GROUNDWATER RESOURCE ASSESSMENT FOR DEVELOPMENT AND USE IN JOZINI, KWAZULU-NATAL

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DECLARATION

I, Mofokeng Setjhaba Seromo Ignatius, hereby declare that this dissertation submitted by me to the Institute for Groundwater Studies in the Faculty of Natural and Agricultural Sciences at the University of the Free State, in fulfilment of the degree of Magister Scientiae, is my own independent work. It has not previously been submitted by me to any other institution of higher education. In addition, I declare that all sources cited have been acknowledged by means of a list of references.

I furthermore cede copyright of the dissertation and its contents in favour of the University of the Free State.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

According to Ukwandu (2009) and Riemann *et al.* (2012) South Africa is a water-stressed country situated in a region with increasing levels of water scarcity and water quality problems. Furthermore, the population growth, coupled with issues of social and economic development adds to the issue of stress on the water resources. Haupt (2001) also noted that this problem could be intensified by potential climate change over a great area of the country. This is the case in most parts of KwaZulu-Natal (KZN) province in South Africa, and to a large extent in Umkhanyakude District Municipality, where the study area is located, and where climate change has led to frequent drought situations, which in turn, has led to surface water resources drying up and therefore communities are struggling to have enough water for their basic needs, as stated in the Constitution of the Republic of South Africa.

Recently, from mid-2014 to date, there have been frequent droughts in South Africa, which has seen five of the provinces namely KwaZulu-Natal (KZN), the Free State (FS), the North West (NW), Mpumalanga (MP) and Limpopo (LP) being declared disaster areas, due to drought. The effects of climate change appear in various forms, which are affecting communities in the world. This is according to the Intergovernmental Panel on Climate Change (IPCC, 2007). The drought conditions brought about water scarcity in the Umkhanyakude District Municipality in Northern KwaZulu-Natal, especially in the town of Jozini.

This project came about as part of the KZN provincial government and the Department of Water and Sanitation (DWS) who tried to come up with interventions to rectify the drought situation. The town of Jozini is more of a rural town with dwellings and villages scattered from one another. The better part of the town, to a large extent the entire district municipality, depends on the Pongolapoort Dam also known as Jozini Dam for its water supply; but with the current drought situation, the dam is experiencing a drop in water levels. This means that the town's reliance on surface water as the primary water supply for the town and its surrounding villages has decreased. This dissertation will look into the assessment of groundwater resources for the purpose of supplying the community of Jozini.

1.2 PROBLEM STATEMENT

The Department of Co-operative Governance and Traditional Affairs (CoGTA) report on the drought situation in the KwaZulu-Natal Province (CoGTA, 2014), states that the province has been affected by the prevailing extraordinary climatic changes. This led to the province experiencing persistent drought, which in turn, has affected the domestic water supply, as it has continued to receive below the normal and expected rainfall throughout past seasons

(2013-2014) and this has affected water levels in various catchments; and eventually having an effect on the storage of the dams. As a result, even the largest dam in the province (Pongolapoort Dam also known as Lake Jozini) is also experiencing a drop in water levels and the communities are suffering from water shortages.

According to DWA (2013), there is enough water available from the Pongolapoort Dam to meet domestic and significant irrigation needs in the area, but this water has not been utilised yet. This might have been the case during the time of this study, and eventually its publication. However, it is no longer the case; because the dam is currently 45.2% full (DWS, 2016).

Much of Africa is poorly endowed with water. South Africa itself is a water scarce country (Robins *et al.,* 2006) and there is an increasing demand, with groundwater as the only practical means of meeting the rural community's needs at a relatively low cost.

Groundwater is an important source of water supply, especially in the rural areas of South Africa, where the cost of constructing surface water schemes is very high and in some instances not feasible, due to the scattered nature of the rural population. In areas where surface supplies are inadequate, developing groundwater through boreholes with sufficient and permanent supplies is important over large parts of rural South Africa (Lurie, 1989; Robins *et al.,* 2006).

The current drought seems to be exerting pressure on the surface water resource in the town of Jozini, as the municipality struggles to supply potable water to its residents. Drought exists when the actual water supply is below the minimum normal operation and reflects a deficit in the water balance (Hazelton *et al.,* 2009). The occurrence of drought is one of the climatic extremes with both short and long-term effects on water supply.

According to the DWS (2016) the dam levels of the Pongolapoort Dam dropped to about 45.2% in May 2016, compared with 60.2% at the same time in 2015. This situation has led to a point where members of the community vent out their anger at not having water by engaging in public service strikes, as what happened in September 2015 and again in May 2016 (News24, 2015; The Citizen 2016). Interacting with some people from the town, showed that, apparently the problem with the water supply is not new, as it has been going on for close to ten years now. This situation has led to most people drilling private boreholes for domestic use; consequently, making it difficult to know the level of groundwater usage.

This study will focus on groundwater resource assessment in Jozini Town, KwaZulu-Natal, as the town has been negatively affected by the current drought. Jozini is a settlement in the uMkhanyakude District Municipality in the KwaZulu-Natal province of South Africa. It is a small town with an estimated population of 186 502 people; according to Statistics South Africa (SSA, 2011).

1.3 AIMS AND OBJECTIVES

This dissertation aims to assess the potential for groundwater resource development and use in Jozini, KwaZulu-Natal, South Africa. In order to achieve this goal, the following objectives were set out at the beginning of the project:

- The assessment of groundwater occurrence;
- To determine the geological characteristics of the aquifer;
- To determine aquifer hydraulic and storage properties;
- The estimation of groundwater recharge;
- To determination borehole sustainable yields; and
- To characterise hydrogeochemical processes and to evaluate the groundwater quality.

1.4 STRUCTURE OF THE DISSERTATION

This dissertation is structured as follows:

Chapter 1: Introduction

This chapter introduces the research framework, the problem statement, the aims and objectives, the research methodology and also describes the structure of the dissertation.

Chapter 2: Literature Review

This chapter reviews the concepts and methods used for groundwater assessment and development.

Chapter 3: A description of the Study Area

This chapter describes the study area in terms of its climate, geology and hydrogeology.

Chapter 4: Desktop Study

This chapter deals with all the desktop studies done, including geological maps and their interpretation, and the hydrocensus conducted.

Chapter 5: Geophysical Investigations

The use of geophysical methods (Magnetic and Electromagnetic) used for this report is discussed and interpreted in this chapter.

Chapter 6: Drilling and Geological Characterisation

This chapter will deal with the exploration drilling and the description of the geological logs.

Chapter 7: Aquifer Testing and the Determination of Aquifer Parameters

This chapter discusses the aquifer pump testing results and hydraulic characterisation of the aquifer.

Chapter 8: Groundwater Recharge and Estimation of Sustainable Yields

This chapter deals with the estimation of groundwater recharge and the sustainable yields across the study area. The current and future water demands are also discussed.

Chapter 9: Assessment of the Groundwater Quality

In this chapter the quality of groundwater sampled during pump testing will be analysed and discussed in detail.

Chapter 10: Conclusion and Recommendations

Finally, this chapter draws conclusions on the groundwater resource assessment for supply in the rural town of Jozini. It further gives recommendations based on the results obtained.

1.5 SUMMARY

This chapter was to give an introduction of the study, also providing the aims and objectives of the study and the methods which would be used to achieve the said aims.

The following chapter will review the concepts and methods used in groundwater resource assessment.

CHAPTER 2: LITERITURE REVIEW

2.1 INTRODUCTION

Groundwater is a valuable natural resource providing a primary source of water for agriculture, domestic and industrial purposes in many countries; therefore, it should be developed for sustainable use (Busari & Mutamba, 2014). Therefore, for this purpose, this chapter will review literature which is aimed at considering general methods, as well as basic concepts for groundwater resources assessment.

Some of the basic concepts to be understood and taken into consideration for groundwater resource assessment include the investigation of groundwater occurrences, and its flow and storage. The understanding of these methods and concepts ensures that sustainable development is achieved.

Groundwater sustainability refers to the development and the use of groundwater in a manner that can be maintained for an indefinite time, without causing unacceptable environmental, economic, or social consequences (William *et al.*, 1999). Because of the growing importance of water in the health, agriculture, and environmental sectors, the development of groundwater sources is becoming increasingly central to the success of integrated rural development programs (Vincent *et al.*, 2009).

The bulk and retail water supply in the town of Jozini (and the entire Jozini Local Municipality) is serviced by the Umkhanyakude District Municipality (UDM), who acts as the Water Service Provider (WSP). Water is then supplied to the town of Jozini and the surrounding communities by the Jozini-Malobeni Water Supply Scheme.

This chapter will look into reviewing the concepts and methods of the groundwater resource assessment related to groundwater occurrence, groundwater flow, groundwater recharge and groundwater quality assessment.

2.2 WATER SUPPLY IN KWAZULU NATAL

There are approximately 11 800 rural settlements within jurisdiction of the KwaZulu-Natal Regional office of the Department of Water and Sanitation (DWAF, 2008a). In all probability, most of these settlements are largely or wholly dependent on groundwater for their domestic supplies and thus it represents a large component of the domestic water use sphere. However, very little or no data is available on:

- Their dependence on groundwater;
- Their vulnerability to droughts; and
- The volumes being abstracted.

All of this needs to be assessed to define the level of the impact on the groundwater resources of the underlying aquifers. Furthermore, no proactive action can be taken in terms of mitigating either vulnerability or augmentation of the supply where there are shortages.

The Jozini-Malobeni Water Supply Scheme obtains its water from the Pongolapoort Dam. The Pongolapoort Dam was constructed in the late 1960s for the purpose of irrigation on the Makhathini Flats, downstream from the dam. With a full supply capacity of 2 445 million m³ and a historic firm yield of 530 million m³/a (DWAF, 2004a), the dam is one of the largest in South Africa. The Jozini WTW and the Makhathini package plants extract raw water from the Makhathini Flats irrigation canal; fed from the Pongolapoort Dam. Raw water is pumped to the treatment plants where it is treated to potable drinking water quality standards.

Based on Jozini (2016) there has been an increase in the number of households in the Jozini Local Municipality who have access to piped water. The majority of the households still rely on natural resources for their water supply. Only 10.9% of households have access to piped water inside their dwellings, this means that those without piped water are relying on boreholes, springs and rainwater harvesting, Table 2-1 below shows the water supply for the entire Jozini Local Municipality. It should be noted that the town of Jozini is part of the Jozini Local Municipality.

Table 2-1: Summary of the water supply in the Jozini Municipal area (Jozini, 2016).

Water Source	Households	Percentage (%)
Regional/Local Water Schemes (Municipality/Water Service Provider)	17 162	44
Boreholes	3 682	9
Spring	1 147	3
Rainwater Tanks	7 83	2
Dam/Pool/Stagnant Water	2 486	6
River/Stream	10 098	26
Water Vendor	4 76	1
Water Tanker	1 472	4
Other	1 543	4
Total	**38 849**	**100**

Furthermore, Jozini (2016) stated that the water requirement in the Jozini-Malobeni Water Supply Scheme area will continue to increase, mainly due to the demand to meet the growth in the population as people move from the surrounding villages in search of a better life, because of the economic growth in the town, including improving the level of service delivery by the municipality. What this report didn't take into consideration is the current drought that has put a strain on the water supply to the community.

2.2.1 Competing water users

Based on DWA (2011), there is stiff competition amongst the different water users. While water remains a stumbling block for economic development through agricultural activities, water for domestic purposes that is potable water, becomes crucial, and is hence a priority.

There has been some growth in the population in the Jozini-Malobeni Water Supply Scheme area, due to tourism development, which has become increasingly important to the economy of the area. The commercial activities taking place in the area are mainly driven by tourism and industries related to tourism. These economic activities and associated developments in the Jozini-Malobeni area, together with the growing population are driving the increase in water requirements (DWA, 2011).

2.2.2 Infrastructure management

The Integrated Development Plan (IDP) for Jozini Municipality (Jozini, 2016), states that, based on the municipal wards IDP participation meetings; water remains the main priority at Jozini Municipality. Jozini comprises seventeen water schemes, but most of these schemes are not properly maintained and are therefore dysfunctional. In areas not covered by the scheme and/or in cases where the schemes are dysfunctional, there are boreholes. Unfortunately, most of these boreholes are non-functional due to poor maintenance. Other boreholes are privately owned, and therefore it is not clear how many boreholes in total are in use. This is the big problem as even the municipality couldn't provide data when requested to. On providing the borehole information or data, the coordinates for the municipal boreholes were not available. This could partly be due to an assertion that boreholes are frequently being abandoned and new ones are being drilled in Northern KwaZulu-Natal (Groundwater Development Services, 1994).

Groundwater is the most valuable freshwater resource on earth, and is the main reliable source of good quality water for rural supply. However, it has mostly been neglected in favour of surface water (Busari & Mutamba, 2014), in terms of its importance for human use and the attention to dedicate it to the general public and water sector managers.

In most rural areas of South Africa, people struggle to access fresh water resources, this being the case even in Jozini. This is because mostly, surface water resources are preferred by the municipalities or authorities over groundwater and in most cases surface water might not be adequately available in remote rural communities. Where surface water is available, in the form of perennial rivers, storage and distribution, infrastructure is needed to transport the water to the communities; which is usually lacking, as it is expensive.

DWAF (2000), states that groundwater is the key component of the water resources of South Africa and it will provide much of the water required for basic human needs, especially since the country's surface water resources are unevenly distributed and cannot cope with the growing demand for water.

2.3 GROUNDWATER DEVELOPMENT AND MANAGEMENT IN SOUTH AFRICA

2.3.1 Groundwater development

Groundwater has historically been given limited attention, and has not been perceived as an important water resource in South Africa, as it has long been managed as private water, before being declared to be a public resource under the new National Water Act of 1998 (Act 36 of 1998). This made the government the only custodian of all the national water resources; both surface and groundwater (DWAF, 2004a, DWAF, 2004b and DWAF, 2009). Fundamental principles and objectives of the Act with regard to groundwater are:

- All water resources are common to all, and are subject to national control;
- All water has a consistent status in law, irrespective of where it occurs;
- There shall be no ownership of water, but only a right (for environmental and human needs) or an authorisation for its use; and
- Groundwater is an integral part of the water resource and must be managed as such.

Globally, the number of people who still do not have access to an improved drinking water source have decreased to below one billion, from when the data was first collected in 1990 (Xu & Braune, 2010). It was said that by 2010 about 87% of the global population had access to drinking sources, with the trends projecting that by 2015 the numbers would have risen to 90% (WHO and UNICEF, 2004); but in Africa only about 62% of the population had access to an improved water supply in the year 2000 (UNEP, 2007).

In most cases, urban areas have better services as compared with rural areas. This is where groundwater comes into use for rural areas, as a good option for water supply, because it is mostly a partially unexploited resource. It is found close to where it is needed. Its natural quality is usually good, so it can be used with minimal treatment. It can be developed more often and as needed. It also offers a relatively conflict-free way of offering water to the rural poor, across the country (DWAF, 2009 and Cobbing, 2013).

Traditionally, groundwater has been the only source of water supply in most of South Africa's rural areas, comprising about 65% of the total supply (DWAF, 2000). This means it has long been realised that it would be practically impossible to meet all the national water needs using surface water resources only (Busari & Mutamba, 2014). Still, with this realisation, in

2014 only 10% of South Africa's water supply is from groundwater, with only 4% of that being for urban usage, and 84% being used for irrigation and for the watering of livestock (Busari & Mutamba, 2014). According to DWAF, (2008b) just over three hundred towns are dependent on groundwater in South Africa. It can therefore be deduced that a large part of the groundwater underlying the country, is still not used (Busari & Mutamba, 2014).

Boreholes should be sited by an expert hydrogeologist and located where the best yields are to be expected and the sustainable yields must be determined, and the abstraction rules must be adhered to.

2.3.2 Groundwater management

Although a lot has been said about a water crisis in Africa, the management of groundwater resources has to date failed to feature prominently in the national and regional water agendas in Africa, except for countries which are essentially dependent on groundwater resources (Xu & Usher, 2006), this could be due to:

- The failure to recognise major groundwater related issues and problems on the continent;
- The lack of proper valuing of groundwater;
- The lack of suitable regional development approaches/instruments;
- The degradation of groundwater resources; and
- The lack of information and information management relating to groundwater resources management.

All the points stated above can be addressed through proper groundwater management, which will have to involve the training of administrators in local government and water services institutions.

Most of the Southern African countries such as Namibia, Botswana and the north-western part of South Africa have semi-arid or arid conditions. As a result of these conditions, there are low precipitation rates in these countries (Xu & Braune, 2010). This means that recharge may be limited, and this is probably largely due to line and point sources such as streambeds and dam basins, respectively. Surface water resources are mostly not permanent and perennial rivers in these areas receive their recharge from humid areas. Hence groundwater, in most cases has assumed great importance as the major source of fresh water. The strategic importance of groundwater for rural water supply cannot be over-stressed; hence comes the need for its management.

Successful water use depends mostly on good management of the resource. This applies to all the water resources but is more important where the supply is perceived as being “invisible” to the user, such as with groundwater.

Southern African countries exercise an increasingly integrated adaptation to their water resources management, with surface water, groundwater, socio-economic and other issues being considered together (UNEP, 2005). In South Africa specifically, there is a Water Act (NWA 1998), with the purpose of developing, managing, using, protecting, conserving, and the controlling of national water resources.

The South African Water Act (NWA 1998), provides for the establishment of catchment management strategies by the Catchment Management Agencies (CMA); of which seven are currently in the process of becoming operational. Only two CMAs are currently active in the form of Breede-Gouritz water and Inkomati-Usuthu CMAs. In places where CMAs are not yet active, the DWA acts as a CMA. The purpose of the catchment management strategy is:

- To set principles for allocating water to existing and new users;
- To provide the framework for managing water resources within the water management area; and
- To ensure that water resources in the water management area are protected, used, developed, conserved, managed and controlled.

The other means of managing the national water resources are by means of authorisations according to the act. There are four types of authorisations, namely:

- **Schedule 1 water use:** This is for water use that will have very little or no impact on the water resource; for example, the drawing of water from any water resource in one’s household, if one has lawful access to that water. For this water use there is no registration.
- **Existing Lawful Use (ELU):** This is for the water use which was exercised legally within the two year period prior to the implementation of the National Water Act. An ELU is determined through a process of Validation and Verification (V & V).
- **General Authorisation:** This is an authorisation for slightly larger uses from certain less-stressed sources. This authorisation allows the user to use water without a licence, provided that the water use is within the conditions of the general authorisation.
- **Water Use Licence:** A licence should be applied for any water use that is not covered as a schedule 1 water use or general authorisation. A water use licence is used to control water use that exceeds the limits of the other abovementioned authorisations.

Groundwater management for community water supply commitments requires maintaining a groundwater management system and integrating it into Operations and Maintenance (O&M) activities. Different institutions need to contribute to the operation of the system (DWAF, 2004c, & DWAF, 2008b). Their responsibilities include one or more of the following:

- The responsibility for data collection;
- The responsibility for ensuring that the data is analysed by an experienced groundwater professional (including payments for these services if consultants are used);
- The responsibility for ensuring that the data is passed on to the relevant authorities, such as the DWS and Catchment Management Agencies (CMAs); and
- The responsibility for ensuring that the management recommendations are observed.

Regional groundwater management will have to address the following issues as highlighted by (Meyer, 2002):

- A regional groundwater information system;
- Compilation of regional groundwater monitoring hydrological maps and atlas;
- Establishment of a regional groundwater monitoring network;
- Regional groundwater resource management and aquifer characterisation;
- The establishment of regional training and a research institute;
- Capacity building and institutional framework; and
- The development of minimum common standards for groundwater development.

Monitoring of groundwater, especially for rural water supply helps with the following (DWAF, 2008b):

- Preventing the aquifer from being over-pumped, as this may result in a long-term depletion of the groundwater throughout the entire aquifer;
- Optimising individual borehole pumping rates, because if the pumping rate of an individual borehole is too high, it will result in localised groundwater depletion;
- Preventing poor quality groundwater from entering the aquifer; and
- Minimising groundwater contamination from surface sources such as pit latrines, animal kraals, fertilisers and dripping tanks.

2.4 GROUNDWATER RESOURCE ASSESSMENT

DWAF (2006) describes Groundwater Resource Assessment as a model applied to estimate groundwater allocation scenarios. This has been used to further quantify groundwater use on a local and regional scale.

In late 2003, the Department initiated the Groundwater Phase II (GRAII) Project, which was aimed at the quantification of the groundwater resources of South Africa on a national scale (DWAF, 2006). The project was completed in June 2005. Algorithms have been developed for the estimation of storage; recharge, base-flow and the impact of the reserve and present groundwater used have been recorded. The results, in addition to methodology, include several valuable datasets and maps and provide input on various levels of planning and management of water resources (DWAF, 2006).

The occurrence of groundwater, types of aquifers in the area of study, geological structures, estimation of groundwater parameters, sustainable yields of the local boreholes, groundwater quality analysis; among other things, need to be understood, in order to succeed in having a groundwater resource assessment study (DWA, 2006; Witkowski *et al.*, 2007).

2.4.1 Groundwater occurrences

Scientific and geophysical methods have been used to determine or locate areas of groundwater occurrences. Geophysical methods measure natural or induced physical phenomena in the Earth's crust and interpret the results thereof, to obtain information on the subsurface (Mandel & Shiftan, 1981).

Some of the methods used for groundwater exploration are: the remote sensing method, the magnetometric method, the Electromagnetic Method (EM), the Electrical Resistivity (ER) method, and the gravimetric method.

2.4.1.1 The remote sensing method

This method collects data with the aid of airborne or satellite-borne instruments (Mandel & Shiftan, 1981). With remote sensing methods it is easy to locate mapped intrusions and faults (Woodford & Chevallier, 2002).

Remote sensing has an advantage in that it provides information from large areas without being hampered by difficulties due to access (Mandel & Shiftan, 1981). Satellite imagery also makes it possible to monitor transient phenomena such as floods, snow cover, droughts, volcanic eruptions, etc. However, these advantages carry little weight in groundwater investigations, except in the preliminary phases (Kirsch, 2006). It is nonetheless advisable that this method be used alongside other geophysical methods which will be explained below, to better explore for drilling of boreholes.

2.4.1.2 The magnetometric method

The magnetometric method is the oldest geophysical method (Chandra, 2016). This method observes anomalies in the earth's magnetic field, which are caused by different magnetic susceptibilities of rocks.

Magnetic measurements are probably the most rapid, uncomplicated, and inexpensive geophysical observations available, therefore making them the most used method for groundwater investigations. The advantages of this method are that it can detect dykes in country rock concealed under alluvial overburden, detection of fault zones within the magnetically susceptible minerals, subsurface extension of basic igneous rocks (basalts), and to some extent, the differentiation between clay and gravel-sand deposits in an alluvial plain (Mandel & Shiftan, 1981; Chandra, 2016).

2.4.1.3 The Electromagnetic Method

The Electromagnetic Method (EM) is a combination of the magnetic and electrical methods. This method makes use of a small transmitter and a receiver coil. The transmitter signal, which is a primary magnetic field, is generated by sinusoidal current flow through the transmitter coil at a discrete frequency (Kirsch, 2006). The time-varying magnetic field produced from the alternating current in the transmitter coil induces small currents into the earth (Woodford & Chevallier, 2002). These currents will therefore generate a secondary magnetic field, which is picked up by the receiver coil, which is usually placed a short distance away and which may be related to the primary magnetic field expected at the centre of the receiver coil (Kirsch, 2006). This method makes use of Vertical Dipole (VD) and Horizontal Dipole (HD) coil orientation. When the coils are aligned in a plane parallel to the earth’s surface, with the axes of the coils vertical, the orientation is referred to as VD, while the HD is when the coils are aligned in a plane perpendicular to the earth’s surface, with the axes of the coils horizontal. This method can easily be used for geophysical studies in areas where the surface layer is highly resistive, and an electrical resistivity survey is difficult due to poor conduction of electrolytic current (Rodriguez *et al.*, 2006 and Chandra, 2016).

For the purpose of this study an EM34-3 was used. The coils of the EM34-3 system can be separated by a distance of 10 m, 20 m or 40 m. The farther apart the two coils are, the greater the depth of investigation. The 40 m coil-separation investigates to depths approximately four times greater than the ten metre coil-separation and twice as deep as the twenty metre coil-separation. For this study, the twenty metres and the forty metre coil-separations were employed to investigate various depths; similar traverse lines for magnetic investigation were used also for electromagnetic investigations.

The depth of penetration for the EM34-3 system is generally influenced by the following factors (McNeill, 1983):

- **Orientation of the coils:** The VD mode has a greater depth of investigation than the HD mode.
- **Coil separation:** Larger distances between the transmitter and receiver loops lead to greater depths of investigation.

- **Source frequency:** Lower frequencies lead to larger skin depths and hence greater depths of investigation.
- **Terrain conductivity:** Terrain conductivity affects the skin depth. Higher conductivities lead to smaller skin depths and a decrease in the depth of investigation.

The interpretation of EM data is always complex since the response changes significantly with changes in the geological setting. Even if the surveys are done across similar structures in similar environments (for example dolerite intrusive in Karoo rocks), minor differences in the geological and/or geohydrological conditions may lead to different responses (Rodriguez *et al.*, 2006 and Makhokha, 2016). In general, interpretations of geophysical anomalies are inherently ambiguous because any given anomaly could be attributed to an infinite number of possible sources (Parasnis, 1986).

EM methods have the following limitations (Huang, 2005; Letellier 2012):

- The quantitative interpretation of EM anomalies is complex;
- The data is often affected by cultural noise;
- The EM methods are sensitive to external sources of EM radiation;
- The penetration is not great if conductive superficial layers are present;
- The fragile instrumentation;
- The rapid decrease in resolution with an increase in coil-separation; and
- The ground frequency-domain systems generally have shallow depths of investigation, rarely greater than sixty metres.

The EM34-3 system offers a number of advantages in mapping the subsurface conductivity distribution, when compared with other geophysical methods (McNeill, 1983; Hinze & von Frese, 1990; Botha *et al.,* 1998; Kirsch, 2006). These advantages include the following:

- Six conductivity measurements can be taken at each survey point (using all three-coil separations for both HD and VD modes). This allows insight into the distribution of conductivities in the subsurface, both laterally and vertically.
- Recording conductivity data is less time-consuming than other geophysical methods, such as the resistivity method.
- The system does not require physical contact with the ground. Unlike the resistivity method, no electrodes need to be inserted into the earth to take a measurement. This also eliminates the problems associated with an electrically resistive overburden.
- The method measures changes in the subsurface conductivities. It is therefore suitable for the detection of fractures, conductive body and weathered zones.

There are some disadvantages to using the EM34-3 system, as compared to other geophysical techniques (Heiland, 1968; Reynolds, 1997), namely:

- The EM34-3 system measures the apparent conductivity of the subsurface by calculating the ratio of the quadrature component of the secondary magnetic field to the primary magnetic field. When lateral changes in the subsurface conductivities occur, the measured apparent conductivity profiles do not always make intuitive sense. For example, negative conductivity anomalies are often recorded across highly conductive materials. This characteristic of the system complicates the interpretation of the recorded anomalies.
- When low source frequencies are used, the induced currents may be small, leading to noisy data.
- High frequencies lack depth penetration and cause interference from near-surface conductors and from topography (Heiland, 1968).
- It is difficult to operate in bushy and rocky terrain, owing to the coil separation that has to be maintained at each station, and the interconnecting cable getting stuck in the vegetation or rocks
- The horizontal dipole mode has a high sensitivity to near-surface conductivity changes. Such variations in the shallow conductivity can mask changes at greater depths.
- At low values of terrain conductivity, it becomes difficult to magnetically induce sufficient current in the ground to produce a detectable magnetic field at the receiver coil.
- At high values of conductivity (>100 mS/m) the quadrature component of the received magnetic field is no longer linearly proportional to terrain conductivity. The apparent conductivity values calculated by the system therefore becomes poor.
- The maximum coil separation of forty metres limits the exploration depth to a claimed maximum of sixty metres.

2.4.1.4 The Electrical Resistivity Method

This is the most commonly used geophysical method in groundwater investigations (Mandel & Shiftan, 1981). According to Chandra (2016), in hard rocks this method is used to identify the weathered zone, its thickness and groundwater yielding character, bedrock topography, saturated fractured zones and their depths, lateral extension and orientation, other structures like dykes controlling groundwater movement and the quality of groundwater in terms of electrical conductivity. Based on Woodford and Chevallier, (2002), the resistivity of Karoo sediments, generally, is considerably lower than that of the crystalline rocks. This will mean that shale and mudstones are less resistive than sandstone units, while on the other hand; dolerites are highly resistive, making them good targets for electrical resistivity methods.

The resistivity measurements are normally made by inserting current into the ground through two electrodes and measuring the resulting voltage difference at two potential electrodes, resulting in apparent resistivity.

2.4.1.5 The gravimetric method

This method measures and interprets small anomalies in the force of gravitational attraction exerted by the earth. The anomalies/variations are mainly caused by the density differences within the different formations (Mandel & Shiftan, 1981). The application of the gravity method in South African groundwater investigations is limited to (Vegter, 2001):

- Locating valleys in dolomite that has solution cavities and channels filled with residual products, younger unconsolidated deposits, and collapsed Karoo sedimentary rocks.
- Estimating groundwater storage capacity of dolomitic groundwater compartments from the gravity deficiency.
- Locating filled-in pre-tertiary river valleys and determining the configuration of the floor on which Neogene sediments were deposited along the coast. However, its applicability is questionable, owing to the steep gravity field gradients along the South African coast.

Boreholes should be sited by an expert hydrogeologist where best yields are to be expected and the sustainable yields must be determined, and the abstraction rules should be adhered to, using the methods mentioned above. It should be noted that for this study, only magnetic and electromagnetic methods were used.

2.4.2 Groundwater recharge assessment

Groundwater recharge is defined by Xu and Beekman (2003) as an addition of water to the groundwater reservoir. They further distinguish recharge in the following four modes:

- Downward flow of water through the unsaturated zone reaching 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

The Groundwater Dictionary (DWA, 2011b) summarizes groundwater recharge as the addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers (Figure 2-1).

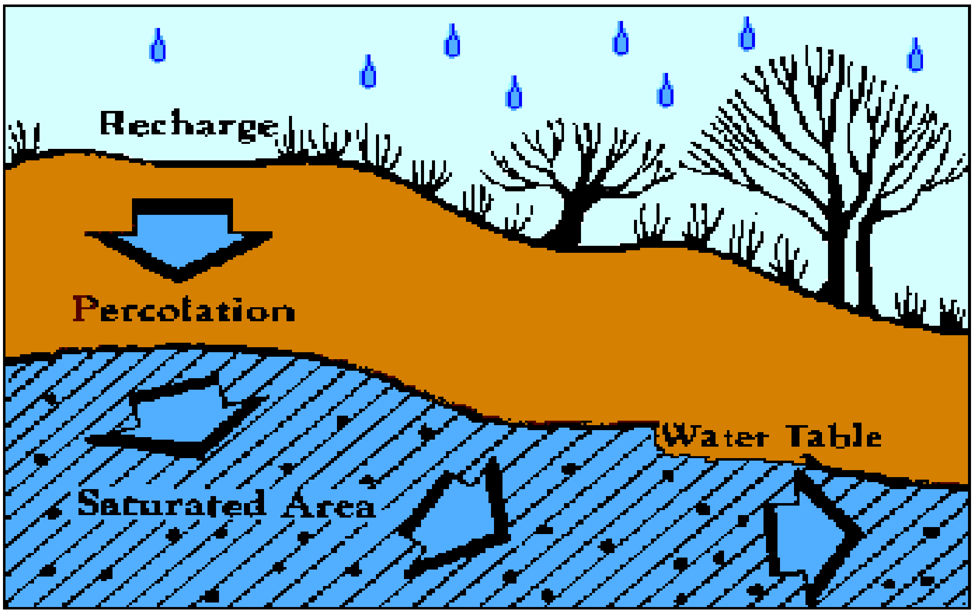


Figure 2-1: A simplified schematic representation of recharge (United States Geological Society- USGS, 2017).

Lerner *et al.* (1990) states that groundwater recharge may occur naturally from precipitation, rivers, canals, lakes and via man-induced phenomena such as irrigation and urbanisation. Groundwater recharge can be categorised into two types, namely: direct recharge and indirect recharge (Lerner *et al.*, 1990, Murray & Tredoux, 1998; Healy, 2010).

- **Direct Recharge:** This is the kind of recharge where water is added to the groundwater reservoir more than soil moisture deficits and evapotranspiration, by direct vertical percolation of precipitation through the unsaturated zone.
- **Indirect Recharge:** Is the type of recharge that results from percolation to the water table following runoff and localisation of joints, as ponding in low-lying areas and lakes, or through the beds of surface watercourses.

Lerner *et al.* (1990) further lists the following as factors that can affect groundwater recharge:

- **Irrigation:** nature of irrigation scheduling, losses from canals and watercourses, application of fields, land precipitation and losses from fields.
- **Aquifer**: ability of the aquifer to accept water and variability of the aquifer condition with time.
- **Land surface:** topography, precipitation magnitude, intensity, duration, spatial distribution, runoff, ponding of water, cropping pattern and actual evapotranspiration.
- **Rivers:** rivers flowing into the study area, rivers leaving the study area, rivers gaining water from or losing water to the aquifer.
- **Soil zone:** nature of the soil, depth, hydraulic properties and vulnerability of the soil.
- **Unsaturated zone between soil and aquifer:** flow mechanism through unsaturated zone and zones with different hydraulic conductivities

Bredenkamp *et al.* (1995) also stated that recharge is governed by the complex balance between several components of the hydrologic cycle, each of which is a function of several controlling factors:

- **Rainfall:** intensity, frequency, variability and spatial distribution;
- **Evapotranspirative losses:** temperature, wind and humidity;
- **Discharge losses:** interflow, springs, base-flow, lateral flow and artificial discharge;
- **Catchment:** soil type, thickness, spatial distribution, topographical features and vegetation; and
- **Geology:** rock types, structural geology and igneous intrusions.

Lerner *et al.* (1990) continues, stating that, the actual frequency of recharge events and the transit time until recharge takes place are also important differences obviously influencing both the choice of method for recharge estimation and eventual resource management.

There is no single method that will produce good estimates of recharge in all cases (van Tonder & Xu, 2000). However, the Excel program "RECHARGE" developed by van Tonder and Xu (2000), includes most of the methods in Table 2-2 and helps to estimate recharge comparing the results of the different methods.

There are a couple of methods used to estimate groundwater recharge in South Africa. An overview of these methods is given in Table 2-2. The other method not included in the table below is what is referred to as a "qualified guess", where projections are used in cases of insufficient data or information. These estimates are based on the knowledge of the area and its specifics, mathematical theories, and readily available data, like the Vegter maps.

According to Xu and Beekman (2003), Chlorine Mass Balance (CMB), Cumulative Rainfall Departure (CRD), Extended model for Aquifer Recharge and moisture Transport through unsaturated Hardrock (EARTH), Water Table Fluctuation (WTF), Groundwater Modelling (GM) and Saturated Volume Fluctuation (SFV) are the methods that can be used with greater certainty in arid and semi-arid Southern Africa, these methods have commonality in that they estimate recharge based on linking specific information from the atmosphere, and from the unsaturated and saturated zones.

Two of these methods will be discussed as they will be used for the purpose of this study; the methods are CMB and Qualified Guess.

Table 2-2: Recharge estimation methods applied in semi-arid Southern Africa (Xu & Beekman, 2003).

Zone	Approach	Method	Principle
Saturated-Unsaturated	Physical	CRD	Water level response from recharge proportional to cumulative rainfall departure.
		EARTH	Lumped distributed model simulating water level fluctuations by coupling climatic, soil moisture and groundwater level data.
		WTF	Water level response proportional to recharge/discharge.
	Tracer	CMB	Amount of Cl into the system balanced by amount of Cl out of the system for negligible surface runoff/run-on.
Saturated	Physical	GM	Recharge inversely derived from numerical modelling groundwater flow and calibrating on hydraulic heads/groundwater ages.
		SVF	Water balance over time based on average groundwater levels from monitoring boreholes.
		EV-SF	Water balance at catchment scale.
	Tracer	GD	Age gradient derived from tracers, inversely proportional to recharge; Recharge unconfined aquifer based on vertical age gradient (^{3}H, CFCs, ^{3}H/^{3}He); Recharge confined aquifer based on horizontal age gradient (^{14}C).
CRD: Cumulative Rainfall Departure. **EARTH**: Extended model for Aquifer and moisture Transport through Unsaturated Hardrock. **WTF**: Water Table Fluctuation. **CMB**: Chloride Mass Balance. **GM**: Groundwater Modelling. **SVF**: Saturated Volume Fluctuation. **EV-SF**: Equal Volume-Spring Flow **GD**: Groundwater Dating.			

2.4.2.1 Chlorine mass balance (CMB)

This method assumes the conservation of mass between the input of atmospheric chloride and the chloride flux in the subsurface (Xu & Beekman, 2003). Application of this method assumes that the increase in chloride concentrations is from evapotranspiration losses and that no additional chloride is added by contamination from or leaching of rocks or from the overburden (Woodford & Chevallier, 2002). Van Tonder and Xu (2000) make the following assumptions:

- Chloride is conservative in the system;
- Steady-state conditions are maintained with respect to long-term precipitation and chloride concentrations in the precipitation; and
- In the unsaturated zone a piston flow regime, which is defined as a downward vertical diffuse flow of soil moisture, is assumed.

However, this last assumption may be invalidated if the flow is along preferred pathways. Equation 2-1 by Eriksson and Khunakasem (1969) can be used to calculate groundwater recharge using CMB.

$$\boldsymbol{R} = \boldsymbol{P}\frac{\mathbf{Cl}\boldsymbol{rain}}{\mathbf{Cl}\boldsymbol{groundwater}}$$

Equation 2-1

Where R (mm/a) is groundwater recharge, P is Precipitation (mm/a), Cl_{rain} (mg/l) is the concentration of Chloride in rainwater and $Cl_{groundwater}$ (mg/l) is the concentration of chloride in groundwater.

However, there are limitations to this method, as stated by Xu and Beekman (2003):

- This method should not be applied in areas underlain by evaporates or areas where up-coning or mixing of saline (ground) waters occurs.
- This method should be applied with great caution in areas close to the sea where rainfall chloride contents are highly variable.
- For fractured rock systems, its applicability is complicated if: a) additional chloride is produced through weathering of rock matrix; and b) when time is needed to develop a new equilibrium between groundwater chloride concentrations in the rock matrix and fractures.

2.4.2.2 Qualified guess method

This method is based on the interpretation of the knowledge about an area under study, with mathematical theories and information already available for the area of interest. The following methods can be used as a part of determining groundwater recharge by means of qualified guess:

- Vegter Maps (Vegter, 2001);
- Harvest Potential Map (Baron *et al.,* 1998);
- ACRU (Schulze, 1995);
- Soil and vegetation information;
- Geology and soil cover and slop information; and
- Expert’s opinion.

For the purpose of this study only three methods were used namely Vegter Maps (Vegter, 2001) for mean annual groundwater recharge, Harvest Potential Maps (Baron *et al.,* 1998) and ACRU Maps (Schulze, 1995).

Vegter maps according to Vegter (1995) are as a result of a programme of hydrogeological mapping which was embarked on in 1993 as a means of providing a quick overview of groundwater information and which was published in 1995 (Vegter, 2001). These maps include the following information:

- Prospects of the boreholes;
- Saturated interstices;
- Depth to groundwater level;
- Groundwater component of the river flow;
- Groundwater quality; and
- Hydrochemical types.

The Groundwater Harvest Potential Map of the Republic of South Africa (Baron *et al.,* 1998) is a deviation of sets of maps "Groundwater Resources of the Republic of South Africa" published in 1995 (Vegter, 1995 and Vegter, 2001). The map quantifies groundwater resources. It permits direct comparison of different groundwater areas and facilitates comparison with surface resources. Harvest Potential is the sustainable volume of groundwater that may be abstracted per km² per annum.

ACRU maps (Schulze, 1995) determines the mean annual recharge based on the different soil profiles that groundwater penetrates and flows through to the vadose zone (Schulze & Pike, 2004).

2.4.3 Borehole Sustainable Yields

The Groundwater dictionary (DWA, 2011b) defines the sustainable yield or safe yield as the maximum rate of withdrawal that can be sustained by an aquifer without causing an unacceptable decline in the hydraulic head or deterioration in the water quality in the aquifer.

A manual by van Tonder *et al.* (2002), the FC programme; helps in determining the sustainable yields for boreholes which will not stress the aquifer. This manual, together with the guidelines and methods by Kruseman and De Ridder (1994) will be used in this study to help with the interpretation of pump test data, eventually determining the sustainable yields (Q), and other aquifer parameters such as transmissivity (T) and storativity (S) values through the use of Cooper-Jacob (1946), Theis (1935) and other theoretical equations.

The following assumptions based on Cooper-Jacob (1946) are made when interpreting pump test data:

- The aquifer is confined;
- The aquifer has an infinite areal extent;
- The aquifer is homogeneous, isotropic and uniform in thickness;

- After pumping, the piezometric surface is horizontal or almost horizontal over the area;
- The aquifer is pumped at a constant discharge rate;
- The well penetrates the entire aquifer thickness, with water being pumped influenced by the horizontal flow;
- Water being removed from the storage is discharged instantaneously with a drop in the water level; and
- The diameter of the well is small; therefore, storage in the well can be ignored.

In confined aquifers both steady-state flow and unsteady state-flow methods are available for the evaluation of pump tests.

Van Tonder *et al*. (1999) explained a practical approach to estimating the long-term sustainable yield of a borehole from pumping tests, which includes the following important features:

- It is easy to apply;
- It is applicable to both porous and fractured-rock aquifers;
- Observation boreholes are not a necessity;
- Does not require a storativity value a priori;
- It incorporates the effects of well-losses;
- The rate of water level recovery is considered;
- The Late-T (Kirchner & Van Tonder, 1995) and Drawdown-to-Boundary Methods (Murray, 1996) are special cases of the FC-Method;
- It incorporates various characteristic flow regimes; and
- The influence of other production boreholes on the estimated sustainable yield is also considered.

The method was tested on more than thirty pumping-tests in fractured-rock formations in Southern Africa and the results look promising (Woodford & Chevallier, 2002).

2.4.4 Groundwater quality

Traditionally, groundwater has been the only source of water supply in most of South Africa’s rural areas, making up about 65% of the total supply (DWAF, 2000). So, the increasing levels of development, urbanisation, agriculture, mining and industrialisation pose a severe threat to the quality of the resource, because of both over abstraction and contamination.

With the study focusing on groundwater development for community use, it is important to assess the quality of water for human consumption, therefore areas vulnerable to pollution or already polluted areas will assist in the development of groundwater quality management plans. Drinking water quality standards from South African National Standards (SANS, 2011), the guidelines for South Africa (DWAF, 1996) and the World Health Organization (WHO) Guidelines for Drinking Water Quality (2011) will be used as a guideline for the assessment and the determination of the groundwater quality.

The guidelines by DWAF (1996) provide the limits of variables which should be accepted for domestic, industrial and agricultural water use. However, exceeding these limits doesn't necessarily imply that there will be health risks. The WHO (2011) Guidelines for Drinking Water Quality on the other hand, provides the limits of elements and adverse health effects associated with exceeding the limits. The WHO guidelines were aimed at providing recommendations for managing the risk from hazards that might compromise the safety of drinking water.

According to Aastrup and Axelsson, (1984) the chemical composition of groundwater depends on the natural quality of the aquifer, and to some extent, precipitation, recharge rate, meteorological characteristics, saline water and flow patterns that have an impact on the chemical composition of groundwater. Aastrup and Axelsson (1984) further identified factors that mostly determine the natural composition of groundwater as:

- The reaction velocity between water and minerals in the sediment or the rock;
- Residence time of water in the aquifer; and
- Minerals as well as water contact areas.

2.4.4.1 Chemical data analysis and interpretation

There are different methods and diagrams used for the analysis and interpretation for chemical data; these include the Piper diagram, the Durov and the Expanded Durov diagrams, the Sodium Adsorption Ratio (SAR) and the Schoeller diagram (Hem, 1985; Suk & Lee, 1999). Their use will be discussed briefly below. Although three methods will be discussed, only two will be used for the purpose of this study namely; the Piper diagram, and the SAR.

2.4.4.1.1 The Piper and Durov diagrams

The Piper diagram (Piper, 1944), is a trilinear diagram most useful in sorting and filtering chemical data in groups. Hem (1985) further explains that the diagram plots the milliequivalent percentages of cations and anions as a single point on the left and right triangles. Water samples shown on the Piper diagram can be grouped in hydrochemical facies. The cation and anion triangles can be separated in regions, based on the dominant cation(s) or anion(s) and their combination creates regions in the diamond shaped part of the diagram (Piper, 1944; Back & Hanshaw, 1965; Hem, 1970 & Hem, 1985). Refer to Figure 2-2 for a simplified Piper diagram.

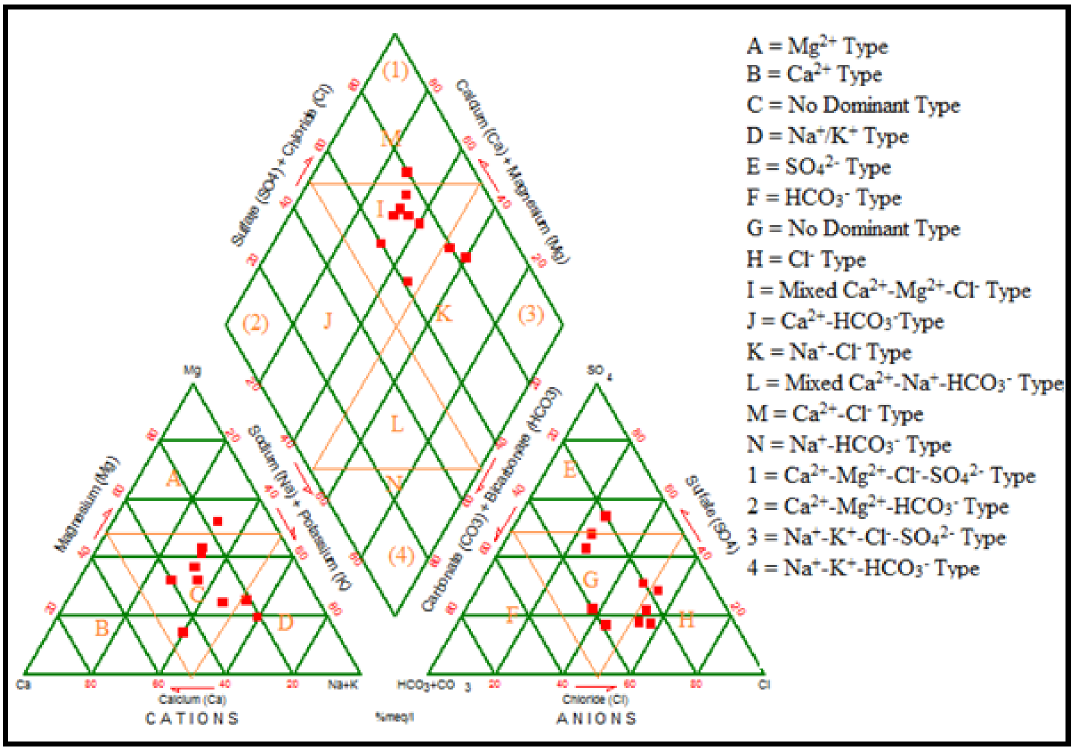
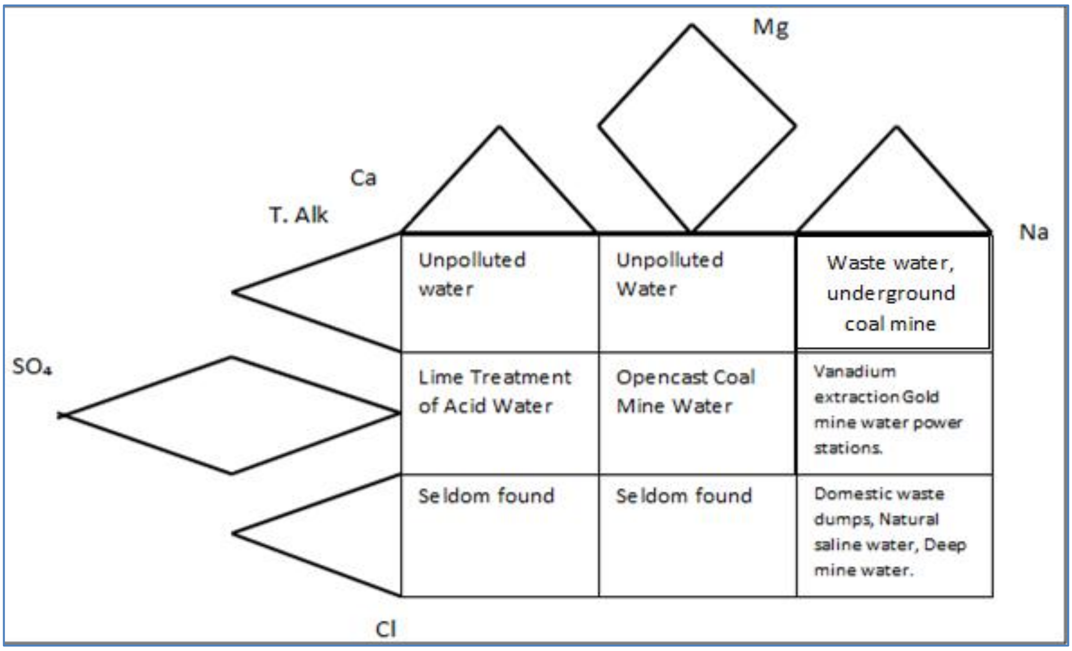


Figure 2-2: A typical sketch of a Piper Diagram and how it is interpreted (Back & Hanshaw, 1965).

The Durov or Expanded Durov (Durov, 1948), plots chemical data on separate anion and cation triangles for analysis, similarly to the Piper diagram. The three corners for each triangle are separate from one another in an Expanded Durov. Water falling within those triangles is analysed and interpreted similarly to the Piper diagram; while the nine squares within the Expanded Durov give the characteristic of water type (Figure 2-3).



Unpolluted water	Unpolluted Water	Waste water, underground coal mine
Lime Treatment of Acid Water	Opencast Coal Mine Water	Vanadium extraction Gold mine water power stations.
Seldom found	Seldom found	Domestic waste dumps, Natural saline water, Deep mine water.

Figure 2-3: A typical Expanded Durov diagram showing different water types (reproduced from Lloyd & Heathcote, 1985).

2.4.4.1.2 The Sodium Adsorption Ratio (SAR)

The Sodium Adsorption Ratio (SAR) is an irrigation water quality parameter used in the management of sodium-affected soils. It is an indicator of the suitability of water for use in agricultural irrigation, as determined from the concentrations of the main alkaline and earth alkaline cations present in the water (Reeves *et al.*, 1954, Asadollahfardi *et al.*, 2013). It is also a standard diagnostic parameter for the sodicity hazard of a soil, as determined from analysis of pore water extracted from the soil.

The SAR diagram (Figure 2-4) plots water according to its classes, based on the sodium content. If groundwater falls within the medium SAR and lower (Class 2) it can be used in most cases without any special practices for salinity control (Khodopanah *et al.*, 2009). Consequently, water samples that fall in the high salinity hazard class (Class 3) may be detrimental to sensitive crops. If these samples were used for irrigation of crops, careful management practices would be required. The very high salinity water (Class 4) is not suitable for irrigation for crops, except for salt tolerant crops.

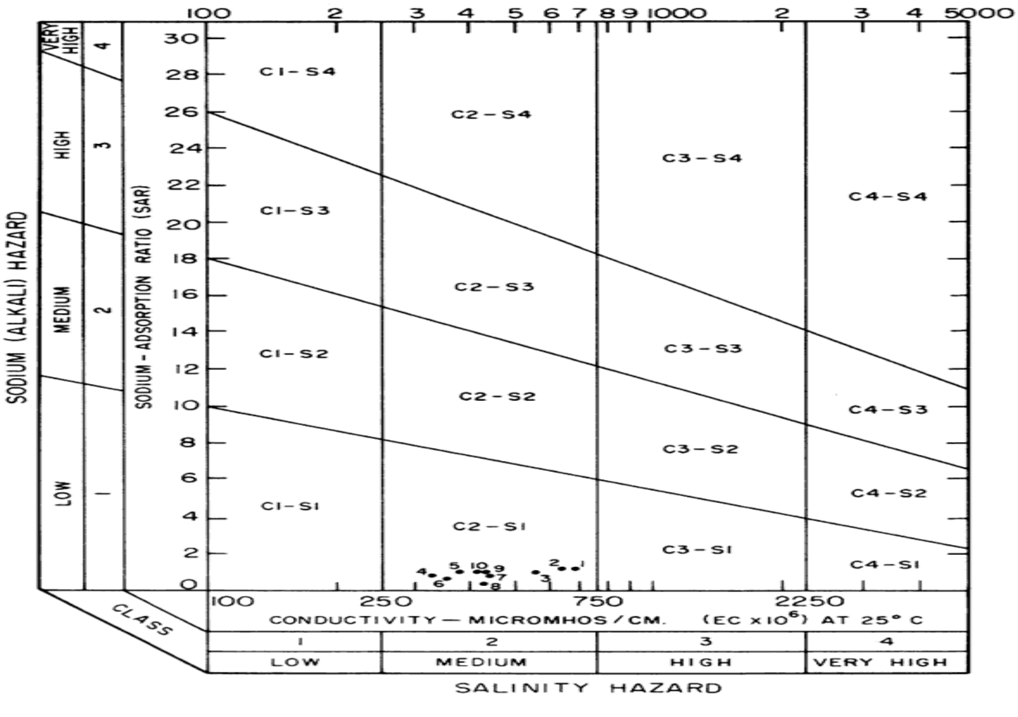


Figure 2-4: A typical plot for Sodium Adsorption Radio (Reeves *et al.*, 1954).

2.5 SUMMARY

This chapter gave a brief summary of water situation in the town of Jozini and further reviewed literature with regard to the basic concepts and methods in groundwater resource assessment. This was done by looking at previous studies which explained how these concepts and methods are used on site when conducting groundwater resource assessment and how such studies should be conducted.

Geophysical investigation methods and drilling methods were discussed, looking at how different studies used such methods to achieve their desired results. Furthermore, basic concepts and methods regarding groundwater quality assessment, aquifer parameters and sustainable yields were looked into.

The following chapter will describe the study area, looking into the climate, geology and hydrogeology.

CHAPTER 3: SITE DESCRIPTION

3.1 INTRODUCTION

This chapter will give a description of the study area; focusing mainly on the climate, geology and the hydrogeology of the area. Data from the South African Weather Services (SAWS), geological maps and hydrogeological information was used to better give an understanding of the study area.

3.2 STUDY AREA LOCATION

Jozini is a settlement in the uMkhanyakude District Municipality in the KwaZulu-Natal province of South Africa. It is a small town on the main route to Mozambique, and it is close to the Pongolapoort Dam also known as Lake Jozini; an area of 3442 km^{2,} with an estimated population of 186 502 people (SSA, 2011).

Jozini is located in the catchment of the Pongola River, which is a major river in the Usutu to Mhlathuze Water Management Area (WMA), in the northern KwaZulu-Natal province, and which also occupies the south-eastern corner of the Mpumalanga province, west of Swaziland, (Figure 3-1). The WMA borders on Mozambique and Swaziland and shares two of the major rivers (Usutu and Pongola) with these countries (DWAF, 2004a) (Figure 3-2).

