Hydrogeological Characterisation of the Shingwedzi and Mphongolo River Basins in Kruger National Park, South Africa

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HWR 6990

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DECLARATION

I **Fhedzisani Ramusiya** hereby declare that the dissertation for the Master of Earth Sciences in Hydrology and Water Resources Degree has not been previously submitted by me at the University of Venda or any other institution under the same topic, and that it is my own work in design and in execution and that all referenced material contained therein has been duly acknowledged.

Signature: _____

Date: 05 March 2010

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ABSTRACT

A hydrogeological study has been undertaken as part of linking groundwater to ecosystem in the northern part of the Kruger National Park along Shingwedzi and Mphongolo River basins, in South Africa. This has been conducted as a basis of understanding the condition of groundwater resources. Geophysical investigation, borehole drilling, borehole pumping, and groundwater monitoring was carried in the area. Eight boreholes were drilled along the geophysical lines to obtain a detailed geology of the area and also for monitoring purposes. Rainfall data was obtained from the South African Weather Services to obtain the general cause of groundwater fluctuation in different times of the year. The study established that groundwater occurs in alluvial aquifers in those boreholes drilled along the river banks, basalt aquifers with alluvial material as overburden in deep boreholes (>22m) and also granite gneiss aquifers for those boreholes drilled in granite lineaments and bare patches. The study reveals that groundwater occurs in unconfined alluvial aquifers and semi-confined aquifers dominated by weathered basalts and granite gneiss. Groundwater within the study area shows some response to the occurrence of precipitation (rainfall). During each rainfall event, water level rises sharply in some of the boreholes located close to the river as a result of flow of water in the rivers due to rainfall events. In time of no rainfall event in the area, groundwater levels drops gradually. The hydraulic conductivity (K) in the area as obtained from grain-size analysis shows that the overburden alluvial materials of sand and gravel have high permeability as compared to the overburden material of loamy-clay. Borehole pumping data, as pumped by DWAF, provided the preliminary values for transmissivity (T) and storativity (S). High transmissivity values were obtained in alluvial boreholes and low values were obtained in granite gneiss boreholes and basalt boreholes. Groundwater quality is characterised into two major groundwater types dominated by sodium and chloride. The TDS values shows that groundwater within the study area is characterised as fresh water. By comparing the water quality results to the SANS 241:2005 and the SAWQG (DWAF 1996) for livestock watering, the results show that water quality in the area is suitable for both domestic and livestock use even though some of the elements are elevated above the guidelines.

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NOMENCLATURE

°C	: Degree Celsius
ADEs	: Dependent Ecosystem
b	: Aquifer thickness in metres
BH	: Borehole
Ca	: Calcium
Cl	: Chloride
CSIR	: Council of Scientific and Industrial Research
D_{10}	: Grain size at 10% passing
D_{50}	: Grain size at 50% passing
Δs_w	: Slope of the time-drawdown graph
DWAF	: Department of Water Affairs and Forestry
EC	: Electrical Conductivity
FC	: Fracture Characteristic
FIA	: Flow Injection Analysis
FTA	: Fracture Tests Analysis
HCO_3^-	: Bicarbonate and
I_o	: Intercept of the line formed by D_{50} and D_{10} with the grain size axis
ICPAES	: Inductively Coupled Plasma Atomic Emission Spectrometry
K	: The hydraulic conductivity
KNP	: Kruger National Park
l/s	: Litres per second
m/s	: Meters per second
mamsl	: Meters above mean sea level
mbgl	: Meters below ground level
Mg	: Magnesium
MHz	: Megahertz
mm	: Millimetres
mS/m	: Milli Siemens per meter
Na	: Sodium
PLM	: Polarizing Light Microscope
r	: Distance from the pumped well to the observation well or the radius of the well for a single well
s	: Drawdown
S	: Storativity
SAWQG	: South African Water Quality Guidelines
SEM	: Scanning Electron Microscope
SO_4^{2-}	: Sulphate
T	: Transmissivity
t	: Time since the beginning of pumping
TDS	: Total Dissolved Solids
t_o	: Time when s=0
μ	: Well function
USDA	: United States Department of Agriculture

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Ωm	: Ohm per metre
WRC	: Water Research Commission
XPL	: Cross Polarised Light

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CHAPTER 1: INTRODUCTION

1.1. Preamble

The study focused on the hydrogeology of the Shingwedzi and Mphongolo river basins within the Kruger National Park (KNP) as part of linking groundwater to ecosystem, which is part of the Water Research Commission (WRC) programme of Aquifer Dependent Ecosystem (ADEs) in South Africa. Within this programme, the dynamics of groundwater has been investigated in relation to the aquifers in which they depend. Exploitation of groundwater and vulnerability of these systems, have also been given consideration.

ADEs are ecosystems which depend on groundwater in, or discharges from, an aquifer (Colvin et al., 2005). They are distinctive because of their connection to the aquifer and would be fundamentally affected (altered) in terms of their structure and function if groundwater was no longer available (Colvin et al., 2005). ADEs occur throughout the landscape at various ecosystem scales and levels. They are found in discharge areas of the local and regional scale aquifer system. Riparian zones highlight the artificial distinction between aquatic, terrestrial, and wetland ecosystem. The most important reason for understanding the dependence of ecosystems on aquifers is for sustainable use of renewable resources such as groundwater and understanding which aquifers they depend on and also the nature of dependence (Colvin et al., 2005).

1.2. Background

Kruger National Park is an enormous nature reserve stretching 350 Km along the Mozambican border and is 60 km wide on average (Denis and Brett, 2001). Geologically the KNP is divided into two almost equal sections predominately granitic formation in the western half and the basalt formation in the eastern half. The two major formations are divided by a narrow belt of shale and sandstone (Schutte,

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1986). The geology of the Kruger National Park is dominated by a diverse combination of igneous, sedimentary and metamorphic rocks stretching over a geological timescale from the quaternary over to the Swazian system (over 3000 million years) (du Toit, 1998). The park is composed of the Swazian Goudplaats and Makhutswi gneiss, Swazian Nelspruit Suite granite and migmatite, Radian granite plutons, subordinate metamorphosed sedimentary and igneous rocks and also alluvium deposits (Vegter, 2001). The igneous metamorphic rocks ranging from Swazian to Jurassic periods lack adequate primary openings (interstices) to function as primary water bearing formations (aquifers). The depth of weathering and the depth to open fractures are generally not uniform in any particular area.

In places, older rock units of the KNP are covered by surficial deposits of the Quaternary age (Schutte, 1986). These include alluvium, scree, calcrete, ferricrete, gravel and sand. Large, fairly thick alluvial deposits are found along the rivers (Schutte, 1986). These alluvial deposits are present along the lower reaches of the Shingwedzi River, Timbavati River, Nwanetsi River, the Sweni River, Nwaswitsontso River and their tributaries, and also along the Sabie-Sand River and its tributaries within the KNP (du Toit, 1998). These are present before these rivers cross over on to the Karoo rocks (Vegter, 2003). Vegter (2003) indicated that primary aquifers, usually unconsolidated sand, are generally better aquifers for water and are found along the rivers (alluvium sand). Jurassic Cretaceous contains sandstones and conglomerate beds that may have adequate primary porosity and permeability to function as primary aquifers. They are formed by rivers depositing sand during floods. Very little is known about these water-bearing formations in South Africa (Vegter, 1995) and so is the case in KNP.

According to Vegter (1995), groundwater can be found everywhere on regional basis, but within local context groundwater occurrence is generally restricted to zones or areas of deepest weathering and open fractures. Groundwater in KNP generally occurs in fractured gneiss of the Goudplaats formation, basalts, gabbro, schist, diabase and sandstone, sandstone, dolerite-conglomerate, and also limestone ryolite. Groundwater

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in some cases also occurs in gneiss, schist contact and in alluvial materials to a limited extent (du Toit, 1996, 1998). The Quaternary formations compose of the alluvium sand, gravel and also volcanic rocks are also present along the Shingwedzi, Mphongolo, Bububu, and also the Phugwane river basins.

The chemical composition of surface and groundwater is controlled by many factors that include composition of precipitation, mineralogy of the watershed and aquifer, climate, and topography (Guler et al., 2002). These factors combine to create diverse types that change spatially and temporarily. Groundwater frequently has high concentrations of mineral salts that in some cases have a harmful degree. These may be caused by natural processes within the aquifer, or by human activities (anthropogenic sources). Groundwater chemistry is comprised of different hydro-chemical types depending on the aquifer types and the activities occurring in a certain area. In some areas of SA, most of groundwater quality is of one principal hydro-chemical types while in other areas the hydro-chemical types are approximately equally represented (Vegter, 1995). Hydrogeological studies conducted in KNP by du Toit (1996 & 1998) show that groundwater is generally of good quality dominated by different ions including sodium, magnesium, calcium, bicarbonate, and chloride (du Toit, 1996). It is considered as recently recharged groundwater which is rich in calcium, magnesium, and hydrogen carbonate, with ion exchange having taken place with time (du Toit, 1996).

Water level measurements from monitoring wells and precipitation are the principal sources of information about the hydrologic stresses acting on the aquifer and how these stresses affect groundwater recharge, storage, and discharge. The magnitude of fluctuations in water levels can vary greatly from season to season and from year to year in response to varying climatic conditions (Taylor and Alley, 2001). Changes in groundwater recharge and storage caused by climatic variability commonly occur over decades, and water levels in aquifers generally have a delayed response to the changes (Taylor and Alley, 2001). Groundwater within an aquifer fluctuates continuously in response to rainfall, evapotranspiration, barometric pressure,

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groundwater movement (including recharge and discharge), and groundwater abstraction (Schrader et al., 2002). The response time for most natural groundwater fluctuations is controlled predominantly by the local geology (weathered overburden) (Schrader et al., 2002). Taylor and Alley (2001) illustrated that the range and timing of seasonal water level fluctuations may vary in different aquifers in the same geographic area, depending on the source of recharge to the aquifers and the physical and hydraulic factors of each.

1.3. Statement of the research problem

The linking of groundwater to ecology in a specific area (site) requires that the hydrogeology of the area (site) be clearly understood. Local variations in underlying geologic formation, limited recharge during winter months, and expected high dependence of ecosystem (especially riparian vegetation) on groundwater during dry periods may cause rapid decline of groundwater level. This may be the cause of periodic flows of some major rivers in KNP. Alluvial aquifers along the lower reaches of Shingwedzi and Mphongolo rivers are of limited extent and of only local importance (Vegter, 2003) in both supporting the ecosystem and also human consumptions.

Characterisation of the aquifers along the Shingwedzi and Mphongolo River Basins requires an understanding of the hydro-geological parameters of the area which include geological formation connectivity, seasonal water level response to rainfall and dry periods, hydrochemistry and also aquifer parameters. This generally focuses on spatial and seasonal variations of groundwater quality and availability.

1.4. Motivation

The role of groundwater in the sustainance of the environment, particularly the riparian vegetation in the KNP needs determination (Vegter, 2003). Groundwater availability needs to be identified and known at the first stage in identification of

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terrestrial aquifer dependent ecosystems in South Africa (Colvin et al, 2005). This includes the assessment of groundwater quality conditions for use by different ecosystem media including human, animals and plants. Though the main water use in the KNP is for ecological purposes, minimum human use (near the Shingwedzi Rest Camp) also occurs. A detailed hydro-geological investigation needs to be undertaken along the Shingwedzi and Mphongolo River basins in the KNP in order to produce information on the condition of groundwater. Such a study is necessary to provide information required to link the ecosystem to groundwater.

Groundwater level fluctuation versus precipitation events needs special attention in order to understand the seasonal variation and contribution of recharge water from rainfall in different aquifer types. Hydrogeological data which include geological profiles (geophysical and drilling logs), aquifer parameters (hydraulic conductivity, transmissivity, and storativity), and also hydrochemical data also need a special attention in order to understand the hydraulic contact between different aquifers within the study area.

The Shingwedzi and Mphongolo Rivers flow seasonally in the summer months (from December to February - rainy season). During dry seasons, the Mphongolo and Shingwedzi Rivers courses tend to contract into strings of pools due to lack of recharge (Dennis and Brett, 2001) but dominated by big trees with green leaves (riparian vegetation) along the river banks. These pools are believed to be dependent on groundwater.

The lack of surface water during dry periods causes the ecosystem along the Mphongolo and Shingwedzi river basins to mainly depend on groundwater. The Shingwedzi and Mphongolo River basins form part of the corridors of botanical diversity (Dennis and Brett, 2001). These abundant corridors are favourable habitat for many species of mammals and birds. The forests occur on alluvial deposits in the flood plains (macro-channel) of the river and are generally characterized by large

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trees (Colvin et al, 2005). The dependence of this botanical diversity on groundwater makes the understanding of the hydrogeology an issue of primary importance.

1.5. Research Hypotheses

(a) Alluvial aquifers at Shingwedzi and Mphongolo river basins in the KNP are better yielding aquifers than fractured or weathered aquifers.

(b) Groundwater level fluctuations at Shingwedzi and Mphongolo river basins in the KNP follow the seasonal variation of precipitation and lag time.

(c) Groundwater chemistry is affected by the geology of the area and similar hydro-chemical fingerprints occur within the same aquifer.

(d) Boreholes located at the same geographical location in different aquifers shows different hydraulic behaviour.

(e) Groundwater quality at Shingwedzi and Mphongolo river basins is suitable for both human consumption and game watering

1.6. Research Objectives

1.6.1 The Main Objective

To determine the hydrogeological conditions of aquifers by means of geophysical investigation, borehole drilling, pumping tests, groundwater sampling and analysis and water level monitoring in the study area.

1.6.2 Specific Objectives

(a) To identify geological characteristics of aquifers and aquitards and their connectivity using geophysical data.

(b) To estimate the hydraulic conductivity of the soil by grain size distribution.

(c) To determine aquifer flow and storage parameters using pumping test data.

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(d) To monitor groundwater chemistry in order to: (i) characterize the type of water in each aquifer, (ii) obtain information on the exchange of water between different aquifers, and (iii) confirm the suitability of groundwater quality for human and ecosystem use.

(e) To measure water levels seasonally and determine the response to wet and dry seasons.

1.7. Description of the study area

1.7.1. Location of the study area

The area is situated within the northern part of the KNP, about 60 km south of the Punda Maria gate and about 300 km northeast of the Phalaborwa gate. It is located within latitudes 23°00', 23°30'E and longitudes 31°00', 31°30'S (Fig. 1.1). The area falls within the low-veld groundwater region in South Africa (Vegter, 2001), within the Shingwedzi catchment area of the KNP.

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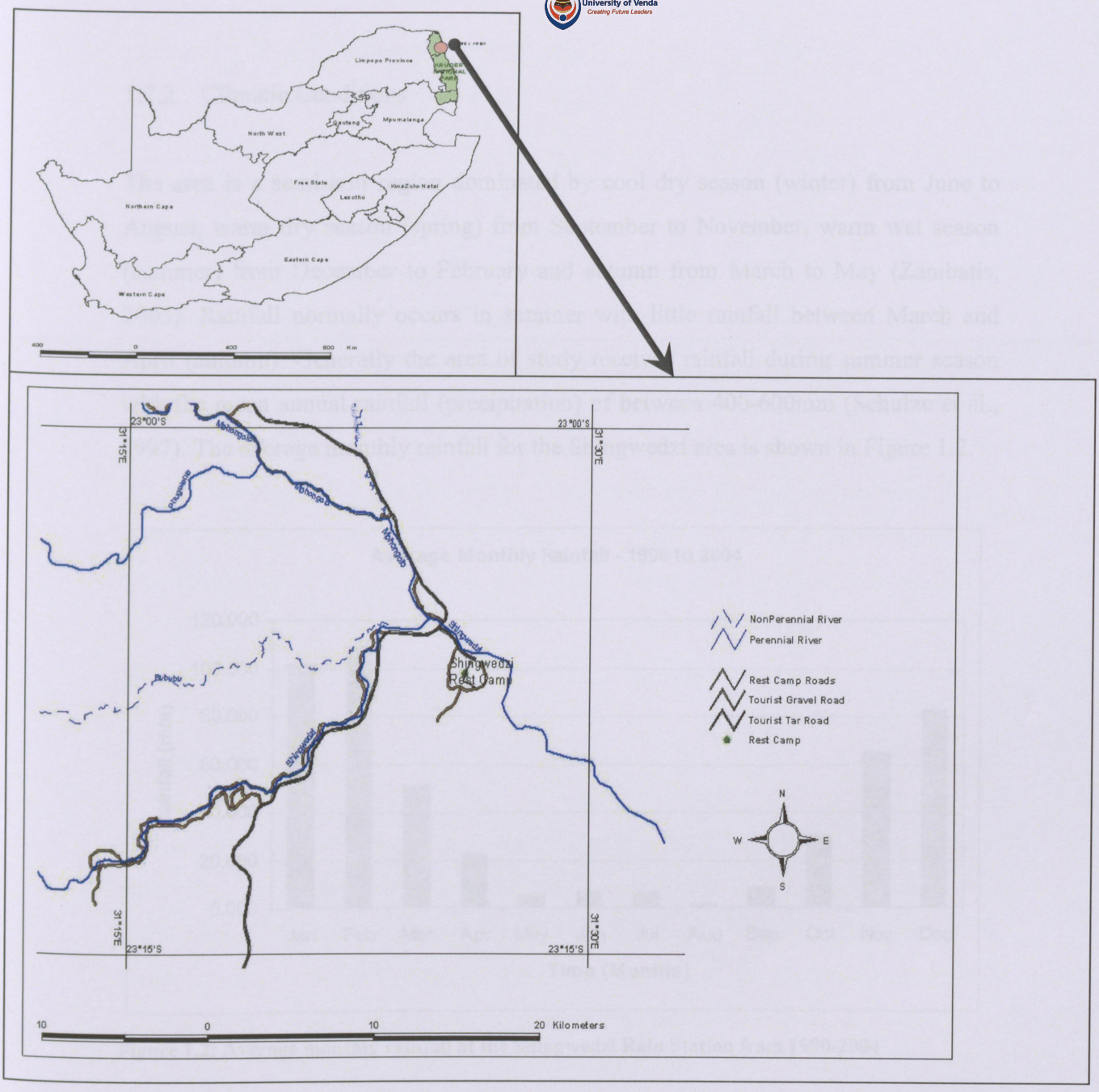

Figure 1.1: The location of the study area (Shingwedzi and Mphongolo river basins in Kruger National Park)

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1.7.2 Climatic Conditions

The area is a semi-arid region dominated by cool dry season (winter) from June to August, warm dry season (spring) from September to November, warm wet season (summer) from December to February and autumn from March to May (Zambatis, 2003). Rainfall normally occurs in summer with little rainfall between March and April (autumn). Generally the area of study receives rainfall during summer season with the mean annual rainfall (precipitation) of between 400-600mm (Schulze et al., 1997). The average monthly rainfall for the Shingwedzi area is shown in Figure 1.2.

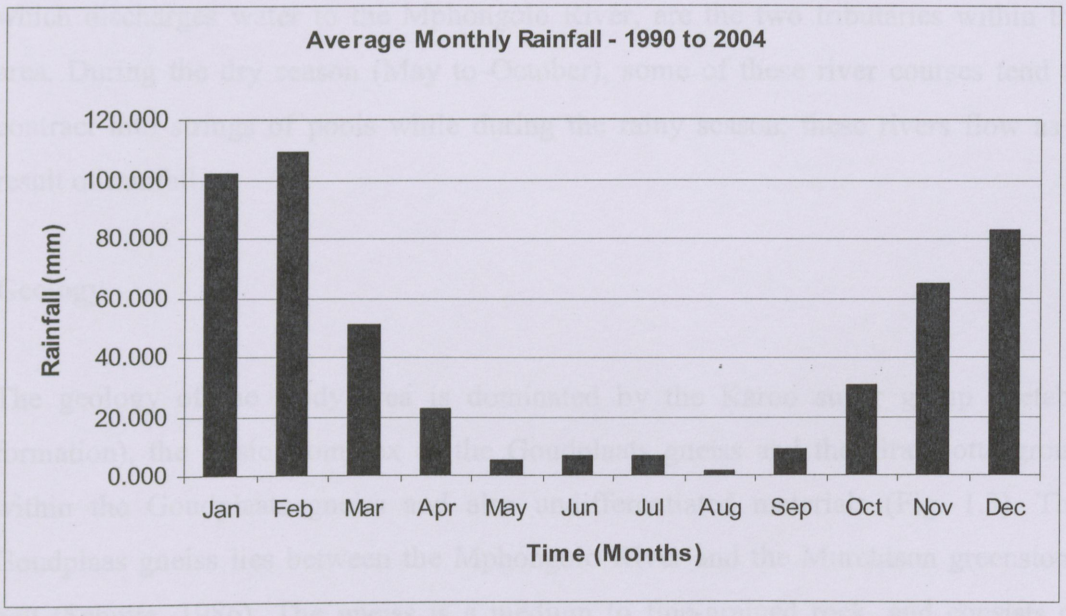

Figure 1.2: Average monthly rainfall at the Shingwedzi Rain Station from 1990-2004

1.7.3 Ecological setting of the area

Along the Shingwedzi and Mphongolo riverbanks, tall apple-leaf *(Lanchocarpus capssa)*, sycamore fig *(Ficus sycomorous),* nyala *(Xanthocercis zambesiaca),* tamboti *(Spirostchys Africana) and* jakal-berry *(Diospyros meliformis)* trees generally form narrow corridors that differ markedly from the surrounding stunned *mopani* in the

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surrounding area (Dennis and Brett, 2001). These tall trees form part of the biodiversity concentrated along the riverbanks.

1.7.4. Hydrogeological setting of the study area

The area of study is drained by two major rivers, the Shingwedzi River and Mphongolo River (Fig. 1.1). The Mphongolo River drains from the north western side to the south eastern side before it joins the Shingwedzi River before the Shingwedzi River flows pasts the Shingwedzi Rest Camp., The Shingwedzi River drains the area from the western flowing to the eastern part of the Shingwedzi Rest Camp. The Bububu River, which discharges water to the Shingwedzi River, and Phugwane River, which discharges water to the Mphongolo River, are the two tributaries within the area. During the dry season (May to October), some of these river courses tend to contract into strings of pools while during the rainy season, these rivers flow as a result of rainfall.

Geology

The geology of the study area is dominated by the Karoo super group (Letaba formation), the Basic Complex of the Goudplaats gneiss and the Gravelotte group within the Goudplaats gneiss and also undifferentiated materials (Fig. 1.3). The Goudplaas gneiss lies between the Mphongolo River and the Murchison greenstone belt (Schutte, 1986). The gneiss is a medium to fine-grained rock, and consists of oligoclace, quartz, microcline, biotite and some muscovite (Schutte, 1986). The Timbavati gabbro comprises of maffic to ultramafic rocks that intrude the various older granites and gneiss. The Letaba formation which occurs in the eastern part of the KNP consists of extrusive mafic volcanic rocks which rest comfortably on the Clarens formation (Shutte, 1986). The basalts are considered to represent flood basalts that extruded along fissures associated with the fragmentation of the Gondwanaland. Venter (1986) indicated that the Letaba basalts (olivine rich) area easily weathered and have formed large dark clays which generally contain an excessive amount of

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calcium carbonate. In some places, cementation of soil particles have been sufficient as to form continuous layers of hardpan calcrete. The Clarens formation within the area consists of a fine grained, pink argillaceous sandstone, containing irregular patches of cream coloured sandstone (Schutte, 1986) Recent Quaternary alluvial materials, including alluvium sand, river terrace gravel, and high terrace gravel, are found along the Mphongolo, Shingwedzi, Bububu, and Phugwane river basins (du Toit, 1996; Vegter, 2001).

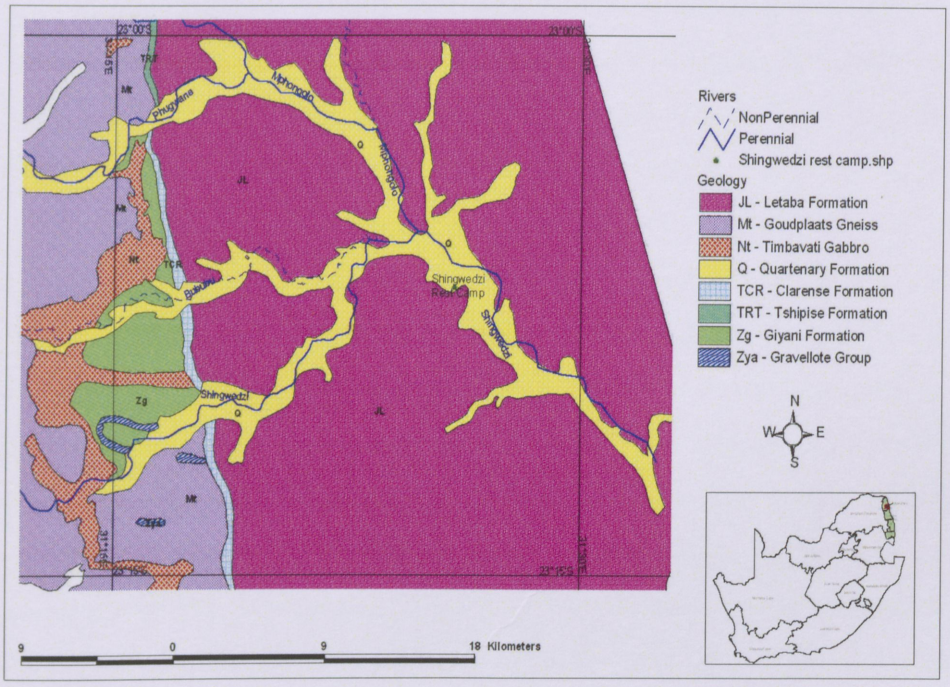

Figure 1.3: Simplified geological map of the Shingwedzi and Mphongolo River basins in Kruger National Park

Groundwater Quality

The area contains different types of groundwater, which include the following: sodium-magnesium bicarbonate water, sodium-magnesium-calcium-bicarbonate-water, sodium-bicarbonate water, sodium-chloride-bicarbonate water, sodium-magnesium-chloride-bicarbonate water, sodium-magnesium-calcium-chloride-bicarbonate water (du Toit, 1996). The chemistry of groundwater for the whole study area is good and is classified as fresh to moderately brackish water (du Toit, 1996).

