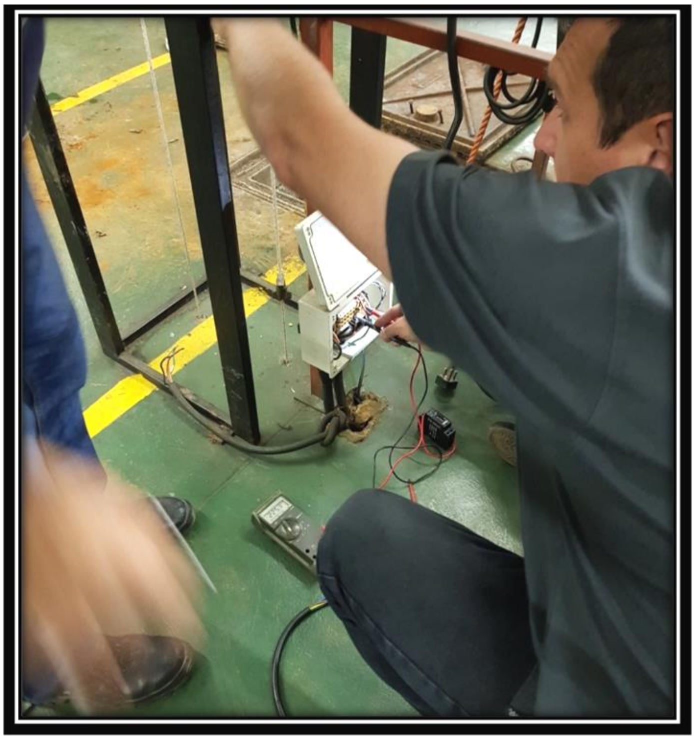


Figure 8A: Connecting Hour meter at State Theatre

The connecting of the Hour meter is shown in Figures 7A and 8A above.

Figure 11A: Wet floor and collecting drain system in Demar Building

Appendix B
Calculations of estimating the sump yield

State Theatre

Total sump yield for the period of water level monitoring is determined by:

Sump 1

$$Sump\ yield = \frac{(Total\ water\ level\ increase) * (Sump\ area)\ (cubic\ meters)}{Total\ period\ of\ monitoring\ (seconds)}$$

= 1.6×10^{-4} m^3/s

= 0.16 l/s

Sump 2

$$Sump\ yield = \frac{(Total\ water\ level\ increase) * (Sump\ area)\ (cubic\ meters)}{Total\ period\ of\ monitoring\ (seconds)}$$

= 1.6×10^{-4} m^3/s

= 0.162 l/s

Estimating Sump Yield (Calculations) - Measuring Power used to pump out water (Sump 3)

Table 1: Estimating sump yield

Time	Date	Readings	Difference
11:00:00	15/05/2018	0 kWh	0
11:00:00	16/05/2018	4.3 kWh	4.3
11:00:00	23/05/2018	9.5 kWh	5.2
11:00:00	25/05/2018	14.7 kWh	5.2
11:00:00	28/05/2018	20.0 kWh	5.3
8 days		**Sum**	20
8 days *24= 312 hours			**20 kWh**

$P_{(w)} = \frac{1000 * \mathrm{E(kWh)}}{t(hr)}$

$= \frac{1000*20kWh}{312}$

$= 64.10$ W

P = Q * p*H*G

$Q = \frac{P}{p*H*g}$

$= \frac{64.10}{1000*16*9.81}$

= 4.1e–4 m^3/s

= **0.408 l/s**

Multiply by 3 because its 3 phases while the hour meter measured only one phase

Q = 0.408 l/s * 3

= **1.22 l/s**

The total yield of these sumps (from sump 1 and sump 2) was estimated at around 1.54 l/s (133 056 l/d).

Tshwane House

Total sump yield for the period of water level monitoring is determined by:

$$Sump\ yield = \frac{(Total\ water\ level\ increase) * (Sump\ area)\ (cubic\ meters)}{Total\ period\ of\ monitoring\ (seconds)}$$

= 4.14E–4 m^3/s

= 0.414 l/s

$$Sump\ yield = \frac{(Total\ water\ level\ increase) * (Sump\ area)\ (cubic\ meters)}{Total\ period\ of\ monitoring\ (seconds)}$$

= 1.9×10^{-4} m^3/s

= 0.188 l/s

The total yield of these sumps (from sump 1 and sump 2) was estimated at around 0.602 l/s (52012.8 l/d).