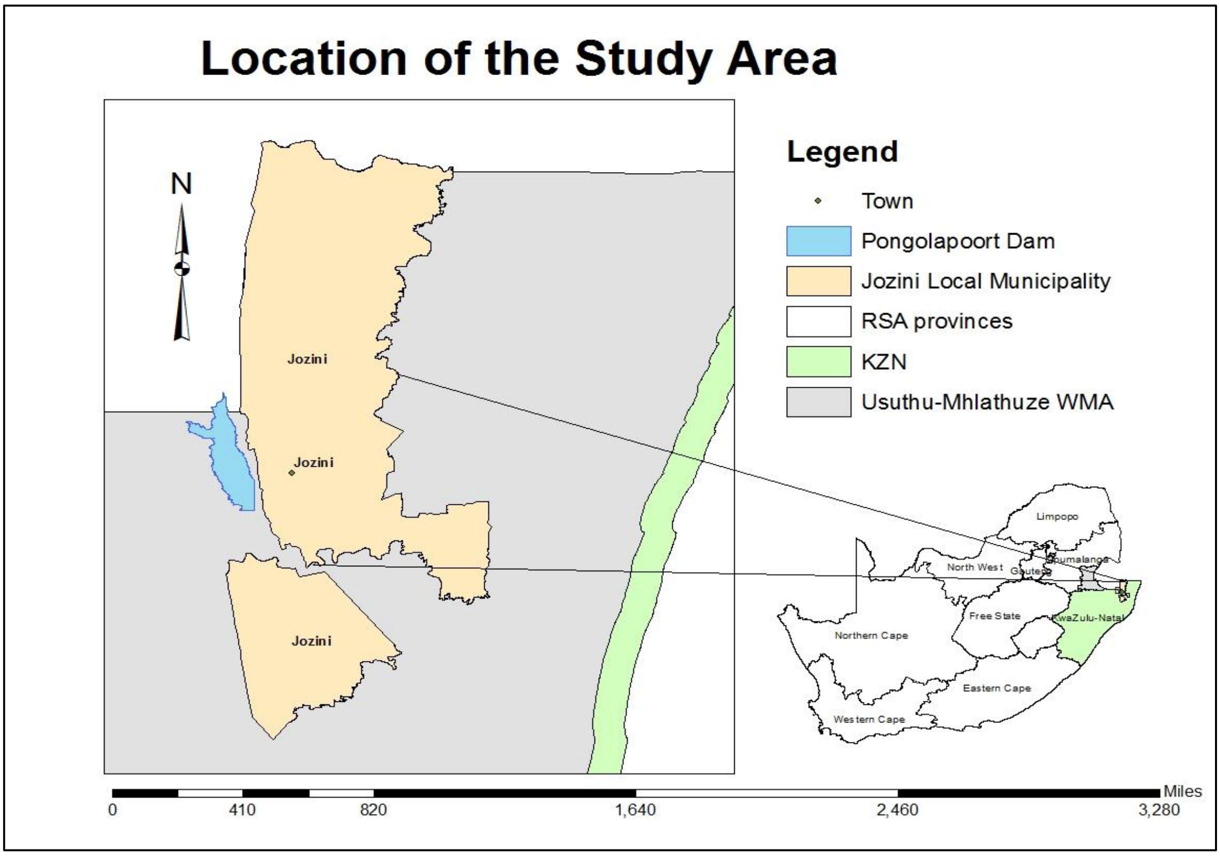


Figure 3-1: The locality map of the study area.

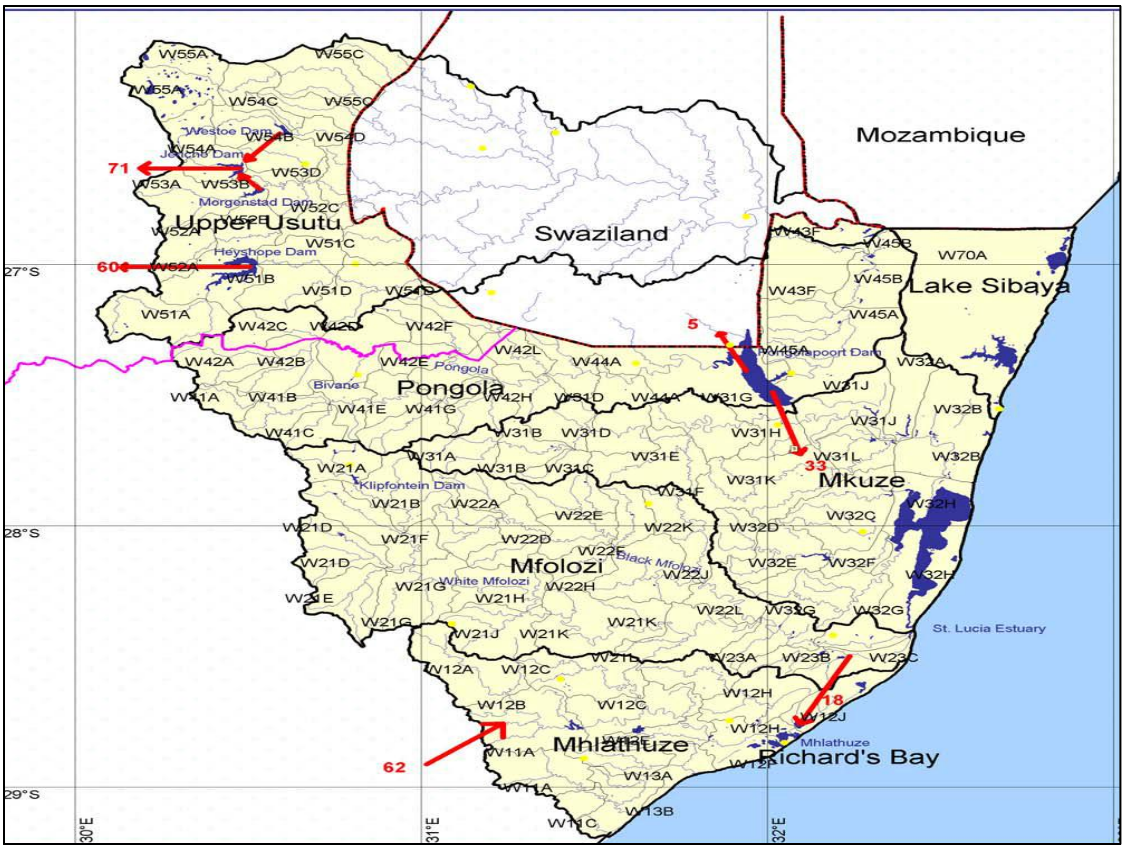
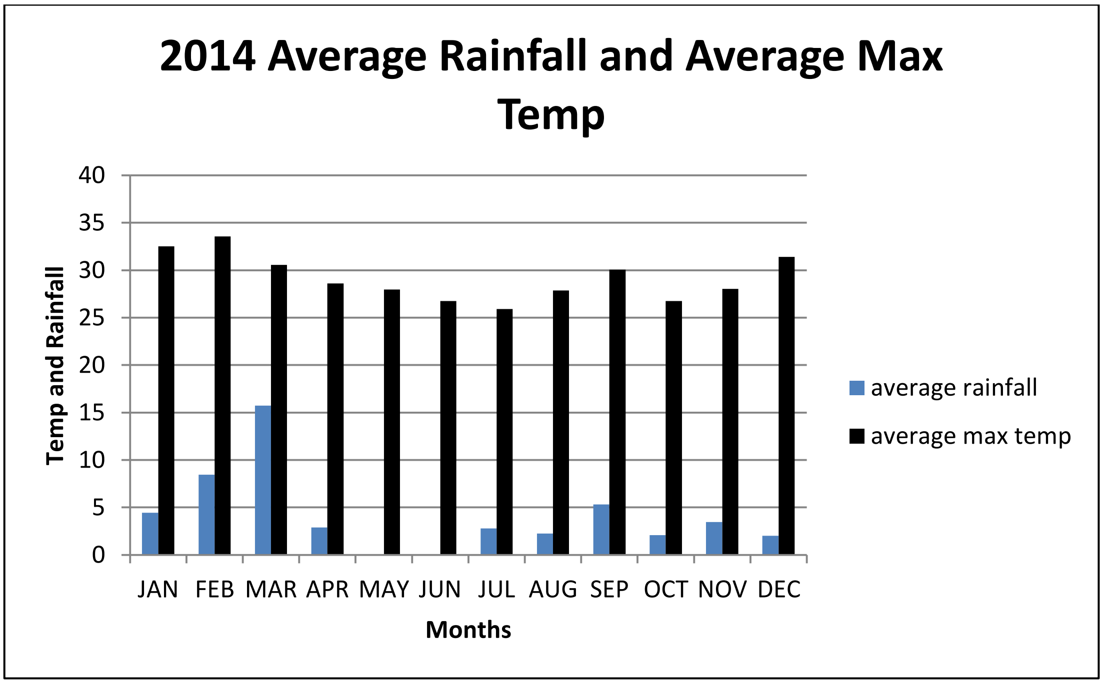


Figure 3-2: The Usutu to Mhlathuze Water Management Area, showing this WMA's sub-catchments (DWAF, 2004a).

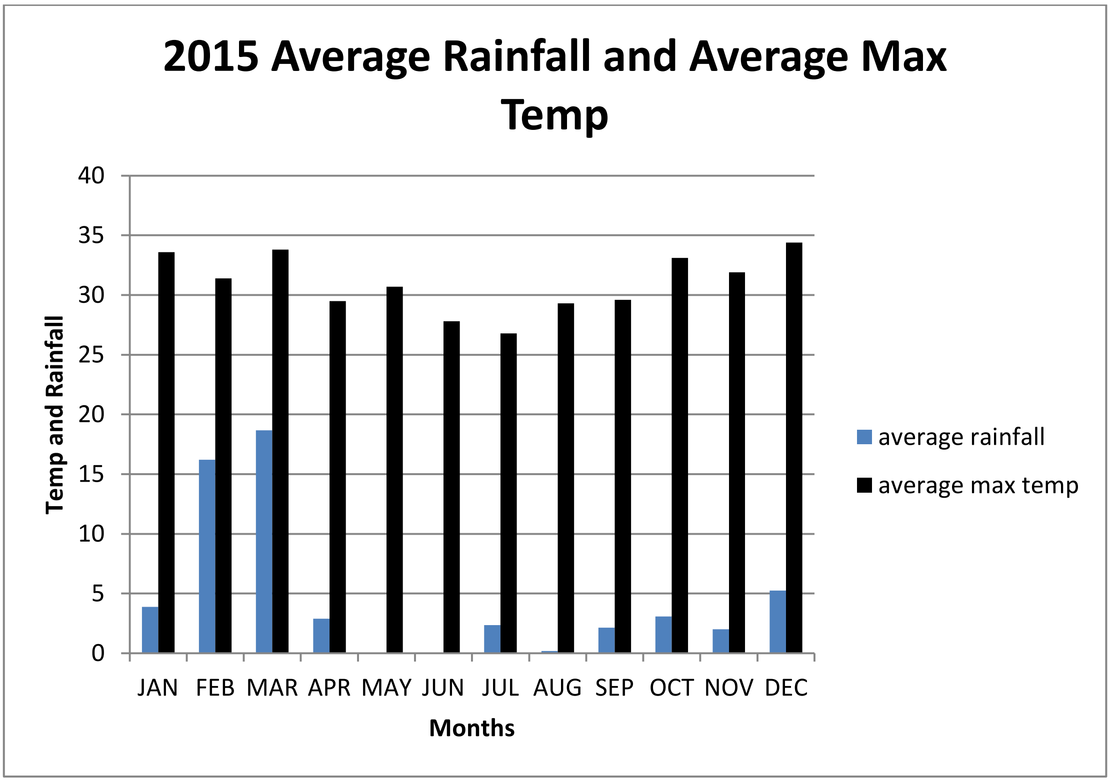
Raw water is sourced from the Pongolapoort Dam situated in the Pongola River, where it is thereafter treated at Jozini-Malobeni Water Treatment Works (WTW). The study area is rural and is characterised by commercial and subsistence dry-land agriculture. The main forms of commercial agriculture are sugarcane and timber, with cotton, sisal and pineapples (DWA, 2010).

3.2.1 Climate

According to data provided by the South African Weather Services (SAWS) for 2014 and 2015, Jozini normally receives on average about 498 mm of rainfall per year; most of the rainfall occurs in mid-summer to the beginning of autumn (Graph 3-1 and Graph 3-2). On average the month of March receives the highest rainfall. The months of May and June hardly see precipitation, while there's little rain between July and December.

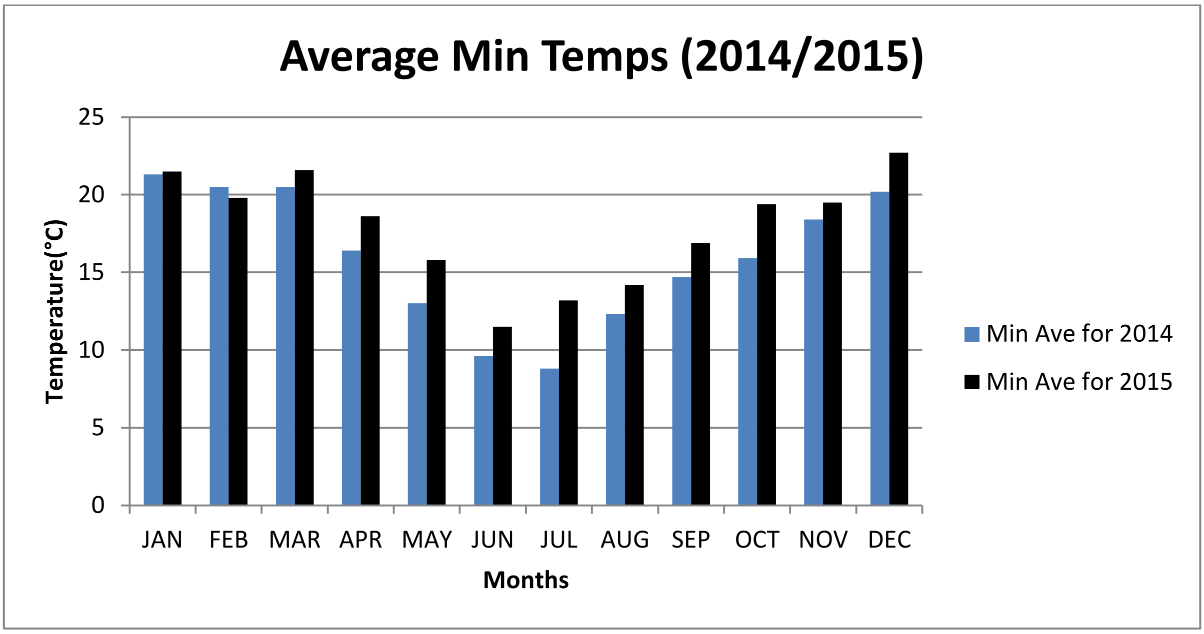


Graph 3-1: Comparison of maximum average temperatures with average rainfall for the year 2014.



Graph 3-2: Comparison of average temperatures and average rainfall for the year 2015

The monthly distribution of average daily maximum temperatures shows that the Jozini area had midday temperatures ranging from 25.91°C in July to 33.56°C in February for 2014 (Graph 3-3). The months of June and July are the coldest in the area, as the temperatures can drop to 9.6°C and 8.8°C, respectively. The same can be observed for 2015, even though the nights were a bit warmer as compared with the year before.



Graph 3-3: Average of maximum monthly temperatures for 2014 and 2015.

3.2.2 Geology

Jozini area is underlain mostly by the rocks of the Lebombo Group (Figure 3-3). The Lebombo Group is the uppermost of the Karoo Supergroup (Botha & Singh, 2012). The easternmost outcrops of the Karoo Supergroup in South Africa occur as a relatively narrow monoclonal belt, dipping to the east or southeast along the eastern margin of South Africa (Johnson *et al.*, 2006). These exposures are known as the Durban-Lebombo Belt, extending from the south west of Durban in a north-easterly direction north of Empangeni, from where they trend northwards along the western flank of the Ubombo and Lebombo Mountains.

The Lebombo Group consists of the Letaba and Jozini Formations and temporarily also the Mpilo formations. The Letaba Formation overlies the Clarens formation with a minor disconformity, representing a buried, arid land surface; and dips to the south-east, east and north-east at angles varying from eight to 45˚. It is built up of a massive pile of basalts, characterised by the absence of pillow lavas. There is an elongated body of acid lava in the upper part of the Letaba Formation, west of the Bumbeni Complex, comprising a number of rhyolitic lava flows (Wolmarans & Du Preez, 1986). Overlying the Letaba Formation are the rhyolites of the Jozini Formation; however, the lavas of this formation are in fact rhyodacitic to rhyolitic in composition. Thin layers and lenses of amygdaloidal rhyolite with amygdales either partly or completely filled with quartz and rhyolitic glasses, are found at places in these lavas (Wolmarans & Du Preez, 1986; van Wyk, 1963).

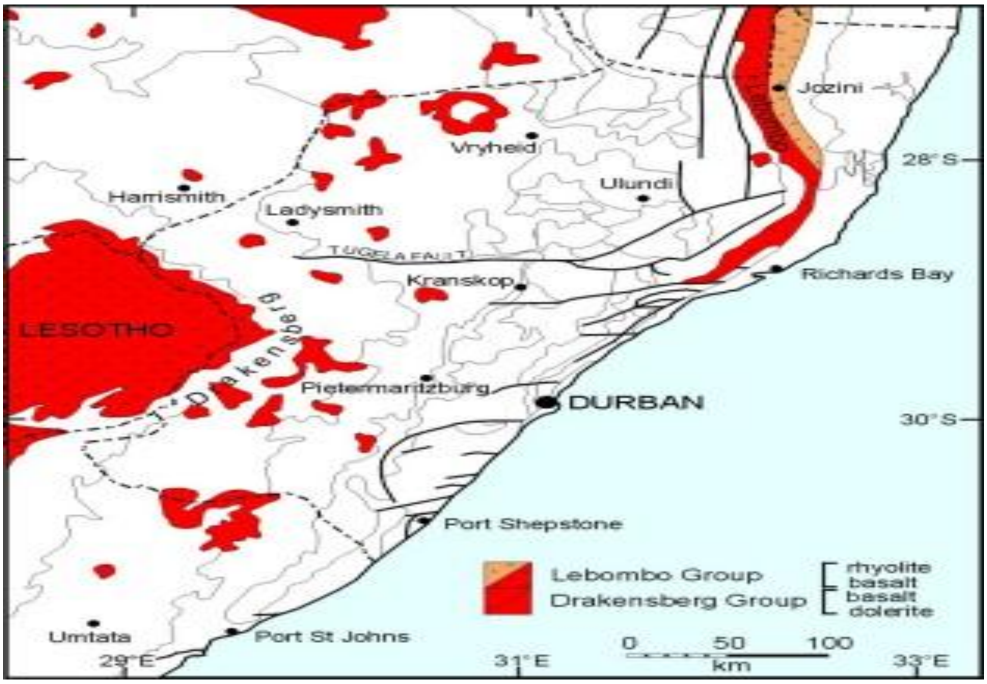


Figure 3-3: The geological map of Karoo Supergroup, showing Drakensburg group as well as Lebombo group (Botha & Singh, 2012).

3.2.3 Hydrogeology

In a Water Research Commission study on the fundamental groundwater concept of interstice the open spaces that form receptacle and conduits, Vegter (1990) subdivided the country into sixty-four hydrogeological regions, based on lithology and climatology. These regions are therefore referred to as Vegter-Regions. According to the KwaZulu-Natal groundwater Plan (DWAF, 2008a), at least five of these regions falls either wholly or largely within the KwaZulu-Natal Region and another four partially fall in this region. Table 3-1 below shows the Vegter-Regions within the study area.

The study discussed how these openings are formed due to a number of geological processes, distinguishing two types of openings, namely primary openings and secondary openings. Primary openings are formed during the deposition of sediment and solidification and recrystallization of igneous and metamorphic rocks. This is where primary aquifers are found. Vegter (1990) further states that these openings are viewed as of little or no importance in South African geohydrology.

Table 3-1: Lebombo Belt and Natal monocline Vegter Regions Vegter (1990).

Regions	Sub-regions	Geological strata
Lebombo Belt	Northern Lebombo	Karoo Sandstone, Mudstone, Shale, Clarens Sandstone, Siltstone, Basalt, Rhyolite.
	Southern Lebombo	Complete Karoo strata. Hlabisa outcrop of Natal Group Sandstone and Basement rocks.
Natal Monocline	Northern monocline	Pre-Cambrian rocks overlain by Natal Group Sandstone, Arkose, Dwyka Tillite, Pietermaritzburg formation shale
	Tugela sub-region	
	Central and southern monocline	

Secondary openings are formed in the hard rock formations through tectonic deformation, weathering and unloading, by erosion and melting of the ice caps. Geological formations which yield water to boreholes through secondary openings are known as secondary aquifers. A larger part of South Africa is underlain by secondary aquifers (DWAF, 2004a). This, according to Vegter (1990), comprises about 90% of the country, being weathered and fractured hard rock formations, ranging from the earlier Pre-Cambrian to Jurassic in age and comprising sedimentary, metamorphic and extrusive igneous rocks.

3.2.3.1 Water bearing properties

The western or inland portion of the WMA in which the study area falls, comprises “hard rock” secondary porosity aquifers of the “weathered and fractured” and “fractured” class. Groundwater abstraction is usually done entirely by using 60 to 120 m deep rotary-percussion drilled hard rock boreholes in the secondary porosity aquifers that are present there. Springs and seepages, although their flows are very markedly seasonally affected, are extensively exploited as a domestic water supply source in rural residential and agricultural use (DWAF, 2004a).

The rhyolites of the Lebombo Group have a minimal primary water yielding porosity (Groundwater Development Services, 1994). The rhyolites of the Lebombo Group, in comparison to their basalt rock counterparts are more resistant to weathering; therefore, giving rise to hills and ridges with very little soil cover or weathered overburden. This makes it easy for abundant dolerite dykes and fractures and faults to the north-south or north-north-west to the south-south-east to be visible on satellite images. These geological structures form the majority of the secondary porosity of the rhyolite rocks.

These Lebombo rhyolites, according to Groundwater Development Services (1994) have an expected borehole yield ranging from marginal to good (>0 - >3 l/s). This is also supported by (DWAF, 2004a) stating that groundwater yields from “hard rock” boreholes in the WMA, are generally low in the range of 0.15 to 0.65 l/s; although higher yields in the order of 2.5 l/s and more can be found from boreholes located in hydrogeologically favourable situations. Table 3-2 below shows the borehole yields grouped in accordance with volumes that boreholes can yield.

Table 3-2: Classification of the borehole yields (Groundwater Development Services, 1994).

Group	Borehole Yield	Meaning
Group 1- High borehole yield	>3 l/s	Medium to large scheme supporting small town and/or small to medium scale irrigation schemes
Group 2- Moderate borehole yield	>0.5 l/s <= 3 l/s	For reticulation schemes for villages, clinics and schools
Group 3- Low borehole yield	>0.1 L/S <=0.5 l/s	Primary water supplying hand pump or wind pump for non-reticulated community and stock watering purposes.
Group 4- very low borehole yield	<0.1 l/s	Suitable for marginal supply for domestic and stock watering only.

3.3 SUMMARY

The study area is located in the semi-arid region. It receives an annual average rainfall of 414 mm. Understanding the climate of the study area is important because the climate influences water availability and quality. Jozini area is underlain mostly by the rocks of the Lebombo Group, which are the uppermost rocks of the Karoo Supergroup. Boreholes drilled in this area generally have low yields in the range of 0.15 to 0.65 l/s.

The following chapter will look into the desktop study. Different maps will be used to help in locating geological structures which could be targeted for drilling of groundwater resources, hydrocensus and acquiring of data from different databases from the Department of Water and Sanitation (DWS).

CHAPTER 4: DESKTOP STUDY

4.1 INTRODUCTION

In commencing with the study, previous reports pertaining to the study area were collected and reviewed, these included reports from within the Department of Water and Sanitation (DWS) - published and unpublished; as well as reports by private consultants.

A desktop data search resulted in sourcing of all accessible sources of information, including the satellite images from Google Earth, data from the National Groundwater Archive (NGA) and the Groundwater Resource Information Project (GRIP); with databases of the DWS being used to identify the existing boreholes, springs and other water sources near the study area.

The following reports were used for the understanding of the general and geohydrological characteristics of the area of study:

- A geohydrological investigation into the water supply to various areas for the Umkhanyakude District Municipality (EngeoLab Cc, 2016)
- The Umkhanyakude District Municipality, Jozini Local Municipality - Refurbishment of Hand pump application Boreholes (Jeffares and Green (Pty) Ltd., 2015)
- The KwaZulu-Natal Groundwater Characterisation and Mapping Program Report on the Groundwater Resources and Hydrogeology of Unit 3. Department of Water and Forestry (Groundwater Development Services, 1994).

The Department of Mineral and Energy Affairs (DMEA) has published a 1:250 000 geological map series of the region, including the study area, which falls within the Kosi Bay, St Lucia and Vryheid geological map series (DMEA, 1985a, 1985b and 1988).

The 1:500 000 hydrogeological series for Vryheid published by the DWAF (1998), has also been used to better understand the geohydrological characterisation of the study area.

4.2 REMOTE SENSING

Potential drilling zones were selected by identifying geological lineaments through remote sensing. This was done by using the geological map for the area, as well as aerial photographic interpretation for the specific areas under investigation. For this study, the geological maps (DMEA 1985a and 1985b) were used, but due to their poor resolution these maps were only used during desktop study and they are not included in this report, however, a simplified map produced through ArcGIS is used to show the geological structures that could be targeted (Figure 4-1). A hydrogeological map (Figure 4-2), was also used to identify the possible water bearing features, structures and lineaments in the study area.

The use of remote sensing has been widely used in South Africa for groundwater investigations (Woodford & Chevallier, 2002). Possible lineaments; geological structures along the designated area were identified and targeted for subsequent field investigation, using geophysical methods. The identification of the dolerite structures is of paramount importance in groundwater exploration; especially in Karoo sediments (Woodford & Chevallier, 2002). From a hydrogeological map, faults were identified, as shown on Figure 4-2. Vegter (1995) further stated that the contact between dolerite structures and the host rocks within the weathered zone is important, as it is the target for exploration of groundwater.

According to the Groundwater Development Services (1994), the rhyolites of the Lebombo Group in comparison to their basalt rock counterparts, are more resistant to weathering; therefore giving rise to hills and ridges with very little soil cover or weathered overburden, therefore making it easier for dolerite dykes and fractures or faults to be easily identified.

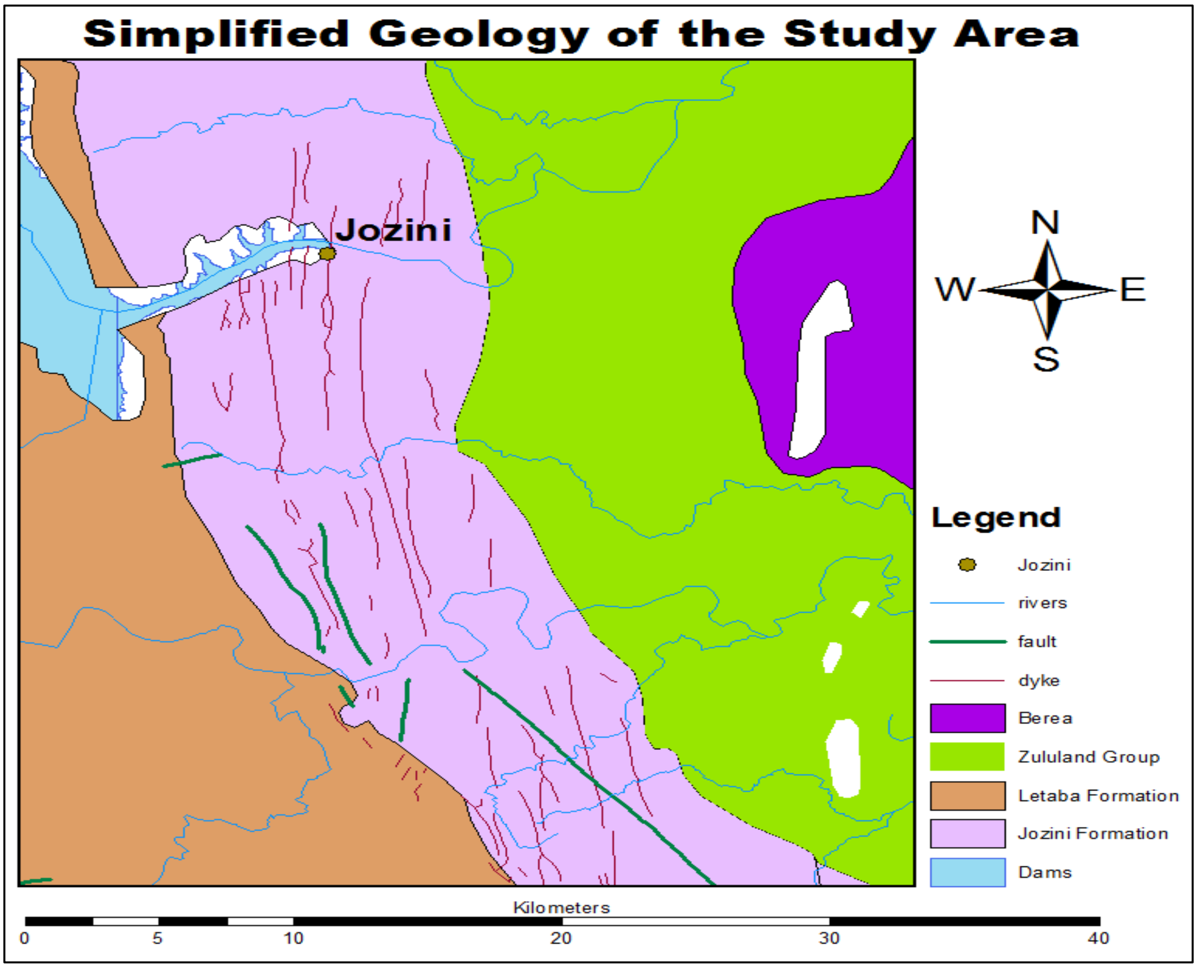


Figure 4-1: A simplified geological map of the study area, with structures that could be targeted for drilling.

Some of these dykes could be identified visually on site, while others (dykes and faults) could only be identified using maps and geophysical methods. These geological structures form most of the secondary porosity of the rhyolite rocks. Secondary porosity develops, because of fracturing, faulting or dissolution, representing the path the water molecule can follow in the subsurface.

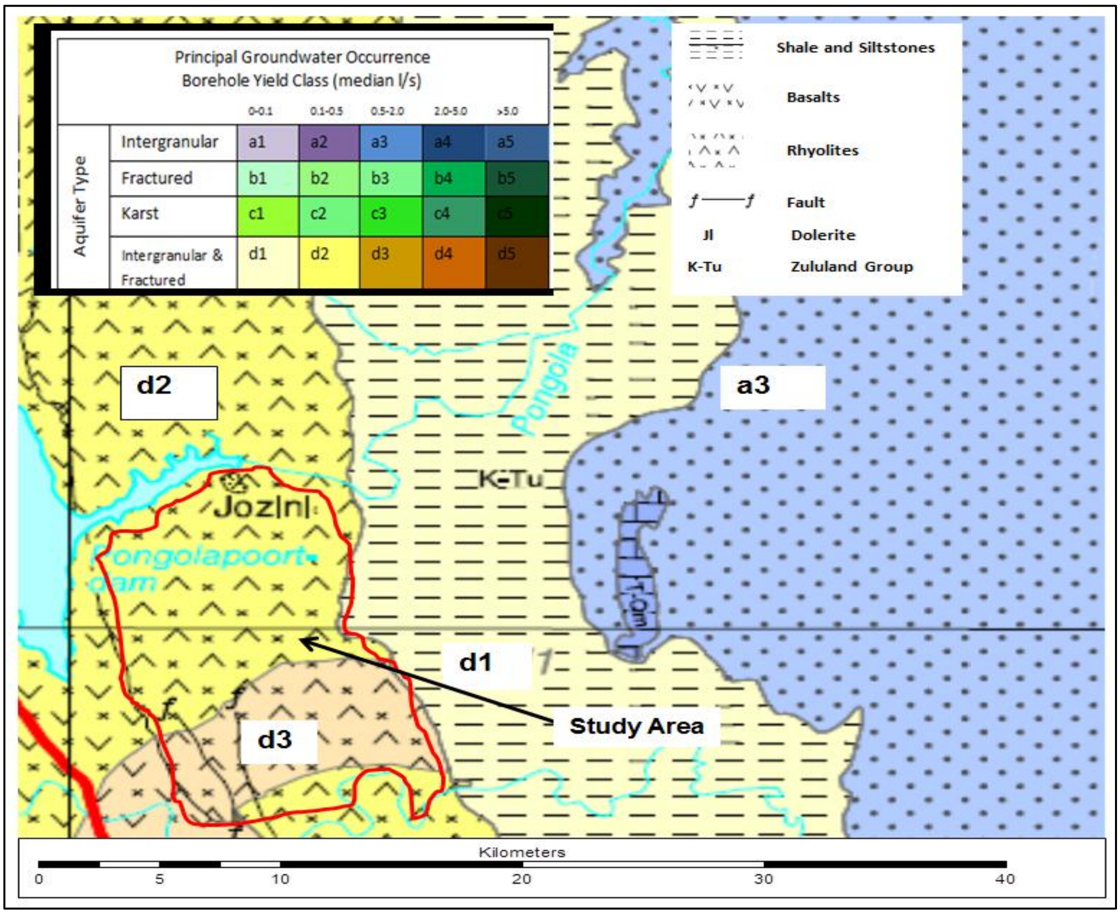


Figure 4-2: The portion of the hydrogeological map of Vryheid (2730) with reference to the study area (DWAF, 1998).

4.3 HYDROCENSUS

The Department of Water and Sanitation’s National Groundwater Archive (NGA) and Groundwater Resource Information Project (GRIP) data was used to source boreholes within the study area and find out their status.

After this task was completed then a hydrocensus was undertaken to locate those boreholes found from NGA and GRIP. This was also to determine the state which these boreholes are in and to assess whether these existing boreholes can still be used in their current state for water supply or whether they will need to be refurbished before being used.

During the search it was found that there are six boreholes registered on the NGA and five as part of the GRIP data (Figure 4-3). However, basic information like depth of the boreholes, water strikes, static water levels and the intended use of the boreholes is not recorded on these databases. This made it difficult to deduce from the desktop study whether these boreholes are in a good state and whether they could be incorporated into the boreholes to be used by the community.

This led to a field hydrocensus with the aim of verifying the sites identified through NGA and GRIP. Interestingly, during field hydrocensus a total of thirty seven boreholes were found in the vicinity of the study area (Figure 4-3). Most of these do not correlate in any way with either the NGA or the GRIP. However, the format of numbering those boreholes is in line with the numbering methodology set out by the Department.

Most boreholes which were visited during hydrocensus were equipped with hand pumps; thereby making it difficult to record water levels. Resources which were able to be confirmed within one hundred metres (100 m) of the desktop datasets were deemed a positive match. Hydrocensus results are given in Appendix A.

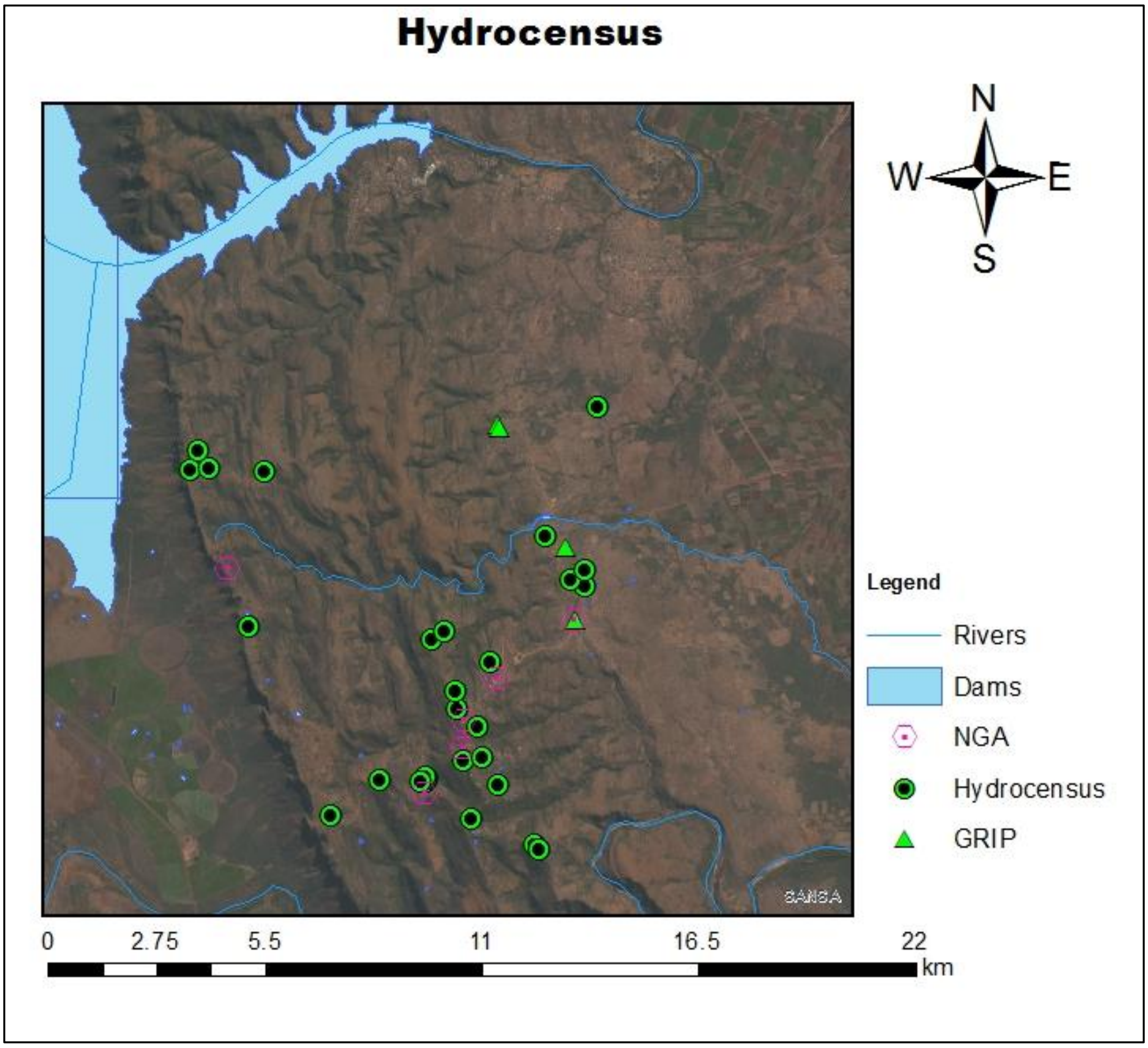


Figure 4-3: The boreholes as identified during hydrocensus, most of which are neither on the NGA nor the GRIP data.

Four boreholes (UMK 2003, UMK 2017, UMK 2026 and UMK 2041) in Appendix A, were found to have been refurbished by an eternal consultant, Jeffares and Green (Pty) Ltd in 2015, while ten other boreholes are in good working condition, are fitted with hand pumps.

4.3.1 Drilling Targets

Promising localised geological structures associated with groundwater movement were identified, based on the knowledge of the area, as well as the usage of the remote sensing and geological maps of the study area, for potential drilling targets (Figure 4-4). The dolerite intrusions were identified as primary drilling targets. From the geological maps, the zones attributed to intrusion discontinuities such as fracturing and or faulting, were identified as targets for drilling. According to Woodford and Chevallier (2002), occurrence of groundwater in the Karoo is confined to fractured hard rock terrains and weathered zones. It is for these reasons that these structures (dolerite intrusions, faults, fractures and weathered zones) were targeted.

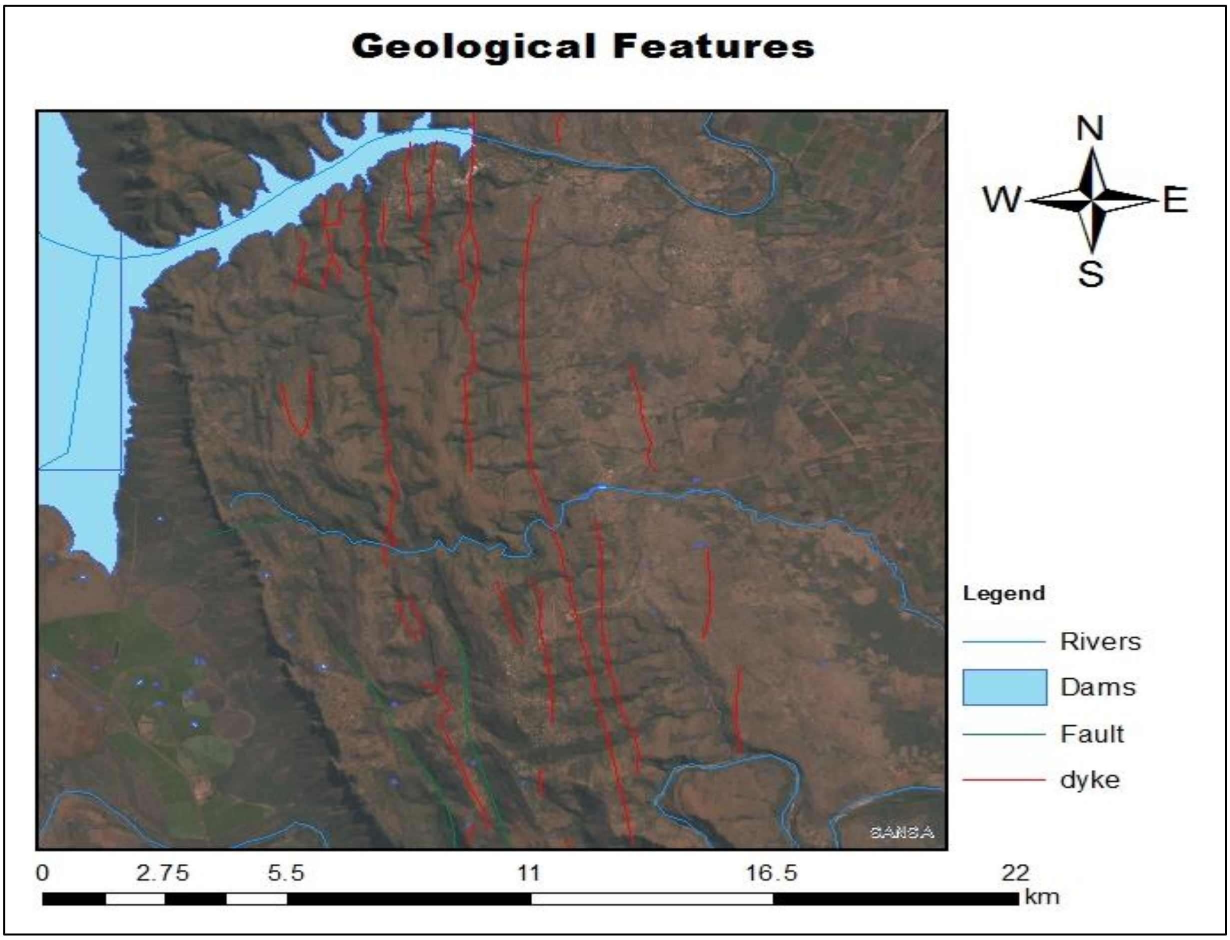


Figure 4-4: A map of the study area showing geological features which would be targeted for drilling of boreholes.

The geophysical investigations magnetic method (proton G5 magnetometer) and the electromagnetic method (EM34-3) are going to be used to investigate the potential localised anomalies or contact zones, these geophysical investigations will be discussed in the next chapter. The potential sources of groundwater will then be targeted by means of percussion drilling. Table 4-1 gives the information about the targeted sites.

Table 4-1: List of sites targeted for drilling based on the geological structures identified in the study area.

Drilling Target Site	Target ID	Latitude	Longitude	Elevation (m)	Target
Jozini	T01	-27.433	32.05963	277	Dyke
Machibini	T02	-27.443	32.04503	360	Dyke
Ophande	T03	-27.477	32.103	160	Dyke
Majozini	T04	-27.494	32.02281	520	Topography
Nkangala	T05	-27.526	32.02972	510	Topography
Mahangule	T06	-27.576	32.09644	565	Dyke
Madinyana	T07	-27.579	32.08391	540	Dyke

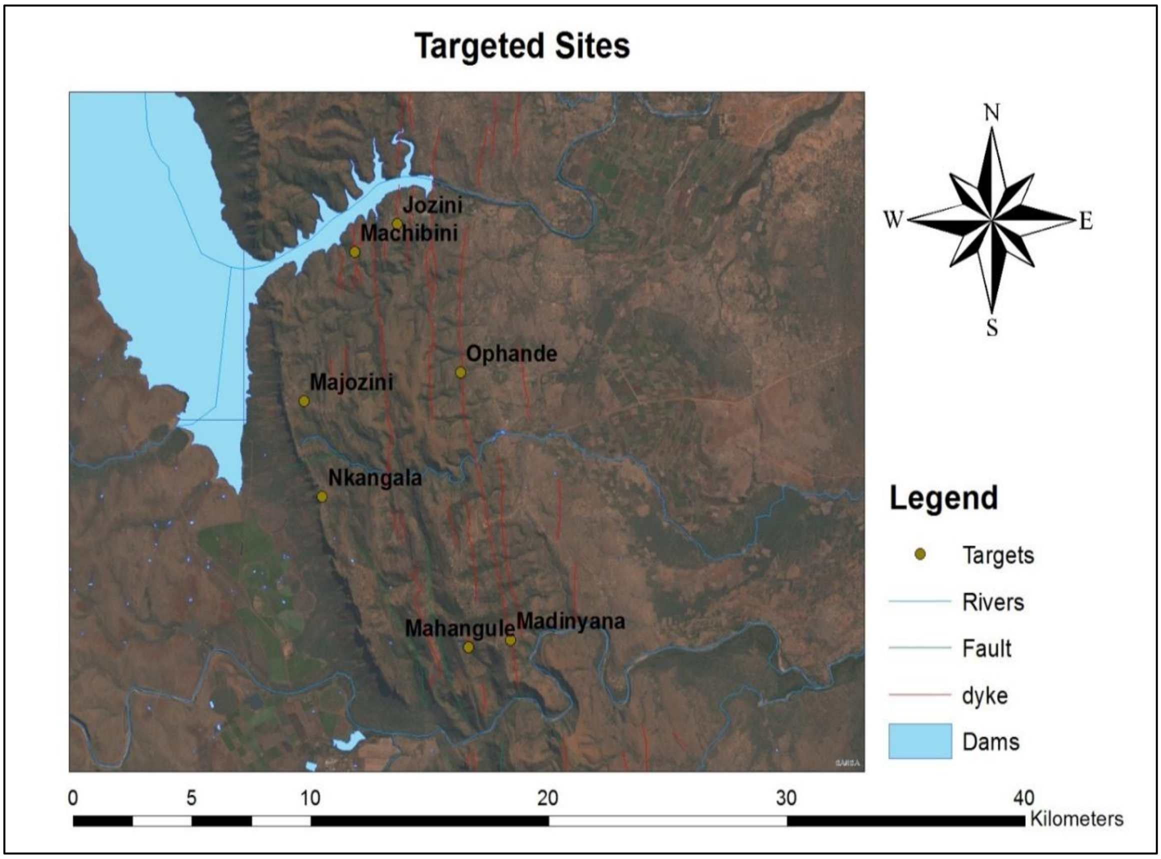


Figure 4-5: Sites targeted for drilling in relation to the identified geological structures targeted for drilling (map produced using Arc GIS).

Figure 4-5 above displays a location of each target from Table 4-1.These sites were identified, based on geological observations and the knowledge of the study area. The targeted sites are named after the area of the village where a borehole was to be drilled. Dolerite intrusions and faults were identified as the primary drilling target. Two boreholes

(Majozini and Nkangala) were sited, based on topography, with the knowledge of the area by the consultant assuming that groundwater follows topography. These targets can also be verified by using geophysical methods like magnetic survey and electromagnetic survey. The methods will be discussed in Chapter 5.

The targeted drilling sites are in areas where there are no boreholes in the closest vicinity, or where the available boreholes are damaged, and the community depends on water tankers from the municipality, since the drought started. These targeted boreholes will add to the already existing boreholes and four which were destroyed but were refurbished by a consulting company Jeffares and Green (Pty) Ltd.

4.4 SUMMARY

This chapter gives details regarding the desktop study, which included GIS, the hydrocensus taking into consideration data from DWS databases such as the NGA and the GRIP, and interpretation of maps. Some of the maps interpreted include hydrogeological maps and geological maps. Boreholes which were verified during the desktop study are plotted on the satellite images to show their locations in the study area and those which were identified during field hydrocensus are populated on the tables.

Furthermore, the information gathered was used to determine the preliminary targets for drilling, for example, dolerite intrusions that could be targeted during geophysical methods and subsequent drilling. Five sites were targeted on a dolerite intrusion and the other two were targeted, based on topography, using the consultant’s knowledge of the study area, assuming that groundwater follows topography. During hydrocensus it was found that four boreholes which had collapsed or were destroyed had been refurbished by external consultants Jeffares and Green (Pty) Ltd.

The next chapter will deal with the geophysical investigations that were undertaken, their analysis and interpretation of the methods used, namely; magnetic and electromagnetic methods.

CHAPTER 5: GEOPHYSICAL INVESTIGATIONS

5.1 INTRODUCTION

According to Mandel and Shiftan (1981) geophysical methods are used to measure natural or induced physical phenomena in the earth's crust and to interpret the results to obtain information on the subsurface. Once the information on the subsurface is known, then the potential drilling targets can be sited. For the purpose of this study, magnetic and electromagnetic methods will be used. This chapter will focus on the geophysical investigations along the geological features determined in chapter 4.

5.2 METHODS AND MATERIALS

There are various techniques used to locate favourable positions and targets for the exploitation of groundwater resources, with magnetic and electromagnetic being commonly and widely used mostly in Karoo rocks for exploration and drilling purposes (Woodford & Chevallier, 2002).

For the purpose of this study, magnetic, together with electromagnetic methods, were chosen as the preferred methods. The reason for the magnetic method is because it is easy to operate, analyse and interpret anomalies from a structure such as a dolerite intrusion, using Roux (1980) standard anomaly curves (Appendix B). The electromagnetic method, on the other hand, was chosen based on the fact that it determines the resistivity of the rock, and the resistivity of variations with depth and lateral extent of geological structures, whereupon these variations are then interpreted to identify the drilling targets (Mandel & Shiftan, 1981; Kirsch, 2006). EM allows for penetration through a very sensitive zone, where it is difficult to get penetration using galvanic or direct current techniques (Kaufman & Keller, 1993).

5.2.1 Magnetic methods

Magnetic methods are based on the observation of the anomalies in the magnetic field of the earth that are caused mainly by the different magnetic susceptibility of rocks (Mandel & Shiftan, 1981). The rocks, soils and structures (for example dykes, sills, and fault zones) which contain these minerals have strong magnetic properties, and hence act as magnetic features. Geophysical surveys were conducted using the G5 Proton magnetometer (Figure 5-1) in the project area, to locate and delineate any subsurface structures which were identified during the desktop study.

Figure 5-1: The G5 Proton Magnetometer on the left side and the field investigation using magnetometer on the right side.

Magnetometer surveys indicate that there are many unexpected variations in this model, called “magnetic anomalies”. A magnetic high anomaly is where the measured field strength is higher than the value predicted by the global model, and a magnetic low is where the measured field strength is lower than the value predicted by the global model (Kearey & Brooks, 1992; Mariita, 2007). This method involves the measurement of the earth’s magnetic field’s intensity. The anomalies in the earth’s magnetic field are caused by induced or remnant magnetism. Induced magnetic anomalies are the result of secondary magnetization induced in a ferrous body by the earth’s magnetic field (Mandel & Shiftan, 1981; Kirsch, 2006; Mariita, 2007). Its portability and simplicity does give this method an advantage in field use.

The aim of the magnetic survey is to investigate subsurface geology on the basis of the anomalies in the earth’s magnetic field which are caused by the magnetic properties of the underlying rocks. Generally, the magnetic susceptibility of the rock varies depending on the rock type. These variations could be caused by dykes and lava flows. In areas where rocks have high magnetic susceptibility, the local magnetic field will be strong and will show up as areas of high magnetic field strength, and where the rocks have low magnetic susceptibility, the local magnetic field will be weak (Kirsch, 2006; Mariita, 2007; Chandra 2016).

A station spacing of 5 m was used during the survey for all traverses. All traverse profiles are named based on the part of the community where a geophysical study is to be conducted (Figure 4-5). The aims of the profiles were to define the geological structures such as dykes, as well as geological contact zones in the area of study.

All data from magnetic investigation was plotted on line graphs using Microsoft Excel to produce the magnetic profile for each traverse. Thereafter, there was a removal of the regional magnetic anomalies, the determination of the true zero-line, the determination of the depth, and the centre and the thickness of the geological structures.

Smoothing of the magnetic data was performed to remove the regional magnetic anomalies, in order to determine the true zero line; the removed anomaly is known as the residual anomaly - a geologically significant problem specific anomaly in a particular study area (Hinze & von Frese, 1990; Chandra 2016). Removal of the regional field which, according to Roux (1980), is usually caused by the deep seated effects was done by obtaining the difference between the smoothed data and the field anomaly; by drawing the regional trend manually over the residual anomaly and subtracting the regional trend from the smoothed observed profile data.

Once the regional magnetic field has been removed, then the centre of the anomaly was determined, using a method used by Logochev (1961). This method uses the distance from the zero line, which is determined to the minimum of the trend line. A parallel line with the same distance as estimated from the zero line is then drawn from the middle of the anomaly to the minimum distance. A parallel line to the zero line is then drawn where it intercepts the curve. That point where the curve is intercepted represents the centre of the dyke of the geological structure as shown in Figure 5-2.

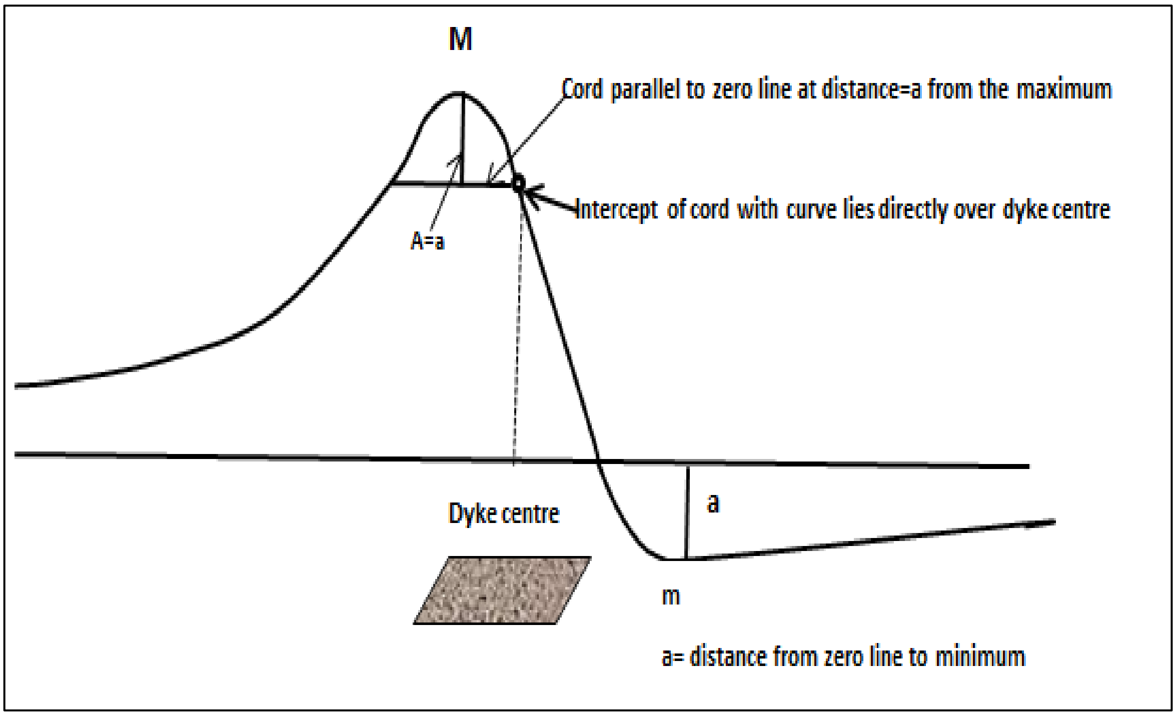


Figure 5-2: A schematic representation of how the centre of the dyke is determined, M is the maximum value and m represents the minimum value (Logochev, 1961).