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Boreholes within the study area are used for game watering and also for domestic purposes (at the Shingwedzi Rest Camp).

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CHAPTER 2: LITERATURE REVIEW

2.1 Preamble

This chapter contains a review of literature pertinent to the research. It covers borehole drilling methods, lithological logging (borehole logging), thin-section methods, pumping tests, groundwater levels, and groundwater sampling. The purpose of borehole logging is to determine and understand the basic geology of the site and the materials in which boreholes are drilled, and also to link different data types (e.g. linking borehole logs with geophysical data). Groundwater level helps to understand the hydraulic contact between different aquifers in a given area and also to understand the fluctuation of groundwater in different times of the year. Pumping tests help in understanding the flow and storage characteristics of aquifers in a given area. Thin section analysis assists in identifying the type of mineral composition the geologic materials are made of, helping in tracing the source of some elements in groundwater. Groundwater sampling is performed with the aim of collecting a water sample representative of the hydrochemical conditions in the aquifer. This assists in characterising the water type in each aquifer and also to obtain information on the exchange of water within different aquifers. It also assists in understanding the standards in which they are acceptable to the living environment/ecosystem.

2.2. Drilling methods

Various borehole drilling methods have been developed for different geological conditions ranging from hard rock such as granite and dolomite to completely unconsolidated sediments such as alluvial sand and gravel (Conrad et al., 2002). Different drilling methods include the cable tool method, direct circulation (mud rotary) method, reverse circulation (mud rotary), the rotary air percussion drilling method, and also boring with earth augers (manual drilling) (Driscoll, 1986; Conrad et al., 2002; Elson and Shaw, 1999).

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2.2.1. The rotary air percussion drilling method

Two different methods use air as a primary source of drilling fluid (Driscoll, 1986; Conrad et al., 2002). These are the direct rotary air and the down-the-hole air hammer drilling method.

In the down the hole drilling system, a pneumatic drill operated at the end of the pipe rapidly strikes the rock while the drill pipe is slowly rotated (Driscoll, 1986). This rotation helps to assure even penetration and therefore a straighter hole even in extremely abrasive or resistant rock types. Cuttings are removed continuously by air used to drive the hammer. This is effective in penetrating dense resistance formation such as basalt, quartzite, and also granite (Elson and Shaw, 1999). Different advantages for this method are that cuttings removal is extremely rapid, aquifer drilled is not plugged with drill fluid (water and mud), no maintenance cost for mud pumps, the drill bit life is longer, penetration rates are high especially in resistant rocks such as basalt, dolomite and also granite material (Driscoll, 1986; Elson and Shaw, 1999).

In the rotary air method, air alone lifts the cuttings from the borehole (Conrad et al., 2002; Todd, 1980). A large compressor provides air that is piped to a swivel connected to the top of the drill pipe. The air forced down the drill pipe, escapes through small ports at the bottom of the drill bit, thereby lifting the cuttings and cooling the bit (Conrad et al., 2002). The cuttings are blown out of the top of the hole and collect at the surface around the borehole (Driscoll, 1986). An important advantage of the rotary air method is its ability to drill through fissured rock formations with little or no water required (Todd, 1980; Elson and Shaw, 1999)

Air drilling can be done only in semi-consolidated or consolidated materials (hard rock) and is used for 90% of South African drilling (Conrad et al., 2002). To achieve the capability to operate in completely unconsolidated as well as consolidated

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formation, air rotary drilling system can be equipped with a mud pump in addition to a high capacity air compressor (Conrad et al., 2002; Driscoll, 1986). For the case of South Africa's geologic materials, the down the-hole hammer drilling system can be the best option for drilling effective and fast boreholes in hard rock formations.

2.2.2. Summary of advantages and disadvantages of drilling methods

Advantages and disadvantages of drilling methods are presented in Table 2.1 below.

Table 2.1: Comparison (advantages and disadvantages) of drilling methods (Elson and Shaw, 1999, Conrad et al., 2002)

Drilling Method	Advantages	Disadvantages
The rotary air Percussion drilling Method	• Drill hard rocks • Possible to penetrate gravel • Fast • Operation is possible above and below the water table • No water required	• Expensive • Air compressor required • Requires experience to operate and maintain
Cable tool Drilling method	• Simple to operate and maintain • Suitable for a wide variety of rocks • Operation is possible above and below the water table • Possible to drill to considerable depths	• Slow, compared with other methods • Equipment can be heavy • Problems can occur with unstable rocks • Water is needed for dry holes to help remove cuttings
Mud Rotary (direct circulation and reverse circulation)	• Most rock formation can be drilled • Water and mud supports unstable formations • Fast • Operation is possible above and below the water table • Possible to use compressed air flush	• Requires capital expenditure in equipment • Water is requires for pumping • There can be problems with boulders • Rig requires careful operation and maintenance

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2.3. Geologic Logs and Grain size distribution

It is a detailed description of underground features discovered during the drilling of a well or borehole. A geologic log is constructed from sampling and examination of well cuttings collected at frequent intervals during the drilling of a well or test hole (Todd, 1980). Such logs provide the description of the geologic character at each of the stratum thickness encountered as a function of depth, thereby providing the delineation of the aquifers (Cogho et al., 1989).

2.3.1. Formation sampling for borehole geologic logs

When drilling a new borehole, the drilling contractor will supply samples of the rock formations (sediments) being drilled out of the new borehole (van Tonder et al., 2002). Borehole logs are created by inspecting the rock chips or drill cuttings brought out to the surface during drilling. These samples are normally taken at one-meter intervals and are placed on the ground in the order that they are taken from the newly drilled borehole (Conrad et al., 2002). Visible changes of colour, lithology, grain size and other soil describing factors are recorded. The samples are then described according to the guidelines such as in Conrad et al. (2002). In South Africa, a guideline for soil and rock logging (SAIEG-AEG-SAICE, 1990) is available for describing the soil samples during drilling.

2.3.2 Grain size distribution for Hydraulic Conductivity calculation from soil samples

Grain size analysis is a process in which the proportion of materials of each grain size present in a given soil sample is determined (grain size distribution) in order to measure the distribution of particle sizes in the sample (Atkinson, 2005).

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In a hydrogeological study, grain-size distribution can be used to estimate the hydraulic conductivity of aquifer. Compared to aquifer tests, statistical grainsize methods are less expensive and less dependent on the geometry and hydraulic boundaries of the aquifer but reflect almost all the transmitting properties of the media (Alyamani and Sen, 1993). In general, K represents the ability of porous medium to transmit water through its interconnected voids (Alyamani and Sen, 1993).

Several methods are used to obtain information on the grain size distribution (Driscoll, 1986). The most widely used method involves passing the materials through a stacked sieve set which are then shaken in a special vibration machine (Driscoll, 1986) and the amount of material retained in each sieve is then weighed. In some cases small diameter sieves (76mm) can be effectively shaken by hand.

During the sieving process, each sieve filters out a certain percentage of the entire sample, with the finest materials collecting in the bottom pan (Driscoll, 1986). The sample materials retained in each sieve are then emptied into a pan or a large sheet of paper starting with the one at the top (coarsest materials) to the one in the bottom (finest materials) and are then transferred to a weighing pan. During this process of emptying the sieves, the weight of each sieve with the material retained is measured (i.e. by recording the sieve number and the materials retained in each sieve). The materials retained in each sieve are added together by emptying each sieve successively and recording the cumulated weight. The total cumulated weight should be equal to the original weight of the sample if there are no losses. The percent retained is then calculated by dividing the cumulative weight retained by the total weight of the sample (Driscoll, 1986).

2.3.3. Particle size analysis

The cumulative percentage quantities finer than certain sizes (passing on each sieve test) are determined by weighing (Driscoll, 1986). Points are then plotted of % finer against log size. A smooth S-shaped curve drawn through these points is called a

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grading curve (Atkinson, 2005). Percent passing is given on the vertical scale of the graph and the opening size or the particle size on the horizontal log scale. The position and shape of the grading curve determines soil class (Atkinson, 2005). The range of particle size encountered in a given soil is very large: from boulders with controlling dimension of over 200 mm down to clay particle less than 0.002mm (Driscoll, 1986).

2.4 Hydraulic Conductivity estimates

A variety of methods can be used to estimate hydraulic conductivity (K) of the soil (sediments). These methods, which are summarized below, include estimates based on (a) grain size information, (b) laboratory permeameter tests (Cheong et al., 2005), and (c) field measurements /Piezometer tests (Freeze and Cherry, 1979).

(a) K estimates based on grain size information

A variety of methods are available for estimating saturated hydraulic conductivity values from grain size information. The determination of a relation between conductivity and soil texture requires the choice of a representative grain size diameter (Freeze and Cherry, 1979). One of the most simple and most commonly used approaches is the Hazen equation (Massman, 2003). These estimates from soil gradation data are more reliable than estimates based solely on USDA soil type (Massman, 2003). The Hazen's traditional method directly relates the coefficient of permeability, K, to effective diameter, D_{10}, which can be obtained from the grading curves. According to Hazen, K is given by Eq. 2.1 (Farag, 2005):

$$K = \frac{(D_{10})^2}{100} \qquad \textbf{(2.1)}$$

Another method, which can be used to determine hydraulic conductivity of the sediments, is the method developed by Alyamani and Sen (1993), where K is given by:

$$K = 0.015[I_o + 0.025(D_{50} - D_{10})]^2 \qquad \textbf{(2.2)}$$

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Where D_{50} is the grain size at 50% passing of soil in each sieve and I_o is the intercept of the line formed by D_{50} and D_{10} with the grain size axis, i.e. it has the same dimension as D_{10} and D_{50} (Alyamani and Sen 1993). In all the above equations, D_{10} and D_{50} are in mm and the estimated value of K is in m/s.

The method of Alyamani and Sen (1993) considers both sediment grain size (D_{10} and D_{50}) as well as the sorting (well sorted implies poorly graded and vice versa). In order to obtain the hydraulic conductivity of the sediments in m/day, Eq. 2.2 can be resolved to Eq 2.3 below.

$$K = 1300[I_o + 0.025(D_{50} - D_{10})]^2 \quad \textbf{(2.3)}$$

(b) K estimates based on laboratory tests

Laboratory saturated hydraulic conductivity tests are recommended for fine-grained soils or whenever feasible (Massman, 2003). Values of K, determined carefully by conducting experiments in the laboratory are quite accurate and reproducible (McWhorter and Sunda., 1977). The saturated hydraulic conductivity of a soil sample can be measure with two types of laboratory apparatus which are the constant-head permeameter and the falling-head permeameters (Freeze and Cherry 1979; Massman, 2003).

In the constant head permeameter the steady upward flow through the sample is established (McWhorter and Sunda, 1977). Freeze and Cherry (1979) indicated that in a constant head test, suppose a soil sample of length (L) and a cross-sectional area (A) is enclosed between two porous plates in a cylindrical tube, and a constant head differential (H) is set up across the sample, the following equation can be derived:

$$K = \frac{QL}{AH} \quad \textbf{(2.4)}$$

where Q is the steady volumetric discharge through the system.

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The falling head permeameter is used to determine K where the rate of discharge through the sample decreases with time because the driving head decreases as the water level falls in the inflow standpipe (McWhorter and Sunda, 1977). In a falling head permeameter, the head as measured in a tube of a cross-sectional area *a*, is allowed to fall from H_0 to H_1 during time *t*, the hydraulic conductivity is obtained using Eq. 2.5 (Freeze and Cherry, 1979):

$$K = \frac{aL}{At} \ln\left(\frac{H_0}{H_1}\right) \quad \textbf{(2.5)}$$

Where H_o is the initial head before the water is released, H_1 is the head after the water is released.

(c) K estimate based on field tests / Piezometer tests

Freeze and Cherry (1979) indicated that in situ hydraulic conductivity values can be determined by means of tests carried out in a single piezometer. Both tests are initiated by causing an instantaneous change in the water level in a piezometer by a sudden introduction (slug test) or removal (bail test) of a known volume of water and observe the recovery of water level with time (Freeze and Cherry, 1979). From these measurements the aquifer's hydraulic conductivity can be determined (Kruseman and de Ridder, 1991). Different methods of analysing the response by the water level in order to obtain the hydraulic conductivity and transmissivity have been developed which include the Cooper's method (for confined aquifers) and the Bouwer and Rice method (for unconfined aquifers).

The Cooper's method consider that if a volume of water (V) is instantaneously withdrawn or injected into a well of finite diameter ($2r_c$), this will cause an instantaneous change of the hydraulic head in the well (h_0) and can be represented by Eq. 2.6 (Kruseman and de Ridder, 1991):

$$h_0 = \frac{V}{\pi r^2} \quad \textbf{(2.6)}$$

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After this change, the head gradually return to its initial head, thus the following solution for the rise or fall in the well's head with time can be represented using equation 2.7:

$$h_t = h_0 F(\alpha, \beta) \tag{2.7}$$

Where $\alpha = \frac{r_{ew}^2 S}{r_c^2}$, $\beta = \frac{KDTt}{r_c^2}$, h_0 is the instantaneous change of head in the well at t_0=0, h_t is the head in the well at time $t > t_0$, r_c is the radius of the unscreened part of the well where head is changing, and r_{ew} is the effective radius of the screened part of the well (Kruseman and de Ridder, 1991).

The Bouwer and Rice method determines hydraulic conductivity of an unconfined aquifer from a slug test using Eq 2.8:

$$K = \frac{r_c^2 \ln(R/r_w)}{2d} \frac{1}{t} \ln \frac{h_0}{h_t} \tag{2.8}$$

Where r_w is the horizontal distance from the well centre to the undisturbed aquifer, R_e is the radial distance over which the difference in head, h_o is dissipated in the flow system of the aquifer, d is the length of well screen, and the other parameters are as described above (Kruseman and de Ridder, 1991). Freeze and Cherry (1979) indicated that the main limitation of these tests is that they are heavily dependent on a high-quality piezometer intake.

2.5 Borehole pumping test

2.5.1 Purpose and Scope of borehole testing

Borehole pumping test is a process whereby an aquifer is subjected to pumping from a borehole under controlled test conditions in order to determine the hydraulic parameters of the groundwater system through its response to the abstraction stress (van Tonder et al., 2002). Borehole testing on the other hand is the process whereby a

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borehole is subjected to pumping under controlled test conditions in order to determine the performance characteristics of the borehole (van Tonder et al., 2002). Borehole/Aquifer pumping test consists of pumping a well at a certain rate and recording the changes in water levels (drawdown) in the pumping well and in nearby observation boreholes at specific time intervals (Driscoll, 1986). Pumping tests are generally of larger scale and duration compared with piezometer tests and therefore more expensive, but can provide measurements of aquifer flow and storage parameters (T, S, and K) that are representative of a larger volume of the aquifer (Hiscock, 2005). Borehole pumping test provides an understanding on the condition of groundwater flow and storage within an aquifer. Pumping tests provide *in-situ* measurements that are averaged over a large aquifer volume (Freeze and Cherry, 1979).

Various types of borehole tests are performed separately and often sequentially in order to obtain information for the determination of aquifer parameters. Prior to the start of any test, the initial water levels relative to a local datum must be measured and monitored for effects external to the pumping tests (Driscoll, 1986). The details of the site hydrogeology must also be recorded including well depths and diameters, strata penetrated, and the location of the nearby streams that could act as recharge boundaries (Hiscock, 2005). These borehole pumping tests include the calibration test, the stepped discharge test, the constant discharge test and the recovery test, and are performed as described below:

The Calibration Test

A calibration test requires that water be pumped from the borehole at three or more different rates over short (15 minutes), sequential periods of time (DWAF, 1997). The response of the water level to each known pumping rate is measured and recorded. The calibration test provides a means of assessing the yield potential of a borehole according to the magnitude of the water level decline associated with each pumping rate (DWAF, 2007). This information is used to select appropriate pumping

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rates at which to perform a stepped discharge test or a pumping rate at which to perform a constant discharge test (DWAF, 2007).

The Stepped Discharge Test

The stepped drawdown test is a single-well test and is performed to evaluate the productivity of a borehole (van Tonder et al., 2002; DWAF, 1997 It also serves to more clearly define the optimum yield at which the borehole can be subjected to constant discharge testing if required (DWAF, 1997).

The test involves pumping the borehole at three or more sequentially higher pumping rates each maintained for an equal length of time. The time per pumping rate should be between 60 and 120 minutes (van Tonder et al., 2002; DWAF, 1997). The test is done by pumping a borehole at a constant discharge rate until the drawdown stabilizes. The pumping rate is then increased for the second step until the drawdown in the borehole stabilizes again. The pumping rate is then increased again and the process is repeated. The drawdown in the borehole in response to each of the pumping rates must be measured and recorded in accordance with a prescribed time schedule (DWAF, 1997). At the end of the pumping steps, the recovery inside the borehole should at least be measured for the same period of pumping (van Tonder et al., 2002).

The Constant Discharge Test

The constant discharge test is performed to assess the productivity of the aquifer according to its response to the abstraction of water (van Tonder et al., 2002). The constant discharge test measures aquifer characteristics and help to identify the nature of the aquifer and its boundaries (Hiscock, 2005). This response can be analysed to provide information in regard to the hydraulic properties of the groundwater system (Driscoll, 1986; van Tonder et al., 2002; DWAF, 1997). This test entails pumping the borehole at a single pumping rate which is kept constant for an extended period of

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time. The test duration should not be less than 12 hours and, in some instances, might last up to 72 hours or more (van Tonder et al., 2002; DWAF, 1997).

The pumping rate is set at the rate at which it can be sustained for the period of the pumping. Before starting with the constant rate test the borehole should be allowed to recover completely from the stepped and multi-rate discharge tests (van Tonder at al., 2002). From the start of the test, the pumping rate is monitored and paired values of drawdown and time are measured in the pumped and observation boreholes (if available) at a specific intervals that increases as the test progress (Hiscock, 2005). Initially, the cone of depression expands rapidly, but the expansion slows logarithmically with time as the volume of the aquifer contributing to the pumped well increases (Hiscock, 2005; Driscoll, 1986). A state of quasi or equilibrium conditions may be reached, when the rate of recharge to the borehole catchment balances the rate of abstraction (Hiscock, 2005). On cessation of the constant test, groundwater levels will recover to a static water level following a drawdown versus time that is the converse of the drawdown curve (Hiscock, 2005).

The Recovery Test

When pumping is shut down after a pumping test, the water levels in the well and piezometers will start to rise, and this rise in the water level is known as the residual drawdown (Freeze and Cherry, 1990). This test provides an indication of the ability of a borehole and groundwater system to recover from the stress of abstraction (DWAF, 1997). This ability can again be analysed to provide information in regard to the hydraulic properties of the aquifer (Hiscock, 2005). The residual drawdown data are more reliable than pumping test data because recovery occurs at a constant rate, whereas a constant discharge dicshcrge during pumping is often difficult to achieve in the field (Freeze and Cherry, 1990). This test represents a period of monitoring activity following a period of pumping (DWAF, 1997). The rate at which the water level in the tested borehole or any other borehole affected by the abstraction recovers towards its starting level (the groundwater rest level before pumping started) is

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monitored in this period (Hiscock, 2005). Freeze and Cherry (1990) indicated that it is expressed as the difference between the original water level before the start of pumping and the water level measured at time t' after the cessation of pumping. The duration of this monitoring is generally equal to that of the preceding period of pumping unless the rate of recovery is sufficiently rapid so that the starting water level is reached in a shorter period of time (DWAF, 1997). Freeze and Cherry (1990) indicated that the recovery-test measurements can allow the transmissivity of the aquifer to be calculated using equation 2.9 below.

$$\Delta s' = \frac{2.30Q}{4\pi T} \quad \textbf{(2.9)}$$

Where Δs' is the residual drawdown difference per log cycle of t/t' (t is the time since pumping started and t' is the time since cessation of pumping), Q is the rate of discharge in m^3/d, and T is the aquifer transmissivity. Equation 2.10 can be written as:

$$T = \frac{2.30Q}{\Delta s' \times 4\pi} \quad \textbf{(2.10)}$$

2.5.2 Pumping test data evaluation

The data gathered from the field during borehole pumping test should be prepared and evaluated to determine the different parameters and characteristics of the aquifer including storativity (S) and transmissivity (T) (van Tonder et al., 2002). Different analytical methods can be used to evaluate the borehole pumping tests data including the Theis method, Cooper Jacob Method, the Fracture Analysis Method. The determination of pumping test parameters normally involves a direct application of the Theis or Cooper-Jacob formulas (Freeze and Cherry, 1979) depending on the type of aquifer tested. These methods are easily applicable in unconsolidated formation. However, for consolidated aquifers with secondary porosity, the FTA method is normally used to determine the storage and flow characteristics of aquifers.

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(a) The Cooper-Jacob Method

This method is based on the Theis equation and is used for computing transmissivity (T) and storativity (S) as presented in eq. 2.11 below from the Theis non-equilibrium equation by assuming a small value of radial distance from the pumped well (r) and a large value of time since the beginning of pumping t, so that the well function u is small (Todd, 1980). The assumptions inherent in the Theis equation are that the aquifer is confined, homogeneous, isotropic, of uniform thickness, of infinite areal extent, pumped at a constant discharge and the flow is radial to the well (Todd, 1980).

$$s = \frac{Q_w}{4\pi T}\left(-0.5772 - \ln\frac{r^2 S}{4\pi T t}\right) \qquad \textbf{(2.11)}$$

where s is the drawdown, r is the distance from the pumped well to the observation well where the drawdown measurements would be made or the radius of the well for a single well, Q_w is the discharge or pumping rate, S is the storativity, T is the transmissivity.

Cooper Jacob method uses Eq. 2.5 to compute T derived from Eq. 2.12.

$$T = \frac{2.3 Q_w}{4\pi \Delta s_w} \qquad \textbf{(2.12)}$$

where Δs_w is the slope of the time-drawdown graph expressed as the change in drawdown between any two times on the log scales whose ratio is 10 (one log circle) or Δs_w is simply the drawdown difference per log cycle of t.

The coefficient of storage (S) is calculated from Eq. 2.13 derived from the procedures presented in Todd (1980):

$$S = \frac{2.25 T t_0}{r^2} \qquad \textbf{(2.13)}$$

where t_o is the time when s=0.

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(b) The Fracture Test Analysis (FTA)

This method calculates the flow and storage characteristics of aquifers by considering the fracture and matrix characteristics of the media separately. The pumping tests plot from fractured aquifers when plotted on the semi-logarithmic graph paper produce an S –curve consisting of three stages which are, stages one, two and three and these are used to obtain well bore storage changes, fracture flow and storage parameters, and matrix flow and storage parameters respectively. The aquifer parameters are computed using the procedures described by Vivier and van Tonder (1997) as summarised below:

The main parameters are identified from a familiar Cooper Jacob formula:

$$s_w = \frac{2.3Q_w}{4\pi T}\log\frac{2.25Tt_0}{r^2S} \qquad \textbf{(2.14)}$$

where, s_w is the drawdown in meters, Q_w is the constant discharge in m³/day, T is the transmissivity in m²/day, t is the time in days, S is the storativity (dimensionless) and r is the radius of the well.

The method identifies the parameters of the fracture system first which are the fracture transmissivity, fracture storativity, fracture aperture, fracture flow velocity, as well as the distance to the boundary.

The aquifer fracture transmissivity is determined by calculating the gradient per log cycle and an average transmissivity is calculated for the final value. The fracture transmissivity is computed using eq. 2.15:

$$T_f = \frac{2.3Q_w}{4\pi\Delta s_{wf}} \qquad \textbf{(2.15)}$$

where Δs_{wf} is the drawdown in the fracture

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$$T_f = \frac{2.3Q_w}{4\pi\Delta s_{wf}} \qquad \textbf{(2.15)}$$

where Δs_{wf} is the drawdown in the fracture

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The fracture storativity is calculated for each observation of the fracture flow period once the fracture transmissivity is known and the average value is obtained. The aquifer fracture storativity (S_f) is obtained using Eq. 2.16:

$$\log S_f = \frac{\log 2.25T_f}{r^2} - \frac{s_{wf}\,4\pi T_f}{2.30Q_w} \qquad \textbf{(2.16)}$$

Secondly, the method identifies the matrix parameters which are matrix transmissivity, the yield of the matrix as well as the matrix storativity.