Centre Walk

Total sump yield for the period of water level monitoring is determined by:

$$Sump\ yield = \frac{(Total\ water\ level\ increase) * (Sump\ area)\ (cubic\ meters)}{Total\ period\ of\ monitoring\ (seconds)}$$

= 5.3E-6 m^3/s

= 0.0053 l/s

The total yield of these sumps was estimated at around 0.0053 l/s (4320 l/d).

Demar Building

Total sump yield for the period of water level monitoring is determined by:

$$Sump\ yield = \frac{(Total\ water\ level\ increase) * (Sump\ area)\ (cubic\ meters)}{Total\ period\ of\ monitoring\ (seconds)}$$

= 1.8×10^{-4} m^3/s

Convert cubic meters per second (m^3/s) into litre per second (l/s) multiplied by 1 000

= 0.182 l/s

The total yield of these sumps was estimated at around 0.182 l/s (15 724.8 l/d).

Upscaling calculations:

I used the Google earth to group buildings into Blocks then I assign each block yield value close to the buildings that have sump yield then added them to come up with sum (total) of the yields of the blocks at the CBD (Tshwane). When I'm grouping them each block, the assumption is that all the buildings are used to calculate the upscaling and have basement water. The figure below was used.

Figure 1B:

Reserve Bank (155 kl/d) = 4 Blocks = 62 2080 l/d

State Theatre (133 kl/d) = 4 Blocks = 53 2224 l/d

Tshwane House (52 kl/d) = 18 Blocks = 93 6230.4 l/d

Centre Walk (43 kl/d) = 19 Blocks = 64 800 l/d

Demar building (15 kl/d) = 9 Blocks = 14 1516

Total: **2.3Ml/d**

Other methods that I used

Preliminary assessment investigated **20 buildings** but only collected the data at the **5 buildings**.

Based on the 5 buildings (sum of sump yield =360632.8 l/d) = average yield is 72 126.56 l/d

Water demand is 78 000 l/d

Out of 20 buildings; 15 buildings have a basement with groundwater seepage (**yes I did the hydro census before I started with the fieldwork. The 5 buildings were chosen from the 20 buildings**.

The total yield of 15 buildings = No of buildings * Averaged yield

= 15 * 72 126.56 l/d

= **1.1Ml/d**

Water demand $_{\text{(total)}}$ = Water demand average * Number of buildings

= 78 000 l/d * 20

= 1 560 000 l/d

Estimated water demand $_{\text{(could be saved)}}$ = Total water demand – Estimated potential basement water

= Total water demand – Estimated potential basement water

= 1 560 000 l/d - 1081898.4 l/d

= 478 101.6 l/d

Percentage % = Potential/ Water demand * 100

= 1081898.4 / 1 560 000 * 100

= 69.35%

This is how the buildings is divided into blocks:

