

**GROUNDWATER PROBLEMS AND MANAGEMENT STRATEGIES – A CRITICAL REVIEW
OF THE GROUNDWATER SITUATION IN JOHANNESBURG**

Gladys Esther Anaman

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the degree of Master of Science in Development Planning.

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DECLARATION

I declare that this research report is my own unaided work. It is submitted for the degree of Master of Science in Development Planning in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination at any other University.

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Gladys Esther Anaman

..... day of 2013

ABSTRACT

With the prediction that South Africa will be water-stressed by the year 2025, it becomes necessary for all the cities in the country, including Johannesburg to take the necessary measures to ensure that they manage their water resources effectively in order to ensure the water security of their cities.

This research report is a secondary case study of the groundwater situation in Johannesburg, which delves into the literature on groundwater and presents a review of the groundwater problems in Johannesburg and the management strategies used in managing the problems. Some of the groundwater issues identified in Johannesburg include recharge problems due to the geological formation and nature of aquifers in Johannesburg, and the growth and urbanization of Johannesburg, which places increasing demands on water. There is also the problem of pollution, the sources of which in Johannesburg are mainly municipal waste, industrial processes and mining activities. There are also institutional capacity problems regarding the management of groundwater in Johannesburg.

The second aspect of the research report delves into the management strategies employed in the city of Johannesburg for the management of groundwater resources. Some of the management strategies or tools discussed include the National Water Resource Strategy 2 (NWRS), the Groundwater Strategy 2010, the guideline for the assessment, planning and management of groundwater resources in South Africa and the NORAD toolkit. Although these tools are well developed for the management of groundwater, there are deficiencies in implementation, which are mainly due to the undervaluation of the importance and significance of groundwater resources, shortage of expertise and adequate data, centralization of power, disregard of groundwater ecosystems and associated goods and services, and the lack of adaptive management.

In order to deal with the issues and problems surrounding groundwater in Johannesburg, some of the solutions recommended include effective administration, capacity building and cooperative governance, acknowledging the importance of groundwater-dependent ecosystems, the need for adaptive management, and integrating supply side and demand side measures in the management of groundwater, and the development of a groundwater management framework (GWMF) for the city of Johannesburg.

Key Words: Groundwater, sustainable development, management strategies, Johannesburg

DEDICATION

To my dad, Kodjo Esseim Mensah-Abrampa, thank you.

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ACRONYMS

AGW-NET – The African Groundwater Network

AMCOW – African Minister's Council on Water

AMD – Acid Mine Drainage

AMO – Atlantic Multi-decadal Oscillation

AMS – Anglo American Platinum

BCM – Billion Cubic Metres

BGS – British Geological Survey

CJSER - City of Johannesburg State of Energy Report

CMA – Catchment Management Agencies

CMED – Compliance, Monitoring and Enforcement Directorate

CoJ – City of Johannesburg

CSIR – Council for Scientific and Industrial Research

CSO – Country Status Overview

DANIDA – Danish International Development Agency

DAFF – Department of Agriculture, Fisheries and Forestry (Australia)

DE – Drought Emergency

DWAF – Department of Water Affairs and Forestry

EIA - Environmental Impact Assessment

ENSO – El Nino-Southern Oscillation

FETWater – Framework Programme for Research, Education and Training in the Water Sector

GS – Groundwater Strategy

GWMF – Groundwater Management Framework

GW-MATE – Groundwater Management Advisory Team

GDAEC – Gauteng Department of Agriculture, Environment and Conservation

GTZ – German Technical Corporation

IAH – International Association of Hydrogeologists

IDP – Integrated Development Plan

IWRM – Integrated Water Resource Management

IWRMP – Integrated Water Resource Management Plan

IWWMP – Integrated Waste and Wastewater Management Plan

LHWP – Lesotho Highlands Water Project

MAR – Mean Annual Runoff

MCM – Million Cubic Metres

NAO – North Atlantic Oscillation

NDP – National Development Plan

NGS – National Groundwater Strategy

NPC – National Planning Commission

NWA – National Water Act

NWRS – National Water Resource Strategy

PDO – Pacific Decadal Oscillation

RoD – Record of Decision

RSA – Republic of South Africa

SADC – South African Development Community

SANBI – South Africa National Biodiversity Institute

SDF – Spatial Development Framework

SETA – Sector Education and Training Authority

UNEP – United Nations Environment Programme

UNESCO – United Nations Educational, Scientific and Cultural Organization

USA – United States of America

USGS – United States Geological Survey

VIP – Ventilated Improved Pit Latrine

WARFSA – The Water Research Fund for Southern Africa

WDCS – Water Discharge Charge System

WSA – Water Services Authority

WSDP – Water Services Development Plan

WSP – Water Services Provider

WRC – Water Research Commission

WUA – Water Users Association

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CHAPTER ONE

AN INTRODUCTION TO GROUNDWATER RELATED PROBLEMS

1.1 Introduction

Groundwater is the most utilized of all freshwater sources and therefore its protection is of fundamental importance to human life. Groundwater has been exploited for domestic use, livestock and irrigation purposes (Foster *et al.*, 1987). In the United States of America, groundwater accounts for 50% of livestock and irrigation water. Less than 40% is used for public water supplies, but 96% of water supplies in the rural areas are from groundwater (Todd, 1980). In Latin America, in the valley of Mexico City, over 1000 deep wells supply $3200 \times 10^6 \text{m}^3$ per day, which is about 95% of the total supply to a population of nearly 20 million people (Foster *et al.*, 1987) and in Europe and Russia, 80% of groundwater is used for drinking water supply (Schreiber and Schneider: undated). In Africa, as much as 75% of the population is dependent on groundwater (The Kampala Statement, 2008). In South Africa, groundwater caters for about 80% of its population (Dennis, 2001).

According to Neir (2004), out of the 3% of freshwater on earth, only 0.003% is available for human consumption. This implies that mismanagement and exploitation of groundwater could lead to countries being water stressed. For instance, it is estimated that about two thirds of the world's countries will be water stressed by 2025 (Overdorf, 2011) and this includes South Africa (Otieno *et al.*, 2004). In the next 20 years, demand for water in Gauteng is expected to increase by 30% (Waterwise: undated). For these reasons, there is a need for the conservation and loss reduction of water resources and protection from pollution. About 80% of South Africa's population is dependent on groundwater and if it is contaminated, it becomes a potential killer to communities. It is also important that groundwater is protected from pollution due to the difficult and costly nature of remediation projects (Schmoll *et al.*, 2006). For instance, Canada spends between US \$2billion to 5billion per annum on remediation projects (Harries, 1997 cited in RICAMD, 2010). Moreover, there are instances where groundwater remediation is impossible (Tredoux *et al.*, 2004).

Groundwater is mostly invisible to people and as a result there is the tendency for it to be neglected. Therefore, for effective management of the resource, there is a need for the aquifer systems to be understood, as well as their recharge and most importantly, to be aware of potential sources of pollution of groundwater (Tredoux *et al.*, 2004).

1.2 Statement of Problem

Groundwater, as already mentioned, is an important resource. However, there are many problems associated with it and it is important that these are given due attention, especially in terms of the water budget, which is an account of all the inflows, outflows and changes in storage of a groundwater system (USGS: undated). Some of these problems include reduced quality due to pollution and reduced recharge as a result of development (Ruohong, 2009) and climate change (WRC, 2012) and this invariably is linked with its availability for supply.

1.2.1 Groundwater recharge problems

South Africa is a relatively dry country, with an average annual rainfall of about 500mm and this is very low compared to a world average of about 860mm (Woodford *et al.*, 2009). The amount of rainfall suggests that groundwater recharge is almost minimal and this could be exacerbated due to climate change. In certain areas, climate change could reduce the volume of rainfall (Chew, 2003), which could negatively affect groundwater recharge. If there is not enough rainfall, groundwater levels could be reduced and this has the potential to affect the baseflow of surface water bodies, due to the fact that surface water bodies are sometimes recharged by groundwater and vice versa (WRC, 2012).

In addition to this, there is a problem of development, which includes the problem of urban sprawl. Through urbanization and urban sprawl, there is an increase in impervious surfaces over land, such as road surfaces, buildings, parking lots and pavements (Frazer, 2005). These impervious surfaces are resistant to water, so rainfall flows over them as runoff into surface water bodies rather than seeping into underground aquifers (Frazer, 2005; Ruohong, 2009).

1.2.2 Groundwater Pollution problems

Groundwater pollution occurs as a result of a wide range of human activities such as:

1. Agriculture: This is through cultivation of crops with agrochemicals, irrigation and sewage sludge and waste water. It can also occur through animal feedlot operations such as leakage from unlined effluent lagoons and land discharge effluent.
2. Sanitation: This occurs as a result of leakage from on-site sanitation, land discharge of sewage, leakage from oxidation lagoons and sewer leakage.

3. Industry: Pollution is through leakage of effluent lagoons (process water), tank and pipeline leakage, accidental spillages, land discharge effluent and well disposal of effluent.
4. Waste disposal and landfills: This is mainly due to leaching from waste disposal or landfill sites.
5. Traffic: This occurs through highway soakaways, tank leakage and the application of chemicals.
6. Mining: This is through acid mine drainage (AMD), leakage from sludge lagoons, leaching from solid mine tailings and oilfield brine disposal (Chilton *et al.*, 2006).

In all of these activities, it is evident that the challenge for these sectors is in relation to waste disposal. For instance in the case of mines, impoundments on land have been used for the disposal of solid waste and the liquid wastes are generally channeled into water systems or sustained in unmaintained ponds which pollute water resources (Oelofse *et al.*, 2007). The environmental implications of these disposal methods include contamination of streams by AMD, contamination of streams due to surface run-off from the impoundment area, air and water contamination due to wind erosion of dried-out tailings, possible risk of catastrophic dam failure and release of slimes, physical and aesthetic modification to the environment and difficulty of establishing vegetative cover to permanently stabilize the tailings due to unfavourable soil conditions (Oelofse *et al.*, 2007).

From the foregoing, it is clear that there is a need for effective management of groundwater resources. A problem with limited groundwater recharge, coupled with the problem of groundwater pollution could be disastrous for South Africa. For these reasons, it is important to critically examine and rethink methods of its management not only to avoid pollution, but also as a way of harnessing groundwater for both domestic and industrial usage.

Therefore, the research seeks to answer the following question:

What are the groundwater issues and problems facing Johannesburg, and what are the means of dealing with these problems?

The sub-questions are:

- What are the implications of groundwater problems for Johannesburg?
- What groundwater management strategies are employed in Johannesburg?

1.3 Objectives and Scope of Report

This research sought to find appropriate measures instituted for the management of groundwater. As stated, due to concerns about South Africa being a water-stressed country, there is a need for water resources to be conserved. South Africa has been forecast to be water stressed by the year 2025, and freshwater availability could be less than 1000 m³ per capita, annually (Otieno *et al.*, 2004). This should be mitigated because, 'it could result in increased pressure on water that is available and could result in increased conflicts over its allocation, resulting in further stress on the resource and eventually leading to its scarcity' (Otieno *et al.*, 2004). Therefore, as indicated, the specific objectives of this research were:

- To determine the problems and issues associated with groundwater in Johannesburg.
- To outline the current groundwater management strategies employed in Johannesburg.
- To outline some of the reasons for Johannesburg's inability to effectively implement the groundwater management strategies.
- To provide recommendations for planners in relation to some of the approaches that could be implemented for effective management of groundwater.

The scope of the research was on the management strategies instituted by the City of Johannesburg in relation to groundwater. These management strategies employed were studied with a view to providing appropriate recommendations as to how to make the City of Johannesburg's strategies effective.

1.4 Conceptual Framework and Proposed Research Method

1.4.1 Conceptual framework

The conceptual framework was divided into three sections: the problems, solutions and sustainability dimensions of groundwater. The first aspect identified the groundwater problems, especially those related to recharge, pollution and the impacts of polluted groundwater. The solution aspects dealt with the South African water law on groundwater, as well as the policies that have been enacted to ensure groundwater safety. This process led to identifying the best ways of managing groundwater in the city, to ensure that there is minimal pollution on groundwater, as well as, its conservation.

Furthermore, it is important to note that, when dealing with groundwater issues, not only the legal issues are to be dealt with. There is a need to deal with capacity as well. Do the various

institutions have the people with the expertise to deal with groundwater issues? Are there more professionals being trained to manage these problems? These are some of the questions that need to be taken into consideration, in order for people to be empowered for a more efficient and effective management of groundwater resources.

The research also delved into the aspect of sustainable development. Over the past two decades, a lot of concerns have been raised in relation to sustainable development. Sustainable development was defined as “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987: 8). Therefore, how do we ensure that there is adequate water for the present generation and the future generations as well? There is a need for effective planning and proper management of water resources. Water has to be protected and conserved. This means that households would have to make use of water efficiently to reduce costs. Industrial and commercial users can increase water use efficiency to maximize profits.

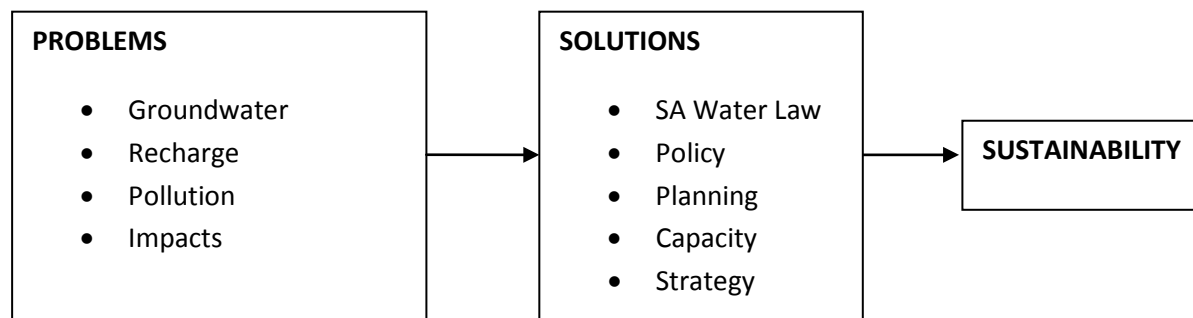


Figure 1.1: The Conceptual Framework for the Literature Review

1.4.2 Research Method

The research is a secondary case study. The secondary research method is basically making use of findings from already existing research (Charles Sturt University, undated). The findings may be gathered from books, reports and the internet (*ibid.*), etc. This approach entails a review of existing literature journals, government and other institutional reports, internet and newspaper articles (Matousek and Associates Inc., 2006).

Secondary research may also include a case study (*ibid.*). The use of a case study allows for an “in-depth examination of a single event or series of events” (*ibid.*: unpaginated). A secondary research also enables a proper analysis of information obtained, and through this means

provide an understanding of “what happened, why and what was done about it” (*ibid.*: unpaginated).

It is important to note that through secondary research, researchers come into contact with a wide range of information and for that matter it is important for the researcher to identify what is relevant and what is not, to the area being understudied (*ibid.*).

It is for the aforementioned reasons that this approach was used. Furthermore, due to time limitations, a desktop-study (secondary) research approach was employed, so the main sources of information were from secondary materials. Basically, pertinent information published on this topic were reviewed. These consisted of relevant published articles, books, government documents, and websites as sources of information. Interviews could not be conducted due to time constraints.

The following chapter is a discussion on the groundwater situation around the world and also the groundwater situation in South Africa.

CHAPTER TWO

GROUNDWATER IN THE GLOBAL AND SOUTH AFRICAN CONTEXTS

2.1 Groundwater: A Global Overview

Many countries of the world are endowed with natural resources which are very important for development and one of these resources is groundwater (UNESCO, 2004). Freshwater in the rock and soil layers (aquifers) beneath Earth's land surface is termed groundwater (USGS, undated). It is important to note that aquifers are also often partially fed by seepage from streams and lakes. In other locations, these same aquifers may discharge through seeps and springs to feed the streams, rivers, and lakes (Idaho State University: undated). The geological conditions and hydrogeological characteristics of the rocks are critical controls on groundwater quantity, quality and flow regime (USGS: undated). These determine the extent and rate to which groundwater is refilled and for this reason groundwater recharge varies all over the world (USGS: undated).

In terms of water supply, groundwater in its natural state has advantages over surface water. These advantages include: "higher quality, better protected from possible pollution including infection, less subject to seasonal and perennial fluctuations and much more uniformly spread over large regions than surface water" (UNESCO, 2004, p. 13). In most cases, groundwater is present in areas without surface water. Due to these advantages over surface water, it is widely used for water supply in many countries (UNESCO, 2004). Some of the differences between groundwater and surface water are further summarized in the table below:

Table 2.1: Comparative Features of Groundwater and Surface Water

Feature	Groundwater Resources & Aquifers	Surface water Resources & Reservoirs
Hydrological Characteristics		
Storage	Very large	Small to moderate
Resource areas	Relatively unrestricted	Restricted to water bodies
Flow velocities	Very low	Moderate to high

Residence time	Generally decades/ centuries	Mainly weeks/months
Drought vulnerability	Generally low	Generally high
Evaporation losses	Low & localized	High for reservoirs
Resource evaluation	High cost & significant uncertainty	Lower cost & often less uncertainty
Abstraction impacts	Delayed & dispersed	Immediate
Natural quality	Generally (but not always) high	Variable
Pollution vulnerability	Variable natural protection	Largely unprotected
Pollution persistent	Often extreme	Mainly transitory
Socio-economic Factors		
Public perception	Mythical, unpredictable	Aesthetics, predictable
Development cost	Generally modest	Often high
Development risk	Less than often perceived	More than often assumed
Style of development	Mixed public and private	Largely public

Source: Cap-Net *et al.*, 2010: 14

Groundwater serves the basic needs of more than one-half of the world's population (Mechlem, 2003), and it is mostly the only source of water in arid and semiarid countries (UNESCO, 2004). Annually, it is estimated that groundwater withdrawn is about 20% of global water, which is 600 to 700km³ (UNEP, 2002) of groundwater (mostly withdrawn from shallow aquifers) (UNDP *et al.*, 2000 cited in UNEP, 2002). This gives a clear indication that there is a high dependency on groundwater, and this is the case especially for rural dwellers, who have groundwater as their sole source of water (UNEP, 2002).

Countries such as Denmark, Saudi Arabia and Malta have only groundwater as their only source of water supply and for some countries, it forms an integral and major part of their total water resources (UNESCO, 2004). For instance, groundwater constitutes 93% of the total water

resources in Tunisia, 83% in Belgium, 75% in Morocco and Germany (*ibid.*). Groundwater usage in European countries such as Austria, Belgium, Denmark, Romania, Hungary and Switzerland, is more than 70% of the total water consumption (*ibid.*). In some European cities such as Budapest, Copenhagen, Hamburg, Rome, Munich and Vienna, groundwater is the main source of municipal domestic and drinking water supply, while for other cities, it supplies more than half of their total water demand (*ibid.*). In arid and semiarid climate countries, groundwater is usually used for irrigation and it covers about one-third of landmass irrigated. In the United States of America, groundwater irrigation covers 45% of the total land irrigated, 58% in Iran, and 67% in Algeria (*ibid.*).

Thus, it is evident that all over the world, groundwater is an important source of water supply. However, there are problems associated with it. This is mainly due to increasing negative effects of human activities on groundwater. These human activities pose a wide range of threats to groundwater quality (UNEP, 2002) and they are as summarized in the following table:

Table 2.2: Groundwater Quality Problems

Problems	Causes	Concerns
Anthropogenic pollution	Inadequate protection of vulnerable aquifers against human-made discharges and leachate from: urban and industrial activities; intensification of agricultural cultivation.	Pathogens, nitrates, ammonium salts, chlorine, sulphates, boron, heavy metals, DOC, aromatic and hydrogenated hydrocarbons. Nitrates, chlorine, pesticides
Naturally occurring pollution	Related to pH-Eh ¹ evolution of groundwater and dissolution of minerals (aggravated by anthropogenic pollution and/or uncontrolled exploitation.	Mainly iron and sometimes arsenic, iodine, manganese, aluminium, magnesium, sulphates, selenium and nitrates (from paleo-recharge)
Well-head contamination	Inadequate well design and construction allowing direct intrusion of polluted surface water or shallow groundwater	Mainly pathogens

Source: Foster, Lawrence and Morris, 1998 cited in UNEP, 2002: 154

From the table above, it is evident that the potential for groundwater pollution to occur is a function of microbiological or chemical pollutant loading, which might be applied to the subsurface environment as a result of one or more types of human activity (Chilton *et al.*, 2006). The ability for pollutant loading to get to the water is dependent on the aquifer vulnerability, which depends on the intrinsic physical characteristics of the soil and strata separating the aquifer from the land surface (*ibid.*).

There are two aspects of aquifer vulnerability to contamination and they are unsaturated zone vulnerability and saturated zone vulnerability (WRC, 2009). Unsaturated zone vulnerability is defined as “the ease with which groundwater at the water table may become contaminated by a contaminant source located at the soil surface or within the unsaturated zone” (*ibid.*: 1) and saturated zone vulnerability is defined as “the length of time from cessation of contamination

¹ pH is the measure of the acidity or alkalinity of solution and Eh is a measurement of electrical potential of a solution (Railsback, 2006).

activities to when a given contaminant can be detected in the groundwater and, also, the volume of the aquifer in which the contaminant exceeds a preset concentration" (*ibid.*: 1).

The presence of a shallow aquifer with unconsolidated sand and gravel strata implies the aquifer will be highly sensitive to contamination. This is mainly due to high porosity and permeability, which means that water, is able to easily infiltrate through to groundwater within a very short time (Frederick, 2012). Therefore, the pollutants are not absorbed or naturally degraded before getting to the water (*ibid.*). However, in the case of a deep, confined aquifer, there is low permeability and as such, infiltration of water could take years. This allows the contaminants to be absorbed over time or allow natural degradation of contaminants before it gets into the water (*ibid.*).

The diagram below shows the pollution potential of an aquifer. It uses the characteristics of the aquifer and the pollutant loading to determine the pollution potential of an aquifer. A combination of high pollutant loading and high aquifer vulnerability provides the most extreme pollution potential as indicated in the diagram's top right corner. This makes it easier to predict situations in which an aquifer is highly vulnerable (Chilton *et al.*, 2006).

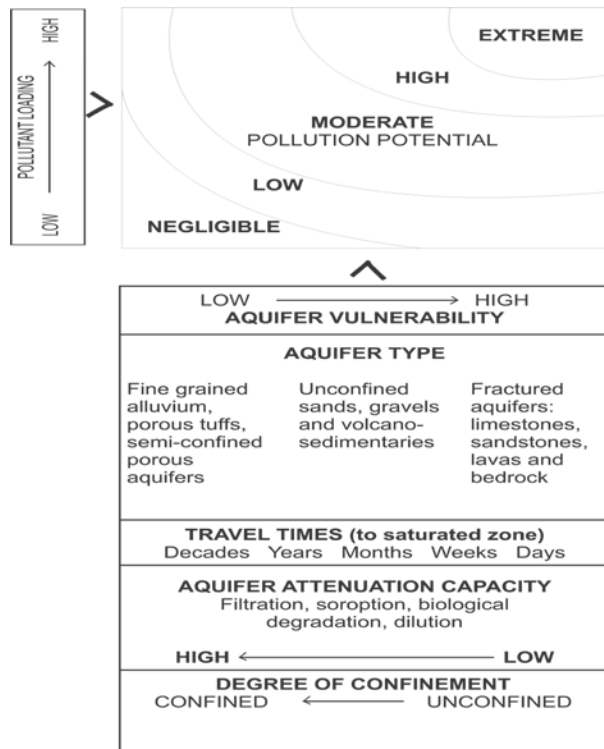


Figure 2.1: Groundwater Pollution Potential

Source: Chilton *et al.*, 2006: 3

There is also the aspect of natural pollution. Under normal circumstances, unpolluted groundwater is of good quality. However, there are instances where groundwater may naturally contain trace elements such as iron, fluoride and arsenic, which are liberated from the surrounding rock matter (IAH, 2003) or arsenic compounds in soils (Safiuddin and Karim, 2001). For instance, in eastern New England, arsenic concentration in groundwater is greater than $10\mu\text{g/L}$ (micrograms per litre) and many areas within the region have their groundwater polluted by arsenic (Ayotte *et al.*, 2003). This concentration level can have serious repercussions for human health when used for water supply (*ibid.*). The increase in reports of arsenic contamination of groundwater in different areas of New England is indicative that the pollution is natural and the source is the minerals in the rock formation in the region (*ibid.*).