The apparent matrix transmissivity (T''_m) which is the matrix transmissivity (T_m) over the length of the fracture is determined by calculating the gradient per log cycle on the last slope for every observation is obtained using eq. 2.17:

$$T''_m = \frac{2.3Q_w}{4\pi\Delta s_{mw}} \qquad \textbf{(2.17)}$$

In order to determine the matrix storativity, the yield of the matrix (Q_m) must then be determined. The yield of the matrix will be according to Darcy's law:

$$Q_m = T_m \blacktriangledown F \qquad \textbf{(2.18)}$$

Where, ▼F is the gradient of the piezometric pressure (Vivier &Van Tonder, 1997), which can be obtained for every time drawdown measurement as:

$$Q_m = T_m\left(\frac{s_{mw_{(i)}}}{r}\right) \qquad \textbf{(2.19)}$$

where $s_{wm\,(i)}$ is the drawdown at each observation during the matrix flow period.

The matrix storativity(S_m), which is determined for each observation in the last stage, is the obtained using Eq 2.20:

$$\log S_m = \frac{\log 2.25T_m}{r^2} - \frac{s_{wf}\,4\pi T_m}{2.30Q_m} \qquad \textbf{(2.20)}$$

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(c) The Flow Characteristics Program

This is an Excel spreadsheet Program used to analyse pump-testing data. This FC Program uses different methods and formulas to analyse pumping test data. The following analyses could be performed with the FC program: Constant rate pumping test analysis with the Cooper-Jacob analysis for confined and water table aquifers, Hantush analysis for Leaky aquifers (Hantush and Jocob, 1955), Fractal pumping tests analysis with the Barker-Bangoy method, Variable rate tests (step drawdown and multirate) using the Bierschenk method, Slug tests using the Bouwer and Rice method, and estimation of borehole protection zones (only fracture rock aquifers) (van Tonder et al., 2002). The programme evaluates the aquifer flow and storage characteristics by applying these methods as fitted in the excel spreadsheet. It also determines the sustainable yields of a borehole using derivatives, boundary information and error propagation, borehole protection zones, well performance, fractal pumping test analysis and slug test analysis (van Tonder et al., 2002).

(d) The rule of thumb relationship

In some cases, analytical methods, including the classical Cooper-Jacob and the FTA and other methods for analysing the pumping tests data have proved not to be reliable methods for storativity computation from fractured aquifers (secondary aquifers) unless there are monitoring boreholes within the matrix responsible for monitoring the drawdown with time on a discharge borehole. In this case the monitoring borehole should be drilled some distance away from the discharge borehole within the same aquifer. If there is lack of spatially distributed monitoring boreholes, the computation of S within the discharge borehole is not reliable. The relationship between storativity and aquifer thickness, therefore can be used to compute the storativity of the discharge boreholes using the rule-of-thumb-relationship, (Eq. 2.21) (see Todd, 1980).

$$S = 3\times10^{-6}b \qquad \textbf{(2.21)}$$

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where b is the saturated aquifer thickness in metres (Todd, 1980) for confined aquifers.

2.6 Groundwater Quality

Groundwater chemistry or hydrochemistry is useful for the interpretation of the distribution of hydrochemical parameters in groundwater which helps in the understanding of hydrochemical conditions (Hiscock, 2005) of an area. This is done by sampling boreholes drilled in an aquifer. Groundwater is sampled for a variety of reasons which are, (1) to assess the groundwater quality for fitness of use; (2) to understand the hydrogeology of an aquifer; (3) to investigate pollution; and (4) to identify changes in water body (Weaver et al., 2008). Groundwater mainly contains salts in solution that are derived from the location and past movement of the water (Todd, 1980). The composition of surface water and groundwater is dependent on natural factors (geological, topographical, meteorological, hydrological, and biological) in the drainage basin and varies with seasonal differences in runoff volumes, weather conditions, and water levels (Meybeck et al., 1996).

2.6.1 Chemical composition of groundwater

The chemical and biochemical interactions between groundwater and the geological materials provide a wide variety of dissolved inorganic and organic constituents (Hiscock, 2005). Meybeck et al. (1996) indicated that groundwater quality is dependent on the composition of the recharge water, the interactions between the water and the soil, soil-gas and rocks with which it comes into contact in the unsaturated zone, and the residence time and reactions that take place within the aquifer.

The principal dissolved components of groundwater, in common with freshwaters in the terrestrial aquatic environment, are the six major ions, which are sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), and sulphate

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(SO_4^{2-}) (Meybeck et al., 1996; Hiscock, 2005; Todd, 1980). These ions normally comprise over 90% of the total dissolved solid content (Hiscock, 2005). The major natural sources and its concentration in natural waters are summarised in Table 2.3 below:

Table 2.3: Major (ions) Constituents, its natural sources and concentrations in groundwater (Adapted from Todd, (1980) and Hiscock (2005))

Constituent	Major Natural Sources, Concentrations in Natural waters
Sodium	Feldspars, feldspathoid, some micas, and clay minerals. Generally less than 200 mg/l, 10 000 mg/l in sea water.
Calcium	Amphiboles, Feldspars, gypsum, pyroxenes, calcite, dolomite and clay minerals.
Magnesium	Amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals. Less than 50mg/l, in ocean water is more than 1000 mg/l and
Bicarbonate	Limestone and dolomite. Commonly less than 500 mg/l, may exceed 1000 mg/l in water highly charged with carbon dioxide
Sulphate	Sulphide oxidation, Gypsum, anhydrite, < 300 mg/l except in wells influenced by acid mine drainage
Chloride	Sedimentary rock (evaporates) and igneous rocks. Commonly less than 10 mg/l in humid regions but up to 1000 mg/l in more arid regions

The level of total dissolved solids (TDS) determines the salinity of water and in general, water with a TDS of greater than 450 mg/l tastes salty, but up to 1000 mg/l it is safe for humans to drink (DWAF, 1996). The TDS concentration can be obtained as an estimate of the electrical conductivity (EC) value (DWAF, 1996), and for any investigation, it is possible to relate the TDS value to the EC (Hiscock, 2005). For most natural waters, EC is related to the dissolved salts concentration by conversion factor ranging from 5.5 – 7.5 with the average conversion fator for most waters of 6.5 (DWAF, 1996). The conversion equation is as follows:

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$$TDS(mg/l) = EC(mS/m) \times 6.5 \quad (2.22)$$

The degree of salinization of groundwater expressed as the TDS is a widely used method for categorizing groundwater (Table 2.4).

Table 2.4: Simple classification of groundwater based on total dissolved solids (TDS) content (Freeze and Cherry (1979))

Category	TDS (mg/l) range
Freshwater	0 – 1000
Brackish water	1000 – 10 000
Saline water (sea water)	10 000 – 100 000 (35 000)
Brine water	>100 000

NB: TDS >2000 – 3000 mg/l is too salty to drink.

2.6.2 Groundwater sampling

The aim of groundwater sampling is to collect raw water samples that are representative of the hydrochemical conditions of the aquifer (Hiscock, 2005). This is done in order to characterize the type of water at a specific location or area. This also provides information on the interchange of water between different water-bearing formations (inter-aquifer flow).

To obtain groundwater samples for analysis, sampling devices are required such as bailer, syringe, air-lift sampler, suction lift sampler, gas operated pumps, bladder pump, submissive pump, and also inertial pump (Jiwan and Gates, 1992; Hiscock, 2005). Care must be taken to first flush the water standing in the well or borehole by removing up to three or four times the well or borehole volume prior to sampling (Hiscock, 2005). This is called well or borehole purging in order to remove stagnant water, that may not be representative of the hydrochemical condition of the aquifer.

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A bailer is a sampling device that is used to collect water from the borehole by repeatedly lowering it into the borehole and retrieving it to remove water (Kaminski, 2003).

2.6.3 Laboratory water analysis methods

Different methods are applied in analysing water samples in the laboratory. These include (a) Inductively-Coupled Plasma Atomic Emission Spectrometry (ICPAES) and (b) the Flow Injection Analysis (FIA) and are described below. The former method determines metals and the latter determines non-metals (CSIR, 2005).

(a) Determination of metals by Inductively-Coupled Plasma Atomic Emission Spectrometry (ICPAES)

ICPAES method is applicable for the determination of Calcium, Magnesium, Potassium, Sodium, Aluminium, Copper, Iron, Manganese, Zinc, Boron, Barium, Lithium, Cadmium, Chromium, Cobalt, Gold, Lead, Titanium, Molybdenum, Nickel, Silver, Antimony, Vanadium, and Zirconium in water by means of (direct) inductively-coupled plasma atomic, emission spectrometry (ICPAES) (CSIR, 2005).

ICPAES method was developed in the mid 1960's as a rapid, sensitive and convenient method for determination of metals in water and wastewater (CSIR, 2005). In ICP, spectrometric atoms absorb energy (are excited) from a hot excitation source (argon plasma) and then emit the absorbed energy as light (Manning and Grow, 1997). Each element emits light as a spectrum of discrete wavelength (or emission lines), and the spectrum is a characteristic of the element (Manning and Grow, 1997). The intensity of light at emission line is a good measure of the amount of atoms preset in the sample. A major advantage of ICPAES as a measurement technique is the wide linear dynamic range (about 6 orders of magnitude) of the response ((Manning and Grow, 1997; CSIR, 2005). A monochromator separates the emission lines spatially, so that a

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photo multiplier tube can be placed directly at the location of a specific emission line and measure its intensity (Mannig and Grow, 1997) (Fig 2.2).

Steps involved in the analysis of aqueous samples by ICP-AES

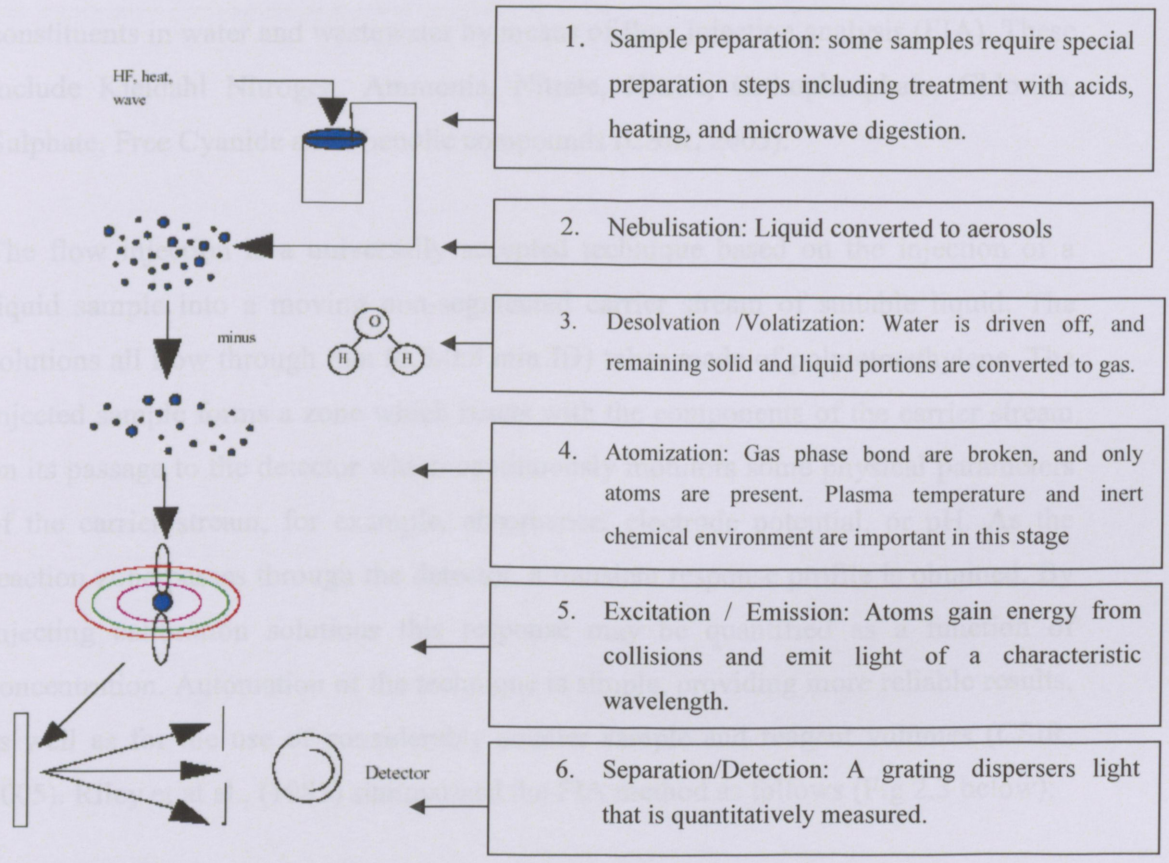

Figure 2.2: Steps involved in determining the elemental content of an aqueous phase sample by ICP-AES method (Manning and Grow, 1997)

The monochromator separates the emission lines widely enough to avoid overlap, so that the photo multiplier tube detects light from only one emission line (CSIR, 2005).

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Reagents used in the ICPAES analysis include water (deionised distilled –grade III); argon (99.9999% purity –Argon 5.0); Nitric acid (concentrated, AR grade) and also Nitric Acid (dilute 1:1 HNO_3-AR grade) (CSIR, 2005).

(b) Determination of non metallic constituents by Flow Injection Analysis (FIA)

This method is applicable for the determination of the following non-metallic constituents in water and wastewater by means of flow injection analysis (FIA). These include Kjeldahl Nitrogen, Ammonia, Nitrate, Nitrite, Orthophosphate, Chloride, Sulphate, Free Cyanide and Phenolic compounds (CSIR, 2005).

The flow injection is a universally accepted technique based on the injection of a liquid sample into a moving non-segmented carrier stream of suitable liquid. The solutions all flow through thin (0.5-0.8 mm ID) tubes made of polytetraethylene. The injected sample forms a zone which reacts with the components of the carrier stream on its passage to the detector which continuously monitors some physical parameters of the carrier stream, for example, absorbance, electrode potential, or pH. As the reaction zone passes through the detector, a transient response profile is obtained. By injecting calibration solutions this response may be quantified as a function of concentration. Automation of the technique is simple, providing more reliable results, as well as for the use of considerably smaller sample and reagent volumes (CSIR, 2005). Riley et at al., (1983) summarised the FIA method as follows (Fig 2.3 below):

Types of flow systems apparatus is composed of the pump, P, driven by a stepping motor under microcomputer control, propels fluids through the reaction coil, RC, through the photometric detector, D, and to waste, W. (a):The probe moves from reagent R, to sample cup, S, and the pump rotates through several degrees, aspirating a small quantity of sample. The probe is then returned to the reagent reservoir and the pump restarts, propelling the sample through the reaction coil where it mixes with the reagent to produce a colour. (b): In this arrangement the pump is placed downstream of the detector. (C): Sample and reagent are simultaneously aspirated into independent

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carrier streams C, of de-ionized water. The sample and reagent zones merge at T (Riley et at al., 1983).

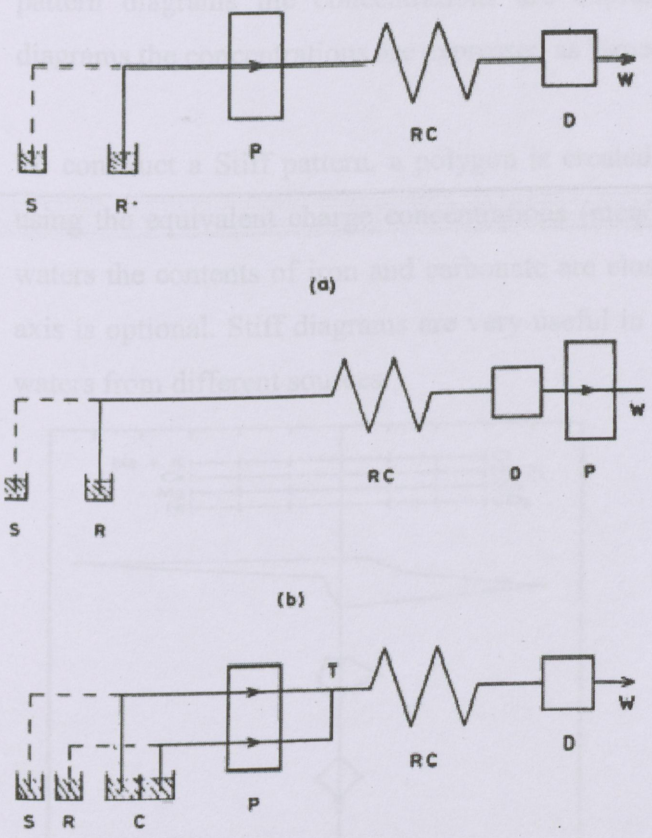

*Figure 2.3: Flow Injection Analysis (*Riley et at al., 1983)

Equipment used for FIA method includes volumetric glassware, filter apparatus (glass or plastic syringe with 0.45um syringe filter, automated flow injection analysis system (QuickChem 8000 analyser). The QuickChem analyser is computer-controlled equipment consists of an auto-sampler, reagent pump, 32 cartridges, system unit and a computer and printer.

2.6.4 Describing chemical data

Different graphical and statistical techniques have been developed to describe the concentration or relative abundance of major and minor constituents and the pattern of

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variability in different water samples (Hiscock, 2005). The most common graphical approaches to describe the abundance or relative abundance of ions in individual water samples are the Stiff pattern (Fig 2.4) and the Piper diagram (Fig 2.5). In Stiff pattern diagrams the concentrations are expressed as meq/L, whereas in Piper diagrams the concentrations are expressed as %meq/L.

To construct a Stiff pattern, a polygon is created from four parallel horizontal axes using the equivalent charge concentrations (meq/L) of cations and anions. In many waters the contents of iron and carbonate are close to zero and the use of the fourth axis is optional. Stiff diagrams are very useful in making quick comparison between waters from different sources.

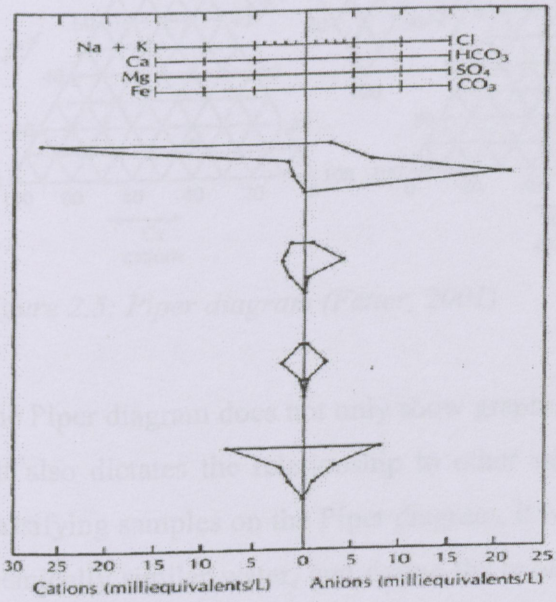

Figure 2.4: Analysis represented by Stiff patterns. The horizontal distance from the vertical axis is based on the number of meq/L of each cation or anion (Fetter 2001).

The Piper plot (Fig 2.5) is useful for showing multiple samples and trends in major ions (Fetter, 2001). The major ionic species in most natural waters are Na^+, K^+, Mg^{2+}, Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-}. The Piper plot can show the percentage composition of three ions (Fetter, 1994). In Piper plots, major ions are plotted as cation and anion

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percentages of milliequivalents in two triangles (Fetter, 2001). A Piper diagram can also show how samples can be classified according to setting (Zhang, 2004).

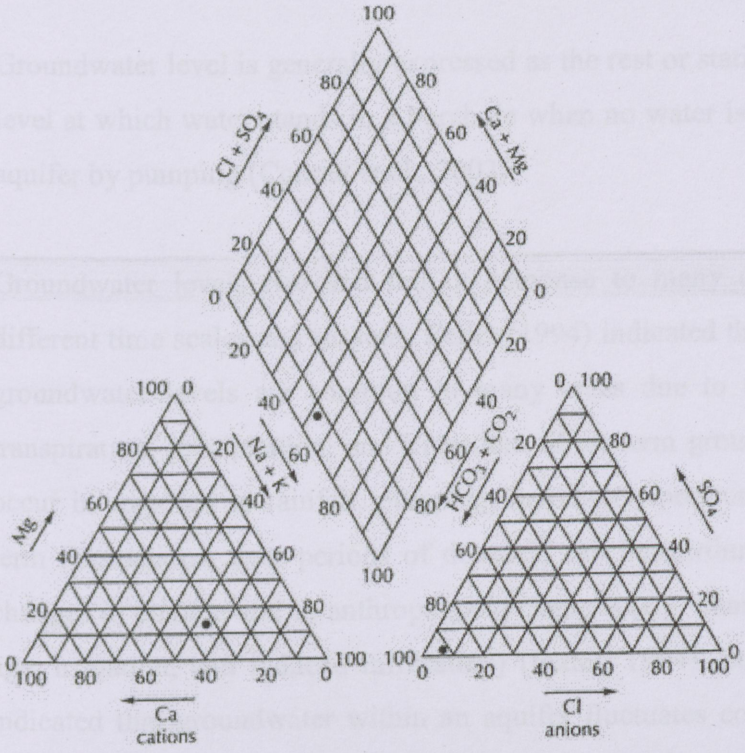

Figure 2.5: Piper diagram (Fetter, 2001)

The Piper diagram does not only show graphically the nature of a given water sample, but also dictates the relationship to other samples (Zhang, 2004). For example, by classifying samples on the Piper diagram, it is possible to identify geologic units with chemically similar water, and define the evolution in water chemistry along the flow path (Zhang, 2004; Fetter, 1994).

As water flows through an aquifer it assumes a diagnostic chemical composition as a result of interaction with lithologic framework (Fetter, 1994). The term hydro-chemical facies is used to describe the bodies of groundwater, in an aquifer, that differ in their chemical composition and they are the function of the lithology, chemical kinetics, and flow patterns of the aquifer (Back, 1966). Hydro-chemical facies can be classified on the basis of the dominant ions in water by means of the tri-linear diagram (Hiscock, 2005).

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2.7. Groundwater levels response to rainfall

Groundwater level is generally expressed as the rest or static water level, which is the level at which water stands in a borehole when no water is being abstracted from the aquifer by pumping (Conrad et al., 2002).

Groundwater levels rise and fall in response to many different phenomena over different time scales and seasons. Fetter (1994) indicated that seasonal fluctuations in groundwater levels are common in many areas due to the seasonality of evapo-transpiration, precipitation, and irrigation. Short-term groundwater level fluctuations occur in response to rainfall, pumping, barometric pressure fluctuation, while long-term fluctuations, over periods of decades, can be attributed to naturally occurring changes in climate and to anthropogenic changes (e.g. changes in land usage, pump-age, irrigation, and induced infiltration) (Fetter, 1994). Schrader et al. (2002), also indicated that groundwater within an aquifer fluctuates continuously in response to rainfall, evapotranspiration, barometric pressure, groundwater movement (including recharge and discharge), and groundwater abstraction. In general the fluctuations are indicative of groundwater recharge or discharge. Healy and Cook (2002) further indicated that temperature variation, natural changes in surface water elevation as well as pumping of wells also causes groundwater level fluctuations in aquifers.

Water level measurements from monitoring wells and precipitation are the principal sources of information about the hydrologic stresses acting on the aquifer and how these stresses affect groundwater recharge, storage, and discharge (Taylor and Alley, 2001). The magnitude of fluctuations in water levels can vary greatly from time to time (seasonally and annually etc) in response to varying climatic conditions, thus changes in groundwater recharge and storage, in some cases, commonly occurs over decades, and groundwater levels in this case generally have a delayed response to the changes (Taylor and Alley, 2001). Schrader et al. (2002), indicated that the response time for most natural groundwater fluctuations is controlled predominantly by the

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local geology. Taylor and Alley (2001), illustrated that the range and timing of seasonal water level fluctuations may vary in different aquifers in the same geographic area, depending on the source of recharge to the aquifers and the physical and hydraulic factors of each.

2.7.1 Water level Measurement

One of the most common measurements in groundwater investigations is the determination of the depth to groundwater (Todd, 1980). The measurement and collection of groundwater level data are of fundamental importance in hydrogeology (Hiscock, 2005). Water level data is also important for the determination of changes in water levels over time, and effects of pumping (Conrad et al., 2002). Groundwater level for an aquifer unit can be used for several purposes including plotting a hydrograph, determining the direction of groundwater flow by constructing a map of the potentiometric surface, and in completing flow nets (Fetter, 1994).

Measurement of groundwater level in the field is traditionally undertaken using a dip meter. In modern days a submersible pressure transducer positioned just below the lowest expected groundwater level is used to measure water level (Hiscock, 2005).

In a dip meter, groundwater levels are obtained by lowering an electrical water level sounder into a borehole (Hiscock, 2005). It consists of batteries, voltmeter, a calibrated two wire cable on a reel and an electrode (Todd, 1980). When the electrode contacts water, the circuit is completed which activates either a light or a buzzer or both (Hiscock, 2005), thus readings are taken.

A pressure transducer consists of a solid-state pressure sensor encapsulated in a stainless steel, submersible housing. A water proof cable, moulded to a transducer, connects the water pressure sensor to a monitoring device such as a data logger from which a record of groundwater level fluctuations can be obtained (Hiscock, 2005).

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CHAPTER 3: METHODOLOGY

Geophysical data, borehole drilling data, groundwater samples, water level and rainfall data, and borehole pumping data were collected during the study.