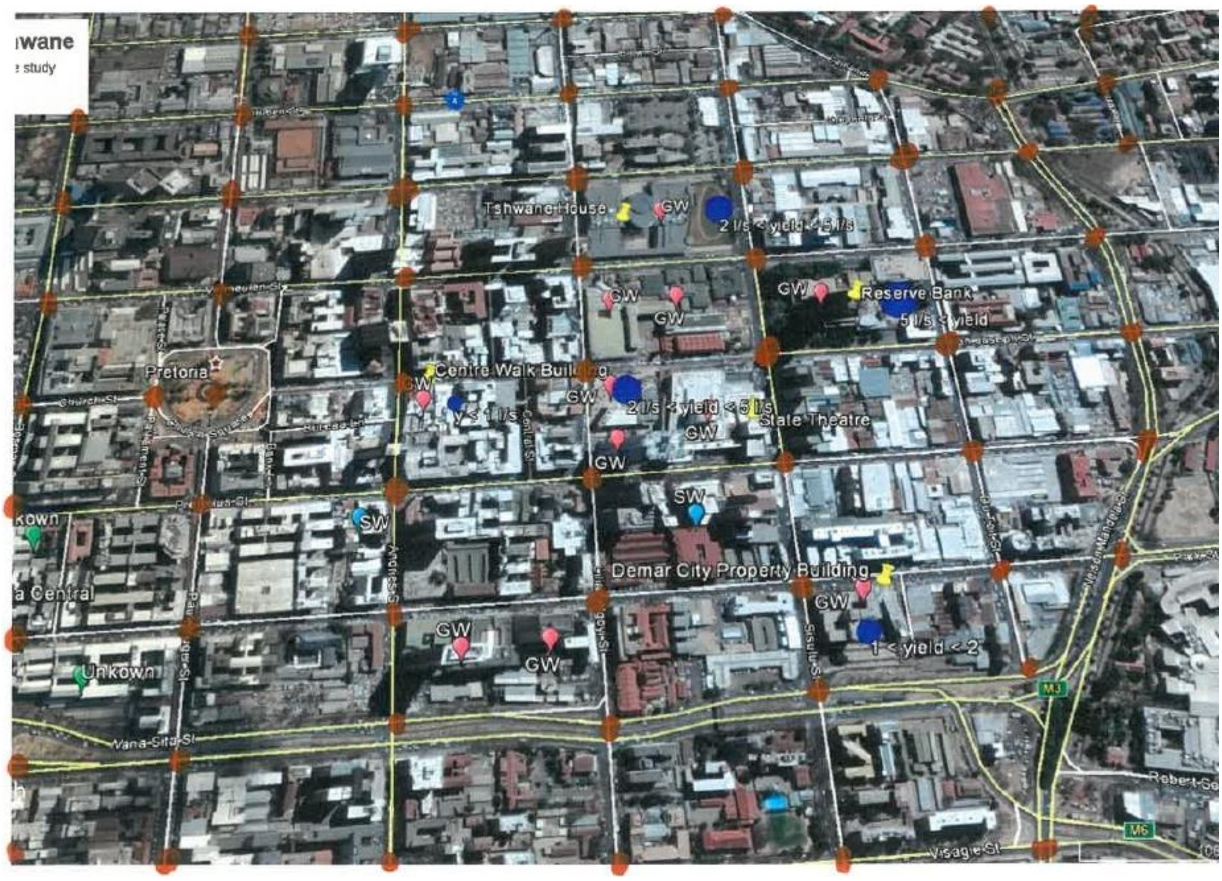
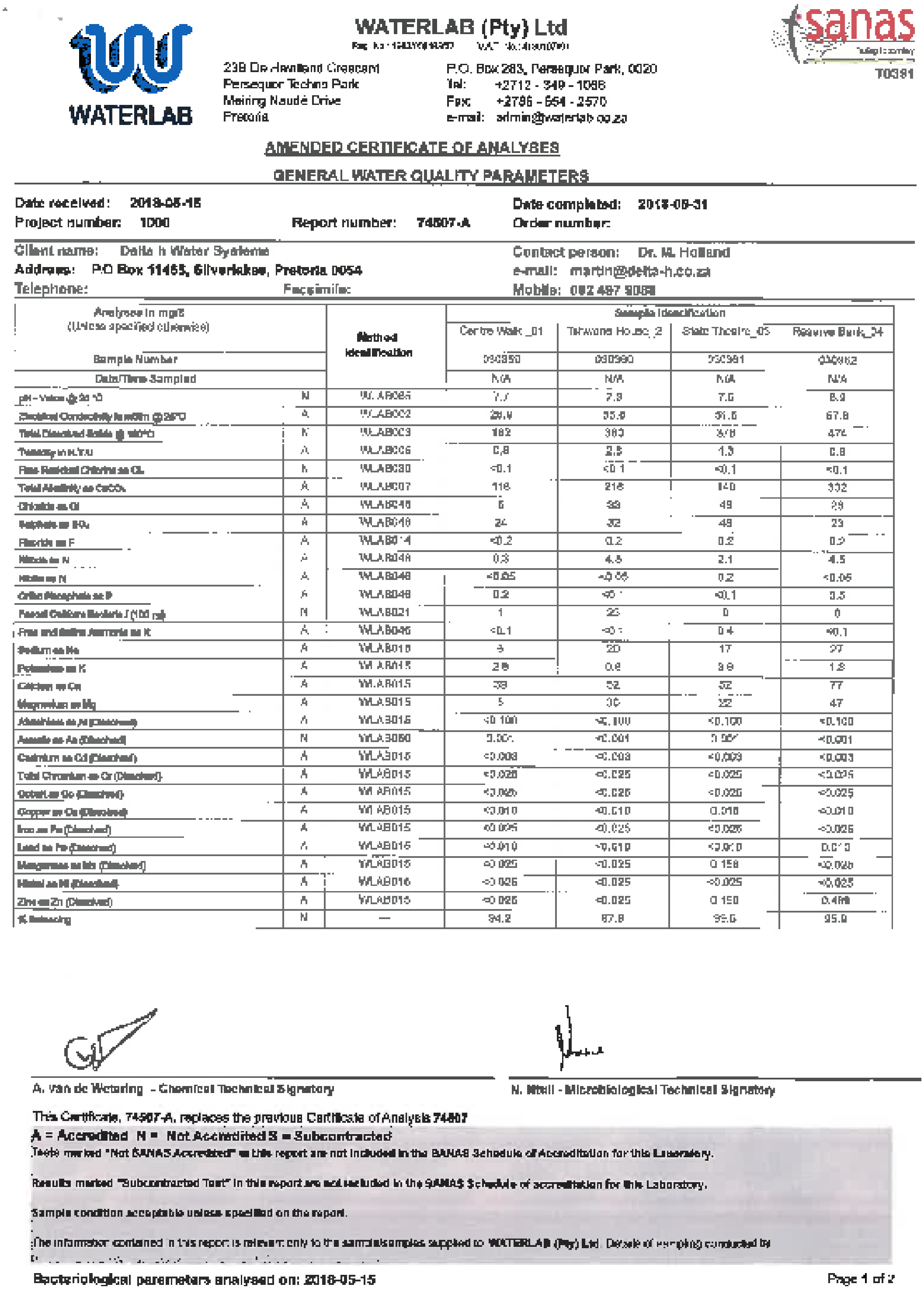