In the case of Bangladesh, it was found that the arsenic contamination of groundwater was from the alluvial and deltaic sediments in the area. A geological study undertaken showed that the alluvial and deltaic sediments contained high levels of arseno-pyrite, pyrite, iron sulphate and iron oxide (Safiuddin and Karim, 2001).

There is also the problem of salination which could occur due to the following: a rise in the groundwater table, associated with the introduction of inefficient irrigation with imported surface water in areas of inadequate natural drainage; natural salinity having been mobilized from the landscape, consequent upon vegetation clearing for farming development with, in these cases, increased rates of groundwater recharge; excessive disturbance of natural groundwater salinity stratification in the ground through uncontrolled well construction and pumping” (IAH, 2003: 6).

Furthermore, there is the problem of recharge. The over abstraction of groundwater with very minimal natural recharge can cause a reduction in groundwater levels (UNEP, 2002) and this is one of the reasons many countries are water stressed. The growth in industry, agriculture and global population is leading to increasing levels of use of the resource and to growing dependence on it (UNESCO *et al.*, 2005). As a result, over the past fifty years, groundwater resources have come under pressure from over-abstraction and pollution, and this is threatening its sustainability (*ibid.*).

2.1.1 Climate variability and change

It is important to note that climate affects “all life on Earth, human health and well-being, water and energy resources, agriculture, forests and natural landscapes, air quality, and sea levels” (U.S. Geological survey, 2007a cited in USGS, 2009: unpaginated). Although there are natural processes “ranging from interannual, multidecadal and longer geologic-time scales” which result in climate variability and change, there is also evidence to show that human activities have led to climate change (USGS, 2009: unpaginated).

Some of the global experiences as a result of climate change include ‘increases in global average air and ocean temperature, widespread melting of snow and ice, rising sea levels, widespread changes in precipitation amounts, ocean salinity, wind patterns and the increasing occurrences of extreme weather conditions such as droughts, heavy precipitation, heat waves and intensity of tropical cyclones’ (U.S. Geological Survey, 2007a cited in USGS, 2009: unpaginated).

Over the years, studies have been focused on the effect of climate variability and change on surface water. This is due to the fact that surface water can be seen and is accessible, and also the fact that all the changes that occur with surface water as a result of climate variability is very noticeable unlike with groundwater, which is underground. In effect, groundwater has not had many studies undertaken on it (Green, 2009 cited in USGS, 2009). In recent times, more

studies are being carried out in relation to groundwater in order to ensure a better understanding of the effects of climate variability and change on groundwater quantity and quality, and even though globally there is acknowledgement of the potential effects of climate variability and change on groundwater, there is still a poor understating of the effects (Green *et al.*, 2007 cited in USGS, 2009).

Climate variability and change can affect the components of the global hydrologic cycles in terms of quantity and quality (Loaiciga *et al.*, 1996; Sherif and Singh, 1999; Milly *et al.*, 2005 cited in USGS, 2009). In the surface hydrologic cycle, there may be changes to the hydrologic components such as “atmospheric water vapour content, precipitation and evapotranspiration patterns, snow cover and melting ice and glaciers, soil temperature and moisture, and surface runoff and stream flow” (Bates *et al.*, 2008 cited in USGS, 2009: unpaginated) and these changes have the potential to affect “the subsurface hydrologic cycle within the soil, unsaturated zone and saturated zone, and may affect recharge, discharge and groundwater storage of many aquifers” in the world (Green, 2009 cited in USGS, 2009).

It must be noted that determining the potential effects of climate variability and change on groundwater is much more intricate than dealing with surface water (Holman, 2006 cited in USGS, 2009). Groundwater residence time, which is a “measure of the period elapsed between recharge and discharge of groundwater from an aquifer flow system” (Loaiciga, 2004: 682), also presents challenges to identifying how groundwater responds to climate variability and change (Chen *et al.*, 2004 cited in USGS, 2009). This is because the residence time can span from days to tens of thousands of years or more and so has the ability to ‘delay and disperse’ the effects of climate on groundwater (Chen *et al.*, 2004 cited in USGS, 2009: unpaginated).

In addition, further stress on groundwater is from human activities such as the pumping of the resource and the implications of this activity can be the same as the effect of climate variability and change, and this presents a challenge to distinguishing between human and climatic sources of stress on groundwater (Hanson *et al.*, 2004 cited in USGS, 2009).

The most important climate modes are the interannual El Nino-Southern Oscillation (ENSO), the interdecadal Pacific Decadal Oscillation (PDO) and the multi-decadal North Atlantic Oscillation (NAO) (Enfield and Mestas-Nunez, 1999), also known as Atlantic Multidecadal Oscillation (AMO) (USGS, 2009). These climatic oscillations can result in a wide range of geomorphological impacts such as “changes in streamflow and sediment yield, mass movement

frequencies and coastal erosion” and these impacts may be different for different areas and also vary in time (Viles and Goudie, 2003: 105).

The magnitude and interaction of these modes of climate may lead to the occurrences of “average or extreme climate conditions” which may influence “drought, infiltration, recharge, discharge” and the demand for groundwater resources by people (USGS, 2009: unpaginated). As such, these modes of climate make it clear as to the impacts they can have on groundwater, and for this reason it is important that variability on the time scales associated with the modes of climate are understood for groundwater resource management (USGS, 2009).

2.2 Groundwater in South Africa

In South Africa about 98% of groundwater is found in fractured, hard rock aquifer systems (Kok and Simonis, 1989 cited in DWAF, 2004). There are key primary aquifer and secondary aquifer systems. The primary aquifers constitute 18% of the aquifers in South Africa. The primary aquifers are only found in the coastal sand deposits located on the west and south coasts of the Cape and on the coast of KwaZulu Natal (DWAF, 2004).

The primary aquifers have high yielding boreholes and the water is of good quality as well (*ibid.*). Some areas with primary aquifers include Atlantis, Cape Flats and Richards Bay. The geologic formations for primary aquifers are dolomitic rocks, quartzite and sandstone of the Table Mountain Group and sandstone and shale of the Karoo Sequence (*ibid.*). Some cities and towns which are dependent on groundwater from primary aquifers include Pretoria, Atlantis, St Francis Bay, Beaufort West and Graaff-Reinet (*ibid.*).

However in South Africa, the dominant aquifers are the secondary or minor aquifers. They constitute 67% of the aquifer systems in South Africa (*ibid.*). They are predominantly hard rocks and they are only able to discharge water when the hard rock undergoes weathering, fracturing or faulting (*ibid.*). The hard rocks are rocks of the Karoo Sequence and also older rocks located in the north-eastern parts of South Africa. The challenges with the secondary aquifers are that they are not easily managed and protected, appropriate sites for drilling are not easily identified and aquifer yield is variable (*ibid.*). Some towns that are dependent on groundwater from secondary aquifers are Nylstroom, Williston, Carnavon and Richmond (*ibid.*).

2.2.1 Groundwater usage in South Africa

Groundwater is widely but variably used in South Africa. It constitutes 15% of overall water consumption but a greater proportion, which is 64% of the total groundwater extracted, is used for irrigation purposes (Woodford *et al.*, 2009). About 400 towns are dependent on the resource for water supply (DWAF, undated). Some of the towns include Beaufort West, Prince Albert, Graaff Reinet, Atlantis and Mussina (DWAF, 2004; Adams, 2011). There is high dependence on groundwater in the rural areas as well (Tewari and Kushwaha, 2008). Primary cities such as Johannesburg and Pretoria are highly dependent on surface water for water supply, due to high water requirements. However, these cities are still dependent on groundwater (Abiye, 2011) which supplements their water requirements.

In recent times, many concerns have been raised about the sustainability of the groundwater resources of South Africa. First of all, South Africa has problems with natural recharge, due to the climatic conditions of the country. As a result, there are fluctuations in the groundwater recharge rates. The volume of groundwater available in South Africa is estimated to be between 10,343 million m³/annum or 7,500 million m³/annum under drought conditions. However, there are only a few primary aquifers and the geological formations of South Africa which are mostly fractured hard rock have relatively low yields (CSIR, 2010). Only 20% of the groundwater occurring in major aquifers can be used for large scale water supply (DWAF, 2004). Furthermore, some anthropogenic practices such as mining, agriculture, sanitation and industrial activities are negatively affecting the resource and thus, threatening water security of South Africa.

2.2.2 Groundwater recharge in South Africa

Groundwater recharge is the process whereby there is an addition of water to a groundwater reservoir (UNESCO, 2003). There are four modes in which groundwater can be recharged. These include:

- The downward movement of water through the unsaturated zone into the water table.
- “Lateral and/or vertical inter-aquifer flow
- Induced recharge from nearby surface water bodies resulting from groundwater abstraction and
- Artificial recharge such as from borehole injection or man-made infiltration ponds” (UNESCO, 2003: 6).

It must be noted that the most important recharge process for arid and semiarid areas is the natural recharge process, which is the downward movement of water through the unsaturated zone into the water table (UNESCO, 2003) and through this downward movement, according to the Department of Agriculture, Fisheries and Forestry (DAFF) of Australia (2007: 2), “a portion of the water will be lost to evaporation, some will be taken up by plants (evapotranspiration) and some will remain within the unsaturated zone and these processes determine a rainfall threshold above which groundwater recharge can effectively occur.” This implies that if the amount of rainfall is below the recharge threshold, there will be little recharge or no recharge will occur (*ibid.*). Some of the factors affecting recharge include:

- “Climate, which affects the amount and intensity of rainfall and evaporation,
- Soil and aquifer hydraulic properties,
- Type and amount of vegetation cover and types of land use,
- Topography, in particular the slope of the land surface
- The nature and geometry of aquifers in the catchment
- Residual (or antecedent) soil moisture stored in the soil profile from previous rainfall events” (*ibid.*: 3)

There is the need to understand that the aforementioned factors together with other factors such as evaporation, surface runoff, interflow, groundwater inflow and outflow, affect recharge (Senarath and Rushton, 1984 cited in Conrad *et al.*, 2004), and therefore in dealing with groundwater recharge estimation, they would have to be dealt with in a holistic manner. Thus, for successful recharge estimation, there is the need to use a total water catchment balance approach (Miles and Rushton, 1983; Simmers, 1989 cited in Conrad *et al.*, 2004), which requires that all the aforementioned factors are included in the estimation (Senarath and Rushton, 1984 cited in Conrad *et al.*, 2004).

Over the years, South Africa (a semiarid nation) has undertaken projects in assessing the groundwater resources of the country. This was done with the view to amply manage the limited water resources for sustainability reasons (UNESCO, 2003). However, this has not been an easy task. This is mainly as a result of “the time variability of precipitation in arid and semiarid climates, and spatial variability in soil characteristics, topography, vegetation and land use” (Lerner *et al.*, 1990 cited in UNESCO, 2003: 7).

Rainfall in South Africa is low and of an unpredictable nature (Woodford *et al.*, 2009). The annual mean rainfall is 500mm and this is very small compared to the world average of 860mm.

However, the amount of rainfall recorded is not the same for all areas, as “some 21% of South Africa receives less than 200mm of rainfall per year” (*ibid.*: 1). The water resources are limited and for this reason it is considered a water-stressed country and indeed, it is one of the twenty most water-stressed countries in the world (*ibid.*). It is for these reasons that it is imperative that the little groundwater that is available is protected from pollution and also conserved to ensure water security of South Africa.

The other contributing factor to the low levels of groundwater recharge is urbanization and urban sprawl (Ruohong, 2009; McGuffin, 2012). Many cities, especially the primary cities of South Africa are faced with the problem of sprawl as a result of an increase in the number of people moving into the cities. Through urbanization and urban sprawl there is an increase in hard surfaces such as parking lots, streets, driveways, buildings, etc on land. These surfaces are non-porous, as a result, there is an increase in runoff into surface water bodies rather than water infiltrating through the soil into the ground (McGuffin, 2012) to recharge groundwater. This aspect will further be explained in the research report.

2.2.3 Groundwater pollution in South Africa

In South Africa, pollution of water resources has been reported from many areas in the country. There have been reports of AMD pollution on water resources and the environment from coal mines in Mpumalanga and from gold mines in Johannesburg (DWAF, 2010). Residents of Carolina, a town about 270km from Johannesburg, have been exposed to water contaminated by AMD (Kings, 2012). Also, improper sanitation in many informal settlements in Johannesburg has resulted in groundwater pollution (Kunene, 2009).

The Crocodile River in Limpopo has also been polluted by AMD and radioactive sludge from the West Rand mines (FarmiTracker, 2010). The Vaal River has also been polluted by municipal effluent as well (McCarthy and Venter, 2006).

From 1993 to 2007, there were outbreaks of diarrhea and typhoid in Delmas, a town in the Mpumalanga Province (Nealer *et al.*, 2009). Studies showed that groundwater abstraction boreholes located downstream of the town's oldest waste water treatment facility had been contaminated by the effluent from the treatment facility (Nealer *et al.*, 2009).

Although there are so many factors that impact negatively on water resources in South Africa, one activity that has the greatest impact on water resources and the environment is mining. South Africa is a world leader in mining and it is well known for its abundance of mineral

resources, which accounts for a significant proportion of world production and reserves (GDAEC, 2008). It is the biggest producer of platinum and the leading producer of diamond, base metals, coal and gold (Kearney: undated). The exploitation of these minerals has been very important for development. For instance, the exploitation of gold mines has been the catalyst in sustaining the development of the South African economy and also the growth of its impressive infrastructure (GDAEC, 2008). In addition, this industry has contributed and still contributes significantly to economic activity, job creation and foreign exchange earnings (Kearney: undated).

However, through mining of resources such as gold and coal, AMD is formed and it has damaging effects on water resources. This aspect needs attention due to the fact that mining is an important component of the South African economy and unlikely to end anytime soon. Although many mines have been closed down, especially gold mines in the Witwatersrand basin, it is important to note that AMD is continuously being discharged even after mines have been shutdown (Oelofse et al., 2007). AMD can have serious consequences, especially in cases where the discharge is not attended to (*ibid.*). It is therefore imperative that appropriate measures are taken to protect water sources from being contaminated by AMD from the mines.

The above discussions make it clear that there is the need to be mindful of the fact all the water that is available to us in the world is all we have, there is no more of the resource coming from anywhere else. This has implications for a growing population. A growth in population will result in a growing demand of water and this in turn could result in water scarcity (Abrams, 2001). It must be noted that the bulk of the water goes into the development needs of the growing population and also the cultivation of food (*ibid.*). A relatively small portion is directly consumed by the population (*ibid.*).

The total national stock of water in all dams for South Africa is 31.7 billion cubic metres ($10^9\text{m}^3/\text{yr}$) (BCM) (Turton, 2012). This constitutes about 65% of the total surface water resource, consisting of “all the water in all the rivers flowing across the entire country in an average year, which is 49.2 BCM” (Middleton and Bailey, 2008 cited in Turton, 2012: unpaginated). Technically, this is known as the naturalized Mean Annual Runoff (MAR), and it is represented by the “surface runoff” component of the hydrological cycle (Turton, 2012).

Table 2.3: Reconciliation of the Requirements for and Availability of Water as it Existed in 2000.
(All volumes given in millions of cubic metres (MCM) per year ($10^6\text{m}^3\text{yr}^{-1}$)).

WMA	Reliable Yield	Transfers In	Local Requirements	Transfers out	(Shortfall) Surplus (+)
Limpopo	281	18	322	0	(23)
Levuvhu/Letaba	310	0	333	13	(36)
Crocodile West & Marico	716	519	1,184	10	41
Olifants	609	172	967	8	(194)
Incomati	897	0	844	311	(258)
Usustu to Mhlatuze	1,110	40	717	114	319
Thukela	737	0	334	506	(103)
Upper Vaal	1,130	1,311	1,045	1,379	17
Middle Vaal	50	829	369	502	8
Lower Vaal	126	548	643	0	31
Mvoti to Umzimkulu	523	34	798	0	(241)
Mzimvubu to Keiskamma	854	0	374	0	480
Upper Orange	4,447	2	968	3,149	332
Lower Orange	(962)	2,035	1,028	54	(9)
Fish to Tsitsikamma	418	575	898	0	95
Gouritz	275	0	337	1	(63)
Olifants/Doring	335	3	373	0	(35)
Breede	866	1	633	196	38
Berg	505	194	704	0	(5)
Total for Country	13,227	0	12,871	170	186

Source: Turton, 2012: unpaginated

From the table above, the total amount of water available in the country as of 2000 was 13,227 million cubic metres ($10^6\text{m}^3/\text{yr}$) (MCM) and the total local requirement was 12,871 MCM. The difference between the total available and the total local requirements and also after taking out the total transfers out resulted in a national surplus of 186 MCM (Turton, 2012). However, it is important to note that due to the fact that some of the local requirements were higher than what was available in their WMAs and also the problems of having some amounts being transferred out resulted in major deficits being recorded for areas such as Olifants (194 MCM), Incomati (258 MCM), Thukela (103 MCM) and Mvoti to Umzimkulu (241 MCM).

Based on the information above, projections were made for the year 2025 in which two different analyses were made: a Base Scenario, which assumes a limited economic growth, which is represented by Table 2.4 and a High Scenario which assumes that there will be higher levels of economic growth and employment, which invariably will lead to a high demand for water represented by Table 2.5 (Turton, 2012).

Table 2.4: Reconciliation of the Requirements for and Availability of Water for the Year 2025 in terms of the Base Scenario. (All volumes given in millions of cubic metres per year ($10^6\text{m}^3/\text{yr}$).

WMA	Reliable Yield	Transfers In	Local Req'ts	Transfers Out	(Shortfall) Surplus (+)	Potential for Devpt
Limpopo	281	18	347	0	(48)	8
Levuvhu/Letaba	404	0	349	13	42	102
Crocodile West & Marico	846	727	1,438	10	125	0
Olifants	630	210	1,075	7	(242)	239
Incomati	1,028	0	914	311	(197)	104
Usutu to Mhlatuze	1,113	40	728	114	311	110
Thukela	742	0	347	506	(111)	598
Upper Vaal	1,229	1,630	1,269	1,632	(42)	50
Middle Vaal	55	838	381	503	9	0
Lower Vaal	127	571	641	0	(57)	0
Mvoti to Umzimkulu	555	34	1,012	0	(423)	1,018
Mzimvubu to	872	0	413	0	459	1,500

Keiskamma						
Upper Orange	4,734	2	1,059	3,589	88	900
Lower Orange	(956)	2,082	1,079	54	(7)	150
Fish to Tsitsikamma	456	603	988	0	71	85
Gouritz	278	0	353	1	(76)	110
Olifants/ Doring	335	3	370	0	(32)	185
Breede	869	1	638	196	36	124
Berg	568	194	829	0	(67)	127
Total for Country	14,166	0	14,230	170	(234)	5,410

Source: Turton, 2012: unpaginated

Table 2.4 shows a national water deficit of 234 MCM in 2025. In the projection of the Base Scenario the assumption made was that all the sewage plants will be working properly, however, this is not the case (Turton, 2012). It is noteworthy that as much as a third of the existing water stored in dams may be polluted due to 'dysfunctional sewage systems and the flow of AMD from derelict and non-operational coal and gold mines', and in the projected deficit, this aspect is not accounted for (*ibid.*: unpaginated).

Table 2.5: Reconciliation of the Requirements for and Availability of Water for the Year 2025 in terms of the High Scenario. (All volumes given in millions of cubic metres per year ($10^6\text{m}^3/\text{yr}$)).

WMA	Reliable Yield	Transfers In	Local Req'ts	Transfers Out	(Shortfall) Surplus (+)	Potential for Devpt
Limpopo	295	23	379	0	(61)	8
Levuvhu/Letaha	405	0	351	13	41	102
Crocodile West & Marico	1,084	1,159	1,898	10	335	0
Olifants	665	210	1,143	13	(281)	239
Incomati	1,036	0	957	311	(232)	104
Usutu to Mhlathuze	1,124	40	812	114	238	110
Thukela	776	0	420	506	(154)	598
Upper Vaal	1,486	1,630	1,742	2,138	(764)	50

Middle Vaal	67	911	415	557	6	0
Lower Vaal	127	646	703	0	70	0
Mvoti to Umzimkulu	614	34	1,436	0	(788)	1,018
Mzimvubu to Keiskamma	886	0	449	0	437	1,500
Upper Orange	4,755	2	1,122	3,678	(43)	900
Lower Orange	(956)	2,100	1,102	54	(12)	150
Fish to Tsitsikamma	452	653	1,053	0	52	85
Gouritz	288	0	444	1	(157)	110
Olifants/Doring	337	3	380	0	(40)	185
Breede	897	1	704	196	(2)	124
Berg	602	194	1,304,	0	(508)	127
Total for Country	14,940	0	16,814	170	(2,044)	5,410

Source: Turton, 2012: unpaginated

In the case of the High Scenario projection, a very high demand for water due to high economic growth and employment would result in a national deficit of 2,044 MCM in 2025 (Turton, 2012). In this scenario, there is also the assumption that “sewage treatment plants would be operating optimally and does not take AMD flows into consideration, simply because these issues were not relevant when the work was being done on the National Water Resource Strategy” (*ibid.*: unpaginated).

The High Scenario projects that by the year 2025 as much as 50% of the water stored in an annual cycle in large dams would no longer be fit for usage which indicates a worse situation than what has been projected for the Base Scenario (*ibid.*). Furthermore, areas such as KwaZulu Natal, Upper Vaal and Western Cape are projected to have specific localized deficits due to anticipated economic growth (*ibid.*).

The subsequent sections will delve into the South African law on groundwater, specifically the National Water Act, citing what it sets out to achieve in relation to water resources. It will also touch on the policy set out by the DWAF, the custodian of water resources in South Africa, and

what it sets out to achieve in relation to groundwater protection, usage, conservation and management.

2.2.4 South African law on Groundwater

The Constitution, which is the supreme law of the land, states in section 24 that “everyone has the right – (a) to an environment that is not harmful to their health or wellbeing and (b) to have the environment protected for the benefit of present and future generations through reasonable legislative and other measures that – (i) prevent pollution and ecological degradation (ii) promote conservation and (iii) secure ecological sustainable development and use of natural resources while promoting justifiable economic and social development” (The Constitution of RSA, 1996: 11).

The Constitution clearly outlines the responsibilities of the state in relation to the environment and these are to be adhered to. It must be noted that water forms part of the environment and therefore, the outlined law is applicable to it. In order for the state not to contravene what has been outlined in the Constitution, certain legislation and policies have been passed in relation to water resources in South Africa. They include the National Water Act of 1998 and some policies by DWAF, such as the National Water Resource Strategy, 2004 and the Waste Discharge Charge System (WDCS), 2007.

2.2.4.1 The National Water Act of 1998 (NWA)

The National Water Act, 1998 (Act 36 of 1998) provides the framework within which to protect, use, develop, conserve, manage and control our water resources (DWAF, 2000). The Act is grounded on the principle of sustainability and equity which serve as a guide in the protection, use, development, conservation, management and control of water resources (NWA, 1998).