3.1 Geophysical Data collection

Surface geophysical surveys have been conducted as part of the preliminary site evaluation by the CSIR. The geophysical transverse locations are shown in Figure 3.1 below:

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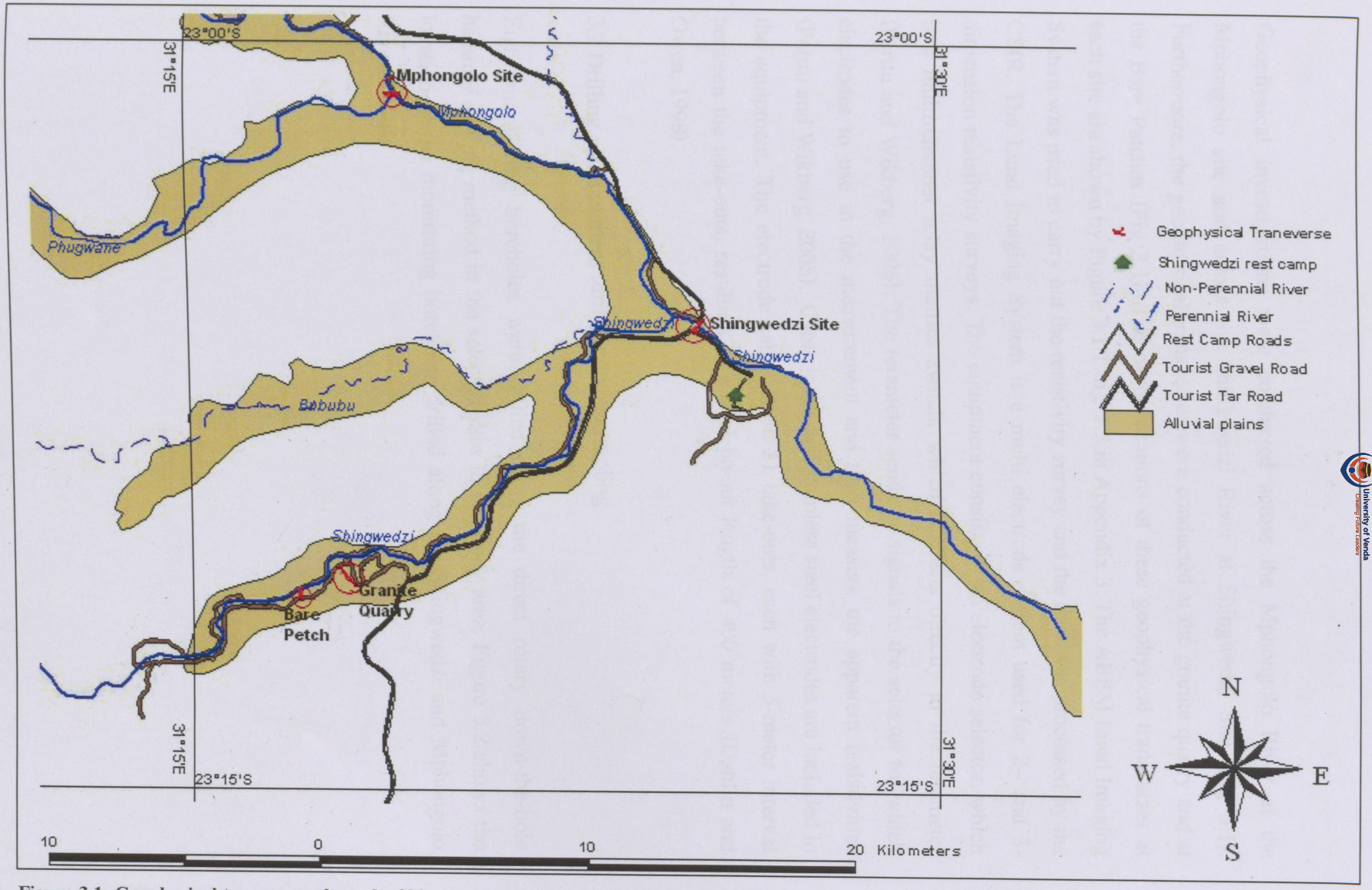

Figure 3.1: Geophysical transverse along the Shingwedzi and Mphongolo River Basins (SRB) in Kruger National Park

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Geophysical investigations were conducted across the Mphongolo River at the Mphongolo site and across the Shingwedzi River at Shingwedzi Site (Fig 3.1). Furthermore, the geophysical transverses were conducted at the granite quarry and at the Bare Patches (Fig 3.1). The exact locations of these geophysical transverses at each site are shown by Figure 3.1.1 to 3.1.3 in Appendix 3. The ABEM Lund Imaging System was used to carry out the resistivity survey and the data was processed by the CSIR. The Lund Imaging System is a multi electrode system used for 2– and 3-dimension resistivity surveys. The equipment consists of an electrode selector, which is a multi-channel relay matrics switch, which connects directly to the terameter (Perttu and Wikberg, 2005). The terameter sends its signals to the selector for which electrodes to use in the measurement and then measure the apparent resistivities (Perttu and Wikberg, 2005). Cable joints and stainless steel electrodes are included in the equipment. The electrode cables have 21 take-outs, each with 5-meter interval between the take-outs, resulting in a total layout length of 400 meters (Dahlin and Owen, 1998).

3.2 Drilling and Sediment (drill cuttings) sampling

Eight monitoring boreholes were drilled using the direct rotary down-the-hole hammer drilling method in the selected sites in the study area. Figure 3.2 shows the location of the monitoring boreholes drilled along the Shingwedzi and Mphongolo River Basins.

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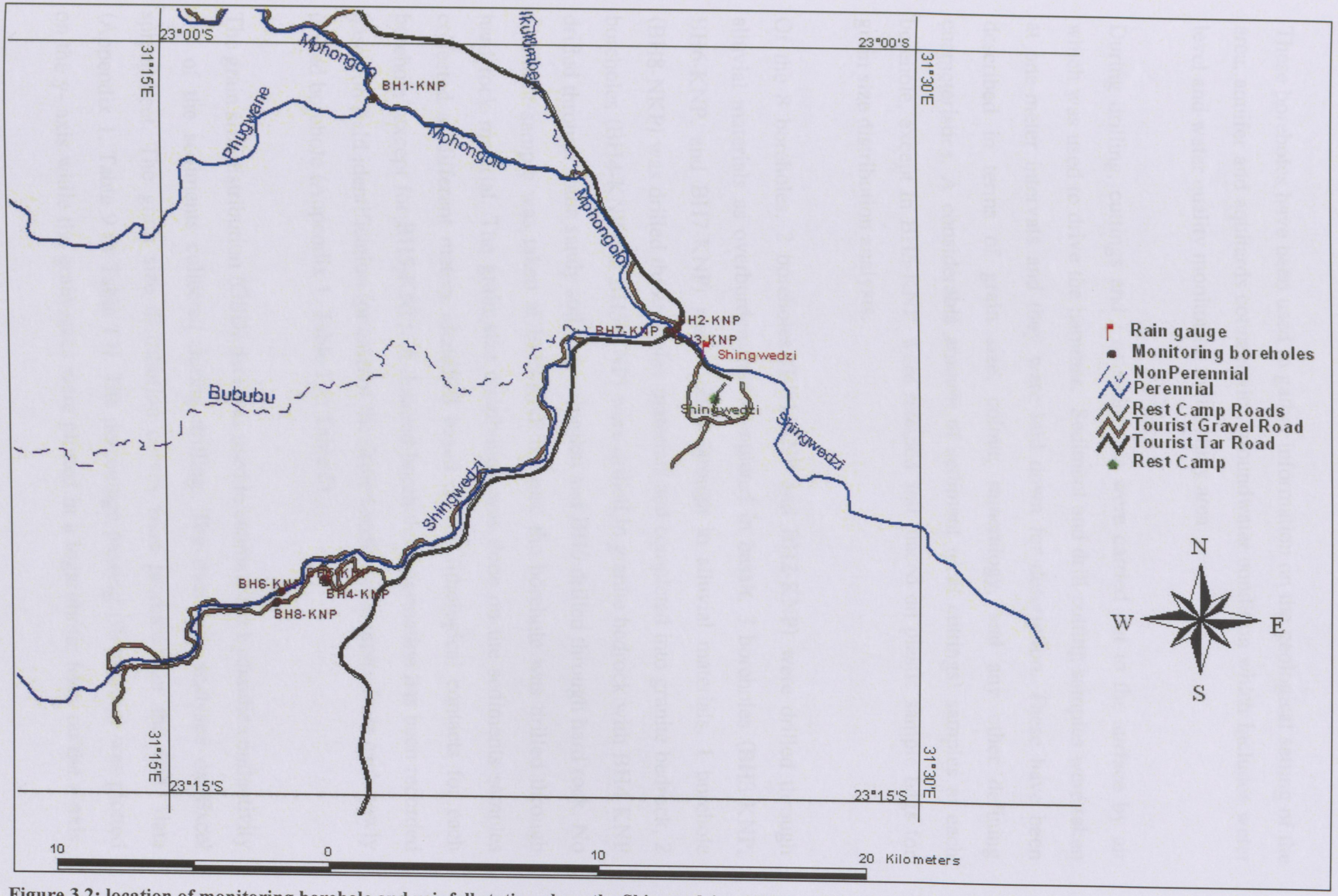

Figure 3.2: location of monitoring borehole and rainfall station along the Shingwedzi and Mphongolo River Basins

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These boreholes have been used to gather information on the geological setting of the area, aquifer and aquitards connectivity, groundwater condition which includes water level and water quality monitoring in the study area.

During drilling, cuttings and / or sediments were carried out to the surface by air which was used to drive the hammer. Sediment and drill cutting samples were taken at one-meter intervals and they were laid down for description. These have been described in terms of grain size, colour, mineralogy, and any other defining characteristics. A considerable amount of sediment (drill cuttings) samples at each borehole, except in BH5-KNP, were retained and placed on plastic sample bags for grain size distribution analysis.

Of the 8 boreholes, 2 boreholes (BH1-KNP and BH2-KNP) were drilled through alluvial materials as overburden then completed in basalt, 3 boreholes (BH3-KNP, BH6-KNP, and BH7-KNP) were drilled through in alluvial materials, 1 borehole (BH8-NKP) was drilled through clay materials and completed into granite bedrock, 2 boreholes (BH4-KNP and BH5-KNP) were drilled in granite bedrock with BH4-KNP drilled through some sandy soil as overburden and BH5 drilled through hard rock. No sediment sample was taken at BH5-KNP because the borehole was drilled through hard rock material. The grain size distribution was done on the sediments samples collected at different meters identified based on the lithological contacts for each borehole (except for BH5-KNP). A detailed boreholes information has been recorded based on field identification for each of the drilled sediment samples from each newly drilled borehole (Appendix 1, Table 1 to Table 8).

The grain size distribution (GSD) data was used to estimate the hydraulic conductivity (K) of the sediments collected during drilling. The data was analysed on Excel spreadsheet. The grain size distribution curves were produced for the GSD data (Appendix 1, Table 9 to Table 13). The percentage passing (% passing) was plotted on the y- axis while the grain-sizes were plotted in a logarithmic form on the x-axis.

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Two methods using Eq 2.1 (Hazen, 1893) and Eq. 2.3 (Alyamani & Sen, 1993) were used to obtain *K* values from the grain size distribution data following procedures described in sub-section 2.4.

In addition, rock samples were collected from the surface (outcrops) of geologic materials along the riverbanks for the thin-section analysis.

3.3 Borehole pumping

8 boreholes (BH1-KNP, BH2-KNP, BH3-KNP, BH4-KNP, BH5-KNP, BH6-KNP, BH7-KNP, and BH8-KNP) were subjected to pumping in order to determine the aquifer parameters. The boreholes pumping were conducted by Mr Nico de Meilon of the Department of Water Affairs and Forestry (DWAF) using submersible pump. Drawdown measurements were made at the pumping borehole only as there were no observation boreholes available.

Version 3 of the Excel spreadsheet developed for fractured rock pump test analysis by van Tonder et al. (2001) was used to determine the aquifer parameters for the boreholes within the study area. The borehole pumping data was analysed using the Cooper Jacob Method and the Hantush Method as built in the FC-excel workbook. The analyses were performed by finding the best fit line in the drawdown data. The FC excel sheets are shown in Appendix 2, for analysis performed by the Cooper Jacob Method and the Hantush Method. The transmissivity (*T*) and storativity (*S*) of the aquifers were obtained from the Cooper Jacob and the Hantush methods. The storativity was further determined by the basic FC solution program which is also fitted on the FC-excel workbook.

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3.4 Water level monitoring and rainfall

Groundwater level monitoring is important for the determination of groundwater fluctuation during dry and wet periods. Groundwater level data loggers were installed in five boreholes by DWAF in the study area in November 2004. Three boreholes (BH3-KNP, BH6-KNP, and BH7-KNP) of these five boreholes were drilled in alluvial aquifers, and two boreholes (BH1-KNP and BH2-KNP) were drilled in basalt materials with alluvial materials as an overburden. No water level data loggers were installed at BH4-KNP, BH5-KNP, and BH8-KNP; however manual water levels were obtained using the dip meter. The boreholes with data loggers were visited after every three months for data downloading. Rainfall data for the surrounding rainfall station, which is the Shingwedzi rainfall station (Fig 3.2) was obtained from the South African Weather Services (SAWS, 2005) in order to compare the response of water levels to rainfall.

Water level data and daily rainfall from the Shingwedzi rainfall station was plotted in Excel workbook in order to identify the fluctuation of water levels in relation to rainfall at each borehole. The time (in days) was plotted on the x-axis and the water level (in meters) and rainfall (in mm) on the y-axis. This has been done in order to identify the links between recharge (rainfall) and discharge and groundwater level changes.

3.5 Water Quality Monitoring

8 monitoring boreholes and two surface water points were sampled in the study area (Figure 3.2). Three sampling runs were undertaken for groundwater quality and 1 sample was taken from surface water points due to the dryness of the area during the first two monitoring.

Groundwater sampling was undertaken in order to understand the hydrochemical composition of the aquifer in the study area. Groundwater samples were collected

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using a hand bailer. Before sampling, each borehole was subjected to purging using a 1-litre hand bailer. Borehole purging was done in order to remove stagnant water in the borehole casing prior to sampling so as to obtain representative sample of *in-situ* groundwater. Purging was performed by inserting a bailer in the boreholes and removing water several times (for a minimum of 10 times) until the stabilisation of Electrical Conductivity (EC) and temperature (T - ^{0}C) was achieved. By noting the stabilization of temperature and EC of discharging water, the sample was taken. Field pH, EC, and temperature were taken during sampling of each borehole. The bailed water was transferred into a sample bottle and was placed in a cooler bag with ice pack.

Water samples that were collected from each monitoring borehole and surface water were submitted to the CSIR laboratory for analysis following procedures described in subsection 2.6.3 *(a)* and *(b)*. Analysis requested were for major cations and anions which are Calcium (Ca), Magnesium (Mg), and Sodium (Na), Chloride (Cl), Sulphate (SO_4) and alkalinity (Carbonate plus Bicarbonate). Other parameters including Electrical Conductivity (EC at 25^{0}C), pH and Alkalinity ($CaCO_3$) were also determined. These parameters are the main source of salinity in groundwater and they determine the general character of the water (Weaver et al., 2007).

Groundwater quality results from the laboratory were also used to assess the suitability for use for domestic and livestock watering as some of the boreholes are located close to the rest camp (Shingwedzi Rest camp) and some close to the boreholes used for animal watering. The results were compared to the SANS 241:2005 for domestic purposes. Since there are no game watering standards available, the DWAF livestock watering guidelines were used for game watering.

Groundwater and surface water results were also compared to each other, in order to identify the linkages between surface and groundwater interchange based on the parameters analysed. The analyzed results of surface water samples which were collected at the granite quarry were compared to the results of the boreholes located close to it which are BH4-KNP and BH5-KNP. On the other hand the analyzed results of surface water samples collected at the

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Shingwedzi Bridge were compared to the water quality results of boreholes BH2-KNP, BH3-KNP, and BH7-KNP as these boreholes are located close to the surface water sampling point.

Water quality results were graphically presented by plotting the laboratory results in AquaChem v.5.0, which is a computer software for analysing water sample results by Waterloo Hydrologic. This was used to characterise the type of water within the Shingwedzi and Mphongolo River Basins.

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CHAPTER 4: PRESENTATION AND DISCUSSION OF RESULTS

4.1. Preamble

This chapter presents the field data collected and results analysed. The data include geophysical data, drilling data, pumping test data, groundwater level data, rainfall data, and water quality data.

4.2. Geophysical investigation, borehole drilling and borehole logging along the Shingwedzi and Mphongolo River Basins

The geophysical logs produced from geophysical investigation data collected along the Shingwedzi and Mphongolo River Basins (Fig 3.1) with the aim of mapping the extent and occurrence of alluvial aquifers in this area, are shown in Figs. 4.1 to 4.4 below.

A map showing the geophysical transverse conducted at the Mphongolo site across the Mphongolo River is shown in Figure 3.1.1 (Appendix 3). Figure 4.1 below shows the geophysical profile log for the Mphongolo site and approximate location of drilled borehole (BH1-KNP).

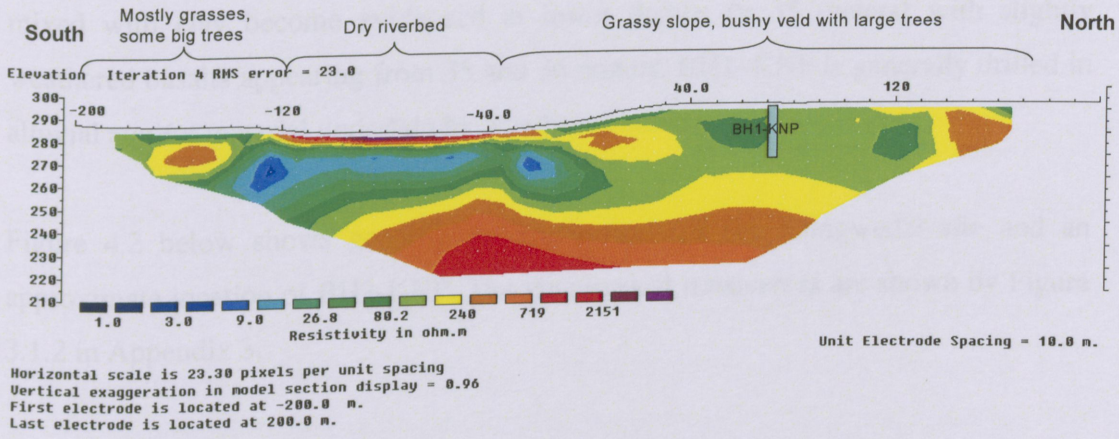

Figure 4.1: Geophysical log for Mphongolo site and expected location for BH1-KNP (CSIR, 2004)

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Geophysical lines were constructed at 10.0m-unit electrode spacing across the Mphongolo River. Relatively high resistvities (>719Ωm) were seen on the top layer of the dry riverbed. This high resistivity on the top layer continues and thickens outside the stream channel giving a total width of this layer of about 80 meters. The layer corresponds to coarse-grained alluvium as evident at the surface in the stream channel. The estimated thickness of the layer varies from a few meters to about 5 meters below the riverbed with no indication of this dry material outside the river channel. At the north-eastern side of the river (about 10-40m), a thick layer with estimated resistivities well below 100 Ωm reaches the surface and the layer thickens below the river channel. Low resistivities of about less than 10 Ωm were seen below the river channel and these are due to groundwater occurrence in alluvium. Borehole (BH1-KNP) was drilled at 50 m (Fig. 4.1) away from the stream channel in alluvial plain.

Borehole description during drilling shows that BH1-KNP is drilled in fine sandy-clay materials and calcrete as the over-burden materials underlain by clay and weathered to slightly weathered basalts. The alluvial sandy-clay materials occur at a depth of 5.00 to 10 meters below the ground level (mbgl), sandy clay and calcretious materials occur at a depth of 11 to 13 mbgl, and a mixture of alluvium sand, clay, and calcrete are dominant for a depth between 14 to 28 mbgl. The materials between 28 and 34 m at this borehole are of weathered basalts with some clay content. Weathered basalts mixed with clay become evidenced at lower depths (> 35 meters) with slightly weathered basalts appearing from 35 and 36 meters. BH1–KNP is generally drilled in alluvial aquifer material underlain by weathered basalts.

Figure 4.2 below shows geophysical profile log for the Shingwedzi site and an approximate location of BH2-KNP. The geophysical transverses are shown by Figure 3.1.2 in Appendix 3.

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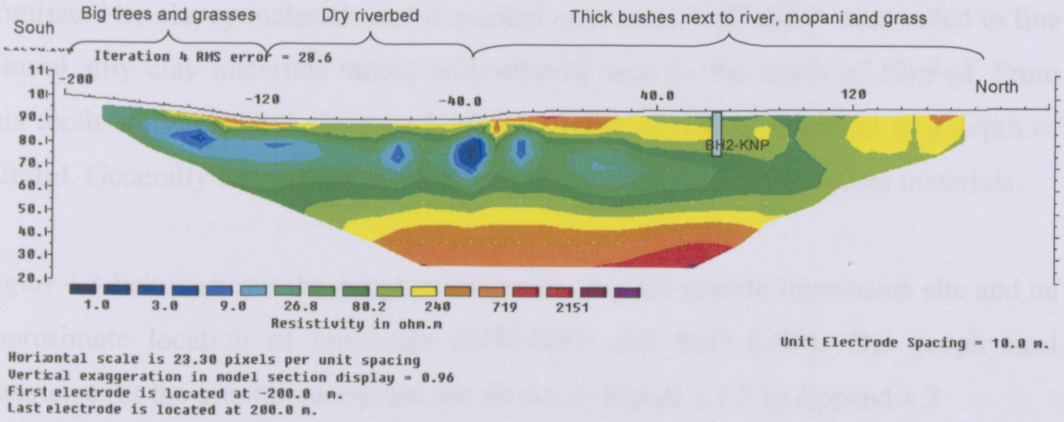

Figure 4.2: Geophysical log for Shingwedzi site and expected location for BH2-KNP (CSIR, 2004)

Relatively high resistivities (above 700Ωm) occurred outside the dry river channel. This relatively high resistivity top layer occurs for a few meters below the ground surface and is attributed to basalts and calcrete (see Sample 2- thin section analysis) outcrops along the riverbank. This widens for about 60 meters away from the river channel. At the end of the cross-section low resistivities (ranges between 9-10Ωm) were seen from the ground surface with high resistive materials towards the riverbed. BH2-KNP is drilled at 60m position in the geophysical line to the north, with BH3-KNP and BH7-KNP drilled at – 165 m geophysical line to the south and at about 100 m west of this line (south of the Shingwedzi river). The resistivities of dry riverbed at the Mphongolo site (Fig 4.1) are much higher than that of the dry riverbed at the Shingwedzi Site. The riverbed at the Shingwedzi site (Fig 4.2) was having some moisture as compared to that at the Mphongolo site (Fig 4.1) which was dry.

Geological description at BH2-KNP during drilling shows that the borehole is drilled in fine sand materials for the first few meters with a mixture of sandy clay and calcrete extending to a depth of 9-10mbgl. From this depth (9-10m), alluvium (sand and clay materials) occurs to a depth of 13 mbgl. Weathered basalts mixed with clay materials become dominant to the depth of 23mbgl. In general, BH2-KNP was drilled in alluvium (sand materials, mixture of clay, calcrete and alluvial sand) underlain by weathered basalts. On the other hand, BH3-KNP was drilled in fine sandy clay material to a depth of 8mbgl with alluvium sandy materials (clay and calcrete) to a depth of 14mbgl. Alluvium sand occurs from this depth to 20mbgl. This alluvium is

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dominated by clayey materials and deposited river sand. BH7-KNP was drilled in fine alluvial silty clay materials mixed with alluvial sand to the depth of 13mbgl. From this depth alluvium sand composed of clay and ferricrete is dominant to a depth of 22mbgl. Generally BH 3-KNP and BH7-KNP are both in alluvial aquifer materials.

Figure 4.3 below shows the geophysical profile log for granite lineaments site and an approximate location of boreholes (BH4-KNP and BH5-KNP). The geophysical transverses at the granite quarry site are shown in Figure 3.1.3 in Appendix 3

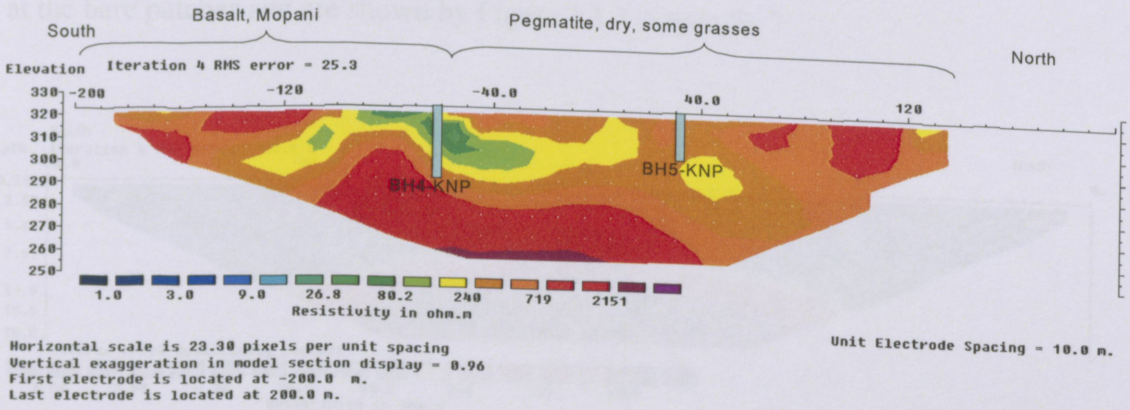

Figure 4.3: Geophysical log for granite Quarry boreholes and expected location for BH4-KNP and BH5-KNP (CSIR, 2004)

High resistivities were obtained in this area. Lower resistivities of about 80-90Ωm were seen in isolation at points between –40 to –100 m (south of the cross-section). The high resistivity materials are attributed to granitic materials (quartz and pegmatite), with the low resistivity materials attributed to weathered gneiss. Two boreholes were drilled in this area, one targeting the low resistivity materials (BH4-KNP), and the other borehole targeting high resistivity materials (BH5-KNP).