Figure2B: The City of Tshwane central business district divided into blocks to estimate the potential basement water use across the city

Potential basement water across the Tshwane CBD ranged from **1.2 to 2.3 Ml/d**

Appendix C

Quality results



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T0391

AMENDED CERTIFICATE OF ANALYSES

GENERAL WATER QUALITY PARAMETERS

Date received: 2018-05-15
Project number: 1000
Report number: 74507-A
Date completed: 2018-05-31
Order number:

Client name: Delta h Water Systems
Address: P.O Box 11465, Silverlakes, Pretoria 0054
Telephone:
Facsimile:
Contact person: Dr. M. Holland
e-mail: martin@delta-h.co.za
Mobile: 082 497 9088

Analyses in mg/ℓ (Unless specified otherwise)		Method Identification	Sample Identification			
			Centre Walk_01	Tshwane House_2	State Theatre_03	Reserve Bank_04
Sample Number			030359	030360	030361	030362
Date/Time Sampled			N/A	N/A	N/A	N/A
pH – Value @ 20 °C	N	WLAB065	7.7	7.9	7.6	8.2
Electrical Conductivity in mS/m @ 25°C	A	WLAB002	29.9	55.9	51.5	67.8
Total Dissolved Solids @ 180°C	N	WLAB003	182	383	378	474
Turbidity in N.T.U	A	WLAB005	0.8	2.5	1.3	0.8
Free Residual Chlorine as Cl_2	N	WLAB030	<0.1	<0.1	<0.1	<0.1
Total Alkalinity as $CaCO_3$	A	WLAB007	118	218	140	332
Chloride as Cl	A	WLAB046	5	39	49	29
Sulphate as SO_4	A	WLAB046	24	32	49	23
Fluoride as F	A	WLAB014	<0.2	0.2	0.2	0.2
Nitrate as N	A	WLAB046	0.3	4.5	2.1	4.5
Nitrite as N	A	WLAB046	<0.05	<0.05	0.2	<0.05
Ortho Phosphate as P	A	WLAB046	0.2	<0.1	<0.1	0.5
Faecal Coliform Bacteria / (100 ml)	N	WLAB021	1	23	0	0
Free and Saline Ammonia as N	A	WLAB046	<0.1	<0.1	0.4	<0.1
Sodium as Na	A	WLAB015	3	20	17	27
Potassium as K	A	WLAB015	2.5	0.6	3.9	1.2
Calcium as Ca	A	WLAB015	39	52	32	77
Magnesium as Mg	A	WLAB015	5	30	22	47
Aluminium as Al (Dissolved)	A	WLAB015	<0.100	<0.100	<0.100	<0.100
Arsenic as As (Dissolved)	N	WLAB050	0.001	<0.001	0.001	<0.001
Cadmium as Cd (Dissolved)	A	WLAB015	<0.003	<0.003	<0.003	<0.003
Total Chromium as Cr (Dissolved)	A	WLAB015	<0.025	<0.025	<0.025	<0.025
Cobalt as Co (Dissolved)	A	WLAB015	<0.025	<0.025	<0.025	<0.025
Copper as Cu (Dissolved)	A	WLAB015	<0.010	<0.010	0.018	<0.010
Iron as Fe (Dissolved)	A	WLAB015	<0.025	<0.025	<0.025	<0.025
Lead as Pb (Dissolved)	A	WLAB015	<0.010	<0.010	<0.010	0.010
Manganese as Mn (Dissolved)	A	WLAB015	<0.025	<0.025	0.158	<0.025
Nickel as Ni (Dissolved)	A	WLAB015	<0.025	<0.025	<0.025	<0.025
Zinc as Zn (Dissolved)	A	WLAB015	<0.025	<0.025	0.150	0.498
% Balancing	N	—	94.2	97.8	99.5	95.9