The DWAF's water resources management mission is “to act as the public trustee of the nation's water resources to ensure that the country's water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner” (DWAF, 2000: viii).

The groundwater mission is “to manage groundwater quality in an integrated and sustainable manner within the context of the National Water Resource Strategy and thereby to provide an adequate level of protection to groundwater resources and secure the supply of water of acceptable quality” (*ibid.*: viii).

In the implementation of strategies, the guiding principles include subsidiarity and self regulation, pollution prevention, integrated environmental management, equity, sustainability,

the polluter pays, and public participation (*ibid.*). Furthermore, groundwater protection will be based on a precautionary principle as well. That is, all groundwater will be assumed to be vulnerable unless proven otherwise and the approach to protection will be implemented for source-directed, resource-directed and remedial management measures (*ibid.*).

2.2.4.2 The National Water Resource Strategy (NWRS)

The main objectives of the South African government are to ensure that water resources are equitably shared amongst the citizens of the nation and also to ensure the usage in a sustainable and efficient manner (DWAF, 2004). Equity in this sense is not only limited to the needs of the current population but also taking measures to ensure that future generations are also able to meet their needs (*ibid.*).

In order to ensure equity and also the sustainability of water resources, two strategies have been instituted in relation to the protection of water resources. These are resource-directed measures and source-directed controls (*ibid.*). These strategies specify the desired conditions of the water resources and also institute measures for their usage (*ibid.*).

Resource-directed measures are mainly about the quality of the water resource. That is how clean, healthy or the conditions of the water resource. It is also indicative of its ecological standing (*ibid.*). Some aspects taken into consideration in relation to resource quality are “water quantity and quality, the character and condition of in-stream and riparian habitats, and the characteristics, condition and distribution of the aquatic biota” (*ibid.*: 56). Thus the main aim of resource-directed measures is to be able to measure the quality of the water resource in order to determine whether or not the quality is in accordance with what has been set out as the desired level of quality (*ibid.*).

Source-directed controls “define the limits and constraints to be imposed on water resource usage in order for the desired level of protection to be realized” (*ibid.*: 56). This is mainly done through water standards and authorization. This ensures that people who are authorized to use water go by water standards and regulations in relation to its usage and also protection (*ibid.*).

It is important to note that both strategies can be used as tools in dealing with the protection of groundwater, but there are aspects in which they are more effective. Resource-directed measures would ensure the sustainability of the resource, but, the most appropriate strategy to be used in relation to the protection of groundwater quality is the source-directed controls (*ibid.*).

The main concerns here are land-based activities that have the potential to directly impact on groundwater quality and these include the siting and construction of waste disposal sites and sewage treatment plants (*ibid.*).

2.2.4.3 The Waste Discharge Charge System (WDCS)

The Waste Discharge Charge System policy by the DWAF seeks to promote waste reduction and water conservation (DWAF, 2007). It is based on the polluter-pays principle, which simply means that in a case where there is any negative impact on the environment, the person responsible for the negative impact must pay the cost of remediation or the costs of the impacts or compensate the society (*ibid.*). Therefore the polluter-pays principle aims to achieve the following:

- “Promote the sustainable development and efficient use of water resources
- Promote the internalisation of environmental costs by impactors
- Create financial incentives for dischargers to reduce waste and use water resources in a more optimal way
- Recover the costs of mitigating water quality impacts of waste discharge” (*ibid.*: 1).

This chapter has sought to provide a general overview of the groundwater situation in the world, including South Africa. It provided information on the groundwater usage, identified problems such as climate change and variability, recharge and pollution. In relation to South Africa, it is apparent that in the future, our water needs may not be met, partly due to the increasing level of pollution on groundwater resources. Thus, there is dire need for such problems to be dealt with, and legislation such as the NWA, NWRS, and WDCS, is part of the tools to provide a framework for dealing with issues on groundwater.

This research report focuses on the issues surrounding groundwater in Johannesburg, and so chapter three will discuss the groundwater issues in Johannesburg and show why these problems need to be taken seriously.

CHAPTER THREE

GROUNDWATER ISSUES IN JOHANNESBURG

3.1 Introduction

The City of Johannesburg is the largest metropolitan municipality in South Africa “in terms of both population and local government budget and revenue and is part of the Gauteng economic heartland” (The Water Dialogues, 2009: 65). The City of Johannesburg went through a restructuring process which saw the integration of “13 previously race-based administrations” into a “single metropolitan structure for greater Johannesburg” (*ibid.*: 65).

The current population of Johannesburg is 3.8 million (CoJ, 2012)². In 2015, it is estimated that the population will increase to 4.1 million (and households will also increase from 1.3 million to 1.5 million) (*ibid.*). The movement of people into the City of Johannesburg is inevitable, due to the fact that it is the wealthiest city (*ibid.*), and the economic hub of South Africa (CoJ, 2008; CoJ, 2012³).

Johannesburg accounts for 17% of the country’s Gross Domestic Product (GDP) (CoJ, 2012) and 74% of the company head offices in South Africa are located in Johannesburg (The Water Dialogues, 2009). Johannesburg also employs 12% of the national workforce (*ibid.*). Since 1996, Johannesburg’s GDP growth rate has outpaced the national growth rate, and this is due to the “dominance of fast-growing financial and business services sectors in Johannesburg’s economy” (CoJ, 2012: unpaginated)⁴.

In 2008 the annual per-capita income was R53,830, which was the highest in the country (The Water Dialogues, 2009). However, half of households earn below R1,600 on a monthly basis (*ibid.*). There is also a high level of inequality in the city (*ibid.*). For instance in 2005, the Gini-coefficient was as high as 0.56 (*ibid.*).

The City of Johannesburg has a vision of becoming a world-class African city. However, the city is characterized by high levels of poverty and inequality (*ibid.*). The city is fragmented both socially and spatially (*ibid.*). There is also the case of splintered urbanism. For instance in terms of services, “wealthy and middleclass neighbourhoods in the northern suburbs are well

² http://www.joburg.org.za/index.php?option=com_content&view=article&id=7865:the

³ http://www.joburg.org.za/index.php?option=com_content&task=view&id=5612&Itemid=266

⁴ http://www.joburg.org.za/index.php?option=com_content&id=92&Itemid=58&limitstart=2

supplied and well maintained, while working class areas in the eastern and southern parts of the city are less so" (*ibid.*: 65).

Johannesburg is a city not built on a major water body. As a result it is highly dependent on water from the two major transfer schemes, Vaal River and the Lesotho Highlands Project (*ibid.*). It is important to note that these sources of water supply are stretched due to the fact that many cities are also dependent on these same sources. Furthermore, it has been projected that South Africa and all its cities including Johannesburg will be water stressed by 2025 (Otieno *et al.*, 2004). For this reason, it is necessary for the city to develop its groundwater resources to ensure the water security of the city.

Johannesburg has a semiarid climate with a mean annual rainfall of 700mm/year which is also highly erratic (Abiye, 2011). However, during late summer, which is from January to March, the distribution of rainfall is much better, thus the rainfall during this period is a vital contributor to groundwater recharge in the city (*ibid.*).

Johannesburg is a primary city in South Africa and Africa, and engages in a wide range of industrial activities which require large volumes of water for its activities. As a result, the city is mainly dependent on surface water for large scale supply (*ibid.*). Groundwater basically supplements water supplies for domestic and industrial activities (*ibid.*). It is important to note that surface water sources are stretched (DWAF, 2011) due to the high dependency on them. That is why it is important that groundwater is developed and protected to provide a continuous supply of water, thus ensuring the water security of the city.

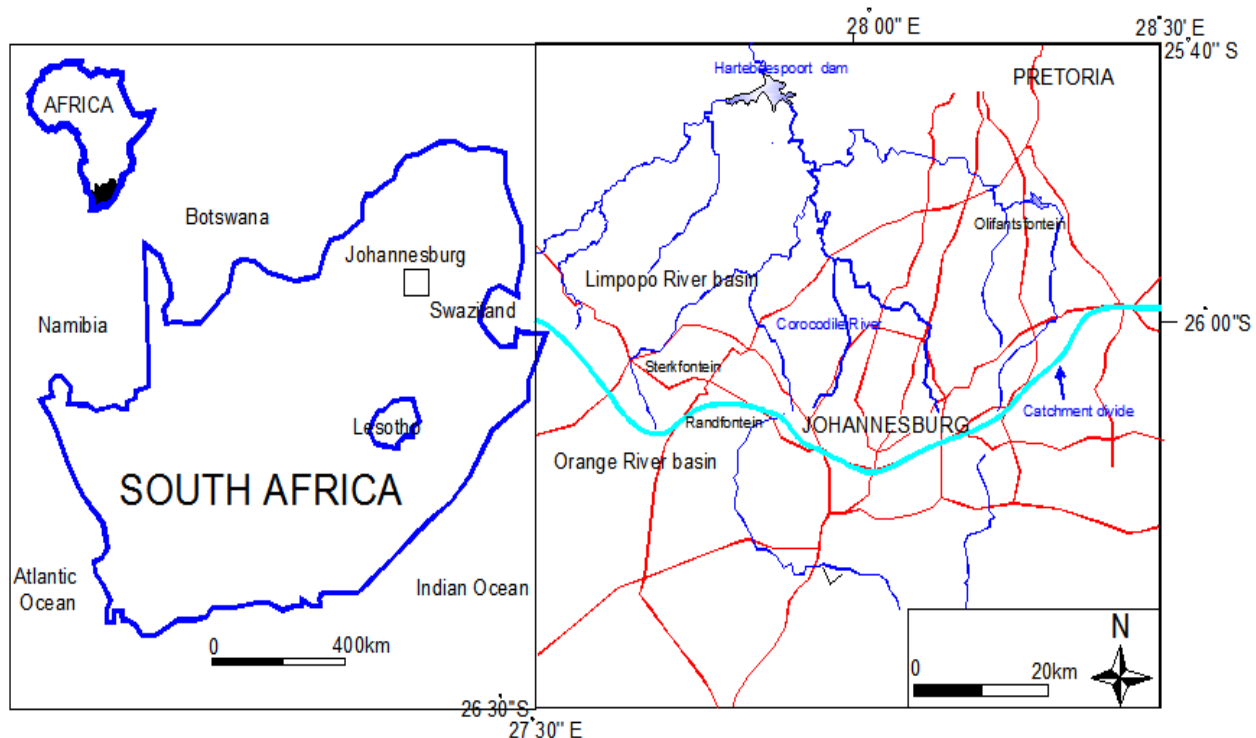


Figure 3.1: The Location and the Water Catchment of Johannesburg

Source: Abiye, 2011: 99

The East-west solid line (cyan) on the figure above is the water divide between Limpopo and Orange Rivers, the blue lines represent streams and the red lines represent roads (Abiye, 2011: 99).

Figure 3.1, shows that Johannesburg is situated on a watershed, the Limpopo River basin to the north and the Orange River basin to the south, and these two rivers are important sources of water to many areas in South Africa including Johannesburg and even in some of the neighbouring countries.

3.2 Recharge of Groundwater in Johannesburg

This aspect will be discussed in terms of the geological formation and nature of aquifers in Johannesburg and urbanization in Johannesburg.

3.2.1 The geological formation and nature of aquifers in Johannesburg

The movement of groundwater is largely controlled by geological conditions (CoJ, 2009). The City of Johannesburg has a geological formation which is predominantly hard rock. As a result groundwater yield is very low and therefore cannot be used for large scale water supply for

domestic, agriculture and industrial activities (*ibid.*). However, in the southern part of Johannesburg, there are dolomites with karst conditions covering a small area and due to these characteristics of the rocks within the area, groundwater occurs in large volumes (*ibid.*). The dolomite aquifer is classified as a major aquifer and can also serve as an important source of water supply in the case of prolonged droughts (*ibid.*). It also contributes to the base flows of streams and rivers and also sustains wetlands and other ecosystems that are dependent on groundwater in and around Johannesburg (*ibid.*).

However, dolomite aquifers are highly permeable, thus they pose a threat to groundwater quality, due to the fact that they can easily be contaminated (CSIR, 2010). As has been experienced from some of the gold mines with dolomitic geological formations in Johannesburg, there have been reports of groundwater pollution as a result of the formation of Acid Mine Drainage. Furthermore, dolomitic rocks dissolve in the presence of water and carbon dioxide, and this causes the ground to cave in, resulting in the formation of sinkholes (DWA, 2009).

3.2.2 Urbanization of Johannesburg

One other factor that affects groundwater recharge, quantity and quality is development due to urbanization (Foster, 1990). There is an increase in the movement of people from the rural areas and other neighbouring countries into the City of Johannesburg, which could put more stress on already stressed water resources (Matuszewska, 2010).

Johannesburg is mainly dependent on the Vaal Dam and Lesotho Highlands Water Project (LHWP) for water supply (Orange-Senqu, undated) but considering the effects climate change can have on water resources, it is important that groundwater is given due attention because at some point it will be the resource to save the city. It is for this reason that it is important that the groundwater resources are protected from pollution, over-abstraction and are managed appropriately. In this way, the water needs of the ever growing population and industries can be met now and in the future.

As already stated, urbanization comes with a growth in population and this would require an increase in infrastructure, which means more impervious structures such as roads, pavements, hospitals, schools, houses, will be built. In the case of housing in Johannesburg, they are anticipated to increase by 200,000 units (CoJ, 2012). These structures impact on the hydrological cycle of the area resulting in “(a) impermeabilisation of a significant proportion of

the land surface and (b) major water imports from beyond the urban limits” (Foster, 1990, p. 189). Thus, urbanization poses a threat to groundwater recharge and also can lead to occurrence of runoff.

These impervious structures constructed on land of permeable soil underlain by aquifers will prevent water from infiltrating through the soil, thereby resulting in high yields of runoff, and this negatively affects the quality of surface water bodies due to the sediments and waste products carried by the runoff (Foster, 1990; Frazer, 2005). It is clear that these impervious surfaces can have substantial effects on recharge. Foster (1990) asserts that even low residential development can result in more than 20% of land surface being impermeable and in urban and industrial areas, the impermeability of land surface can be as high as 60% or even 80%.

Furthermore, the growth in industries contributes to economic growth of the city and the country at large however there are negative aspects to them. These industries discharge effluent such as “spent lubricants, solvents, and disinfectants” and other types of wastes generated from their activities directly to the soil (Foster, 1990: 200). In addition, these wastes generated tend to contain heavy metals and some chlorinated hydrocarbons which poses a long-term threat to groundwater quality (Zoetmann *et al.*, 1981; Cavallaro *et al.*, 1985; Lawrence and Foster, 1987 cited in Foster, 1990). The impacts of these activities by industries on groundwater will be discussed in the subsequent part of the report which is about the problem of pollution.

3.3 Pollution of Groundwater in Johannesburg

3.3.1 Sanitation related pollution (Municipal)

“Human settlement and activity results in the generation of large quantities of waste” (Sililo *et al.*, 2001: 22). In order to manage the waste generated, “sewage networks and solid waste collection infrastructures have been designed to transfer these wastes to treatments points (*ibid.*). Some of the municipal sources of pollution of groundwater are sewer leakage, septic tanks, sewage effluent and sludge, storm water runoff, landfills and cemeteries and through these sources, pollutants such as nitrates, organic compounds, inorganic minerals, heavy metals, bacteria and viruses may pollute groundwater or surface water bodies (*ibid.*).

The other aspect has to do with informal settlements in the City of Johannesburg. Most of the informal settlements in Johannesburg do not have proper sanitation and there are others without sanitation at all (Kunene, 2009). Due to the lack of proper basic sanitation or not having

sanitation, people could dump their wastes and faecal matter onto bare land. These practices have the potential of polluting groundwater and this is mainly through the seepage of leachate from the waste dumps into groundwater (Zanoni, 1972). Furthermore, in cases where settlements are situated close to a water body, people dump waste directly into them. There is also the possibility of runoff from the area to pollute the water. Runoff could introduce bacteria, litter, sediments and other hazardous substances into surface water bodies, rendering them unsafe for consumption (McGuffin, 2012).

In Johannesburg, for instance, the basic sanitation provided in informal settlements is the Ventilated Improved Pit (VIP). Inappropriately sited VIPs have the potential to pollute groundwater. In order to reduce the pollution potential from them, the VIPs are lined with an impermeable material (Kunene, 2009). Although this is a good step in terms of protecting groundwater, it is not sustainable (CSO, 2009). This is because of the high operational and maintenance costs involved in this sanitation technology (CSO, 2009; Kunene, 2009). Improper maintenance could lead to the system breaking down and this could result in the leakage of faecal matter into groundwater.

3.3.2 Mine related pollution of groundwater

Mine processing may range from simple mechanical sorting to crushing and grinding followed by physical or chemical processing materials (Robertson, 1985). In a case where the former is used, such as, in placer mining and processing, the tailings and mine wastes are removed from their original location, broken up and placed in piles in which the conditions of oxidation, seepage, leaching and erosion differ considerably from those at their original location. This increases the potential of the material to be transported through wind or water erosion into the environment, as well as result in contaminants being carried into groundwater (*ibid.*).

Furthermore, where mine wastes are hydraulically placed, some contaminants may be in solution, which may also be released into the environment and eventually may contaminate groundwater. Wastes with acid generating potential can produce highly contaminated seepage flows and this is dependent on the rate at which water enters the waste deposit (*ibid.*).

The pollution of groundwater occurs through these means in many of the mines in Johannesburg. For instance, the West Rand Gold Mine has a slimes dam complex located north of Randfontein on the West Rand, Gauteng Province, South Africa occupies some 300 ha, is about 50 m high and situated on the continental water divide (Oelofse *et al.*, 2007). The dam is

mainly devoid of vegetation, and dust contained by water spraying activities facilitates the formation of AMD. In addition, AMD is formed as a result of rain percolating through the dump and as a result, there is an increased volume of AMD pouring out from a nearby shaft (*ibid.*).

The area has both dolomitic and quartzite geological formations. Groundwater drainage from the dolomitic strata is mainly by a spring discharge flowing at a rate of 25L/s in March 2007 (Hobbs *et al.*, 2007 cited in Oelofse *et al.*, 2007). A secondary groundwater is a borehole located about 590m from the toe of the facility on a neighbouring property (Oelofse *et al.*, 2007). Water samples from the spring and borehole were taken and tested for quality and the results compared to the natural dolomitic groundwater in the wider area. The spring water showed high levels of acidity, and sulphate and manganese content (*ibid.*). The borehole had excessive sulphate and as such it did not comply with the South African National Standard for drinking water (SABS, 2005 cited in Oelofse *et al.*, 2007).

The spring water drains through a shallow open ditch across private property towards the west (Oelofse *et al.*, 2007). It also passes through a farm dam which is used for recreational purposes (*ibid.*). The water was tested and it showed high levels of trace metals such as aluminium, cadmium, cobalt and nickel in the spring water (Hobbs *et al.*, 2007). The water eventually drains into a surface water drainage, where it combines with effluent discharge from a municipal waste water treatment works located upstream of the confluence (Oelofse *et al.*, 2007). This implies that the groundwater pollution could be as a result of the municipal waste water or AMD or both.

Furthermore, AMD from nonoperational and flooded underground mine workings first reported to surface through a borehole in August 2002 (*ibid.*). It has also occurred at various mine shafts and diffuse surface seeps in the area. Before the rehabilitation work in 2005, AMD flowed through a game reserve further downstream of which lies the Cradle of Humankind World Heritage Site (*ibid.*). Aquatic biomonitoring programmes carried out in 2000 and in 2004, that is before and after decant commenced, revealed a drastic drop in macro-invertebrates in the water course (Du Toit, 2006 cited in Oelofse *et al.*, 2007). As a result of the impact of AMD on the drinking water supply of the game reserve, there has been a significant decrease in the populations of animals such as Blesbuck, Springbuck and Lion (Oelofse *et al.*, 2007). It has also resulted in diseases such necrosis and testicular degeneration (Du Toit, 2006).

It is important to note that the discharge of AMD has been reported from many gold mines in the Witwatersrand basin, which, as has been explained, has resulted in the pollution of water

resources and also the environment, and is posing a threat to the natural ecosystems (Oelofse *et al.*, 2007). Although many of these mines are no longer in operation, there is still the discharge of AMD and this according to Oelofse *et al.*, (2007), suggests that an end to mining in an area does not necessarily mean the end of the impacts from mining and the mining waste dumps.

Another example is the pollution of the Klip River due to the fact that mine wastes are discharged into it (McCarthy and Venter, 2006). According to McCarthy and Venter (2006), when Wittmann and Forstner (1976) first reported AMD on the Witwatersrand, as well as the presence of heavy metals in the surface water and sediments in the Klip River basin, the source was taken to be the surface runoff from mining tailings dumps in the catchment area, as well as, the waste water pumped during mining operations. This was not the case. Later studies undertaken in the area showed that the mine tailings were polluting the underlying groundwater and through seepage it was also polluting the surface water (McCarthy and Venter, 2006).

The continuous seepage of water from mine tailings also resulted in the pollution of the soil, and as such, there are chemical footprints in the underlying soils and so there is continuous contamination of the groundwater, even though the dumps have been removed from the sites (*ibid.*). There has also been an increase in the water discharged on surface water bodies from the underground workings from the mines in the Central basin, and even though the water is treated, it is of poor quality (*ibid.*).

The poor quality of the water pumped from the mines, together with the polluted groundwater, have resulted in an increase in the mineral load in the Vaal River at the Vaal Barrage downstream, where the Klip and Vaal rivers meet (*ibid.*). Furthermore, due to the establishment of settlements around the Witwatersrand area, there have been cases where untreated sewage and water from industrial activities have been discharged into the Klip River (*ibid.*).

From these discussions, it is evident that a wide range of human activities impact negatively on groundwater and they cannot be ignored. There is the tendency for people to neglect groundwater due to the fact that the resource is not visible to them. People become alarmed only when surface water bodies change colour or become odorous as a result of pollution, but it is important for people to be aware that pollution on surface water implies, pollution on groundwater.

As has been established earlier, surface water bodies sometimes recharge groundwater and vice versa. There is therefore, the need for an understanding that groundwater and surface water bodies are linked and as such, whenever there is pollution on a surface water body, there is a high probability that the pollutants have been transmitted to groundwater and vice versa. An understanding of these media through which water resources are polluted is the right step in being able to develop strategies that would be helpful in dealing with the problem of pollution.

It must be said that in recent times, scientists around the world have put in a lot of effort to make us understand the problems with groundwater. For instance, in the case of the link between groundwater and surface water, scientists are seeking for the resources to be managed together, thus, the development of the management tool, the Integrated Water Resource Management (IWRM) (refer to chapter five), and this is becoming an important approach for water managers in many parts of the world including South Africa. However, it is important for us to note that without proper understanding of the processes of the IWRM and the necessary resources (capacity), we will not be able to achieve any positive outcome in the IWRM. Some of the problems with institutional capacity are discussed in the section below.

3.4 Institutional Capacity of the Johannesburg Metropolitan Municipality

Capacity is an important aspect for the development and management of groundwater resources and in dealing with this aspect two main factors are to be considered: capacity in terms of availability of experts and monetary means. Without the appropriate people to deal with groundwater issues, groundwater resources may be jeopardized and without the financial means, groundwater projects such as protection and remediation cannot be undertaken.

The water legislation of South Africa calls for a decentralized management in the water sector and a move from supply driven to demand oriented approach (DWAf, 2009). However, there are not enough experts in the sector to make this realizable. This is due to challenges such as “an ageing workforce, emigration of professionals and constraints on university training” (*ibid.*: 1-1), and in terms of university training, the number of skilled people being provided is not matching up the demand (*ibid.*).

Groundwater development, problems and management require the expertise of hydrologists, groundwater engineers and groundwater scientists and therefore it is imperative that a lot of these experts remain within the sector (*ibid.*). Although these people have the technical

knowhow, it is important that from time to time they are provided with training programmes especially in new concepts to keep them informed and also improve on their work.