BH4-KNP was drilled between 50-55m positions. The geological description at BH4-KNP shows that the borehole was drilled in fine sandy soil to a depth of 2mbgl, from this depth, a hard rock materials of granitic formation (quartz and feldspar) becomes evidenced to a depth of 9mbgl. A weathered material of metamorphic rock (gneiss) becomes evidenced from 9mbgl to 13mbgl. Hard rock formation of gneiss with white

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quartz veining becomes evidenced to the depth of 38mbgl. BH5-KNP was drilled at 100 m north of BH4-KNP and is in hard rock- granite (feldspar and quartz as dominant minerals).

In general, BH4-KNP and BH5-KNP were drilled in hard rock formation of gneiss and granitic rocks respectively, with BH4-KNP drilled in weathered gneiss.

Figure 4.4 below shows the geophysical profile log for the Shingwedzi Bare Perches site and an approximate location of borehole BH8-KNP. The geophysical transverses at the bare patches site are shown by Figure 3.1.3 Appendix 3

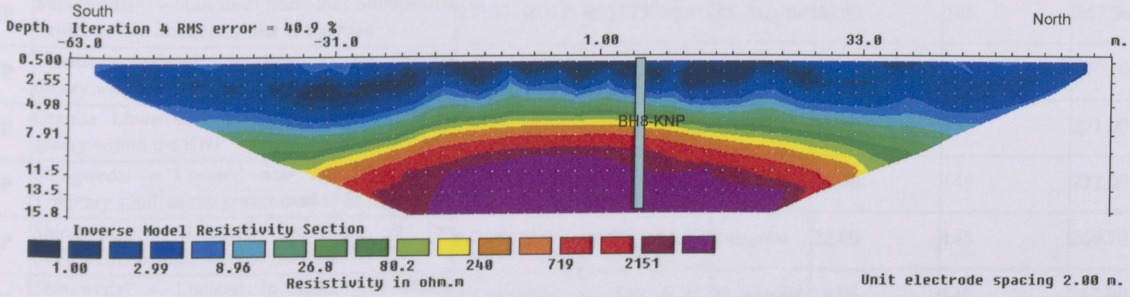

Figure 4.4: Geophysical log for Bare Patches and location for BH8-NKP (CSIR, 2004)

Geophysical investigation at the bare patches was conducted at 2 m unit electrode spacing. Very low resistivities were seen on the top layers of the cross-section. The thickness increased towards both ends of the cross-section. The thickness of these materials constituted a depth of 4.98mbgl in the centre of the cross-section and a depth of 8.0mbgl at the end of the cross-section. BH8-KNP was drilled in this cross-section. The borehole logs from borehole drilling shows that BH8-KNP was drilled through fine silty-clay soil to a depth of 5mbgl with a limited mixture of calcrete materials from 5mbgl to 9 mbgl. From this depth, clayey materials with a mixture of calcrete granules were dominant to a depth of 10m. From the depth of 10mbgl, the most dominant material was fresh granitic materials (quartz and feldspar).

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Soil samples and rock chips or returns taken during drilling for lithological descriptions are summarised in Tables 1 to 8 (Appendix 1).

Table 4.1 below summarises the general information for all boreholes drilled along the Shingwedzi and Mphongolo river basins for the study.

Table 4.1: General borehole information at the Shingwedzi and Mphongolo River basins

General Borehole Information							
Borehole No.	**Borehole Location/description**	**Latitude**	**Longitude**	**Date Drilled**	**Borehole Depth (mbgl)**	**Diameter (mm)**	**Surface Topography (mamsl)**
BH1-KNP	Mphongolo - Located at the confluence of the Mphongolo and Phugwane River	23° 1'3.55"	31°19'16.83"	30-Aug-04	36.00	145	387.50
BH2-KNP	Shingwedzi – Located near the Shingwedzi Bridge to the north.	23^0 05' 34.6"	031^0 25'12. 8"	2-Sep-04	23.00	165	266.50
BH3-KNP	Shingwedzi - Located near the Shingwedzi Bridge to the South and east of the road	23^0 05' 40.03"	031^0 25' 05.5"	31-Aug-04	20.00	145	267.50
BH4-KNP	Granite - Located Southeast of the Granite quarry within the KNP	23^0 10' 42.8"	031^0 18' 10"	1-Sep-04	38.00	165	270.50
BH5-KNP	Granite Lineaments Northeast of the granite quarry within the KNP	23^0 10' 40.0"	031^0 18'07. 2"	1-Sep-04	25.00	165	271.00
BH6-KNP	Shingwedzi – Located near the Shingwedzi Tributary south of the gravel road to Shingwedzi	23^0 10' 55.0"	031^0 17'15. 3"	2-Sep-04	18.00	145	272.00
BH7-KNP	Shingwedzi – Located Southwest of the Shingwedzi Bridge, west of the road.	23^0 05' 38.9"	031^0 25' 00.7"	2-Sep-04	22.00	145	269.70
BH8-KNP	Shingwedzi – Located in sodic soil (Bare Perches)	23^0 11' 07.9"	031^0 17'10. 9"	31-Aug-04	18.00	145	267.00

Geological Characteristics of Aquifers and Aquitards and their connectivity at the Mphongolo and Shingwedzi River Basins

Boreholes along the Mphongolo and Shingwedzi River basins were drilled along the geophysical transverses (Fig 3.1). Geophysical data is discussed in section 4.2 above.

The drilling results are summarised in Table 4.2 for the Shingwedzi and Mphongolo sites, and Tables 1 to 8 (Appendix 1) show geological logs for each borehole.

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Table 4.2: Borehole Geology summary

BH No.	Drilled BH Depth (m)	Water Strike (mbgl)	Water level (mbgl) after 24 hours	Overburden Thickness (mbgl)	Aquifer type	Geology	
						Lithology Overburden	Lithology of Bedrock
BH1-KNP	36	14m (saturated)	13.76	27	Basalt	Brown fine sand, clay and Calcrete & Alluvium	Fresh to slightly weathered Basalt
BH2-KNP	23	12 & 15m	13	3	Basalt	Fine sandy-clay soil, calcrete & Alluvium	Calcrete and Weathered Basalt
BH3-KNP	20	12m (saturated)	11.99	12	Alluvium	Brown, sandy clayey soil & Alluvium	-
BH4-KNP	38	Dry	28.8	2	Granite-Gneiss	Reddish fine sandy-clayey	Undifferentiated materials (Weathered gneiss)
BH5-KNP	25	Dry	21.2	-	Granite		Granite
BH6-KNP	18	11 m	11.82	4	Alluvium	Soil (sandy-clay), clay & Alluvium	-
BH7-KNP	22	12m (saturated)	11.59	6	Alluvium	Sandy clay soil, Ferricrete & Alluvium	-
BH8-KNP	18	Dry	8.36	10	Granite	Silty-clayey soil	Granite

During drilling, three boreholes (BH4-KNP, BH5-KNP, and BH8-KNP) were drilled dry with no water strike recorded, however water level were recorded in these boreholes after 24 hours. Since groundwater strikes occurs below the static water levels in these boreholes, it is considered as shallow semi-confine aquifers in weathered zone and confined in fractured bedrock. The water strikes at boreholes drilled in alluvial aquifers (BH3-KNP, BH6-KNP, and BH7-KNP) are similar to the water levels measured 24 hours after these boreholes were drilled and these aquifers are considered as unconfined alluvial aquifers. Boreholes drilled in basalt materials with alluvial aquifer materials as overburden have similar water level vs. water strike relationship as those in alluvial aquifers.

Generally, the hydrogeology of the Shingwedzi and Mphongolo river basins is composed of three aquifer type settings, which are alluvium aquifer (Quaternary formation), basalts aquifer (Letaba formation), and also granite-gneiss (Goudplaas formation) aquifers. These aquifer types setting are described below.

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Alluvium aquifer of Quaternary formation

These boreholes were drilled in alluvial materials of sandy clay, and alluvium sand. BH3-KNP, BH6-KNP and BH7-KNP fall within this category with their depths ranging from 18.00mbgl to 22.00mbgl and can be classified as shallow boreholes. Groundwater levels after drilling in this type of aquifer were ranging from 11.59 to 11.99mbgl. The boreholes are generally in deposits of Quaternary age, unconfined aquifer and consist of sand and gravel with some clay and silt composed of cemented calcrete and some ferricrete nodules. The aquifer materials are commonly segregated by size and beds of fine sand, gravel and silty clay and in some cases a mixture of these. These alluvial aquifers lay above the weathered basalts at the Mphongolo area (BH1-KNP) and also at BH2-KNP) which is located north of the Shingwedzi Bridge.

Basalts Aquifer of the Letaba formation

These boreholes were drilled through alluvial materials of sandy-clay, calcrete, and alluvium sand into weathered to slightly weathered basalts. BH1-KNP and BH2-KNP fall within this category. The depth of these boreholes, BH1-KNP and BH2-KNP, are 36 and 23mbgl respectively with water level of 26.76mbgl and 13.00mbgl after drilling. These aquifers are generally in deposits of quaternary alluvial materials as an overburden material (Table 4.2) on top of weathered to slightly weathered basalt segregated by fine alluvial silty clay beds and cemented alluvial sand by calcrete. At the Mphongolo site, these alluvial overburden materials reach a depth of 28 mbgl with a thickness of 23-27m. These boreholes are drilled in weathered to slightly weathered basalts materials consists of black to dark coloured rocks. This aquifer is characterised as semi-confined aquifer composed of alluvial materials as overburden, underlain by weathered basalt.

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Granite-Gneiss borehole Aquifer – Goudplaats formation

Boreholes BH4-KNP and BH5-KNP were drilled in granitic materials and gneiss (undifferentiated materials) with BH8-KNP drilled through fine silty-clay material. The depths of these boreholes, BH4-KNP, BH5-KNP, and BH8-KNP are 38.00mbgl, 25.00mbgl, and 18mbgl respectively. BH5-KNP is in hard rock which consists of granitic materials composed of mica and quartz with feldspar. BH4-KNP is in hard rock which consists of undifferentiated dark grey muscovite to pinkish biotite rock chips with white veining of quartz. The aquifer material is generally segregated by highly weathered gneiss resulting from weathering of granitic materials. This highly weathered gneiss later stretches to a thickness of 3m and this is the major supply of water to the boreholes. BH8-KNP is in fresh granite composed of quartz and feldspar with silty clay materials as overburden. This aquifer is a semi-confined aquifer characterised by some sandy clay materials as overburden, underlain by granite bedrock and some weathered gneiss materials.

Generally the area is composed of semi-confined basement aquifer formed in the weathered overburden materials (primary aquifers) underlain by a weathered and fractured aquifer (secondary aquifers).

4.3. Hydraulic conductivities of aquifers obtained from grain-size distribution analysis

Hydraulic conductivity (K) values in m/s were estimated from the grain size distribution analysis using equations 2.1 (Hazen, (1893) Method) and 2.2 (Alyamani and Sen, (1993) Method) as described in sub-section 2.4. The grain-size distribution curves produced from the sieved data are presented in Figure 3.2.1 to Figure 3.2.5 in Appendix 3. The grain-size distribution curves were used to estimate the hydraulic conductivity (K in m/s) where possible for the sediments encountered during drilling of each borehole.

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The K (m/s) values for the sediments as determined by the Hazen (1893) method and Alyamani and Sen (1993) Method at each borehole within the study area are shown in Table 4.3 below.

Table 4.3: K Values as determined by Alyamani and Sen and Hazen Method.

Soil Sample Analysis For Shingwedzi and Mphongolo River Basins					Hydraulic Conductivity (m/s)		Field description of sediments materials during drilling
					Hazen Method: $K=(D10)^2/100$	Alyamani & Sen Method (1993): $K=1300[I0+0.025(D_{50}-D_{10})]^2$	
Site	Depth (m)	D_{10}	D_{50}	I_0			
Shingwedzi Bridge South (BH3-KNP)	3-4m	0.1	0.81	0.059	0.00010	0.00009	Fine cemented sand to clay soil with white materials - reddish brown in colour
	6-7m	0.08	0.49	0.052	0.00006	0.00006	Fine clay sandy materials with coarse white cemented materials (calcrete) - light to reddish brown in colour
	8-9m	0.079	0.25	0.056	0.00006	0.00005	Fine sandy clay soil (yellowish in colour) with white cemented materials (calcrete)
	12-13m	0.056	0.18	0.043	0.00003	0.00003	Fine yellow moist sand with clay (sticky) and white cemented materials (calcrete)
	14-15m	0.15	0.096	0.092	0.00023	0.00021	Saturated alluvium sand (quartz) and fine clay materials which makes the soil to be sticky - red yellow in colour
	17-18m	0.27	1.35	0.18	0.00073	0.00064	Saturated alluvium sand (quartz) with boulders and fine clay materials which make the soil to be sticky - red yellow in colour
				Av.	0.00020	0.00018	
Shingwedzi Bridge West (BH7-KNP)	6-7m	0.061	0.24	0.043	0.00004	0.00003	Finer (silt), rusty in colour with white cemented materials (calcrete) grain size ranges from 0.1 to 5mm
	9-10m	0.095	0.28	0.069	0.0001	0.00008	Rusty fine sand (clay / silt), grain size of between 0.1 to 0.5mm with white cemented materials (calcrete) of about 1-5mm,

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Soil Sample Analysis For Shingwedzi and Mphongolo River Basins					Hydraulic Conductivity (m/s)		Field description of sediments materials during drilling
					Hazen Method: $K=(D10)^2/100$	Alyamani & Sen Method (1993): $K=1300[I0+0.025(D_{50}-D_{10})]^2$	
Site	Depth (m)	D_{10}	D_{50}	I_0			
	13-14m	0.235	0.43	0.195	0.0006	0.00060	Alluvium sand with fine materials (0.1-0.5mm) with red moist ferricrete materials cementing fine clayey (silt), and also white cementing materials (calcrete) (about 10mm size) and some boulders
	14-15m	0.23	0.77	0.16	0.0005	0.00045	Alluvium sand (0.1 - 0.5mm), saturated materials
	21-22m	0.29	1.02	0.245	0.0008	0.00104	Saturated alluvium sand with brown colour, and sticky clay materials with white cemented materials (calcrete) that are breakable when wet, grain size ranges from 0.1 to 7 mm.
				Av.	**0.0004**	**0.00044**	
Mphongolo (BH1-KNP)	9-10m	-	-	-			Moist fine sandy clay, yellowish in colour
	15-16m	0.049	0.42	0.028	0.00002	0.00002	Saturated clay with alluvium sand, and white cemented materials (calcrete) and basalt boulders
	20-21m	0.093	0.43	0.063	0.00009	0.00008	Saturated clay mixed with alluvium sand (medium sand mixed with coarse grained black materials (basalts) or boulders
	26-27m	0.099	0.79	0.058	0.00010	0.00008	Sand (alluvium) mixed with white cementing materials (calcrete) and cemented sand (quartz)
				Av.	**0.00007**	**0.00006**	
Bare Perches (BH8-KNP)	4-5m	0.071	0.578	0.043	0.00005	0.00005	Brown to yellowish sticky materials with isolated white cemented material(calcrete)
	9-10m	0.092	0.89	0.053	0.00008	0.00008	Yellowish brown soil with mixture of coarse granular sand (black to dark brown colour)
				Av.	**0.00007**	**0.00006**	
Granite South (BH4-KNP)	7-8m	0.185	0.88	0.149	0.00034	0.00042	Fine to medium (coarse) grains of grey (green) to brown colour with green

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Soil Sample Analysis For Shingwedzi and Mphongolo River Basins					Hydraulic Conductivity (m/s)		Field description of sediments materials during drilling
					Hazen Method: $K=(D10)^2/100$	Alyamani & Sen Method (1993): $K=1300[I0+0.025(D_{50}-D_{10})]^2$	
Site	Depth (m)	D_{10}	D_{50}	I_0			
							rounded pebbles (copper)
				Av.	0.00034	0.00042	
Shingwedzi Tributary (BH6-KNP)	10-11m	0.251	0.96	0.19	0.0006	0.00065	Light brown alluvium sand (grain size ranges from 1mm to above 15mm - boulders), sticky (slight mixture of clay)
				Av.	0.0006	0.00065	
Shingwedzi Bridge North (BH2-KNP)	1-2m	0.092	0.25	0.072	0.00008	0.00009	Brown sand with cemented sand by white material (calcrete) and loose sandy soil
	3-4m	0.33	3.01	0.19	0.00109	0.00099	Fine to medium sandy soil, light brown in colour, with slightly white cemented materials (calcrete)
	7-8m	0.0629	0.43	0.038	0.00004	0.00003	Fine sand with clay, yellowish in colour, with alluvium sand (quartz & basalt)
	10-11m	0.24	4	0.12	0.00058	0.00069	Saturated yellowish sand (clay) with cemented sand by white material (calcrete)
	12-13m	0.09	0.79	0.053	0.00008	0.00007	Fine to medium sandy soil, with white coarse grain of cemented materials (calcrete), yellowish in colour
	13-14m	0.43	3.01	0.251	0.00185	0.00149	Damp clay mixed with alluvium sand and calcrete, yellowish in colour
				Av.	0.00062	0.00056	

The hydraulic conductivity (K) of the sediments at the Shingwedzi Bridge South (BH3-KNP), Shingwedzi Bridge West (BH7-KNP), Shingwedzi Bridge North (BH2-KNP), Mphongolo (BH1-KNP) borehole changes with the depth based on the values obtained from both the Hazen Method, and Alyamani and Sen (1993). The highest K values in these boreholes were obtained in saturated alluvium materials. The hydraulic conductivity at the Bare Perches site (BH8-KNP) increases with an increase in depth

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based on values obtained using both the Hazen method and Alyamani and Sen (1993) method. One sample was collected at BH4-KNP and BH6-KNP and the K results are shown in Table 4.3. The K values for all samples as computed by both methods fall within the range for alluvial materials of 0.00001 to 0.01m/s (Hiscock, 2005). No soil samples were obtained for grain-size distribution analysis at borehole BH5-KNP (Granite North) as the borehole was drilled through hard rock

Generally, the K values (m/s) computed using both the Hazen Method and Alyamani and Sen Method are higher in those area overburdened by alluvial materials than those overburdened by clay (BH8-KNP) and sandy clay materials (BH4-KNP). This shows that groundwater infiltrated much quicker through the alluvial materials into the underlying bedrock in case of boreholes drilled through alluvial materials into basalts (BH2-KNP and BH1-KNP). However, the ability of the clay rich materials to allow water to pass through is limited in those boreholes overburdened by clayey materials into granite bedrock (BH8-KNP). This is the reason why BH8_KNP was dry during drilling with no strike depth. In those boreholes drilled in alluvial aquifers (BH3-KNP, BH6-KNP and BH7-KNP), the K values were much higher than that of the overburden materials in granite and basalts boreholes, thus groundwater flows through the porous media into the borehole. Although BH4-KNP was drilled through sandy materials into granite gneiss materials, relatively high K values for the overburden materials were obtained, thus the ability of these materials to allow water to infiltrate into the bedrock is good. It must be noted that the K values were determined for unconsolidated materials and not for the bedrock as it is imposable to apply the Hazen Method and Alyamani and Sen Method to determine K for bedrock materials.

4.4. Thin-Section analysis

Two rock samples collected on the surface outcrops along the Shingwedzi and Mphongolo Rivers were analysed using thin-section analysis in order to determine the mineral composition of the rocks. A thin section analysis is a laboratory preparation

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of rock sample for use with a polarizing microscope in order to investigate the optical properties of minerals in a rock sample. These tests where conducted in order to understand the mineral composition of the rock outcrops within the study area, Young (1992) indicated that thin section analysis are seldom applied to hydrogeological problems although they allow the direct measurement of grain size, pore size and porosity, from which it is possible to gather information clearly valuable where direct measurement of hydraulic conductivity, specific yield and solute retardation factors is impossible to estimate. The results from this study are shown below:

Sample 1: Calcrete

Location: North of Shingwedzi River –Next to the Bridge (Basalts and Calcrete Outcrop)

Site Description: The site is composed of weathered basalts, and calcrete. The colour of the sample is cream-white with some black stain (cemented on it) and some colourless grains (quartzite nature).

Analysis: The sample produces some bubbles when hydraulic acid is poured on it, which shows an evidence of calcite. Under the Microscope, the sample is composed of grains of sub-angular to sub-rounded quartz materials. Sub-angular to sub-rounded grains attributed to calcite are also evidenced. The calcite crystals were observed to be only few in the field of view of the microscope. The individual cement crystals were distinguished by their slight interference colour (high order grey and pink) in the XPL photograph. The quartz grains were distinguished by their colour differences from cream white to colourless when the microscope was rotated. In general, the rock sample was classified as cemented sandstone (alluvial sand) and calcite dominated by quartz and calcite minerals (Fig 4.5).

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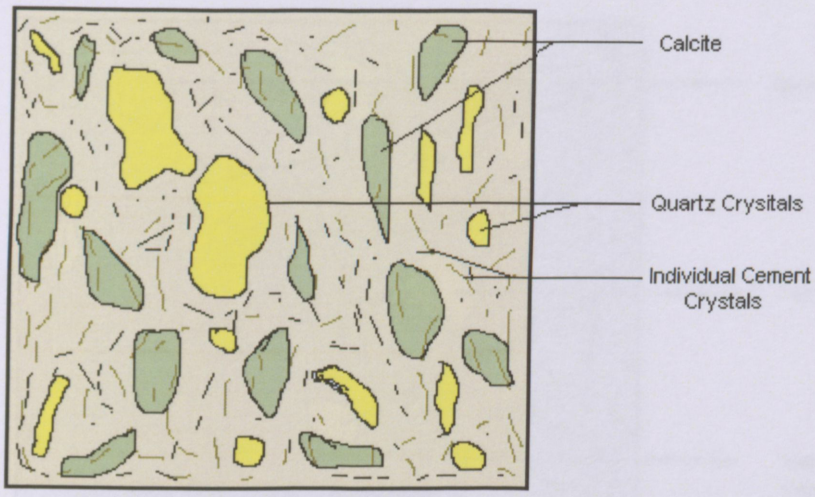

Figure 4.5: Thin-section for Shingwedzi bridge north rock outcrop (calcrete) under microscope

Sample 2: Fine sandstone

Sample Description: Fine sandstone, pinkish colour with white crystals of calcite (identified by pouring hydrochloric acid). It produces fine sand grains, when crushed, as dominant materials. Analysis: Under Microscope, the sample is composed of colourless sub-rounded grains in the XPL photograph, and large rounded with sub-angular to sub-rounded colourless grains in a fine-grained matrix having high relief (Fig. 4.6). The former is attributed to calcite crystals, and the latter being attributed to quartz crystals. Generally, the sample is characterised as cemented sandstone composed of quartz and feldspar crystals as dominant minerals with high order interference colours of calcite characteristics.

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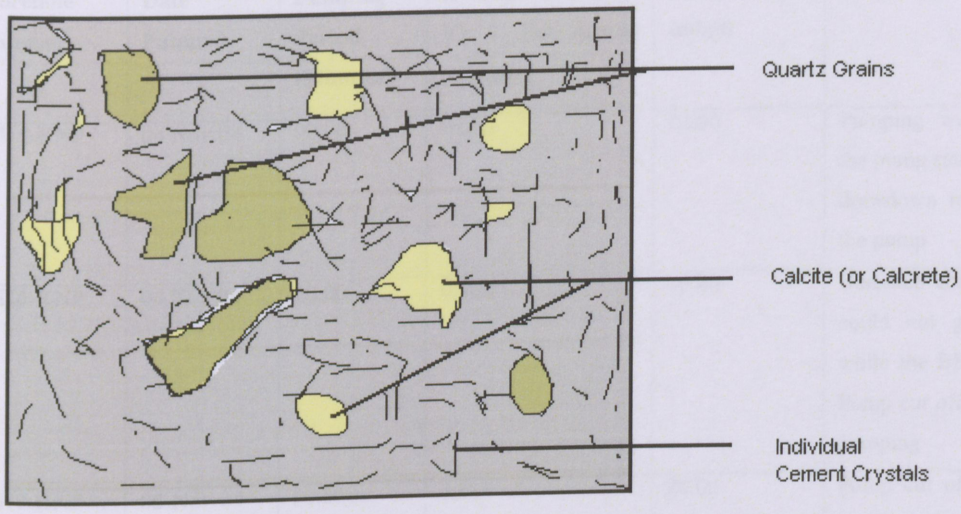

Figure 4.6 Thin-section for sandstone under microscope

4.5. Borehole Pumping for T and S

It was not possible to conduct the full borehole pumping tests due to one or a combination of factors. However, DWAF pumped the boreholes for a limited time and these limited data were available to give a preliminary indication of aquifer parameters. Table 4.4 below shows the borehole pumping details at each pumped borehole.