The other important factor to determine is the depth of these geological structures (dykes). In determining these depths, the Horizontal Slope Distance (HDS) method as described by Roux (1980) was used. This method uses the horizontal distance between the points where the curve deviates the maximum slope of the anomaly (Figure 5-3).

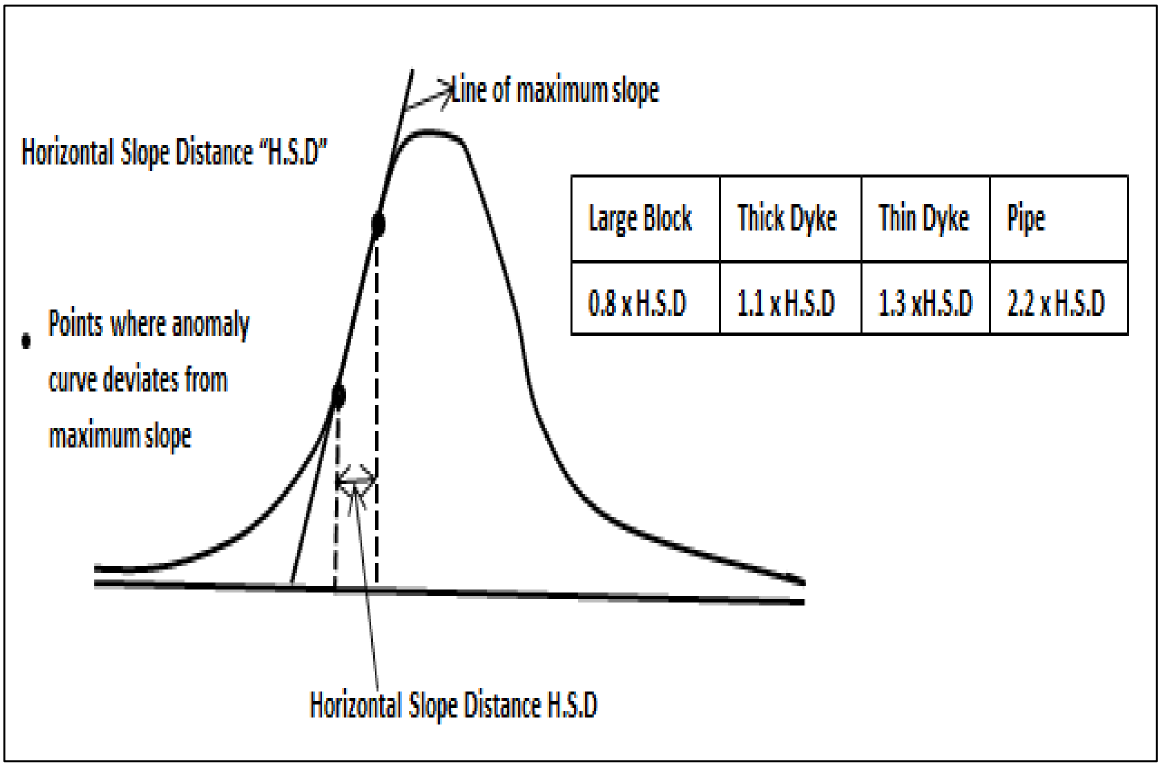


Figure 5-3: Determining the depth of the dyke with Horizontal Slope Distance HSD (Roux, 1980).

The calculations for the determination of the centre and the depth of the geological structures analysed and discussed in this chapter are shown in Appendix C. These parameters assist with determining the contact between the host rock and the intrusion, which could be targeted for drilling (Roux, 1980).

5.2.2 Electromagnetic methods

For the purpose of this study, the Geonics EM 34-3 system (Figure 5-4), was used for the interpretation of anomalies recorded across the dolerite in the study area, these structures are often considered as targets during groundwater exploration in Karoo rocks (Woodford & Chevallier, 2002). The Geonics EM34-3 system is a two-person, portable, frequency domain electromagnetic instrument, which measures the in situ electrical conductivity of the subsurface, using a pair of wire coils (transmitter and receiver coils). The coils are connected with a reference cable of fixed lengths, (10 m, 20 m, and 40 m) to provide variable depths of exploration, down to a claimed maximum depth of 60 m (McNeill, 1983; Murray, 2012). For this study coil separations of 20 m and 40 m were used.

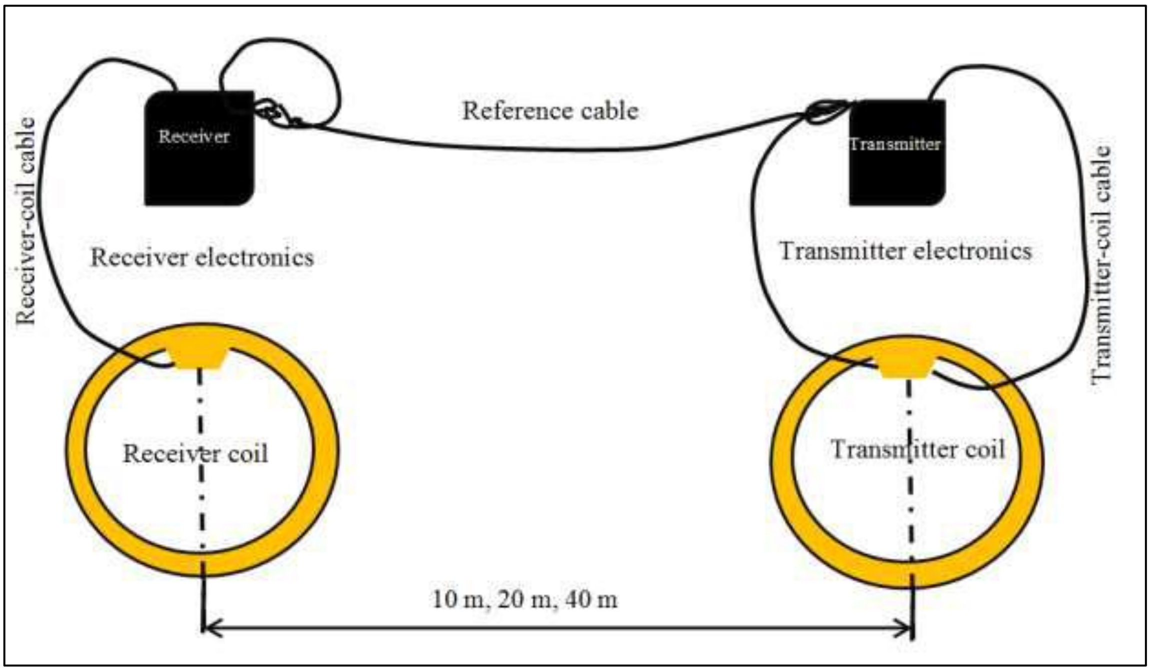


Figure 5-4: Geonics EM 34-3 system (Makhokha, 2016).

This geophysical method was chosen due to its advantage of providing four conductivity measurements at each survey point, using two coil separations (20 m and 40 m) for both Vertical Dipole (VD) and Horizontal Dipole (HD). The other reason for choosing this method was the fact that it does not require physical contact with the ground and it is suitable for the detection of fractures, conductive body and weathered zones.

The same traverse lines which were used for the magnetic methods were also used for electromagnetic method investigations. This was to allow for ease comparison from the results obtained from both methods. The surveys were done using both vertical dipole (VD) and horizontal dipole (HD), with a coil separation of 20 m and 40 m. These dipole orientations give a significantly different response with depth and in the presence of lateral changes in the conductivity of the subsurface (van Zijl & Kostlin, 1985). When the coils are aligned in a plane parallel to the earth's surface, with the axes of the coils vertical, the orientation is referred to as VD, while the HD is when the coils are aligned in a plane perpendicular to the earth's surface, with the axes of the coils horizontal.

Coil separations of 20 m and 40 m were used. Using different coil separations helps in the greater depth of investigation. Coil separation of 40m investigates to depths approximately two times greater than 10m coil separation.

The expected depths of investigation as provided by the manufacturer of the system (Geonics (Pty) Ltd.) for different coil-separation, source frequency and loop orientations when using EM34-3 are given on Table 5-1 (McNeill, 1983).

Table 5-1: Expected exploration depths of various intercoil separations and fixed operating frequencies (McNeill, 1983).

Inter-coil separation (m)	EM Wave Frequency (Hz)	Depth of penetration (m)	
		Vertical Dipole	Horizontal Dipole
10	6 400	15	7.5
20	1 600	30	15
30	400	60	30

All data obtained from the EM survey was also plotted in Microsoft Excel to produce the traverse profiles for interpretation; the results thereof will be discussed later in this chapter.

5.3 RESULTS AND DISCUSSIONS

Data collected from magnetic and electromagnetic geophysical investigations will be interpreted and discussed. The primary aim is to assess the quality of the data collected. Part of the process involves checking whether the data provides a typical magnetic intensity for the area which will in turn, help in making conclusive recommendations.

One (1) proposed drilling position and one (1) alternative drilling position were identified through geophysical traverses. These were clearly marked in the field for easy identification by the drilling contractor.

5.3.1 Jozini

The traverse (Figure 5-5) is 220 m long from a south-west to a north-east direction. The magnetic field shows an increase in the magnetic signature at the 50 m station, resulting in a positive anomaly between a 55 m and a 70 m station. No apparent cultural effects were observed that could have caused the positive anomaly; therefore, the observed increasing anomaly was attributed to the presence of the dolerite intrusion. Using guidelines by Roux (1980) this observed anomaly was estimated to have a dip of 120° (Appendix B).

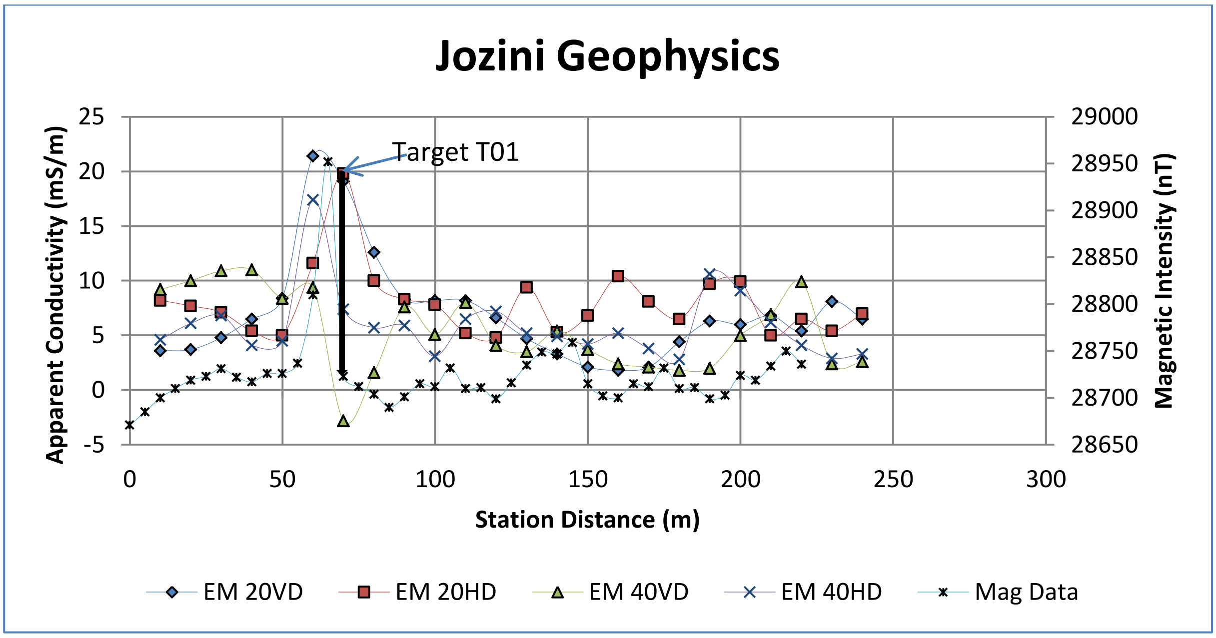


Figure 5-5: Geophysical survey results for the traverse in Jozini

Using the Logochev method (1961), the centre of this dolerite intrusion was estimated to be at a 60 m station, while the edges were about 5 m from the centre at 65 m. Using the Horizontal Slope Distance method by Roux (1980) the depth of the dolerite intrusion was estimated to be 6.5 mbgl (Appendix C).

With all these parameters determined, it was then decided to site the target at 70 m along the traverse line (T01) This was in order to be able to target the edges of the possible dolerite intrusion and possibly the contact between the intrusion and the host rock. Another small positive anomaly is seen between a 120 m and a 155 m. It was however, regarded as being caused by a cultural effect associated with a fence or toilet which is situated in the vicinity of the traverse which could have had an influence on the magnetic survey.

In the EM data, both HD modes show the presence of the dolerite intrusion between a 50 m and 80 m, reaching their highest apparent conductivity on the either side of the intrusion when compared to the magnetic profile. A 20 m coil separation has its maximum apparent conductivity on the right side of the intrusion while a 40 m coil separation is on the left of the intrusion at the targeted edges. These elevated EM values could be linked to the weathered or fractured dolerite edges which could possibly be saturated.

For VD modes, 20 m coil separation also shows the presence of the intrusion as local maxima, having its maximum apparent conductivity on the left side of the edges of the intrusion. The anomaly detected with this coil separation fully covers the detected intrusion. With 40 m coil separation the presence of the intrusion is observed as local minima. This is the only anomaly that shows a decrease in apparent conductivity. This observation could imply that there is a discontinuity or faulting of the intrusion. However, there could have been an error as all other investigations (magnetometer, EM 20HD, EM 40HD and EM 20VD) show a positive anomaly.

The borehole was therefore sited based on magnetic data, EM 20HD and 40HD coil separation at approximately a 70 m station to target the edges on the right side of the intrusion and possibly the contact between the host rock and the intrusion. This side was chosen based on topography considering that the traverse was running in a southwest to a northeast direction and assuming that groundwater flow follows topography, then water will be flowing towards the southwest. This would mean that the intrusion will sort of trap water, or act as a catchment area on this side (southwest), therefore making the side a better one to drill a borehole.

An alternative traverse (Figure 5-6) was set 10 m away from the original traverse, for a total length of 120 m in the similar orientation to the preferred or original traverse. The purpose of this traverse was to compare the results with the first traverse and to assess the quality of the data obtained. In comparison to the original traverse, the alternative traverse shows the presence of the dolerite intrusion with the anomaly being detected at the 100 m station. Both EM 20HD and 40HD shows their highest apparent conductivity on the detected intrusion, when compared to magnetic data this is the same intrusion which was detected using the magnetic method.

For this alternative traverse, a borehole was sited at the 110 m station to target contact between the intrusion and the host rock, based on magnetic data and HD (20 m and 40 m coil separation).

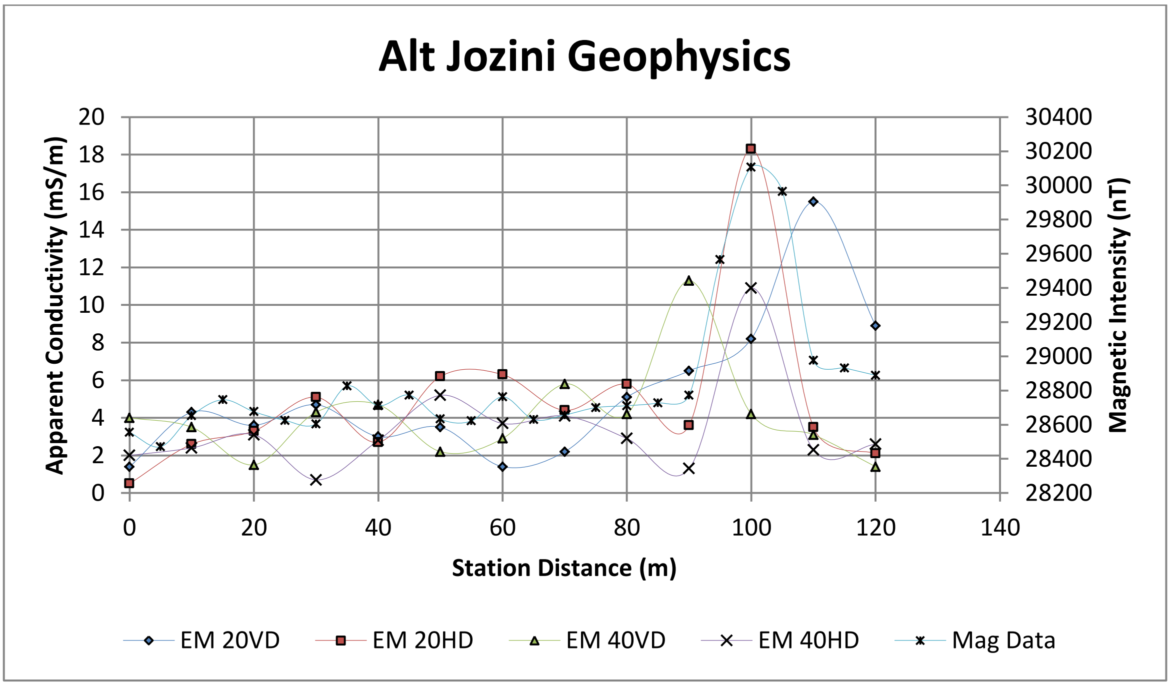


Figure 5-6: An alternative geophysics traverse results for Jozini

5.3.2 Machibini

The traverse in Machibini was 120 m long, running from east to west, with a station spacing of 5 m for magnetic investigation and 10 m station spacing for EM (Figure 5-7). Between the 10 m and 60 m stations, a parallel fence was crossed, and a power line was also crossed at the 60 m station. These materials are magnetic and have an effect on the magnetic survey. This could be seen as noises on the profile in that vicinity. The fluctuations were considered to be caused by the presence of those materials and not due to dolerite intrusions. A positive anomaly is seen between 80 m and 100 m. In the absence of any cultural effects that could have caused such an anomaly, this was considered to be a detection of the suspected dolerite intrusion.

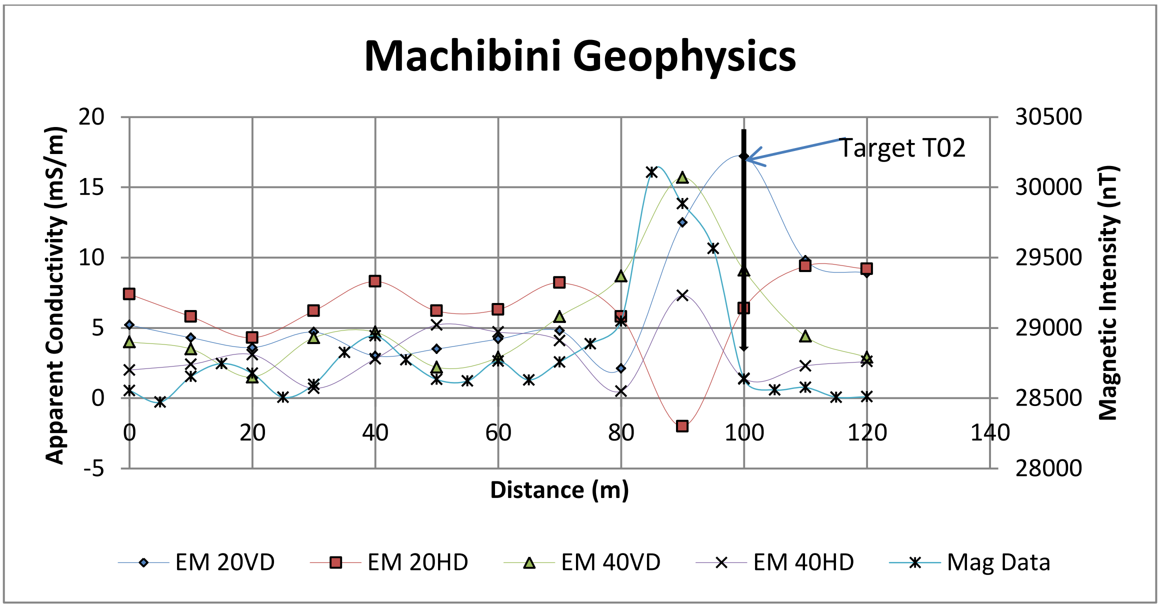


Figure 5-7: The geophysical investigation result plot for Machibini survey

The parameters for this geological structure were estimated as follows: the centre was estimated at the 95 m station while its depth was estimated to be 6.5 mbgl, using H.S.D from Roux (1980) guidelines. Calculations for these parameters are displayed in Appendix C. The dip was estimated to be 105˚ to the west (Appendix B).

The EM profiles show an increase in apparent conductivity when using 20VD, 40VD and 40HD coil separation. Both VD coil separations are more pronounced in the vicinity of the identified intrusion. However, the 20VD coil separation reaches its highest apparent conductivity at the edges, when compared with magnetic data, while for 40VD a maximum apparent conductivity was encountered, closer to the centre of the intrusion. A 40HD coil separation is not as pronounced as the two VD profile, but it also shows an increase in apparent conductivity, being the highest towards the centre of the dyke, as well as at the 90 m station. These increases in apparent conductivity suggests that there could be a conductive geological body in the vicinity of those anomalies, which could be fractured or weathered and possibly saturated with water; which therefore, could be targeted for groundwater exploration.

EM 20HD shows a decrease in apparent conductivity in the same area where other coil separations showed a positive anomaly, thereby suggesting that there could be a discontinuous conductive body. This occurrence is suspicious, as other coil separations showed positive anomaly and could imply that there was an error when investigating with this coil separation. A drilling target (T02) was sited based on the magnetic and EM 20VD investigations at the 100 m station.

An alternative traverse is shown as a plot on Figure 5-8 below. The purpose of this traverse was for comparison and assessment of concerns that might have arisen in the first traverse. This traverse was set 10 m from the original traverse for the same distance and orientation.

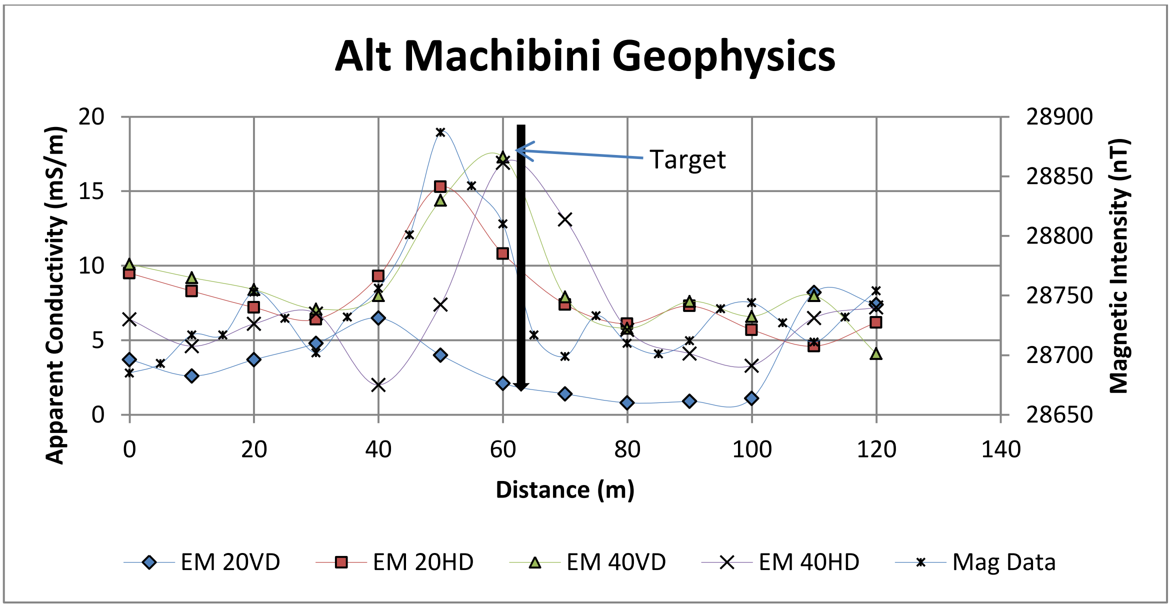


Figure 5-8: The alternative geophysics investigations for a traverse in Machibini.

The alternative traverse with magnetic investigation also proves the presence of a dyke just like the preferred or first traverse. The anomaly which is suspected to be a dolerite intrusion was seen between the 40 m and 65 m station, with its highest magnetic reading at the 50 m. There were no cultural effects which could have caused this anomaly.

In the EM data, the presence of dyke is observed as local maxima in the HD profiles and 40VD profile, however 20VD is not clear. Profiles for 40VD and 40HD have their highest apparent conductivity away from the centre of the dyke, towards its edges, while 20HD has its highest apparent conductivity at the centre of the dyke and decreases towards the edges. These anomalies suggest the presence of a conductive geological body that can be targeted for groundwater exploration. Comparing magnetic data and EM data using 40 m coil spacing for HD, a drilling target was sited at the 65 m to target the edges of the intrusion, it should be noted that the parameters such as the centre, and the depth of this structure were not calculated, an assumption based on the profile and the orientation of the traverse was used to site this target.

5.3.3 Ophande

The traverse in Figure 5-9 is 400 m long from north-east to south-west. A power cable and a fence were crossed between the 30 m and 50 m. This could have caused the increase in the magnetic intensity as these materials are magnetic; therefore the increase in the magnetic intensity in this vicinity should be viewed as a response of the magnetic method to these cultural effects.

There is an anomaly with amplitude of 29469 nano Tesla (nT) between the 55 m and 85 m. This anomaly could be attributed to the presence of the suspected dolerite intrusion. The centre of the dyke using the Logochev method was estimated to be at 80 m, while its depth is estimated to be 6.5 mbgl. The depth of the magnetic body was determined using the horizontal Slope Distance (HSD) by Roux (1980) (Annexure C), dipping at 75˚ south-west.

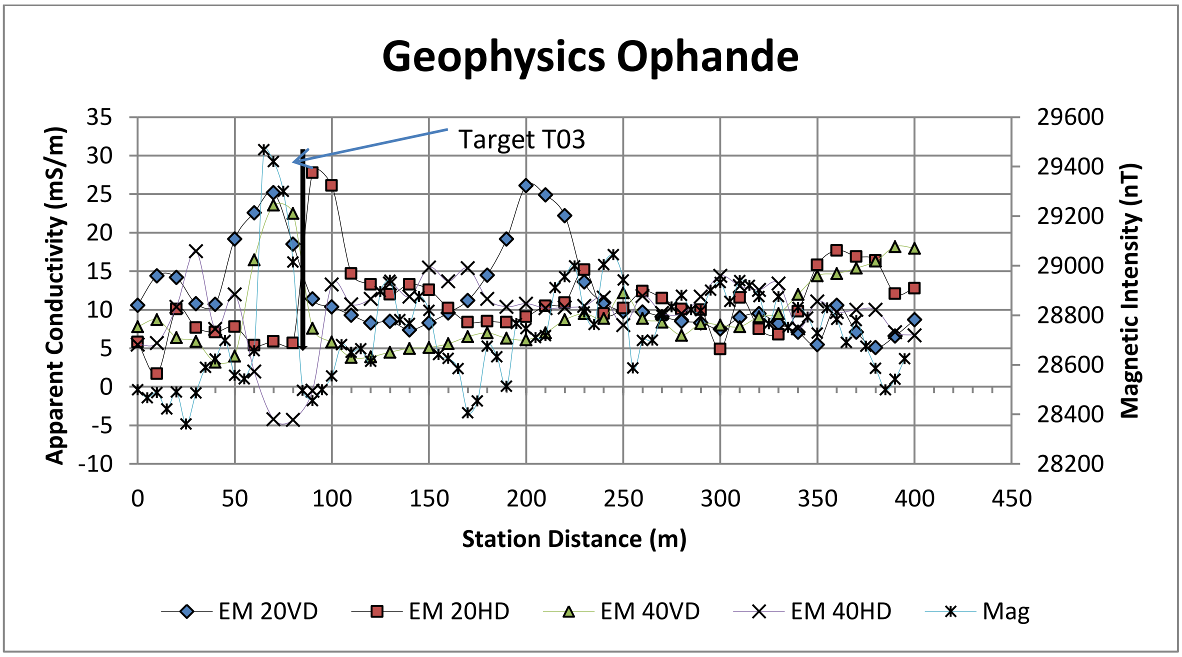


Figure 5-9: The geophysical investigation for a traverse in Ophande.

The edge of the dyke is estimated at 85 m. The drilling target (T03) along this line was sited at the 85 m station. This was in order to target the edges of the possible dolerite intrusion. Topography was also taken into consideration when siting this target, as it is believed that groundwater flow follows topography. In this case the assumption is that groundwater flows towards the southwest. This choice is also supported by EM data, which shows an increase in apparent conductivity for 20VD, as well as 40VD. These apparent conductivity suggest that there could be weathering or faulting of the intrusion which forms storage and a preferential pathway for groundwater, which could then be targeted for drilling.

Other anomalies are seen along the traverse from the 105 m station, but these anomalies were not targeted as they were believed to be caused by cultural effects like a parallel fence crossed at 105 m, power line at the 110 m station, three graves at the 130 m station, a toilet at the 160 m station and again at the 230 m station, from 240-270 m a cattle kraal and finally a parallel fence was crossed from 280-330 m. EM data is also not suggesting any possibility of groundwater occurrence, with the exception of EM 20VD which shows an increase in apparent conductivity between the 180-230 m station. However, this anomaly could not be targeted as it was in an area where there were lot of cultural effects.

An alternative drilling site was investigated about 10 m away from the original or preferred site for 270 m and the similar orientation as the first survey (Figure 5-10). For magnetic survey, two positive anomalies were identified; a more defined one between 10-25 m stations and the other one although not more defined, was identified immediately after the first one, between the 35-50 m stations. Since there were no cultural effects that could have caused an increase in the magnetic intensity. These anomalies were considered to have been caused by the presence of an intrusive magnetic body.

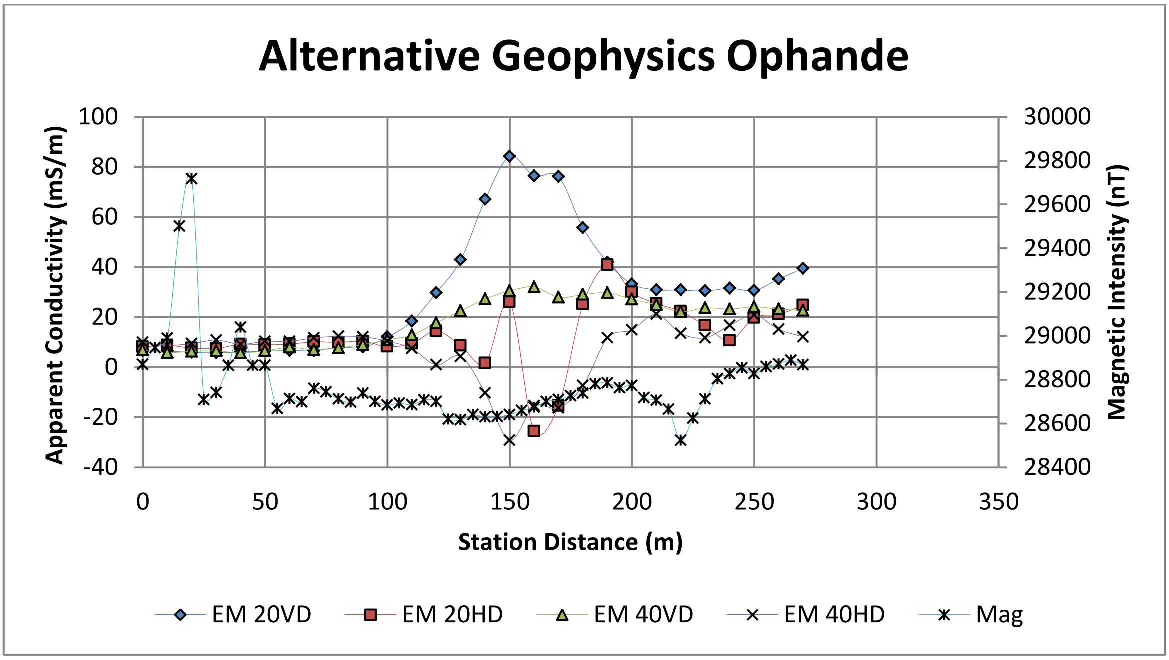


Figure 5-10: An alternative geophysical investigation for Ophande.

However, as can be seen on the profile, magnetic data after both anomalies shows featureless data. Because of this observation, this data was considered to be “bad data”. This assumption was based on Roux (1980), who suggests that monotonous flat data could be due to the operator omitting the earth’s local magnetic field. Based on this observation no drilling target was sited.

EM profiles also show flat apparent conductivities for all four profiles from the beginning of the survey to about 110 m station. There are possible discontinuous geological structures (conductive faults or weathering) between the 130 m and the 190 m stations, for HD profiles both 20 m and 40 m coil separation. However, the minima for these profiles are displaced from one another, and don't coincide in any way to the position of the dyke positioned at the 20 m station, as observed from magnetic profiling.

The VD profile for 20 m coil separation shows the presence of dyke as local maxima, while a 40 m coil separation is not clearly defined, this profile also does not coincide with the position of dyke from the magnetic data. No target was sited along this traverse as both magnetic survey and electromagnetic survey suggests that the study could have been wrongly conducted.

5.3.4 Majozini

Magnetic and electromagnetic data were recorded along the 260 m long traverse in the north-east to south-west direction. This traverse was not chosen based on any geological structure, as no structure was identified during desktop study, but it was based on topography according to the consultant's knowledge of the study area, and on trying to place the resource closer to the community. Figure 5-11 indicates the results of the survey presented as profile plot.

The magnetic investigation shows that the regional magnetic field is about 29100 nT. The magnetic field signature was within the regional magnetic field range from point 0 m to about 105 m, thereafter an increase in magnetic field was experienced with the highest magnetic field intensity being reached between 110-140 m, and this anomaly has amplitude of about 29350 nT or around 250 nT after the removal of the regional magnetic field. In the absence of any visible effects that could have an effect on the magnetic survey, this strong magnetic response indicates possible presence of a highly magnetic geological body that could be targeted for drilling.

The centre for this suspected magnetic body was estimated at the 150 m station using the Logochev (1961) guideline (Appendix C), while its depth was estimated to be 19.5 m using Horizontal Slope Distance (HSD) and the anomaly is estimated to have a dip of 150˚, based on guidelines by Roux (1980).

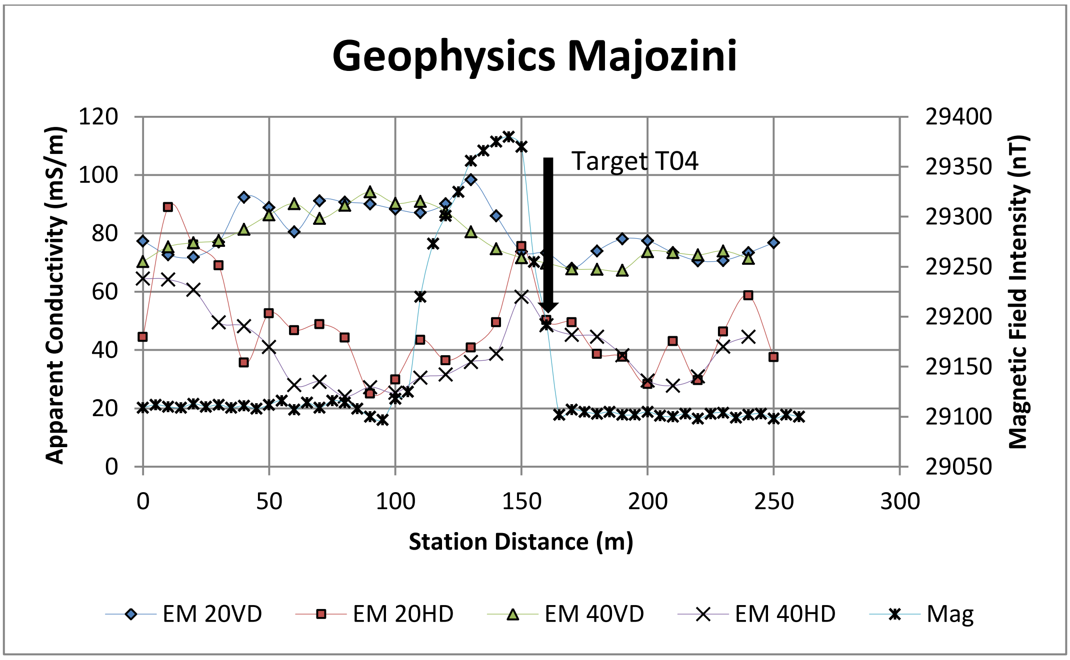


Figure 5-11: The geophysical investigations for Majozini

In the EM data, with the exception of the EM 20HD other coil separations were not clearly defined along the traverse. EM 20HD shows a positive anomaly between station 0-40 m. Both 20HD as well as 40HD reveals an increase in apparent conductivity towards the centre of the intrusion when compared to the magnetic investigation. This increasing apparent conductivity could be associated with fracturing and weathering of the intrusion, which therefore forms storage and preferential flow path for groundwater and therefore could be targeted for drilling.

Based on the above, a borehole was sited at approximately 160 m (T04), to target the contact between the intrusion and the host rock. This target is based on magnetic investigation and EM 20 m and 40 m coil separation for HD.

An alternative investigation (Figure 5-12) was conducted along the traverse discussed above about 10 m away from the original traverse, with the aim of determining an alternative drilling target; furthermore to evaluate and make comparison to the data from the original traverse.

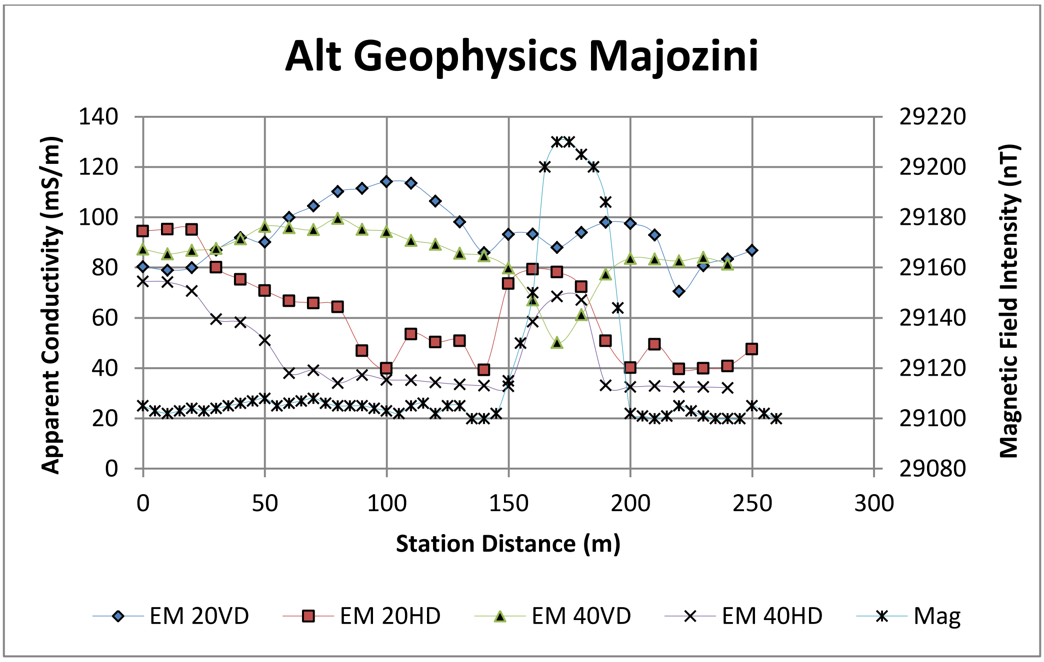


Figure 5-12: An alternative Majozini geophysics traverse investigations.

The alternative traverse corresponds with the original traverse in the sense that an intrusion was detected, this being a proof that the magnetic investigation for the first or original traverse was performed correctly. The EM data, similarly to the original traverse, is not clearly defined however; a 20 m and a 40 m coil separation for HD still shows an anomaly in the vicinity of the intrusion.

5.3.5 Nkangala

The investigation was done over a distance of 460 m in a North-East to South-Westerly direction (Figure 5 13). A soccer field was crossed between 40 m and 90 m. This resulted in fluctuation in the magnetic field, and with a positive anomaly being encountered on the side where the goal post is still standing upright at about 100 m. A negative anomaly could be seen between the 105 m and the 140 m station, this in the absence of any cultural effects, which anyway could have caused a positive anomaly, was considered to be attributed to the presence of the discontinuous geological feature such as fault or weathered formation, which could be targeted for drilling.

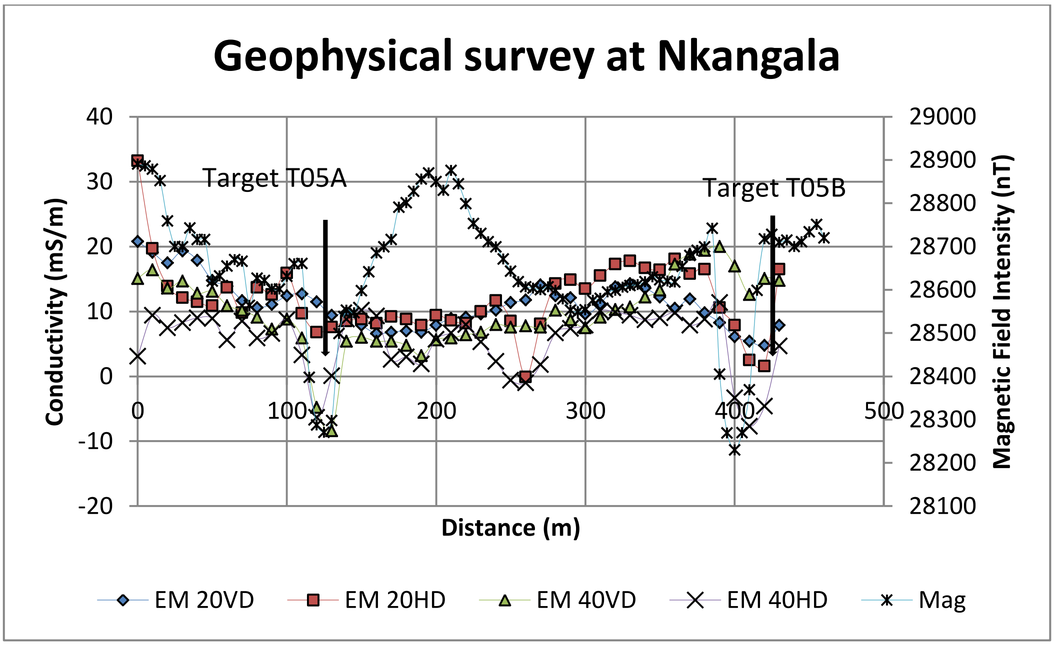


Figure 5-13: The geophysical investigations for Nkangala traverse

Another cultural effect was recorded between 160-220 m as a fence was crossed. That is believed to be the reason for the anomaly which can be seen on the plot. Thereafter was no cultural effect that could influence the magnetic reading. At the 385 m station the magnetic data displayed a decrease in magnetic intensity up to about the 400 m station and thereafter increasing again to a 420 m station in the absence of any apparent cultural factors, the resulting negative anomaly was considered to be triggered by the discontinuity of the possible geological feature such as faults, fractures, or weathered formations thus could be targeted for drilling. The two negative anomalies discussed above resulted in two targets being identified along the traverse at the 135 m station (T05A) and the other one at 415 m station (T05B).

Using Logochev (1961) methods, the centre of this possible discontinuous magnetic intrusion was determined to be at 120 m, and the edges were estimated to be 135 m. Drilling target T05A was sited at 135 m to target the edges of the discontinuous magnetic intrusion, while its depth was estimated to be about 6.5 mbgl. For the second anomaly, the centre was determined to be at 390 m along the traverse line, with the edges estimated to be 413 m. Based on these estimates drilling target T05B was sited at 415 m, also to target the edges of the discontinuous magnetic body (Appendix C).

The EM data as represented on a plot in Figure 5-13 is not really clear with regard to readings taken using 20 m coil separation for VD. A 40VD shows a decline in apparent conductivity from 115 m station until a 135 m station. This negative anomaly is an indicative of a discontinuous geological body that could be explored for groundwater since such discontinuities are good for groundwater movement/flow, a slight decrease in apparent conductivity appears at 390 m. This could be caused by the detection of the discontinuity of the possible geological features. These anomalies also correspond with magnetic survey results.

EM reading with HD coil separations suggests that there could have been a possible discontinuity of the geological features between a 240 m and a 270 m station for a 20HD reading, another anomaly which presents the presence of the geological body as local minima is seen at a 380 m station to a 430 m station, this anomaly is within the magnetic body as determined with magnetic survey reaching its peak towards the edges. While 40HD also shows a negative anomaly between the 100-135 m stations, negative apparent conductivity suggests the presence of possible discontinuities. This anomaly corresponds with the one detected using magnetic methods. Another discontinuity was detected at the centre of the geological body at the 390m station reaching its lowest apparent conductivity at 410 m station, which is the edge of the body. For drilling target T05A a borehole was sited using magnetic results together with 40VD as well as 40HD, while siting of T05B was done using the results as obtained with magnetic methods and EM using 20HD, and 40HD as all were able to detect the position of the discontinuous geological body.

An alternative drilling site was investigated about 10 m away from the original/preferred site for the same station distance and orientation as the first survey. The results are interpreted as a plot on Figure 5-14.

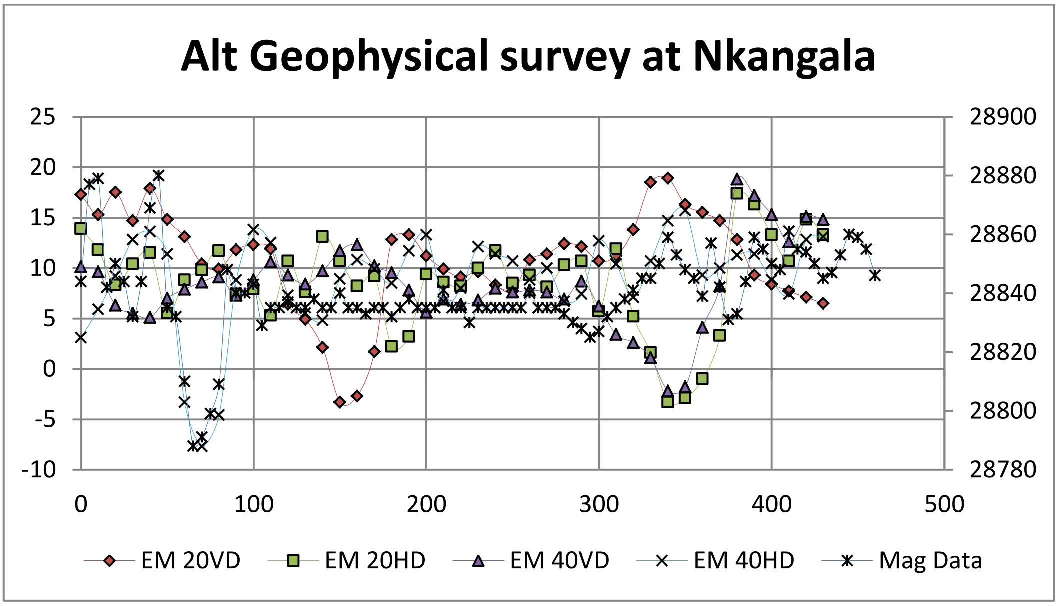


Figure 5-14: An alternative geophysics results for a traverse in Nkangala.

The alternative traverse shows the presence of a negative anomaly between a 55 m and an 85 m station. This anomaly was detected by both magnetic and EM 40HD. It is suspected that this is the same anomaly where T05B was sited; it should however be noted that this time around 20HD did not detect any possible discontinuity as it did for the original traverse.

The magnetic data from a 105 m station appears to be within the regional magnetic field and starts fluctuating from 295 m up to the end of the traverse. These fluctuations are suspected to be due to cultural effects in that vicinity which includes three graves, a fence and a steel pole.

5.3.6 Mahangule

The traverse for the Mahangule survey was 300 m running from north to south with a station spacing of 5 m. Data from this traverse was plotted on a profile and the results are shown on Figure 5-15. A power line and steel pipe bridge were crossed at 60 m. An increase in magnetic intensity in this vicinity could be attributed to those encountered magnetic materials, and other materials, which could possibly have an effect on the magnetic survey, were a toilet and a metal pole at the 265 m.

The profile shows a sharp decrease in the magnetic field between the 20 m and 40 m stations. This based on the guideline by Roux (1980) could be treated as “bad data”. Thereafter, the readings were within the regional magnetic field until there was an increase in the anomaly from 195 m to about two hundred and twenty metres. This increase in magnetic intensity could be attributed to the suspected intrusion.

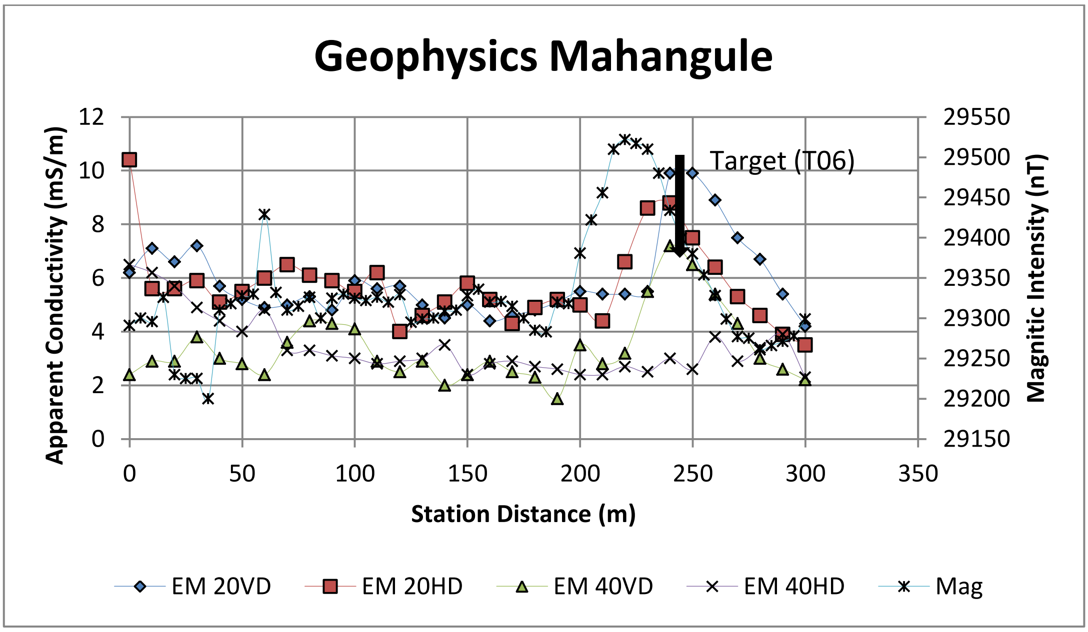


Figure 5-15: Mahangule traverse geophysical survey results

A centre of this magnetic body was estimated to be at 235 m station with the assistance of methods by Logochev (1961), while its depth was estimated to be 26 mbgl using Horizontal Slope Distance (HSD). Appendix C shows calculations for these parameters. The anomaly is estimated to have a dip of 120˚ based on guidelines by Roux (1980) (appendix B).

The EM profiles as shown in Figure 5-15 depict the 20HD coil separation increasing in apparent conductivity from 230 m station with the highest apparent conductivity in the vicinity of the edges of the dyke. An anomaly with 40HD modes is not clearly visible. Both VD coil separations show the presence of the dyke local minima around the 210 m station but increasing towards the edges of the dyke. With the exception of 20HD, all other three coil separations (20VD, 40HD and 40VD) show an increase in the vicinity of the target edges of the intrusion, as determined using magnetometer which could all be targeted for drilling. Therefore, drilling was targeted at the 240 m station, T06.

Another survey was done along the traverse discussed above. The purpose of this survey was to further evaluate and make comparison to the data from the original or preferred traverse. A new survey was conducted about 10 m away from the original surveys, in a similar orientation from north to south. The results thereof are presented as a profile plot on Figure 5-16.

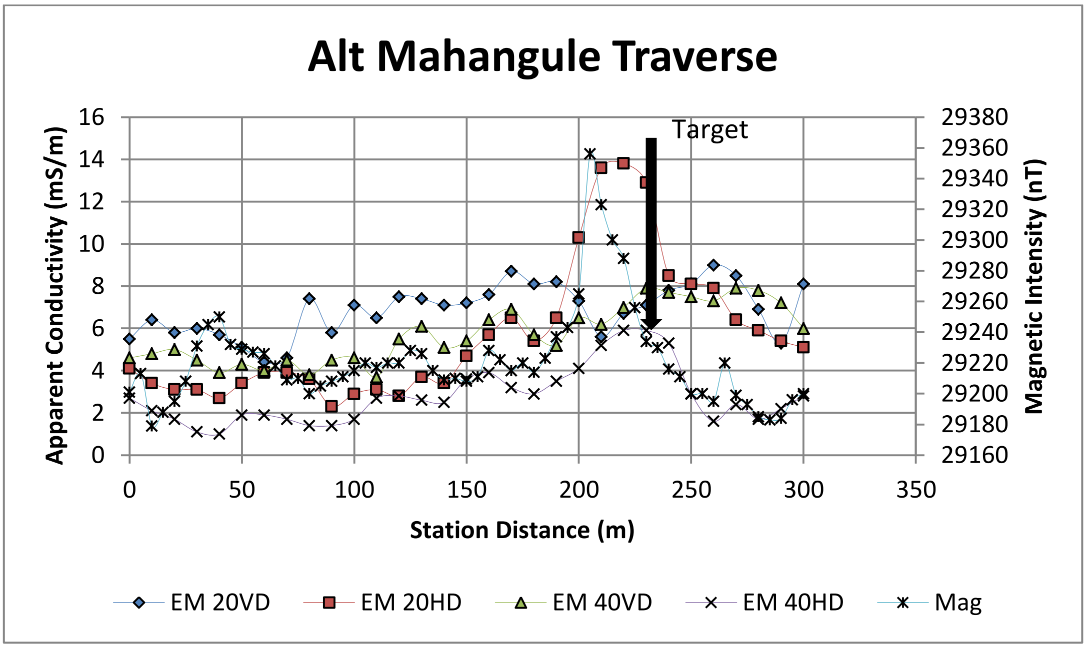


Figure 5-16: Alternative geophysics traverse for Mahangule.

The plot for magnetic survey shows an increase in magnetic intensity from about the 20 m to about the 50 m stations. This anomaly could have been caused by cultural effect in the vicinity such as power lines, parallel fence and still bridge. These materials are magnetic and can influence the magnetic reading, therefore creating a sort of anomaly; this area was not targeted for drilling for that reason. Thereafter, the magnetic readings were within the range of regional magnetic intensity until the 195-235 m stations where a positive anomaly is seen. Due to the absence of the cultural effects this anomaly was suspected to be an intrusion. A drilling target was sited on the edges of the intrusion on the 235 m station. The anomaly was also detected with EM 20HD as well as 40HD.

5.3.7 Madinyana

The traverse (Figure 5-17) is 320 m long running from west to east. This traverse was to investigate a dyke which was determined during desktop study. For magnetic survey, there is a positive anomaly from 10-50 m station; however this anomaly is not clear as it has some small fluctuations within itself.