The Department of Water Affairs and Forestry (DWAF) lacks hydrologists and this does not augur well for the Department, due to the fact that it can hinder the progress in groundwater operations and management, and also the activities of water resource management institutions could be monitored less (*ibid.*). This can also present challenges to the realization of a successful implementation of the National Groundwater Strategy (NGS) (*ibid.*). It is therefore important that this aspect is given due consideration and the necessary measures such as capacity building and training are taken into consideration, and this would be the right approach to ensuring an abundance of hydrologists in the water sector.

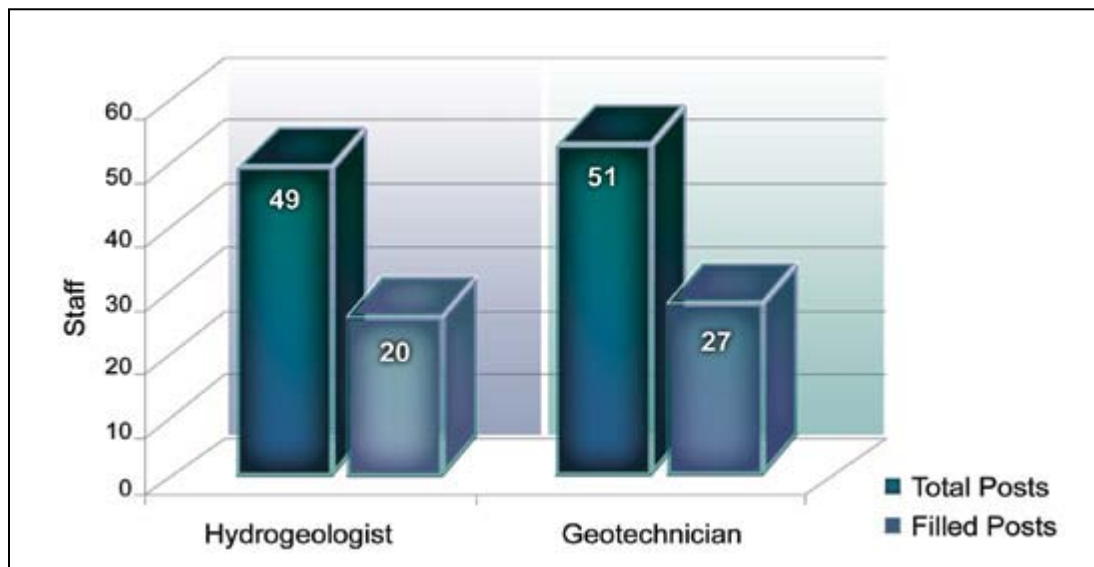


Figure 3.2: Staff Vacancies at DWA (2008 figures)

Source: DWAF, 2011: 13

Furthermore, there is a lack of co-operation and co-ordination in the activities of the various tiers of water planning and management (DWAF, 2011). Also, water planning documents are not supportive of each other, and they are also not in line with integrated development plans (*ibid.*). As much as possible there should be some form of coordination in order to provide coherent instructions for effective planning (*ibid.*).

According to a survey undertaken by DWAF, the institutions involved in capacity building in groundwater are as shown in Table 3.1.

Table 3.1: Institutions involved in Capacity Building in Groundwater in South Africa

Institution	Department
University of the Free State – only post graduates	Institute for Groundwater Studies (UFS)
University of the Western Cape – post and undergraduates	Earth Science Department
University of the Western Cape – post and undergraduates	The UNESCO Chair Centre on Groundwater Earth Science Department
University of Pretoria - post and undergraduates	Department of Geology
University of KwaZulu Natal – post and undergraduates	School of Bioresources Engineering and Environmental Hydrology
University of the Witwatersrand – post and undergraduates	School of Civil and Environmental Engineering
	School of Geosciences
University of Venda – post and undergraduates	Department of Hydrology and Water Resources
Rhodes University – post and undergraduates	Department of Environmental Science
	Department of Geology
Tshwane University of Technology – post and undergraduates	Department of Environmental, Water and Earth Science
Stellenbosch University – post and undergraduates	Department of Geology, Geography and Environmental Studies

Source: DWAF, 2009: 4-1

Other institutions involved in the training of water experts include Framework Programme for Research, Education and Training in the Water sector (FETWater), Water Research Commission, SETAs, CAPNET, WaterNet, the Water Research Fund for Southern Africa (WARFSA), the African Groundwater Network (AGW-NET), DWAF Learning Academy and the University of Western Cape UNESCO Chair of Geohydrology (DWAF, 2009).

In dealing with capacity in terms of monetary means, the question to be asked is, do the various organizations have the financial means in dealing with the problems associated with groundwater management? In terms of budgeting, how much is allotted for development, protection and management of groundwater? It is important that these aspects are also given due consideration because they are of fundamental importance to the effective management of the groundwater resources. This implies that when dealing with groundwater, concerns should not only be limited to the amount of water being pumped to households or the revenue being obtained by the city from the supply of water. Groundwater management requires a holistic approach, which entails budgeting for development, protection and management of the resource and most importantly, having groundwater experts in the field for effective management of groundwater resources.

Figure 3.2 shows that there is a shortage of groundwater experts in the DWAF. Comparing the total number of posts available for hydrogeologists and geotechnicians and the number that has been taken up, it is indicative of capacity problems being faced by the Department. However, it is important that in an effort to employ personnel, the Department should not make filling vacant posts the priority, thus focusing on quantity. Priority should be given to quality, in terms of skill, ability and knowledge. The experts are knowledgeable in groundwater matters as such are in a better position to develop appropriate measures to deal with the problems associated with groundwater and also the management of the resource.

Having an adequate number of experts in the DWAF implies that the department would be able to deploy many experts into the field to monitor the activities of Johannesburg Water, the water services provider for Johannesburg, with the mandate to provide water and sanitation services to Johannesburg residents (Johannesburg Water: undated). For instance, proper monitoring of activities of Johannesburg Water by the DWAF would ensure that purifying standards are enforced (CoJ, 2012)⁵. In addition, there is the need for groundwater experts in the city of Johannesburg's Department of Environmental Planning and Management, responsible for the

⁵ http://www.joburg.org.za/index.php?option=com_content&do_pdf=1&id=35&limitstart=3

management of catchments, impoundments and wetlands, monitoring water quality and implementing rehabilitation programmes (CoJ, 2012)⁶, to provide the necessary support to DWAF (Eberhard: undated), by also checking on the activities of Johannesburg Water.

It is also important to note that Johannesburg Water focuses mainly on surface water, that is, the water bought from Rand Water and the Lesotho Highlands Projects for water supply in the city (The Water Dialogues, 2009). Very little attention is paid to groundwater, and in most reports on Johannesburg Water, groundwater is only acknowledged as a resource, without any mention of strategies to be implemented for their development and monitoring (Johannesburg Water: unpaginated). This is a problem because it creates the impression that groundwater is not important to Johannesburg.

It is difficult to ascertain the nature and extent of any capacity issues experienced by Johannesburg Water, because, according to Johannesburg Water's annual report for 2010/2011, they experienced "a reduction in the turnover for scarce and skilled staff such as engineers and artisans" and their development programmes for employees and student yielded positive results (Johannesburg Water, 2011, p. 10). The question then, is why are the water problems of Johannesburg still persistent? There are still cases of water losses due to "unaccounted for water" and there is still pollution of water from wastewater treatment facilities, and these activities are to be carried out by experts from Johannesburg Water. A possible reason for these problems could be that the DWAF is not properly monitoring the activities of Johannesburg Water staff and ensuring that they do their work according to the required standards and specifications.

These discussions make it clear that the groundwater problems of Johannesburg are pressing and it is imperative that they are dealt with due to the repercussions it can have on Johannesburg and even beyond.

Pollution of groundwater in Johannesburg can result in the pollution of Limpopo and Orange Rivers and this can have a ripple effect on all the areas dependent on these rivers as sources of water supply. It is important to note that the Limpopo River basin is shared by Botswana, South Africa, Zimbabwe and Mozambique (Bigcon Consortium, 2010), and therefore the effects of pollution on the river could be experienced beyond Johannesburg and South Africa. In the case of Orange River basin, neighbouring countries such as Lesotho, Namibia and again, Botswana could be exposed to polluted water (DWAF: undated). It is, therefore, important that

⁶ http://www.joburg.org.za/index.php?option=com_content&task=view&id=968&Itemid=114&limitstart=2

groundwater problems in Johannesburg especially aspects related to human activities are taken seriously and most importantly dealt with effectively. The next chapter will delve into the implications of the groundwater problems discussed above for Johannesburg.

CHAPTER FOUR

THE IMPLICATIONS OF GROUNDWATER PROBLEMS FOR JOHANNESBURG

4.1 Introduction

The problems associated with groundwater need to be dealt with due to the impacts they can have on the lives of the people in Johannesburg, as well as the environment. If the problems associated with groundwater are not addressed, they will have negative effects on water supply and economic development, food security, livelihoods and health of residents. It will also affect the environment and groundwater dependent ecosystems. Furthermore, groundwater problems will have implications for remediation. The aspect on capacity is of paramount importance because without dealing with capacity issues, Johannesburg is unlikely to manage its groundwater resources in a sustainable manner.

4.2 The Implications of Groundwater Water Problems for Water Supply and Economic Development in Johannesburg

There are challenges to groundwater recharge due to the semiarid conditions of the city and this can deteriorate as a result of climate change. Johannesburg is predicted to experience very high levels in temperature and variability in rainfall and it is also predicted to experience a rise in the occurrence of droughts due to climate change, and these are a potential threat to the availability and sustainability of the water resources of the city (Matuszewska, 2010). This is because if there is none or less rainfall, then neither the groundwater systems, nor surface water bodies can be recharged. The problem of reduced recharge, coupled with over-abstraction can have serious repercussions such as the occurrence of droughts in the city.

Reduced recharge, together with over-abstraction can affect the availability and sustainability of the water resources and can have both economic and social impacts (*ibid.*). Due to shortages in water, there might be increases in the cost of water (*ibid.*). This will cause financial strain on people because they would have to spend more money on water, and this could reduce the quality of life for the people because they would have to cut down on things such as food, shelter and clothing (*ibid.*). Water shortages or scarcity can result in conflicts over its allocation (Otieno *et al.*, 2004).

Furthermore, water scarcity or “peak water” could result in a “supply-constrained economy” and this can limit the capacity to create new jobs (Turton, 2012: unpaginated). The unavailability of

jobs can cause the movement of labour from one place to another and this can result in social instability due to the fact that there are not many job opportunities and due to the pursuit of efficiency, human labour is replaced with mechanization (*ibid.*). This is further compounded by the “uncontrolled inflow of foreign refugees” (from neighbouring countries) faced with similar circumstances in their home countries (*ibid.*).

Furthermore, water scarcity can result in “substantial constraints to the economic growth potential of the country” (*ibid.*: unpaginated). This is mainly because many of the economic activities of the country require water. Water is very important to the energy sector, mining industry, manufacturing industry, construction industry and also used for running businesses such as restaurants, hotels, etc. Constraints in the supply of water due to water scarcity to these industries and businesses can result in their collapse, and this can further affect the economic growth of the country.

A reduction in the manufacturing of products will affect exports, thus making it difficult for the realization of revenue for development. For instance, the Johannesburg-based Anglo American Platinum Ltd (AMS), the world’s largest producer of platinum group metals, has indicated that water scarcity poses a “very real” threat to their activities (Bloomberg, 2012: unpaginated). Disruptions in the supply of water would result in a reduction in the manufacturing of metals which will invariably affect exports and thus affecting income generation and tax collection of the country (*ibid.*). Furthermore, the scarcity of water may affect the generation of electricity and this may pose a threat to the energy security of the city (Turton, 2012).

There is the aspect of flooding due to high rainfall and this is an area that also needs attention in order for the appropriate measures to be instituted in order to deal with this problem. High rainfall occurrences in a moderate manner cannot be a bad thing due to the fact that it would result in aquifers being recharged. However, the occurrence of high rainfall over a longer period of time can be disastrous for the city.

High rainfall implies high occurrences of surface runoff, increase flow of storm water through sewerage and increased groundwater flow from points of recharge, and all of these can cause the water table to rise above normal levels (Sommer, 2006; BGS, 2010). High groundwater levels can affect houses causing instability and this is mainly due to buoyancy effects (Sommer, 2006). It can also affect infrastructure and services. For instance, groundwater can seep into sewerage systems and also flood roads. There is also the contamination of soil due to polluted

groundwater and the transportation of pollutants into wells, which could be fatal to communities that are dependent on these wells for water supply (Sommer, 2006).

It must be noted that groundwater flooding and surface water flooding often occur together. However, it takes a longer time for flooding as a result of groundwater to recede, than flooding caused by surface water (BGS, 2010). Groundwater flooding disrupts the lives of people and businesses, and also causes damage to property and even loss of lives. The flooding of roads means that transport operators will be unable to operate, thereby making it difficult for people to move from one place to another. The economy can also be affected in the process due to the fact that people and businesses become unproductive and a lot of money have to be channeled into providing emergency services as well as paying insurance claims (BGS, 2010).

4.3 The Implications of Groundwater Problems for Food Security

In every part of the world, water is very important for the agricultural sector and it is the sector that uses the largest amount of water (Kundzewicz *et al.*, 2007 cited in Clifton *et al.*, 2010). Furthermore, in most places including Johannesburg, groundwater is an important source of water for irrigation, which means that in the case where groundwater is unavailable or there is a shortage in the quantity, irrigation becomes impractical especially when there is not enough to provide drinking water to the people (Clifton *et al.*, 2010). Thus, access to drinking water becomes an area of “higher priority” than the provision of water for the agricultural purposes (*ibid.*: 25).

It must be noted that both access to drinking water and food is very important for human survival. However, when there is a water scarcity, food cultivation may be put on hold in order to cater for the growing need for drinking water. Furthermore, the very little cultivated food will not have sufficient water for growth, as a result crops may die or will have very low yield (FAO, 2011). The scarcity of water can also cause a reduction in livestock production and increase the death of livestock due to lack of drinking water (*ibid.*). It can also lead to increases in “insect infestation” which can result in the outbreak of plant and animal diseases (*ibid.*: 1). The dry weather conditions can also result in “forest and range fires, land degradation and soil erosion” (*ibid.*: 1), and these can render land non-cultivable. All of these together affect the “availability, stability, access and utilization” of food (*ibid.*: 1).

Pertaining to health, people become susceptible to contracting food-borne and water-borne diseases and the lack of food may cause malnourishment in people (*ibid.*). It can also displace people and result in death (*ibid.*) as has been shown in table 4 below. In relation to socio-

economic development, people may lose their sources of income (*ibid.*). Food prices might increase due to the fact that there is a reduction in production and supplies, which can cause financial strain on families, especially the poor and the vulnerable (*ibid.*). In addition, food will have to be imported from other places to meet the needs of the local people and can lead to “increased fiscal pressure on national budgets” (*ibid.*: 1).

Some examples of countries that have been affected by drought include USA, Australia, Ethiopia, Sudan, China, India, etc. USA had cases of drought in the 1980, 1988, 1998 and 2002 and this affected mainly agriculture production. Australia's agriculture sector was seriously hit in 1981-82 and 1991-1995. India has had many cases of drought as indicated in the table below, and in terms of the event that was experienced in 2002, “the impact covered over half of the Indian land mass and threatened the livelihoods of 300 million people across 18 states” (FAO, 2011, p. 2). In addition to these losses, many lives were lost in the areas that were hit by droughts, as shown in the table below:

Table 4.1: Drought Disasters of the World from 1900-2011

Country	Year	Fatalities, Thousands
Ethiopia	1982-84	300
Sudan	1982-84	150
Ethiopia	1973	100
India	1965	1500
Bangladesh	1943	1900
India	1942	1500
China People's Republic	1928	3000
Soviet Union	1921	1200
China People's Republic	1920	500
India	1900	1250

Source: EM-DAT: The OFDA/CRED International Disaster Database cited in FAO, 2011: 2

From the above discussions, it is obvious that the need to protect and manage groundwater effectively cannot be overemphasized. It is evident that the effects of water scarcity are far-reaching. South Africa is prone to droughts, and all of its cities, including Johannesburg, are prone to drought.

In the 1990s and in 2003/2004, South Africa was hit by drought (Austin, 2008). This threatened the food security of the country. South Africa consumes 7.8 million tons of maize annually, however, in 1991/1992, due to drought, there was only 2.7 million tons available and this led to the importation of 4 million tons of maize (*ibid.*).

The 2003/2004 droughts resulted in a financial strain for South Africa, due to the need to provide drought relief funds to areas and sectors that were gravely affected, in order to minimize the impacts (*ibid.*). The government of South Africa allotted R250 million for flood rehabilitation, the provision of emergency water supply for poor communities, drilling of boreholes, saving timber in state farms that had been affected by fires and the provision of fodder for both commercial and communal farmers (International Federation of Red Cross, 2004 cited in Austin, 2008).

Provinces such as Limpopo, Northern Cape, Eastern Cape and the Free State were in a state of emergency. As a result, they were provided drought relief: Limpopo received R33 million, Northern Cape R68 million, Eastern Cape R13 million and the Free State received R10 million (The Sowetan, 2004 cited in Austin, 2008).

Furthermore, another R250 million had to be channeled into the provision of drought relief for the purposes in the table below:

Table 4.2: A Breakdown of the Allocation of Funds during the 2003/2004 Drought in South Africa

Amount	Drought Relief Assistance Area
R60 million	Emergency relief to vulnerable rural communities
R30 million	The provision of fodder to established or emerging farmers
R100 million	Water for human consumption
R20 million	Water for livestock
R5 million	The safeguarding of boreholes
R35 million	The prevention of communicable diseases in affected poor rural areas

Source: International Federation of Red Cross, 2004 cited in Austin, 2008: unpaginated

Considering the impacts of drought, it cannot be taken lightly. For a city that is highly populated and also has the greatest number of industries in South Africa, water scarcity or shortages, coupled with the occurrence of droughts will be disastrous for the city and the nation as a whole.

It will also present challenges to the realization of the developmental goals of the city of Johannesburg. Dealing with groundwater issues require long range planning, therefore the time to act is now. Waiting for the situation to deteriorate can make it difficult to resolve some of the problems or even make it impossible to recover from some of the problems. Therefore, there is the need for the authorities of the city of Johannesburg to understand these effects in order to take appropriate measures to deal with these impacts.

4.4 The Implications of Groundwater Problems for Livelihoods of People

Many economic activities are dependent on groundwater and therefore the unavailability of groundwater implies that most of the activities will come to a standstill. This is the case for the poor and vulnerable, who depend solely on the natural resources of the environment (IUCN *et al.*, 2003). One of such important resource is groundwater. They depend on it for domestic activities and farming. Groundwater availability and the conditions under which it occur will determine if farmers will yield bountifully or not. Thus, there is the recognition that without water, crops and livestock cannot grow, livestock grazing becomes impossible, and dried up or polluted streams will not be able to support aquatic life (Clifton *et al.*, 2010), and this may result in farmers losing their sources of income.

Furthermore, when there is surface water scarcity, businesses that were using groundwater partially may resort to using the resource on a full time basis. This may result in further stress on the groundwater resource that is already stressed due to a high dependency on the resource by the various water-related sectors. And as stated under food security, when there is insufficient water to meet every need, the need to supply drinking water becomes a priority, as such, there is minimal amount of water allocated for other activities. This could result in the closure of many businesses and sectors, thus, resulting in increased unemployment.

4.5 Health and Environmental Implications of Groundwater Problems

“The pollution of groundwater resources is often a consequence of poor land-use planning, resulting in the location of high risk activities in areas where they have a negative impact on groundwater resources” (Sililo *et al.*, 2001, p. 21). Groundwater may be polluted by bacteria and other micro-organisms, inorganic ions, heavy metals and organic chemicals (*ibid.*) and these have health implications for people who are exposed to such contaminated water, as well as the environment.

In Johannesburg, the major sources of pollution on groundwater are mine and municipal wastes. In the Witwatersrand Basin many of the gold mines use impoundments on land for the disposal of solid waste and the liquid wastes are generally channeled into water systems or sustained in unmaintained ponds which pollute water resources (Oelofse *et al.*, 2007). This leads to an increase in compounds at toxic levels in groundwater (Sililo *et al.*, 2001), which can result in a wide range of health problems for people who are exposed to such compounds (APEC Water, 2012). This includes “reduced growth and development, cancer, organ damage, nervous system damage, and in extreme cases, death” (*ibid.*: 1). Metals such as mercury and lead can cause autoimmunity, a situation whereby “a person's immune system attacks its own cells” (*ibid.*: 1). Exposure to heavy metals can also result in “joint diseases such as rheumatoid arthritis, and diseases of the kidneys, circulatory system, and nervous system” (*ibid.*: 1).

The environmental implications of these disposal methods include contamination of streams by acid mine drainage (AMD), contamination of streams due to surface run-off from the impoundment area, air and water contamination due to wind erosion of dried-out tailings, possible risk of catastrophic dam failure and release of slimes, physical and aesthetic modification to the environment and difficulty of establishing vegetative cover to permanently stabilize the tailings due to unfavourable soil conditions in the presence of pyritic tailings (Oelofse *et al.*, 2007). AMD contamination also degrades soil quality and harms aquatic sediment and fauna (Adler *et al.*, 2007). Furthermore, contaminated groundwater may result in diseases such as necrosis and testicular degeneration in wildlife (Du Toit, 2006).

Pollution by municipal sources can introduce pollutants such as nitrates, minerals, organic compounds, inorganic minerals, heavy metals, bacteria and viruses into groundwater, rendering them unsafe for human consumption (Sililo *et al.*, 2001). In addition to the list of diseases mentioned above, the presence of bacteria and viruses can result in an outbreak of diseases such as diarrhea, dysentery, cholera, typhoid, etc, which can lead to the loss of lives. The environmental implication is that, it can result in eutrophication of water bodies and make water bodies odorous (*ibid.*). This becomes a potential killer of aquatic life and does not augur well for the aesthetics of the environment.

Furthermore, it is anticipated that climate change can also impact on the occurrence of groundwater pollution. In the case of high rainfall leading to flooding, floods can transport waste water from sanitation facilities into groundwater resources. “The risk of such contamination is

likely to be greater in urban areas due to higher population density and concentration of source pollutants” (Clifton *et al.*, 2010: 25).

The need to identify and obtain safe, efficient and cost effective methods for the disposal of mining waste cannot be overemphasized. Given that groundwater is a major source of drinking water, it is important to critically examine and rethink methods of mine and municipal waste disposal not only to avoid contamination, but also as a way of harnessing groundwater for both domestic and industrial usage.

4.6 Implications of Groundwater Problems for Groundwater-dependent Ecosystems

The lack of groundwater recharge may negatively affect groundwater dependent ecosystems. It is important to note that there are ecosystems that depend on groundwater in order for them to function. Terrestrial, aquatic and marine ecosystems depend on groundwater for sustainability (Clifton *et al.*, 2010), and some ecosystems depend on groundwater as their habitat, source of water supply or depend on it for survival in the case of water scarcity or drought (Hatton and Evans, 1998; Clifton and Evans, 2001 cited in Clifton *et al.*, 2010).

The reduction in the level of groundwater due to low recharge has environmental implications. These include “the reduction or elimination of stream baseflow and refugia for aquatic plants and animals, dieback of groundwater dependent vegetation, and reduced water supply for terrestrial fauna” (Clifton *et al.*, 2010: 26). This makes it clear that groundwater is not only important to human life, it is also very important and serves as a support system for many ecosystems. It is important that ecosystems are valued because they provide important services such as the purification of water, the maintenance of biodiversity, which ensures a balance in the environment.