Table 4.4: Borehole pumping details during constant pumping

Borehole Number	Date Pumped	Pumping Period (Minutes)	Average Discharge (Q – l/s) during pumping	Pump Depth (mbgl)	Comments
BH1-KNP	06-Nov-04	130.00	0.337	29.00	Pumping was stopped because the pump started to cut off because the drawdown reached the depth of the pump.
BH2-KNP	03 Nov 04	78.00	0.132	12.43	Pump started to cut off
BH3-KNP	04 Nov 04	60.00	0.479	12.153	Water level was recovering during pumping
BH4-KNP	05 Nov 04	120.00	0.040	34.00	Pump started to cut off after 60 minutes of pumping

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Borehole Number	Date Pumped	Pumping Period (Minutes)	Average Discharge (Q – l/s) during pumping	Pump Depth (mbgl)	Comments
BH5-KNP	04 Nov 04	90.00	0.058	23.00	Pumping was stopped because the pump started to cut off as the drawdown reached the depth of the pump
BH6-KNP	04 Nov 04	60.00	0.360	16.00	Borehole collapsed – the pump could not go below 16 mbgl while the BH depth is 18 mbgl. Pump cut off after 40 minutes of pumping
BH7-KNP	06-Nov-04	90.00	0.515	20.00	Pump cut off at 30 minutes of pumping. Recovery was difficult to measure as the water level kept on fluctuating
BH8-KNP	05 Nov 04	48.00	0.610	16.00	Pump cut off after 45 minutes, borehole was pumped dry

Boreholes along the Shingwedzi and Mphongolo River basins were pumped for a period ranging between 48 minutes to 130 minutes. Boreholes pumping in the study area were aimed at conducting full pumping tests in order to determine the aquifer transmissivity (*T*) and Storativity (*S*). However, boreholes were pumped for a limited period, which resulted in incomplete pumping tests, due to one or a combination of the following factors:

- Some boreholes recovered during pumping as they were located near the stream in alluvial aquifers, which were BH3-KNP and BH7-KNP.
- The pump used for borehole pumping was very weak / low
- The drawdown reached the depth of the pump during borehole pumping and this caused the pump to cut off (BH1-KNP and BH5-KNP).
- One of the boreholes became dry during pumping (BH8-KNP)
- The recovery were incomplete in some of the boreholes
- Some boreholes collapsed, and the pump did not reach the desired level (e.g. BH6-KNP – borehole depth was 18mbgl and the pump could not go below 16 mbgl)

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For these reasons the aquifer parameters (T &S) determined, using the FC Excel spreadsheet, are considered preliminary. The borehole pumping data is presented in Appendix 2. The FC Excel sheets with *T* and *S* analysis is presented in Appendix 2 for each borehole pumped. The preliminary aquifer transmissivity (T) and storativity (S) as determined from the FC spreadsheet by using the Cooper Jacob method and the Hantush method fitted in the FC spreadsheet are shown in Table 4.5 below.

Table 4.5: Preliminary T and S for boreholes along the Shingwedzi and Mphongolo River basins in KNP

Borehole Number	Methods					
	Cooper Jacob Method		Hantush Method		Basic FC Method	
Parameters	T Late (m^2/d)	S Late	T (m^2/d)	S	T Late (m^2/d)	S Late
BH1-KNP	0.4	-	0.3	-	0.6	0.001
BH2-KNP	12.7	-	10.7	-	-	0.001
BH3-KNP	123.9	-	118	-	121.3	0.001
BH4-KNP	0.1	-	0	-	0.06	0.001
BH5-KNP	0.1	-	0	-	-	0.001
BH6-KNP	57.4	-	46.2	-	93.14	0.001
BH7-KNP	70.3	-	35.7	-	19.7	0.001
BH8-KNP	0.3	-	0.1	-	-	0.001

The $T(m^2/s)$ values in the study area as determined by the Cooper Jacob Method and Hantuch method ranges from 0.1 to 123.90 m^2/d, and from 0- 118.00 m^2/d respectively (Table 4.5). The transmissivity as determined by the Basic FC method ranges from 0.6 to 121 m^2/d (Table 4.5). No storativity values were obtained from this data with both the Cooper –Jacob and the Hantush Methods. A storativity value of 1.1×10^{-3} was obtained from the Basic FC method. Higher *T* values were obtained at BH3-KNP with both the Cooper Jacob (123.9 m^2/d) and the Hantush (118.0 m^2/d) methods as well as the Basic FC method (121.3 m^2/d) and this borehole was drilled in alluvial materials. BH6-KNP (Value) and BH7-KNP (Values) were also drilled in alluvial materials, but the T (m^2/d) values (Table4.5) are fairly high but less than that of BH3-KNP. A transmissivity value of 0.1 m^2/d was obtained from the Cooper Jacob method at both BH4-KNP and BH5-KNP boreholes. These boreholes were drilled in hard rock material of granite and weathered gneiss. The Basic FC method also computed the T value of BH4-KNP to be 0.06 m^2/d, with no T value computed for

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BH5-KNP. With the Hantush Method, no T values were obtained for BH4-KNP and BH5-KNP. At BH8-KNP, which was drilled through clay materials into granite bedrock, the T values are 0.3 and 0.1 m^2/d as computed from the Cooper Jacob and the Hantush Method respectively.

In summary, the preliminary borehole pumping data shows that, $T(m^2/d)$ within the study area is higher in boreholes drilled in alluvial materials (BH3-KNP, BH6-KNP and BH7-KNP) and lower in those boreholes drilled in basalt (BH1-KNP and BH2-KNP), granite (BH5-KNP and BH8-KNP), and gneiss (BH4-KNP) aquifers. This shows that alluvial materials within the study area have high transmissivity as compared to hard rock aquifers composed of basalt and granite/ gneiss materials.

The storativity, *S* (Dimensionless), in the study area of 0.001, as obtained by the FC Basic Solution, falls within the recommend *S* values for a confined aquifer (0.001 to 0.000001), but outside the range for unconfined (0.03 to 0.3) (Todd, 1980). The implication of these low *S* values computed in unconfined alluvial aquifers within the study area is that boreholes were pumped at a low rate while high rates pumping is required to cause substantial water level drop during pumping. This was evidenced in alluvial aquifers as some of the boreholes were recovering during pumping. Although these *S* values fall within the range for confined aquifers, van Tonder et al (2001) indicated that the value of *S* as determined by the Basic FC method can be erroneous. However, one particular advantage of the flow charateristic method is that it also allows one to obtain realistic estimates of the storativity and transmissivity of Karoo aquifers in particular, which is required in the estimation of the sustainable yield of a borehole (van Tonder et al., 2001).

4.6. Water Level Fluctuation and Rainfall

Manual water level measurements made at each borehole are presented in Table 4.6 below:

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Table 4.6 Manual water level measurements for boreholes at Shingwedzi and Mphongolo River Basins

Manual Water Level measurement (Deep-meter reading)												
Borehole No.	Date	Water Level (mbgl)	Date	Water Level (mbgl)	Date	Water Level (mbgl)	Date	Water Level (mbgl)	Date	Water Level (mbgl)	Date	Water Level (mbgl)
BH1-KNP	31-Aug-04	26.76	6-Nov-04	12.61	8-Nov-04	12.60	15-Feb-05	12.55	22-Apr-05	13.11	08-March-06	11.68
BH2-KNP	3-Sep-04	13.00	3-Nov-04	12.43	8-Nov-04	12.35	15-Feb-05	12.58	22-Apr-05	12.60	09-March-06	11.78
BH3-KNP	1-Sep-04	11.99	4-Nov-04	12.15	8-Nov-04	12.13	15-Feb-05	12.11	22-Apr-05	12.31	09-March-06	11.38
BH4-KNP	2-Sep-04	28.80	5-Nov-04	10.72	8-Nov-04	12.55	15-Feb-05	12.76	22-Apr-05	13.01	09-March-06	14.06
BH5-KNP	2-Sep-04	21.20	4-Nov-04	11.75	8-Nov-04	14.16	15-Feb-05	12.50	22-Apr-05	12.20	09-March-06	10.05
BH6-KNP	3-Sep-04	11.82	4-Nov-04	12.52	8-Nov-04	12.52	15-Feb-05	13.29	22-Apr-05	13.73	09-March-06	10.79
BH7-KNP	3-Sep-04	11.59	6-Nov-04	12.19	8-Nov-04	12.16	15-Feb-05	12.19	22-Apr-05	12.35	09-March-06	11.39
BH8-KNP	1-Sep-04	8.36	5-Nov-04	8.82	8-Nov-04	8.83	15-Feb-05	9.60	22-Apr-05	10.03	09-March-06	7.75

Boreholes which had data loggers installed in them were BH1-KNP, BH2-KNP, BH3-KNP, BH6-KNP and BH7-KNP. Groundwater level data from groundwater level data loggers is not presented due to the huge amount of data recorded *(this data can be obtainable in electronic format–CD attached)*. Rainfall data for Shingwedzi rainfall station from January 2004 to March 2006 is shown in Table 14 (Appendix 1). Groundwater level fluctuation and daily rainfall data for the area were plotted on an ordinary graph paper. Fig 4.7 below presents the water level data for the 5 monitoring boreholes (BH1-KNP, BH2-KNP, BH3-KNP, BH6-KNP and BH7-KNP); where groundwater levels were measured with data loggers during the period of November 2004 to March 2006. The gaps that can be seen from mid August 2005 to mid November 2005 are due to missing data.

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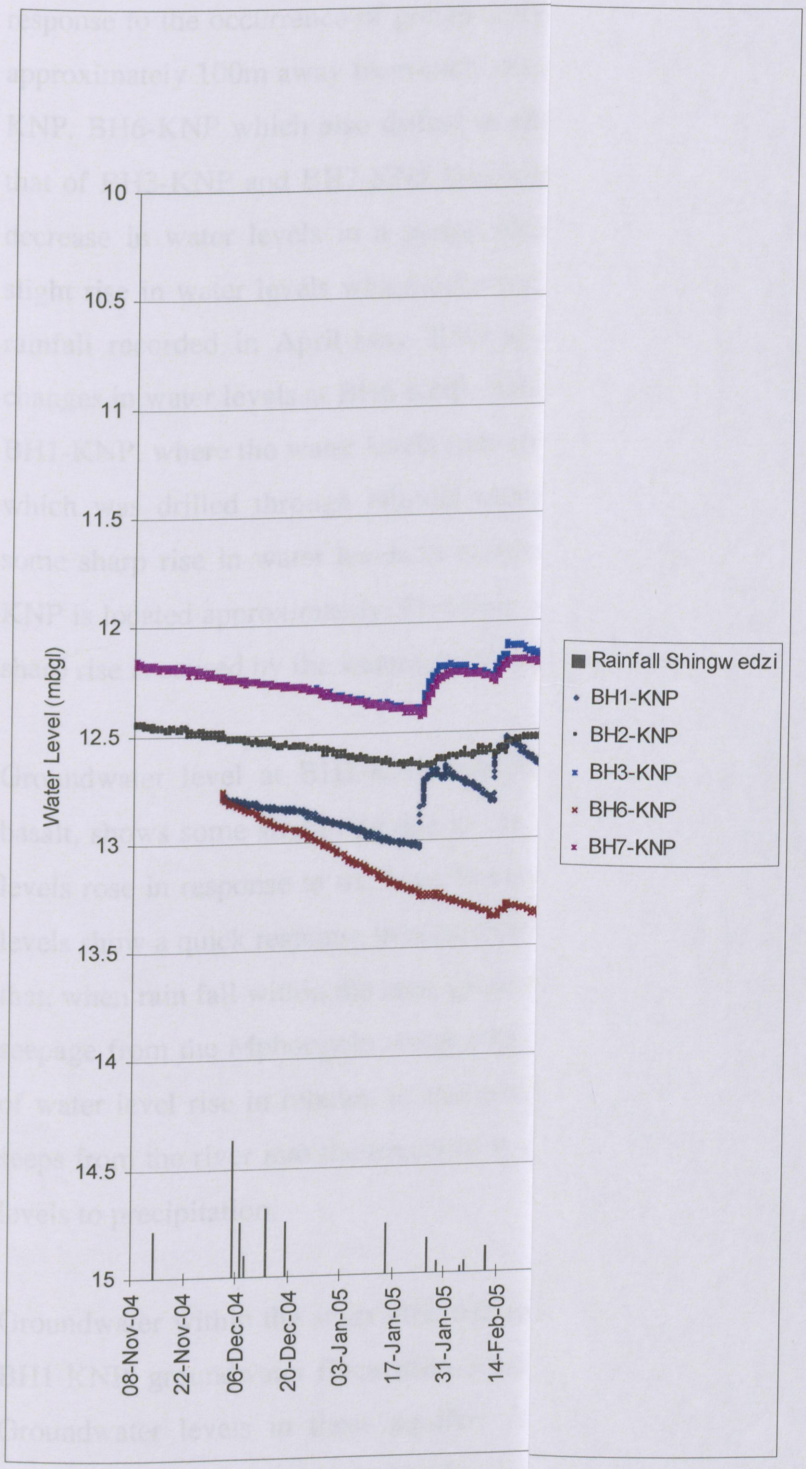
Figure 4.7: Groundwater level fluctuati



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Groundwater levels at boreholes drilled in alluvial aquifers within the study area near the Shingwedzi Bridge (BH3-KNP and BH7-KNP) show similar fluctuations in response to the occurrence of precipitation (Fig 4.7). These boreholes were drilled at approximately 100m away from each other with BH7-KNP located upstream of BH3-KNP. BH6-KNP which also drilled in alluvial aquifer shows a different response to that of BH3-KNP and BH7-KNP boreholes. BH6-KNP hydrograph shows a gradual decrease in water levels in a period November 2004 and November 2005, with a slight rise in water levels which occurred in late January –early February 2005. The rainfall recorded in April-May 2005 at the Shingwedzi rain gauge did not cause changes in water levels at BH6-KNP, BH2-KNP, BH3-KNP, and BH7-KNP except in BH1-KNP, where the water levels rose sharply. Water level fluctuation at BH1-KNP, which was drilled through alluvial materials into weathered basalt aquifer, shows some sharp rise in water levels in relation to the occurrence of precipitation. BH1-KNP is located approximately 30 meters away from the Mphongolo River banks. The sharp rise is caused by the water contributed by the river flow as a result of rainfall.

Groundwater level at BH2-KNP, which is drilled through alluvial materials into basalt, shows some slight rise due to the January 2005 rainfall. All boreholes water levels rose in response to the later November 2005 rainfall. At BH1-KNP, the water levels show a quick response in relation to the occurrence of precipitation. This shows that, when rain fall within the area, groundwater rise as a result of infiltration and also seepage from the Mphongolo riverbanks. At BH1-KNP there is no lag time in terms of water level rise in relation to the rainfall occurrence. At BH1-KNP, groundwater seeps from the river into the borehole as can be seen by the quick responses of water levels to precipitation.

Groundwater within the study area rise and fall as a result of rainfall, however at the BH1-KNP, groundwater fluctuation is also as a results of surface water contribution. Groundwater levels in these aquifers follow a natural cyclic pattern of seasonal fluctuation, typically rising during the summer and autumn period due to precipitation

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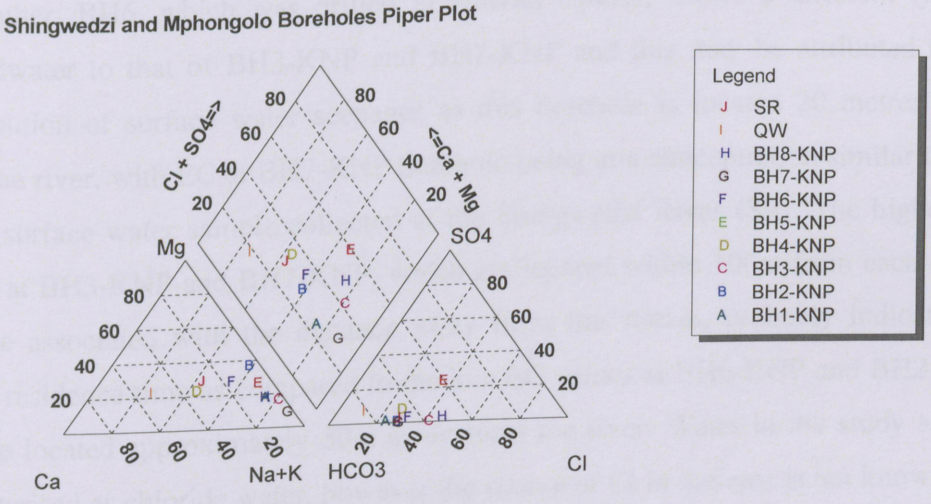
and recharge, then declining during winter and spring period owing to less recharge and expected high evapotranspiration.

4.7. Water Quality

The laboratory water quality analysis results for the three monitoring programmes are shown in Table 15 in Appendix 1. The first monitoring occurred in February 2005 which is the end of the summer season with the second monitoring exercise which occurring in April 2005, and the third (final) monitoring occurred in March 2006. The major ionic composition of the water samples (in %-meq/l) is visualised using a Piper plot (Figure 4.8).



Key: SR- Shingwedzi River Water, QW – Granite Quarry Water

Figure 4.8: Mphongolo and Shingwedzi hydrochemistry Piper diagram

The hydro-chemical data shows that the groundwater in the study area falls within two hydro-chemical types, which are Na-Mg-HCO_3-Cl and Na-HCO_3-Cl (see Table 4.7 below).

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Table 4.7: Groundwater types summary at the Shingwedzi and Mphongolo River Basins

Borehole Number	Groundwater Type (March 2006)	Geology (Aquifer)
BH1-KNP	$Na\text{-}HCO_3\text{-}Cl$	Basalt
BH2-KNP	$Na\text{-}Mg\text{-}HCO_3\text{-}Cl$	Basalt
BH3-KNP	$Na\text{-}HCO_3\text{-}Cl$	Alluvium
BH4-KNP	$Na\text{-}Mg\text{-}HCO_3\text{-}Cl$	Granite-Gneiss
BH5-KNP	$Na\text{-}Mg\text{-}HCO_3\text{-}Cl$	Granite
BH6-KNP	$Na\text{-}Mg\text{-}HCO_3\text{-}Cl$	Alluvium
BH7-KNP	$Na\text{-}HCO_3\text{-}Cl$	Alluvium
BH8-KNP	$Na\text{-}HCO_3\text{-}Cl$	Granite
Granite Quarry	$Ca\text{-}Na\text{-}Mg\text{-}HCO_3$	n/a (Surface Water)
Shingwedzi River	$Na\text{-}Mg\text{-}Ca\text{-}HCO_3\text{-}Cl$	n/a (Surface Water)

Alluvial aquifer borehole water is dominated by sodium-bicarbonate-chloride. These are from BH3-KNP and BH7-KNP (Table 4.7), which show the same fingerprint of groundwater type and these boreholes are situated at approximately 100m away from each other. BH6, which was drilled in alluvial aquifer, shows a different type of groundwater to that of BH3-KNP and BH7-KNP and this may be attributed to the contribution of surface water seepages as this borehole is located 20 metres away from the river, with EC at BH7-KNP borehole being at a concentration similar to that of the surface water sample collected at the Shingwedzi River (SR). The higher EC values at BH3-KNP and BH7-KNP, which are located within 100m from each other, may be associated with the distance away from the stream, probably indicating a longer residence time as compared to the low EC values at BH6-KNP and BH2-KNP that are located approximately 30m away form the river. Water in the study area is characterised as chloride water, however the source of Cl in the area is not known. Du Toit (1996) indicated that high chloride concentration shows that it is old water which is probably caught up with the sediments during deposition.

Generally, sodium is the dominant ion in groundwater at the Shingwedzi and Mphongolo River basins (Table 4.7) and this may be attributed to the clayey content of the materials as the major natural source. Leyland and Witthuser (2008) conducted a study in the KNP and indicated that the increased Na concentration can be assigned to the Karoo lava. Most of the boreholes were drilled in or through alluvial materials, which are dominated by clay. The bicarbonate (Table 4.7) dominance suggests

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recently recharged water with the source of calcium ion being attributed to the presence of calrete in alluvial materials along the Mphongolo and Shingwedzi River basins.

The study area has the following general groundwater quality characteristics based on the type of aquifers:

Alluvial aquifer boreholes (Quaternary formation): pH of 7.7-9.0, EC of 65-245 mS/m, Na is major parameter, Total alkalinity 197 –1033 mg/l, Cl of 89 –269 mg/l
Basalt boreholes: pH of 8.0-8.3, EC of 33 – 153 mS/m, Na and $CaCO_3$ are major ions, Total alkalinity 141 –710 mg/l, Cl of 22 –748 mg/l
Granite-Gneiss boreholes: pH of 6.9-8.2, EC of 27.9 – 183 mS/m, Na and Mg are major parameters, Total alkalinity 141 –484 mg/l, Cl of 26 –344 mg/l

The average groundwater quality laboratory analysis values for each parameter analysed at each borehole in the Shingwedzi and Mphongolo River basins were compared to the South African National Standards (SANS241: 2005) and also the South African Water Quality Guidelines (SAWQG) for stock watering use in order to asses the suitability of groundwater quality for use in KNP. The results are presented in Table 4.8 below:

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Table 4.8: Average groundwater quality analysis results compared to the South African National Standards (SANS 241:2005) and SAWQG (1996) livestock watering

Determinant	Units	SANS 241: 2005			(SAWQG) DWAF (1996) - Livestock Watering	BH1-KNP	BH2-KNP	BH3-KNP	BH4-KNP	BH5-KNP	BH6-KNP	BH7-KNP	BH8-KNP	Granite Quarry	Shingwedzi River Water
		Class I (recommended operational limit)	Class II (max. allowable for limited duration)	Class II water consumption period											
Conductivity at 25 °C (aesthetic)	mS/m	< 150	150 – 370	7 years	0 – 150	60.4	141.33	156.03	59.65	77.07	61.4	211	145.23	20.3	41.9
Dissolved solids (aesthetic)	mg/L	< 1 000	1 000 – 2 400	7 years	0 – 1000	39.26	91.86	101.42	38.77	50.09	39.91	137.2	94.39	13.19	27.23
pH value at 25 °C (aesthetic/operational)	pH Units	5.0 – 9.5	4.0 – 10.0	None	NS	8.2	8.05	8.6	6.9	7.6	7.6	8.45	7.8	7.8	8.5
Calcium as Ca (aesthetic/operational)	mg/L	< 150	150 – 300	7 years	0 – 100	8.67	11	4.33	36	20.67	18.33	7.63	14.33	18	22
Chloride as Cl^- (aesthetic)	mg/L	< 200	200 – 600	1 Year	NS	44	90.67	202	71.33	72	81	199	254	8	38
Magnesium as Mg (aesthetic/ health)	mg/L	< 70	70 – 100	7 years	0 - 500	12.67	70	25	23	23	20.67	24	21.33	5	14
Sodium as Na (aesthetic/health)	mg/L	< 200	200 – 400	7 years	0 – 2000	107.33	205.33	324.33	97.67	104.67	74	456.7	275	11	40
Sulfate as SO_4 (health)	mg/L	< 400	400 – 600	7 years	0 – 1000	<5	5.3	<5	20.33	22.33	12.33	5.4	10.57	6.4	<5

Keys: Grey- Values exceeding SAWQG livestock watering guideline, Green – Values within Class II of the SANS241:2005 standards, Red – Values exceeding the SANS Standards, NS-No Standard

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The water quality results for the samples collected at BH1-KNP, BH4-KNP, BH5-KNP, BH60-KNP, as well as the surface water samples collected at the Granite Quarry nest to BH4-KNP and BH5-KNP, and at the Shingwedzi river (near BH2-KNP, BH3-KNP and BH7-KNP) falls within class I of the SANS 241:2005 standards. The water quality at BH2-KNP, BH3,-KNP, and BH8-KNP falls within Class II of the SANS 241:2005 due to the elevated EC (BH3-KNP & BH7-KNP), Chloride (BH3-KNP and BH8-KNP), and Sulphate (BH3-KNP, BH3-KNP, and BH8-KNP). BH7-KNP fall outside the SANS 241: 2005 recommended class due to high concentrations of sulphates (456.7 mg/l) (Table 4.8).

Comparing the borehole water quality results to the surface water quality results collected in the area, no surface water groundwater interchange was identified based on the similarities in terms of water quality results. The surface water quality collected at the granite quarry was compared to the borehole results at BH4-KNP and BH5-KNP, while the surface water quality collected at the Shingwedzi River was compared to the results for BH2-KNP, BH3-KNP, and BH7-KNP.

The electrical conductivity is elevated at BH3-KNP (156.03 mS/m) and BH7-KNP (211.00 mS/m) (Table 4.8), which are above the recommended livestock water use (DWAF, 1996). Considering Table 4.8, the estimated TDS of the quality of water in the area is within the range of 0-1000mg/l, which shows that water in the study area is characterised as fresh water.

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CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of this study which was concerned with the determination of the hydrogeological conditions of aquifers has been achieved by the use of geophysical data to site the boreholes thereby drilling boreholes and performing geological logging. Borehole pumping, water quality and level monitoring also made it possible to achieve the objective of characterising the hydrogeology and groundwater condition in the Shingwedzi and Mphongolo River Basins.