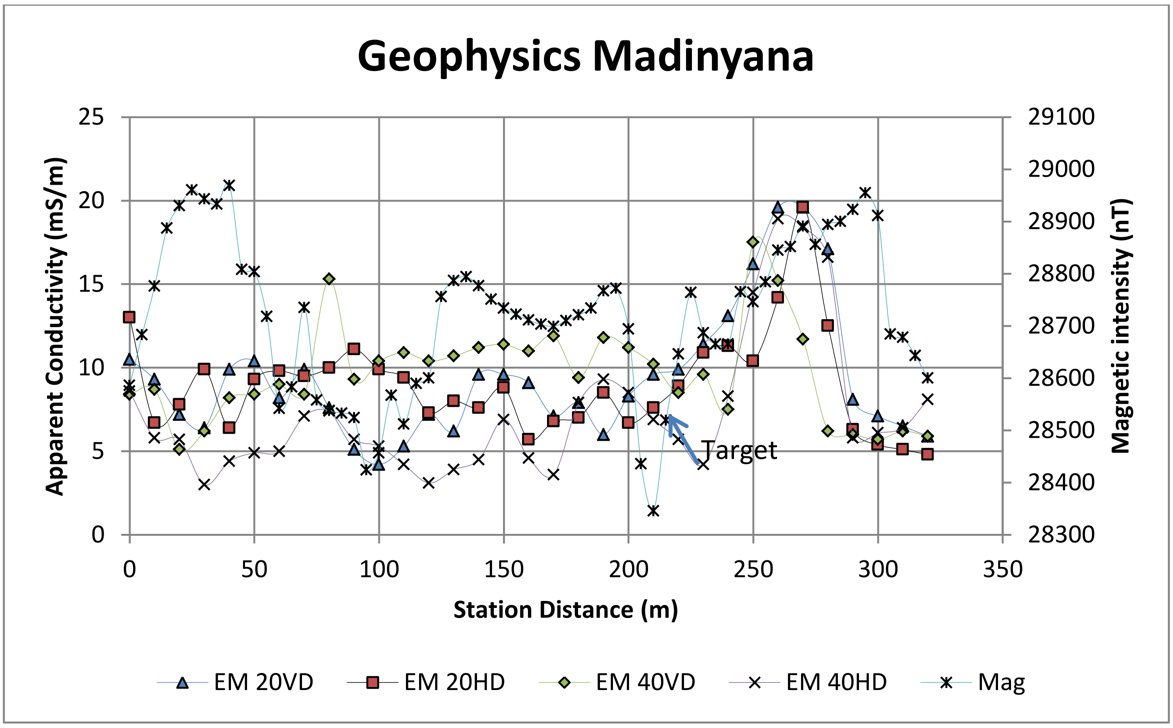


Figure 5-17: Geophysics investigation results for Madinyana traverse.

From 55 m to 105 m parallel fences were crossed which were about 20 m apart from each other, these structures are magnetic and could have an effect on the magnetic survey, but data shows a decline in magnetic intensity, suggesting there could be a discontinuous magnetic body in the vicinity. Yet again this discontinuity is not clear to target for drilling.

A more significant negative anomaly is seen at the 210 m station. This anomaly may be attributed to discontinuous magnetic intrusion, which may be due to weathering or fracturing or perhaps faulting, which therefore can be targeted as a preferential pathway for groundwater flow. A drilling target was sited at the 215 m station without any evidence of the parameters of the detected discontinuity such as the centre and the depth. The target was chosen based on topography to the south of traverse as it is believed that groundwater follows topography, therefore in this instance groundwater will be flowing from north to south. However, in general data for this survey suggests that the survey was conducted inappropriately, or the instrument might have malfunctioned during the survey. The other reason could be that the operator carried a magnetic object close to the sensing element or perhaps the operator took insufficient care in levelling the fluxgate or may have set the turning dial incorrectly.

The EM surveys all show positive anomalies between the 240 m to the 290 m stations. This anomaly could be caused by the presence of the targeted dolerite dyke from the desktop study. However, this anomaly could not be detected by the use of the magnetic method. It seems this whole traverse was done incorrectly. A new or alternative survey for Madinyana traverse was conducted to investigate the concerns raised above. The traverse profile (Figure 5-18) is 320 m long from west to east, like the original traverse.

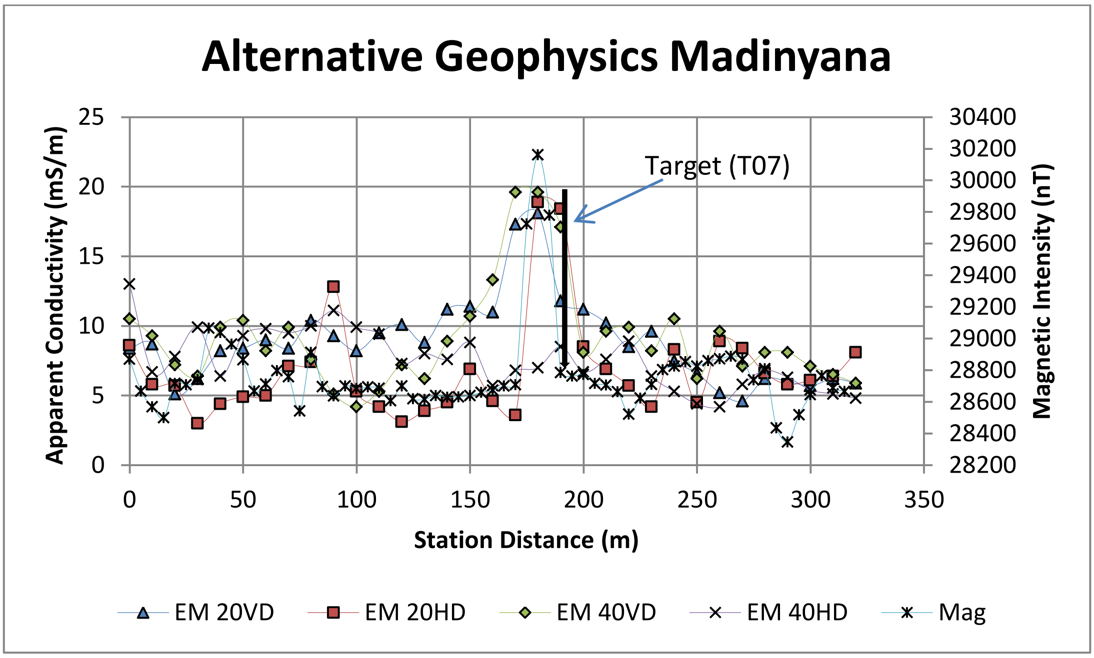


Figure 5-18: Alternative geophysics traverse for Madinyana.

A magnetic profile shows a significant positive anomaly between the 165 m station and the 190 m station, with an amplitude of 30161nT (1611nT) after the removal of the regional magnetic field intensity at 180 m. The presence of this anomaly was considered to be triggered by the magnetic geological structures.

For this anomaly a drilling target was sited at the 190 m station (target T07). A centre of this geological structure was estimated to be at the 180 m station using the Logochev methods, while the edges were estimated to be 185 m along the traverse (Appendix C). Furthermore, using H.S.D by Roux (1980), the depth of the suspected dolerite intrusion was estimated to be 6.5 mbgl, with a dip of 75º. The EM profiles with VD coil separations shows the presence of the targeted dolerite intrusion as local maxima with 20VD reaching its peak at 180 m station before declining towards the edges of the dolerite intrusion. While 40 VD also shows an increase in apparent conductivity from the 160 m station reading and then declining at around 10 m away from the estimated edges of the geological body.

Investigations with 20 HD shows a presence of a conductive geological structure with its highest conductivity detected at the 90 m station, but this suspected conductive structure is not supported by any other geophysical survey in this traverse, therefore, it was not targeted for drilling. Another positive anomaly was further detected starting from the 170 m station to the 200 m station. This anomaly suggests that there could be a highly conductive geological structure that could be targeted for drilling.

Based on the comparison of the magnetic data with EM, it was decided that the drilling target T07 be sited at 190 m station targeting the contact between the host rock and the identified geological intrusion. This traverse proves that the original traverse could have been wrongly conducted.

5.4 SUMMARY

This chapter focused on the geophysical investigations, providing the details on geophysical methods used, focusing mainly on magnetic and electromagnetic methods. Seven drilling targets were identified (Table 5-2).

Table 5-2: Summary of geophysics

Traverse	Target	Target Station (m)	Lat	Long	Comments
Jozini	T01	60	-27.428	32.05960	Contact between the host rock and the intrusion
Machibini	T02	100	-27.439	32.04500	Contact between the host rock and the intrusion
Ophande	T03	85	-27.479	32.105	Targeting edges of an intrusive formation.
Majozini	T04	155	-27.498	32.02277	Contact between the host rock and the intrusion
Nkangala	T05	415	-27.526	32.02972	Targeting possible discontinuity of the negative anomaly
Mahangule	T06	249	-27.577	32.09647	Targeting edges of an intrusive formation
Madinyana	T07	185	-27.582	32.08395	Contact between the host rock and the intrusion

For each traverse an alternative survey was conducted 10 m away from the original one, with the aim of comparing and assessing the quality of data derived from the preferred or original data. For magnetic data this was also to help identify if the data was typical of the expected magnetic field intensity in the area, or whether the shape of the anomaly and the length of the traverses were sufficient to make conclusive judgments.

EM data was also used to deduce whether the results obtained from the magnetic survey could be trusted and relied on for decisions in the study area. The study has also shown that both magnetic and EM techniques could be used in the study area to site boreholes. As in most cases these techniques managed to detect the presence of a geological structure that could be targeted for drilling.

Table 5-2 is inclusive only of the sites identified for drilling. Manual for the standard Anomaly Curves in the South African Geophysics Association by Roux (1980) was used to interpret the shapes of the anomalies for the above discussed targets, with the exception of the target at Nkangala, as it was difficult to interpret it using this method.

CHAPTER 6: DRILLING AND GEOLOGICAL CHARACTERISATION

6.1 INTRODUCTION

There are various drilling methods employed in the development of groundwater. According to Misstear *et al.* (2006), most of these many different drilling techniques are traditionally classified as either percussion or rotary techniques, depending on the predominant drill action (although some methods involve a combination of the two actions). Rotary techniques can be further classified according to the method used, to circulate the drilling fluid: direct circulation or reverse circulation (Sterrett, 2007).

Drilling was conducted in order to explore the detected and observed anomalies as discussed in Chapter 5. The Percussion (Rotary-Percussion Air) drilling method was utilised to drill the boreholes for the water supply. This method is the most economical way of rapidly drilling boreholes into the hard rock and semi-consolidated formations, which are self-supporting (Woodford & Chevallier, 2002), the method is the most economical because the cuttings produced as drilling progresses are removed from the borehole via the annulus between the drill-stem and the wall of the hole by circulating air at high pressure. This continuous cleaning of the hole exposes new formations to the bit and thus energy is not expanded re-drilling old cuttings (Sterrett, 2007; Woodford & Chevallier, 2002). This chapter will discuss the drilling method used and the drilling logs, to further understand the geology in which the boreholes were drilled so as to allow for easer geological characterisation.

6.2 METHODS AND MATERIALS

6.2.1 Borehole drilling

6.2.1.1 Rotary-percussion air drilling

A rotary percussion air drilling method was used to drill boreholes at the targeted sites, as discussed in the previous chapter. This method was used as explained already because it is the most economical way of rapidly drilling boreholes into hard-rock and semi-consolidated formations (Woodford & Chevallier, 2002). Drilling was conducted by T&T drilling under the supervision of external consultants ENGEOLAB and officials from the Department of Water Sanitation (DWS). Drilling was initiated using a 219 mm diameter hammer until the more stable rock formation had been penetrated for at least 3 m, followed by the installation of a 4 mm thick 165 mm diameter, solid mild steel casing, piloting the 165 mm diameter borehole to the final depth.

A bit was attached to the lower end of a string of drill-stems. Cuttings were removed by a continuous flow of air or other fluid in the annular space between the borehole and drill pipe-stem, while at the surface, settling pits or mechanical equipment extracted the cuttings, allowing clean drilling fluid to recirculate downhole. The continuous cleaning of the hole exposes new formations to the bit and thus energy is not expended re-drilling old cuttings (Sterrett, 2007; Woodford & Chevallier, 2002). These cuttings are used to better understand the geological or drilling logs.

Furthermore, Woodford and Chevallier (2002) stated that this method has a major advantage in that water is blown to the surface as soon as a water-bearing zone is encountered, which would allow the geohydrologist to obtain a progressive indication of the available supply (known as a blow yield) and to monitor any changes in the quality and quantity of water, as drilling progresses. Blow yields provide good information about the potential yield of the borehole and consequently the local aquifer (Malefane, 2016).

Table 6-1: Borehole yields groups based on Groundwater Development Services (1994).

Group	Borehole Yield	Meaning
Group 1- High Borehole Yield	>3 l/s	Medium to large schemes supporting small towns and/or small to medium scale irrigation schemes
Group 2- Moderate Borehole Yield	>0.5 l/s <=3 l/s	For reticulation schemes for villages, clinics and schools
Group 3- Low Borehole Yield	>0.1 l/s <= 0.5 l/s	Primary water supplying hand pump or wind pump for non-reticulated community and stock watering purposes
Group 4- Very low borehole Yield	<0.1 l/s	Suitable for marginal supply for domestic and stock watering only

Table 6-1 above gives groups of blow yields, as suggested by Groundwater Development Services (1994) and this will be used to analyse and classify the blow yields obtained during the drilling process. Although drilling targets were sited, based on expert guesses and interpretation of the geophysical investigations, it should be noted that unsuccessful boreholes could be drilled. Even though expert opinion is believed to be based on experience coupled with knowledge of groundwater, it should be kept in mind that at times, the complex nature of the subsurface could lead to the drilling of unsuccessful boreholes.

6.2.1.2 Borehole logging

During the drilling, the geological logs were recorded together with the encountered water strikes, and their respective blow yields. In a case where multiple water strikes were encountered in a single borehole; their blow yields were combined to get a cumulative blow yield for that borehole.

It should be noted that there might be factors that could have positively or negatively affected the measured blow yields as drilling progresses, such as the capacity of the compressor depth of the water strike below the water level, the annulus between the drilling stem and the wall of the hole, emplacement of casing and screens, and fracture permeability, (Woodford & Chevallier, 2002). For example, from his study in the Karoo area around De Aar, Vegter (1992) reported that there was a 100% to a 300% increase in the blow yields from shallow boreholes (<20 m), as a result of enlarging the diameter of the hole from 165-250 mm. The methods of flow measurement, whether by visual estimates or by a v-notch measuring device would also have affected the accuracy of the yield estimates. The newly drilled boreholes are shown below in Figure 6-1.

The Windows Interpretation System for Hydrogeologist (WISH) program was used to plot the geological logs after drilling, these geological logs for the newly drilled boreholes are analysed and discussed in detail below.

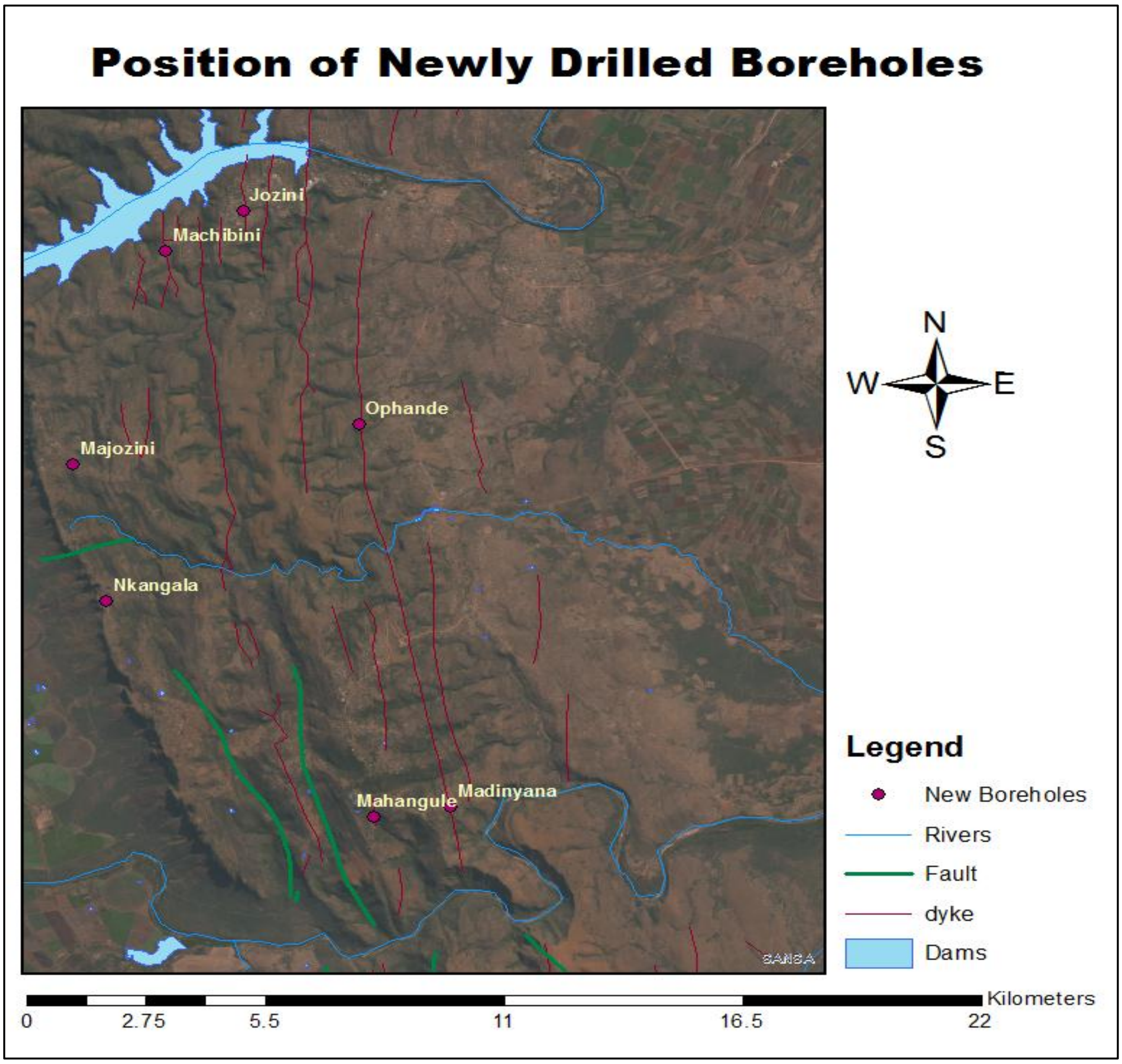


Figure 6-1: Map of the positions of the newly drilled boreholes.

6.3 RESULTS AND DISCUSSION

The general lithology obtained from the borehole drilled in the study area shows the alternating layers of rhyolite of the Jozini formation, Letaba basalts and dolerite rocks. The dolerite intrusions were intersected in all the drilled boreholes, as targeted from geophysical investigations (refer to Chapter 5). These intrusions, particularly the dykes, are one of the more important targets for high-yielding boreholes in the Karoo rocks (Woodford & Chevallier, 2002; Jalloh *et al.*, 2016).

6.3.1 Jozini geological log

The geological log for the borehole drilled in Jozini (Figure 6-2), an area known to locals as “sixteen”, showing alternating layers of pink rhyolite of the Jozini formation and dolerite. Drilling across rhyolite through to dolerite is expected in the area of study (Groundwater Development Services, 1994). In some instances, basalts of the Letaba formation could be encountered underlying the Jozini rhyolites (Botha & Singh, 2012 and groundwater Development Services, 1994).

The Jozini borehole (T01) was targeted at the 60 m station of the traverse, to target the contact between the host rock and the intrusion. It was determined that the geological intrusion had a depth of 6.5 mbgl, as discussed in Chapter 5. In the drilling processes a dolerite was intersected at a depth of 6 mbgl, which is within the range of the estimated depth.

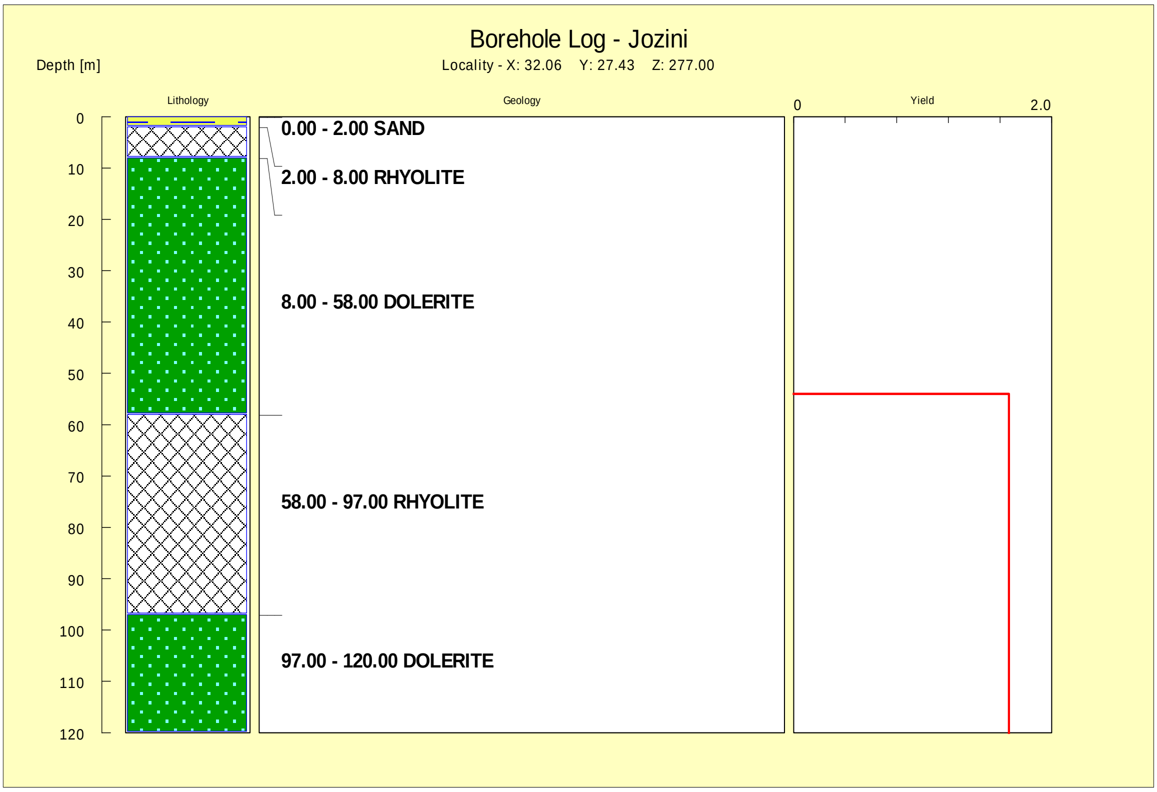


Figure 6-2: Borehole geological log in metres below ground level for the borehole drilled at Jozini, with the water strike at 54 mbgl and the Static Water Level (SWL) at 16.02 mbgl.

This borehole was drilled for a total depth of 120 m and only one water strike was intersected at 54 mbgl, on the dolerite intrusion, about 6 m away from the contact with the host rock. The dolerite intrusions are considered to be the water bearing structures and are often considered as the primary targets for groundwater exploration in the Karoo Supergroup (Woodford & Chevallier, 2002). This borehole had a blow yield of 6000 l/h an equivalent of 1.67 l/s, meaning that this is a low yielding borehole (Table 6-1).

A second dolerite intrusion was intersected at a depth of 97 mbgl, but no water strike was intersected from the contact of the intrusion and the host rock to the total depth of the borehole at 120 m; not that it is a must for the contact zone between the host rock and the intrusion to yield water, but based on the previous study by van Wyk (1963) in Northern

Natal, Zululand and the surrounding areas, yields of most successful boreholes drilled in Karoo sediments were obtained in the contact zone adjacent to the dolerite intrusions.

6.3.2 Machibini geological log

The borehole was drilled to a total depth of 120 m, as shown on Figure 6-3. Dolerite intrusion was intersected at a depth of 7 mbgl; with the estimated depth of the intrusion being 6 mbgl the intersected depth is at a fairly comparable distance.

A first water strike was intersected at a depth of 30 mbgl, with a blow yield of 0.08 l/s at a contact between the intrusion and the host rock, rhyolite, as targeted from geophysics investigations. Dolerite intrusions are considered as the primary targets for groundwater exploration in the Karoo Supergroup (Woodford & Chevallier, 2002). The previous study done in the vicinity of the study area (Groundwater Development Services, 1994) shows that the reported statistical yield data for the boreholes drilled in the rhyolite had a minimum yield of 0.04 l/s, a maximum yield of 36.58 l/s- which the study admitted to be too ambiguous and the mean yield being 1.36 l/s. From his study van Wyk (1963) has also noted that the yields of approximately 80% of the boreholes drilled in the Karoo sediments were obtained in the contact zones adjacent to dolerite intrusions. The expected yields in the Jozini rhyolites, based on DWAF (1998) are between 0.1-0.5 l/s.

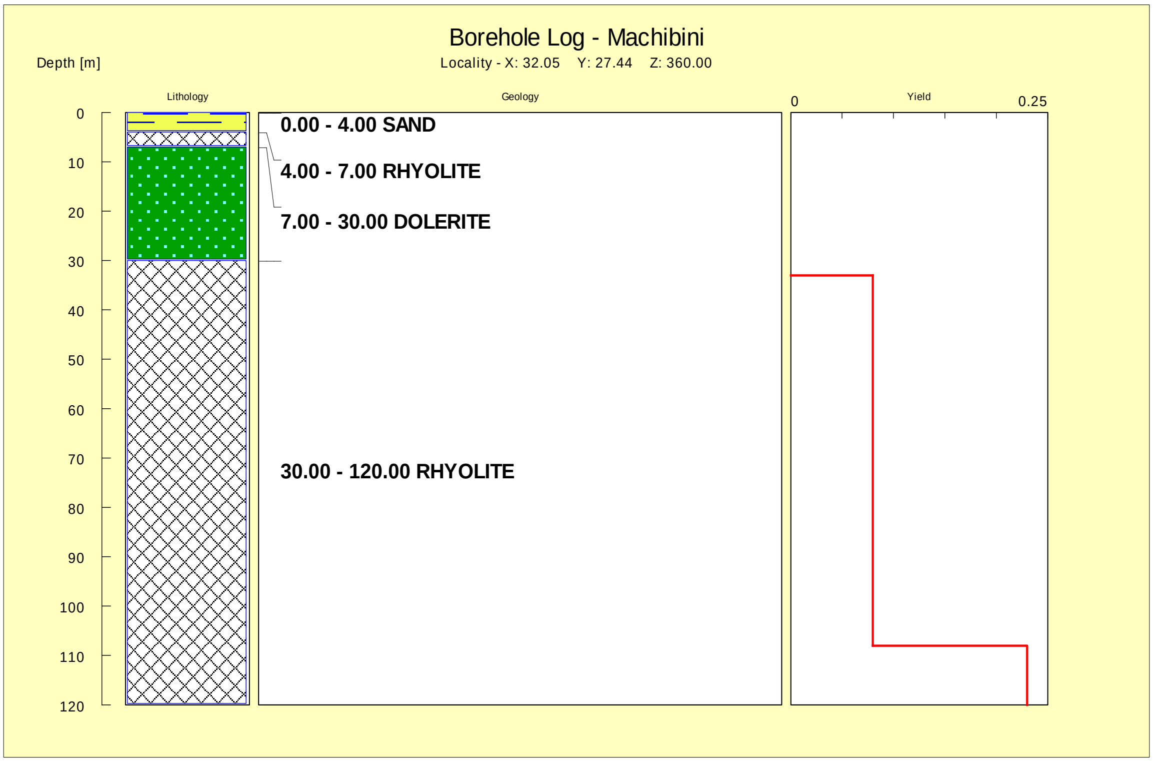


Figure 6-3: Borehole geological log in metres below ground level for the borehole drilled at Machibini with water strikes at 30 m and 108 m, the recorded SWL was 30.55 mbgl.

A second water strike was recorded at a depth of 108 mbgl on a rhyolite formation. This water strike had a blow yield of 0.23 l/s, and this is within the expected yield (DWAF, 1998). The cumulative blow yield being 0.31 l/s, based on the recorded cumulative blow yield. This borehole can be regarded as falling within group 3, suggesting that it is a low yielding borehole, which can be fitted with a hand pump or wind pump for non-reticulated community supply (Groundwater Development Services, 1994; DWAF, 1998).

6.3.3 Ophande geological log

Figure 6-4 below gives a descriptive borehole log for a borehole which was drilled in Ophande (T03). The borehole was drilled for a total depth of 102 mbgl based geological observations, as discussed in Chapter 4.

Clayey sand was seen for about a metre, followed for about 3 m by dull beige decomposed rhyolite of Jozini formation, thereafter intersecting the intrusion at the depth of 4 mbgl. This depth corresponds with the one estimated in Chapter 5 for this traverse. The first water strike was encountered at 18 mbgl where the intrusion came into contact with the host rock with a blow yield of 0.06 l/s. According to Woodford and Chevallier (2002) dolerite intrusions are considered as the primary targets for groundwater exploration in the Karoo Supergroup. Furthermore, according to van Wyk (1963) the yields of approximately 80% of the boreholes drilled in the Karoo sediments were obtained in the contact zones adjacent to dolerite intrusions.

At a further depth of 72 mbgl another water strike was intersected on the rhyolite formation with a blow yield of 0.08 l/s. An expected yield within the rhyolite formation is 0.1-0.5 l/s (DWAF, 1998) implying that the blow yields for this strike are very low. However, the cumulative yield of 0.14 l/s for both water strikes is within the expected yield in this part of the study area.

This blow yield is an indication of a low yielding borehole which would be suitable for a primary water supply with a hand pump or wind pump, for non-reticulated community supply (Groundwater Development Services, 1994 and DWAF, 1998).

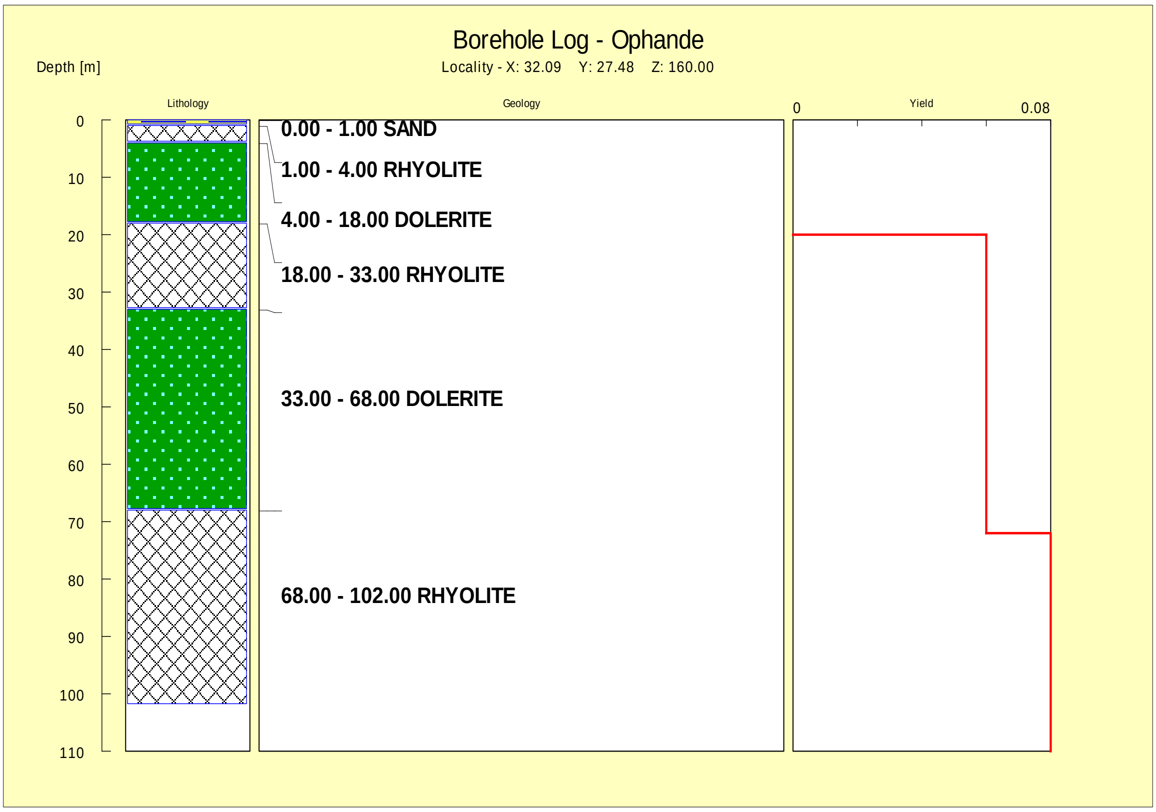


Figure 6-4: Borehole geological log in metres below ground level for the borehole drilled at Ophande water strikes at 18 m and 72 metres, the recorded SWL after drilling was 10.54 mbgl.

6.3.4 Majozini geological log

The geological log of the borehole Majozini (T04) is shown below in Figure 6-5. The borehole was targeted on the 155 m line of the traverse, targeting the contact between the dolerite intrusion and the host rock. The depth of this intrusion was estimated to be at 19.5 mbgl. The borehole was drilled for a total depth of 150 mbgl.

The intrusion was intersected at a depth of 20 m; a very comparable depth to the estimated depth of 19.5 mbgl. The contact at this depth did not yield any water.

The second contact was intersected at the depth of 60 mbgl on the contact between the dolerite intrusion and the host rock, producing a water strike with a blow yield of 0.04 l/s. According to Woodford and Chevallier (2002) dolerite intrusions, in particular dykes are one of the most important targets for high yielding boreholes in the Karoo rocks. These intrusions may host sedimentary deposit contact zones which act as a preferential flow path for groundwater.

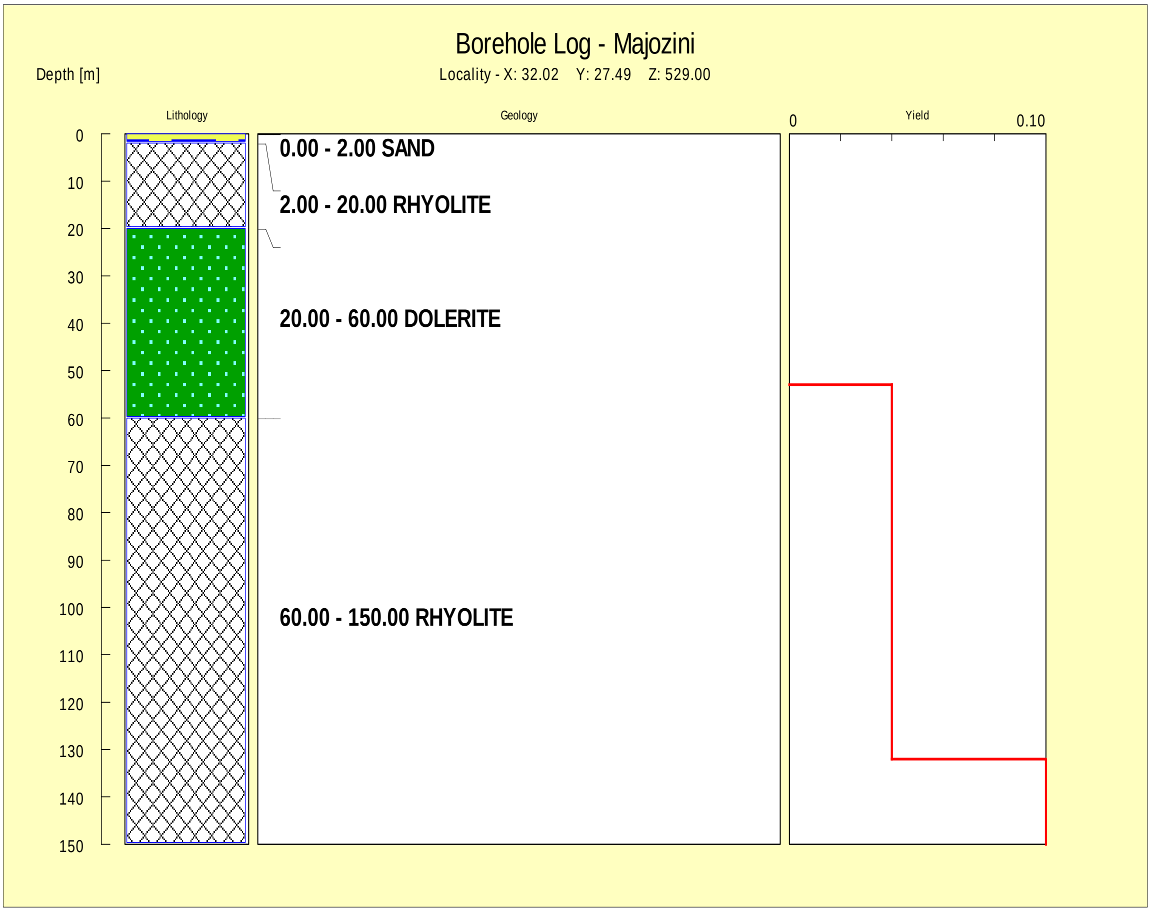


Figure 6-5: Borehole geological log in metres below ground level for the borehole drilled at Majozini with the water strikes at 60 metres and 132 m, the SWL at the end of drilling was 43.80 mbgl.

The second and last water strike was encountered at a depth of 132 mbgl on the rhyolite formation. This water strike had a blow yield of 0.10 mbgl. The boreholes drilled in this formation have an expected yield with a minimum of 0.04 l/s and a mean yield of 1.36 l/s (Groundwater Development Services, 1994), this implies that the boreholes in this formation are low yielding.

A cumulative blow yield for this borehole was recorded to be 0.14 l/s, which is an indication of a low yielding borehole (Groundwater Development Services, 1994 and DWAF, 1998). Although it is a low yielding borehole, this borehole is suitable for primary water, supplying hand pumps or wind pumps for non-reticulated community and stock watering purposes. Therefore, it was decided that this borehole would be fitted with a hand pump for the village of Majozini to use.

6.3.5 Nkangala geological log

In this area two drilling targets were sited, namely T05A and T05B (Figure 6-6 and Figure 6-7) and both targets were drilled. Both boreholes were drilled for a total depth of 120 mbgl, targeting the edges of the discontinuous geological body, which had an estimated depth of 6.5 mbgl for T05A and 19.5 mbgl for T05B.

For target T05A the intrusion was encountered immediately at a depth of 2 mbgl, implying that there might have been a misinterpretation of the geophysical data leading to an incorrect determination of the edges of the discontinuous geological body.

It should be noted that the log shows that another dolerite intrusion was intersected at a depth of 80 m to 120 m. This is however not entirely the intrusion, but dull pink rhyolite of Jozini formation with dolerite stringers.

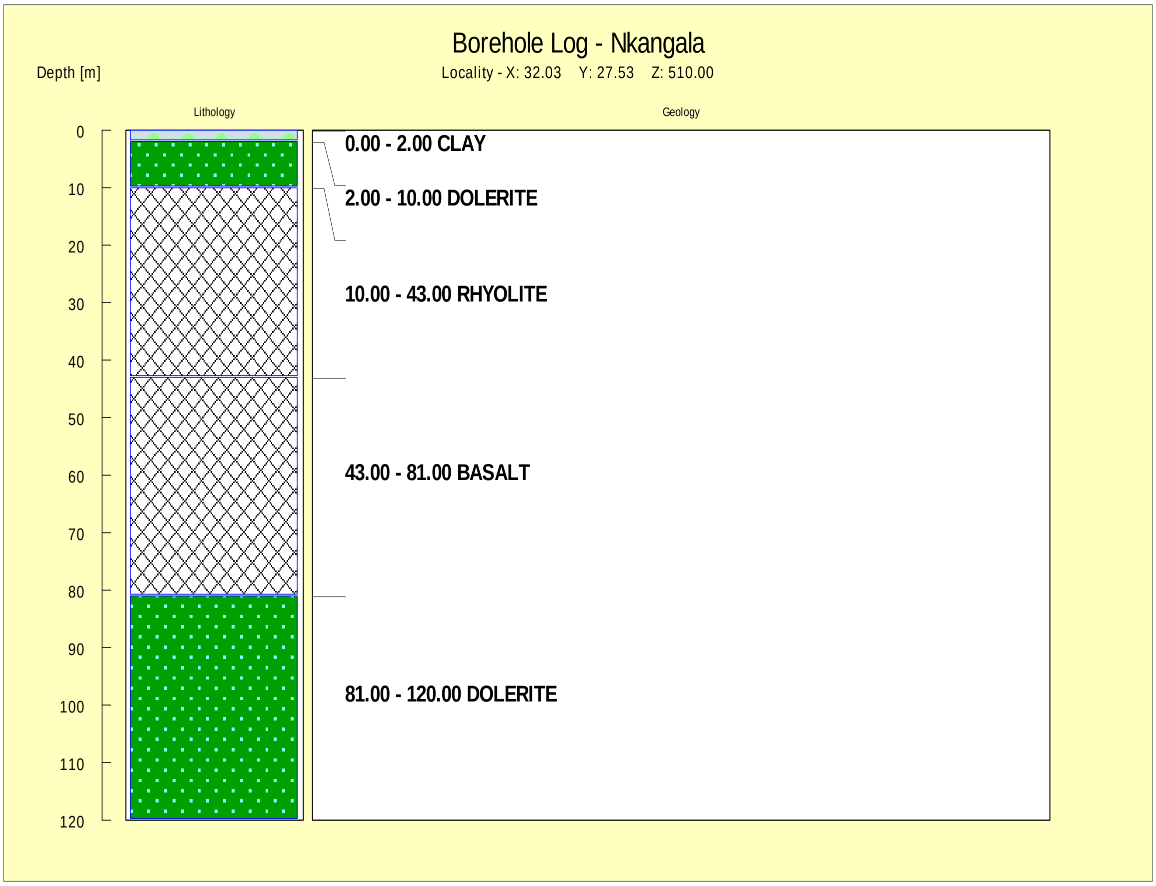


Figure 6-6: Borehole geological log in metres below ground level for the borehole drilled at Nkangala T05A and no water strike was intersected.

For this target no water strike was intersected making this drilling target unsuccessful. This is a common occurrence in the study area as also reported in Groundwater Development Services (1994); namely that a large number of abandoned boreholes are usually as a result of unsuccessful drilling, can be found scattered practically everywhere in the project area amounting to 46% of the total 3760 boreholes which were drilled for that study. Figure 6-7 gives the descriptive geological log for the Nkangala (T05B) borehole. The edges of the discontinuous geological intrusion were targeted for drilling.

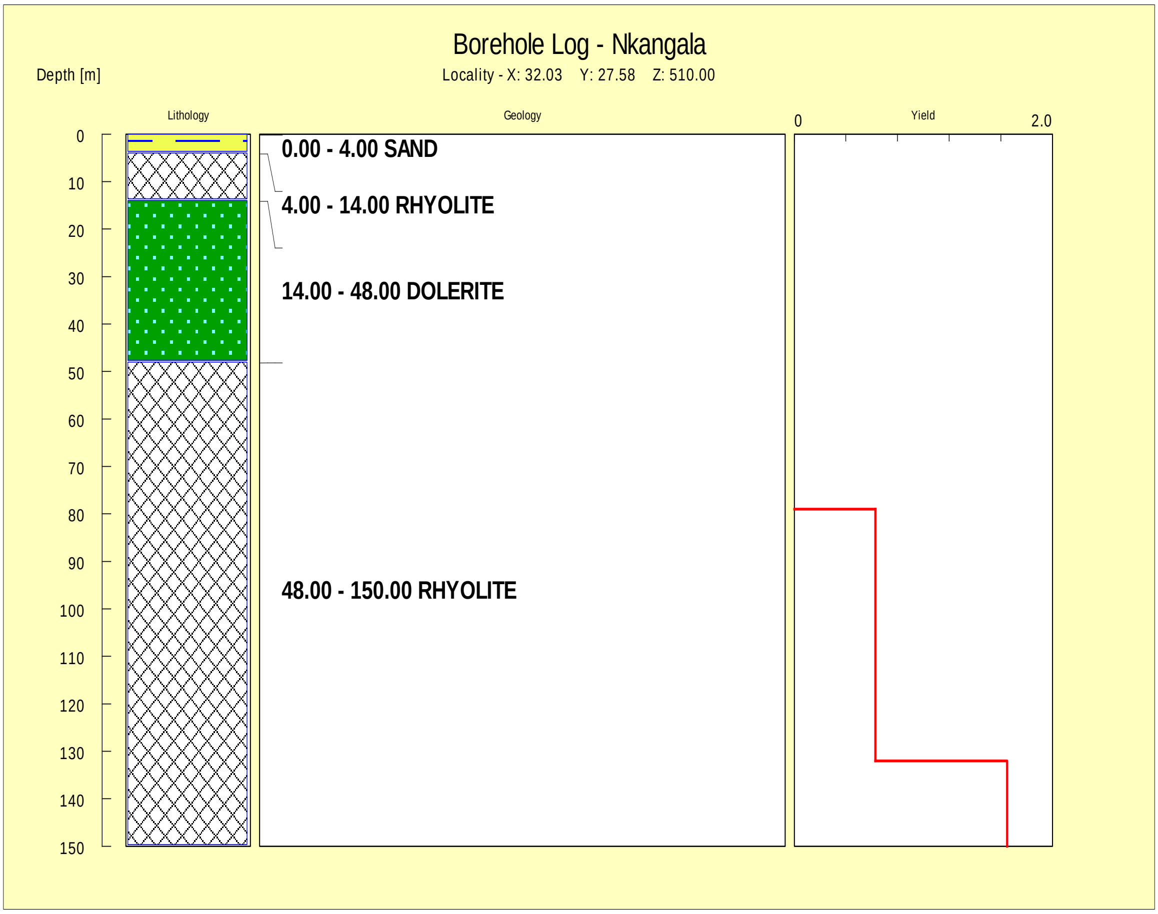


Figure 6-7: Borehole geological log in metres below ground level for the borehole drilled at Nkangala T05B with water strikes at 79 m and 135 m, the SWL at the end of drilling was recorded as 3.79 mbgl.

As discussed in Chapter 5, the edges of the discontinuous geological body were estimated at 19.5 m; however during the drilling process these edges were intersected at a depth of 14 m, a distance which is fairly comparable to the estimated depth.

Two water strikes were intersected at 79 mbgl with a corresponding blow yield of 0.63 l/s. A second water strike was at 135 mbgl with a blow yield of 1.66 l/s; both of these boreholes were on the rhyolite of the Jozini formation. The cumulative blow yield for this borehole was therefore recorded as 2.28 l/s, which suggests that the borehole is a moderately yielding borehole (Groundwater Development Services, 1994; DWAF, 1998).

This is the highest yielding borehole amongst the newly drilled boreholes. It was drilled on the boundary of d2 and d3, where the expected yields are 0.1-0.5 l/s and 0.5-2.0 l/s respectively (DWAF, 1998). According to Groundwater Development Services (1994), a borehole of such yield is suitable for reticulation schemes for villages, clinics and schools but it was decided that this borehole will also be fitted with a hand pump to be used by the community of Nkangala village. This decision was based on the realisation that the project was an emergency for drought relief and the area in which the borehole is drilled is not connected to the municipal's water infrastructure, therefore putting pumps for reticulation would have been costly and time consuming.

6.3.6 Mahangule geological log

The borehole log gives a description of the lithology for the borehole targeted at Mahangule T06 (Figure 6-8). The log shows the water strike with depth and blow yields for this borehole.

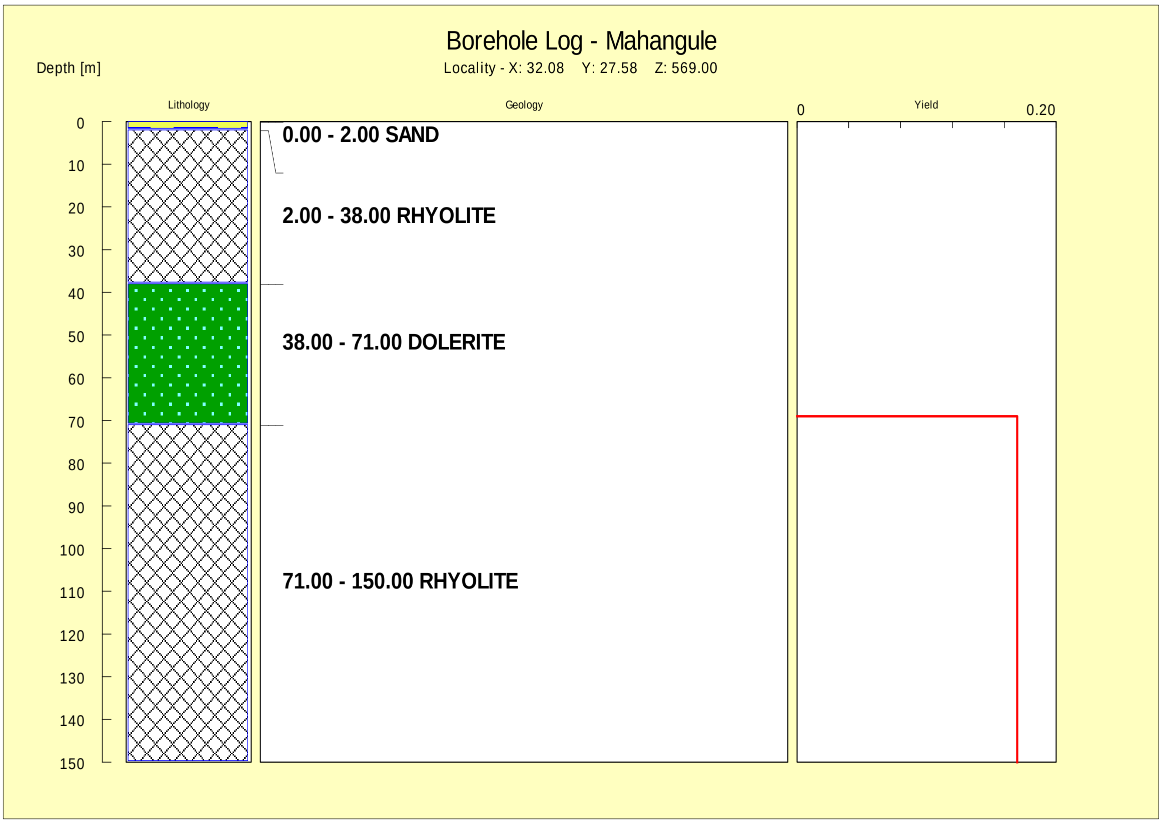


Figure 6-8: Borehole geological log in metres below ground level for the borehole drilled in Mahangule, with a single water strike at 69m and a recorded SWL of 19.13 mbgl.

This borehole was drilled to target the edges of the intrusion estimated to be at a depth of 26 m. However, the intrusion was only encountered at a depth of 36 m, almost 10 m from the estimated depth. The actual depth and the estimated depth are not comparable. This could be attributed to misinterpretation of geophysical data or miscalculation of the depth. A single water strike was encountered at the depth of 69 mbgl on the contact between the host rock rhyolite and the intrusion, with a blow yield of 0.17 l/s.

The contact between the host rock and the intrusion appears to be a good target for drilling of successful boreholes in the study area, as was also noticed from the studies by van Wyk (1963). According to (DWAF (1998), this blow yield is a representation of a low yielding borehole, suitable for primary water supply with either a hand pump or a wind pump for non-reticulated community supply (Groundwater Development Services, 1994). It was decided that once the water quality for this borehole is known, the borehole will be fitted with a hand pump provided that water quality is fit for domestic usage.

6.3.7 Madinyana geological log

Figure 6-9 shows a geological log for Madinyana (T07); this borehole was drilled based on the geological observation and the interpretation of the geophysical surveys. The borehole drilled to target the edges of the discontinuity which could be faulting, fracturing or weathering.

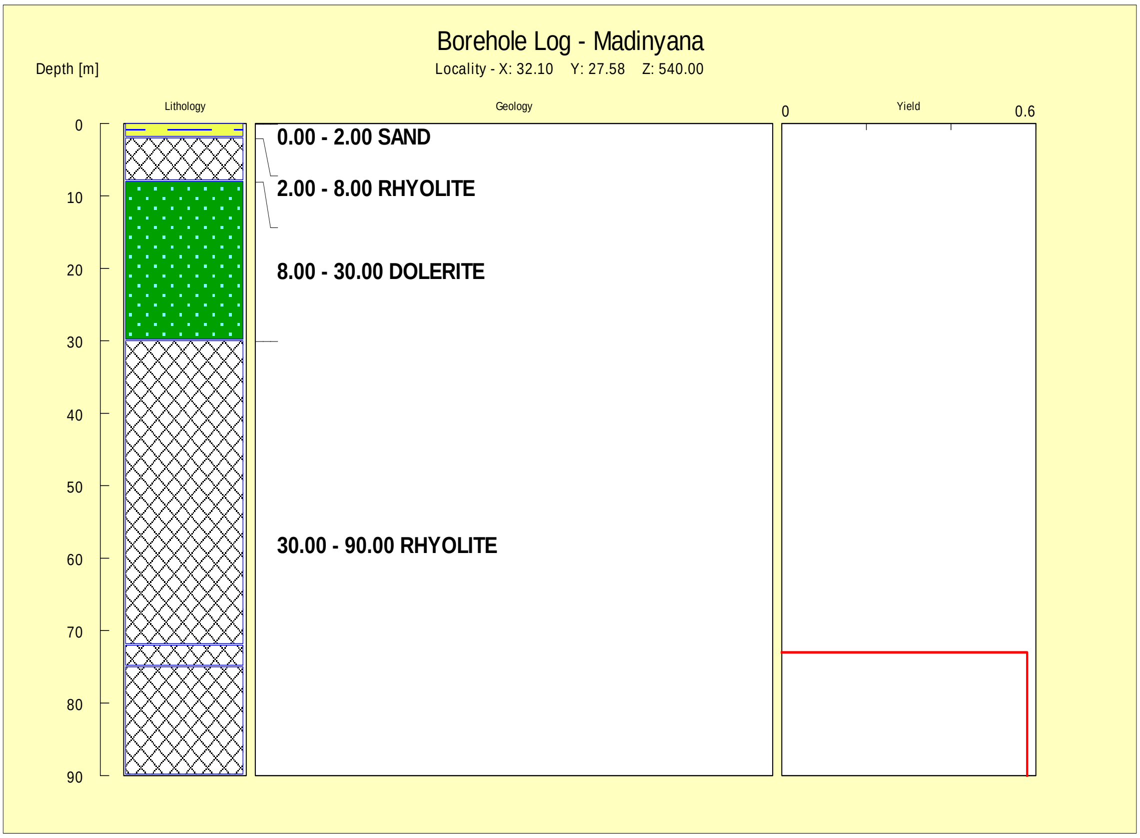


Figure 6-9: Borehole geological log in metres below ground level for the borehole drilled at Madinyana, with a water strike at 75 metres and SWL of 34 mbgl.

For this borehole the edges of the discontinuous geological body were estimated to be at 6.5 mbgl. However, during drilling the edges were intersected at the depth of 10 mbgl which is still very comparable to the estimated depth. A rhyolite of Jozini formation, with changing colour from pink becoming brownish was encountered at 30 m and beige from 72 m, and then at around 75 m light beige becoming pink-brown, fine clayey sand derived from in situ decomposed rhyolite of the Jozini formation was intersected. A water strike was also intersected at this depth of 75 m on the rhyolite formation with a corresponding blow yield of 0.58 l/s-; an indication of a low yielding borehole. This borehole will be fitted with a hand pump to be used by the community of Madinyana village. This blow yield and the others determined on the rhyolite formation in the study area indicate that rhyolite has a low ability to yield groundwater.

6.4 BOREHOLE INFORMATION

Table 6-2 gives the information regarding the boreholes drilled in the study area.

Table 6-2: Information on the boreholes drilled in the study area.

Site	Water Strike (m)	Water Level (mbgl)	Initial Target	Drilled Target	Blow Yield (l/s)
Jozini	54	16.02	Contact between the host rock and the intrusion	Intrusion	1.67
Machibini	30 & 108	30.55	Contact between the host rock and the intrusion	Contact of the host rock/intrusion and on rhyolite	0.31
Ophande	18 & 72	10.54	Edges of an intrusive formation	Both on the contact between the host rock and the intrusion	0.14
Majozini	60 & 132	43.80	Contact between the host rock and the intrusion	Contact of the host rock/intrusion and on rhyolite	0.14
Nkangala	79 & 135	3.79	Possible discontinuity of the negative anomaly	Both on rhyolite formation	2.28
Mahangule	69	19.13	Edges of an intrusive formation	Contact of the host rock/intrusion and on rhyolite	0.17
Madinyana	75	34	Contact between the host rock and the intrusion	On rhyolite formation.	0.58

Based on these blow yields, it can be said that only boreholes at Nkangala and Jozini were successful and therefore can be subjected to aquifer testing, however it was decided that all these boreholes should be tested to stress the aquifer, for determining the sustainable and safe yield, which is the maximum rate of withdrawal that can be sustained by an aquifer without causing an unacceptable decline in the hydraulic head or deterioration in water quality in the aquifer.