4.7 The Implications of Groundwater Remediation for the City of Johannesburg

The pollution of groundwater resources requires that remediation projects are undertaken to render groundwater safe for utilization. In the City of Johannesburg, water resources are polluted by untreated sewage, AMD and also as a result of urban activities, and the presence of pollutants in water reduces the amount of water available (Turton, 2012). In order to deal with this problem, money would have to be channeled into the treatment of the polluted water and this tends to be costly (*ibid.*).

As has been indicated under the High Scenario projections, it is anticipated that by the year 2025 about 50% of the total water stored in dams will not be fit for usage due to pollution (Turton, 2012). This implies that remediation projects would have to be undertaken to render the water usable or safe for usage. Remediation of polluted water is very necessary due to the danger polluted water poses to human health and the surrounding environment. However, this has serious cost implications for the economy of a country. This is the situation for groundwater as well.

In Johannesburg, the human activity that poses the greatest threat to water resources is mining. According to AngloGold Ashanti (2005: unpaginated), "South Africa produces 450 million tonnes of waste annually, with 70% of this generated by the mining industry". Annually, 105 million tonnes of waste, which is 23% of the total, is generated from the Witwatersrand gold mines with about 200,000 tonnes of waste generated per ton of gold produced (*ibid.*). There are about 270 tailings dams for the storage of waste on the Witwatersrand basin, covering an area of about 400 km² (*ibid.*). However, these dams were neither lined with impermeable material, nor covered in vegetation, as a result, are a potential source of pollution to water and soil, and they are also a source of dust (*ibid.*).

Pulles (1992 cited in AngloGold Ashanti, 2005) suggests that about 400MI of water passes through the major South African gold mines daily with 260MI going into groundwater and 130MI going into surface water. It is estimated that 'more than 6,000 km² of soil is polluted in the Witwatersrand basin as a result of gold mining, and more than 30,000km² of land overlying polluted groundwater' (Weiersbye and Cukrowska, 2005 cited in AngloGold Ashanti, 2005: unpaginated).

In an attempt to deal with the problem of water and soil pollution and for control, the mining industry introduced pasture grassing. This involved the planting and irrigation of pasture grasses. The cost involved in pasture grassing for slopes is an average of R90, 000 per hectare and R30,000 per hectare for tops (AngloGold Ashanti, 2005). Furthermore, up to three times of annual rainfall is used for the irrigation of the pasture grass, which is a waste of water and resources, considering that pasture grassing is able to prevent surface erosion for less than 10 years (*ibid.*). Therefore, this approach is considered unsustainable due to the fact that it results in the wastage of water and financial resources of the country.

From the foregoing, it is clear that there is the need for us to have an understanding that leaving groundwater to deteriorate or to be polluted incurs more cost than protecting it (Schmoll *et al.*, 2006). It is therefore imperative that we stay committed to instituting measures for the protection of our groundwater resources. This way, we will be able to save money for other developmental projects and also have groundwater which can serve as our “lifeline” in times of water shortages.

4.8 The Implications of Capacity Problems for the City of Johannesburg

From the foregoing it is evident that capacity is an area of priority. This is because, if this aspect is not put on top of the development agenda, many of the objectives that we intend to achieve for our water resources will not be realized. Without planners, hydrologists and engineers, we cannot develop or monitor our groundwater resources appropriately and we would not have the appropriate protective strategies in place. In addition, without these experts, groundwater cannot be developed to its full potential in order for it to be beneficial to the city.

There is also the need for the various tiers of water planning and management to co-operate and co-ordinate their activities in order for effective management of groundwater (DWAF, 2011). In addition, in the development of water planning documents, it is important they do not invalidate each other and they also have to be in line with integrated development plan (IDP). The lack of alignment and harmonization between the water planning documents and the IDP of Johannesburg can present challenges to water planning and planning in general. Thus, it is essential for water planning documents to reflect the objectives of the IDP.

It must be noted that without adequate professionals, co-ordination amongst various water planning institutions and a more integrated approach to planning of our water resources, we are headed for disaster.

Another area of much needed attention in our institutions is corruption, due to the fact that it is very detrimental to the integrity of any organization. It is important that the representatives of our institutions are credible. There is the need for our representatives to know that they are accountable to the people and whatever they do must be in the interest of the general public. It is the reason that it is important for institutions to have codes of conduct and codes of ethics to guide their employees, and in the case where people do not adhere to these codes they can be sanctioned appropriately.

“Corruption in the water sector can seriously undermine the effectiveness of institutions” and it is for this reason that it cannot be ignored (Pietersen *et al.*, 2011, p. 22). The management of water resources is guided by the provisions of legislation and regulations as well as policies and therefore, it is important that institutions are committed to enforcing these laws and policies. There is the need to realize that these laws and policies provide a framework for decision-making and for this reason they need to be clear and must have ‘teeth’.

A framework which is unclear can present challenges in implementation as has been experienced with the National Water Act and the National Water Resource Strategy (Pietersen *et al.*, 2011). Unclear legislation and policies can provide the platform for people to be corrupt. Rules and regulations can be bent due to selfish interests. For instance, companies could be allowed to discharge untreated waste water from their activities directly into water bodies.

It is not enough to say that the Department of Water Affairs is committed to dealing with corruption and so it has set up a Compliance, Monitoring and Enforcement Directorate (CMED) with water management inspectors. Water issues are always best dealt with from a local level rather than from a central level. Although the DWA is the national custodian of water in South Africa, it is important that they also involve the other institutions that are involved in water management and in the monitoring process as well, especially local level institutions. For instance, every institution could have a CMED set up in their organization. This will provide the means for efficient coordination and monitoring, and will also result in resolving issues more effectively.

The discussions above make it clear that groundwater problems can have implications that are far-reaching for present and future generations. These discussions make us understand the complexities of groundwater, and how important it is for sustaining the growth of the city. Therefore, there is the need for us to understand the nature of the resource in order for us to institute appropriate measures for its management. As mentioned earlier, dealing with groundwater problems can be challenging, especially in cases whereby the problems have worsened, and for this reason it is important to apply the sustainable development precautionary principle of ‘prevention is better than cure’ in the management of the resource. Thus, there is the need for us to realize that our inability to take the necessary measures to deal with these groundwater problems can be disastrous for Johannesburg and the country as a whole.

Some legislation and policies necessary for the management of groundwater have been discussed in chapter two. The following chapter will delve into some of the strategies and guidelines that have been developed for the management of the resource.

CHAPTER FIVE

GROUNDWATER MANAGEMENT STRATEGIES

5.1 Introduction

According to Sharma (2012: 1), “management is the process of reaching operational goals by working with and through people and other organizational resources.” It entails organizations and enterprises having clear objectives and taking measures to ensure that these objectives are realized and that these measures need to be aligned with policies for effectiveness (*ibid.*).

The most important four functions of management are planning, organizing, leading or directing and controlling or monitoring (Riemann *et al.*, 2011). Planning is about the pursuit of future goals of an organization and in order for organizations to achieve their goals, there is the need for a systematic approach to decision-making and outlining the necessary actions to be taken for the achievement of those goals (Sharma, 2012). The decisions and actions can be taken by an individual, a group, or work unit, or the overall organization (*ibid.*). Organizing is mainly about the implementation of plans and entails the provision of the necessary resources (human, financial, physical, information, etc.) for implementation (Riemann *et al.*, 2011; Sharma, 2012).

Directing or leading is mainly a manager's responsibility. A manager is responsible for determining what needs to be done and ensures the right people are available to do whatever is required (Riemann *et al.*, 2011; Sharma, 2012). Lastly, controlling or monitoring mainly deals with checking the progress of projects and programmes, and where there are deficiencies they can be reviewed for the necessary changes to be made in order to ensure that the organization stays on track in achieving its goals (Riemann *et al.*, 2011; Sharma, 2012).

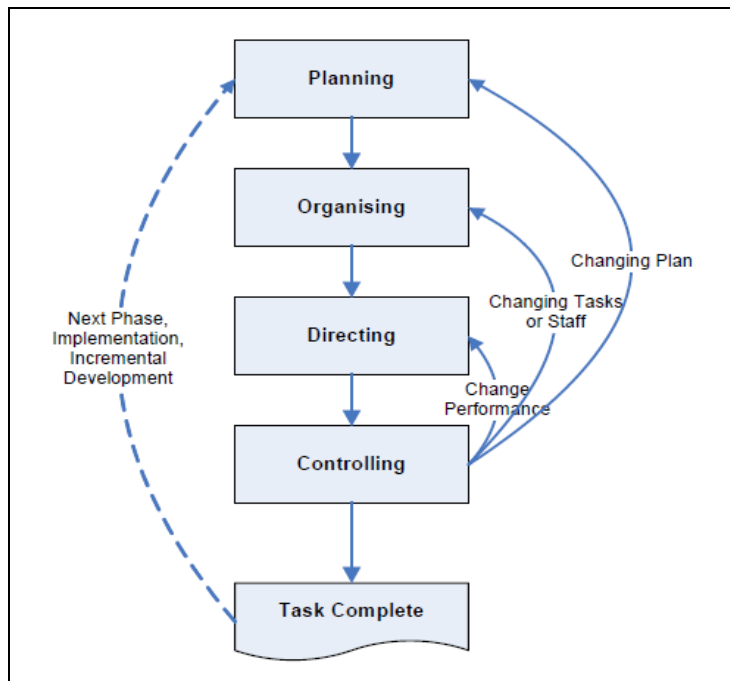


Figure 5.1: Review and Revise Cycle of Management Functions

Source: Riemann *et al.*, 2011: 446

These functions are vital and it is important that they are applied in the management of groundwater. Organizations responsible for the management of water in different parts of the world make use of different management strategies, approaches or policies for the management of groundwater. The institution of management strategies or policies provides a framework for the general management of water resources, and the institution of the necessary legislation and regulations serves as the tool for enforcement.

5.2 A Global Overview of Groundwater Management

Globally, the sustainable development and management of water resources is at the centre of all national water strategies. It is important to note these strategies developed for water and land use influence the sustainability of groundwater and also poses a challenge to the management of the resource (Cap-Net *et al.*, 2010). In selecting appropriate management measures for groundwater, assessing their feasibility in the specific setting is very important. Feasibility is dependent on cultural values, public perception, land tenure rights, socio-economic status, legal requirements and institutional capacities and they have to be evaluated in relation to the management responses anticipated (Schmoll *et al.*, 2006).

The management of water resources is the responsibility of national governments of countries and it is therefore imperative that water institutions are strengthened, as well as improving the capacity of these institutions for effective management of the water resources (Cap-Nat *et al.*, 2010). The separation of institutions responsible for surface water and groundwater management has resulted in a communication gap. There is a communication gap between technical experts and policy developers, operational managers and water users, which needs to be addressed (*ibid.*). This is because these communication barriers present challenges to understanding groundwater-surface water interactions and their implications (*ibid.*).

Traditionally, the management of water was done via “compartmentalized approaches”, particularly in the case of groundwater and development planning (Foster and Ait-Kadi, 2012, p. 415). Very little attention was paid to the linkages between groundwater, economic development and land-use planning (*ibid.*). This approach has hindered the realization of sustainable outcomes. However, in recent times, many countries, especially developing countries, have realized the need for a more holistic approach whereby groundwater becomes an integral part of development planning for the attainment of “economic efficiency, social equity and environment sustainability” (*ibid.*: 415). The need for the management of water resources in a sustainable manner has led to the development of the Integrated Water Resource Management (IWRM) strategy (Cap-Net *et al.*, 2010; Foster and Ait-Kadi, 2012).

5.2.1 Integrated Water Resource Management (IWRM)

The IWRM “is an approach that promotes the coordinated development and management of water, land, and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (Cap-Net *et al.*, 2010: 9). It includes the development and management of “land and water, surface water and groundwater, the river basin and its adjacent coastal and marine environment and upstream and downstream interests” in a coordinated manner (*ibid.*: 9).

The IWRM also deals with the human aspect of development. It recognizes the need to reform human systems for the development of water resources in order for it to be beneficial to all members of society (*ibid.*). It also recognizes the interdependencies between different water uses and the effect of each use on the other, and therefore the need for them to be considered together. For instance, an increase in demand of water for irrigation, coupled with the flow of polluted water from agricultural land would invariably result in a reduction in the availability of

freshwater for drinking or industrial use (*ibid.*). Therefore, the IWRM seeks the development of a coherent policy which is relevant to all sectors.

The IWRM also acknowledges the different users of water resources such as farmers, communities and environmentalists and the role they play in the development and management of water resources. There is the recognition that the effectiveness of water management strategies requires the participation of all stakeholders (water users, planner and policy makers), and for this reason, the IWRM incorporates participation in decision-making (*ibid.*). For instance, in dealing with water conservation and catchment protection issues, it would be effective to use local self-regulation, rather than using central regulation or surveillance (*ibid.*).

Furthermore, the IWRM seeks to integrate various sectors involved in the management of water resources. For instance, in some areas, the approach is to have an agency in charge of drinking water, another in charge of water for irrigation and another being in charge with the environment, etc. (*ibid.*). This approach to managing water is not ideal, due to the fact that it can result in “conflicts, waste and unsustainable systems” (*ibid.*).

The general framework for IWRM is based on a set of water management principles. These are based on the Dublin statements and principles and the three principles of sustainability, namely economic efficiency, environmental sustainability and social equity (*ibid.*). The Dublin principles are as follows:

Principle No.1 – Fresh water is finite and vulnerable resource, essential to sustain life, development and the environment.

Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer.

Principle No. 2 – Water development and management should be based on a participatory approach involving users, planners and policy-makers at all levels.

The participatory approach involves raising awareness of the importance of water among policy-makers and the general public. It means that decisions are taken at the lowest appropriate level with full public consultation and involvement of users in the planning and implementation of water projects.

Principle No. 3 – Women play a central part in the provision, management and safeguarding of water.

This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

Principle No. 4 – Water has an economic value in all its competing uses and should be recognized as an economic good.

Within this principle, it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price. Past failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.

Figure 5.2: Dublin Statements and Principles

Source: Cap-Net *et al.*, 2010: 10

There are three actions areas which are vital to the implementation of IWRM and these are enabling environment, institutional roles and management instruments, as shown in the figure

below and all of these aspects, if well balanced, would ensure the sustainable implementation of the IWRM.

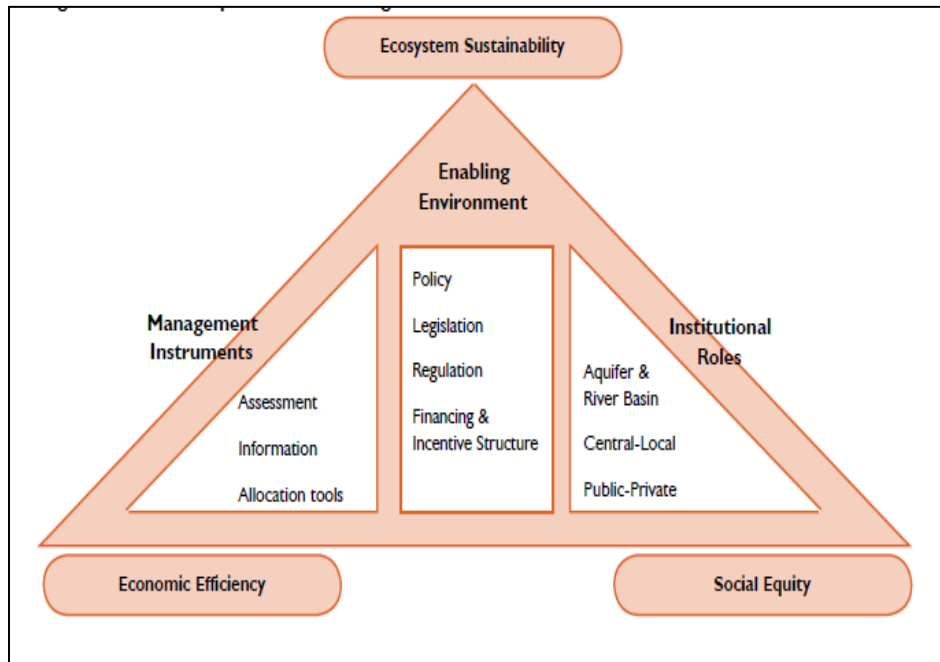


Figure 5.3: The IWRM Implementation Triangle

Source: Cap-Net *et al.*, 2010: 11

5.2.2 The IWRM planning process

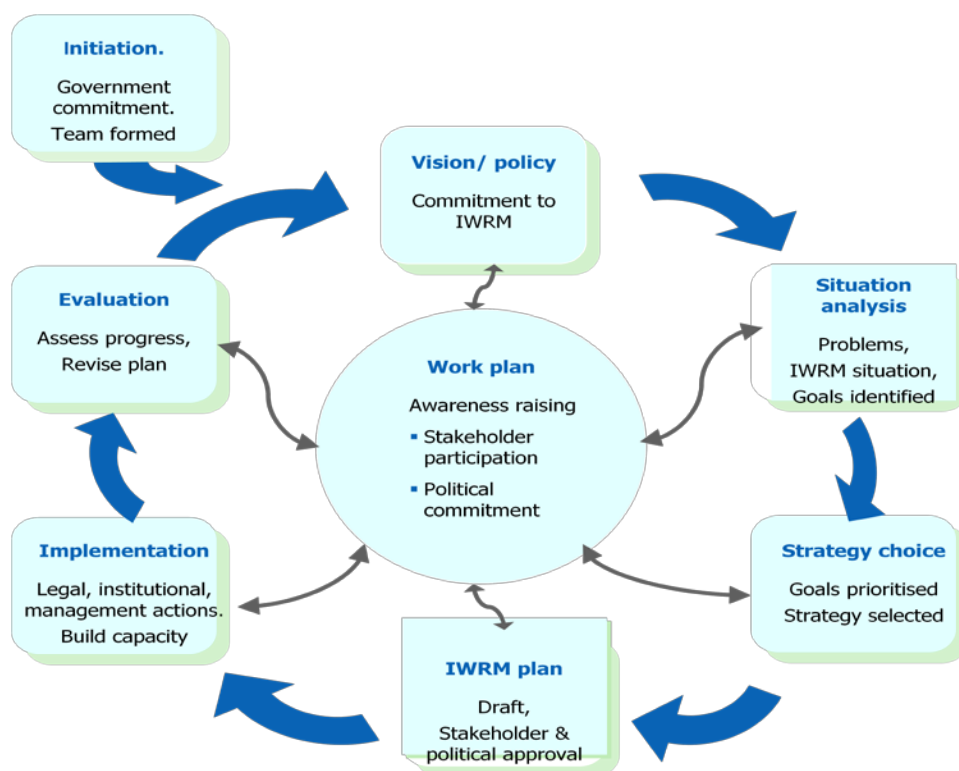


Figure 5.4: Groundwater and National Planning Cycle

Source: Mirghani, 2010: 17

Water planning cannot be done over a short period and neither can it be done over a medium term period. Water planning requires long range planning, thus there is the need for the appropriate structures to be put in place to deal with water-related problems. Ignoring the problems and not implementing appropriate strategies to deal with them will be detrimental to the development of any country. For this reason, the need to adequately plan for water resources cannot be overemphasized. It is important that water forms an integral part of all national plans, where priorities are set and the necessary measures for the management, monitoring and protection can be instituted.

The cycle above provides the approach to water management within an IWRM. It provides guidance in relation to the processes involved and the factors to be considered within an IWRM. The development of an IWRM will serve as the framework for the general management of water resources. Thus, it is important for other water management strategies to be aligned to the principles and targets set out in the IWRM.

5.2.3 Groundwater management within an IWRM

The IWRM approach to groundwater management is important because it can assist to:

- "Overcome traditional institutional separation of surface water from groundwater and resulting fundamental communication barriers.
- Sustainably meet increasing demand for water for broad economic development and livelihoods
- Replace risk management decisions – to address excessive abstraction and/or severe groundwater pollution – by integrated management approaches.
- Lack of institutional capacity, limited fund availability or, simply, politics are other barriers to an integrated groundwater management" (Mirghani, 2010: 6).

There are two very important dimensions to groundwater management and they are socio-economic and hydrological dimensions. The socio-economic dimension mainly deals with demand-side management, where water and land users are managed, and the hydrological dimension is about the management of the aquifer systems, which is termed supply-side management (Mirghani, 2010).

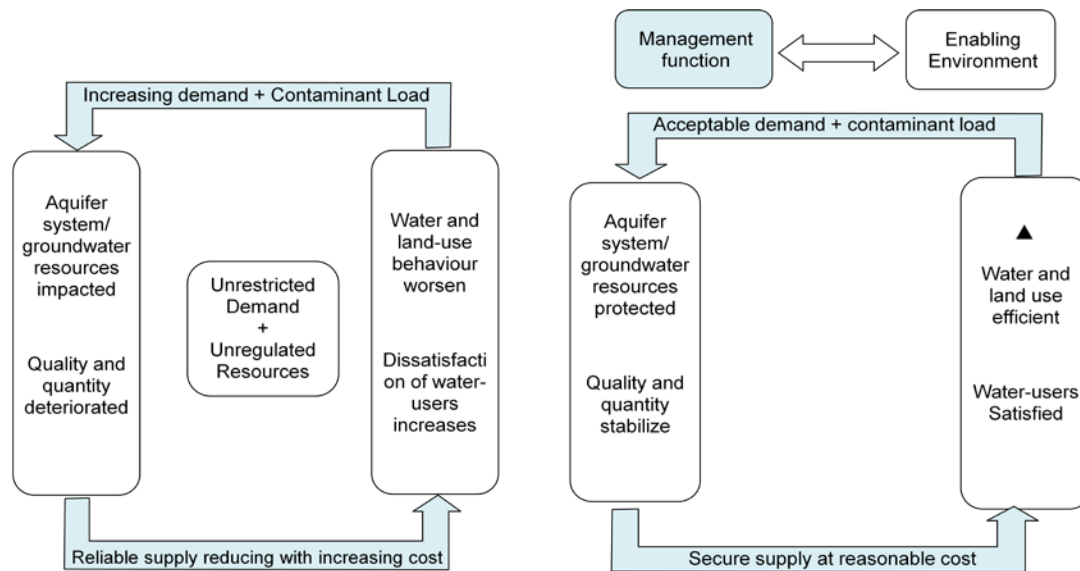


Figure 5.5: Supply driven versus Integrated Groundwater Management

Source: Mirghani, 2010: 24

The IWRM provides the means of jointly managing groundwater, surface water bodies and land. This should be an important approach for Johannesburg, due to the fact that there are a lot of

activities, especially mining, that impact both on groundwater and surface water. Though Johannesburg is not built on a river or harbour, there are streams in the city that are important sources for the biggest rivers in South Africa – the Orange River and the Limpopo River (CoJ, 2012). The pollution of groundwater can result in the pollution of these streams and these streams will invariably transport the pollutants to the above-mentioned rivers.

Due to the fact that some of the water bodies may cross municipal boundaries, there is likely to be a problem with jurisdictional function. There have been cases whereby municipalities have complained of provincial governments taking up their responsibilities, and this brings about challenges in governance. For this reason, it becomes important for the municipality and provincial government to cooperate and co-ordinate their activities for the realization of positive outcomes. For instance, all activities that impact on our water resources occur within a locality and so local governments should become important role players in the management of water resources. Although these levels of government are autonomous, it is important for them co-operate and co-ordinate their activities so that they can find a common ground to sustainably manage our water resources.