The objective of identifying the geological characteristics of aquifers and aquitards and their connectivity in this study was achieved by means of geophysical investigation and borehole drilling and logging conducted along the Shingwedzi and Mphongolo River basins. The aquifers in the study area were found to be shallow unconfined alluvial aquifers along the Shingwedzi river. These alluvial materials are dominated by sandy-clay soil, calcrete, fericrete, and alluvial boulders. The study area is also composed of shallow semi-confined aquifers dominated by alluvial materials (primary aquifers) as overburden, underlain by weathered basalts. In some cases, the underlying materials are of granite bedrock and weathered gneiss with some sandy-clay soil as an overburden. The thin-section analysis conducted on the specimen collected near the Shingwedzi River (Bridge North) show that the high resistivity materials are basalts mixed with calcrete.

The objective of determining the aquifer flow and storage parameters was partially fulfilled through borehole pumping. These boreholes pumping, as performed for a short period, has produced the preliminary aquifer T and S. The borehole pumping conducted at each of the borehole were of short period (< 8 hours), which is a minimum recommended borehole pumping test period with the objective of obtaining the flow and storage characteristics of the aquifers. The T and S obtained from the pumping data shows that high transmissivity values were obtained in alluvial aquifers boreholes. Lower T values were obtained in those boreholes drilled in weathered basalts as well as in granite gneiss aquifers. In relation to K which was obtained

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through soil sample sieving analysis, the higher T values are found were the high K values were obtained which is in alluvial material. As K indicates all the transmitting factor of the median (Alyamani and Sen, 1996), in this case the overburden materials, the alluvial materials along the Shingwedzi and Mphongolo rivers transmit water better than the sity-clay and sandy-clay materials that were encountered when drilling at the granite quarry and the bare patches. This implies that for those boreholes drilled in alluvial sand materials into basalts, water will reach the underlying bedrock in a short period as compared to those overlain by silty-clay. This also proves the assumption that alluvial materials are better yielding aquifers than fractured/weathered aquifers.

The objective of measuring the water levels seasonally and determining the response to recharge and dry seasons was fulfilled by installing the water level data loggers in some selected boreholes especially those in alluvial materials. Daily rainfall from the time the data loggers were installed made it possible to compare the daily water level fluctuation and rainfall variability in order to link the seasonal water level fluctuations to either recharge or discharge. The groundwater levels within those boreholes equipped with data loggers showed that groundwater levels fluctuation occurs constantly in response to rainfall and dry periods. Boreholes drilled in alluvial aquifers have a similar response to precipitation. Groundwater level monitoring and linking rainfall to groundwater level response provided an understanding of seasonal variation of water level with response to rainfall. The significant fluctuations in the water levels at the Shingwedzi and Mphongolo River basins in KNP are to rainfall occurrence in the area. During rainfall event, water levels rises in response to the rainfall, and during a period of no rainfall events, water levels drops significantly. The study area is comprise of higher water levels during rainy seasons (summer and autumn), and low groundwater levels in less rainfall seasons (winter and spring). This also proves the theory that groundwater level fluctuation follows the seasonal variation of precipitation.

Boreholes drilled at the Shingwedzi bridge south (BH3-KNP and BH7-KNP) are in hydraulic contact with each other based on groundwater level fluctuations and its response to rainfall, borehole geologic logs and also similar hydro-chemical type. This proves the hypothesis that boreholes located close to each other and in the same aquifer show hydraulic contact to each

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other and also the assumption that boreholes located at the same geographic location in different aquifers have different hydraulic heads (water level fluctuate differently).

The objective of monitoring groundwater in order to characterise the type of water in each aquifer was achieved by sampling each borehole and carrying out laboratory analysis for those sample for major elements found in groundwater. Groundwater in the study area is characterised as Na-HCO_3-Cl and Na-Mg-HCO_3-Cl type, dominated by sodium which is assigned to alluvial clay materials in alluvial aquifers and basalt aquifer and also from weathered granite materials (mica). Surface water in the study area is characterised as Ca-Na-Mg-HCO_3 at the granite quarry and as Na-Mg-Ca-HCO3-Cl at the Shingwedzi river. Leyland and Witthuser (2008) indicated that sodium is assigned to the Karoo lava within the KNP. Most of the magnesium and bi-carbonate ions found in groundwater come from dissolution of carbonate rocks (calcrete materials). Deutsch (1997) also shows that aquifers without primary carbonate minerals, such as granite, basalt, and quartzite aquifers, the source of bicarbonate is carbon dioxide gas in atmospheric air, and soil vapour and low concentration of carbonate minerals present as weathering products. The source of chloride in water within the study area is not know, however, du Toit (1996) indicated that high chloride concentration shows that it is old water caught up with the sediments during deposition. The bicarbonates dominance shows that the water in the study area is recently recharged water. Todd (1980) shows that the presence of calcium in natural groundwater may be attributed to feldspar, pyroxene and others as natural source. Water quality data confirms that the most important influence of water quality in the KNP is natural influences which are geological formation, hydrological and climatic (rainfall) influence.

The objective of monitoring groundwater in order to obtain information on the exchange of water between different aquifers was achieved. Groundwater quality for BH2-KNP as compared to that of BH3-KNP and BH7-KNP that are in the same general area but in different geological composition are different showing no exchange except between BH3-KNP and BH7-KNP which show some exchange to each other. Boreholes drilled at the Mphongolo site along the Mphongolo River show no difference in chemical types to those boreholes drilled south of the Shingwedzi Bridge. This shows that similar chemical processes are in play.

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Groundwater quality monitoring in the study was also conducted with the aim of confirming suitability for use (domestic and livestock watering) as some of the borehole within the study area are located close to the water supply borehole (Rest Camp) and game watering boreholes. This objective was achieved by comparing the water quality results to the SANS 241:2005, drinking water standards and the South African Water Quality Guidelines (DWAF 1996) for livestock watering. The results for the analysed elements show that water quality in the area is suitable for domestic use even though some of the elements are elevated above the guidelines. These elements (calcium, chloride, magnesium, and sodium) occur in concentrations not harmful to human health (see Table 4.13). Two additional samples taken at the Shingwedzi River and the granite quarry are also suitable for both domestic and livestock (game) watering. The low concentration of TDS (within the range 0-1000 mg/l) makes the water to be classified as fresh water. Generally, groundwater quality along the Shingwedzi and Mphongolo River basins has been classified as good quality water.

5.2 Recommendations

This is an ongoing study on groundwater dependent ecosystem in riparian zones of the Shingwedzi and Mphongolo River basins in Kruger National Park. Boreholes drilled during 2004 drilling programme by CSIR are shallow monitoring boreholes aimed at understanding ecological links to groundwater. Based on the findings of the study the following recommendations can be made:

- Complete pumping tests need to be conducted to fully determine the aquifer flow and storage parameters as the determined parameters in this study are preliminary.
- Seasonal groundwater quality monitoring need to be conducted to fully understand the seasonal water quality variation
- Studies need to be conducted in order to understand, in detail, the behaviour of diurnal evapotranspiration in order to link it to plants and groundwater along the riparian zones of the Shingwedzi and Mphongolo river basins.
- More piezometers need to be put in place especially along the river channel in order to improve on the groundwater monitoring network along Shingwedzi and Mphongolo river basins

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- More rainfall stations and weirs need to be introduced in the study area in order to have a broad understanding on the rainfall patterns and its influence on groundwater recharge.

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APPENDICES

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APPENDIX 1: TABLES

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1.1 SUMMARISED BOREHOLE LOGS

1.1.1 Borehole Number: BH1-KNP

Borehole Depth (mbgl): 36

Water Strike (mbgl): None (wet at 15m)

Rest Water Level (mbgl): 26.76

Table1: Geologic description (log) for the Mphongolo site borehole (BH1-KNP)

Drilling Depth		Lithology	Casing Details			Drill Diameter (mm)
			Depth		Materials	
Top	Bottom		Top	Bottom		
0	6	Brown, fine to medium grained sand	0	6	Solid	165
6	8	Pale brown, fine grained sand - damp	6	18	Slotted/ Screen	165
8	15	Pale brown, clay, calcrete and coarse sand - saturated	18	30	Solid	165
15	18	Saturated clayey sand	30	36	Solid	140
18	30	Brown clay, sand and calcrete				
30	35	Weathered basalt and chips				
35	36	Solid Basalt				

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1.1.2 Borehole Number: BH2-KNP

Borehole Depth (mbgl): 23

Water Strike (mbgl): 12 (first strike depth), and 15 (second strike depth)

Rest Water Level (mbgl): 13

Table2: Geologic description (log) for the Shingwedzi Bridge North borehole (BH2-KNP)

Depth		Lithology	Casing Details			Drill Diameter (mm)
			Depth		Materials	
Top	Bottom		Top	Bottom		
0	15	Pale brown alluvial sand, calcrete, granitic boulders, clayey weathered basalt [water strike 12 m, 15 m]	No Details	No Details	No Details	No Details
15	18	Black, slightly weathered basalt and chips	No Details	No Details	No Details	No Details
18	23	Dark black, fine grained chips with some clay	No Details	No Details	No Details	No Details

1.1.3 Borehole Number: BH3-KNP

Borehole Depth (mbgl): 20

Water Strike (mbgl): 12 (first strike depth), and 15 (second strike depth)

Rest Water Level (mbgl): 13

Table 3: Geologic description (log) for the Shingwedzi Bridge South borehole (BH3-KNP)

Depth		Lithology	Casing Details			Drill Diameter (mm)
			Depth		Materials	
Top	Bottom		Top	Bottom		
0	8	Brown, fine to medium grained sand	0	15	Solid	165
8	13	Pale brown, fine grained sand - damp	15	20	Slotted/ Screen	140
13	18	Pale brown, clay, calcrete and coarse sand - saturated				
18	20	Reddish brown, alluvium sand with boulders, saturated				

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1.1.4 Borehole Number: BH4-KNP

Borehole Depth (mbgl): 38

Water Strike (mbgl): None

Rest Water Level (mbgl): 28 (measured after 24 hours from drilling date)

Table4: Geologic description (log) for the Shingwedzi Granite South borehole (BH4-KNP)

Depth		Lithology	Casing Details			Drill Diameter (mm)
			Depth		Materials	
Top	Bottom		Top	Bottom		
0	6	Pinkish, granitic surface material	No Details	No Details	No Details	No Details
6	8		No Details	No Details	No Details	No Details
8	15	Brown, softer, fine grained material with some clay - damp	No Details	No Details	No Details	No Details
15	33	Purple/pink dust. Chips of Fe to Mg crystalline rock.	No Details	No Details	No Details	No Details
33	35	Dark grey/greenish - darker. Some white calcite veins.	No Details	No Details	No Details	No Details
35	38	Dust from hard rock. Dark to pinkish	No Details	No Details	No Details	No Details

1.1.5 Borehole Number: BH5-KNP

Borehole Depth (mbgl): 25

Water Strike (mbgl): None

Rest Water Level (mbgl): 21.2 - Warm water (measured after 24 hours from drilling date)

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Table5: Geologic description (log) for the Shingwedzi Granite North borehole (BH5-KNP)

Depth		Lithology	Casing Details			Drill Diameter (mm)
			Depth		Materials	
Top	Bottom		Top	Bottom		
0	2	Brown, fine grained soil	No Details	No Details	No Details	No Details
2	25	Pale pink/white, coarse to medium grained granite; visible quartz and feldspar. White/ grey dust. No dampness.	No Details	No Details	No Details	No Details

1.1.6 Borehole Number: BH6-KNP

Borehole Depth (mbgl): 22

Water Strike (mbgl): Damp at 10m

Rest Water Level (mbgl): 11.59

Table6: Geologic description (log) for the Shingwedzi Tributary borehole (BH6-KNP)

Depth		Lithology	Casing Details			Drill Diameter (mm)
			Depth		Materials	
Top	Bottom		Top	Bottom		
0	2	Dark brown, fine grained, clayey soil	0	16	Solid	140
2	10	Rusty brown, silty material, damp with fine grained sand	16	22	Slotted / Screen	140
10	13	Light brown, fine grained sand with some silt and compacted clayey clods; some rusty ferricrete nodules; damp				140
13	22	Brown, poorly sorted, medium to coarse grained sand; visible sub-rounded grains of quarts; very wet				140

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1.1.7 Borehole Number: BH7-KNP

Borehole Depth (mbgl): 18

Water Strike (mbgl): None

Rest Water Level (mbgl): 11.82

Table 7: Geologic description (log) for the Shingwedzi Bridge West borehole (BH7-KNP)

Depth		Lithology	Casing Details			Drill Diameter
			Depth		Materials	
Top	Bottom		Top	Bottom		
0	4	Brown, fine grained silty soil	0	12	Solid	140
4	10	Dark brown silty clay; unsaturated	12	18	Slotted / Screen	140
10	11	Grey brown silty sand with coarse sub-angular quartz (75 mm). Strike				140
11	12	Brown and pale grey, poorly sorted, sub-angular sand with sub-angular granitic gravel.				140
12	18	Brown, coarse, poorly sorted sand (0.5 - 2 cm). Running sand.				140

1.1.8 Borehole Number: BH8-KNP

Borehole Depth (mbgl): 18

Water Strike (mbgl): None

Rest Water Level (mbgl): 8.36

Table 8: Geologic description (log) for the Bare Perches borehole (BH8-KNP)

Depth		Lithology	Casing Details			Drill Diameter
			Depth		Materials	
Top	Bottom		Top	Bottom		
0	10	Dark brown, fine grained unconsolidated clay/silt	0	6	Solid	
10	18	White/pink, coarse grained, fresh granite with visible quartz and feldspar	6	12	Screen / Slotted	
			12	18	Solid	

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1.2: SOIL SAMPLES SIEVING DATA

1.2.1 Site #1: Mphongolo Site Borehole (BH1-KNP)

Table 9: Mphongolo (MP) sieving data summary

Mphongolo Grain-size Distribution Data						
Sieve No.	% Passing at each depth					
	MP/9-10m	MP/26-27m	MP/15-16m	MP/20-21m	MP/31-32m	
4	92.859	95.005	77.861	95.039	88.487	
2	86.293	79.634	71.138	92.678	72.282	
1	78.954	56.283	63.645	84.298	48.148	
0.5	70.694	38.323	53.027	54.934	28.301	
0.25	56.534	21.850	35.366	26.877	15.173	
0.125	31.531	12.450	21.373	13.064	9.247	
0.063	17.101	5.942	11.949	7.471	4.858	
0.04	10.882	3.626	8.933	5.091	3.115	
0	0.000	0.000	0.000	0.000	0.000	

1.2.2 Site #2: Shingwedzi Bridge North (BH2-KNP)

Table 10: Shingwedzi Bridge North (SBN) sieving data summary

Shingwedzi Bridge North Grain-size Distribution Data							
Sieve No.	% Passing at each depth						
	SBN/12-13m	SBN/7-8m	SBN/10-11m	SBN/20-21m	SBN/3-4m	SBN/1-2m	SBN/13-14m
4	92.951	68.498	49.868	95.665	59.968	99.907	57.690
2	77.941	63.588	39.542	75.637	36.302	99.485	38.898
1	56.537	58.608	28.085	38.682	24.067	98.007	22.402
0.5	38.488	52.749	18.872	15.249	16.281	91.308	11.950
0.25	23.115	35.520	10.463	3.510	6.678	50.009	4.369
0.125	13.922	28.943	6.477	3.500	3.591	16.825	3.062
0.063	6.190	10.557	2.563	1.845	1.040	5.420	1.468
0.04	3.527	6.613	1.167	1.165	0.426	3.011	0.960
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

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1.2.3 Site #3: Shingwedzi Bridge South (BH3-KNP)

Table 11: Shingwedzi Bridge South (SBS) sieving data summary

Shingwedzi Bridge South Grain-size Distribution Data						
Sieve No.	% Passing at each depth					
	SBS/8-9m	SBS/6-7m	SBS/12-13m	SBS/3-4m	SBS/17-18m	SBS/14-15m
4	88.172	88.741	99.840	87.830	82.618	85.527
2	82.258	74.930	97.258	70.167	64.837	72.790
1	76.344	60.983	94.458	60.042	39.723	50.730
0.5	67.742	50.893	89.417	23.590	20.302	27.762
0.25	48.387	31.876	63.545	16.753	8.840	14.533
0.125	20.430	16.459	30.131	11.824	5.074	8.761
0.063	6.989	7.442	11.846	6.117	2.273	4.993
0.04	4.301	4.137	7.304	3.784	1.360	2.198
0	0.000	0.000	0.000	0.000	0.000	0.000

1.2.4 Site # 4, 6, and 8: Granite South, Shingwedzi Tributary, and, Bare Perches

Table 12: Site #4, 6 and 8: Granite South (GS), Shingwedzi Tributary (ST), and, Bare Perches (BP) sieving data summary (BH4-KNP, BH6-KNP, and BH8-KNP)

Shingwedzi Tributary, Granite South & Bare Perches Grain-size Distribution Data						
Sieve No.	% Passing at each depth					
	ST/10-11m	GS/7-8m	GS/9-10m	BP/9-10m	BP/4-5m	
4	81.082	93.611	95.357	91.401	93.365	
2	71.235	80.140	73.217	75.243	81.112	
1	51.155	54.431	44.931	53.086	63.872	
0.5	25.213	36.415	24.890	34.671	46.878	
0.25	9.634	13.471	16.429	18.856	28.804	
0.125	5.044	8.174	9.568	12.589	16.994	
0.063	2.096	3.521	4.326	6.933	8.371	
0.04	1.165	2.145	2.606	4.424	4.605	
0	0.000	0.000	0.000	0.000	0.000	

ST: Shingwedzi Tributary; GS: Granite South, BP: Bare Perches

1.2.5 Site #7: Shingwedzi Bridge West (BH7)

Table 13: Shingwedzi Bridge West (SBW) sieving data summary

Shingwedzi Bridge West Grain-size Distribution Data						
Sieve No.	% Passing at each depth					
	SBW/14-15m	SBW/13-14m	SBW/21-22m	SBW/6-7m	SBW9-10m	
4	97.540	93.299	98.505	92.424	98.664	
2	88.251	91.499	94.526	87.575	97.796	
1	63.001	85.731	79.046	81.012	96.493	
0.5	28.914	58.621	36.432	71.539	92.447	
0.25	11.464	12.436	6.002	50.814	42.305	
0.125	7.560	5.045	3.756	26.794	15.783	
0.063	4.017	1.737	1.821	10.419	5.492	
0.04	2.838	0.806	0.913	6.060	3.243	
0	0.000	0.000	0.000	0.000	0.000	

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1.3: RAINFALL DATA (Shingwedzi 2004 –February 2006)

Daily Rainfall Data (Shingwedzi Rainfall Station)

Station Number: 0725756A8 Shingwedzi

Longitude: 31.4300 Latitude:-23.1000

Height: 215 mamsl

Table 14: 2004 Rainfall Data (SAWS, 2005)

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1				6								
2												
3			13							3.8		
4			22.7									19
5			4.5								30	
6												7.5
7												3
8												
9		3.5										
10												
11												
12			3.5									
13			8.5								6.5	9.5
14												
15												
16												
17												7.7
18												
19												
20												
21			8			12.2						
22				11.5								
23		12.5		16.5								
24		18.5	17									
25		10.7								4		
26		10.5		10.5								
27		14.8										
28		27.6										
29										3.3		
30												
31			3									
TOTAL	0	98.1	80.2	44.5	0	12.2	0	0	0	11.1	36.5	46.7

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Table 14 continues - 2005 and 2006 Rainfall Data (mm)

Year	2005												2006	
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
1												80.5		
2														
3												2.5		
4		0.7										0.5		
5		1.2										4.5		
6										0.8	5.5	9	140	
7				20.1									35	11.5
8							1							45
9												14		
10			24									12		
11		3.5										23		
12														
13														
14														
15	7											33		8.5
16														
17														
18														
19														
20				0.5	5.5							20.5		
21				11.7										
22			35											
23														
24														
25														
26	5			5.5										
27														28.5
28														
29	1.7													
30														
31														
TOTAL	13.7	5.4	59	37.8	5.5	0.0	1.0	0.0	0.0	0.8	19.0	117.5	257.0	93.5

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1.4 WATER QUALITY DATA

Table 15: Water Quality monitoring results for the boreholes at the Shingwedzi and Mphongolo River Basins

Sample Id	Sample Date	Lab No.	Parameters								
			Alkalinity as CaCO3	Bicarbonates as CaCO3	Calcium as Ca	Chloride as Cl	Electrical conductivity as EC [mS/m (25°C)]	Magnesium as Mg	pH [pH units at 25°C]	Sodium as Na	Sulphate as SO4
BH1-KNP	14-Feb-05	43700	329	324	11	54	76	15	8.2	140	<5
	22-Apr-05	51953	141	140	6	22	33.5	7	8	57	<5
	9-Mar-06	55055	304	301	9	56	71.1	16	8	125	<5
BH2-KNP	14-Feb-05	43701	634	628	11	33	143	75	8	211	<5
	22-Apr-05	51954	710	696	10	91	128	63	8.3	189	5.6
	9-Mar-06	55056	630	626	12	748	153	72	7.8	216	7
BH3-KNP	14-Feb-05	43702	678	622	4	235	185	24	9	417	<5
	22-Apr-05	51955	358	335	2	102	96.1	12	8.9	195	<5
	9-Mar-06	55057	638	627	7	269	187	39	8.3	316	<5
BH4-KNP	14-Feb-05	43697	484	484	73	111	64.6	35	7	138	31
	22-Apr-05	51956	326	323	14	69	79.7	25	8	123	16
	9-Mar-06	55058	141	141	21	34	39.6	9	6.9	32	[illegible]
BH5-KNP	14-Feb-05	43698	423	422	18	102	110	35	7.4	169	2[illegible]
	22-Apr-05	51957	340	338	42	88	93.3	28	7.8	116	2[illegible]
	9-Mar-06	55059	48	48	2	26	27.9	6	7	29	2[illegible]
BH6-KNP	14-Feb-05	43703	249	248	25	116	82.9	29	7.7	101	12
	22-Apr-05	51958	197	196	20	89	65.1	22	7.7	79	20
	9-Mar-06	55060	130	130	10	38	36.2	11	7.4	42	<5
BH7-KNP	14-Feb-05	43704	1023	991	9.9	233	241	30	8.5	548	<5
	22-Apr-05	51959	720	702	4	114	147	14	8.4	311	6.2
	9-Mar-06	55061	1033	1022	9	250	245	28	8	511	<5
BH8-KNP	14-Feb-05	43699	475	474	13	344	183	18	7.4	385	<5
	22-Apr-05	51960	261	257	8	173	98.7	12	8.2	179	5.7
	9-Mar-06	55062	468	465	22	245	154	34	7.8261	261	21
Granite Quarry (GQ)	9-Mar-06	55063	86	85	18	8	20.3	5	7.8	11	6.4
River (Shingwedzi) (SR)	9-Mar-06	55064	164	159	22	38	41.9	14	8.5	40	<5

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APPENDIX 2: PUMPING DATA ANALYSIS (FC SHEETS)

A. BH1-KNP – Mphongolo Borehole

Country:	South Africa	Geology:	Basalt (overbuden by Alluvial mterials)
Region:	KNP	Depth of BH:	36
Owner:	CSIR	Water strikes:	
X-coord:	31.32	Date of Test:	6-Nov-04
Y-coord:	23.02	Contractor:	Department of Water Affairs

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Other info:

Borehole: BH1-KNP

s_{max}= 15.73 Recom. AD = 15.7

Distance from Rest WL to main water strike (m) =

T (m^2/d) : Logan eq. 2.1

Recovery data

Q (l/s)=	0.3161										
t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res_s	t/t'	WI rise	s'	Rec_T
1.00	1.692					1	14.256	131	1.476		
2.00	2.228					2	14.256	66	1.476	0.00	
3.00	3.392	8.08	0.55			3	14.256	44.33	1.476	4.62	
5.00	5.303	9.96	0.50	0.49	0.00E+00	5	12.477	27	3.255	6.84	0.9
7.00	7.316	12.17	0.30	0.38	0.00E+00	7	11.779	19.57	3.953	6.24	0.7
10.00	9.321	12.72	-0.27	0.37	0.00E+00	10	10.602	14	5.13	8.65	0.6
15.00	12.385	9.97	-1.09	0.43	0.00E+00	15	8.923	9.667	6.809	11.39	0.4
20.00	12.547	5.88	#NUM!	0.78	0.00E+00	20	7.135	7.5	8.597	14.86	0.4
30.00	13.862	#####	#NUM!	1.83	0.00E+00	30	4.458	5.333	11.27	15.59	0.4
40.00	13.877	#####	#NUM!	-4.46	0.00E+00	40	2.434	4.25	13.3	9.95	0.5
60.00	13.021	#####	#NUM!	-4.46	0.00E+00	60	1.379	3.167	14.35	5.39	0.8
70.00	13.069	#####	#NUM!	-4.46	0.00E+00	90	0.534	2.444	15.2	4.60	1.3
80.00	13.47	1.35	#NUM!	-4.46	0.00E+00	120		2.083	15.73	2.50	#NUM!
90.00	13.169	3.92	8.14	-4.46	0.00E+00	150		1.867	15.73	0.00	#DIV/0!
100.00	13.563	8.38	#NUM!	-4.46	0.00E+00	180		1.722	15.73	0.00	#DIV/0!
110.00	13.909	#####	#NUM!	-4.46	0.00E+00	210		1.619	15.73	0.00	#DIV/0!
120.00	15.322	#####	#NUM!	-4.46	0.00E+00	150		1.867	15.73	0.00	#DIV/0!
130.00	15.732	#####	#NUM!	-4.46	0.00E+00	180		1.722	15.73	######	#DIV/0!