A. van de Wetering - Chemical Technical Signatory

N. Mtali - Microbiological Technical Signatory

This Certificate, 74507-A, replaces the previous Certificate of Analysis 74507

A = Accredited N = Not Accredited S = Subcontracted

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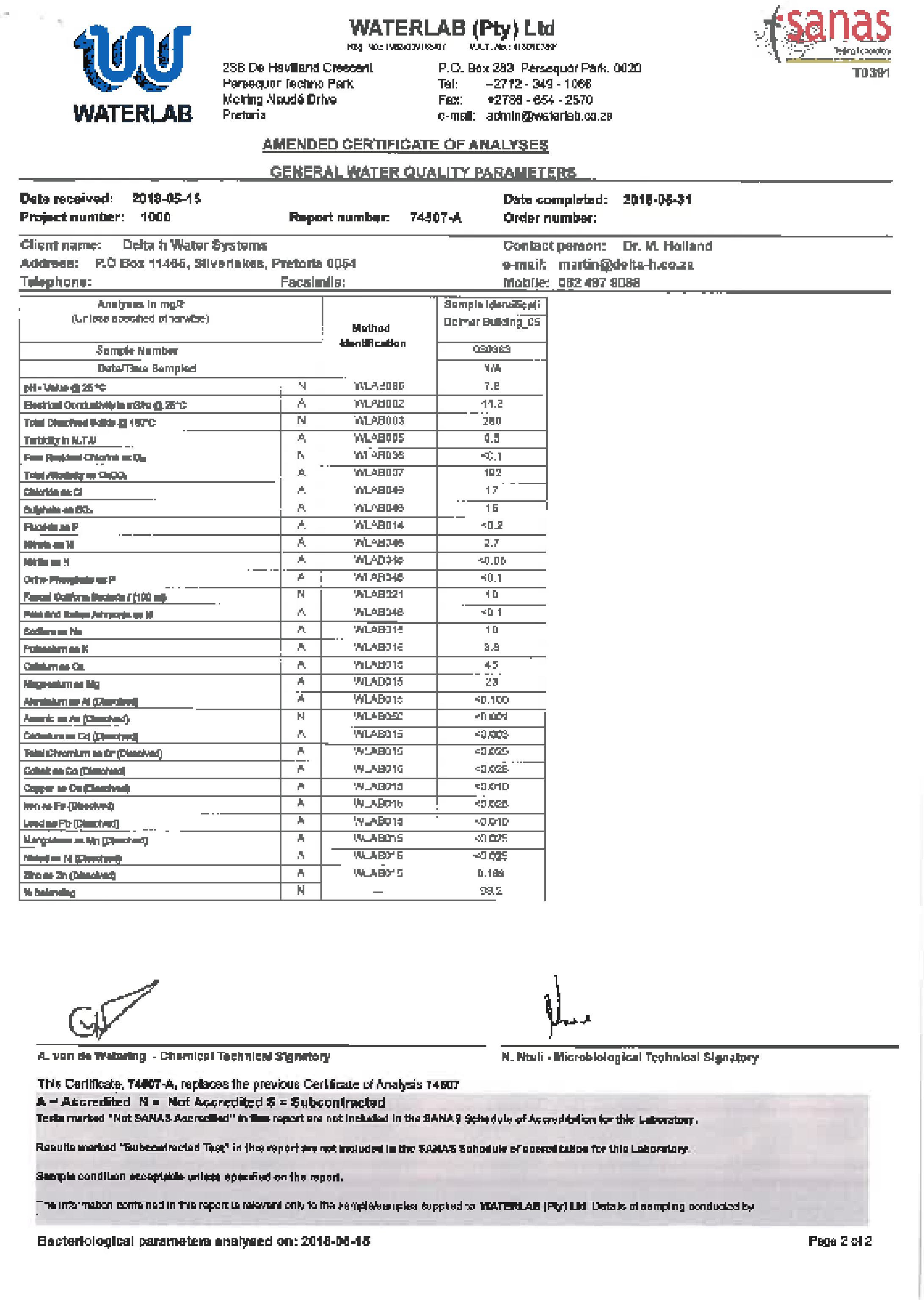
Sample condition acceptable unless specified on the report.