These blow yields are in line with the general yields expected in the study area, based on Groundwater Development Services (1994), DWAF (2004a) and Hydrogeological Map of

Vryheid sheet 2730 to scale of 1:500 000 (DWAF, 1998). It should be noted that, due to the nature of the study area; being a rural community with the “neighbourhoods” being scattered or being some distance from each other, it was decided that all these boreholes would be fitted with hand pumps.

Comparing the blow yields, based on the formations or an area where water strikes were intersected from Table 6-2, one realises that there is not much difference in blow yields for water strikes, which were intersected at the contact between rhyolite and the intrusion. But it can be said that when drilling in this area it would be advisable to target the intrusion or the host rock directly as can be seen from these boreholes (Jozini, Nkangala and Madinyana). Drilling in these formations shows higher blow yields than those drilled on the contact.

6.5 SUMMARY

This chapter focused on the drilling and the description of the geological logs, as obtained during the process of drilling. A total of eight (8) boreholes were drilled, based on the geophysical investigations and interpretation of the results thereof. One borehole was considered unsuccessful, in the sense that no water strike was intersected; while three other boreholes were considered to be unsuccessful, based on their low yielding property (blow yield <1.00 l/s). These blow yields are expected in the study area, as supported by Groundwater Development Services (1994), where it is stated that during that study, a total of 3770 boreholes were drilled. A third of those boreholes were sited to tap water from the Karoo dolerites, with yields tending to be 0.1-0.5 l/s with a median yield of 0.5 l/s. Blow yields for the newly drilled boreholes ranged between 0.14-2.28 l/s, which is an indication of low yielding to moderately yielding boreholes.

During the drilling process, for every metre the drill cuttings were recorded, these cuttings were used for interpretation of the geology of the borehole and presentation of geological logging. Most of the boreholes were drilled at a depth of 150 mbgl as the deepest and the shallowest had a depth of 90 mbgl. Dolerite intrusion was intersected in all drilled boreholes. The following chapter will discuss the pump testing and the interpretation thereof, using diagnostic plots.

CHAPTER 7: AQUIFER TESTING AND THE DETERMINATION OF AQUIFER PARAMETERS

7.1 INTRODUCTION

Pump testing is defined as a simplest way of understanding the physical behaviour of the aquifers and for determining the aquifer parameters (Kruseman & de Ridder, 1994). Furthermore, van Tonder, *et al.* (2002) stated that pumping tests are important tools that provide information on the hydraulic behaviour of a borehole, the reservoir and the reservoir boundaries. All this information is essential for efficient aquifer and well field management. In general, the objectives of a pumping test are:

- To obtain an understanding of the aquifer;
- To quantify the aquifer’s hydraulic and physical properties; and
- To determine the sustainable yield and efficiency of a borehole.

This chapter will therefore deal with the pump tests, with the aims of determining the aquifer parameters like transmissivity and storativity - where observation boreholes are available (Theis, 1935; Woodford & Chevallier, 2002), for the boreholes drilled and discussed in Chapter 6, as well as for the four boreholes which were refurbished, and pump tested by Jeffares and Green (Pty) Ltd.

7.2 METHODS AND MATERIAL

The pumping tests were carried out in accordance with the guidelines of the South African National Standard- Part 4 (SANS10299-4:2003): the following processes were implemented:

- Step drawdown test
- Constant discharge test

A brief explanation of how these processes are used for this project is given below.

7.2.1 Step drawdown test

The boreholes were step-tested, four-step each, taking 60 minutes and being allowed to recover at the end of the last step test. The steps were conducted at increasing rates and drawdown measured to ascertain the potential borehole yields. The purpose of the step test was to stress the boreholes across their yield range for short intervals, to extrapolate a suitable rate to be used for constant discharge (CD) test (Woodford & Chevallier, 2002).

7.2.2 Constant discharge test

A constant discharge test was performed with the aim of determining the aquifer parameters and borehole sustainable yield. This chapter will only focus on aquifer parameters, while the following chapter (Chapter 8) will focus on the determination of the borehole sustainable yields). The constant discharge rates were deduced from the step test data. According to Woodford and Chevallier (2002) it is common practise to run the test for about eight hours for boreholes to be equipped with hand, solar or wind driven pumps, and for about forty-eight hours for boreholes to be equipped with electricity or diesel driven pumps, which are to be operated daily.

During the tests, there were only two observation boreholes, to evaluate the possible impact of the pumping boreholes on the surrounding boreholes and to evaluate whether the boreholes are hydraulically connected. Borehole UMK2013 was used as an observation borehole for the newly drilled Nkangala (T05) borehole, which is about 10 m apart from each other. Borehole UMK2022 was on the other side; an observation borehole for the newly drilled borehole Mahangule (T06) at about 15 m apart (Figure 7-1).

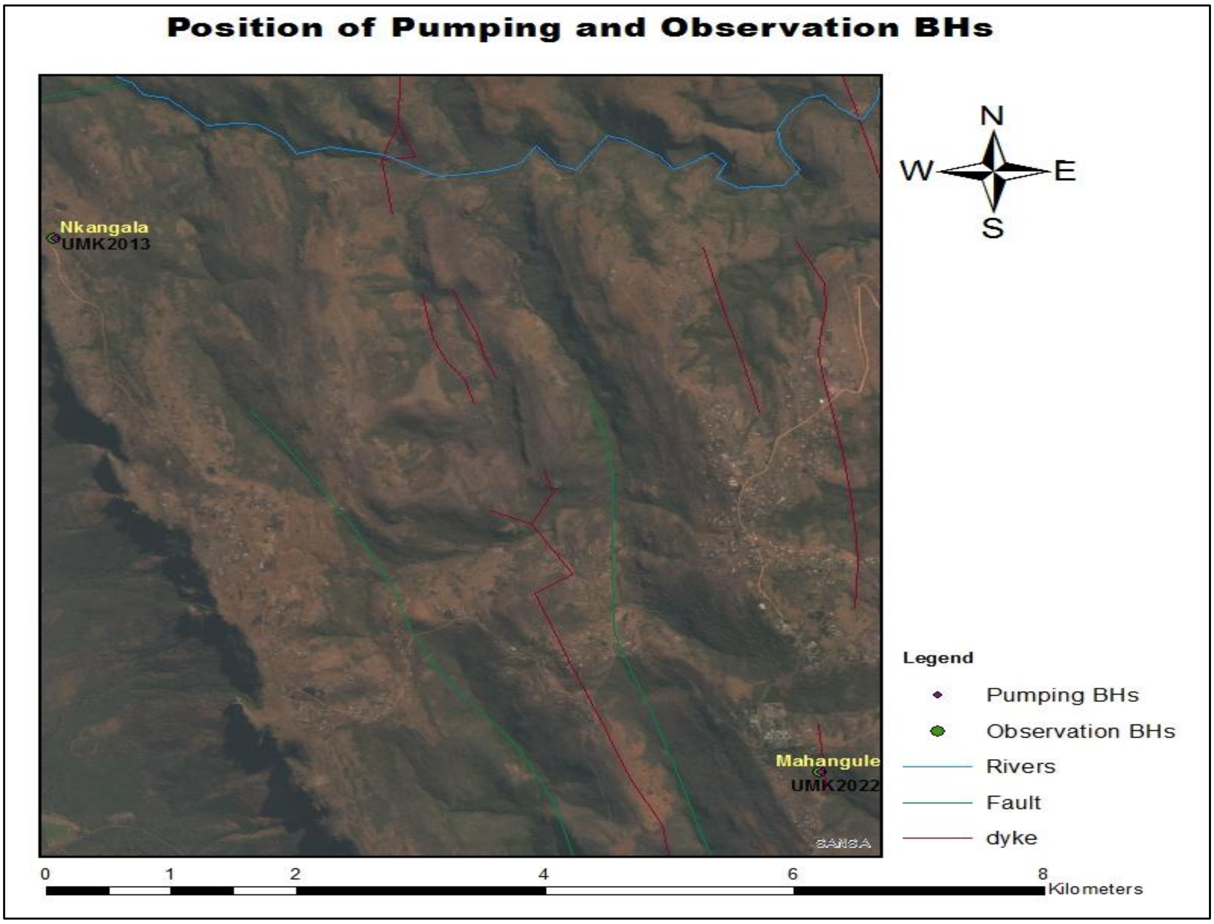


Figure 7-1: Pumping boreholes (Nkangala and Mahangule) in relation to the observation boreholes (UMK2013 and UMK2022).

According to Kruseman and de Ridder (1994) the period of pumping tests depends on the type of aquifer and the degree of accuracy desired in establishing its hydraulic characteristics. For this study, pumping tests lasted for a period of between 12 hours to 24 hours based on the DWAF (1997a) guidelines, as well as Woodford and Chevallier (2002). This choice of pumping duration was because of the nature of the drilled boreholes; being low yielding, therefore caution was exercised because long pumping duration might lead to the boreholes collapsing. This also took into consideration that the boreholes would be fitted with hand pumps. This pump test data for the determination of aquifer parameters would be analysed using the Cooper-Jacob (1946) method because of its simplicity. Based on Halford *et al.* (2006) transmissivity (T) is estimated by the fitting of a straight line to drawdowns on an arithmetic axis in a semi-log plot.

Kruseman and de Ridder (1994) and Abdel-Ghafour (2005) have stated that in some tests, steady-state or equilibrium conditions occurred a few hours after the start of pumping; while in others, they occurred within a few days or weeks. In others, they never occurred, even though pumping would continue for years. This was the case in this study where steady-state conditions occurred for some boreholes and did not for others; hence guidelines by DWAF (1997a) and Woodford and Chevallier (2002) were followed, with regard to the duration of pumping. The guideline stated that the test duration should not be less than 12 hours, and, in some instances, might last up to 72 hours or more. Table 7-1 gives the ranges of intervals used to take water levels during the period of pumping tests.

Table 7-1: Range of intervals between water level measurements in the well (Kruseman & de Ridder, 1994).

Time since start of pumping	Time intervals
0-5 minutes	1 minute
5-10 minutes	5 minutes
10-60 minutes	10 minutes
60-240 minutes	30 minutes
240-600 minutes	60 minutes
600 to shutdown	120 minutes

7.2.3 Recovery monitoring

This test provides an indication of the ability of a borehole and a groundwater system to recover from the stress of abstraction. According to Driscoll (1986) and Samani *et al.*, (2006) the recovery test can be used to calculate an aquifer's hydraulic parameters, to establish whether recharge has taken place during or shortly after constant discharge test.

Furthermore, Atanga (2014) has stated that recovery test measurements allow the transmissivity of the aquifer under the investigation, to be determined more accurately, this is because the residual drawdown field data is more reliable than the pumping test data, because recovery occurs at a constant rate, whereas in practise, it is often difficult to achieve constant discharge during pumping (Kruseman & de Ridder, 1994). The recovery monitoring was done until the water level recovered within 95% of the original water level or a period equal to the pumping test, whichever came first.

7.2.4 Data analysis

7.2.4.1 Flow diagnosis

For the analysis of test data, diagnostic plots were used. Diagnostic plots can be used to improve and assist with the interpretation of pump test data. According to Renard *et al.*, (2008), a diagnostic plot is a scatter plot of both drawdown and its logarithmic derivative versus time; usually plotted in log-log scale. A diagnostic plot allows the dominating flow regimes to be identified; these yield straight lines on specialized plots. One of the main advantages is that the techniques allow for identification of certain flow regimes and facilitate the selection of an appropriate model. It is for this reason that the diagnostic plots are used for this study. According to Kruseman and de Ridder (1994), there are diagnostic plots for confined aquifers, unconfined aquifers and the leaky aquifers of unconsolidated nature, as well as for the confined consolidated aquifers (Figure 7-2).

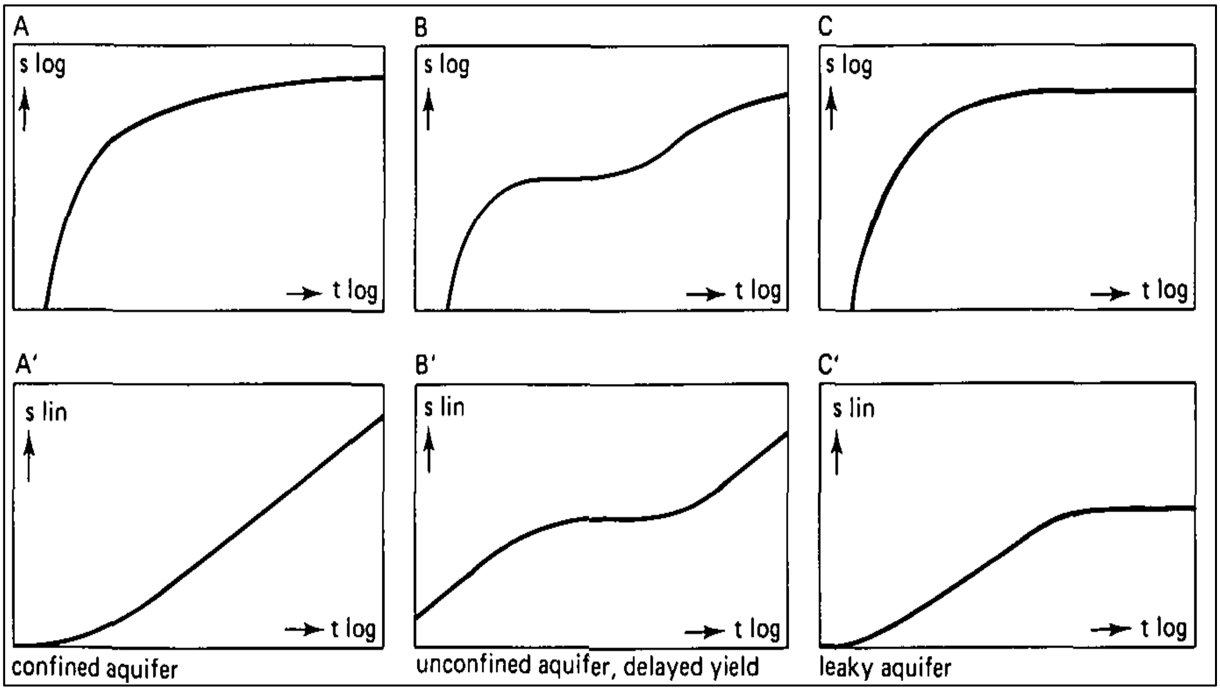


Figure 7-2: Log-log and semi-log plots of the theoretical time-drawdown relationship of unconsolidated aquifers: Part A and A'- Confined aquifer, Part B and Unconfined aquifer, Part C and C'- Leaky aquifer (Kruseman & de Ridder, 1994).

Figure 7-3 shows the typical derivative plot graph for various boundary conditions, adopted from Van Tonder *et al.* (2001). These will be used to further evaluate and explain the type of derivative obtained from pump testing data.

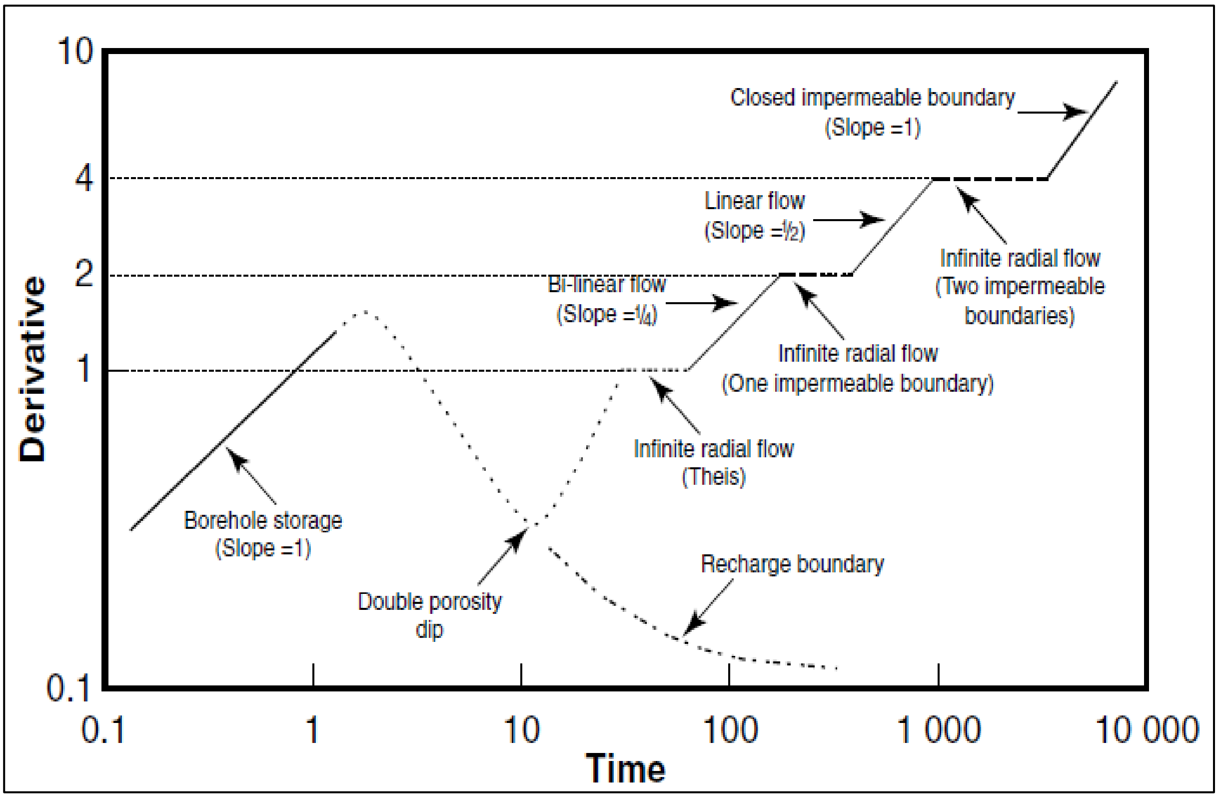


Figure 7-3: Typical derivative plot graph for different boundary conditions (van Tonder *et al.,* 2001).

In determining the aquifer characteristics, the drawdown log-log plot against pumping time, drawdown semi-log plot against time, and the derivative of drawdown log-log plot against time are used to identify the boundary conditions. Different lines are used to interpret the information of the derivative plot graph. Explanation of these lines is given in the tables below (Table 7-2,

Table **7-3** and Table 7-4).

Table 7-2: Characteristics of drawdown semi-log plot for a typical Copper-Jacob plot (van Tonder *et al.,* 1998)

Feature	Characteristic
Straight line segment	Indicates radial flow
Two parallel line	Double porosity
Flat Line	Recharge boundary or period where leakage from matrix abstraction rate or water level has reached position of a fracture
Steepening segment at late time	Boundary reached, or matrix flow becomes dominant

Table 7-3: Derivative plot (van Tonder *et al.*, 1998; Woodford & Chevallier, 2002)

Feature	Characteristic
Slope = 1 at early time	Well Bore Storage (WBS)
Slope = 0.5 at early time	Long fracture (usually factor 2 differences between drawdown and derivative): limited fracture network
Slope = 0.25 at early time	Finite fracture with factor 4 differences between drawdown and CJ-derivative: good fracture network
Slope = 1 at late time (upwards)	Closed boundary
Slope = downwards and then upwards	Position of fracture reached and then fracture dewatered
Strong downward trend	Recharge boundary
Dip in derivative	Double porosity aquifer

Table 7-4: Drawdown Log-log plot typical of the Theis plot (van Tonder *et al*, 1998)

Feature	Characteristic
Slope = 1 at early time	Well Bore Storage
Slope = 0.5 at early time	Linear flow in fracture: if difference between drawdown and derivative = factor 2, the fracture has a large areal extent. Water is coming from the fracture and not from the matrix
Slope = 0.25 at early time	Bilinear flow: water is leaking from the matrix to the fracture
Flat Line	Recharge boundary or leakage from matrix = abstraction rate or position of fracture is reached

Van Tonder *et al.* (1998) also stated that the log-log plot is the most generally useful plot; in that almost all the common aquifer responses are easily identified if the derivative is also used. With this in mind both log-log and semi-log plots will be used in the interpretation of data where possible, but where other aquifer responses are not easily identifiable with semi-log plot, only log-log and log-log derivative plots will be used.

7.2.5 Estimation of parameters

7.2.5.1 Pumping test data

This pump test data for the determination of aquifer parameters will be analysed using the Cooper-Jacob (1946) method because of its simplicity. The Cooper-Jacob method is the simplification of the Theis (1935) solution. Analysis with this method involves matching a straight line to drawdown data, plotted as a function of the logarithm of time since pumping began (Cooper-Jacob, 1946; Meier *et al*,. 1998; Halford *et al.*, 2006). The T-value is estimated by fitting the line at the Radial Flow (or Radial Acting Flow). T-values were estimated using Equation 7-1

$$\boldsymbol{T = 2.3Q/4\pi\Delta s}$$

Equation 7-1

Where: T = transmissivity, Q = Pumping rate and Δs = Gradient. This equation is applicable for both a single well and multiple well tests.

This method has been used by many practitioners to analyse drawdowns in confined and unconfined aquifers, regardless of differences between field conditions and theory (Halford *et al.*, 2006), however, it should be noted that the method is theoretically applicable for confined aquifers.

7.2.5.2 Recovery test data

The recovery data interpretation will be based on the Theis recovery model (Theis, 1935), related to late time drawdown, in an infinite homogeneous aquifer. The recovery test has the following advantages (Willmann *et al.*, 2007):

- A recovery test follows naturally from a pump test, because it only requires the recording of a head after pumping has ceased;
- Can be used even when pumping rates are difficult to control;
- Tests are fairly inexpensive, and no equipment or additional observation wells are required, apart from a water-level measuring device; and
- Results are usually not sensitive to well losses.

An approximation to the late data which leads to Equation 7-2 is the most common and easiest way to interpret a recovery test.

$$s = \frac{2.3.3Q}{4\pi T}\log\left(t + \frac{tp}{t}\right) = 0.183\frac{Q}{T}\log(t *)$$

Equation 7-2

Where: s is residual drawdown, Q is the pumping rate, T is the transmissivity, tp is the pumping time, and t is the elapsed time since pumping stopped. The variable t* = (t+tp)/t is termed equivalent time.

According to Willmann *et al.* (2007) and Neuman et al. (2007) the use of equivalent time causes late time to be displayed on the left side, corresponding to small residual drawdown (Figure 7-4). Equation 7-2 indicates that the late time data displays a straight line passing through the origin, provided that no residual drawdown remains when the aquifer reaches equilibrium, therefore the slope (m) of this line is the coefficient in Equation 7-2. The knowledge of m allows for the estimation of transmissivity using:

$$T = 0.183\frac{Q}{m}$$

Equation 7-3

The recovery method takes heterogeneity of the aquifer into consideration (Willmann *et al.*, 2007) because field data cannot be explained by the homogeneous theory as transmissivity (T) is heterogeneous over an evolving range of scale (Samani *et al.*, 2006; Willmann *et al.,* 2007).

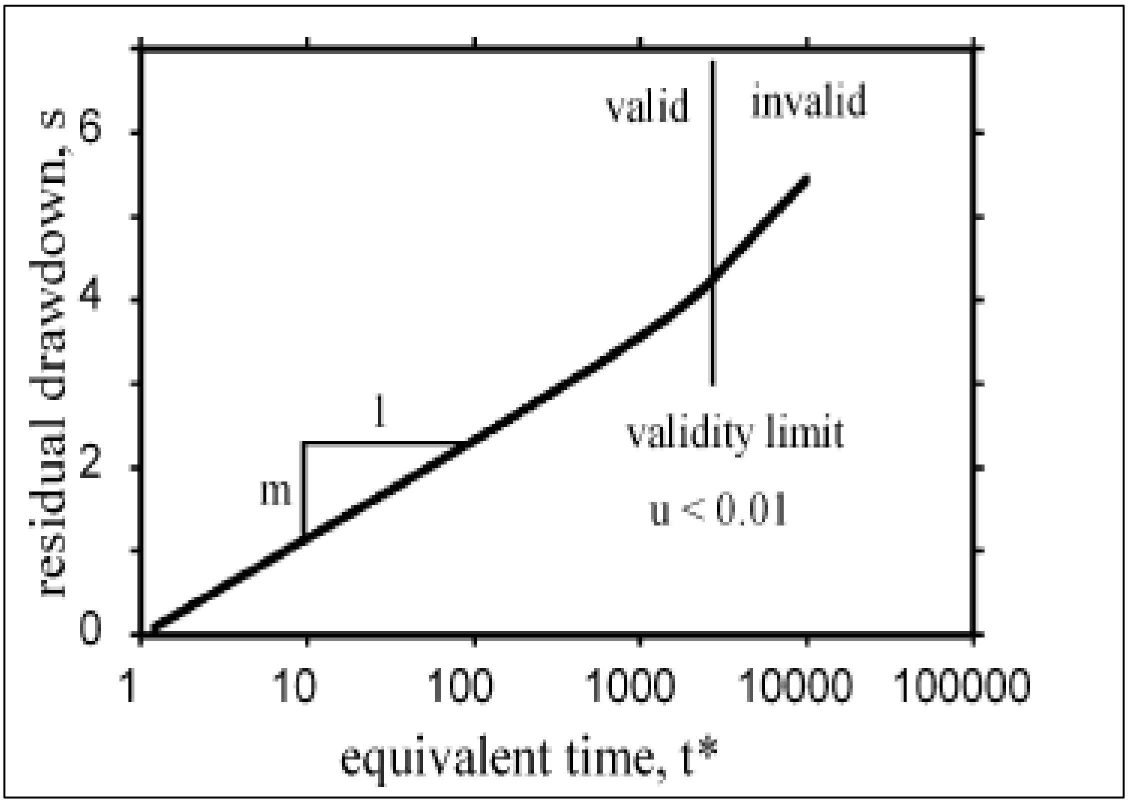


Figure 7-4: The "ideal" Theis recovery plot. Transmissivity can be calculated from the slope m through Equation 7-3 (Willmann *et al.*, 2007).

7.3 RESULTS AND DISCUSSION

7.3.1 Step drawdown test

Figure 7-5 below shows the results of the step tests undertaken for borehole Jozini (T01), with a blow yield of 1.67 l/s. From this graph it can be seen that the flow conditions started being stable from 135-180 minutes of the test, which was during the third step test. A pumping rate of 0.56 l/s was used for that step; therefore, it was decided to use this rate of 0.56 l/s for a constant discharge test for this borehole. Only one of the existing boreholes

(UMK2003) was subjected to four step test other boreholes had three step tests and proceeded to constant discharge (CD) refer to Table 5.

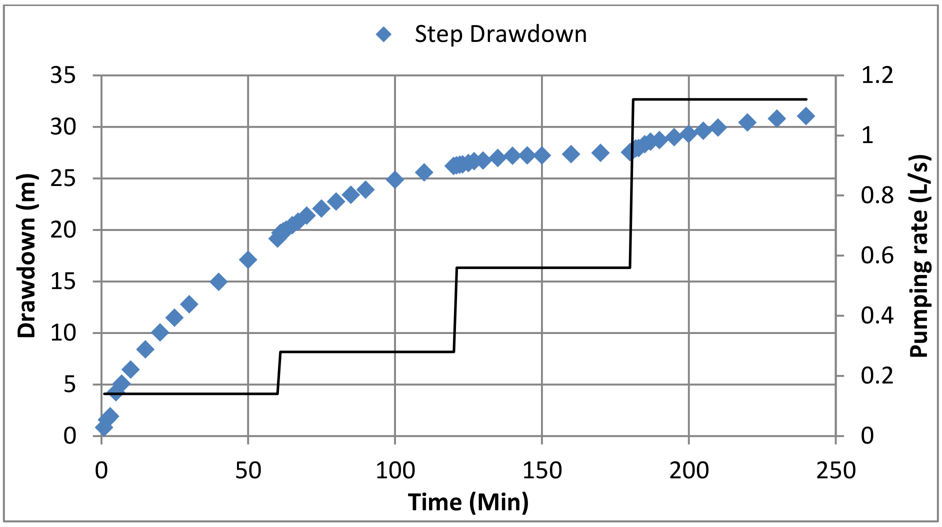


Figure 7-5: The results of step drawdown test for borehole T01.

The calculations and determination of constant discharge rates for the other boreholes are given using similar interpretation as above in Appendix D.

Table 7-5: Summary of pump testing information for both step discharge tests and constant discharge rate test.

Target	Name	Steps (l/S)				Step Duration (min)				Constant Discharge	
		1	2	3	4	1	2	3	4	Rate (l/s)	Duration (min)
T01	Jozini	0.14	0.28	0.56	1.12	60	60	60	60	0.56	1320
T02	Machibini	0.08	0.17	0.25	0.32	60	60	60	60	0.32	720
T03	Ophande	0.04	0.10	0.14	0.19	60	60	60	60	0.14	720
T04	Majozini	0.04	0.09	0.14	0.22	60	60	60	60	0.22	720
T05	Nkangala	0.83	1.11	1.67	2.22	60	60	60	60	1.32	1440
T06	Mahangule	0.06	0.11	0.17	0.22	60	60	60	60	0.14	720
T07	Madinyana	0.17	0.22	0.33	0.44	60	60	60	60	0.33	720
UMK2003	UMK2003	0.34	0.63	0.75	1.25	60	60	60	60	0.50	720
UMK2018	UMK2018	0.10	0.21	0.56	to CD	60	60	20	-	0.26	540
UMK2026	UMK2026	1.15	2.21	4.9	to CD	60	60	30	-	0.19	240
UMK2041	UMK2041	to CD	-	-	-	-	-	-	-	1.60	1200

7.3.2 Constant rate test

All drilled boreholes were pump tested at constant discharge rates, which were determined through step tests and the results thereof are given in Table 7-5.

7.3.2.1 Flow characteristics and estimation of parameters

7.3.2.1.1 Jozini (T01)

A constant pumping rate of 0.56 l/s was used during the pumping for T01 (Jozini). The plots are shown in Figure 7-6 and Figure 7-7.

These plots reveal behaviour of unconfined aquifer (Kruseman & de Ridder, 1994) when compared with plots on Figure 7-2. The straight-line segment on the semi-log plot/Cooper-Jacob plot (Figure 7-7) is an indication of radial flow. A derivative plot (Figure 7-6) at 15 minutes to 40 minutes shows a horizontal line for radial acting flow which can also be seen on the semi-log plot by a sort of straight line in the same time.

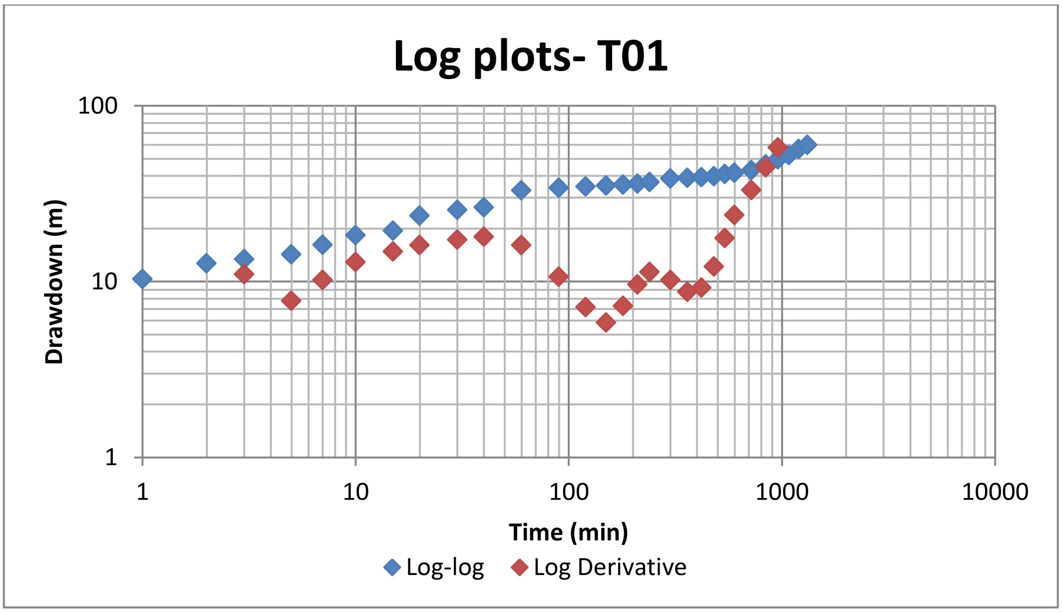


Figure 7-6: Log plots (log-log and log derivative) for Jozini borehole (T01).

The straight-line segment on the semi-log plot (Figure 7-7) is an indication of radial flow. A derivative plot at 15-40 min shows a horizontal line for radial acting flow which can also be seen on the semi-log plot by a sort of straight line in the same time. The derivative plot shows a downward trend at 60 minutes, while at this time a log-log plot shows a flat line. This observation is associated with a recharge boundary.

A porosity dip is seen at 150 minutes on the derivative plot. Another hump in derivative can be seen at t 360 min. This is thought to be an influence of the water strike which was intersected at the depth of 40 m during drilling. Both derivative and semi-log plot further shows boundary at late time (480 min).

Furthermore, as stated in the methods and material section the Cooper-Jacob (1946) method was used to determine the transmissivity (T) value. The T value was determined where the pumping test revealed acting radial flow at time 15-40 min (Figure 7-7); the T-value was estimated to be 0.5 m²/d.

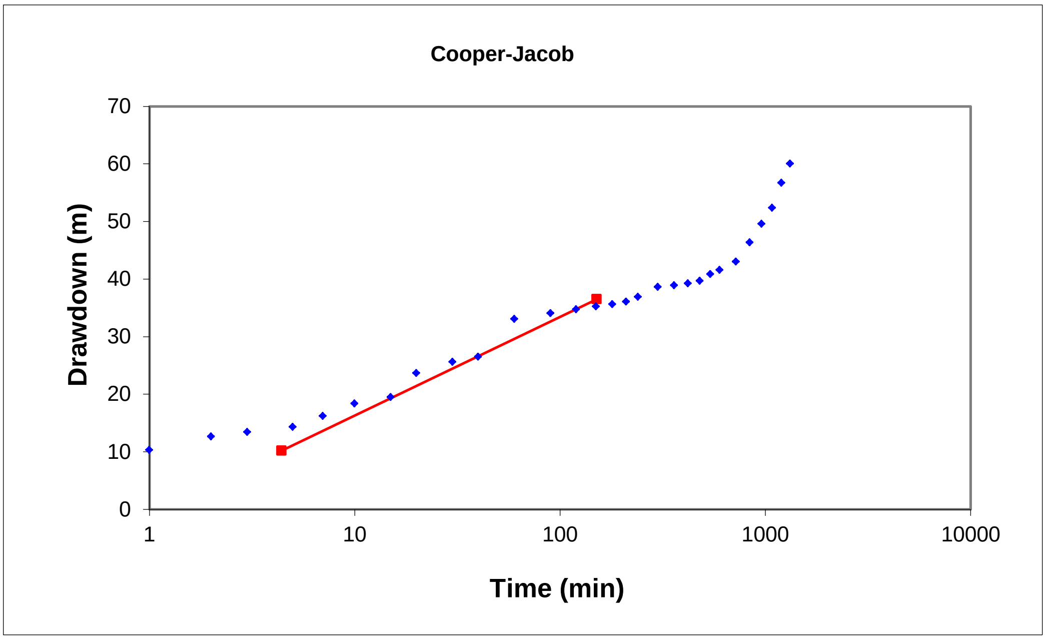


Figure 7-7: Cooper-Jacob fit for the determination of T-value for Jozini (T01) borehole.

7.3.2.1.2 Machibini (T02)

For Machibini, a constant rate of 0.32 l/s was used; Figure 7-8 and Figure 7-9 displays the log-log and semi-log (Cooper-Jacob plot) diagnostic plots for constant tests undertaken for the borehole in Machibini. The test was for a period of 12 hours.

The semi-log/Cooper-Jacob plot shows a radial flow with what appears to be a straight line on the plot. A derivative log plot at early time (5-20 min) shows a well-bore storage. This observation could not be made on the log-log plot.

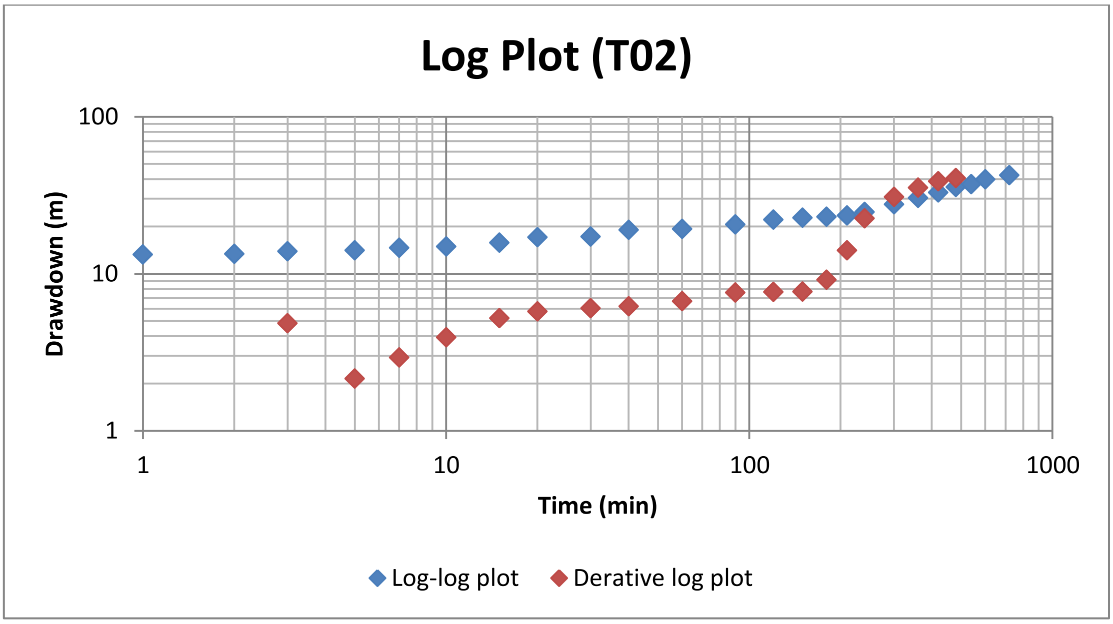


Figure 7-8: Log (Log-log and derivative log) diagnostic plot for a constant rate test for Machibini (T02).

The pumping test data at time 20-60 min shows what appears to be acting radial flow. This is where the T-value can be determined (Cooper-Jacob, 1946). Both log-log and semi-log plot shows a constant rise in drawdown values at late time (300 min). This observation could be associated with water from the water strike which was encountered at 30 m.

Using the Cooper-Jacob method, the T-value for Machibini was estimated to be 1 m²/day. Fitting of the line for this estimation is shown in Figure 7-9.

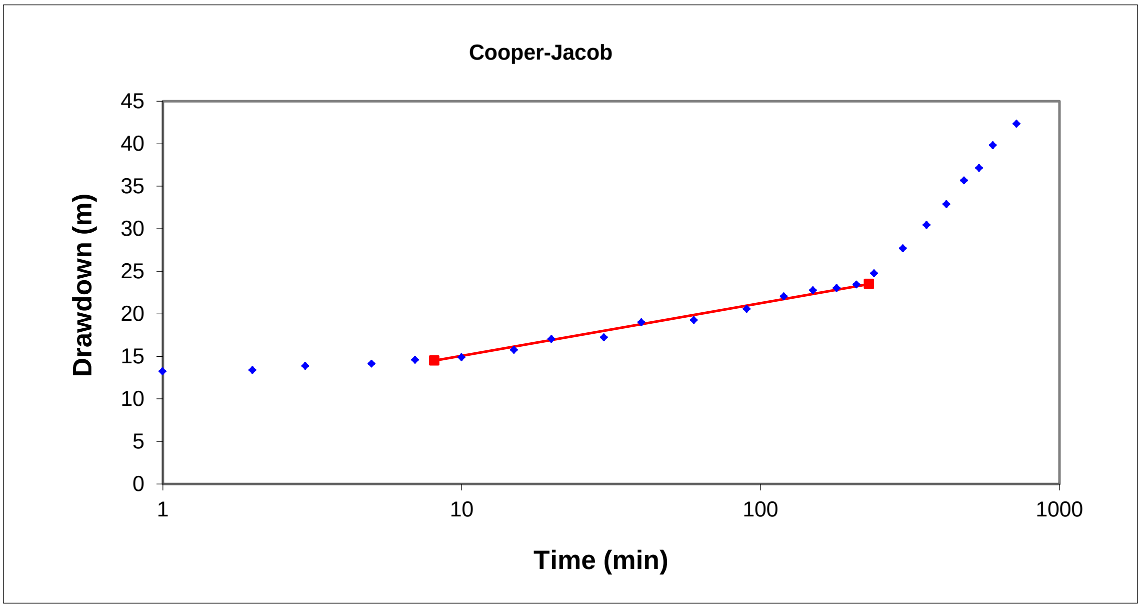


Figure 7-9: Cooper-Jacob fit for the determination of T-value for Machibini (T02) borehole.

7.3.2.1.3 Ophande (T03)

Figure 7-10 and Figure 7-11 represents plots for constant pump testing at the Ophande borehole, with a constant pumping rate of 0.14 l/s for a total pumping period of 12 hours.

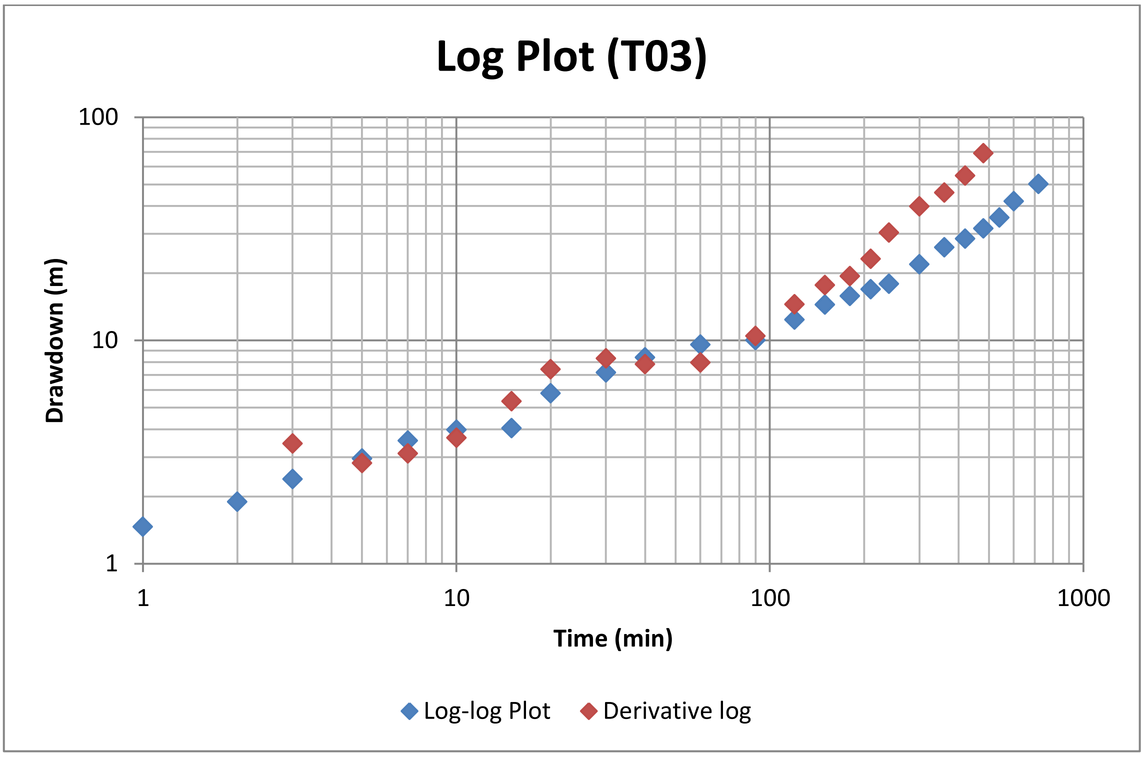


Figure 7-10: Log (Log-log and derivative log) diagnostic plot for a constant rate test for Ophande (T03).

The log-log and derivative plots show a 0.5 slope at early time, 1-15 min and 5-10 min respectively. This is an indication of linear flow, meaning that water comes from the fractures and not from the matrix. An infinite acting flow can be seen on the derivative plot at time 20-60 min. The log-log and semi-log plot shows the slope at late time (210-720 min). This observation could be due to the position of the water strike.

Figure 7-11 shows the Cooper-Jacob fit for the determination of the T-value for the borehole drilled at Ophande. Using this method the T-value was estimated to be 0.4 m²/day.

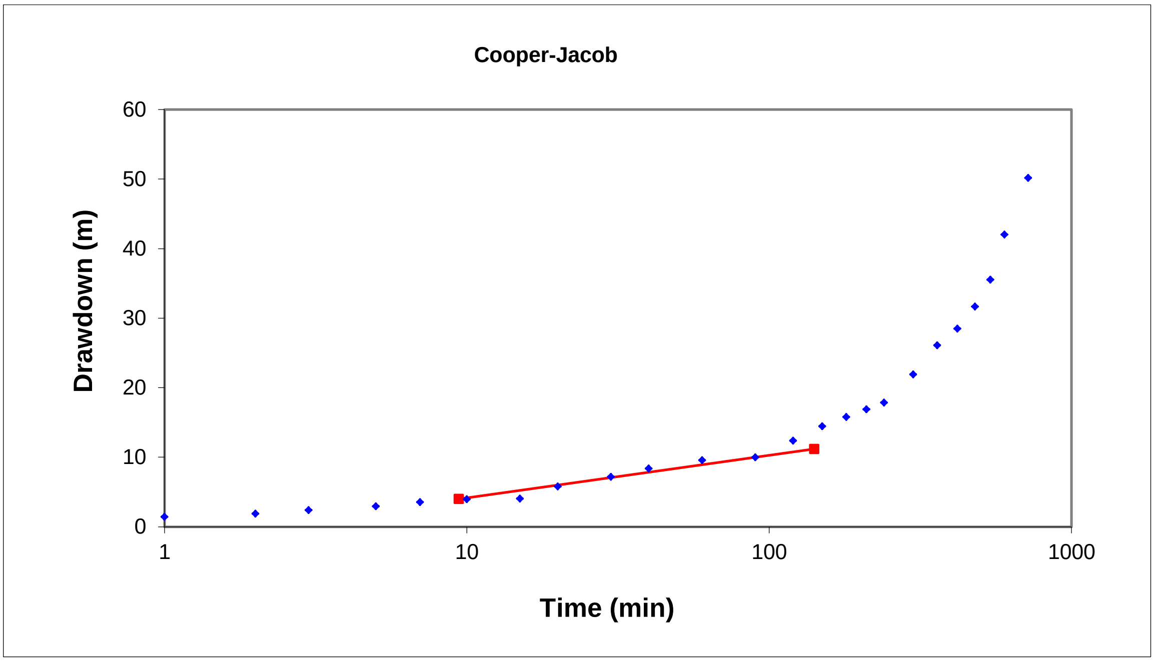


Figure 7-11: Cooper-Jacob fit for the determination of T-value for Ophande borehole.

7.3.2.1.4 Majozini (T04)

For the Majozini borehole, a constant pumping test with the constant rate of 0.22 l/s was conducted for a period of 12 hrs, as can be seen on the plots below (Figure 7-12 and Figure 7-13), displaying a behaviour of confined aquifer, based on plots by Kruseman and de Ridder (1994) refer to Figure 7-2.

The log-log plot shows well-bore storage (WBS) at early time (1-10 min). This observation is seen at time 5-10 min on the derivative plot. The WBS is followed by a strong downward slope on the derivative plot (15-40 min) and a sort of flattening of drawdown on both the log-log and semi-log plot (20-40 min), this is an indication of a recharge boundary being reached. The derivative plot also shows radial acting flow at time 40-210 min, which could be used for the determination of the T-value during the pumping test. A no-flow boundary is then seen at late time (300-480 min) on the derivative plot with the slope of 1.

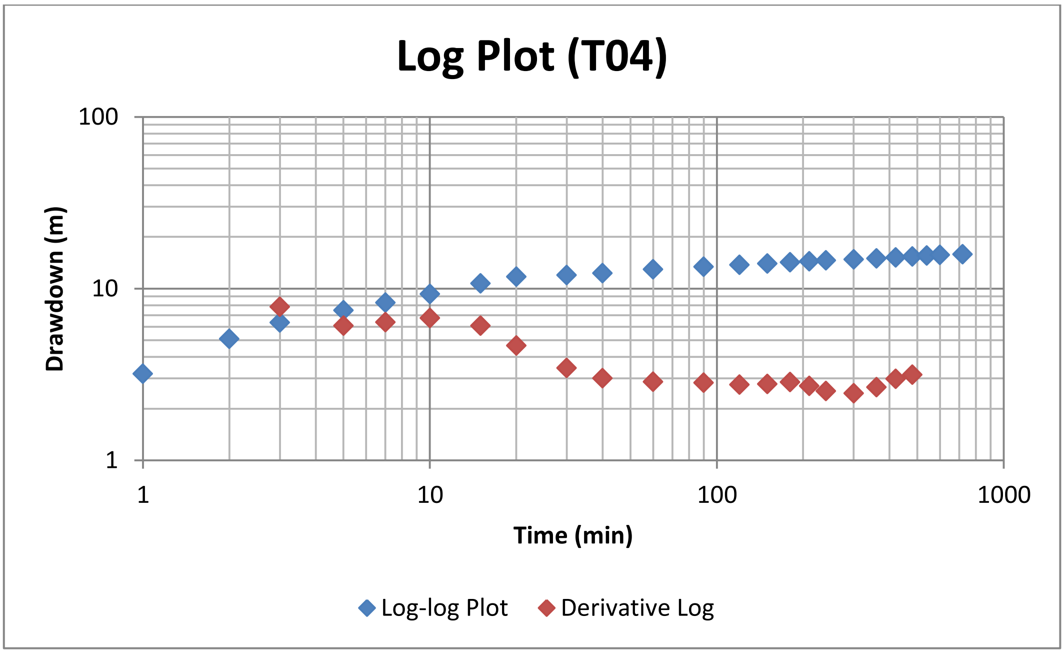


Figure 7-12: Log (Log-log and derivative log) diagnostic plot for constant rate test for Majozini borehole.

With the Cooper-Jacob method, a T-value of 1.2 m²/day was estimated for this borehole (Figure 7-13), the T- value was estimated where the plots displayed acting radial flow behaviour.

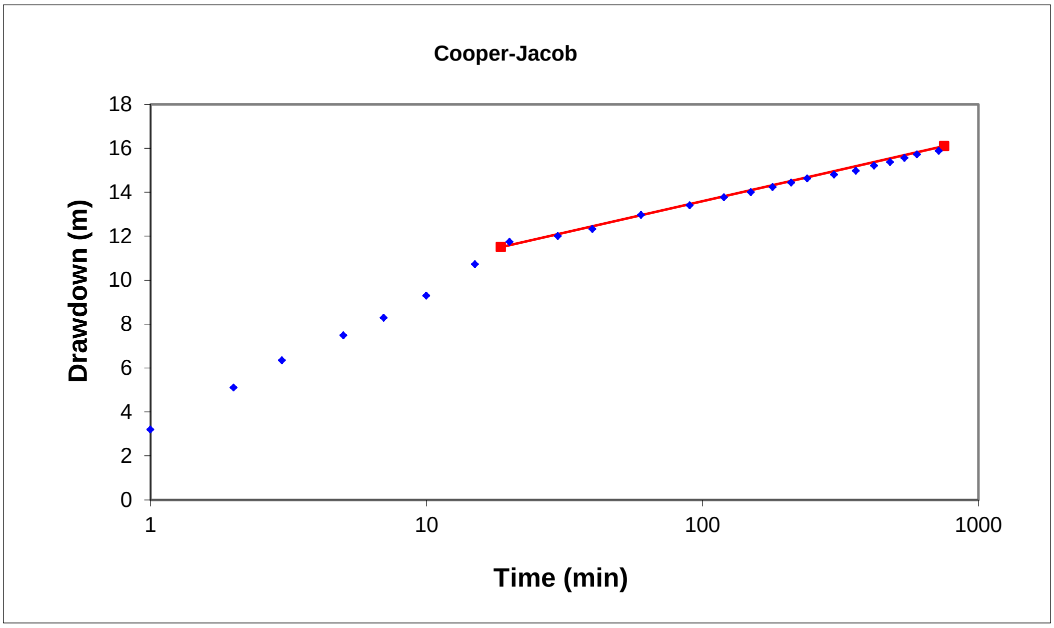


Figure 7-13: Cooper-Jacob T-value determination for Majozini borehole.

7.3.2.1.5 Nkangala (T05)

A constant pumping rate of 1.32 l/s was used at Nkangala with UMK2013, serving as the observation borehole about 10 m apart. These two boreholes are believed to be hydraulically connected, as the observation borehole showed a slight decline in water levels, when pumping was taking place. Figure 7-14 and Figure 7-15 show the results of the constant rate test on log plots and semi-log plots respectively.

Semi-log plot/Cooper-Jacob plot below (Figure 7-15) shows radial flow behaviour for this borehole indicated by the straight-line segment. The derivative plot shows what appears to be a porosity dip at time 5 min. Early time (1-7 min) on log-log plot and 5-10 min on the derivative plot shows WBS, the log-log plot also shows a slope of 0.5 at time 10-30 min as well as time 120-540 min which is an indication of linear flow, implying that water is coming from the fractures and not the matrix. Looking at the derivative plot at time 15-30 min acting radial flow can be seen, this plot also shows a single no flow boundary at time 150-210 min; when looking at the borehole log this is near the intrusion.

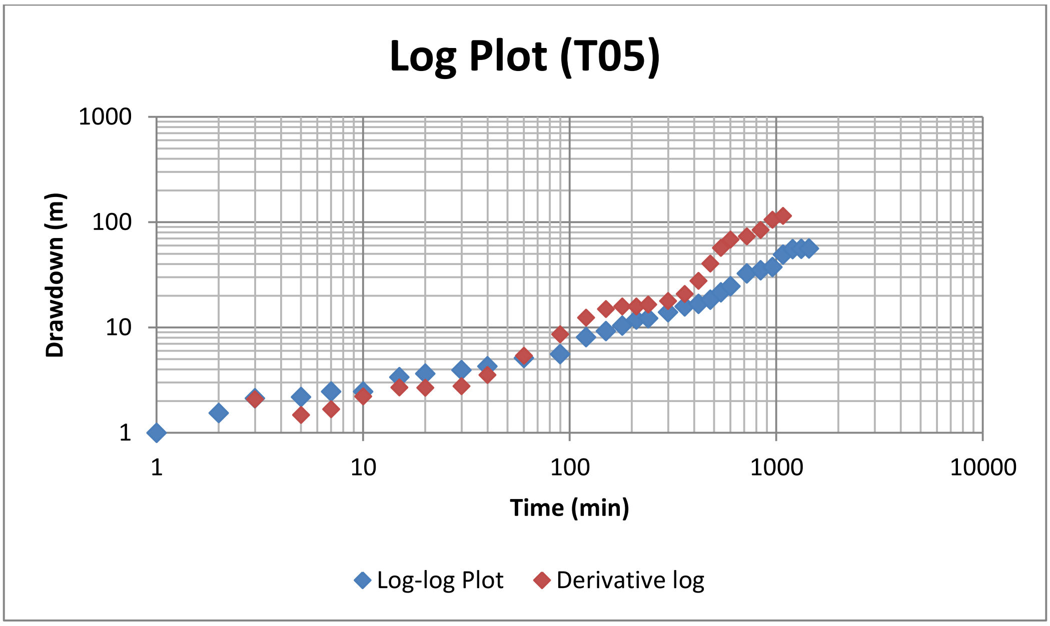


Figure 7-14: Log (Log-log and derivative log) diagnostic plot for constant rate test at Nkangala

The position of the fracture was reached at time 720-960 min., shown by the flat line segment on both log-log and semi-log plots. Thereafter, both these plots show the boundary at time 1080-1320 min.