5.3 Groundwater Management in South Africa

There are quite a number of guidelines that have been developed for groundwater management in South Africa, and there are also international guidelines that inform groundwater management in the country (Riemann *et al.*, 2011). These guidelines include the “NORAD Toolkit, NORAD-Assisted Programme for Sustainable Development of groundwater Sources (DWAF, 2004b), the Guidelines for the Monitoring and Management of Groundwater Resources in Rural Water Supply Schemes (Meyer, 2002), and the Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa (DWAF, 2008), water-quality management protocols, minimum standards, the Framework for a National Groundwater Strategy (DWAF, 2007a), the Groundwater Strategy 2010 (DWAF, 2011), the National Water Resource Strategy (DWAF, 2004c), the Guidelines for Catchment Management Strategies Towards Equity, Sustainability and Efficiency (DWAF, 2007b), DANIDA guideline (DWAF, 2004a) and regional groundwater plans” (Riemann *et al.*, 2011, p. 447).

5.3.1 Institutional arrangement for water management in South Africa

As explained under the National Water Act of 1998, water is considered a national asset and the Department of Water Affairs (DWA) is the custodian and national manager of the resource. The DWA is in charge of most of the large water resource infrastructure and is responsible for the planning and implementing water resource development projects, but these functions are being devolved to the Catchment Management Agencies (CMAs) (Harrison, 2012).

At the local level, there are Water User Associations (WUAs) which have been set up as management institutions, but they are not primarily responsible for water management (Pietersen *et al.*, 2011). The WUAs are made up of individual water users who collaborate on water-related activities that are beneficial to them. WUAs operate within a restricted area and can only undertake management duties that are assigned to them by the Minister (NWA, 1998). There are also Water Boards established under the Water Services Act, 1997 (Act 108 of 1997). They are responsible for bulk water supply to “other water services institutions within their respective service areas” (Pietersen *et al.*, 2011, p. 19). The DWA has devolved certain functions such as groundwater resource management, the management of dams and other water resource infrastructure, monitoring of water quality, water resource planning, etc. to Rand Water and Umgeni Water Boards (*ibid.*).

Furthermore, it is the constitutional responsibility of local governments and municipalities to provide water supply and sanitation to households, and in order for municipalities and local governments to perform this function they act as Water Service Authorities (Harrison, 2012). However, it must be noted that not all municipalities are Water Services Authorities. As required by the DWA, all municipalities and local governments that are Water Services Authorities must prepare Water Services Development Plans (WSDPs) in addition to their respective Integrated Development Plans (IDPs) (Pietersen *et al.*, 2011).

In the case where an aquifer crosses from one WMA to another, the DWAF in 2008 proposed the establishment of an Aquifer Management Committee, consisting of all role-players in the catchments to serve as an advisory body in matters relating to the assessment, planning and management of groundwater resources that are affected (*ibid.*). The Catchment Committee established under Section 82(5) of the National Water Act, is set up to deal with site-specific problems (*ibid.*).

The roles and responsibilities of the various institutions in charge of water management are summarized in the following table:

Table 5.1: Roles and Responsibilities of Institutions in Water Resource Management (after DWAF, 2008)

Level	Institution	Roles and Responsibilities
National	Department of Water Affairs (National Office)	• Responsibility to “protect, use, develop, conserve, manage and control water resources in a sustainable manner for the benefit of all.” • Develop policies, strategies and guidelines for effective resource management. • Organizational approach - Centralised planning and policy making. - Support function to Regional Offices. - Decentralised implementation, regional and catchment level.
	Department of Environmental Affairs	• Protection, conservation and maintenance of terrestrial and aquatic ecosystems and water resources
Regional	Department of Water Affairs (Regional Office)	• Delegated responsibility of water resource management • Implementing agents for the Department of Water Resources policy and strategy • Audit of CMA with its related functions and responsibilities
	Catchment Management Agency (CMA)	• Responsible for the day-to-day management of groundwater resources. • Delegated responsibility for some water management activities, including water use allocation. • Delegation managed and monitored against a specific catchment management strategy for each WMA.

	Environmental Section of the Department of Agriculture and Land Affairs	• Protection, conservation and maintenance of terrestrial and aquatic ecosystems and water resources.
	Aquifer Management Committee	• Responsible for cross-boundary coordination where the aquifer spans more than one WMA.
Local	Catchment Committee	• Responsible for day-to-day management of the groundwater resource within the WMA or local catchment.
	Water Users Association	• Responsible for the management of the water resources being utilized, including groundwater resources.
	District and Local Municipalities	• Planning and developing water services and infrastructure to ensure acceptable minimum levels of provision to their constituents. • Management of local water sources.
	Water Boards	• Organs of state established to provide water services to other water services institutions.
	Water Forums and Reference groups	• Monitoring and management of water resource development schemes.
	Ward Councillors and Ward Committees	• Representation of committee needs. • Local management of water schemes. • Set up and operate water management committees.
	Task Teams	• Responsible for specific projects of a short-term nature, relating to assessment, planning and management of

		water resources.
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Source: Pietersen *et al.*, 2011: 18

The table above outlines the various roles and functions of the three spheres of government in the management of water. However, due to the lack in capacity in the institutions of the various spheres, they are not able to go about their functions effectively and efficiently.

5.4 Groundwater Management Strategies Employed in Johannesburg

Groundwater resources need to be developed and at the same time, it is important that the quantity and quality of the resource is not compromised. It is for this reason that the Department has developed policies and guidelines to serve as a framework for the management of the resource and in the process of management, there is the need for effective monitoring so that it becomes easy to identify areas where there are shortfalls. For instance, it makes it easy to determine whether or not set goals set by the Department are being adhered to as well as assess whether or not the set goals are being met (Riemann *et al.*, 2011).

It is important to note that in the management of water resources, the national government, together with the regional/provincial and local governments make use of legislation, policies, guidelines and management strategies instituted by the DWAF, the national custodian of water resources. Thus, at the local level, there are no different policies and strategies for the management of groundwater. The principles underpinning the policies, guidelines and strategies developed by the DWAF are applied at all levels and scales. However, the Water Research Commission has commissioned the development of a Groundwater Management Framework for the management of the resource at the municipal level (Riemann *et al.*, 2011). This framework is discussed in chapter six of this research report.

As I have indicated, there is a wide range of management strategies and guidelines used in the management of groundwater. However, due to time constraints and the length of the report, only a few of the relevant tools will be discussed. They include the National Water Resource Strategy (draft report) (DWAF, 2012), the Groundwater Strategy 2010 (DWAF, 2011), the NORAD Toolkit (DWAF, 2004b), and the Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa (DWAF, 2008).

5.4.1 The National Water Resource Strategy 2 (draft report) (DWAF, 2012)

As indicated in the earlier section of the chapter, the National Water Act of 1998 is the legislation that governs our water resources, and the Act calls for the development of a National Water Resource Strategy (NWRS). The NWRS is “the legal instrument to plan, develop and manage water resources in an integrated and sustainable manner. It is the primary mechanism to manage water across all sectors towards achieving Government’s development objectives” (NWRS 2, 2012: ii).

The NWRS 2 (2012) acknowledges that water is vital for the socio-economic development of the country. This is because a reliable and sufficient supply of water at desired quality would enable economic growth, social development and create jobs for people. It also acknowledges that water is very important for the realization of the targets set in our macro-development plans such as the National Development Plan (NDP 2030) (DWAF, 2012), and in relation to the City of Johannesburg, water is also vital to the realization of targets set in the Growth and Development Strategy (GDS 2040). However, NWRS 2 acknowledges that our fresh water resources are limited and for the security of our socio-economic development, there is the need to employ innovative approaches to reconcile water demand and supply (DWAF, 2012).

The NWRS 1 (DWAF, 2004) “defined the fundamentals of integrated water resource management and presented a clear perspective of the water situation in South Africa and the critical interventions required” (DWAF, 2012: ii). The NWRS 2 acknowledges that the NWRS 1 has contributed to the socio-economic development of the country through “effective and efficient water resource planning and the development of infrastructure”, however, recognizes that this is not enough considering the water situation of the country (*ibid.*: ii). The NWRS 2 indicates that there are areas of priority which need immediate attention and these include “the implementation of water allocation reform, equity, water conservation and demand management, water resource protection and interventions to improve water governance”, and therefore states that there is the need to put in place the necessary interventions to address the aforementioned areas of priority (*ibid.*: ii-iii).

The NWRS 2 recognizes that in South Africa, a lot of attention has gone into the development of the surface water resources with very little attention being given to groundwater resources (*ibid.*). This does not augur well for the water security of the country, considering the fact that “surface water availability and its remaining development potential will be insufficient to support the growing economy and associated needs in full” (*ibid.*: iii).

In light of this, the Department is committed to reviewing its current approach to water management, and also seeks to provide the needed attention to groundwater, which is an equally important source of water (*ibid.*). The NWRS 2 recognizes the need to adopt the integrated water resource management approach (as explained under 2.5.1.1), a more holistic approach to water management, where all water resources and land management, and other necessary factors are taken into consideration for the realization of better outcomes.

The NWRS 2, in addition to resource development, seeks to employ a business and systems management approach as well as effective water use, use control and regulation, research and technology and also innovative means for the management of our water resources (*ibid.*). The NWRS 2 identifies some core strategies and they have technical and enabling strategies for support. Furthermore, detailed operational strategies such as the Water Investment Framework and Plan and the groundwater strategy, which will be discussed subsequently, have been developed for implementation (*ibid.*). The effective implementation of these strategies would go a long way to contribute to the realization of the vision of the NWRS 2, which are as follows:

- “A democratic, people-centred nation with equitable social and economic development enabled through equitable, sustainable and effective water management;
- Water valued and recognised as a strategic national asset and fulfilling its central role in society and the economy;
- A prosperous society enjoying the benefits of clean water and hygienic sanitation services;
- A healthy, ecologically sustainable and protected water environment;
- A Department of Water Affairs and related water management institutions that serve the public effectively and loyally, meet their responsibilities with integrity, transparency, energy and compassion’;
- A committed and dedicated water sector, actively co-operating and contributing towards sustainable water management and associated outcomes” (*ibid.*: vi).

5.4.2 The Groundwater Strategy 2010 (DWAf, 2011)

Managing groundwater in an effective and efficient manner would ensure a reliable and efficient supply of the resource (DWAf, 2011). For these reasons, it is deemed important to have the necessary legislation and regulations in place to make this achievable. In South Africa, the National Water Act provides regulatory tools for groundwater usage, discharge and also provides regulations on other activities that affect groundwater (*ibid.*).

In 2007, the DWAF developed a framework called the “A Framework for a National Groundwater Strategy” which set the tone and provided guidelines in the development of the GS 2010 (*ibid.*). The GS 2010, being a strategic plan, outlines six priority areas which will enable the effective management of the “nation’s resources in alignment with agreed government-wide priorities” (*ibid.*: 1). These priority areas include.

1. Contribution to economic growth
2. Ensuring equitable and sustainable water resources management
3. Promoting rural development
4. Effective support to local government
5. Contribution to global relations
6. Improving the DWAF’s capacity to deliver services (*ibid.*)

The GS 2010 acknowledges that for the sustainable management of groundwater, there is the need to have a framework to guide aspects such as the assessment, planning and management of groundwater resources and in this case the ‘A Guideline for the Assessment, Planning and Management of Groundwater in South Africa’ serves the purpose (*ibid.*). The Guideline will be discussed subsequently.

The GS 2010 also recognizes that there is the need to have operation and maintenance schemes for groundwater. This aspect touches on the fact that in dealing with groundwater, it is important to ensure that all the necessary infrastructure (boreholes, pumps, pipes, valves, etc) are in place and are maintained as well (*ibid.*). Some of the maintenance activities include cleaning and de-scaling pipes, replacing worn out components, cleaning of boreholes, checking the operation of switchgear, etc and also monitoring of groundwater levels, quality and demand (*ibid.*).

Sustainable groundwater management also takes into consideration the natural groundwater quality. As has been established, groundwater under normal circumstance is safe for direct usage. Table 2.1 shows the advantages groundwater has over surface water. However, due to increasing effects of human activities on groundwater, it has become vital for groundwater resources to be monitored for microbiological quality (*ibid.*) and also the presence of heavy metals. Through this process, we are always up-to-date on the conditions of an aquifer and enable the early detection of problems (*ibid.*).

There is also the aspect on the establishment of “protection zones” at abstraction points in order to curb the occurrences of groundwater pollution. The strategy acknowledges that observation of these protection zones is also dependent on having the necessary rules and regulations in order for them to be enforced (*ibid.*).

The GS 2010 also recognizes the need to make use of adaptive management practices due to aquifer systems being naturally complex and difficult to characterize (*ibid.*). The whole idea behind the usage of adaptive management is to reduce uncertainties associated with aquifers systems. Through this process, groundwater experts are expected to monitor aquifer systems so that whatever problems identified can be dealt with, future predictions can be made and the appropriate measures can be put in place to curb the problem (*ibid.*).

Other areas of importance to the sustainable management of groundwater are artificial recharge and sustainable yield. Artificial recharge “is the process whereby surplus surface water is transferred underground to be stored in an aquifer” (*ibid.*: 21). This is a means of storing and conserving water for future usage. The Department acknowledges that the technique of artificial recharge is underutilized in South Africa and for this reason it is committed to making it an integral part of groundwater management.

The successful implementation of artificial recharge schemes would go a long way into ensuring that we have water to serve current needs and for future usage (*ibid.*). Sustainable yield is about having an aquifer in which the rate of abstraction is balanced with the rate of recharge or reduced discharge, thus, ensuring that the aquifer is always in a state of equilibrium (*ibid.*). Therefore it is important that groundwater protected from over-abstractions due to the fact that it can affect the sustainable yield of the aquifer (*ibid.*).

5.4.3 The Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa (DWAF, 2008)

This guideline is informed by the principles outlined by the National Water Act of 1998. It has been developed to assist in the sustainable development, protection and management of groundwater resources as well as serves as a supportive instrument in the achievement of the overall goal set out in the Integrated Water Resource Management (IWRM) (DWAF, 2008). With the recognition that it is important to manage water resources in a holistic manner, the existence of the guideline becomes very important due to the fact it will be able to provide information on how to assess, plan and manage groundwater within an IWRM (*ibid.*).

This guideline is considered to be important because of the following:

- A guideline has not been instituted to guide Water Managers or Service Providers in relation to procedures to be followed in the assessment, planning and management of groundwater resources.
- It is recognized that groundwater is an important source of water which is used for bulk and local water supply as well as for irrigation. This source of water can be of strategic importance in areas of drought or in areas where groundwater is the only source of water.
- Sustainable development of groundwater can only be achieved through adequate planning and effective management.
- There is the need to do away with the past practices such as ineffective planning, assessment and management of the resource due to the threats it poses to the resource. For instance excessive abstraction can result in the boreholes, wetlands and springs drying up, and in karst systems, the formation of sinkholes.
- It is necessary for an understanding of the rock formation of an aquifer system as this affects the yield or the natural dewatering of the aquifer.
- There is the need for an understanding that, due to the physical characteristics of host rock, aquifer systems are vulnerable to over-exploitation, unsustainable practices and pollution, and further worsened by the impacts of land-use.
- Having a vulnerable aquifer system in direct contact with other ecosystems poses a threat to these ecosystems, due to the fact any negative impact on the resource will affect any ecosystem which is in close contact. It is for this reason that groundwater protection is of paramount importance, and the protection of aquifer systems invariably means protection for other ecosystems (*ibid.*).

The goals of the guideline are to be strategic, and engage in effective management and operational practices for the sustainable development of the resource (*ibid.*). As a strategic tool, it is also employed in order to ensure that people have reasonable access to groundwater resources (*ibid.*).

In the aspect of management, importance is given to the fact that sustainable development will be more realizable if an integrated water resource management approach is taken (*ibid.*).

As an operational tool, it will “provide information that will feed into the Department’s planning process” and the implementation of the tools provided in the guideline will ensure that the

resource is used effectively (*ibid.*: 1-5). Finally, the goal of the guideline is to ensure integration of existing and new initiatives within the Department (*ibid.*). The objectives of the guidelines are as follows:

- “To provide assistance and guidance to all role-players involved in the assessment, planning and management of the groundwater resources of South Africa, and
- To ensure that all role-players in the management of groundwater resources of the country have clear guidance on the processes to follow (*ibid.*: 1-4).

In the development of guidelines for groundwater management, it is important that they are aligned to relevant acts, policies and strategies in order to enable the achievement of overall targets. These acts, policies and strategies provide principles and approaches which are to be incorporated in the management of groundwater. In the case of this guideline, some of the main principles include equity, participation, freedom of information, sustainable development, stewardship, flexibility, continual improvement and delegated responsibility (*ibid.*). In addition to these principles are approaches applied in the management of water resources and they include:

- Precautionary approach: for example instituting measures to ensure that groundwater resources are not polluted due to the fact the resource is vulnerable to threats from pollution (*ibid.*).
- Prevention approach: this is mainly the institution of a hierarchy of control measures to ensure that management is done in order of priority and this is done in the following order:
 - “Waste elimination, substitution, recycling, re-use and disposal, effected through the adoption of Best Practice guidelines and cleaner technology, and
 - Control, through the water use authorization process, either of developments taking place, or of the use of procedures, processes, activities or substances that produce discharges or emissions of water containing waste where there is an unacceptably high risk to the water resource” (*ibid.*: 1-13).
- Differentiated approach: making use of different approaches at different levels of management in order to ensure efficiency (*ibid.*).
- Integration: this approach seeks to bring together all the various departments and sectors in charge of water resource management in order to ensure uniformity and consistency in their work (*ibid.*).

- Risk-based approach: this approach makes it possible to identify areas of risk and the appropriate measures to be instituted to deal with these risks (*ibid.*).

5.4.4 NORAD Toolkit (DWAF, 2004b)

The NORAD toolkit is a set of documents, software and maps which has been developed with support from the Norwegian Agency for Development Cooperation (NORAD) for the management of groundwater at the municipal level (DWAF, 2011). The outputs of the NORAD toolkit are “aimed at municipalities, water services authorities and providers, national water authorities, NGO and consumers, and contain much useful and relevant information on groundwater assessment, management, protection and monitoring” (*ibid.*: 17).

As has been established there are documents which have been developed under the NORAD for the management of groundwater and these include guidelines for protecting springs, guidelines for protecting boreholes and wells, groundwater monitoring for pump operators, etc.

One other important document for the management of groundwater resources is the DANIDA Guidelines for the Management of Groundwater within an IWRM (DWAF, 2004a). The guidelines follows the same principles as presented by CAP-Net and explained under 5.2.1.

5.5 The Problems with Sustainable Groundwater Management in Johannesburg

According to the DWAF (2011, p. 5), “South Africa is often acknowledged to have some of the most modern and progressive legislation governing the use and management of water resources (including groundwater) in the world”. However, the biggest problem is with implementation (*ibid.*). The lack of implementation has resulted in a backlog of people waiting for groundwater licenses to be issued out to them. This has resulted in many water users making use of the resource without proper regulation (*ibid.*).

There is also the problem of dealing with the illegal use of water, and in many cases the possible consequences of such acts are usually not understood (*ibid.*). In South Africa, “all water users are required to register existing lawful use”, and many have done so, however, “only about 20% of this use has thus far been verified” (*ibid.*: 5). This can be attributed to the fact that there is limited capacity in the Department and this makes it difficult for them to undertake verification tasks more effectively to regulate the illegal use of water (*ibid.*).

Limited capacity in the Department has also hindered the enforcement of water use licensing conditions. For instance, the waste discharge charge system (WDCS, based on the “polluter

pays principle”, as explained under 2.2.4.3), is yet to be implemented, and due to the problem with implementation of the WDCS, the Department has had challenges in effectively dealing with a problem such as AMD pollution (*ibid.*). Furthermore, due to the lack in a groundwater monitoring network, there are challenges with controlling the pollution of groundwater (*ibid.*). The Department owns and manages water resource infrastructure worth approximately R100 billion, and being responsible for the entire water infrastructure can result in “regulatory oversight in the form of standard setting, monitoring of performance, setting prices, etc., of the groundwater component of this infrastructure” (*ibid.*: 5). Therefore, there is the need for improvement in this aspect and one of such means is to shift to a more decentralized system of managing groundwater.

In 2009, Knuppe conducted a qualitative assessment of groundwater management in South Africa (Knuppe, 2011). The findings from the research throw more light on some of the issues raised by the DWAF (2010). Interviews were conducted and this involved experts from the national office of the Department of Water Affairs (DWA) and the regional office of DWA in the Northern Cape. Experts from research institutions such as the University of the Witwatersrand, the University of KwaZulu-Natal, Council for Scientific and Industrial Research (CSIR) and the Water Research Commission (WRC) were interviewed as well (Knuppe, 2011). There were interviewees from conservation organizations such as Cap-Net and the South Africa National Biodiversity Institute (SANBI), and then finally consultants from Water Geosciences were also interviewed (*ibid.*).

Through the interviews, some of the reasons identified for our inability to implement sustainable groundwater management are the undervaluation of the importance and significance of groundwater resources, shortage of expertise and adequate data, centralization of power, disregard of groundwater ecosystems and associated goods and services (*ibid.*), and the lack of adaptive management.

5.5.1 Undervaluation of the importance and significance of groundwater resources

In South Africa, groundwater is “barely recognized as being life-essential resource” (Knuppe, 2011, p. 71). It is exploited only in times of droughts. Knuppe asserts that the undervaluation is due to the fact that under the Roman common law, groundwater was given private status, and also the fact that aquifer systems are invisible to us (*ibid.*). Private status meant that there was no control or monitoring of how the resource was used. It was not until recently that DWA

changed access rights, and water managers had to educate people on the new groundwater allocation regulations (*ibid.*).

However, this has been met with a lot of resistance due to the fact that “the attitude of groundwater users, the manner of usage and techniques were established and consolidated mostly across several generations” (*ibid.*: 71). There are still people who consider groundwater on their property as their own rather than as a resource for the benefit of the general public (*ibid.*). This presents challenges to water managers in establishing and implementing new approaches, management tools and also being able to change the attitudes of people towards the resource (*ibid.*).

Furthermore, the experts made mention of the fact that the resource is considered “a poor man’s resource” (*ibid.*: 71). Thus, the resource is not given the due importance it deserves, for instance, in most areas, it is mainly used for “subsistence farming and sanitation purposes” (*ibid.*: 71).

There is also the factor that the people dealing with groundwater in the rural areas are isolated and tend not to have any contact with scientists to advise them or provide the necessary expertise on matters concerning groundwater management (*ibid.*). Coupled with this problem is the fact that water managers, decision-makers and engineers in South Africa were traditionally trained to build and operate large-scale surface water infrastructure” such as dams, basin-transfer systems, and for this reason “the development of groundwater techniques, drilling of wells and the science of hydrology were never a major part of South Africa’s water sector” (*ibid.*: 71). For this reason the experts interviewed pointed out the need for all stakeholders to be made aware of the importance of groundwater and the significant role it plays in our development (*ibid.*).

5.5.2 Shortage of expertise and adequate data

There is a “shortfall in hydrogeological capacity of both human expertise and physical as well as socio-economic data related to groundwater resources, aquifer properties and linkages to human well-being” (Knuppe, 2011: 72). Overall, the main concern raised was that, human resources were inadequate at all levels of government. Important management positions were vacant or being held by people unqualified personnel (*ibid.*). At the local level, there is a lack in technical and professional expertise, and also the management of groundwater is not done in a coordinated manner, and this in the view of the experts, is as a result of the lack in proper

governance, and has contributed to South Africa's inability to fully implement the national water legislation (*ibid.*).

Furthermore, there is the problem of misallocation of roles and responsibilities and this creates problems in the collection of data on aquifer recharge, discharge and storage (*ibid.*). Coupled with the fact that very little investment has gone into groundwater monitoring infrastructure, and this has resulted in the underutilization or the over-abstraction of groundwater (*ibid.*).

5.5.3 Centralization of power

According to Knuppe (2011, p. 72), "the current management of groundwater by the national and regional offices of the DWA exhibits huge disparities in terms of the structures in place for cooperation between the different political agencies, administrative levels and other stakeholders." According to the experts interviewed, the success or failure of groundwater management is dependent on how integrated the horizontal and vertical structures in place are (*ibid.*).