The information contained in this report is relevant only to the sample/samples supplied to WATERLAB (Pty) Ltd. Details of sampling conducted by

Bacteriological parameters analysed on: 2018-05-15

Page 1 of 2



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Telephone:
Facsimile:
Mobile: 082 497 9088

Analyses in mg/ℓ (Unless specified otherwise)		Method Identification	Sample Identification Delmar Building_CS
Sample Number			030363
Date/Time Sampled			N/A
pH - Value @ 25°C	N	WLAB065	7.8
Electrical Conductivity in mS/m @ 25°C	A	WLAB002	41.2
Total Dissolved Solids @ 180°C	N	WLAB003	280
Turbidity in N.T.U	A	WLAB005	0.5
Free Residual Chlorine as Cl_2	N	WLAB036	<0.1
Total Alkalinity as $CaCO_3$	A	WLAB007	192
Chloride as Cl	A	WLAB046	17
Sulphate as SO_4	A	WLAB046	16
Fluoride as F	A	WLAB014	<0.2
Nitrate as N	A	WLAB046	2.7
Nitrite as N	A	WLAB046	<0.05
Ortho Phosphate as P	A	WLAB046	<0.1
Faecal Coliform Bacteria / (100 ml)	N	WLAB221	10
Free and Saline Ammonia as N	A	WLAB046	<0.1
Sodium as Na	A	WLAB015	10
Potassium as K	A	WLAB015	3.9
Calcium as Ca	A	WLAB015	45
Magnesium as Mg	A	WLAB015	23
Aluminium as Al (Dissolved)	A	WLAB015	<0.100
Arsenic as As (Dissolved)	N	WLAB052	<0.006
Cadmium as Cd (Dissolved)	A	WLAB015	<0.003
Total Chromium as Cr (Dissolved)	A	WLAB015	<0.025
Cobalt as Co (Dissolved)	A	WLAB015	<0.025
Copper as Cu (Dissolved)	A	WLAB015	<0.010
Iron as Fe (Dissolved)	A	WLAB015	<0.025
Lead as Pb (Dissolved)	A	WLAB015	<0.010
Manganese as Mn (Dissolved)	A	WLAB015	<0.025
Nickel as Ni (Dissolved)	A	WLAB015	<0.025
Zinc as Zn (Dissolved)	A	WLAB015	0.189
% balancing	N	—	98.2

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The information contained in this report is relevant only to the sample/samples supplied to WATERLAB (Pty) Ltd. Details of sampling conducted by

Bacteriological parameters analysed on: 2018-05-15

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Appendix D

Business Case Calculations/ Quotations

Calculations

Charges (r) for Energy = Energy use for WTP * Energy Tariffs of City of Tshwane

= 0.1 kWh * R151.50 kWh

= R15.15 per kWh

Charges (r) for Water = Water use requirements for Reserve Bank * Water Tariffs of City of Tshwane