Figure 7-15 below shows the plot for Cooper-Jacob, which was used to determine the T-value for the borehole drilled at Nkangala. Using this method the T-value was estimated to be 1.3 m²/day.

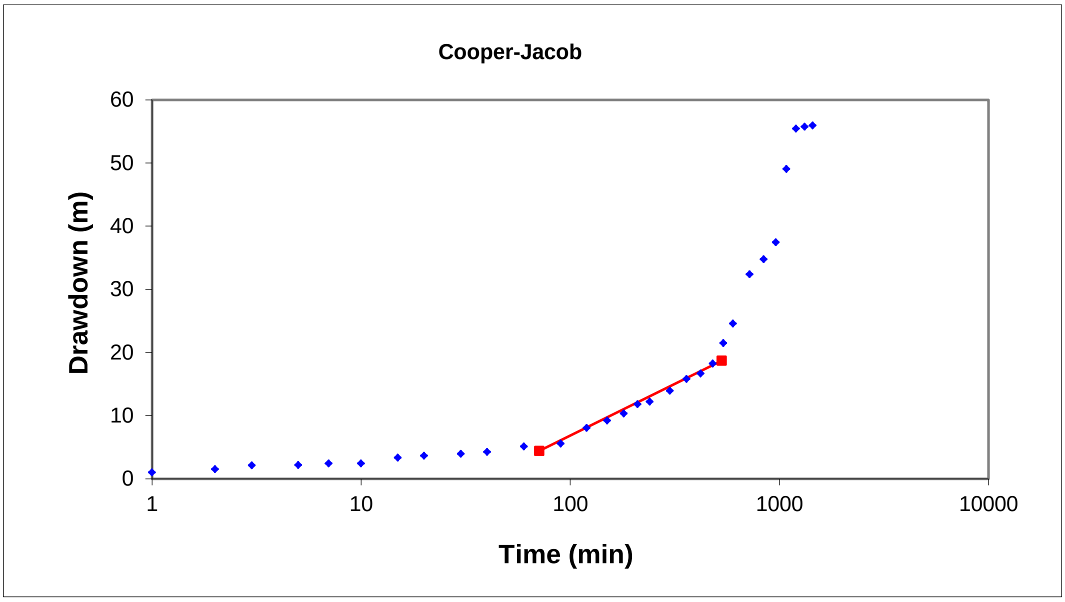


Figure 7-15: The Cooper-Jacob plot for the estimation of transmissivity value for Nkangala borehole.

7.3.2.1.6 Mahangule (T06)

Borehole UNK2022 was used as an observation borehole, at a distance of 15 m. No change in water levels was seen from the observation borehole; suggesting that these two boreholes are not receiving their water from the same source. Figure 7-16 and Figure 7-17 shows the graphical presentation of the constant pumping test results, these plots (Log-log and semi-log/Cooper-Jacob) represent a characteristic of a leaky aquifer, when compared to the theoretical time-drawdown relationship of unconsolidated aquifers (Figure 7-2).

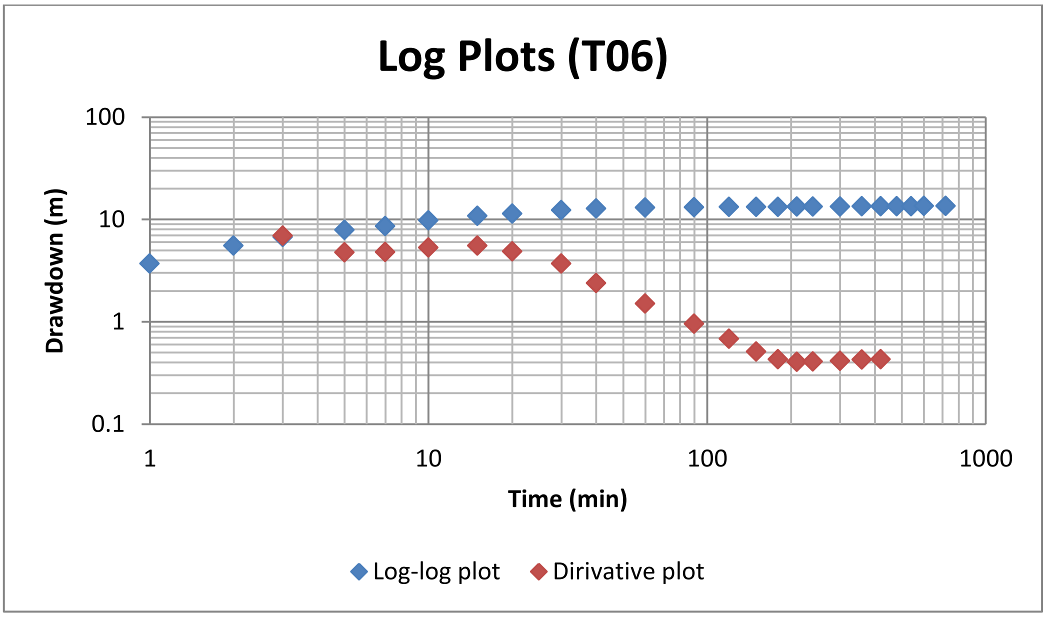


Figure 7-16: Log (Log-log and derivative) diagnostic plot for constant rate test at Mahangule.

Cooper-Jacob plot (Figure 7-17) gives a straight-line segment, which is an indication of radial flow. In Figure 7-16, the log-log plot fits a slope of 1 at early time (1-3 min), but this observation is not made on the derivative plot. At medium time (5-15 min) the log-log plot reveals a bilinear flow characteristic with a slope fit of 0.25, meaning that water is leaking from the matrix into the fracture.

The stabilisation of the drawdown as can be seen on both the log-log and semi-log plots at the late time suggests that the water is now pumped through leakages and flows towards the well (Kruseman & de Ridder, 1994). An acting radial flow characteristic is shown on the derivative plot at time 5-15 min. All the plots show the position of the recharge boundary being reached at late-time (30-180 min) on both the log-log and the derivative plot, only being visible on the semi-log plot at 60-180 min. This observation is supported by the flattening of the drawdown on the log-log and the semi-log; while on the derivative plot, it is supported by a strong downward slope. A semi-log plot still shows a radial flow characteristic at late time (300-720 min).

Figure 7-17 shows the Cooper-Jacob plot used to determine the transmissivity value for the borehole at Mahangule. The T- value was estimated to be 0.4 m²/day.

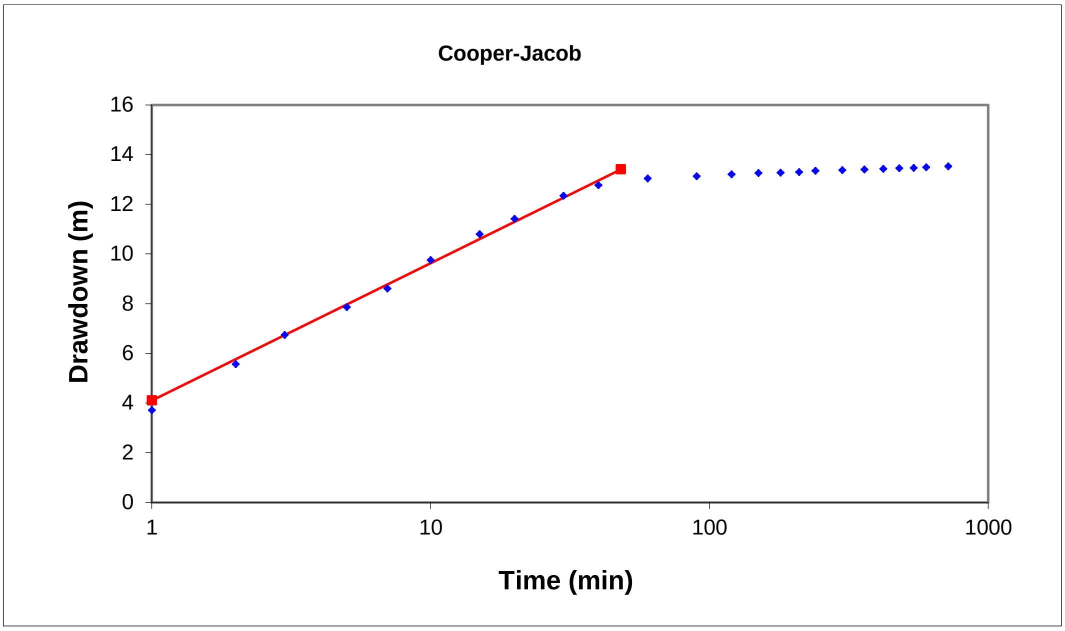


Figure 7-17: Cooper-Jacob methods determination of transmissivity value for Mahangule borehole.

7.3.2.1.7 Madinyana (T07)

A constant pumping test for a borehole at Madinyana was conducted for a total duration of 18 hours, with a constant pumping rate of 0.33 l/s, as determined from step tests. The diagnostic plots used for data analysis are depicted below in Figure 7-18 and Figure 7-19

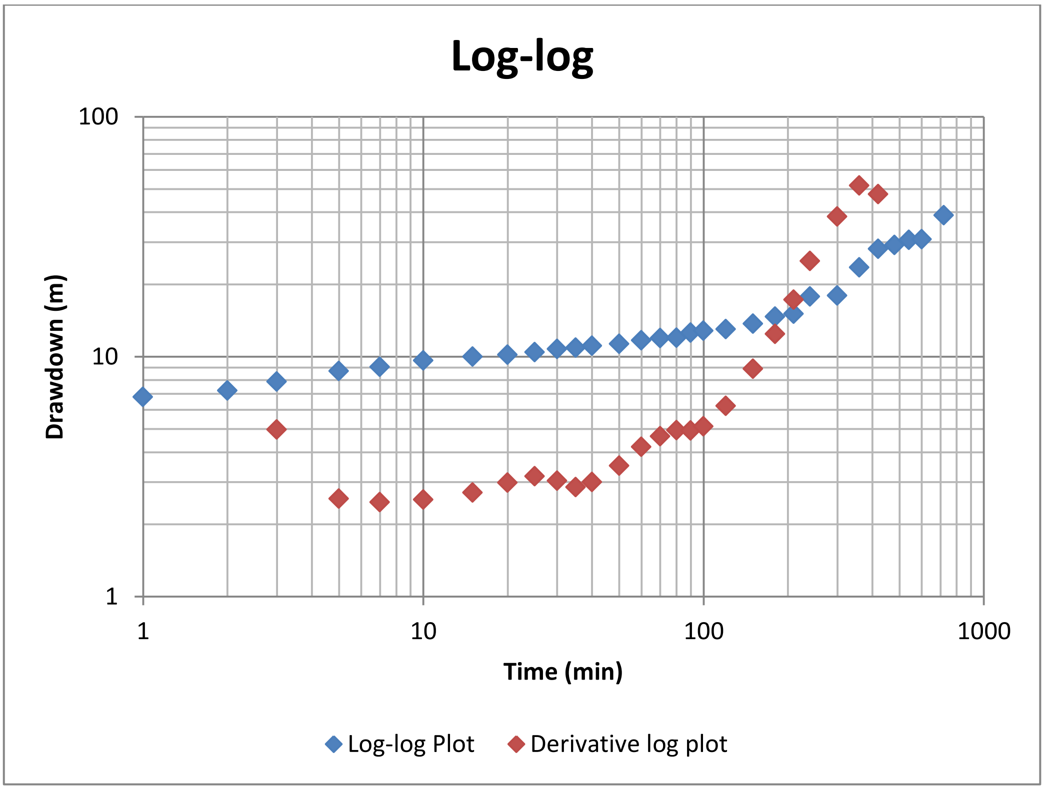


Figure 7-18: Log (Log-log and Derivative log) diagnostic plot for constant rate test at Madinyana.

The Log-log plot (Figure 7-18) shows a slope fit of 0.5 for linear flow, which means that water is coming from the fractures and not the matrix. The derivative plot at early time (5-15 min) reveals a characteristic of porosity dip. A recharge boundary can be seen from all the plots with derivative plot being represented by decline in the drawdown, while on both the log-log and the semi-log plots this characteristic of a recharge boundary can be seen as the drawdown flattens (25-35 min). The acting radial flow can further be seen on the derivative plot at medium time (70-100 min). Looking at the log-log plot/Cooper-Jacob plot (25-240 min) there was a bilinear flow, meaning that water was now coming from the matrix into the fracture. This is near the rhyolite, as can be seen on the borehole log in Chapter 6.

Like other boreholes, the T-value was estimated for Madinyana borehole. The Cooper-Jacob method (Figure 7-19) was used where a line was fitted at the time in which acting radial flow was seen during the analysis of constant rate test. For this borehole the T-value was estimated to be 1.3 m^2/day.

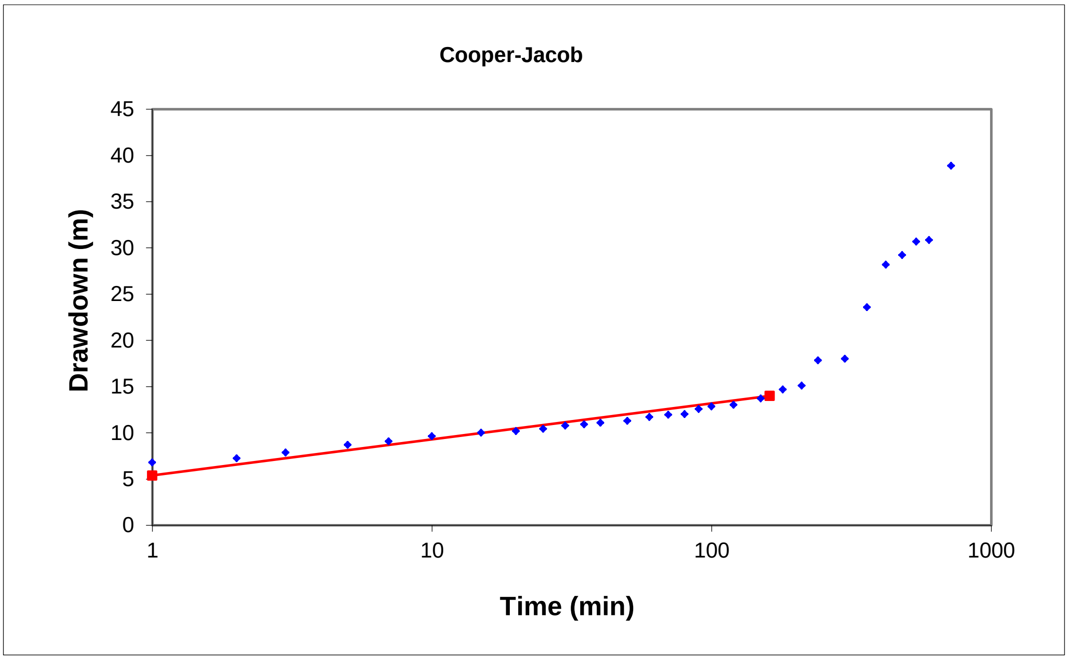


Figure 7-19: Cooper-Jacob methods determination of transmissivity value for Madinyana borehole.

Table 7-6 below gives a summary of the transmissivity values determined through the Cooper-Jacob (1946) method, from constant test data. T-values were estimated by fitting a straight line to drawdowns on an arithmetic axis against time, on a log-arithmetic axis in a semi-log plot. Their plots are shown. The determination of flow characteristics for each borehole above is discussed.

Table 7-6: Summary of transmissivity values determined during constant pump test for both the newly drilled boreholes and the four refurbished boreholes.

Name	Pump Test T-value m²/day
Jozini	0.4
Machibini	0.8
Ophande	0.3
Majozini	1.2
Nkangala	1.3
Mahangule	0.4
Madinyana	1.3
UMK2003	2.0
UMK2018	0.1
UMK2026	1.1
UMK2041	0.2

The transmissivity values during constant pumping ranged between 0.1-5.4 m²/d. The estimated T-values are an indication of very low fractured Karoo aquifers. This conclusion is based on the maps by Murray *et al.*, (2012). However, these T-values are within the ranges of transmissivity values expected in the Karoo, guided by the aquifer transmissivity estimates by hydrogeologists and academics for each of the main geological domains in South Africa (Chevallier *et al.*, 2009). These estimates are shown in Table 7-7.

Table 7-7: Hydrologist estimates of aquifer transmissivity for main geological domains in South Africa (Chevallier *et al.,* 2009)

Lithology/Aquifer	Range in Transmissivity (m²/day)
Shale	<5 (higher on dyke contacts)
Basement granite/gneiss	<5-150
Sandstone	20-40 (higher on dyke contacts)
Volcanics	<5-100
Basic Intrusive	<10
Karoo	<5-150 (higher on intrusive contacts up to 300)
Dolomite	500-5000 (>5000 near compartment dykes)
Coastal Sands	K=20* saturated thickness (m)
TMG Aquifer	20-300

7.3.3 Recovery test

As already stated in the methods and material section, for the interpretation of recovery data the Theis recovery (Theis, 1935) method was used to estimate T-values for recovery test. For the purpose of this report the recovery plots for Jozini (Figure 7-20) and Machibini (Figure 7-21), will be shown for illustration and the results are given in

Table 7-8.

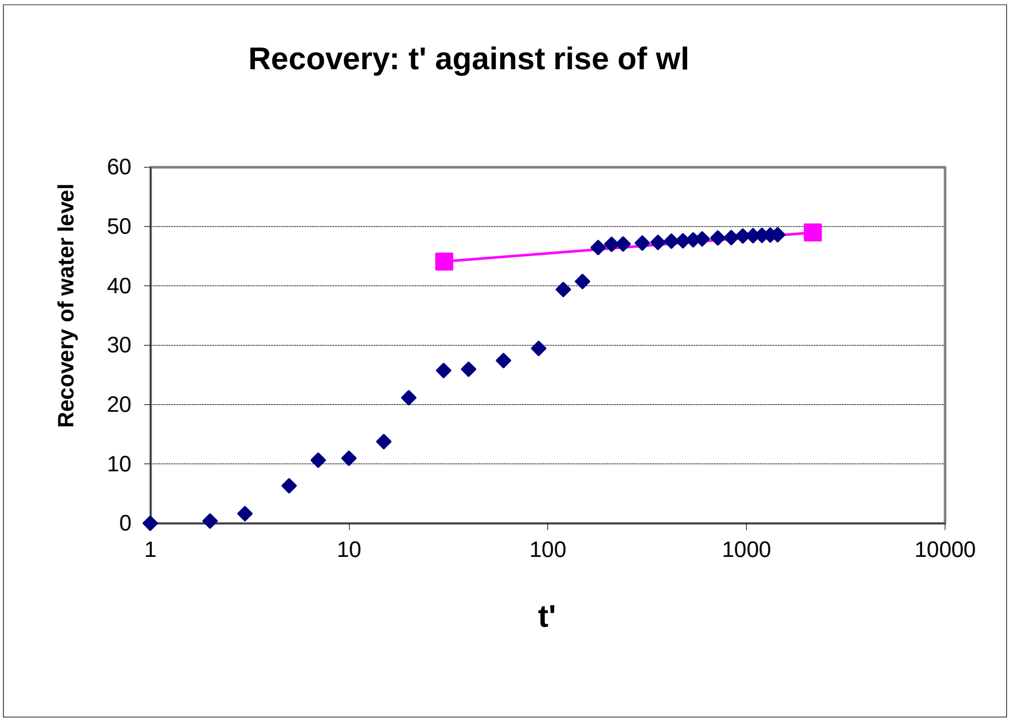


Figure 7-20: Recovery plot for the determination of T-value during recovery test for the Jozini borehole.

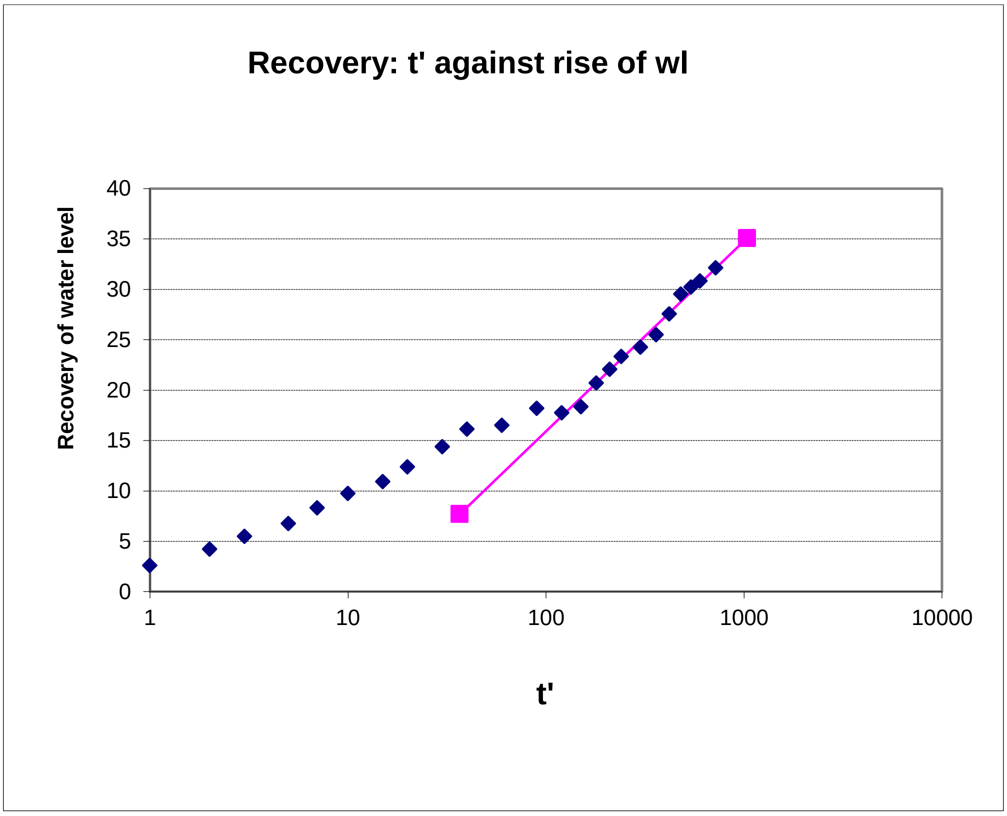


Figure 7-21: Recovery plot for the determination of T-value during recovery test for Machibini borehole.

Table 7-8: Comparison of the T-values determined during constant pumping and recovery test for both the newly drilled boreholes and the four refurbished boreholes.

Name	Constant Pumping Test T-Value (m²/day)	Recovery T- value (m²/day)
Jozini	0.4	3.4
Machibini	0.8	0.6
Ophande	0.3	0.8
Majozini	1.2	0.5
Nkangala	1.3	2.3
Mahangule	0.4	1.0
Madinyana	1.3	1.0
UMK2003	2.0	3.0
UMK2018	0.1	0.1
UMK2026	1.1	0.9
UMK2041	0.2	0.3

Comparison of the T-values estimated with constant pumping data and those estimated with recovery test indicates that Jozini, Ophande, Nkangala, Mahangule and UMK2003 boreholes had higher T-values during the recovery, implying that it was easier for groundwater to move through the subsurface.

Table 7-9: The recovery monitoring information which includes pumping duration, static water level; recovery percentage and recovery duration.

Name	Pumping Duration (hrs.)	Static Water Level (mbgl)	Residual Drawdown (mbgl)	% Recovery	Recovery Duration (hours)
Jozini	22	16.02	13.16	82.20	24
Machibini	12	30.55	25.30	82.81	12
Ophande	12	10.54	10.37	98.4	12
Majozini	12	43.80	30.22	69	12
Nkangala	24	3.79	2.86	75.42	20
Mahangule	12	19.13	17.91	93.64	6
Madinyana	12	34.00	25.69	75.56	12
UMK2003	12	31.30	27.95	89.30	12
UMK2018	3:30	34.55	22.63	65.50	6
UMK2026	3:30	5.40	4.27	79.06	9
UMK2041	20	3.79	2.88	75.89	24

Two other boreholes (Nkangala and Mahangule) took less time to recover when comparing pumping time and recovery duration. Machibini, Ophande, Majozini, Madinyana and UMK2003 boreholes took 12 hours to recover which is equal to the time it took for constant pumping test. However, the Ophande and UMK2003 boreholes had a higher recovery T-values of between 98.4% and 89.30 respectively within those 12 hours of recovery. The following boreholes (Jozini, UMK2018, UMK2026 and UMK2041) took more time to recover in a range of 65.50%- 82.20%. Jozini and UMK2041 had a higher recovery T-values this could imply it was much easier for water to move back in the aquifer than when it was pumped out; the recovery T-value for UMK2018 did not change when compared to the T-value estimated during constant pumping test, while the estimated recovery T-value for UMK2026 has dropped. Nkangala and Mahangule boreholes had shorter recovery duration and their recovery T-values increased.

7.4 SUMMARY

This chapter dealt with the pump test on the boreholes drilled in the study area. These tests on 9 boreholes included step discharge tests and constant rate discharge tests, coupled with recovery tests.

The step tests were for four steps, each taking 60 minutes, where a pumping rate was changed at the end of each step. This was done so as to determine the hydraulic efficiency of the borehole at different pumping rates and to recommend a suitable pumping rate for the constant discharge test. During the tests, drawdown was measured. After the last step for each, the borehole could recover.

Constant discharge tests were performed lasting between 9 and 22 hours. During pumping the drawdown in the borehole was monitored. The purpose of the test was to determine the aquifer parameters. The results thereof were also used to determine the diagnostic plots, which were further used to determine the flow characteristic and boundaries. Prior to shutting of the pump, recovery was monitored as well. The aquifers are characterised by fractures. The transmissivity values during pumping were estimated to be between 0.1-1.3 m^2/day; an indication of the low rate at which water is transmitted through a unit width of fractured Karoo aquifers. For the recovery tests, T-values were estimated to be between 0.1-3.4 m^2/day, this is still a low rate.

The following chapter will focus on groundwater recharge and the estimation of borehole sustainable yields.

CHAPTER 8: GROUNDWATER RECHARGE AND ESTIMATION OF SUSTAINABLE YIELDS

8.1 INTRODUCTION

The estimation of groundwater recharge and sustainable yields is important in groundwater studies, and in this study, it will be more important, since water will be used for community supply. This will help in understanding the amount of water available in the system to be used by the community.

Recharge is one of the most important parameters in assessing the sustainable volume of groundwater that can be abstracted from an aquifer system. Unfortunately, it is also difficult to fully quantify because of rainfall variability and aquifer heterogeneities (Parsons & Wentzel, 2007), however, this study will try to quantify the recharge to the aquifer.

The estimation of groundwater recharge and sustainable yields is usually done using aquifer pump test information, together with geological information and climatic data. Therefore, this chapter will consider the estimation of these two properties (recharge and sustainable yield) for the drilled boreholes in the study area.

8.2 METHODS AND MATERIAL

8.2.1 Recharge estimation

There are many methods used to estimate groundwater recharge but for this study, the Chloride Mass Balance (CMB) method, as well as the Qualified Guess Method was used to estimate the recharge in the study area.

8.2.1.1 Chloride Balance Method

The CMB method is based in the assumption of the conservation of mass balance between the input of atmospheric chloride and the chloride flux in the subsurface (Xu & Beekman, 2003). The method is built on the conservative (non-reactive) and stable state of the ion chloride, which is not taken up by the plants but its concentration in soil water can increase, due to evapotranspiration (Bromley *et al.*, 1997).

According to Dettinger (1989); Gaye and Edmunds (1996); Xu and Beekman (2003); and Zagana *et al.* (2007) in arid and semi-arid regions the following assumptions are necessary for a successful application when determining the mean annual recharge using CMB:

- There is no other source of chloride in the groundwater other than from precipitation;

- Chloride is conservative in the system;
- Stead-state conditions are maintained with respect to the long-term precipitation and chloride concentration in the precipitation;
- Precipitation is evaporated and or recharged to groundwater with no surface runoff leaving the aquifer;
- No recycling of chloride occurs within the basin; and
- No evaporation of groundwater occurs up-gradient from groundwater sampling points.

In the study area the source of chloride could not have only been from precipitation, but from other anthropogenic sources as well, as some sampled boreholes were found to be close to pit toilets and agricultural manure used by most villagers as manure, which could have contributed to the chloride concentrations in groundwater (Olson *et al.*, 2003). However, these sources, together with other factors such as rock weathering, irrigation and pollution were assumed to be negligible. For the assumption that precipitation is evaporated and or recharged, the trend depends on the geological characteristics of the area. As stated by Allison and Hughes (1978) mean annual precipitation values most closely estimate potential recharge for the unconsolidated sediments, whereas infiltration will vary, depending on soil porosity and its permeability and the topology and storm intensity.

Chloride concentrations in groundwater was obtained by sampling from a total of 27 boreholes (7 newly drilled, 4 refurbished and 16 others which were located during hydrocensus) in the study area. Samples were collected during constant pumping tests from the new boreholes and the refurbished boreholes, while, for existing boreholes, the samples were taken from the hand pumps. The concentration of chloride in rain water was obtained from sampling a rain gauge managed and owned by the DWS. This rain gauge is situated at Makhathini Research Centre in the village of Jozini. This method uses Equation 2-1 to calculate the recharge estimates (Eriksson & Khunakasem, 1969).

8.2.1.2 Qualified guess method

This method is based on the interpretation of the knowledge about an area under study, as well as mathematical theories and information already available for an area of interest. The following methods can be used as part of determining groundwater recharge by means of the qualified guess method:

- Vegter Maps (2001);
- Harvest Potential Map (Baron *et al.,* 1998);
- ACRU (Schulze, 1995);
- Soil/Vegetation information;
- Geology and soil cover and slop information; and

- An Expert's opinion.

For this study only three methods were used namely Vegter Maps (Vegter, 2001) for mean annual groundwater recharge, Harvest Potential Maps (Baron *et al.*, 1998) and ACRU Map (Schulze, 1995).

The following assumptions should be noted for the Harvest Potential maps (Baron *et al.*, 1998, Vegter 1995 & Vegter, 2001):

- The map should be viewed as depicting broad trends, rather than laying claim to accurate regional recharge figures. Furthermore, the regional figures should not be translated into values per km² because recharge conditions are variable, not homogeneous within any categorised recharge area.
- Due to the absence of other relevant and better suited information, effective rainfall was used as a guideline in drawing the maps. However, it should not be translated as that recharge is equivalent to rainfall.

Agricultural Catchment Research Unit (ACRU) maps (Schulze, 1995) determine the mean annual recharge based on the different soil profiles which groundwater penetrates and then flows through to the vadose zone (Schulze & Pike, 2004).

All these three maps would be used in this report for a qualified guess method of the estimation of groundwater recharge in the study area given in Appendix E.

8.2.2 Sustainable Yields

DWA (2011b) defined sustainable yield or safe yield as the maximum rate of withdrawal that can be sustained by an aquifer, without causing an unacceptable decline (available drawdown) in the hydraulic head, or deterioration in water quality in the aquifer. Determining the sustainable yield of a borehole is important in the overall management of an aquifer (van Tonder *et al.*, 2002). Factors such as the recharge, aquifer parameters and geological setting can have an influence on the sustainable yield, and therefore they are important in estimating and validating the sustainable yield of the boreholes. Equation 8-1 is used in the determination of the borehole's sustainable yield (van Tonder *et al.,* 2002).

$$\mathrm{Q}_{sustainable} = Q_{pump_{Test}} \left[\frac{sAvailable\left(t_{long}\right)}{sPump_{Test}\left(t_{long}\right)}\right]$$

Equation 8-1

Where: $\mathrm{Qpump}_{\mathrm{test}}$ (l/s) is the rate used during the pumping test; sAvailable (m) is the maximum available drawdown; and $\mathrm{sPump}_{\mathrm{Test}}$ (m) is the available drawdown during pump test.

According to van Tonder *et al.* (2002), the most reliable sustainable yield will be estimated if the position of the main water strike is reached during the constant rate test. However, if the position of the main water strike was not reached during a constant rate test, a good choice would then be to use the geometric mean of the end drawdown and the position of the main water strike; in the case of relatively shallow main water strikes. Van Tonder *et al.* (2002) further explains that if the end drawdown during the constant test was still far above the position of the main water strike, then using the geometric mean could lead to an over-estimation of the sustainable yield.

The basic Flow Characteristic (FC) method for the determination of sustainable yield will be used in this study. The method makes use of a set of inputs and parameters for the determination of the sustainable yields of the boreholes. These inputs are on the sust Q spread sheet of the program. These inputs and parameters are given on Table 8-1. Once these inputs and parameters are entered into the spread sheet the basic solution in FC will determine the sustainable yield in litres per second (l/s) and the average sustainable yield for the borehole. The basic solution uses the derivatives and subjective information about the boundaries. S-value and T-values are not a necessity (Van Tonder *et al.*, 1999; Van Tonder *et al.*, 2013).

The advanced solution uses the derivatives, information about the boundaries, and the influence of other boreholes. For the determination of sustainable yield with advanced solution, S-values and T-values are *a priori.* However, if the information about the boundaries is unknown, the advanced solution can be skipped, and one can continue to the final recommendation. Here one enters one's chosen abstraction rate for 24 hrs. The program will automatically calculate the amount of water allowed to be pumped monthly. For this study, the basic FC solution was used.

Table 8-1: List of inputs/parameters for borehole sustainable yield estimation using the Basic FC program (Van Tonder *et al.,* 1999).

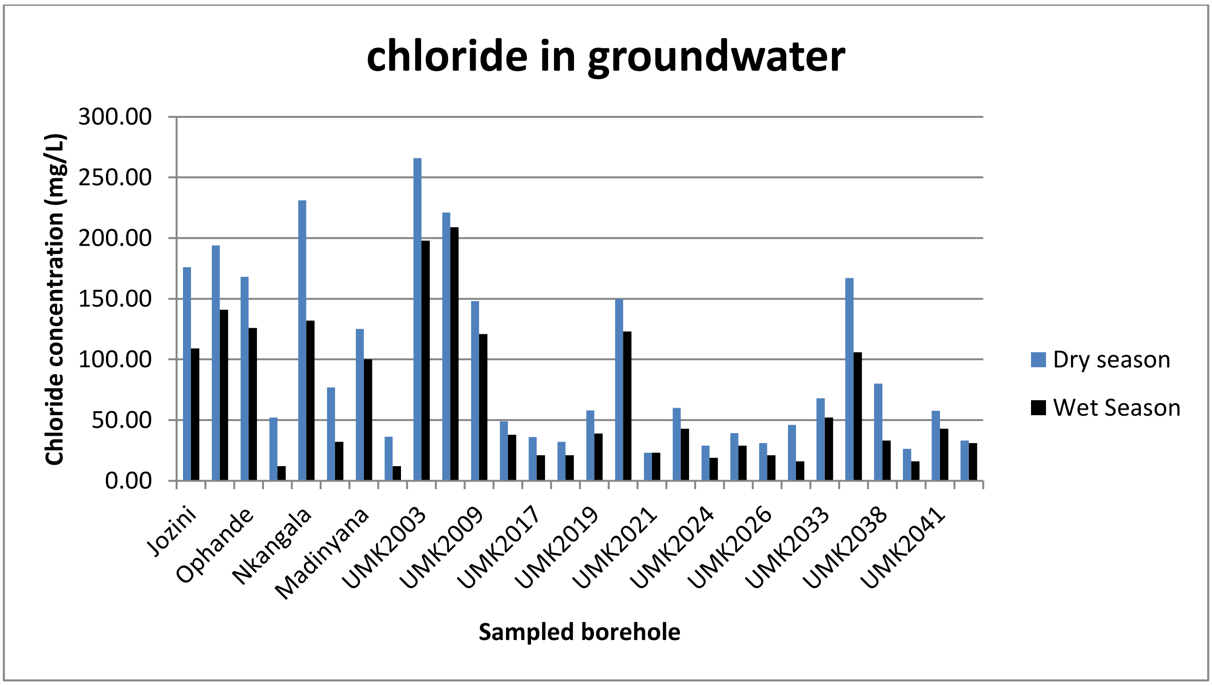
Input/Parameter	Explanation
Exploration time in years	The time of pumping
Q (l/s) from pumping test	Pumping rate used during the pumping test
Sa (available drawdown)- (m)	The distance from rest water level to the position of the main water strike
Annual effective recharge (mm)	The mean annual recharge (inserted if known) – often zero conservative is used
t(end) and s(end) of pumping test	The end time t and drawdown s after pumping
Average maximum derivative	Determined using mathematical expansion integrated on the FC programme
Average second derivative	Determined on FC, if the value is negative then put zero

8.3 RESULTS AND DISCUSSION

8.3.1 Recharge estimates

8.3.1.1 Groundwater chloride concentration in the study area

Graph 8-1 below shows the chloride concentrations in groundwater for the two sampling runs during the dry (October 2015) and wet (March 2016) seasons in the study area. Since one of the assumptions for this method is that the source of chloride in groundwater is only from precipitation, the average chloride concentration per borehole was calculated with other factors that could have contributed to chloride concentration in groundwater; such as irrigation water, pesticides and or fertilizers being neglected.



Graph 8-1: Chloride concentration in groundwater during dry and wet season.

The results in the above graph suggest that more recharge has taken place during the wet season. This observation is made based on the previous studies by Nyangwambo (2006) and Mutoti (2015) who discovered that low chloride concentrations indicate higher recharge, whereas high chloride concentrations in groundwater suggests low recharge. This observation in the wet season could be due to frequent rainfall, which then dilutes the concentration of chloride in groundwater, compared with during the dry season when there is less rain; meaning less groundwater recharge. This then implies that the chloride concentration in groundwater will remain high.

The highest concentration in groundwater chloride in the study area during the wet season was 209.00 mg/L for the existing borehole UMK2007, with the lowest being borehole

UMK2001 with a value of 12.00 mg/L. Although the CMB assumes that the only source of Chloride in groundwater is from precipitation, it is assumed that the high concentration of chloride in UMK2007 could be from the two pit toilets found about 30 m from the borehole and cattle dip about 50m away. However, as already stated, these other factors will be neglected so as to fulfil this method's assumption that the only source of chloride in groundwater is from precipitation. For UMK2001 there was no anthropogenic factor that could have contributed to the chloride concentration. Therefore the assumption that the chloride concentration is only from precipitation is fulfilled.

During the dry season the highest chloride concentration was recorded for UMK2003 (266.00 mg/L) and the lowest concentration was 23.00 mg/L for borehole UMK2021. This implies that the latter borehole had a frequent recharge during this season, in comparison with UMK2003. The calculated average chloride concentration in groundwater for the wet season was 66.64 mg/L and for the dry season was calculated as 95.70 mg/L.

8.3.1.2 Rainwater chloride concentration in the study area

Woodford and Chevallier (2002) have noted that there are few points in Southern Africa, where chloride concentration in rainwater has been measured. This was the case in the study area, as there is only one rain gauge where it appears that rainwater is not sampled therein, as it was difficult to obtain data from either the DWS or SAWS.

An access to the rain gauge was therefore requested from the DWS, to allow for the sampling of the said rain gauge and the sample was then taken in August 2016 and the chemical analysis revealed a concentration of 3.14 mg/L. Woodford and Chevallier (2002) further realised that chloride concentrations decrease as mean annual rainfall increases. This could not be confirmed for the study, because groundwater was sampled only once in August 2016, during the dry season.

8.3.1.3 Recharge estimates in the study area

8.3.1.3.1 Chloride mass balance

Using the above determined parameters, recharge rates were estimated using Equation 2-1. The recharge was calculated using the first groundwater sampling in October 2015 for the dry season because the only rainfall chloride concentration was for this period.

Table 8-2 displays the estimated recharge for all the boreholes sampled within the study area. Groundwater recharge estimates using CMB indicated that the Jozini town and its surrounding villages receives recharge ranging between 5.88 mm/a and 67.99 mm/a representing 1.18% to 13.65% of the total annual precipitation.

Xu and Beekman (2003) have noted that input chloride concentrations can vary significantly from site to site, within the region of investigation as CMB estimates are site-specific. This can also be seen from the estimated recharge in this study.

Table 8-2: Estimated average groundwater recharge estimates using Chloride Mass Balance Method

Site Name	Cl-Dry (mg/l)	Cl rain (mg/l)	Annual Precipitation (mm/a)	Recharge	MAP %
Jozini	176.00	3.14	498	8.88	1.78
Machibini	194.00	3.14	498	8.06	1.62
Ophande	168.00	3.14	498	9.31	1.87
Majozini	52.00	3.14	498	30.07	6.04
Nkangala	231.00	3.14	498	6.77	1.36
Mahangule	77.00	3.14	498	20.31	4.08
Madinyana	125.00	3.14	498	12.51	2.51
UMK2001	36.35	3.14	498	43.02	8.64
UMK2003	266.00	3.14	498	5.88	1.18
UMK2007	221.00	3.14	498	7.08	1.42
UMK2009	148.00	3.14	498	10.57	2.12
UMK2013	49.00	3.14	498	31.91	6.41
UMK2017	36.00	3.14	498	43.44	8.72
UMK2018	32.13	3.14	498	48.67	9.77
UMK2019	58.00	3.14	498	26.96	5.41
UMK2020	150.00	3.14	498	10.42	2.09
UMK2021	23.00	3.14	498	67.99	13.65
UMK2022	60.00	3.14	498	26.06	5.23
UMK2024	29.00	3.14	498	53.92	10.83
UMK2025	39.14	3.14	498	39.95	8.02
UMK2026	31.00	3.14	498	50.44	10.13
UMK2027	46.00	3.14	498	33.99	6.83
UMK2033	68.00	3.14	498	23.00	4.62
UMK2034	167.00	3.14	498	9.36	1.88
UMK2038	80.00	3.14	498	19.55	3.93
UMK2040	26.27	3.14	498	59.52	11.95
UMK2041	57.60	3.14	498	27.15	5.45
2723CAG1256	33.06	3.14	498	47.30	9.50
Min Recharge (mm/a)	**5.88**				
Max Recharge (mm/a)	**67.99**				
Min Recharge %	**1.18**				
Max Recharge %	**13.65**				

The difference in recharge from borehole to borehole could be due to the landscape and other geomorphological controls. Van Wyk (1963) also noted that for the groundwater studies in Northern Natal, Zululand and surrounding areas that there were different ways in which water levels responded to infiltration of rain water in the same geological formation. In some boreholes the water level fluctuated widely after each downpour while in others, it rose steadily during the rainy season.

8.3.1.3.2 Qualified Guess Methods

Vegter Maps (1995) for mean annual groundwater recharge, Harvest Potential Maps (Baron *et al.,* 1998) and ACRU Map (Schulze, 1995), will be used in this section for qualified guess method of groundwater estimation. The maps are provided in Appendix E.

When determining estimating groundwater recharge with the use of these maps, the position of the study area was located on each map, and then the value allocated for the study area on each map was used as the value, to estimate the recharge. The results thereof are provided in Table 8-3.

Table 8-3: Groundwater recharge estimates as determined using the Qualified Guess methods

Method	Recharge (mm/a)	Recharge %
Vegter Map (Vegter,1995)	20	2.15
Harvest Potential (Baron *et al.*, (1998)	50	5.36
ACRU (Schulze, 1995)	10	1.07

From the above methods, the estimation of groundwater recharge using the harvest potential map has given the highest recharge rate per annum (50 mm/a corresponding to 5.36%). This corresponds with the maximum recharge rate per annum determined using CMB, while the ACRU method gave the lowest recharge rate per annum (10 mm/a equivalent of 1.07%), which is in line with the minimum recharge determined using the CMB method. The three qualified guess methods give the average recharge as 26.67 mm/a about 2.86% of the mean annual recharge.

Comparison of the CMB and the Qualified Guess method shows the range of recharge with the CMB method as 5.88-67.99 mm/a which is about 1.18-13.65% of the total annual recharge, while the qualified guess methods shows a range of 10-50 mm/a, corresponding with 1.07-5.36%. However, despite the limitations of both methods used, the results are comparable. Therefore the recharge rates can be assumed to represent a range of averages, based on the available information for this study.

8.3.2 Borehole sustainable yields

The sustainable yield can be influenced by factors such as recharge, aquifer parameters and geological settings. These factors are important in estimating sustainable yields.

DWA (2011b) defined sustainable yield or safe yield as the maximum rate of withdrawal that can be sustained by an aquifer, without causing an unacceptable decline (available drawdown) in the hydraulic head or deterioration in water quality in the aquifer, while van Tonder *et al.* (2002) defined it as the discharge rate that will not cause the water level in a pumping borehole or adjacent boreholes to drop below the prescribed limit of the importance of the aquifer. Both definitions place an importance on not pumping more than the borehole can give; which is the available drawdown - the difference between the static water level and the position of the main water strike. It should be noted that if the available drawdown is exceeded then the borehole will dry up. Table 8-4 below gives the information regarding the available drawdown for each borehole.

The sustainable yield for each borehole was determined and estimated using the basic FC method by following the parameters as stated in Table 8-1 above and the results thereof are given in Table **8-5**, with the population determined based on the Water Service Act of 1997 (DWAF, 1997b; DWAF, 2001). The recommended available drawdown was estimated by the FC program and will be used for groundwater management purposes.

Table 8-4: Information regarding the available drawdown for each borehole, with the position of main water strikes, static water level and depths of the boreholes

Site	Position of Main Water Strike (m)	Static Water Level (mbgl)	Available Drawdown (m)	Depth (m)
Jozini	54	16.02	37.98	120
Machibini	108	30.55	77.45	120
Ophande	72	10.54	61.45	100
Majozini	132	43.80	88.20	150
Nkangala	135	3.79	131.21	150
Mahangule	69	19.13	49.87	150
Madinyana	75	34	41	90
UMK2003	48	31.30	16.70	76.41
UMK2018	90	34.55	54.4	102
UMK2026	34	5.40	28.60	34.85
UMK2041	74	3.79	70.21	78

Table 8-5: The average sustainable yields of the newly drilled boreholes as well as the refurbished boreholes using FC method

Site	Extrapolation time (years)	Average Q_sust (l/s) - 24hr cycle	Recommended Available Drawdown (m)	Average maximum derivative	[a] Population	[b] Ward
Jozini	2	0.11	38	18	566	7
Machibini	2	0.07	57.30	25.6	242	7
Ophande	2	0.03	55.50	37.7	104	5
Majozini	2	0.08	37.4	38.1	173	2
Nkangala	2	0.14	85.7	105	1452	2
Mahangule	2	0.06	26.0	5.5	207	8
Madinyana	2	0.03	39.9	51.7	104	2
UMK2003	2	0.12	12.60	5.7	415	8
UMK2018	2	0.02	54.40	42.3	69	2
UMK2026	2	0.71	28.4	25.40	1223	2
UMK2041	2	0.03	62.4	73.1	104	5
[a] value determined by FC method using 25 litres per person per day (DWAF,1997b; DWAF, 2001) [b] Jozini (2016)						

The results for these boreholes from the pumping test can be summarised as follows:

- The sustainable yield ranges between 0.03-0.14 l/s for newly drilled boreholes only (0.02-0.71 l/s including the refurbished boreholes);
- The average sustainable yield of 0.19 l/s;
- The median sustainable yield 0.07l/s; and
- The total combined sustainable yield is 0.95 l/s which could supply water to about 4 659 people (at 25 litres per person per day) if pumping was to be continuous for 24 hour cycle. This is about 82 080 litres per day and equivalent of 0.0821 ML/day.

Population per ward (SSA, 2011 and Jozini, 2016) is given on Table 8-6

Table 8-6: Number of people per ward expected to be supplied with water (SSA, 2011; Jozini, 2016).

Ward	Population	Number of boreholes
2	8 144	5
5	13 677	2
7	9 574	2
8	8 504	2
Total	**39 899**	**11**

Table 8-5 includes the population that can be supplied with water as determined through the basic FC method while the actual population of the town of Jozini is given on Table 8-6, and the comparison between the two indicates that there will be a deficit in water supply, as only 4 659 people out of a total of 39 988 people can be supplied with water at the basic level of 25 litres per person per day.

It should be noted that the above estimated sustainable yields were determined on only 11 boreholes as those were the only boreholes that could be pump tested. Other boreholes were identified during hydrocensus but they could not be pumped as they were fitted with hand pumps. This meant that the sustainable yields when they are included could be a bit higher than those estimated in this report, but due to low yielding nature of the boreholes in the study area, it is believed that even if there was a way of pump testing those other boreholes, the estimated sustainable yield would still be low.

Based on SSA (2011) and DWA (2011a) there are about 186 502 people staying in the Jozini Local Municipality of which 39 899 people reside in four wards (ward 2, 5, 7 and 8) of the municipality (SSA, 2011; Jozini 2016) that forms the town of Jozini and its surrounding villages. DWA (2011a) further states that there was a demand of 7.98 ML/day in 2008 and the projected demand for the year 2030 is 14.59 ML/day, so it is clear that even with these newly drilled boreholes as part of drought relief, there is already a deficit of 7.81 ML/day (based on 2008 demand) and the available groundwater will not sustain the water requirements for 2030, as there will be a deficit of 14.51 ML/day. This would mean that other avenues should be explored for community water supply.

Looking at the hydrogeological map of Vryheid (DWAF, 1998) the study area falls in an intergranular and fractured aquifer type region, with the expected borehole yields ranging between 0.1-0.5 l/s in the Lebombo area on rhyolite formation. Groundwater Development Services (1994) has stated that the statistics of yield data reported for the boreholes drilled in rhyolite show a minimum yield of 0.04 l/s, a maximum yield of 36.58 l/s and a mean yield of 1.36 l/s. However, the study admitted that the reported maximum yield is very ambiguous. So, it can be concluded that it is generally expected that the boreholes drilled in this area will have low yields.

8.4 SUMMARY

This chapter dealt with groundwater recharge estimations using CMB and three Qualified Guess methods in the form of Vegter Maps (1995), ACRU Map (Schulze, 1995) and Harvest Potential Maps (Baron *et al.*, 1998). These methods gave the range of 10-50 mm/a (1.07-5.36%) which is comparable to the recharge estimates through the CMB method of 5.88-67.99 mm/a (1.18-13.68%).

The sustainable yields were determined using a basic FC programme (basic FC method). The estimated yields ranges 0.03-0.14 l/s for the seven newly drilled boreholes and these boreholes have a combined yield of 0.95 l/s (0.0821 ML/d) which can supply about 4 659 people at 25 litres per person per day at a 24 hour pumping cycle. Considering the severe drought that has hit the area as well as current and future water demands. These are very low yields and the safe yield of these boreholes will not sustain the requirements, more boreholes should be drilled to supplement the current water supply.

The next chapter will consider the groundwater quality in the study area, with samples being taken from the newly drilled boreholes, the refurbished boreholes and other boreholes which were located during the hydrocensus but had hand pumps fitted.

CHAPTER 9: ASSESSMENT OF GROUNDWATER QUALITY

9.1 INTRODUCTION

The assessment of groundwater quality is of the utmost importance for the community water supply. This is conducted to make sure that the water to be supplied to the community is of acceptable or good quality for domestic usage. Samples were collected from all newly drilled boreholes, refurbished boreholes and existing boreholes in the study area. Samples for the newly drilled boreholes were taken at the end of each constant test from the discharge of the test pumping equipment, while for the refurbished and the existing boreholes in the study area, samples were taken from the taps, as these boreholes were already equipped with hand pumps and were operational at the time of sampling, so they could not be purged. All the samples were taken in October 2015.

A second set of sampling was conducted in March 2016. Even with this sampling run, the samples were taken from the taps of the hand pumps because all the boreholes (with the exception of the two newly drilled boreholes Nkangala and Mahangule, that were purged during the second sampling as they displayed poor to unacceptable water quality during the first sampling) were fitted with hand pumps and therefore proper procedures were not followed, according to the guidelines prescribed by Weaver *et al.*, (2007) as these guidelines suggests that a borehole should be purged before a sample is taken. Purging is done to replenish the water in the borehole with water from the aquifer formation (Weaver *et al.*, 2007; Nielsen & Nielsen 2007). Water standing in a well for a period undergoes changes that can affect and alter the water quality; it stagnates.

These changes can impact several parameters including but not limited to: pH, Eh, alkalinity/acidity, hardness, and the concentration of metals, sulphate, dissolved solids, and dissolved oxygen. However, most of the boreholes which were not purged are the boreholes which were already in operation, implying that the sampled water was fresh water.

A second sampling was done to compare if there could be any change in water quality after long-term usage, especially on the newly drilled boreholes which showed an elevated concentration of the determinants. Samples were taken from hand pumps for all the boreholes except for the boreholes at Nkangala and Mahangule, which were purged.

9.2 METHODS AND MATERIALS

A total of twenty-eight samples were collected (Figure 9-1). Due to the nature of the study area the samples could not be submitted to the laboratory on time, as it is best to deliver the samples to the laboratory within one to two days of sampling (Harter, 2003).

Because the samples could not be sent to the laboratory on time, they were therefore preserved by storing them in a cooler box with ice at a temperature of 4° and once the sampling was complete the samples were then delivered to the accredited laboratory for analysis.

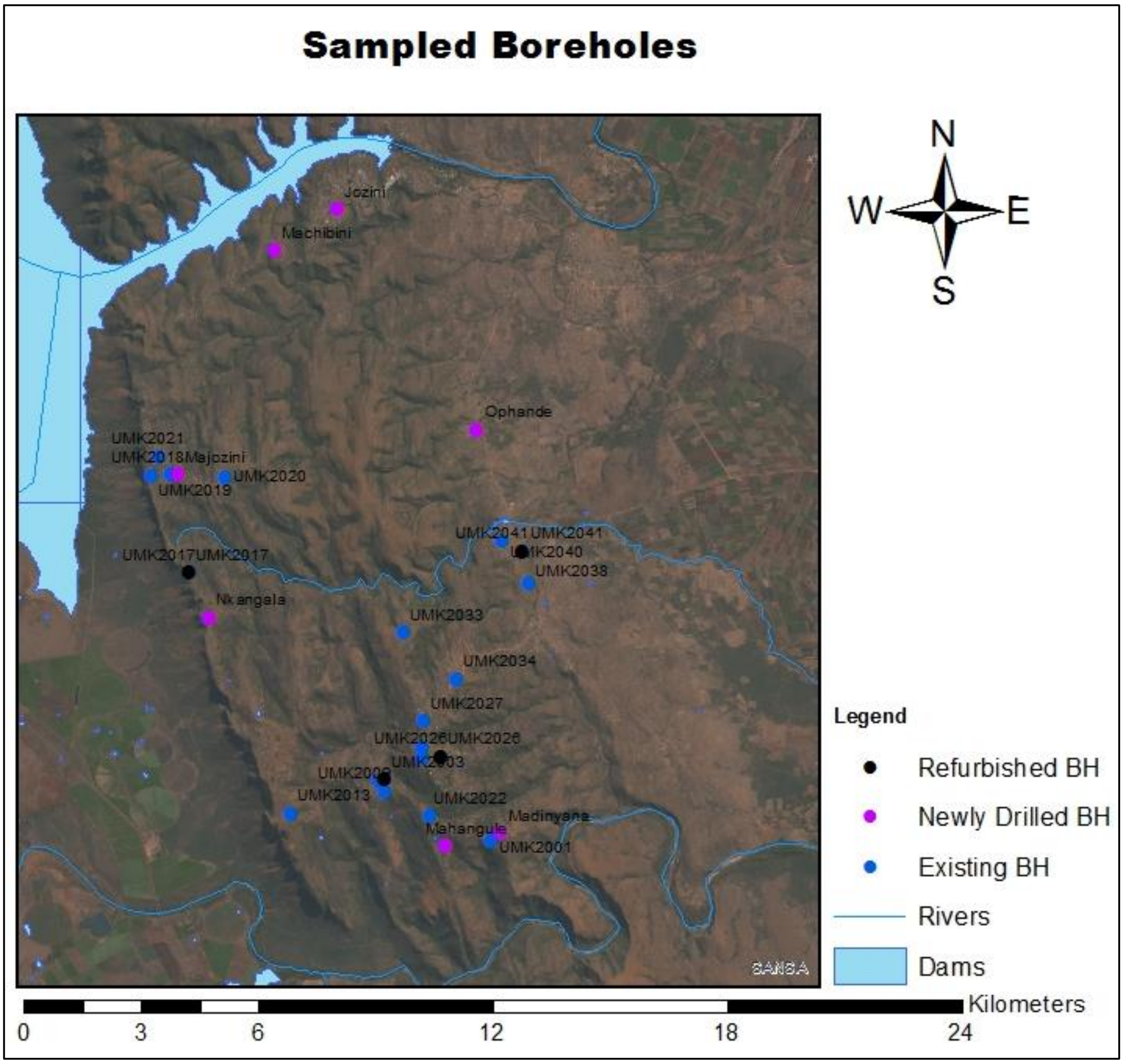


Figure 9-1: Position of all the sampled boreholes in the study area (Drawn using ArcGIS 10.2.2).