The Constitution of South Africa establishes three levels of government - the national, provincial and the local governments, and these spheres of government are "distinctive, interdependent and interrelated" (The Constitution of RSA, 1996: 1267). Furthermore, section 41(h)(i-vi) of the Constitution states that there is the need for the three spheres of government to "co-operate with one another in mutual trust and good faith by –

- (i) fostering friendly relations;
- (ii) assisting and supporting one another;
- (iii) informing one another of, and consulting one another on, matters of common interest;
- (iv) co-ordinating their actions and legislation with one another;
- (v) adhering to agreed procedures; and
- (vi) avoiding legal proceedings against one another" (The Constitution of RSA, 1996: 1269).

Thus, although the spheres of government are autonomous, they are still required to coordinate their activities for the realization of positive outcomes in water management.

It is recognized that the decentralization of the management systems can result in "greater efficiency, effectiveness and equity" (Knuppe, 2011, p. 72). However, we are not realizing the

aforementioned outcomes due to the fact that there are still cases whereby the national government regulators do not “interact nor agree on the management of groundwater and the regulation of aquifer systems” (*ibid.*: 72). In addition, instead of the various sectors working together for a common good, they tend to compete amongst themselves. This results in hydrogeological information not being managed in a coordinated manner (*ibid.*).

A decentralized system also means the participation of stakeholders in decision-making processes and resource utilization. However, this aspect is barely considered by groundwater managers and government agents (*ibid.*). Participation of the various water users would ensure that they are able to present their problems to the national government and also are able to engage in educational or training programmes developed for them (*ibid.*). However, it must be noted that, in most cases, sectors such as large scale farming and mining are able to present their problems, access information and also can afford the training programme, thereby resulting in a group such as rural farmers not having access to the necessary information (*ibid.*).

5.5.4 Disregard of groundwater ecosystems and associated goods and services

According to Knuppe (2011, p. 72), “research into aquifer-dependent ecosystems and groundwater goods and services is subject to little attention in the overall context of management and these issues are, therefore, hardly recognized in the national water legislation.” In groundwater management, hardly are ecological approaches incorporated unless it is in relation to a Reserve (*ibid.*). This is because water managers often do not understand the connection between groundwater storage, recharge and discharge and the production of goods such as food. Also, the services groundwater provides and the role they play in our well-being are not well understood, “and because many benefits associated with groundwater are public goods, the economic value of groundwater often goes unrecognized. As a consequence, South Africa’s groundwater resources tend to be used and managed with little or no regard for economic importance” (*ibid.*: 72).

The experts also indicated that the usage of groundwater for farming and mining activities is deemed important than the services it provides to support ecological functions such as baseflows to rivers and nutrient cycling (*ibid.*). For this reason, the areas identified to be in need of great research are commercial agriculture and mining activities, which have serious impacts on groundwater-dependent ecosystems and related services (*ibid.*). In the case of Johannesburg, as has been established, the one activity that poses the greatest threat on

groundwater is mining, thus, the city needs to be committed to researching into approaches to minimize the impacts of mining on groundwater.

The experts pointed out the need to find appropriate means of putting value on ecosystem service, for instance, the usage of taxes and tradable permits. This will serve as a means for, 'water managers to consider all tradeoffs between groundwater uses and users, as well as have incentives in place for end-users to save water' (*ibid.*: 73).

5.5.5 The lack of adaptive management

According to Allan (2007: 1), "adaptive management is learning from doing; learning comes through the implementation of policies and strategies, so adaptive management complements research-based learning." Thus, through the implementation of policies and strategies, we are able to identify the shortfalls and thereby making it possible for the necessary changes to be made in order for them to be more effective (Knuppe, 2011; Allan, 2007).

Adaptive management is also a means of dealing with uncertainties such as water scarcity and climate change (Knuppe, 2011). However, Allan (2007, p. 2) points out that it is neither a means to 'muddle through', nor is it a means of setting up institutions or organizations "to respond to every social or political whim." This means that every measure taken must be thought through.

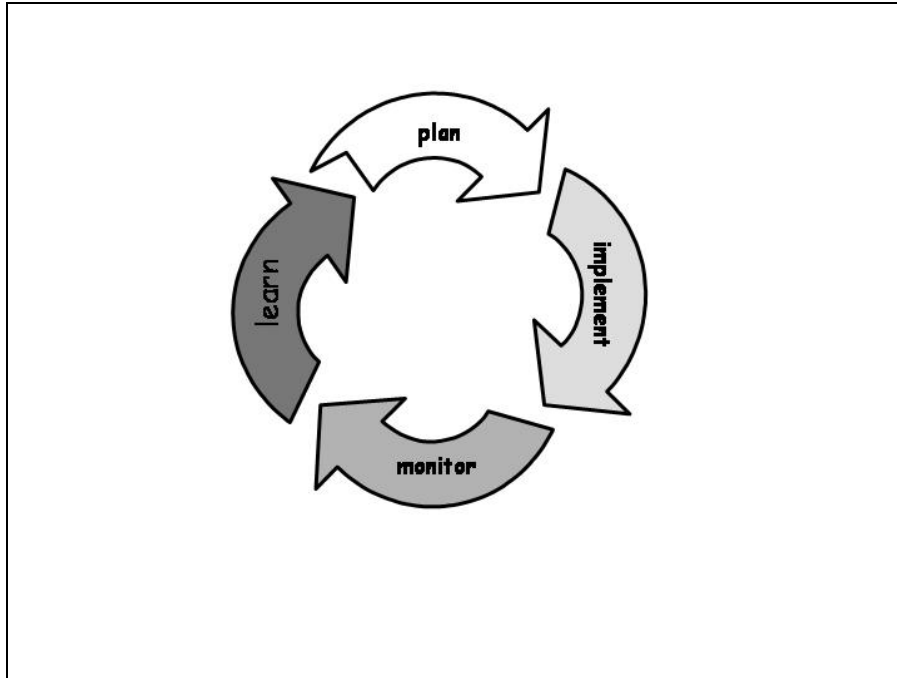


Figure 5.6: Conceptualization of Adaptive Management

Source: Allan, 2007: 2

In Johannesburg and South Africa as a whole, the implementation of adaptive management is important because of the following:

- “Our knowledge of groundwater use is imperfect,
- our knowledge of regional status of groundwater is imperfect,
- our knowledge of groundwater parameters is highly imperfect,
- our ability to predict the impacts of groundwater abstraction on surface water and ecological systems are highly imperfect
- our ability to predict future outcomes is highly imperfect and
- monitoring data are often not diagnostic” (Seward *et al.*,: 478).

The above discussions make it evident that the problems with groundwater are not limited to having the correct legislation, policies, guidelines or strategies in place. As has been established, South Africa has superior legislation on water resources management. However, some factors as have been discussed, are the reason for our inability to sustainably manage our groundwater resources for the realization of the goals set in the NWA. It is therefore important that we take the necessary steps to address these issues. The next chapter will provide some recommendations on how the issues surrounding groundwater can be dealt with.

CHAPTER SIX

RECOMMENDATIONS AND CONCLUSIONS

6.1 Introduction

Groundwater is an important resource for many cities around the world, including Johannesburg, and it provides for domestic water supply, industrial activities, irrigation purposes, etc. In many countries, especially arid and semiarid countries, it is the only source of water, thus, makes the availability of the resource vital for their continued existence.

However, due to climate change and the increasing effects of anthropogenic (human) activities, groundwater resources are under threat. These anthropogenic activities have resulted in a wide range of problems which need to be addressed. In Johannesburg, the resource is being polluted due to agricultural practices, mining activities, municipal waste, etc, and the resource is also under threat from over-abstraction. Groundwater recharge in Johannesburg is affected by climate change and further exacerbated by urbanization, which results in the development of impermeable surfaces such as roads, houses, pavements, etc., on land. In addition, groundwater recharge is also affected by the geological formation and nature of aquifers. Coupled with the aforementioned problems is the problem of capacity within institutions and organizations in charge of water management in Johannesburg.

This research report aims to makes us understand the realities of the groundwater issues in Johannesburg and the need for these issues to be taken seriously, due to the far-reaching implications it can have for city. Groundwater problems have implications for water supply and economic development, food security, livelihoods of people, health and environment, groundwater-dependent ecosystems and remediation.

There is the recognition that in order to deal with groundwater problems, there is the need for effective management of the resource. Effective management requires a proper management structure and the institution of management tools to enable the process. In South Africa, there is a management structure for the management of water which defines the roles and responsibilities of the agencies involved in water management in the various spheres of government (refer to Figure 5.1). To equip these water agencies, there are legislative instruments such as the NWA, WDCS, and there are management tools or strategies such as NWRS 1 and NWRS 2, GS 210, NORAD toolkit and the guidelines for the management of groundwater resources.

These legislative instruments and management tools are adequate for the management of groundwater. However, the persistence of problems such as undervaluation of the importance and significance of groundwater resources, shortage of expertise and adequate data, centralization of power, the lack of coordination amongst water agencies, disregard of groundwater ecosystems and associated goods and services, and the lack of adaptive management, have presented challenges to enforcing legislation and implementing the management strategies. Therefore, this section of the research report seeks to provide some recommendations regarding some of the measures that can be taken by the City of Johannesburg to address some of the groundwater issues in the city.

6.2 Recommendations

6.2.1 Administrative-related recommendations for groundwater management in Johannesburg

The National Development Plan (NDP 2030) (NPC, 2012), recognizes that in order for our water resources to be managed, monitored and protected in a sustainable manner, there is the need for the following:

6.2.1.1 Effective administration

It is important to note that in order for effective administration of groundwater, there is the need to involve water users such as farmers, communities, businesses, water boards, WUAs, etc., so that they will have a better understanding of some of the activities they engage in that affect water, thereby making it possible for them to also respond appropriately to these constraints (NPC, 2012). Thus, it is important for some responsibilities to be decentralized, due to the fact that it is at the local level that the water users can be effectively involved in the management of groundwater (*ibid.*).

Furthermore, legislation and policies need to be clear and coherent. As has been established, the current problem with the administration of water in South Africa is with capacity development and this area should be attended to. The various institutions such as the universities, who are responsible for training experts on water resources, need to be given the necessary support in order for them to provide the necessary training.

There is also the problem of graduates seeking jobs in private firms rather than the government institutions. It is important that government agencies are made attractive in terms of salaries, as

well as reducing the amount of bureaucracy and corruption where possible. It is important for employers to understand that in addition to earning a living, people come into a working environment with the aim of realizing their career ambitions. Therefore, in an environment where there are bureaucratic practices and a lack of support for innovative ideas, there is a high probability of people leaving such organizations to places where they are more likely to be challenged. It is therefore very important that bureaucratic practices and corruption in government institutions are minimized to make them more attractive to job seekers.

6.2.1.2 Evolving water-resource management

There is the need for the DWAF to understand that, due to the increasing development of technology, groundwater management strategies are continuously evolving and as such, there is the need for groundwater management strategies to be regularly reviewed (NPC, 2012). Through comprehensive research, we will be able to obtain the necessary knowledge in order to make the necessary changes in order for the approach to yield positive outcomes.

In South Africa, there is a statutory instrument (NWA) in place to make the review of the approaches for groundwater management possible. The NWA requires the development of a National Water Resource Strategy (NWRS) every five years (*ibid.*), and NWRS is binding on all authorities and institutions which deal with water management in South Africa (TCOE, 2011).. The national water resource strategy is developed based on the catchment management strategies and local government's water services development plans (NPC, 2012). A proper review of the management strategies would ensure that "priority areas for intervention" are identified and can have the appropriate measures implemented (*ibid.*: 179).

6.2.1.3 Capacity building and cooperative governance

Capacity is an aspect that is lacking in our water management institutions and this is an area that should be of great concern for us. Great attention needs to be given to the people who are employed and their qualities in terms of skill, ability and knowledge. This is because without the right people with the required qualifications, the sustainable management of our groundwater resources will be impossible.

It is also important that from time to time, planners, engineers, hydrogeologists, geotechnicians, and all other professionals in the water industry are provided with training in order for them to improve on their abilities, skills and knowledge. This will enable the employees to "(a) perform

core functions, solve problems, define and achieve objectives; and (b) understand and deal with their development needs in a broad context and in a sustainable manner” (UNESCO, 2006: 1).

Dealing with capacity gap is not only limited to providing training for employees. It is essential that resources are channeled into training tertiary level students. Funds should also be provided for research in tertiary institutions as well as other water research institutes in order to build on the knowledge base, which will invariably contribute to dealing with the knowledge gap.

Furthermore, a vital aspect that contributes to proper capacity building is the availability of data on groundwater. According to Knuppe (2011: 75), data is very important to improving upon knowledge, and for capacity building in groundwater areas such as scientific education programmes, academic studies. The availability of data on aspects such as groundwater quantity and quality, climate, geological maps, land-use, water usage, population growth, etc., is crucial for the management of the resource. It is important that resources are channeled into the development of an adequate and reliable groundwater data system.

In addition to the problems of capacity are issues related to co-operation and co-ordination amongst the three spheres of government. Co-operative governance is required under Chapter 3 of the Constitution of South Africa. However, water institutions fall short in observing these principles. For this reason, we have not made any reasonable progress in achieving the goals set out in the National Water Act and the National Water Resource Strategy. It is therefore important for all the relevant sectors (those related to water management) in the various spheres of government to be committed to coordinating their activities to ensure effective implementation of groundwater management strategies and other relevant programmes.

To enable the process of co-ordination, a strong groundwater leadership or coordinator could be appointed, for instance within the DWAF, the hydrogeological unit could facilitate the process of communication amongst stakeholders, sectors and governmental agencies (Knuppe, 2011). This will enable the process of information sharing, making it possible for groundwater problems to be addressed, and invariably resulting in the realization of goals and values for groundwater (*ibid.*).

6.2.2 Recognizing the importance of the services provided by groundwater-dependent ecosystems

Groundwater provides benefits for our well-being, economic growth and also the conservation of biodiversity. However, groundwater-dependent ecosystems and the services they provide are

often not given the necessary attention. They are almost considered unimportant. For example, the Klip River wetland used to be a source of water supply for Johannesburg, but was later used for the purification of polluted water from mining activities and sewage treatment (McCarthy *et al.*, 2007). The wetland is known to remove phosphates and nitrates from polluted water. However, over time, due to intense human activities which result in increased pollutant loading in the wetland, as well as the over-abstraction of groundwater in the area, have made the wetland dysfunctional (*ibid.*). There is an increase in the level of pollution on the wetland and this has affected its natural ability to effectively remove pollutants that are discharge into it.

The Klip River wetland is connected to the Vaal River and this means that the pollutants can be released into it, and the Vaal River is a source of water supply for Johannesburg. The presence of high levels of phosphates and nitrates could result in eutrophication of the river (*ibid.*), which will render the water unsafe for drinking, and can also lead to the loss of aquatic life.

From this example, it is clear that wetlands are important and are vital to ensuring the well-being of humans, as such their health should be maintained at all times. This implies protecting them from excessive pollution, over-abstraction and also need to be monitored effectively.

6.2.3 Adaptive Management

In groundwater management, it is important that adaptive measures are implemented. The usage of adaptive management suggests there is “the recognition of the fact that ecosystems are complex, adaptive and self-organizing systems that must be managed in such a way that it is possible to adjust to changes or unexpected occurrences” (Gunderson and Holling, 2001 cited in Knuppe, 2011, p. 74). Some of the measures to be taken to make adaptive management possible include:

- ‘Incorporating participatory management and collaborative decision-making into the management of groundwater, and should include representatives from all levels of governmental and non-governmental agencies.
- Integrating different research issues as well as the various sectors such as agriculture, water, tourism, environment, mining and forestry
- Developing management approaches that would be more responsive to uncertainties and surprises.
- Incorporating ecological goals and values in formal legislation and also implementing them at all levels of government.

- Monitoring groundwater resources in terms of quality and quantity, data collection should be adequately planned for and there is the need for the information to be more accessible' (Knappe, 2011, p. 74).

6.2.4 Technical recommendations

6.2.4.1 Integration of supply side and demand side measures

To ensure effective management of groundwater, it is important that both supply side and demand side measures are combined (Jha and Sinha, 2007). It should be noted that 'focusing on demand management will contribute to ensuring the sustainability of groundwater resources, which is essential in the longer term' (Foster *et al.*, 2003, p. 1). Some of the actions to be taken in dealing with supply side and demand side are as shown in the following table:

Table 6.1: Demand-side and Supply-side Actions for Groundwater Resource Management

LEVEL OF ACTION	DEMAND-SIDE MANAGEMENT INTERVENTIONS	SUPPLY-SIDE ENGINEERING MEASURES
Irrigated Agriculture	real water savings secured in part from: - low-pressure water distribution pipes - promoting crop change and/ or reducing irrigated area - agronomic water conservation ⁷	local water harvesting techniques appropriate recharge enhancement structures (either capturing local surface runoff or sometimes with surface water transfer)
Main Urban Centres	real water-saving sometimes secured from: - mains leakage and/ or water use reduction - reducing luxury consumption (garden watering, car washing)	urban wastewater recycling and reuse (including controlled and/ or incidental aquifer recharge by both in situ sanitation and mains sewerage)

Source: Foster *et al.* 2003: 2

As part of the supply-side measures, there is the need for water to be recycled and reused. This is a measure that is indirectly conducted in many municipalities in South Africa including

⁷ Agronomic conservation is the process of "reducing the impact of raindrops through interception and thus reducing soil erosion and increasing infiltration rate and thereby reducing surface runoff and soil erosion" and some of the measures include mix cropping, inter cropping, fallowing, etc., (Freie Universitaat Berlin, 2007: unpaginated).

Johannesburg. Water is indirectly recycled in Johannesburg when municipal and industrial wastewater is reintroduced into rivers (NPC, 2012). However, due to the lack of technical capacity to manage waste treatment facilities, the process has rather contributed to the contamination of our water resources. It is therefore important that the City of Johannesburg invests in building wastewater treatment systems and ensure a continued maintenance, to ensure that wastewater is treated effectively for reuse (*ibid.*).

6.2.5 Proposals in Relation to Groundwater Management in Johannesburg

A number of strategies have been developed for the management of groundwater in South Africa. However, there is no “overarching groundwater management framework” (Riemann *et al.*, 2011: 445). As a result, the Water Research Commission (WRC) has commissioned a project to develop a Groundwater Management Framework (GWMF) to serve as “a guideline for optimal incorporation and integration of the management functions in the municipal structure” (*ibid.*: 447). The overall objective of this framework is to provide authorities (Water Services Authorities (WSA), Water Services Provider (WSP) and Water User Associations (WUA)) in charge of groundwater management at the municipal level, with the necessary tools to enable them go about their activities more effectively (*ibid.*).

The Commission asserts that “the current definitions of ‘water resource management’ and more so ‘groundwater management’ vary significantly and are not consistent throughout the legal framework and guidelines” (*ibid.*: 447). However, in this framework, groundwater management entails “aquifer protection, groundwater-quality management, groundwater remediation, groundwater assessment, groundwater monitoring, well-field planning and design, and well-field operation and maintenance”, and these definitions can be grouped into aquifer protection and aquifer utilization, and these are further subcategorized as monitoring, data management and evaluation, and valuation of the groundwater resource (*ibid.*: 447).

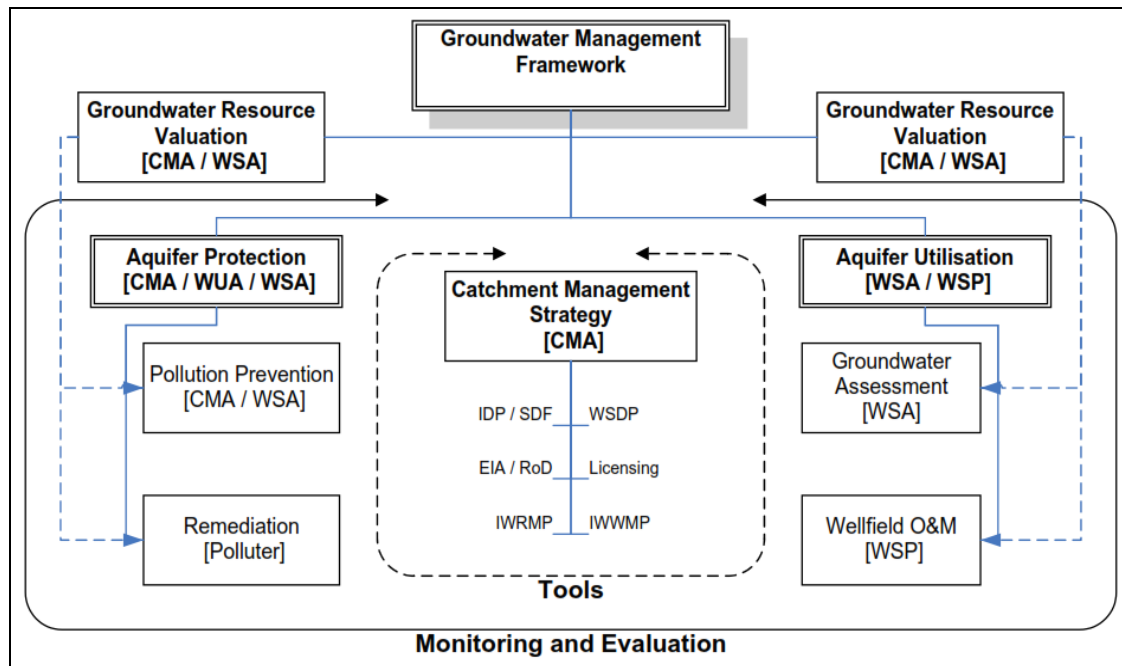


Figure 6.1: Structure of Groundwater Management Framework

Source: Riemann *et al.*, 2011: 448

The framework comes with categories ‘Aquifer Protection’ and ‘Aquifer Utilisation’, their subcategories, overarching functions of ‘Monitoring and Evaluation’ and ‘Groundwater Resource Valuation’ and main available tools (Riemann *et al.*, 2011: 448).

Figure 6.1 above shows the structure for the management of groundwater at the local and groundwater guidelines such as the Groundwater Strategy 2010 provide details in relation to “required actions and responsibilities” (*ibid.*: 448). There is the recognition that a wide range of planning tools (Integrated Development Plan (IDP) together with their Spatial Development Framework (SDF) and Water Services Development Plan (WSDP), Environmental Impact Assessments (EIA) together with their Record of Decision (RoD), water use and discharge licenses and permits, Integrated Water Resource Management Plan (IWRMP) and Integrated Waste and Wastewater Management Plan (IWWMP)) are used at the local level, and it is important for them to be in line with the Catchment Management Strategy (CMS) of the Catchment Management Area (CMA) (*ibid.*).

Considering the fact that in South Africa there is no framework developed exclusively for the management of groundwater at the local level, this proposed framework can contribute to the effective management of the resource. For instance, WSAs are required to develop Water

Services Development Plans (WSDPs) for their municipalities and this framework can serve as the guideline for the development of these plans. As has been established, dealing with groundwater issues at the local level is the most effective approach and having a framework at the local level will contribute to the realization of positive outcomes.

The GWMF is intended to bridge the gaps between the various groundwater management guidelines (Riemann *et al.*, 2011), and such gaps can be in relation to the components of management. For instance, the framework provides a clear definition of groundwater management and the various components (aquifer protection, well-field development, operation and monitoring, etc) to be considered in the process and also assigns roles and responsibilities to officials in the various aspects of groundwater management (*ibid.*). Thus, making it easy for officials to take decisions and go about their activities, and keeping us on track to realizing our targets for our groundwater resources.