= 75.85 kl/day * R25 per kl

= R1896.25 per day

Convert into monthly and yearly

= R56887.5 per month

= **R682 650 annually**

Monitoring and supply the chemicals = R3 400 per month

Yearly is R40 800.00

Table 1D: Reserve Bank Water Consumption Reading

Municipal Meter Readings at the SARB Building				
Date	**Number of Days**	**Meter Readings (kl)**	**Consumption (kl)**	**Daily Consumption (kl/d)**
10/4/2018	-	190,140	-	-
11/5/2018	32	193,093	2,953	92.28
12/6/2018	31	195,531	2,438	78.65
1/14/2019	39	198,324	2,793	71.62
3/5/2019	50	202,224	3,900	78.00
4/5/2019	31	204,694	2,470	79.68
5/6/2019	31	207,184	2,490	80.32
6/6/2019	31	209,432	2,248	72.52
7/5/2019	29	211,566	2,134	73.59
9/5/2019	62	215,627	4,061	65.50
Total Days	**336**	**Total Consumption (kl)**	**25,487**	**-**
Estimated Average Daily Consumption (kl/d)				**75.85**
Estimated Average Annual Consumption (kl/year)				**27,687**
Estimated Average Monthly Consumption for Tariff Calculation (kl/month)				**2,307**

Table 2D: The Cost Model for the SARB Building

Cost Model for the South African Reserve Bank Building Business Case					
Item No	**DESCRIPTION**	**UNIT**	**RATE (November 2019)**	**QUANTITY**	**AMOUNT**
1	Pipelines				
	(a) Supply of ND 150 mm Steel Pipe and Delivery to Site	m	R1,500.00	15	R22,500.00
	(b) Installing & Jointing (% of (a))	%	-	100%	R22,500.00
2	Valves & Telemetry (% of 1 (a) and 1 (b))	%	-	15%	R6,750.00
3	Connecting to Existing Water Supply System (% of 1 (a) and 1 (b))	%	-	5%	R2,250.00
4	Package Water Treatment Plant (WTP)				
	(a) Supply of Package WTP and Delivery to Site	Sum	R800,000.00	1	R800,000.00
	(b) Installation of Package WTP (% of (a))	%	-	20%	R160,000.00
	(c) Commissioning of Package WTP (% of (a))	%	-	10%	R16,000.00
5	Miscellaneous (% of 1 to 4)	%	-	10%	R103,000.00
SUB TOTAL A					**R1,133,000.00**
6	Preliminary & General (% of Sub Total A)	%	-	10%	R113,300.00
7	Site Office Accommodation	Sum	R50,000.00	1	R50,000.00
SUB TOTAL B					**R1,296,300.00**
8	Contingencies (% of Sub Total B)	%	-	10%	R129,630.00
SUB TOTAL C					**R1,425,930.00**
9	Planning Design & Supervision (% of Sub Total C)	%	-	10%	R142,593.00
SUB TOTAL D					**R1,568,523.00**
10	VAT (% of Sub Total D)	%	-	15%	R235,278.45
TOTAL ESTIMATED CAPITAL COST (Incl. VAT)					**R1,803,801.45**

Table 3D: Calculations pertaining to the O&M Costs

Operation and Maintenance Cost Model for the South African Reserve Bank Building Business Case

Item No	DESCRIPTION	AMOUNT	CIVIL WORKS	MECHANICAL & ELECTRICAL WORKS
1	Pipelines			
	(a) Supply of Pipes and Delivery to Site	R22,500	R22,500	
	(b) Installing & Jointing	R22,500	R22,500	
2	Valves & Telemetry	R6,750		R6,750
3	Connecting to Existing Water Supply System	R2,250	R2,250	
4	Package Water Treatment Plant (WTP)			
	(a) Supply of Package WTP and Delivery to Site	R800,000		R800,000
	(b) Installation of Package WTP	R160,000		R160,000
	(c) Commissioning of Package WTP	R16,000		R16,000
5	Miscellaneous	R103,000	R4,725	R98,275
SUB TOTAL A		**R1,133,000**	**R51,975**	**R1,081,025**
6	Preliminary & General	R113,300	R5,198	R108,103
7	Site Office Accommodation	R50,000	R25,000	R25,000
SUB TOTAL B		**R1,296,300**	**R82,173**	**R1,214,128**
8	Contingencies	R129,630	R8,217	R121,413
SUB TOTAL C		**R1,425,930**	**R90,390**	**R1,335,540**
9	Planning Design & Supervision	R142,593	R9,039	R133,554
SUB TOTAL D		**R1,568,523**	**R99,429**	**R1,469,094**
10	VAT (15%)	R235,278	R14,914	R220,364
TOTAL ESTIMATED CAPITAL COST (Incl. VAT)		**R1,803,801**	**R114,343**	**R1,689,458**
Estimated Annual O&M Costs for the Civil Works per Annum (0,25% of Total Estimated Capital Cost for Civil Works)			**R286**	-
Estimated Annual O&M Costs for the Mechanical & Electrical Works per Annum (2,5% of Total Estimated Capital Cost for M&E Works)			-	**R42,236**
TOTAL ESTIMATED ANNUAL O&M COSTS			-	**R42,522**
ESTIMATED REFURBISHMENT COSTS OF MECHANICAL AND ELECTRICAL WORKS (50% Cost for M&E Works)			-	**R844,729**