9.2.1 Laboratory analysis of samples

The samples were taken to an accredited laboratory namely Talbot & Talbot (Pty) Ltd. in Pietermaritzburg for analysis. Table 9-1 provides a list of variables the laboratory analysed for Temperature, pH, turbidity and conductivity were also measured in the field.

Table 9-1: List of variables that the laboratory analysed.

Microbiological Determinants	Physical and Aesthetic Determinants	Chemical Determinants
E. coli (colonies per 100ml)	Colour (mg/l)	Aluminium (µg/l)
Total coliforms (colonies per 100ml)	Conductivity (mS/m)	Chloride (mg/l)
	Turbidity (NTU)	Calcium (mg/l)
	Hardness (mg/l)	Magnesium (mg/l)
	Total alkalinity (mg/l)	Fluoride (µg/l)
	pH at 25°C	Iron (µg/l)
	Colour (mg/l)	Lead (µg/l)
		Manganese (µg/l)
		Nitrate (mg/l)
		Sodium (mg/l)

9.2.2 Analytical data reliability

Mandel and Shiftan (1981) stated that the reliability of chemical analysis can be checked by computation of the ionic charge balance. Furthermore, Aastrup and Axelsson (1984) stated that the Ionic Balance Error (IBE) of the dataset should be less than 5%. An IBE higher than 5% implies that, there was poor or no filtration (removal of suspended solids), Analytical analysis of the individual ions may have been in error or an important constituent of the solution might not have been included in the reaction error calculation (Aastrup and Axelsson, 1984; Ravikumar and Somashekar, 2010; Manoj *et al.*, 2013). The reaction errors for this study were determined using Equation 9-1 and the results are given in Table 9-3.

$$IBE\ (\%) = \frac{\sum Cations(meq/L) - \sum Anions(meq/L)}{\sum Cation(meq/L) + \sum Anions(meq/L)} x100$$

Equation 9-1

9.2.3 Data interpretation

For a better understanding of water types from the boreholes sampled in the study area a Piper diagram (Piper, 1944) and a Sodium Adsorption Ration (SAR) diagram (Oster and Sposito, 1980) was used to evaluate the groundwater quality's suitability for domestic and irrigation purposes, respectively. Both graphs and diagrams were plotted using the Windows Interpretation System for Hydrogeologists (WISH) programme.

The results were compared to the following screening guidelines to assess suitability for human consumption and domestic use: South African National Standards (SANS 241:2011), South African National Standards (SANS 241:2015), Drinking Water Standards for South Africa (DWAF, 1996) and World Health Organisation drinking water quality (WHO, 2011).

9.3 RESULTS AND DISCUSSIONS

9.3.1 Data Statistical Overview

Once chemical analysis results were available, it was important to look at the results statistically, with the aim of ascertaining the quality of the chemical dataset. This statistical overview was done by looking at the ranges and other statistical parameters of all the chemical variables analysed. The results thereof are provided in Table 9-2 compared to guideline values, as given by SANS 241 (2011 or 2015) and WHO (2011), but for most of these variables WHO (2011) does not provide the guideline values, although the effects are given and will be discussed later on in this chapter.

The pH ranges from 6.20-8.8, in this range pH based on water quality classes (DWAF, 1996) is of ideal quality for human consumption. Electrical Conductivity (EC) ranges from 21.00-385 mS/m with the new borehole (Ophande) showing the highest value; usually the elevated EC is due to the chemical parameters associated with rock formation and could also be from pollution. In higher concentration EC may cause an objectionable taste.

The statistical overview shows chloride (Cl) ranging between 23-266 mg/l, which could be due to chemical parameters associated with rock formation. In higher levels the Cl will give water a salty taste (WHO, 2011). Borehole UMK2003 shows the highest concentration of Cl, in comparison with other boreholes. As already stated the elevated chloride is usually due to chemical parameters associated with the rock formation and often high chloride levels are from sediments related to sea deposits (Younger, 2007).

Borehole UMK2033 has the highest concentration of sulphate (SO_4) at 269mg/l, while the lowest concentration was recorded for the newly drilled Majozini borehole. Although there are no guideline limits for SO_4, WHO (2011) notes that in elevated concentrations SO_4 in drinking water can cause a noticeable taste, and very high levels might cause a laxative effect in other individuals.

Table 9-2: Statistical overview of the chemical dataset with WHO (2011) and SANS 241-1 (2011 or 2015).

Variable	N	Mean	Min	Median	Max	WHO (2011)	SANS241
pH	28	7.35	6.20	7.3	8.8	NS	5-9.5 [b]
EC (mS/m)	28	89.10	21.00	70.65	385.00	NS	<170 [b]
TDS (mg/L)	28	417.37	103.00	443.25	1038.00	NS	<1200 [b]
Ca (mg/L)	28	31.30	1.90	25.00	71.09	NS	<150 [a]
Mg (mg/L)	28	15.92	0.40	12.00	40.00	NS	<100 [a]
Na (mg/L)	28	119.00	26.00	93.50	575.00	NS	≤200 [b]
K (mg/L)	28	2.70	0.70	2.38	5.90	NS	<50 [a]
Cl (mg/L)	28	95.70	23.00	59.00	266.00	NS	≤300 [b]
SO_4 (mg/L)	28	35.77	0.30	20.73	269.00	NS	≤250 [b]
NO_3-N (mg/L)	28	0.62	0.03	0.13	2.40	<50	≤1 [b]
F (mg/L)	28	1.01	0.16	0.41	6.15	<1.5	<1.5 [b]
Fe (mg/L)	28	2.10	0.01	0.63	12.90	NS	≤300 [b]
Mn (mg/L)	28	0.17	0.00	0.05	1.25	NS	≤100 [b]
MALK (mg/L)	28	192.04	22.00	191.00	393.00	NS	NS
Total Hardness (mg/L)	28	144.17	6.00	107.00	319.00	NS	NS

[a] SANS 241-1:2011, [b] SANS 241-1:2015, NS- Not Specified.

9.3.2 Reliability of analytical analysis

Table 9-3 indicates that the determined Ion Balance Error percentage is higher than 5% for UMK2007, UMK2009, UMK2022 and UMK2026; all marked in red. This means either analytical analysis of the individual ions might be in error or an important constituent of the solution might have been omitted from the analysis.

Table 9-3: Chemical Data Reliability, Ion Balance Error (IBE) %, Na % and SAR Index

Site Name	pH	EC	TDS	Ca	Mg	Na	K	Cl	Ion Balance Error	Na	SAR Index
		mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	%	%	
Jozini	7,9	139	746	30	8,2	215	2,18	176	-3,3	80,7	9
Machibini	7,4	150	367	59	24	201	1,3	194	1	24,1	11,3
Ophande	7,4	385	1038	34	15	575	2,44	168	-0,2	97	37,2
Majozini	6,6	32	184	3,2	3,7	44	2,98	52	-1,8	77,7	4
Nkangala	8,4	115	506	8,4	0,8	198	2,32	231	-3,6	94	17,5
Mahangule	8,3	67	372	6,5	3,5	114	1,32	77	-4,6	88,4	9
Madinyana	6,8	67	428	6,6	10	100	2,98	125	-0,4	77,5	5,7
UMK2001	7,19	72,5	507,5	64	28,7	49,5	3,75	36,35	-1,7	27,6	1,3
UMK2003	8,8	139	532	1,9	0,4	293	1,5	266	1,1	97,3	50,4
UMK2007	7,2	105	103	20	13	147	3,7	221	10,8	63,7	6,3
UMK2009	7,1	108	234	46	29	129	1,7	148	7,4	52,9	3,7
UMK2013	6,8	30	333	6,1	5	35	0,7	49	-3,4	65,1	2,5
UMK2017	6,2	21	486	2,8	3,9	26	1	36	-6,1	62,8	2,4
UMK2018	7,18	67,9	475,3	68,97	28,42	59,31	2,55	32,13	4,4	30,6	1,5
UMK2019	7,5	54	109	8,4	7,2	87	1,5	58	3,5	77,7	5,3
UMK2020	7,8	111	746	24	11	190	5	150	3,7	78,1	8,1
UMK2021	7,48	79,4	555,8	71,09	34,64	52,69	2,14	23	-2,7	26,2	1,3
UMK2022	8,2	56	175	4,4	3,1	110	1,7	60	5,1	88,8	9,8
UMK2024	7,37	69,5	486,5	57,56	28,84	41,7	2,11	29	-5,1	25,5	1,1
UMK2025	7,25	70,7	494,9	58,89	38,22	45,4	1,32	39,14	-0,1	24,4	1,1
UMK2026	7,3	56	128	17	9,3	110	2,7	31	4,7	59,5	2,9
UMK2027	6,3	37	110	5,3	4,2	34	3,9	46	6,7	60,2	2,7
UMK2033	7	112	350	59	40	111	5,5	68	7,6	41,2	2,7
UMK2034	7	91	330	26	15	114	5,5	167	1,2	63,7	4,4
UMK2038	7,3	50	420	15	8	63	5,9	80	1,9	56	4,8
UMK2040	7,06	73,8	516,6	65,9	29,4	50,5	3,86	26,27	-1,9	27,4	1,3
UMK2041	7,54	65,5	458,5	49,08	20,77	72,87	1,68	57,6	1,2	43	2,2
2723CAG1256	7,39	70,6	494,2	57,3	22,33	63,9	2,44	33,06	4,2	60,8	3,1

*Parameters/variables marked with red are those that indicated an IBE percentage (%) higher than the allowed value of 5%

9.3.3 Potential source of groundwater contamination

Major and minor ions as well as microbial determinants were analysed for a possible source of groundwater contamination, within 150 m of the boreholes (Table 9-4), highlighted in red are total coliforms which were determined to be higher than the recommended limits. The area is characterised by a lot of pit latrine toilets used for sanitation purposes as the area is rural.

Table 9-4: Summary of potential contamination sources within 150 m of the borehole and the microbial determinands using SANS241: 2015.

	Potential contamination sources within 150 m					
					Micro biological Determinands	
Borehole	Type	Distance (m)	Type	Distance (m)	E. coli/Faecal coliforms (per 100ml)	Total coliforms (per 100ml)
UMK2003	Pit Toilet	50			2	14
UMK2007	Pit Toilet *2	30	Cattle dip	50	0	0
UMK2009	Pit Toilet	30	Pit Toilet *2	50	200	2400
UMK2013	Pit Toilet	50			2	32
UMK2019	Cattle Dip	10	Pit Toilet	50	0	14
UMK2020	Kraal	20	Kraal	100	340	900
UMK2021	Pit Toilet	50	Pit Toilet	80	0	0
UMK2026	Pit Toilet	50	Pit Toilet *2	100	0	0
UMK2027	Pit Toilet	75	Pit Toilet *2	100	14	14
UMK2033	Cattle Kraal	50	Pit Toilet	40	0	0
UMK2034	Pit Toilet *2	50			1600	3700
UMK2040	Pit Toilet *4	100			10	296
SANS 241: 2015 recommended limits for E. coli/Faecal coliforms (Not Specified) and Total Coliforms (<10). * Highlighted in red are total coliforms which were determined to be higher than the recommended limits.						

A protocol to manage the potential of groundwater contamination from onsite sanitation (DWAF, 2004c) does not give any specific distance regarding the safe distance between latrines and water points. However, the Guidelines for Protecting Springs (DWAF 2003) define a minimum set back distance of 100 m for waste disposal site from a surface water body.

All these boreholes on Table 9-4 were not purged, as samples were taken from the hand pumps. This could have had an influence on the levels of coliforms measured. Gomo *et al.*,

(2017) concluded from their study where a bailer passive method and purging methods were used for sampling, that it is necessary to purge boreholes when sampling for total coliforms and possibly other microbial analytes. E. coli/Faecal coliforms and total coliforms are indicative of faecal contamination. From the collected samples, neither the microbiological determinands was detected from UMK2007, UMK2021, UMK2026 and UMK2033; however microbiological determinants were detected from other samples which were all within a distance of 100 m of potential contamination sources.

9.4 CHEMICAL DATA ANALYSIS AND INTERPRETATION

9.4.1 Wet season

The physical and chemical interactions that occur between the recharging water and the aquifer material control the hydrogeochemical processes in groundwater (Gomo *et al.*, 2012). As stated in Chapter 6, there were no geological logs for the already existing boreholes in the study area. However, looking at the geological drilling logs for the newly drilled boreholes, the study area can be classified as underlain by the pink rhyolite of the Jozini formation and dolerite rocks. Rhyolite rock is composed of about 60% of SiO_2, quartz, potassium feldspar and plagioclase minerals. On the other hand, dolerite rock is composed of Ca-rich plagioclase, pyroxene or hornblende.

Figure 9-2 displays the location of the boreholes based on their water type, while Figure 9-3 displays these water types on the Piper diagram. However, the water types in comparison to chemistry geology, do not display any visible trend. This occurrence could be linked either to some preferential flow path or yield of the boreholes. For low yielding boreholes changes in aquifer geochemistry can occur when water saturated geologic materials are exposed to oxygen, and this can result in naturally occurring minerals dissolving into the groundwater (Uhlman, 2008). The discussion below on water types indicates mostly the influence of sea water on the sampled sites.

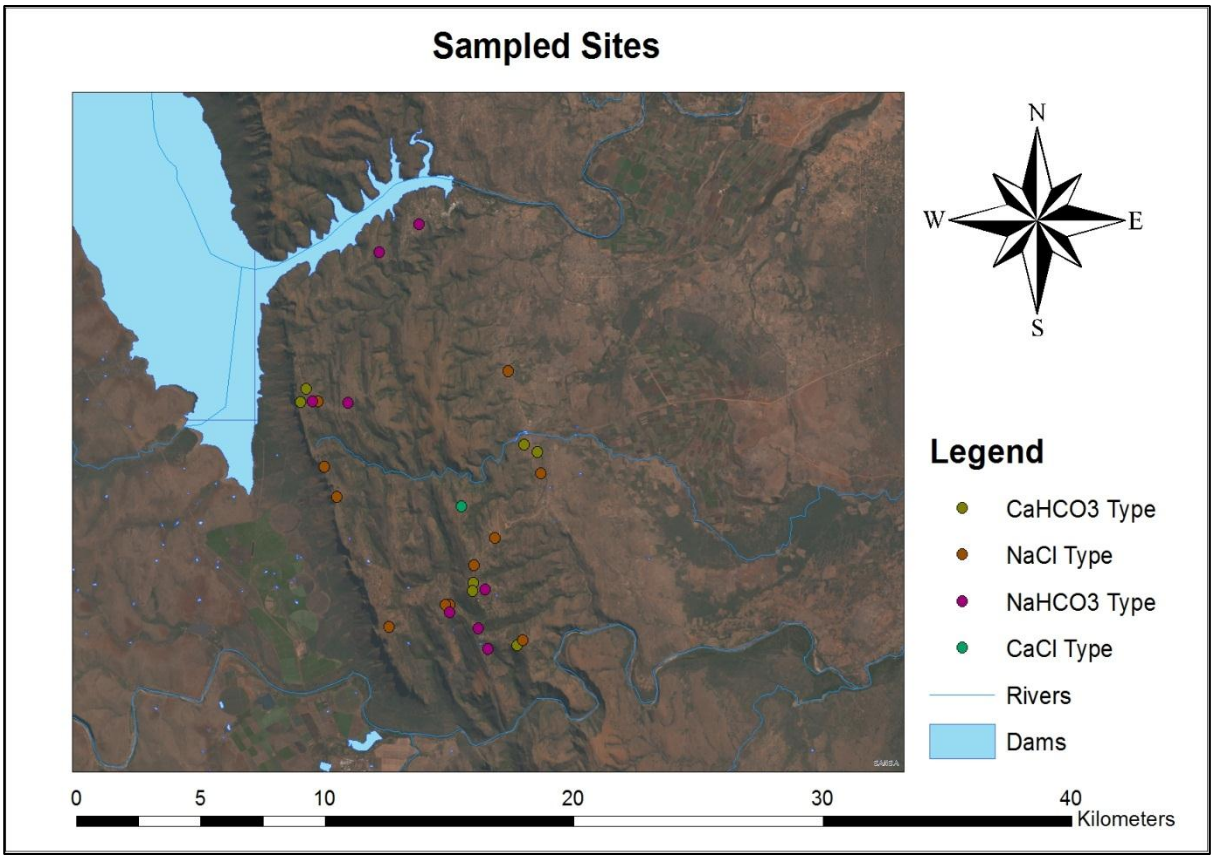


Figure 9-2: A map showing water types from the sampled boreholes (Drawn using ArcGIS 10.2.2).

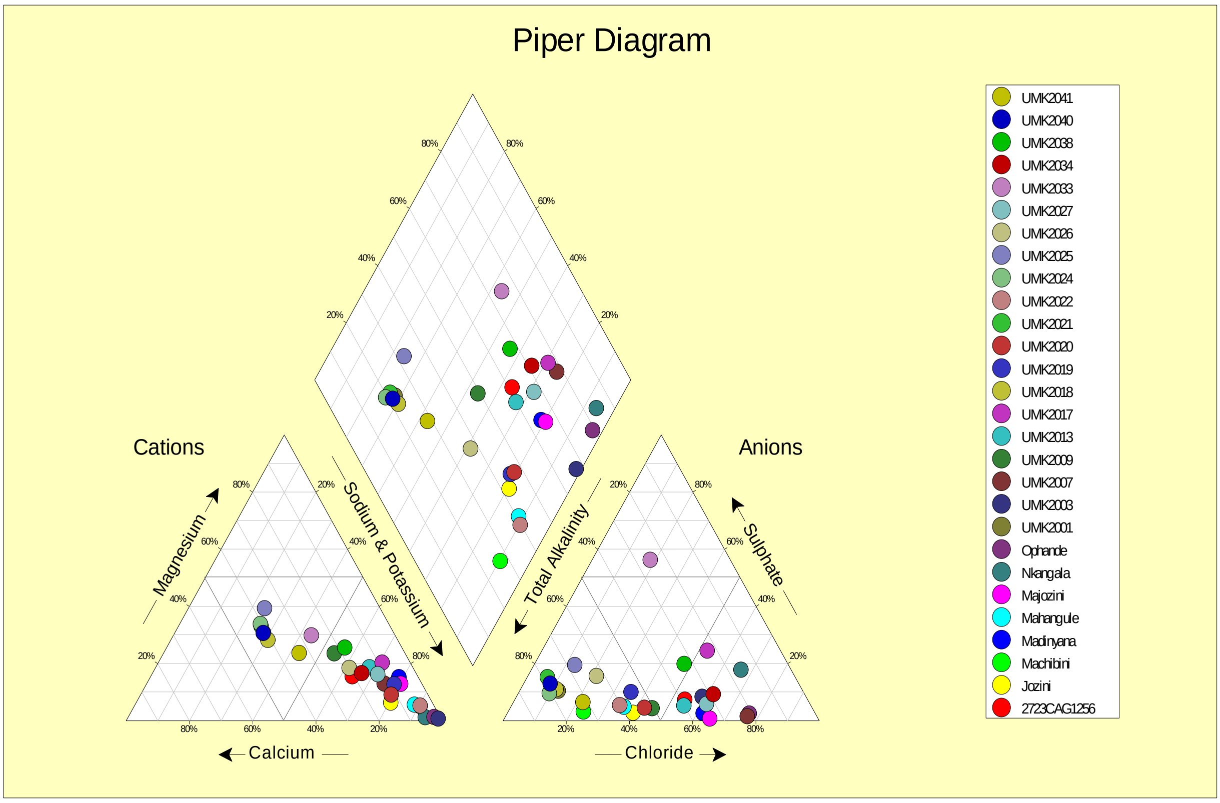


Figure 9-3: Piper diagram for the sampling which took place in the wet/rainy season.

9.4.1.1 $CaHCO_3$

The first water type was classified as $CaHCO_3$ type of water (Figure 2-2 and Figure 9-3), this type of water was evident from the samples taken from the following seven boreholes: UMK2001, UMK2018, UMK2021, UMK2024, UMK2025, UMK2040 and UMK2041 (Figure 9-3). This water type is the indication of fresh groundwater in the recharge area (Lloyd & Heathcote, 1985; Champidi *et al.*, 2011). This water type is dominated by Ca^{2+} and HCO_3^- ions resulting from calcite dissolution. The cation exchanger is also dominated by adsorbed Ca^{2+} (Appello & Postma, 1993).

9.4.1.2 Na-Cl Type

The second and most dominant water type is from the following twelve boreholes UMK2003, UMK2007, UMK2013, UMK2017, UMK2027, UMK2034, UMK2038, 2723CAG1256, Madinyana, Nkangala, Ophande and Majozini could be classified as sodium-chloride water type (Figure 2-2 and Figure 9-3). According to Appelo and Postma (1993), this type of water is associated with the influence of sea water, ancient saline groundwater, or dissolution of halite (NaCl), while Panno *et al.*, (2006) identified the septic effluent and animal waste as other source identification of sodium and chloride in natural waters. These boreholes are located within a range of 375-663 meters above mean sea level (mamsl), meaning this water type could possibly be because of sea water from the Indian Ocean. This assumption is further supported by van Wyk (1963) for the groundwater studies in Northern Natal, where it is stated that the salinity of the water was due to cyclic salts carried from the Indian Ocean inland by prevailing winds.

9.4.1.3 Na-HCO_3 type

The water type was identified from eight boreholes and is the second dominant type found on the samples at Machibini, Jozini, Mahangule, UMK2009, UMK2019, UMK2020, UMK2022 and UMK2026 (Figure 2-2 and Figure 9-3). There is also mixing of Ca^+. This water type is formed due to ion exchange; this is to say the sorption of one ion is matched with desorption of another ion (Langmuir, 1997). Younger (2007) defined sorption as a physical and chemical process by which one substance becomes attached to another and desorption is the opposite of sorption whereby previously sorbed ions are released back into solution. At depth in many confined zones adsorbed Na^+ is present in abundance on mineral surfaces. This is assumed to be the reflection of an earlier period in geological time, when the aquifer sediments were bathed in sea water (Appelo & Postma, 1993; Langmuir, 1997). The elevation for these boreholes is within the range of 277-588 mamsl. For this water type the following could have happened, as freshwater which is rich in dissolved Ca^{2+} penetrated depths of the aquifer, a preferential sorption process took place where Ca^{2+} ions are sorbed onto the mineral surface, while the Na^+ ions are released into the solution. The net result is that incoming groundwater of $Ca\text{-}HCO_3$ facies is transformed into $Na\text{-}HCO_3$ facies (Appleo & Postma, 1993; Abercrombie *et al.*, 1994; Langmuir, 1997).

9.4.1.4 Ca-Mg-Cl type

The last water type, which is a mixed Ca-Mg-Cl type (Ravikumar & Somashekar, 2010, Manoj *et al.*, 2013) was evident from only one sample taken from UMK2033 (Figure 2-2 and Figure 9-3). This water type comes from the mixing of fresh and saline waters. Lloyd and Heathcote (1985) suggest that it is possible that this water type could be due to the influence of reverse ion exchange as well. The water from this sampled borehole is considered as old water, affected by the reverse cation exchange phenomena and is rich in salts. The elements in the water composition of this sample are the major elements of seawater, showing that there could have been seawater intrusion.

9.4.2 Dry season

This sampling was conducted during the month of March in 2016 when there is little rainfall in the study area and the results are presented on a Piper diagram in Figure 9-4. This sampling was done with two aims, to see if low level precipitation would have any impact on groundwater quality, if recharge had taken place and whether long time usage from the first sampling would also cause any change in the quality of groundwater; especially in the newly drilled boreholes.

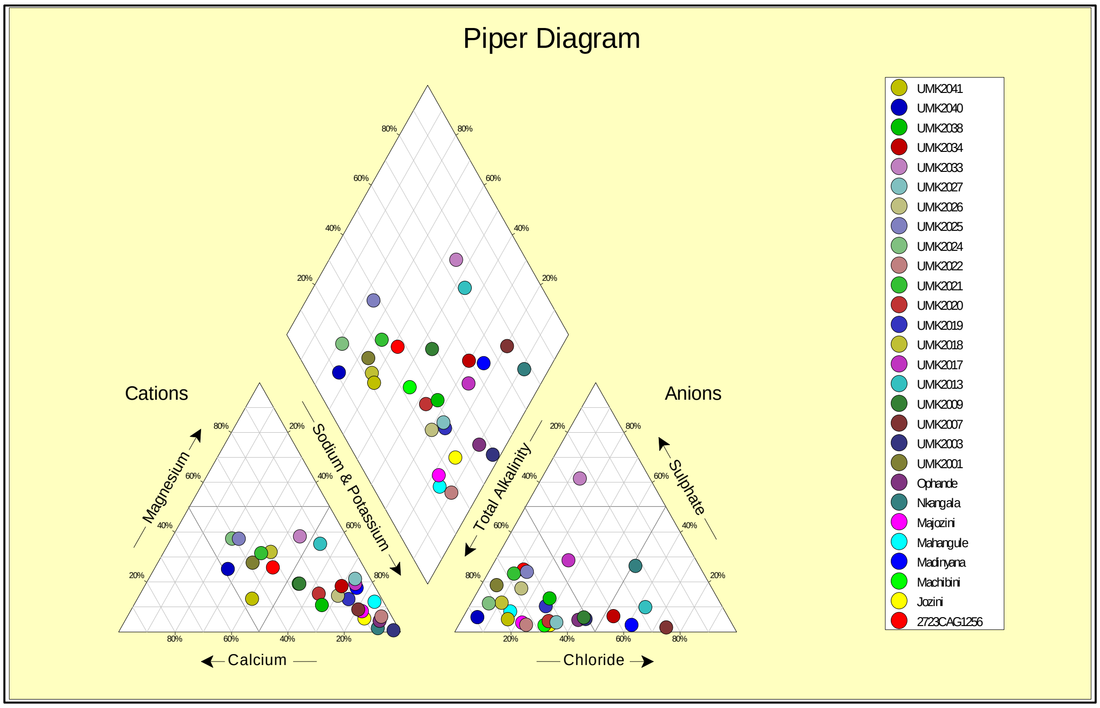


Figure 9-4: Piper diagram for the sampling which took dry wet.

The sampling results from the lab have shown little change in water quality (Figure 9-4). Notable change was for chloride, conductivity and manganese levels which appear to be a little bit higher. This is believed to be because there is less water to dilute them as there has not been much rainfall from the time of first sampling, but again, the elevation of all these determinands is usually due to chemical parameters associated with the rock formation. The water types have not changed much either but there are samples which appear to have moved from one water type to another; for example, sample 2723CAG1256 moved from NaCl water type into the side of $CaHCO_3^-$ indicating fresh water from the recharge area. The other sample that showed a change was taken from the Machibini borehole, this sample is still within the same water type ($NaHCO_3^-$), compared to first sampling, but with has moved closer to the freshly recharged water ($CaHCO_3$). These changes could have been due to recharge in groundwater or anthropogenic factors. Sample from borehole UMK2038 moved from NaCl water type to $NaHCO_{3,}$ this could be due to ion exchange.

9.5 GROUNDWATER QUALITY ASSESSMENT

9.5.1 Hardness

Durfor and Becker (1964) defines hardness of water as a property of water that is a measure of the amount of soap required to form lather, while Briggs and Ficke (1977) defines hardness as the amount of dissolved calcium and magnesium in the water. The total hardness measurements, thus are classified as “soft” to “very hard” (Table 9-5), based on the criteria by Durfor and Becker (1964).

Table 9-5: Water hardness classification (Durfor and Becker, 1964).

Hardness Range (mg/L)	Hardness Description	Percentage (%)
0-60	Soft	36
61-120	Moderately hard	18
121-180	Hard	7
181- above	Very hard	39

Most samples (39% of the samples) display a very hard characteristic followed by soft water, (36% of the samples) based on Table 9-5. Water that is low in hardness causes corrosion of metallic surfaces, while hard water consumes excessive amounts of soap and synthetic detergents in homes, laundries, and textile industries. It forms insoluble scum and curds and causes problems in the processing of foods, beverages, and rubber (Durfor & Becker, 1964; WHO, 2011). However, according to WHO (2011) no health-based guideline value is proposed for hardness in drinking water.

The study area is dominated by groundwater, classified as ideal quality based on its total hardness (Table 9-6). No sample has displayed the characteristic of class 3 water type.

Table 9-6: Total hardness classification of water quality based on DWAF (1998) for all samples.

Total Hardness (mg/l)	Class	Water type	Percentage (%)
0-200	Class 0	Ideal quality	64
200-300	Class 1	Good quality	25
300-600	Class 2	Marginal quality	11
>600	Class 3	Poor quality	0

9.5.2 Domestic and drinking use

In assessing whether the groundwater in the study area is suitable for human consumption, reference was made to drinking water guidelines for South Africa was used (DWAF, 1996). This guideline provides the acceptable limits for variables in water quality for domestic, agriculture and industry water use. Another guideline used is from the World Health Organization for drinking water quality (WHO, 2011). These guidelines provide limits for variables and the health risks associated with those variables when they exceed allowable limits.

As already stated in the beginning of this chapter, the samples were compared to SANS 241:2011 drinking water standards. Safe drinking water should comply with SANS: 241. That way it will not pose significant health risks over lifetime consumption. SANS: 241 have categorized water quality into four (4) classes:

- Class 0 - denotes ideal water quality for lifetime use;
- Class 1 - means good water quality, suitable for lifetime use. Rare instances of sub-clinical effects;
- Class 2 - implies that water is of marginal quality, it may be used without health effects by majority of individuals of all ages, but may cause effects in some individuals in sensitive groups;
- Class 3 - denotes that water quality is poor. It poses a risk of chronic health effects, especially in babies, children and the elderly; and
- Class 4 - water quality is unacceptable will have severe acute health effects, even with short-term use.

The risks associated with each class where there are any, are provided in Appendix F. The sampled water quality results are provided in Table 9-7 and highlighted based on per variable's class according to SANS (241: 2011).

The description of classes according to SANS (241:2006) is presented in Appendix G, while the drinking water quality standards by DWAF (1996) and WHO (2011) are shown in Appendix H. The physical, aesthetic, operational and chemical determinands based on SANS 241-1:2015 are provided as Appendix I(a) and I(b).

Table 9-7: Water Quality results categorized in classes as guided by SANS: 241: 2011

Site	pH	EC	TDS	Ca	Mg	Na	K	Cl	SO4	NO3-N	F	Fe	Mn	MALK	Total Hardness
		mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Jozini	7.9	139.00	746.00	30.00	8.20	215.00	2.18	176.00	13.60	0.14	0.54	0.18	0.09	352.00	109.00
Machibini	7.40	150.00	367.00	59.00	24.00	201.00	1.30	194.00	10.50	1.01	0.18	0.30	0.33	393.00	246.00
Ophande	7.4	385.00	1038.00	34.00	15.00	575.00	2.44	168.00	12.30	0.19	0.31	1.79	0.77	246.00	147.00
Majozini	6.6	32.00	184.00	3.20	3.70	44.00	2.98	52.00	0.30	0.06	0.18	0.24	0.05	38.00	23.00
Nkangala	8.4	115.00	506.00	8.40	0.80	198.00	2.32	231.00	81.00	0.09	6.15	0.11	0.01	76.00	24.00
Mahangule	8.3	67.00	372.00	6.50	3.50	114.00	1.32	77.00	12.50	0.04	3.70	0.14	0.03	176.00	31.00
Madinyana	6.8	67.00	428.00	6.60	10.00	100.00	2.98	125.00	5.75	0.11	0.42	0.96	0.04	99.00	58.00
UMK2001	7.19	72.50	507.50	64.00	28.70	49.50	3.75	36.35	38.26	1.32	0.41	0.02	0.03	307.00	277.67
UMK2003	8.8	139.00	532.00	1.90	0.40	293.00	1.50	266.00	47.90	2.40	0.40	5.18	0.03	206.00	6.00
UMK2007	7.2	105.00	103.00	20.00	13.00	147.00	3.70	221.00	4.23	0.05	0.88	0.04	0.58	88.00	103.00
UMK2009	7.1	108.00	234.00	46.00	29.00	129.00	1.70	148.00	17.00	0.05	0.86	7.75	0.08	231.00	234.00
UMK2013	6.8	30.00	333.00	6.10	5.00	35.00	0.70	49.00	5.76	0.03	0.41	2.16	0.19	50.00	36.00
UMK2017	6.2	21.00	486.00	2.80	3.90	26.00	1.00	36.00	22.10	1.07	0.29	5.11	0.02	22.00	23.00
UMK2018	7.18	67.90	475.30	68.97	28.42	59.31	2.55	32.13	38.29	1.99	0.26	0.01	0.00	293.00	288.00
UMK2019	7.5	54.00	109.00	8.40	7.20	87.00	1.50	58.00	20.80	0.05	1.78	1.03	0.04	123.00	51.00
UMK2020	7.8	111.00	746.00	24.00	11.00	190.00	5.00	150.00	19.20	0.05	3.04	2.26	0.12	259.00	105.00
UMK2021	7.48	79.40	555.80	71.09	34.64	52.69	2.14	23.00	65.00	0.75	0.26	0.03	0.04	358.00	319.00
UMK2022	8.2	56.00	175.00	4.40	3.10	110.00	1.70	60.00	11.60	0.04	1.88	2.37	0.03	146.00	24.00
UMK2024	7.37	69.50	486.50	57.56	28.84	41.70	2.11	29.00	34.00	1.47	0.21	0.02	0.02	312.00	262.15
UMK2025	7.25	70.70	494.90	58.89	38.22	45.40	1.32	39.14	74.00	0.08	0.16	0.02	0.19	273.00	303.92
UMK2026	7.3	56.00	128.00	17.00	9.30	110.00	2.70	31.00	28.40	0.05	3.14	1.53	0.26	122.00	81.00
UMK2027	6.3	37.00	110.00	5.30	4.20	34.00	3.90	46.00	5.40	0.76	0.26	7.18	0.27	34.00	31.00
UMK2033	7	112.00	350.00	59.00	40.00	111.00	5.50	68.00	269.00	0.04	0.75	12.90	1.25	126.00	312.00
UMK2034	7	91.00	330.00	26.00	15.00	114.00	5.50	167.00	31.80	0.96	0.75	3.70	0.30	108.00	127.00
UMK2038	7.3	50.00	420.00	15.00	8.00	63.00	5.90	80.00	13.70	0.05	0.19	3.59	0.05	80.00	78.00
UMK2040	7.06	73.80	516.60	65.90	29.40	50.50	3.86	26.27	48.89	2.19	0.24	0.02	0.04	319.00	285.29
UMK2041	7.54	65.50	458.50	49.08	20.77	72.87	1.68	57.60	20.65	0.44	0.22	0.01	0.00	255.00	207.84
2723CAG1256	7.39	70.60	494.20	57.30	22.33	63.90	2.44	33.06	49.63	1.77	0.39	0.02	0.02	285.00	243.81
Class 0	5 - 9.5	< 70	< 450	< 80	< 70	<100	<25	<100	<200	<6	<0.7	<0.01	0 -0.1		0 - 200
Class 1	4.5 - 5 or 9.5 - 10	70 -150	450 - 1000	60 - 150	70 - 100	100 - 200	25 - 50	100 - 200	200 - 400	6 - 10	0.7 -1	0.5 - 1	<1.5		200 - 300
Class 2	4 - 4.5 or 10 - 10.5	150 - 370	1000 - 2400	150 -300	100 - 200	200 - 400	50 - 100	200 - 600	400 - 600	10 - 20	1 -1.5	1 - 5	1.5 - 4		300 - 600
Class 3	3-4 or 10.5-11	370-520	2400 - 3400	>300	200 - 400	400 - 1000	100 - 500	600 - 1200	600 - 1000	20 -40	1.5 - 3.5	5 - 10	4.0 - 10		>600
Class 4	<3 or >11	>520	>3400		> 400	> 1000	> 500	> 1200	> 1000	>40	>3.5	>10	>10		

With reference to Table 9-7 it is notable that all the samples have the ideal levels of the following analysed variables: pH, calcium (Ca), magnesium (Mg), potassium (K) and nitrates (NO3-N), all of which are characterised as class 0. Only one borehole (Majozini) shows an ideal water quality (Class 0) for all variables sampled. Water from this borehole can be used without any effects and is suitable for many generations to come.

Seven (7) samples (Madinyana, UMK2001, UMK2018, UMK2024, UMK2040, UMK2041 and 2723CAG1256) show that the tested variables are between Class 0 and Class 1. Water from these boreholes is acceptable for human consumption.

Samples taken from Jozini and Machibini boreholes, show marginally acceptable levels of Sodium (Na). This could be due to chemicals associated with the rock formation. It is widely stated that although not considered toxic, Na may be a factor in hypertension. However, according to WHO (2011), no firm conclusions can be drawn concerning the possible association between Na in drinking water and the occurrence of hypertension. Therefore, no health based guideline value is proposed. However, WHO (2011) further notes that concentrations more than 200 mg/l may give rise to an unacceptable taste. This could be the case with both these samples, as their concentrations were 215 mg/l and 201 mg/l respectively, but with proper sampling procedures followed and/or more regular use, these levels might decrease. Therefore these boreholes were considered to have acceptable water quality and therefore were installed with hand pumps for the community to use.

The Ophande sample shows water quality with marginal concentrations of Electrical Conductivity (EC), Total Dissolved Solids and Iron (Fe). However, levels of Na are unacceptable. These parameters are usually naturally occurring in groundwater, as they are associated with the rock formation (Ngah & Nwankwoala, 2013). According to WHO (2011) there are no health and aesthetic effects associated with EC but there is a close relation to TDS, which at high concentrations, may cause an unacceptable taste. Fe in high concentrations may cause tissue damage, caused by hemochromatosis (Hodgson & Manus, 2006), however, based on WHO (2011) at this level (1.79 mg/l) Fe is not a health concern in drinking water. The sample further shows level of Na (575 mg/L) categorized as class 2, at these concentrations it may give water an objectionable taste, but it is not of concern, health wise, according to WHO (2011). The borehole was also fitted with a hand pump to be used by the community.

Nkangala and Mahangule boreholes show unacceptable levels (class 4). According to McCaffrey and Willis (1993) and Fayazi (1994) fluorides are found in varying amounts in practically all the geological formations, especially in most igneous rocks. In high concentrations those associated with class 4 water may cause pitting of the teeth, as well as painful and tender bone (Ncube, 2002; Ncube & Schutte, 2005; WHO, 2011). Due to the levels of fluoride hugely exceeding the acceptable limits, the consultants decided to seal the boreholes off (newly drilled boreholes Nkangala and Mahangule). However, during the second sampling run, these boreholes were resampled following proper sampling procedures according to Weaver *et al.,* (2007) for newly drilled boreholes Nkangala and Mahangule. The results came back showing improvements in fluoride levels characterised as class 2, which implies that the water is marginally acceptable. The boreholes were therefore fitted with hand pumps and given to the community. The existing boreholes could not be resampled using proper sampling procedures, as they were already fitted with hand pumps and were already in use by the community, even before the first sampling in October 2015. So even during resampling in March 2016, samples were taken from the taps of the hand pump. Two of these samples (UMK2019 and UMK2026) also showed improvements for class 2; the other samples (UMK2020 and UMK2022) were still within class 3.

Four samples (UMK2003, UMK2009, UMK2017 and UMK2027) showed poor quality for iron (Fe) - class 3, while the levels for samples taken from borehole UMK2033 are unacceptable (class 4). Fe in groundwater is naturally occurring, for example from weathering of iron bearing minerals and rocks. Fe in high concentrations may cause tissue damage, caused by hemochromatosis (Hodgson & Manus, 2006). In the concentration observed from the samples, water from these boreholes would not be recommended for human consumption, as it may cause severe health effects. However, the community is adamant that they have been using water from these boreholes for a long time and they have not experienced any effects. Even after resampling there was no improvement in the quality as only UMK2033 moved from class 4 to class 3, which is still poor.

9.5.3 Irrigation uses - salinity hazard

Salinity hazards, also known as the Sodium Adsorption Ration (SAR) was used to assess the suitability of groundwater for irrigation (Figure 9-5). Although the aim of this study was groundwater assessment for human consumption, it was important to also assess the suitability for irrigation, as most of the members of the villages within the town of Jozini have small gardens in their yards and they might need to irrigate using water from these boreholes.

According to Khodopanah *et al.,* (2009) and Asadollahfardi *et al.,* (2013) SAR water can be classified in four ways:

- **Class 1 and Class 2:** good water for irrigation and can be used in most cases without any special salinity control;
- **Class 3:** water may be detrimental to some sensitive crops; careful management practices are required; and

- **Class 4:** very high salinity water and is not suitable for irrigation of crops, except for salt tolerant crops.

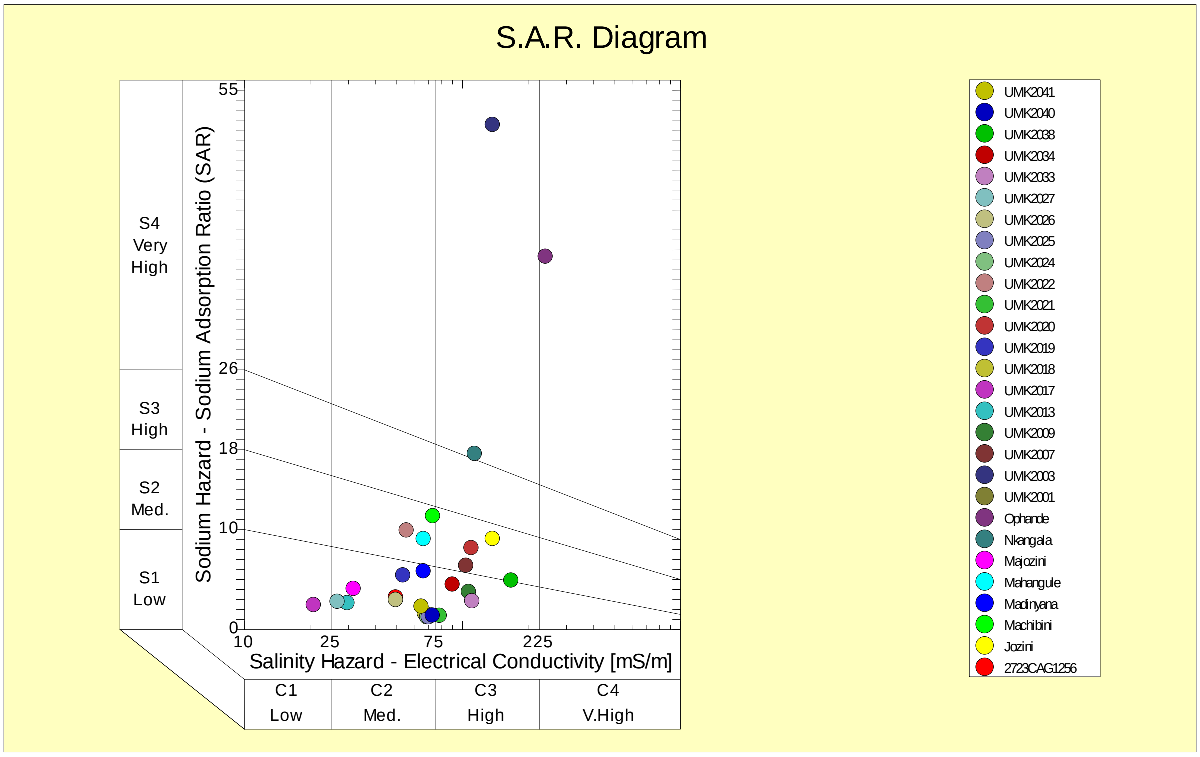


Figure 9-5: SAR diagram for irrigation suitability in the study area

Figure 9-5 gives the irrigation suitability of groundwater in the study area. SAR ranges between 1.1-50.4, with an average of 7.59. Water from the sampled boreholes is mostly suitable for irrigation as SAR is between low and medium, except for three boreholes showing a very high SAR (Ophande, Nkangala and UMK2003), meaning it is not suitable for irrigation.

9.6 SUMMARY

This chapter focused on the analysis and interpretation of groundwater quality in the study area. This was done by performing a statistical overview of the chemical dataset. The reliability of data was tested where ion balance error and SAR index were determined. During this analysis it was found that the boreholes UMK2007, UMK2009, UMK2022 and UMK2027 had an ion balance error higher than 5%, meaning that either the analytical analysis of the individual ions may be in error or that an important constituent of the solution may not have been included in the reaction error calculation.

The Piper and SAR diagrams were used to analyse the quality of groundwater in the study area. It was believed that with continued use, the boreholes with quality issues would improve. However, the second sampling which was done about 5 months after the first sampling still gave similar results. The use of water from these boreholes is not recommended, although the community is already using these boreholes and is content with the quality of water from those boreholes, this is not an occurrence for the town of Jozini only but it seems it happens in most parts of the country where people depend on groundwater for survival (Mpenyane-Manyatsi *et al.*, 2012).

Groundwater quality was further analysed using DWA (1996) and WHO (2011) guidelines, as well as SANS 241-1:2011 and SANS 241-1:2015 standards. The samples taken in the study area showed a mix of class 0 to class 4 for drinking water quality. Most of the samples were within class 0 to class 2, which is acceptable for drinking or human consumption. The following chapter will provide the conclusion of the study and provide the recommendations.

CHAPTER 10: CONCLUSION AND RECOMMENDATIONS

10.1 CONCLUSIONS

A study was conducted to assess the groundwater resource potential for development and use in the rural town of Jozini, KwaZulu-Natal Province in South Africa. The study had the following main objectives: assessment of groundwater occurrence, the determination of the geological characteristics of the aquifer, estimation of groundwater recharge, determination of borehole sustainable yields, and the characterization of hydrochemical processes and evaluation of the groundwater quality.

The main findings of the study are as follows:

Groundwater occurrence

The geophysical studies have shown that groundwater in the study area can be found mostly on the host rock which is a rhyolite of the Jozini formation, as well as on the contact between the host rock and the intrusion (dolerite). Based on the results of the seven newly drilled boreholes, it can be concluded that the boreholes where water strikes were intersected on the host rock or on the intrusion, have much higher yields than those drilled on the contact area between the host rock and the intrusion.

Geological characterization of the aquifer

During the drilling process, for every metre the drill cuttings were recorded, these cuttings were used for interpretation of the geology of the borehole and presentation of geological logging. Most of the boreholes were drilled to a depth of 150 mbgl, as the deepest and the shallowest had a depth of 90 mbgl. Dolerite intrusion was intersected in all drilled boreholes. The study area is mostly underlain by the rhyolite rocks of the Jozini formation of the Karoo Supergroup being intruded by the dolerite.

Estimation of groundwater recharge

The study further found out that the town of Jozini and its surrounding villages receives the recharge of about 5.88-67.99 mm/a (1.18-13.68%) of the average annual rainfall of 498 mm using the Chloride Mass Balance (CMB) method.

Three qualified guess methods in the form of Vegter maps (Vegter, 1995), ACRU map (Schulze, 1995) and Harvest Potential map (Baron *et al.*, 1998) were used and these methods indicated the recharge in the ranges of 10-50 mm/a (1.07-5.36%). Based on the limitations and assumptions made when using these methods, it is concluded that the determined recharge volumes are in line with the groundwater recharge volumes, estimated using the CMB method.

Determination of borehole sustainable yields

A total of eleven boreholes (seven newly drilled boreholes and four existing boreholes) were pump tested to determine borehole sustainable yields, using the basic FC method.

These eleven boreholes had a combined sustainable yield of 0.95 l/s, which could supply water to about 4 659 people (at 25 litres per person per day) if pumping were to be continuous for a 24 hour cycle. This is about 82 080 litres per day and equivalent of 0.0821 ML/day. This volume of water will not be enough for the town and its villages as a total population of 39 899 people need to be supplied with water.

Hydrochemical processes characterization and groundwater quality evaluation

Making use of Piper diagrams to classify water types, it was found that the study area has two dominant water types; namely: the calcium bicarbonate water type and the sodium chloride water type. This is an indication of freshwater in the recharge area and the influence of sea water, ancient saline groundwater, or dissolution of halite (NaCl), respectively. The other minor water types in the study area are a sodium bicarbonate water type and a calcium chloride water type.

Groundwater quality analysis shows that generally groundwater shows a mix of class 0 to class 4 for drinking water quality. The majority of the samples are within class 0 to class 2, which is acceptable for drinking or human consumption.

Water from the sampled boreholes is mostly suitable for irrigation as the SAR is between low and medium; except for three boreholes showing a very high SAR (Ophande, Nkangala and UMK2003), meaning it is not suitable for irrigation.

10.2 OTHER FINDINGS

The following findings were also made during the study:

- It was also found that all the boreholes are low-yielding making them suitable for hand pump installations.
- Many hand pumps although still in use, were found to need some basic housekeeping and operational maintenance.
- From the sampling results, it became clear that the community has been consuming water of poor quality from boreholes UMK2003, UMK2009, UMK2017, UMK2020,

UMK2022, UMK2027 and UMK2033; as these samples are within class 3 water quality, but the community doesn't seem to have a problem with the quality of water from those boreholes as they claim that the water is good for them, but the other reason is that those were their closest water supply.

- There is a need for a groundwater management plan from the municipality (District), as the municipality could not even provide a list of the boreholes owned by the municipality. A groundwater monitoring plan should be in place, where groundwater quality will be given priority. The Department of Water and Sanitation should assist the municipality in this regard.

10.3 RECOMMENDATIONS

From the study and the conclusions drawn the following recommendations are made:

- For future studies, the drilling targets should be sited on the host rock or on the intrusion as the results suggests that these targets have much higher blow yields.
- For the estimation of groundwater recharge using CMB, chloride concentration in rain water should be sampled during both wet and dry seasons and groundwater recharge should be compared between the two seasons, to evaluate and analyse the season in which there is more groundwater recharge taking place.
- The municipality, together with the DWS should avail funds for the drilling of additional boreholes and their sustainable yield should be estimated. This will supplement the current groundwater and surface water resources being used by the community of Jozini.
- The existing boreholes which are in a poor state but could not be refurbished should be refurbished and pump tested, to determine their sustainable yields; subject to the availability of funds.
- Other existing boreholes which had collapsed and were not refurbished, should be refurbished, subject to funding availability. However, an action plan and methodology should be considered with the aim of helping the District Municipality, as it is the water service provider.
- The other option to consider would be to install pumps to deliver water from the desalination plant that is being proposed in Richards Bay to the town of Jozini. However, this might take a long time as the desalination plant is still in the planning phase.

- It is further recommended that the water quality, especially of the marginally to poor quality boreholes be sampled and analysed on a regular basis (monthly or quarterly). This data will also help in establishing a comprehensive dataset, enabling the municipality and DWS to detect changes to the quaternary catchment and will also help with setting up a groundwater quality benchmark.

- A comprehensive groundwater monitoring and management plan must be initiated and implemented to ensure that available groundwater resources are preserved, conserved, protected, managed and controlled for sustainable use.

- The DWS and the District Municipality should work together in training the municipal officials, with regard to developing a groundwater monitoring and management plan.