6.3 Conclusions

Groundwater problems for the City of Johannesburg are a reality and the need for these problems to be attended to cannot be overemphasized. The consequences of these problems are far-reaching and it is imperative that they are taken seriously in order for the necessary steps to be taken in curbing these problems.

Through the research, some of the groundwater problems identified in Johannesburg are problems with recharge, pollution and institutional capacity of the city. Annual rainfall in Johannesburg is 700mm/yr, but it is highly unpredictable. Coupled with this is the problem with the geological formation of the rocks in the city. The city has predominantly hardrocks, as a result groundwater yield is low.

In relation to pollution, the main cause is as a result of AMD. For example, 40 million litres of AMD leak into the Tweelopiespruit everyday (Greenpeace, 2011). In the Central basin of the Witwatersrand, 0.9 metres of AMD rises each day and this is a potential threat to groundwater resources (*ibid.*). Also, the increase in polluted water levels in the East Rand has resulted in the pollution of the Blesbokspruit, which is part of the Vaal Catchment (*ibid.*).

There is also the problem with capacity, due to the fact that DWAF is understaffed. For instance, there are 49 posts for hydrogeologists but only 20 of the posts have been filled. There are also 51 posts for geotechnicians, however, only 27 are occupied.

These problems have implications for water supply and economic development of the city, food security and livelihoods of the people. They also have implications for the health of the people and the environment, and groundwater-dependent ecosystems. They can be costly as well for the city, especially in cases where remediation projects need to be undertaken.

There is legislation, policies and management strategies instituted to serve as a guide in addressing the groundwater problems. However, due to problems such as the undervaluation of the importance and significance of groundwater resources, shortage of expertise and adequate data, the centralization of power and the disregard of groundwater ecosystems and associated goods and services, we have been unable to sustainably manage the groundwater resources.

To make any meaningful and sustained progress in dealing with groundwater problems, it is important that the necessary measures are taken. Some of these include reforming the administrative system in place to make it more effective. There is the need for capacity building to improve upon the abilities of planners, engineers, hydrogeologists, geotechnicians, etc. to enable them go about their activities effectively, which in the long run will enable the realization of the targets of the NWA and NWRS.

Furthermore, the necessary tools need to be provided to water experts at the local level to enable the effective management of groundwater. As has been established, many of the activities that impact on our water resources occurs in a locality and therefore, dealing with them at that level would be more effective. It is necessary that roles and functions which can be undertaken at the local level are conferred on local authorities, with the higher levels of government providing the necessary support when needed. This will go a long way in making our local authorities more competent in dealing with water issues.

It is also important that a lot of future research is conducted on groundwater resources. As has been stated, groundwater is under-researched due to the fact that the main focus has been on surface water, a resource which is visible and accessible. In Johannesburg, groundwater sources from the dolomite aquifers are mainly used for irrigation (subsistence farming) and sanitation (cleaning washrooms, kitchens, disposal of human excreta, etc) purposes. Though subsistence farming and keeping our living environments clean are important, there is the need for us to realize that our groundwater resources can serve more purposes if developed to its full potential.

Furthermore, people have the tendency to think that groundwater is of poorer quality than surface water, and this is mainly due to the fact that the resource is underground. For this reason, people tend to see the resource as being fit for sanitation purposes only. However, studies show that this is not the case; groundwater under normal circumstances is of better quality than surface water. This is a mindset that needs to be changed and this can be done through education. It is important that people are educated on how valuable the resource is and make them aware of the greater purposes the resource can serve. This is to suggest that groundwater can be developed to the extent that it can be used for bulk water supply, thus being supplied for a wide range of activities such as commercial farming, drinking purposes, industrial water supply, etc.

The fact that groundwater is not being used for bulk water supply goes to show that resources have not been channeled into research on groundwater development. Especially since Johannesburg is a major city that is not built on a river or harbour, this resource should be very important to the city, and a lot of effort needs to go into developing it to its full potential. It is important for us to know that the development of groundwater requires investment in groundwater data collection. This will provide planners and other stakeholders with adequate information on the location and the potential of the aquifer systems. It will also provide information on the rate of recharge and discharge of the aquifer system. Having the necessary information on aquifer systems makes it easy for them to be developed to their full potential. This, together with a proper system of management would go a long way to ensuring the water security of the city.

Another important factor that needs attention is the need for the co-operation amongst the various sectors in charge of water management. There are land activities such as mining, industrial, agriculture, municipal wastes, etc., that impact on water resources, and for this reason, it is important that policy makers, municipal planners and water managers coordinate their activities. They also have to ensure that they align and harmonize their plans in order to enable effective monitoring of groundwater sources and the implementation of groundwater strategies, which will invariably contribute to the sustainable management of the resource. This suggests that effective communication amongst the key role players is vital for success. This is because it provides the means for deliberations, and thereby makes it possible to find appropriate solutions to problems they may encounter.

Furthermore, in the coordination of activities, it is important that neighbouring local authorities are engaged in the process. For instance, the effects of groundwater pollution are not limited only to Johannesburg. There are neighbouring areas that can be affected, and for this reason, it becomes necessary to engage other local governments, in order for the development of solutions and the implementation of strategies that are well accepted and beneficial to all.

As part of the NDP, the NPC has proposed a schema for spatial targeting. This is mainly about the development of corridors, and all of these corridors are to be linked to the City of Johannesburg. This means that Johannesburg, which is already a growing city, partly due to urbanization, will experience more growth in population in the future. This is almost inevitable, due to the fact that it is the economic hub of South Africa and Africa. Although there will be settlements developed along the corridors, Johannesburg will still attract migrants. An increase in population means that there will be an increase in the demand for water, which could put further stress on the water resources. For these reasons, it becomes necessary for the city authorities to plan adequately and manage the water resources effectively so that current and future water needs can be met.

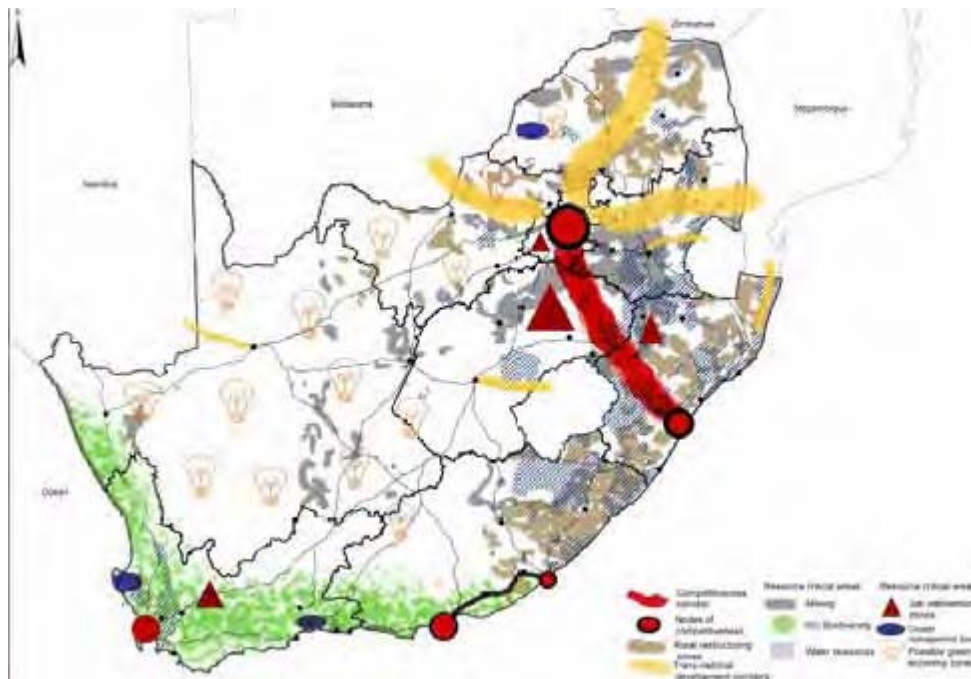


Figure 6.2: Proposed National Schema for Spatial Targeting

Source: National Planning Commission, 2012, p. 279

It is also easy for us not to be concerned or alarmed by the groundwater situation in Johannesburg, due to the fact there is a high dependency on the Vaal River and the Lesotho Highlands Water Project. This may be the current situation, but it is important for us to bear in mind that there are many cities dependent on these same sources, and there will come a time when they will not be able to meet all our needs. Developing the groundwater resources of the city to their full potential would ensure that groundwater and surface water can be used in conjunction, which will ensure the sustainability of the water resources.

This research report shows that water is central to survival: it is essential for our health, the health of other species and the environment. It is also an essential component of development. Without water, many of the plans of the City of Johannesburg may not be implemented. For instance, neither the targets of the Growth and Development Strategy 2040 (GDS), nor the targets of the Integrated Development Plan (IDP) may be realized. The city's inability to implement the GDS 2040 could result in financial crisis for the city, which will invariably affect the country as a whole. This is because the city depends on investments for the implementation of these plans, and without water, it will be unlikely for the city to attract investors in order to implement these plans. Furthermore, the inability of Johannesburg, the driving force of the economy to attract investors implies that, there will be no revenue generated for the implementation of the National Development Plan. Therefore, there is the need for us to understand that water is our future and the time to act is now.

Due to time limitations, I was unable to conduct a primary qualitative study and so in the future I intend to conduct primary qualitative research which will enable me obtain more information on the management of groundwater. This will provide the platform to gain practical knowledge, which, together with the theoretical knowledge, will enable the development of innovative and feasible strategies for the management of groundwater.

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ANNEXURE

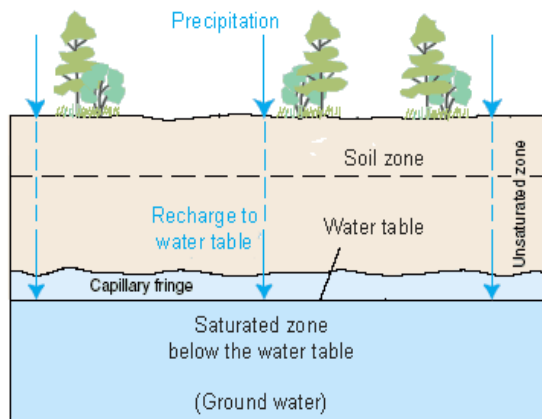


Figure A: The Hydrological Cycle

Source: USGS: undated (ga.water.usgs.gov.edu)

When precipitation occurs, water infiltrates through the soil. The upper layer of the soil is the unsaturated zone and the lower layer is the saturated zone, where the pores, cracks, fractures and spaces between rock particles are totally filled with water. The top surface of groundwater is the water table (ga.water.usgs.gov.edu).

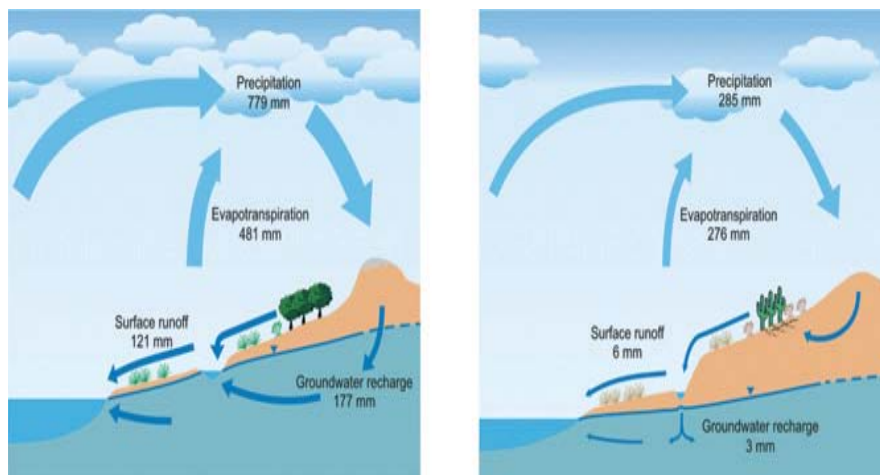


Figure B: The water cycle in different climatic zones of the world demonstrated by the examples of Germany (left) and Namibia (right)

Source: Schreiber and Schneider: undated

From the figure it can be observed that Germany is a country with humid climatic conditions as such it experiences high rainfall. Also the soil conditions are good such that water is able to

infiltrate through to recharge aquifers. As a result there is high level of groundwater recharge as well as surface runoff.

On the other hand, Namibia has a semiarid climatic condition as such records very low rainfall as compared to Germany. It is dry and as such the water that infiltrates through the soil is taken up by plants, with very little recharging groundwater. Also there is also abysmal record of rain as surface runoff.



Figure C: Acid mine drainage on the West Rand goldfields (Land and soil degradation)

Source: www.earthlife.co.za



Figure D: Fishkill due to AMD

Source: Patagonia-under-siege.blogspot.com



Figure E: Animal exposure to AMD through contaminated water in a reserve

Source: www.care2.com



Figure F: Skin lesion due to arsenic contamination

Source: www.topnews.in



Figure G: Cancer, a long term effect of arsenic contamination in drinking water

Source: nation.com.pk

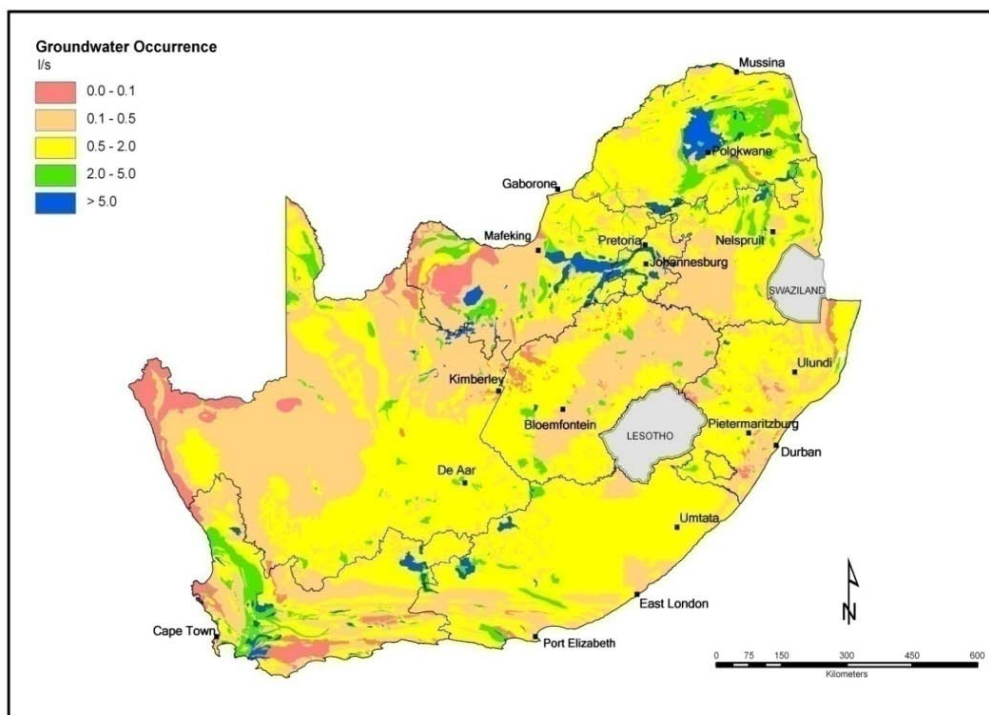


Figure H: Groundwater yield in South Africa

Source: DWAf 2011, p. 24

The natural long-term equilibrium of aquifers is disturbed by pumping and to ensure a continuity of this balance, the abstraction of groundwater must be balanced either by increasing recharge or reducing discharge over a long period (DWAf, 2011). Equilibrium is reached when 'capture'

(i.e. the increase in recharge and decrease in discharge) balances pumping and it is at this point that the yield of the aquifer can be considered sustainable (DWAF, 2011).

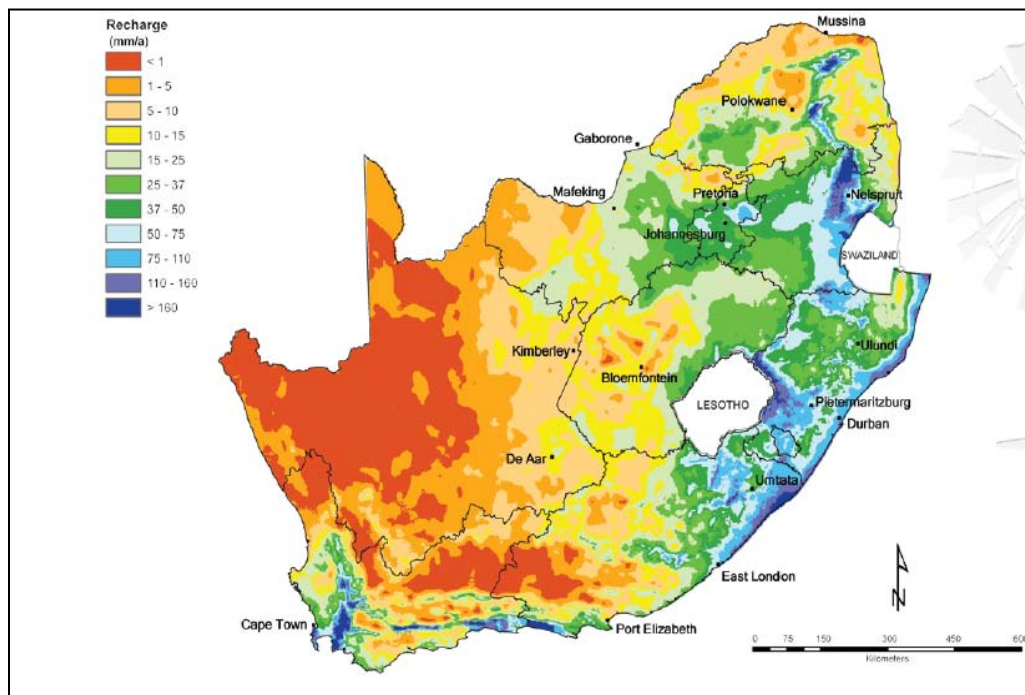


Figure I: Groundwater recharge in South Africa

Source: DWAF, 2011, p. 41

One important component in the determination of the “available and sustainably usable groundwater” of South Africa is the groundwater recharge factor (DWAF, 2011). Some local areas have reliable estimates for groundwater recharge, however, at the national level, these estimates are non-existent (DWAF, 2011).

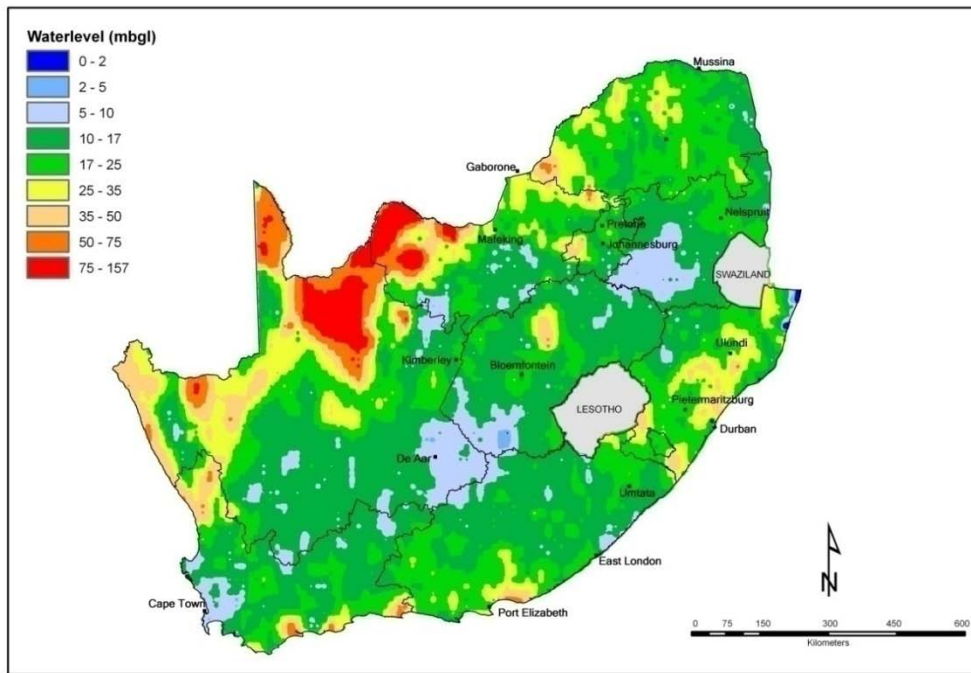


Figure J: Groundwater levels in different areas of South Africa

Source: DWAF, 2011, p. 21

Groundwater level is linked to the yield or recharge rate and it is an aspect that needs to be monitored, especially in the case of excessive abstractions of the resource (DWAF, 2011).

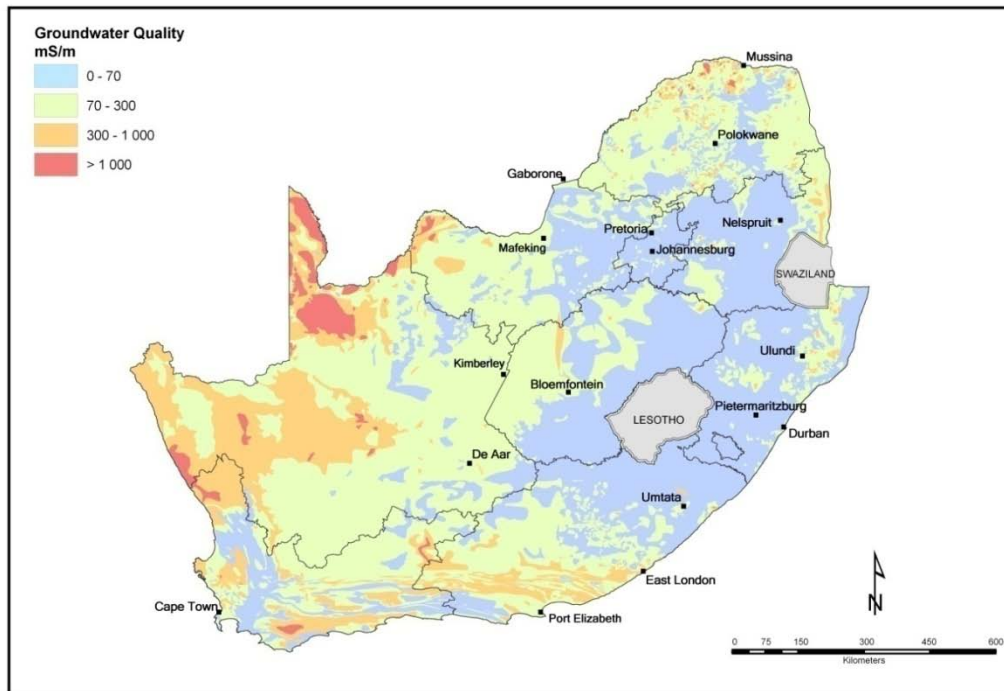


Figure K: The electrical conductivity of groundwater in South Africa

Source: DWAF, 2011, p. 19

Groundwater is of better quality than surface water and can be consumed directly without any treatment (DWAF, 2011). This is because bacteria and viruses cannot survive in aquifers for long periods. Although this is the case, groundwater for public supply is chlorinated as a precautionary measure (DWAF, 2011). The proper monitoring of the microbiological quality of groundwater would ensure that we are made aware of the problems early enough and be able to deal with the problem before they deteriorate (DWAF, 2011).

In terms of dissolved minerals, groundwater contains “chloride, sodium, iron and others” (DWAF, 2011, p. 18). The occurrence of these minerals in groundwater is dependent on factors such as the “aquifer material and groundwater residence time” (DWAF, 2011, p.18). High levels of these dissolved minerals can make groundwater brackish or saline (DWAF, 2011). Furthermore, the presence of naturally occurring pollutant such as fluoride, arsenic or nitrate make groundwater unfit for human consumption although it will taste fresh (DWAF, 2011).