Table 4D: The Life Cycle Cost analysis

Life Cycle Cost Analysis for the South African Reserve Bank Building Business Case												
Year	November 2019 Prices						Discounted Amounts (Costs)			Discounted Amounts for Municipal Water Supply (Benefits)		
	Capital Cost	Annual O&M Total Costs	Annual Water Treatment Costs		Refurbishment Costs of Mechanical & Electrical Works	Total Cost per Annum						
			Energy	Chemicals			6%	8%	10%	6%	8%	10%
2020	R1,803,801	R42,522	R132,597	R40,778		**R2,019,699**	R2,019,699	R2,019,699	R2,019,699	R682,650	R682,650	R682,650
2021		R42,522	R132,597	R40,778		**R215,898**	R203,677	R199,905	R196,270	R644,009	R632,083	R620,591
2022		R42,522	R132,597	R40,778		**R215,898**	R192,148	R185,097	R178,428	R607,556	R585,262	R564,174
2023		R42,522	R132,597	R40,778		**R215,898**	R181,272	R171,386	R162,207	R573,166	R541,910	R512,885
2024		R42,522	R132,597	R40,778		**R215,898**	R171,011	R158,691	R147,461	R540,723	R501,768	R466,259
2025		R42,522	R132,597	R40,778		**R215,898**	R161,331	R146,936	R134,055	R510,116	R464,600	R423,872
2026		R42,522	R132,597	R40,778		**R215,898**	R152,199	R136,052	R121,869	R481,241	R430,185	R385,338
2027		R42,522	R132,597	R40,778		**R215,898**	R143,584	R125,974	R110,790	R454,001	R398,320	R350,307
2028		R42,522	R132,597	R40,778		**R215,898**	R135,457	R116,643	R100,718	R428,303	R368,815	R318,461
2029		R42,522	R132,597	R40,778		**R215,898**	R127,789	R108,003	R91,562	R404,059	R341,495	R289,510
2030		R42,522	R132,597	R40,778		**R215,898**	R120,556	R100,002	R83,238	R381,188	R316,199	R263,191
2031		R42,522	R132,597	R40,778		**R215,898**	R113,732	R92,595	R75,671	R359,612	R292,777	R239,265
2032		R42,522	R132,597	R40,778		**R215,898**	R107,294	R85,736	R68,792	R339,256	R271,090	R217,513
2033		R42,522	R132,597	R40,778		**R215,898**	R101,221	R79,385	R62,538	R320,053	R251,009	R197,739
2034		R42,522	R132,597	R40,778		**R215,898**	R95,492	R73,505	R56,853	R301,937	R232,416	R179,763
2035		R42,522	R132,597	R40,778		**R215,898**	R90,086	R68,060	R51,684	R284,846	R215,200	R163,421
2036		R42,522	R132,597	R40,778		**R215,898**	R84,987	R63,018	R46,986	R268,723	R199,259	R148,565
2037		R42,522	R132,597	R40,778		**R215,898**	R80,177	R58,350	R42,714	R253,512	R184,499	R135,059
2038		R42,522	R132,597	R40,778		**R215,898**	R75,638	R54,028	R38,831	R239,162	R170,832	R122,781
2039		R42,522	R132,597	R40,778		**R215,898**	R71,357	R50,026	R35,301	R225,625	R158,178	R111,619
2040		R42,522	R132,597	R40,778	R844,729	**R1,060,627**	R330,708	R227,556	R157,655	R212,853	R146,461	R101,472
Netto Present Values							**R4,759,417**	**R4,320,648**	**R3,983,320**	**R8,512,592**	**R7,385,008**	**R6,494,434**
Discount Rates							**6%**	**8%**	**10%**	-		
Cost/Benefit Ratios							**0.56**	**0.59**	**0.61**	-		