APPENDIX A

List of resources visited during hydrocensus including NGA and GRIP data

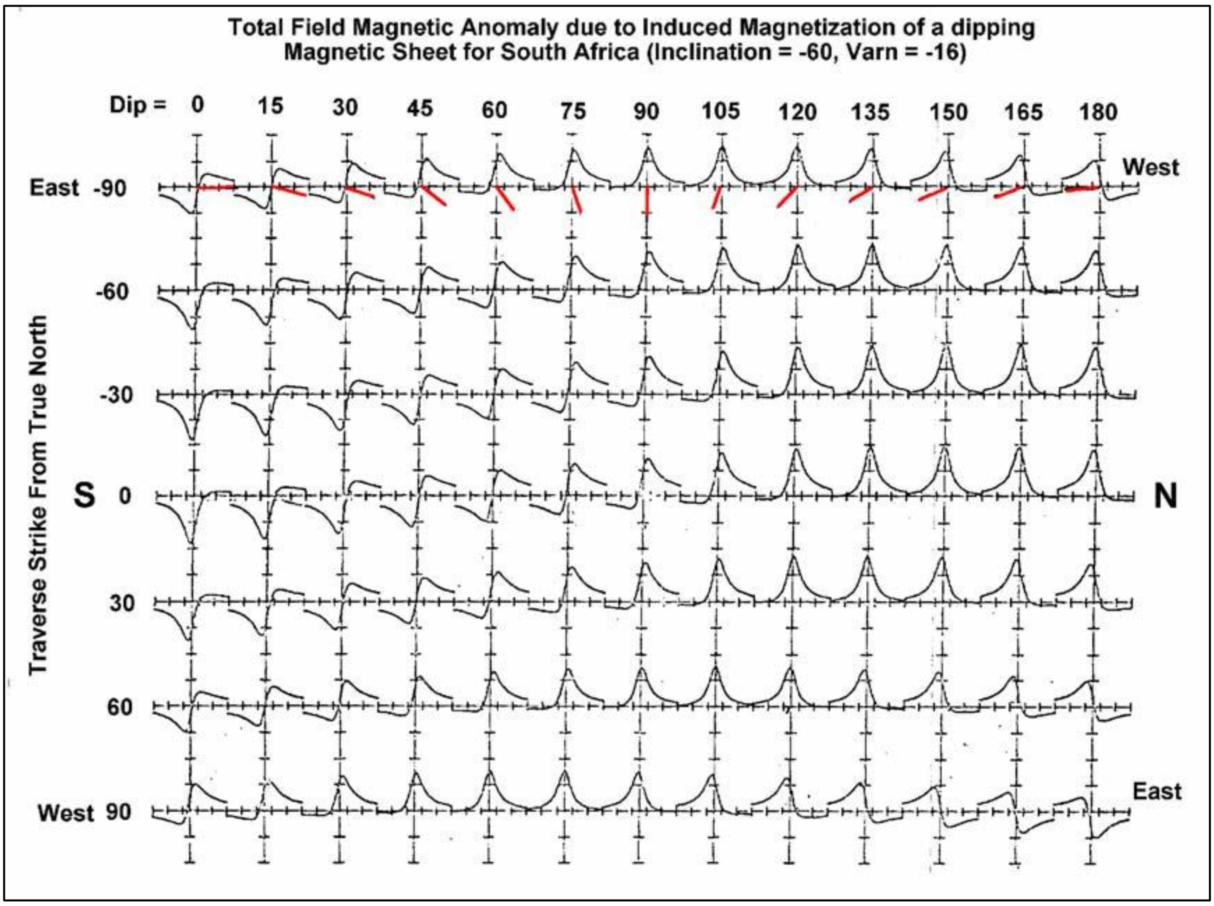
No	Field Identifier	NGA[a]	GRIP[b]	Latitude	Longitude	Total Depth (mbgl)	Operational status	Comment
1	UMK2001	NAD[c]	NAD	-27.57732	32.09491	95	In use	Used
2	UMK2002	NAD	NAD	-27.57845	32.09597	-	Not working	Destroyed
3	UMK2003	NAD	NAD	-27.56335	32.07034	76	Not working	To be re-furbished
4	UMK2005	NAD	NAD	-27.56267	32.07053	-	Not working	Low yield
5	UMK2006	NAD	NAD	-27.56229	32.07007	-	Not working	Low yield
6	UMK2007	NAD	NAD	-27.56356	32.06899	-	In use	Hand pump
7	UMK2009	2732CA00219	NAD	-27.56603	32.07032	85	Working	Farm (domestic use)
8	UMK2011	NAD	NAD	-27.56298	32.05965	120	In use	Hand pump
9	UMK2013	NAD	NAD	-27.57098	32.04847	90	In use	Hand pump
10	UMK2016	NAD	NAD	-27.52898	32.02984	-	Not working	Dry
11	UMK2017	2732CA00195	NAD	-27.51605	32.02522	76	Not working	To be refurbished
12	UMK2018	NAD	NAD	-27.49396	32.01653	120	In use	Hand pump
13	UMK2019	NAD	NAD	-27.49371	32.02085	90	In use	Hand pump
14	UMK2020	NAD	NAD	-27.49419	32.0336	90	In use	Hand pump
15	UMK2021	NAD	NAD	-27.4895	32.01849	95	In use	Hand pump
16	UMK2022	NAD	NAD	-27.57149	32.08074	120	In use	Destroyed
17	UMK2023	NAD	NAD	-27.56427	32.0867	60	In use	Hand pump
18	UMK2024	2732CA00175	NAD	-27.556	32.07897	100	In use	Irrigation
19	UMK2025	NAD	NAD	-27.5586	32.0788	120	In use	Irrigation
20	UMK2026	NAD	NAD	-27.55809	32.08316	-	Not working	To be refurbished
21	UMK2027	2732CA00210	NAD	-27.54985	32.0792	68	In use	Hand pump
22	UMK2028	NAD	NAD	-21.54746	32.07907	-	Not working	Low yield
23	UMK2029	NAD	NAD	-27.5473	32.07728	-	Not working	Not operational
24	UMK2030	NAD	NAD	-27.54317	32.0769	-	Not working	Not operational
25	UMK2031	NAD	NAD	-27.55106	32.08221	-	Not working	Collapsed/dry

26	UMK2032	NAD	NAD	-27.53163	32.07156	-	Not working	Not operational
27	UMK2033	NAD	NAD	-27.52978	32.07461	95	In use	Domestic /private
28	UMK2034	2732CA00133	NAD	-27.54044	32.08672	65	In use	Domestic/private
29	UMK2035	NAD	NAD	-27.53691	32.08484	-	Not working	Destroyed
30	UMK2036	2732CA00211	2732ACG2494	-27.52731	32.10452	-	Not working	Destroyed
31	UMK2037	NAD	NAD	-27.51973	32.10636	-	Not working	Collapsed/dry
32	UMK2038	NAD	NAD	-27.51846	32.10345	100	In use	Hand pump
33	UMK2039	NAD	NAD	-27.51631	32.10668	-	Not working	Not operational
34	UMK2040	NAD	NAD	-27.50859	32.09741	-	In use	Domestic/clinic
35	UMK2041	NAD	2732CAG4853	-27.51116	32.1021	-	Not working	To be refurbished
36	UMK5001	NAD	NAD	-27.47992	32.10936	120	Working	Domestic at school
37	UMK7001	NAD	2732CAG4849	-27.48383	32.08689	-	Not working	Not operational
38	NAD	NAD	2732CAG4856			-	Not working	Not operational
39	NAD	NAD	2732CAG1256			70	Working	Used

NGA[a]**-** National Groundwater Archive, **GRIP**[b]**-** Groundwater Resource Information Project data, NAD[c]- No Available Data

APPENDIX B

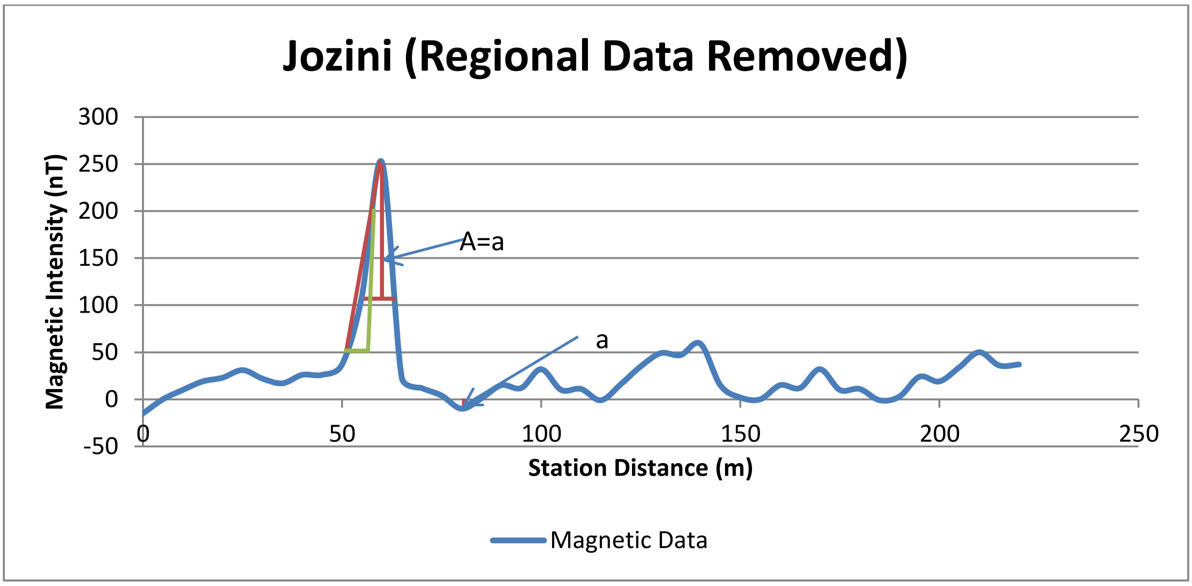
Type curves for magnetic anomalies over dipping dolerite dykes in South Africa (Roux, 1980).



APPENDIX C

Calculations for dolerite intrusion parameters

a. Calculations for Jozini Profile (T01)



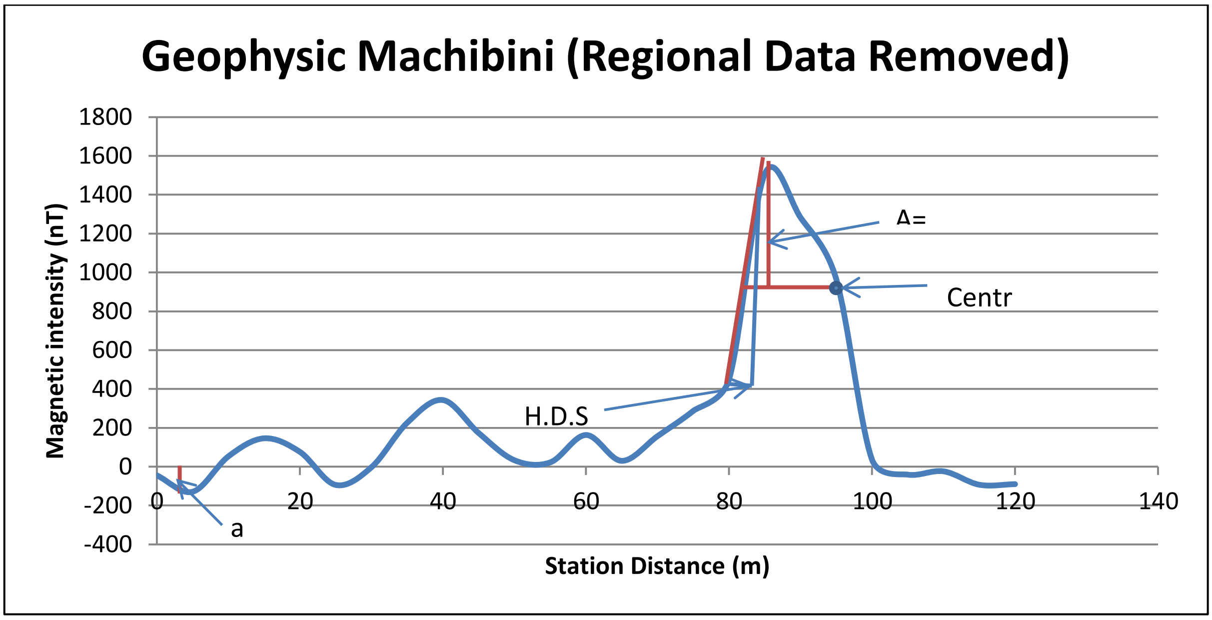
The centre of the geological body is calculated at sixty metres along the traverse.

Then the estimated Horizontal Slope distance (HSD) is five metres.

Using Thin dyke formulae then 1.3*HSD = 1.3*5 m = six and a half metres.

Therefore, the depth of the magnetic body is estimated at 6.5 mbgl.

b. Calculations for Machibini Profile (T02)



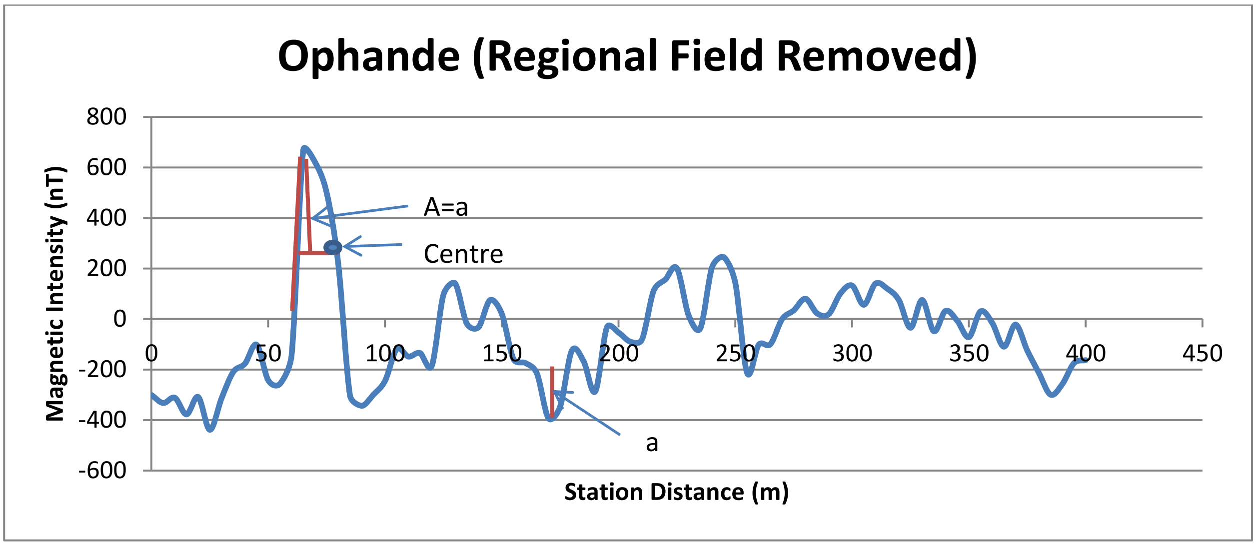
The centre of the geological body is calculated at ninety-five metres along the traverse.

Then the estimated Horizontal Slope distance (HSD) is five metres.

Using Thin dyke formulae then 1.3*HSD = 1.3*5m = six and a half metres.

Therefore, the depth of the magnetic body is estimated at 6.5 mbgl.

c. Calculations for Ophande Profile (T03)



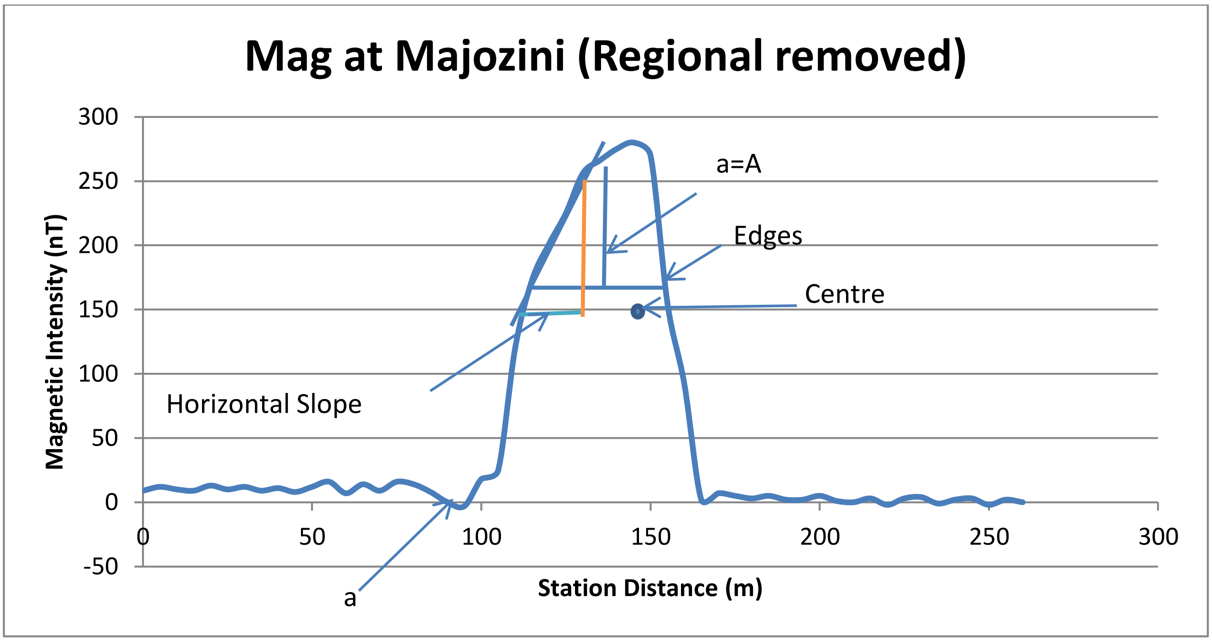
The centre of the geological body is calculated at eighty metres along the traverse.

Then the estimated Horizontal Slope distance (HSD) is five metres.

Using Thin dyke formulae then 1.3*HSD = 1.3*5m = six and a half metres.

Therefore, the depth of the magnetic body is estimated at 6.5 mbgl.

d. Calculations for Majozini Profile (T04)



a is the distance from zero line to maximum.

A=a when the cord parallel to zero line is at the distance A=a, from the maximum line.

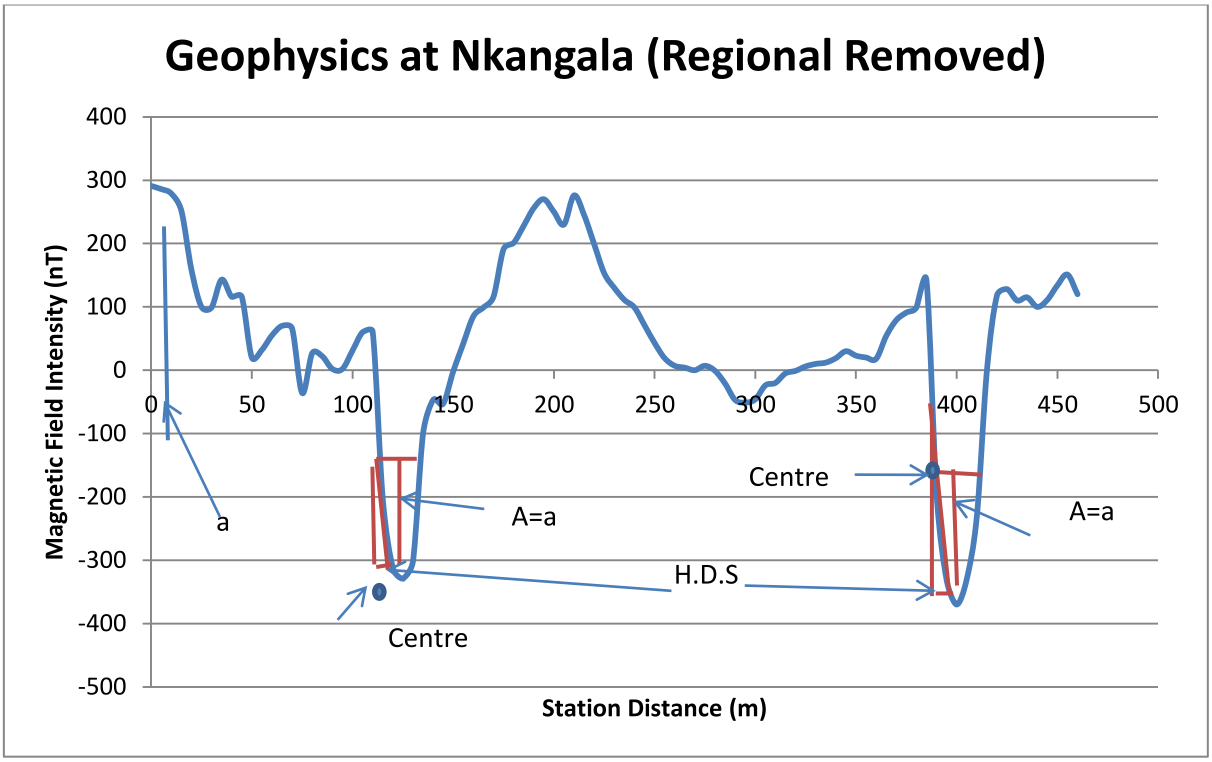
The centre of the geological body is calculated at one hundred and fifty metres along the traverse.

Then the estimated Horizontal Slope distance (HSD) is fifteen metres.

Using Thin dyke formulae then 1.3*HSD = 1.3*15m = nineteen and a half metres.

Therefore, the depth of the magnetic body is estimated at 19.5 mbgl.

e. Calculations for Nkangala Profile (T05A and T05B)



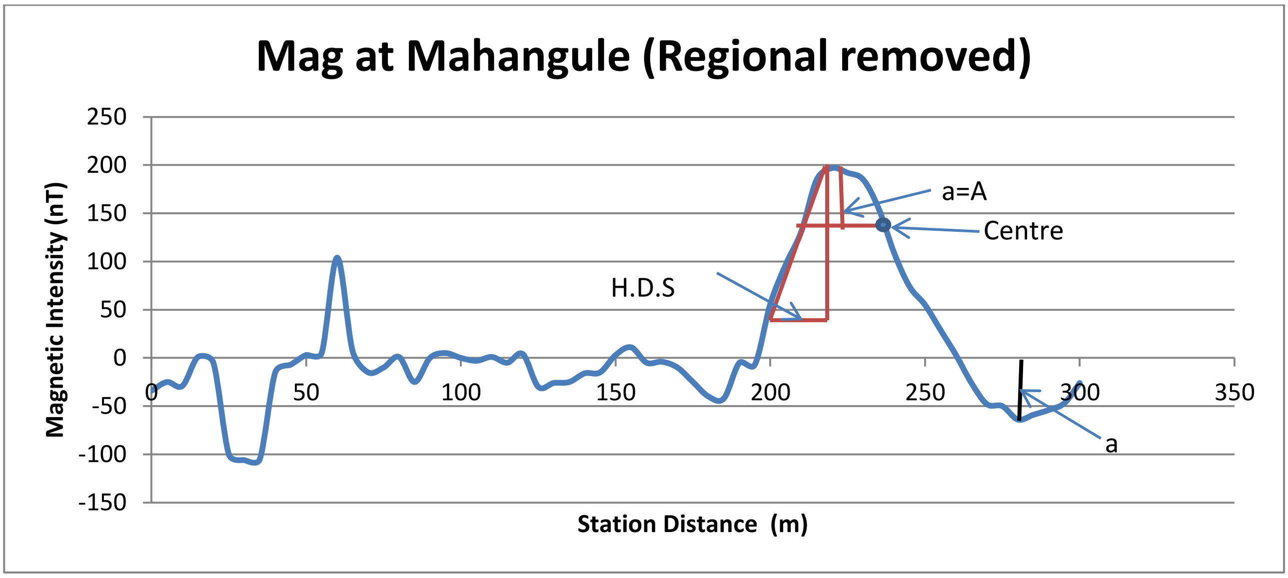
The centre of the geological body is calculated at one hundred and twenty metres for T03A and three hundred and ninety metres for T03B along the traverse.

Then the estimated Horizontal Slope distance (HSD) is five metres and ten metres.

Using Thin dyke formulae then 1.3*HSD = 1.3*5m = six and a half metres and 1.3*10m = thirteen metres.

Therefore, the depth of the magnetic body is estimated at 6.5 mbgl and 13 mbgl.

f. Calculations for Mahangule Profile (T06)



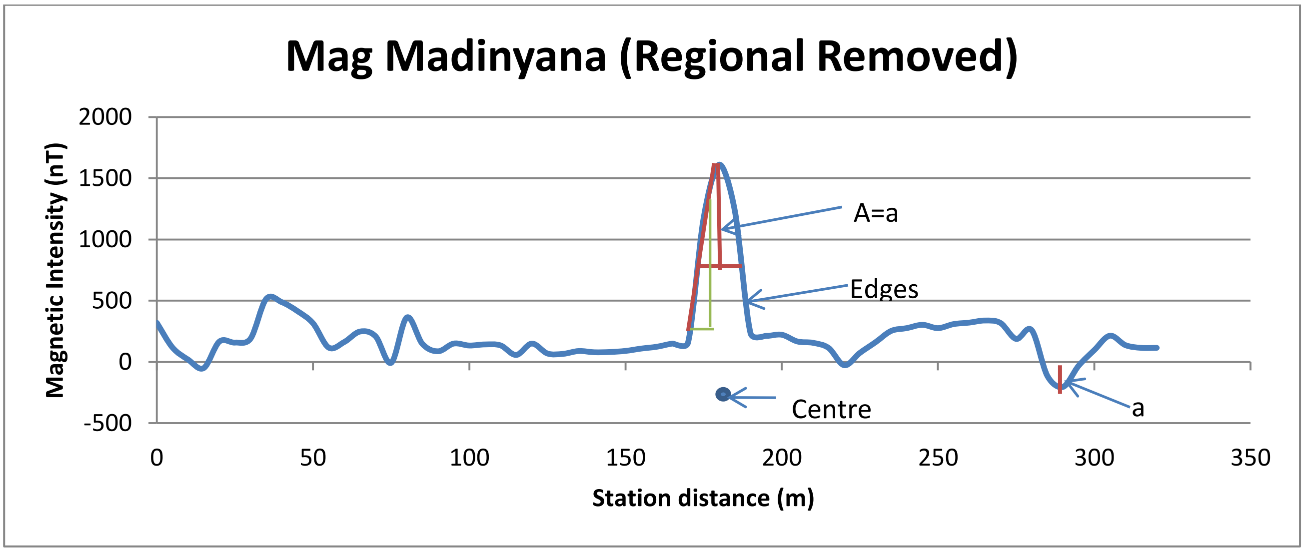
The centre of the geological body is calculated at two hundred and thirty-five metres along the traverse.

Then the estimated Horizontal Slope distance (HSD) is twenty metres.

Using Thin dyke formulae then 1.3*HSD = 1.3*20m = twenty-six metres.

Therefore, the depth of the magnetic body is estimated at 26 mbgl.

g. Calculations for Madinyana Profile (T07)



The centre of the geological body is calculated at one hundred and eighty metres along the traverse.

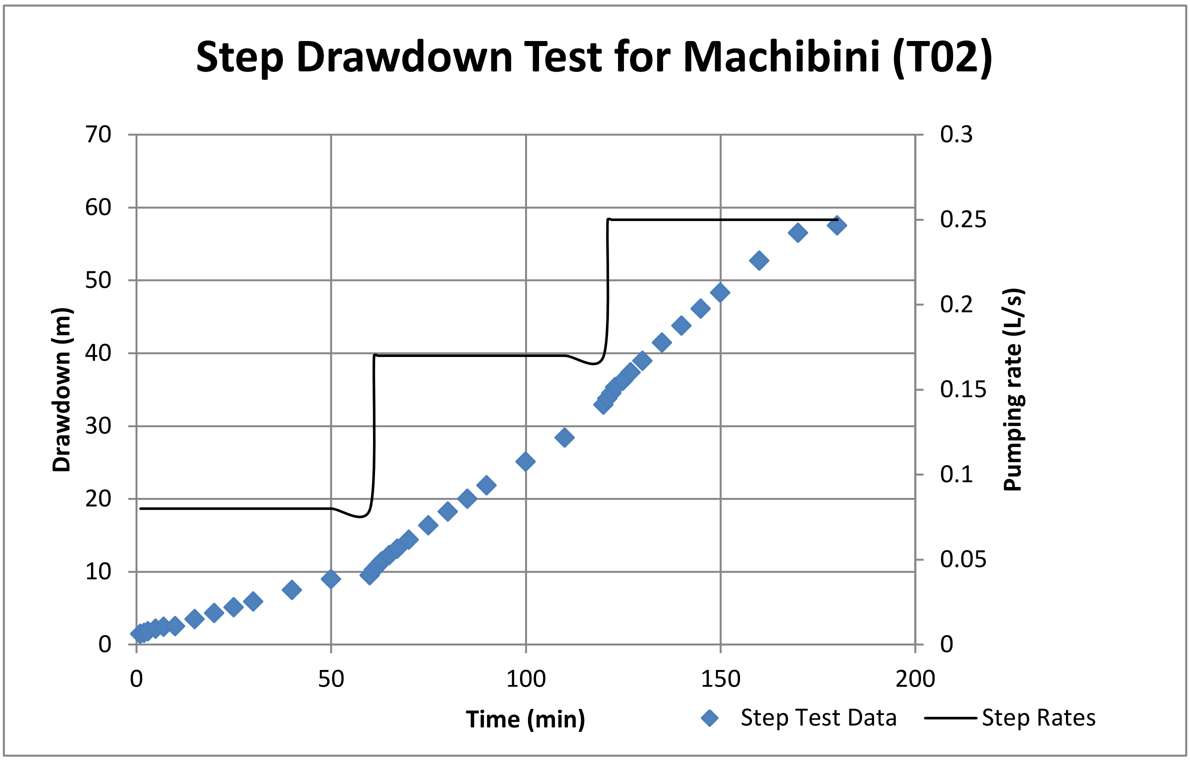
Then the estimated Horizontal Slope distance (HSD) is five metres.

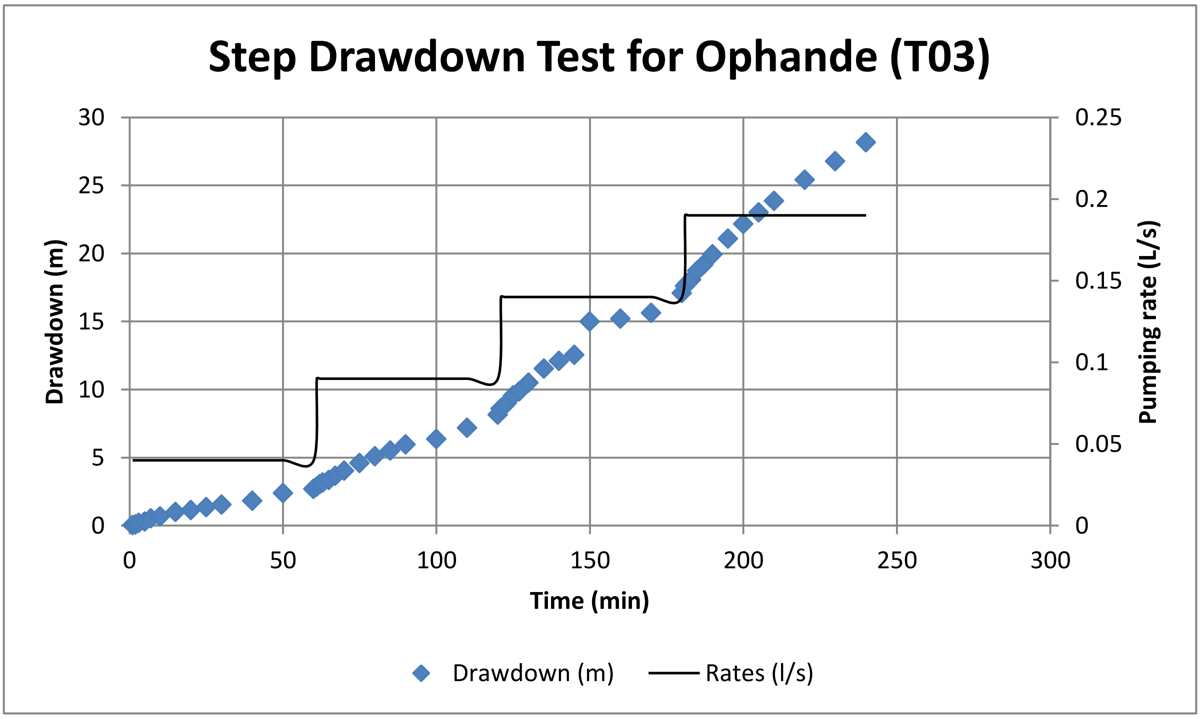
Using Thin dyke formulae then 1.3*HSD = 1.3*5m = six and a half metres.

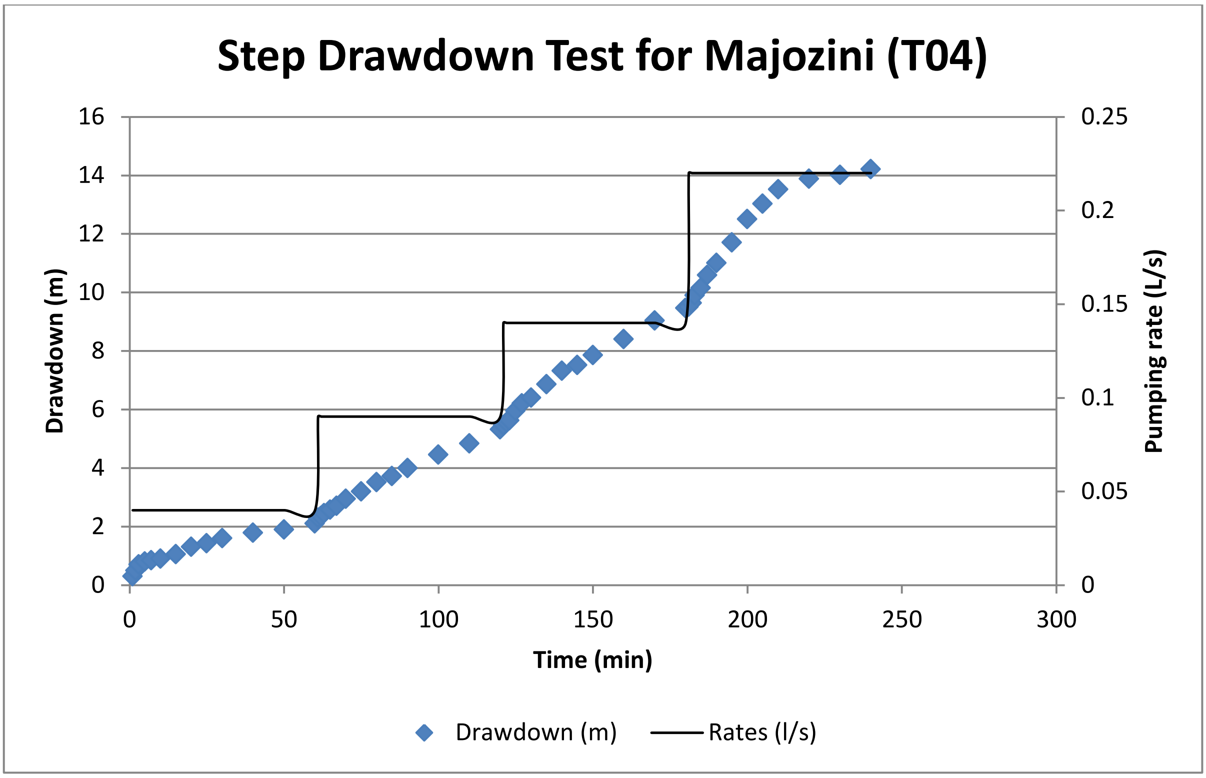
Therefore, the depth of the magnetic body is estimated at 6.5 mbgl.

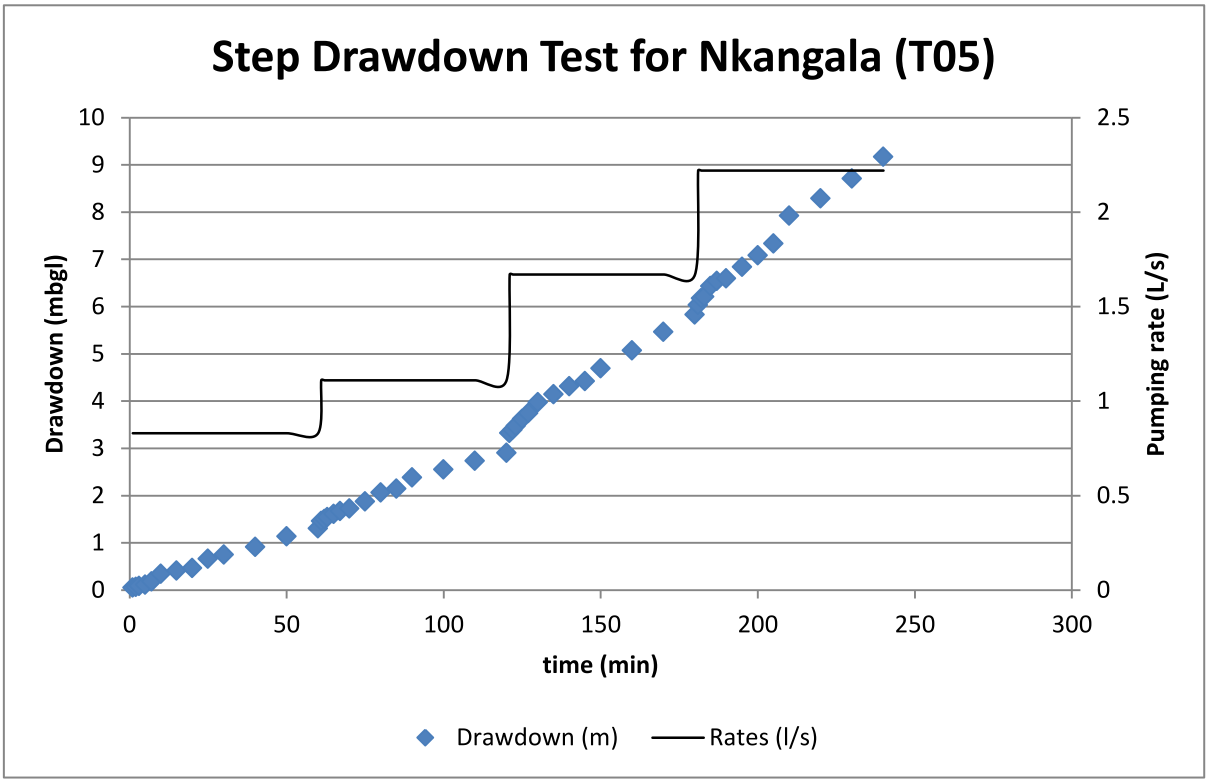
APPENDIX D

Step Drawdown Test Data



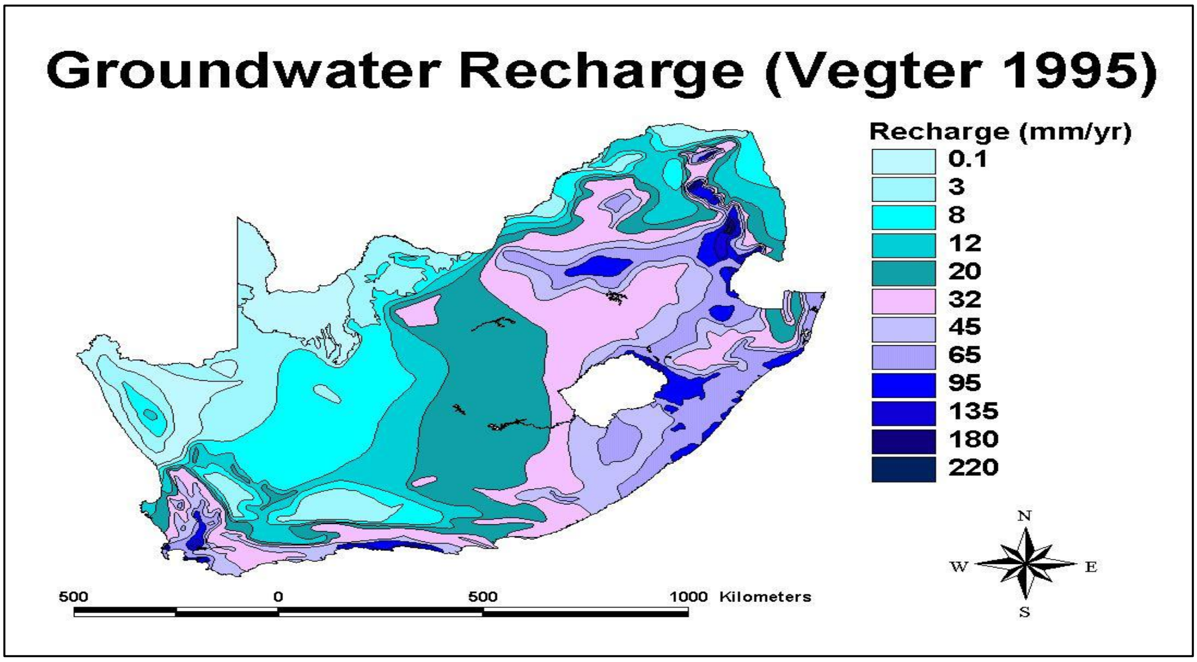



Step Drawdown Test for Majozini (T04)
Drawdown (m)
Pumping rate (L/s)
Time (min)
0
2
4
6
8
10
12
14
16
0
0.05
0.1
0.15
0.2
0.25
0
50
100
150
200
250
300
Drawdown (m)
Rates (l/s)


Step Drawdown Test for Nkangala (T05)
Drawdown (mbgl)
Pumping rate (L/s)
time (min)
0
1
2
3
4
5
6
7
8
9
10
0
0.5
1
1.5
2
2.5
0
50
100
150
200
250
300
Drawdown (m)
Rates (l/s)

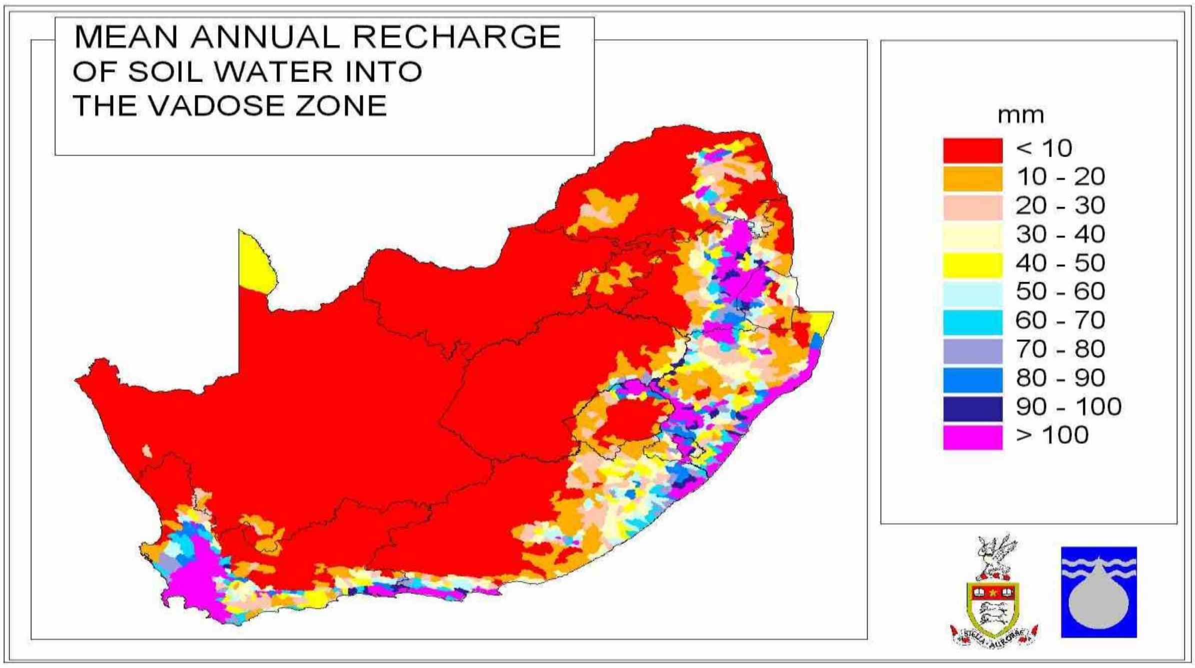
APPENDIX E

Vegters Map



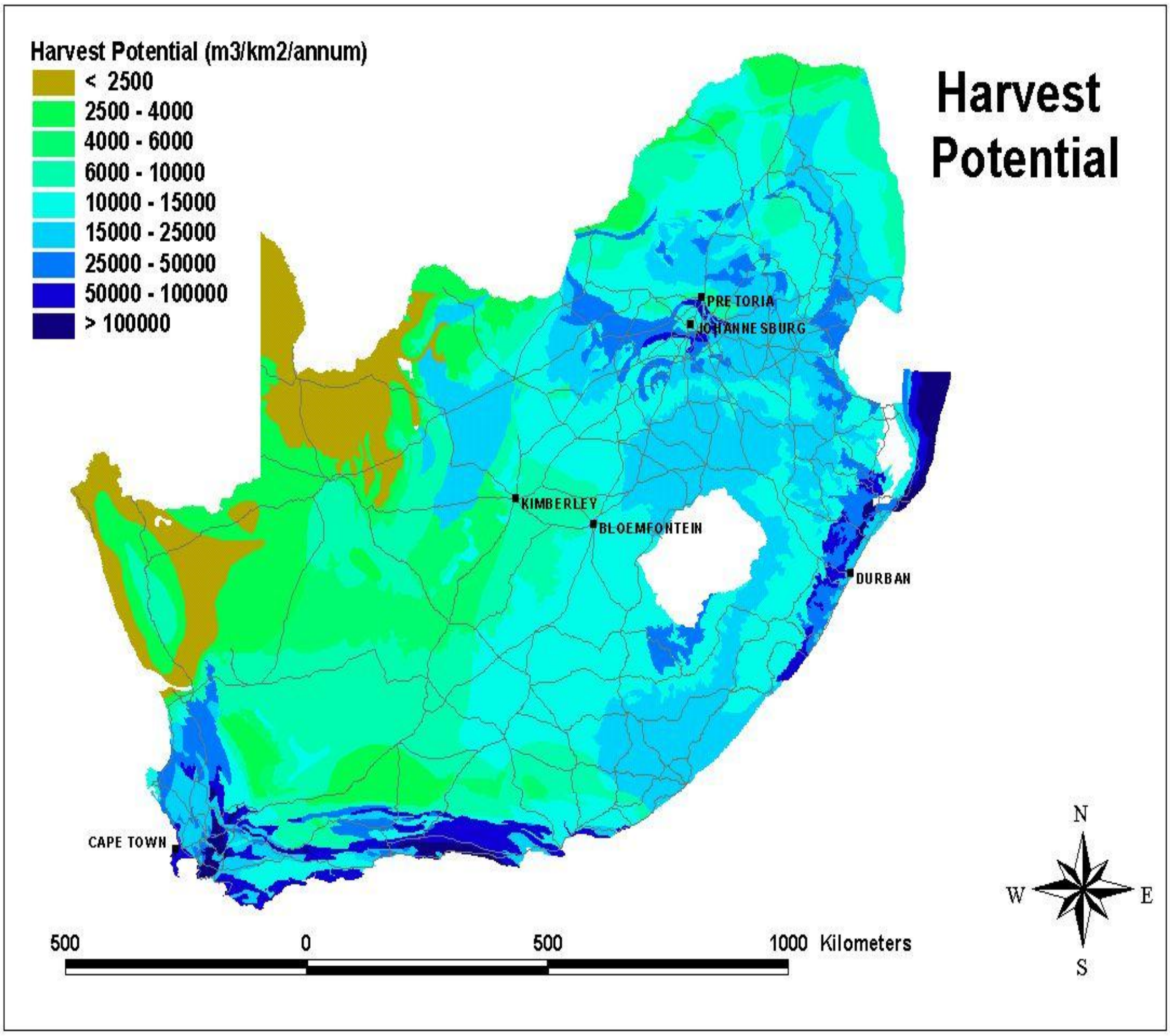
Recharge from map =	20
Recharge (mm/a) =	20
Recharge (%) =	2.15

ACRU recharge by Roland Schulze



From map: ACRU recharge	10
Recharge (%) =	1.07

Harvest Potential Map



Recharge (mm/a)	50.00
% Recharge	5.36
HP from Map [m3/km2/a] =	50000

APPENDIX F

Water quality classes and effects associated with them

Class 0	Drinking health:	No effects, suitable for many generations
	Drinking Aesthetic:	Water is pleasing
	Food preparation:	No effects
	Bathing:	No effects
	Laundry	No effects
Class 1	Drinking health:	Suitable for lifetime use. Rare instances of sub-clinical effects
	Drinking Aesthetic:	Some aesthetic effects may be apparent
	Food preparation:	Suitable for lifetime use
	Bathing:	Minor effects on bathing or on bath fixtures
	Laundry	Minor effects on laundry or on fixtures
Class 2	Drinking health:	May be used without health effects by a majority of individuals of all ages, but may cause effects in some individuals in sensitive groups. Some effects possible after lifetime use
	Drinking Aesthetic:	Poor taste and appearance are noticeable
	Food preparation:	May be used without health or aesthetic effects by the majority of persons
	Bathing:	Slight effects on bathing or on bath fixtures
	Laundry	Slight effects on bathing or on bath fixtures.
Class 3	Drinking health:	Poses a risk of chronic health effects, especially in babies, children and the elderly
	Drinking Aesthetic:	Bad taste and appearance may lead to rejection of water
	Food preparation:	Poses a risk of chronic health effects, especially in children and the elderly
	Bathing:	Significant effects on bathing or on bath fixtures
	Laundry	Significant effects on laundry or on bath fixtures
Class 4	Drinking health:	Severe acute health effects, even with short-term use
	Drinking Aesthetic:	Taste and appearance will lead to rejection of water
	Food preparation:	Severe acute health effects, even with short-term use
	Bathing:	Serious effects on bathing or on bath fixtures
	Laundry	Serious effects on bathing or on bath fixtures

APPENDIX G

SANS 241: 2006 Descriptions for Drinking Water Quality Classes.

Variable	Units	Class I	Class II
Aluminium (Al)	mg/L	<300	300-500
Antinomy (Sb)	mg/L	<10	10 - 50
Arsenic (As)	mg/L	<10	10 - 50
Cadmium (Cd)	mg/L	<5	5-10
Chromium (Cr)	mg/L	<100	100-500
Cobalt (Co)	mg/L	<500	500-1000
Copper (Cu)	mg/L	<1000	1000-2000
Cyanide (CN)	mg/L	<50	50-70
Iron (Fe)	mg/L	<200	200-2000
Lead (Pb)	mg/L	<20	20-50
Manganese (Mn)	mg/L	<100	100-1000
Mercury (Hg)	mg/L	<1	1 - 5
Nickel (Ni)	mg/L	<150	150-350
Selenium (Se)	mg/L	<20	20-50
Vanadium (V)	mg/L	<200	200-500

APPENDIX H

DWAF (1996) and WHO (2011) Drinking Water Quality

Variable	Domestic	Industry	Agriculture (Irrigation)	WHO (2011)
Alkalinity ($CaCO_3$)		0 -1200	0-5	
Aluminum	0 -0.15		0 - 0.1	0.9
Arsenic	0 - 0.01		0 - 0.1	0.01
Cadmium	0 - 5		0 -10	0.003
Calcium	0 - 32			
Chloride	0-100	0-500	0-100	
Chromium	0-0.05		0-0.1	0.05
Cobalt			0-0.005	
Copper	0-1		0-0.2	2
Fluoride	0-1		0-2	1.5
Iron	0-0.1	0-10	0-5	
Lead	0-0.01		0-0.2	0.01
Magnesium	0-30			
Manganese	0-0.05	0-10	0-10	
Mercury	0-0.001			0.006
Molybdenum			0-0.01	
Nickel			0-0.2	0.07
Nitrate+Nitrite	0-6		0-5	53
Potassium	0-50			
Silica			0-150	
Sodium	0-100		~70	
Sulphate	0-200	0-500		
Zinc	0-3		0.1	
pH	0-9	5-10	6.5-8.4	
TDS	0-450	0-1600	~40	
Barium				0.7
Selenium				0.04

APPENDIX I

Physical, aesthetic, operational and chemical determinants (SANS 241-1:2015).

1	2	3	4
Determinants	**Risk**	**Unit**	**Standard Limit**
Physical and Aesthetic determinants			
Colour	Aesthetic	mg/L Pt-Co	≤ 15
Conductivity at 25°C	Aesthetic	mS/m	≤ 170
Total Dissolved Solids	Aesthetic	Mg/L	≤ 1 200
Turbidity	Operational	NTU	≤ 1
	Aesthetic	NTU	≤ 5
pH at 25°C	Operational	pH Units	≥ 5 to ≤ 9.7
Chemical Determinants- Macro Determinants			
Free chlorine as Cl2	Chronic Health	mg/L	≤ 5
Monochloramine	Chronic Health	mg/L	≤ 3
Nitrate as N	Acute Health	mg/L	≤ 11
Nitrite as N	Acute Health	mg/L	≤ 0.9
Combined nitrate plus nitrite	Acute Health		≤ 1
Sulphate as $SO4^{2-}$	Acute Health	mg/L	≤ 500
	Aesthetic	mg/L	≤ 250
Fluoride as F^{-}	Chronic Health	mg/L	≤ 1.5
Ammonia as N	Aesthetic	mg/L	≤ 1.5
Chloride as Cl^{-}	Aesthetic	mg/L	≤ 300
Sodium as Na	Aesthetic	mg/L	≤ 200
Zinc as Zn	Aesthetic	mg/L	≤ 5
Chemical Determinants- Micro Determinants			
Antinomy as Sb	Chronic Health	µg/L	≤ 20
Arsenic as	Chronic Health	µg/L	≤ 10
Barium as Ba	Chronic Health	µg/L	≤ 700
Boron as B	Chronic Health	µg/L	≤ 2 400
Cadmium as Cd	Chronic Health	µg/L	≤ 3
Total chromium as Cr	Chronic Health	µg/L	≤ 50
Copper as Cu	Chronic Health	µg/L	≤ 2 000
Cyanide (recoverable) as CN^{-}	Acute Health	µg/L	≤ 200
Iron as Fe	Chronic Health	µg/L	≤ 2 000
	Aesthetic	µg/L	≤ 300
Lead as Pb	Chronic Health	µg/L	≤ 10
Manganese as Mn	Chronic Health	µg/L	≤ 400
	Aesthetic	µg/L	≤ 100
Mercury as Hg	Chronic Health	µg/L	≤ 6
Nickel as Ni	Chronic Health	µg/L	≤ 70
selenium Se	Chronic Health	µg/L	≤ 40
Uranium as U	Chronic Health	µg/L	≤ 30
Aluminium as Al	Operational	µg/L	≤ 300
Chemical determinants- Organic Determinants			
Total organic carbon as C	Chronic Health	mg/L	≤ 10
Combined Trihalomethane	Chronic Health	µg/L	≤ 1
Total microcystic	Chronic Health	µg/L	≤ 1
Phenols	Aesthetic	µg/L	≤ 10

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ABSTRACT

Due to a shortage of surface water, coupled with the current drought situation that has befallen South Africa, groundwater plays an important role in the water supply for domestic users; mostly for the rural communities in South Africa. Groundwater resource assessment aims to obtain significant data and information required to describe the hydraulic and chemical parameters for the estimation of the available groundwater resource suitable for human consumption. A study was undertaken for groundwater resource assessment for the rural town of Jozini in Northern KwaZulu-Natal, South Africa.

The field investigations included the use of geophysical methods, and for this study magnetic (G5 Proton magnetometer), together with electromagnetic methods (Geonics EM 34-3 system) were chosen as the preferred methods. The reason for the magnetic method was because it is easy to operate, analyse and interpret the anomalies from a possible structure such as a dolerite intrusion. On the other hand, the electromagnetic method was chosen, because it determines the resistivity of the rock, and the resistivity of variations with depth and lateral extent of geological structures, whereupon these variations are then interpreted to identify the drilling targets. Based on the results of the geophysics, drilling targets were sited, and seven boreholes were drilled using rotary percussion air drilling. Blow yields for the newly drilled boreholes ranged between 0.14-2.28 l/s, which is an indication of low yielding to moderately yielding boreholes. An aquifer pumping test was conducted on all newly drilled boreholes and existing four boreholes, for the duration of between 9 hours and 22 hours. Pumping test for the existing boreholes was conducted by another external consulting company, during their refurbishment.

The aquifer parameters were estimated using the Cooper-Jacob (1946) method and the Theis recovery (Theis, 1935) method. The general groundwater flow in the study area is from both the fractures and from the matrix, as seen from other boreholes. The combined yield of 0.95l/s (0.0821 ML/d) was estimated from all eleven boreholes (seven newly drilled and the four existing boreholes). These sustainable yields are very low and cannot sustain the requirement in the study area. The groundwater quality assessment reveals that there are two dominant water types in the study area namely: the NaCl water type (42%) and the Na-HCO_3- water type (28%), other samples show a mix of water types.

The conclusion was therefore made that although the area is characterised by low yielding boreholes, the municipality with the help of the DWS should drill more boreholes which will supplement the existing and newly drilled boreholes. It is then recommended that when drilling boreholes for water supply in the study area, the host rock (rhyolite) or the intrusion should be targeted as these areas have shown to have a bit higher yields than the boreholes which were drilled targeting the contact between the host rock and the intrusion.

OPSOMMING

As gevolg van 'n tekort van oppervlak water, tesame met die huidige droogte situasie wat Suid-Afrika, het speel grondwater 'n belangrike rol in die watervoorsiening vir huishoudelike gebruikers; meestal vir die landelike gemeenskappe in Suid-Afrika. Grondwater en grondwaterbronne poog betekenisvolle data en inligting wat vereis word om te beskryf die hidroliese en chemiese parameters vir die skatting van die beskikbare grondwater bronne wat geskik is vir menslike verbruik te bekom. 'N studie is onderneem vir grondwater grondwaterbronne vir die landelike dorp van Jozini in noordelike KwaZulu-Natal, Suid-Afrika.

Die veld ondersoeke sluit in die gebruik van Geofisiese metodes, en vir hierdie studie magnetiese (G5 Proton magnetometer), tesame met elektromagnetiese metodes (Geonics EM 34-3 stelsel) is gekies as die verkose metodes. Die rede vir die magnetiese metode was, want dit is maklik om te bedryf, ontleed en interpreteer die anomalieë uit 'n moontlike struktuur soos 'n dolerite indringing. Aan die ander kant, die elektromagnetiese metode is gekies, want dit bepaal die resistivity van die rots, en die resistivity van variasies met diepte en laterale omvang van geologiese strukture, waar hierdie variasies word dan geïnterpreteer identifiseer die boor teikens. Gebaseer op die resultate van die verlengde, boor teikens was geplaas, en sewe boorgate geboor was gebruik roterende percussion lug boor. Blaas opbrengste vir die nuut geboor boorgate gewissel tussen 0.14-2.28 l/s, wat 'n aanduiding van lae opbrengs te matig opbrengs van boorgate. 'N waterdraer pomp toets is gedoen op alle nuut geboor boorgate en bestaande vier boorgate, vir die duur van tussen nege ure en twee en twintig ure. Die bestaande boorgate is egter pomp getoets en word deur 'n ander eksterne konsultasie maatskappy, terwyl hulle hulle opknapping was.

Die waterdraer parameters was na raming gebruik die Cooper-Jacob (1946) metode en die Theis herstel (Theis, 1935) metode. Die algemene grondwater vloei in die studiegebied is van beide die frakture en uit die matriks, soos gesien vanaf ander boorgate. Die gesamentlike opbrengs van 0.95 l/s (0.0821 ML/d) was na raming van al elf boorgate (sewe nuut geboor en die vier bestaande boorgate). Hierdie volhoubare opbrengste is baie laag en die vereiste in die studiegebied te kan onderhou. Die grondwater kwaliteit assessering onthul dat daar is twee dominante water tipes in die studiegebied naamlik: die NaCl water tipe (42%) en die Na-HCO3-water tipe (28%), ander monsters wys 'n mengsel van water tipes.

Die slotsom wat bereik is dat alhoewel die gebied gekarakteriseer is deur boorgate wat ñ lae obrengs lewer, the munisipaliteit, met die hulp van Departement van Water & Sanitasie (DWS)meer boorgate moet boor wat die bestaande & nuwe boorgate sal aanvul. Dit word dan aanbeveel dat wanner boorgate in die omgewing geboor word, die gasheer rots (rioliet) of dat die inmenging geteiken sal word omdat hierdie areas bewys het dat dit ñ hoër opbrengs lewer as die boorgate wat geboor was tussen die gasheer rots & die inmenging.