A.1 Data

FC-METHOD : Estimation of the sustainable yield of a borehole

BH1-KNP

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes
Effective borehole radius (r_e) = (enter)	#NUM!	#NUM!	← Est. r_e / From r(e) sheet
Q (l/s) from pumping test =	0.316111111	0.00E+00	← S-late / Change r_e
s_a (available drawdown), sigma_s = (enter)	15.7		← Sigma_s from risk
Annual effective recharge (mm) =		15.73	s_available working drawdown(m)
t(end) and s(end) of pumping test =	130	15.732	End time and drawdown of test
Average maximum derivative = (enter)	8.4	8.4	Estimate of average of max deriv
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv
Derivative at radial flow period = (enter)	#NUM!	#NUM!	Read from derivative graph
	T-early[m^2/d] =	#NUM!	Aqui. thick (m) 20
	T-late [m^2/d] =	0.60	Est. S-late = 1.10E-03
T and S estimates from derivatives	S-late =	1.10E-03	S-estimate could be wrong
(To obtain correct S-value, use program RPTSOLV)			

A.2. Basic FC method estimation at BH1-KNP

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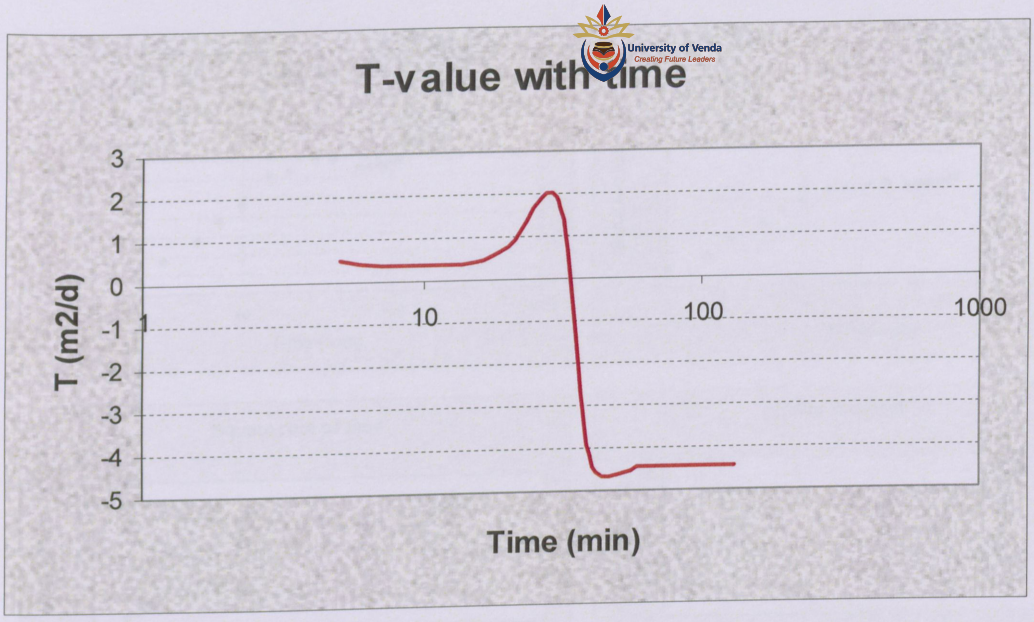

A.3 Transmissivity value with time at BH1-KNP

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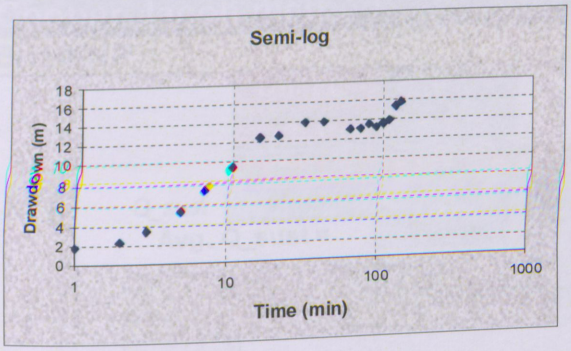

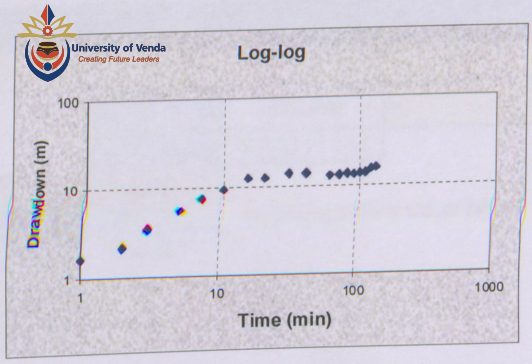

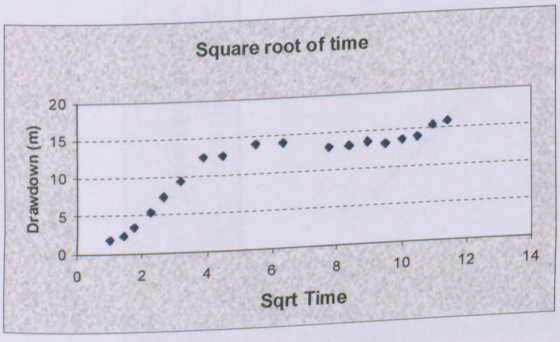

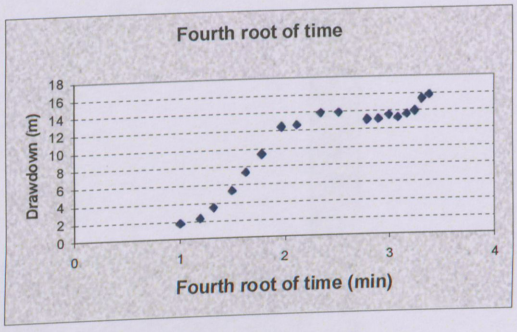

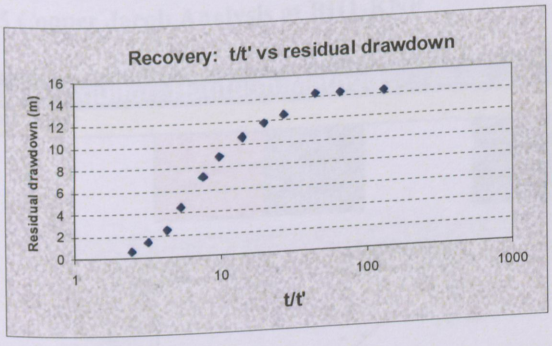

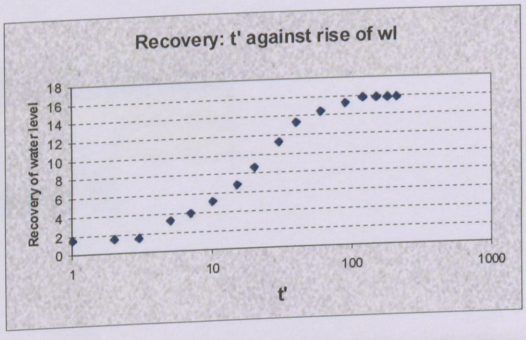

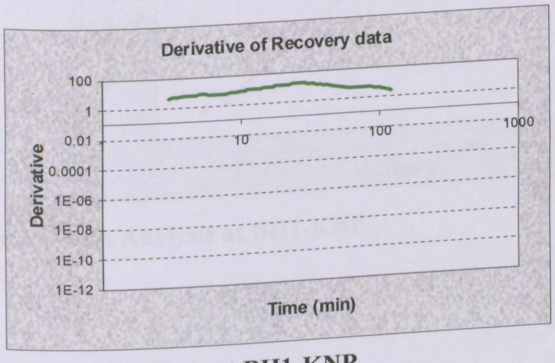

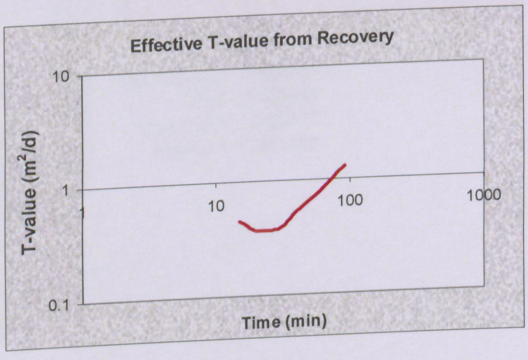

A.4 Diagnostic Plots at BH1-KNP

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Cooper-Jacob method

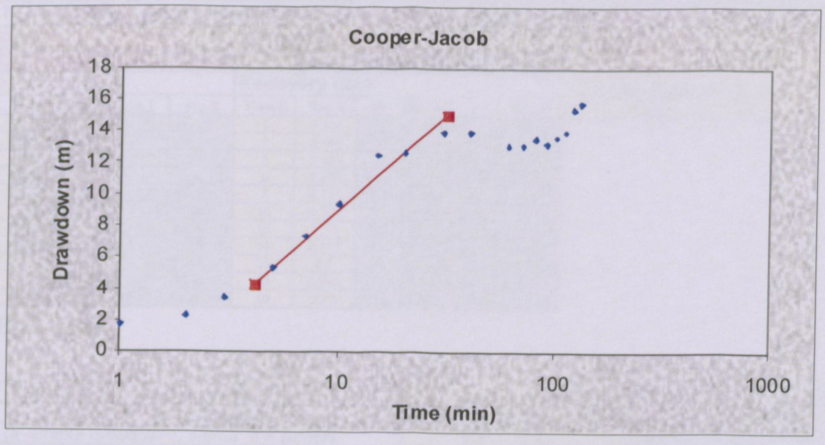
BH1-KNP

$T(m^2/d)$ =	0.4	r_e (m)=	#NUM!
S =	#NUM!	Q (l/s) =	0.31611111

	No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	#NUM!	#NUM!	#NUM!	#NUM!

including influence of bh's

Avg. Q_sust = #NUM! std. dev = #NUM!

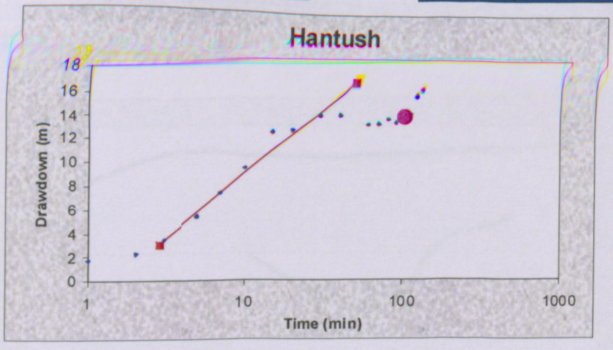


A.5 Cooper Jacob Analysis at BH1-KNP

Leaky Aquifer: Hantush Method

BH1-KNP

$T(m^2/d)$ =	0.3	r_e (m)=	#NUM!
S =	#NUM!	Q (l/s) =	0.31611111
L (m) =	#NUM!	C (d) =	#NUM!



Move purple dot to steady state drawdown

sp =	6.85
tp =	6.4
e(r/L)*K0(r/L)=	1.468887
r/L =	0.423471
exp(-r/L) =	0.65477
K0(r/L) =	0.961783

A.6 Hantush Analysis at BH1-KNP

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B. BH2-KNP – Shingwedzi Bridge North

Country:	South Africa		Geology:	Basalt (alluvial Material as overburden)
Region:	KNP		Depth of BH:	23
Owner:	CSIR		Water strikes:	
X-coord:	31.42		Date of Test:	3-Nov-04
Y-coord:	23.09		Contractor:	Department of Water Affairs

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:	BH2-KNP					Other info:
Distance from Rest WL to main water strike (m) =		s_{max} =	0.688	Recom. AD =	0.7	
Q (l/s)=	0.1487	Recovery data				T (m^2/d) : Logan eq.
						22.8

t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res_s	t/t'	Wl rise	s'	Rec_T
1.00	0.233					1	0.489	79	0.199		
3.00	0.581					2	0.445	40	0.243	0.27	
6.00	0.56	0.09	-2.34			3	0.353	27	0.335	0.52	
11.00	0.55	0.04	-0.42	406.50	0.00E+00	5	0.237	16.6	0.451	0.54	5.0
18.00	0.561	0.04	1.09	29.95	0.00E+00	7	0.155	12.14	0.533	0.36	8.6
28.00	0.586	0.12	1.60	17.45	0.00E+00	10	0.127	8.8	0.561	0.10	23.2
43.00	0.621	0.16	0.86	14.49	0.00E+00	15	0.12	6.2	0.568	0.03	40.3
48.00	0.622	0.19	#NUM!	12.58	0.00E+00	20	0.119	4.9	0.569	0.07	43.8
58.00	0.65	#####	#NUM!	10.11	0.00E+00	30	0.1	3.6	0.588	0.08	32.4
68.00	0.651	#####	#NUM!	10.11	0.00E+00	40	0.095	2.95	0.593	0.07	33.5
78.00	0.688	#####	#NUM!	10.11	0.00E+00	60	0.08	2.3	0.608	0.06	#DIV/0!

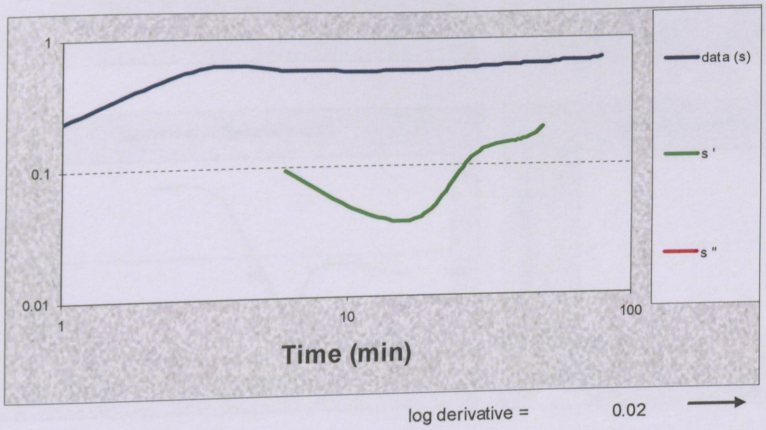
B.1 Data at BH2-KNP

Effective borehole radius (r_e) = (enter)	#NUM!	#NUM!	← Est. r_e ; From r(e) sheet
Q (l/s) from pumping test =	0.148666667	0.00E+00	← S-late ; Change r_e
s_a (available drawdown), sigma_s = (enter)	0.4		← Sigma_s from risk
Annual effective recharge (mm) =		0.43	s_available working drawdown(m)
t(end) and s(end) of pumping test =	78	0.688	End time and drawdown of test
Average maximum derivative = (enter)	0.0	0.0	Estimate of average of max deriv
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv
Derivative at radial flow period = (enter)	#NUM!	#NUM!	Read from derivative graph
	T-early[m^2/d] =	#NUM!	Aqui. thick (m) 20
T and S estimates from derivatives	T-late [m^2/d] =	#DIV/0!	Est. S-late = 1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	1.10E-03	S-estimate could be wrong

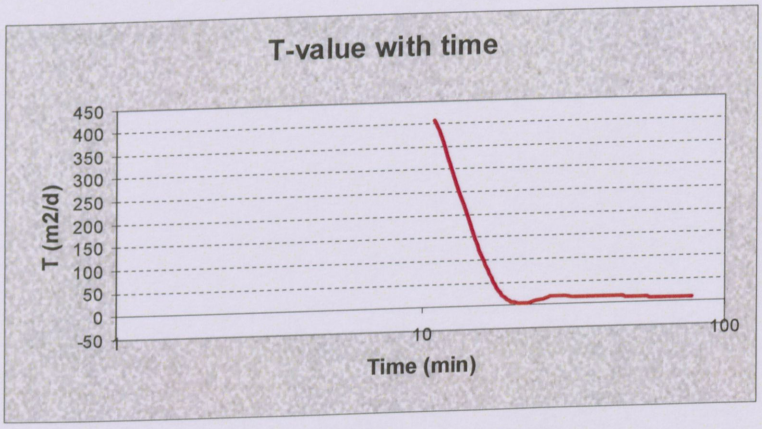
B.2 Basic FC Solution at BH2-KNP

DERIVATIVE PLOTS AND T- AND S - VALUES

BH2-KNP



log derivative = 0.02



B.3 Transmissivity and Storativity Derivative Plots at BH2-KNP

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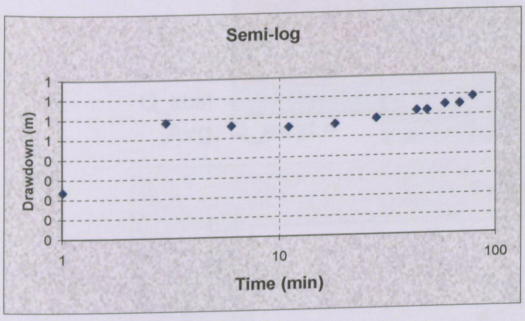
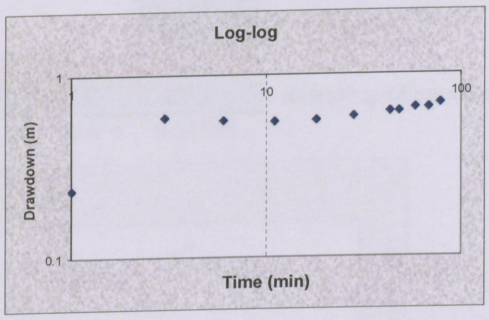
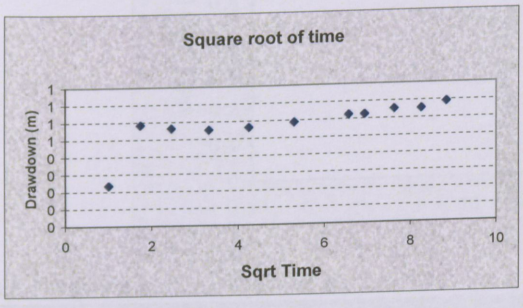
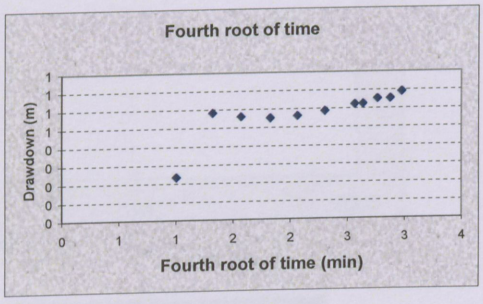
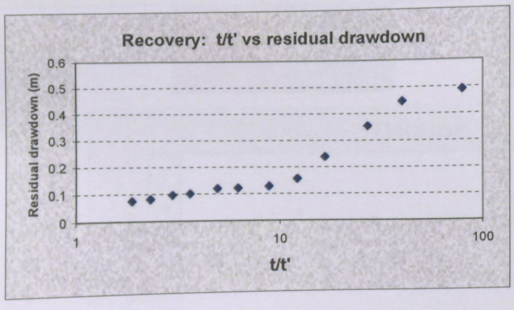
BH2-KNP

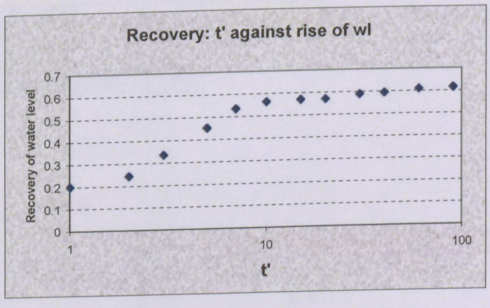


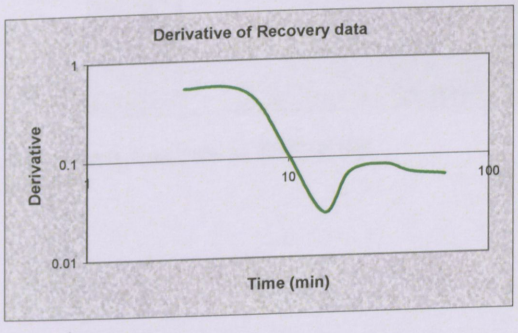


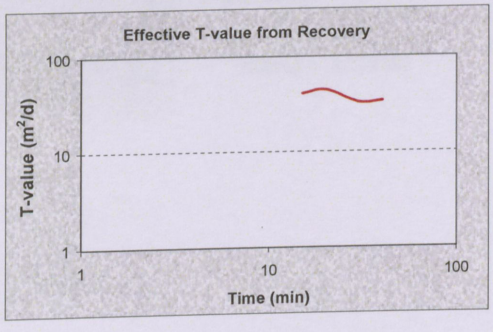












BH.4 Diagnostic Plots at BH2-KNP

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Cooper-Jacob method

BH2-KNP

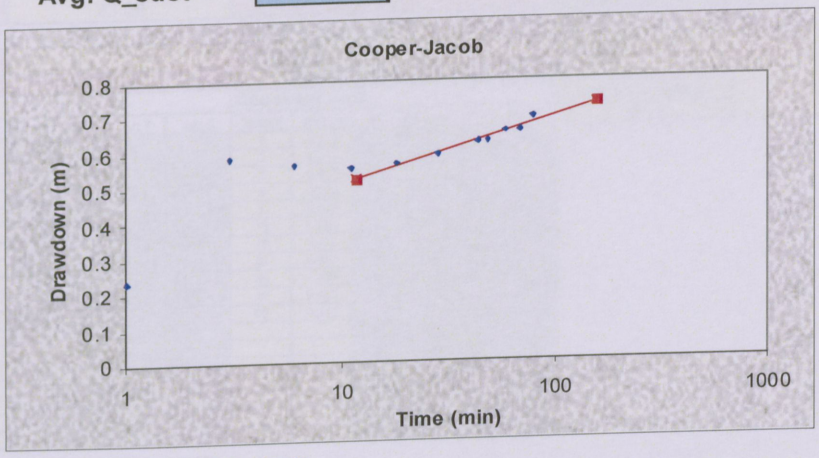
$T(m^2/d)$ =	12.7
S =	#NUM!

r_e (m)=	#NUM! →
Q (l/s) =	0.14866667

	No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	#NUM!	#NUM!	#NUM!	#NUM!

including influence of bh's

Avg. Q_sust = #NUM! std. dev = #NUM!



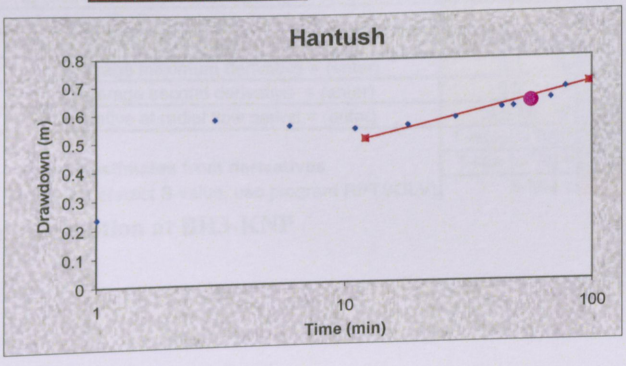
B.5 Cooper Jacob Analysis at BH2-KNP

Leaky Aquifer: Hantush Method

BH2-KNP

$T(m^2/d)$ =	10.7
S =	#NUM!
L (m) =	#NUM!

r_e (m)=	#NUM! →
Q (l/s) =	0.14866667
C (d) =	#NUM!



Move purple dot to steady state drawdown

sp =	0.32
tp =	1.5
e(r/L)*K0(r/L)=	3.4615
r/L =	0.037832
exp(-r/L) =	0.962874
K0(r/L) =	3.332989

B.6 Hantush Analysis at BH2-KNP

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C. BH3-KNP – Shingwedzi Bridge South

Country:	South Africa	Geology:	Alluvium
Region:	KNP	Depth of BH:	20
Owner:	CSIR	Water strikes:	
X-coord:	31.41	Date of Test:	04 Nivember 2004
Y-coord:	23.09	Contractor:	Department of Water Affairs

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Other info:

Borehole:	BH3-KNP											
Distance from Rest WL to main water strike (m) =					s_{max}=	0.086	Recom. AD =	0.1	T (m^2/d) : Logan eq.			
Q (l/s)=	0.5				Recovery data				612.8			
t (min)	s (m)	avg s'	avg s"	avg T	avg S	Time t'	Res_s	t/t'	WI rise	s'	Rec_T	
1.00	0.041					1	0.018	61	0.068			
2.00	0.043					2	0.018	31	0.068	0.00		
3.00	0.051	0.05	-1.51			3	0.018	21	0.068	-0.01		
5.00	0.06	0.02	#NUM!	273.91	0.00E+00	5	0.022	13	0.064	-0.01	#NUM!	
7.00	0.061	#####	#NUM!	1117.29	0.00E+00	7	0.023	9.571	0.063	-0.01	#NUM!	
10.00	0.061	#####	#NUM!	-8904.06	0.00E+00	10	0.025	7	0.061	0.01	#NUM!	
15.00	0.058	#####	#NUM!	-419.95	0.00E+00	15	0.02	5	0.066	-0.02	#NUM!	
20.00	0.062	#####	#NUM!	-756.76	0.00E+00	20	0.031	4	0.055	-0.01	#NUM!	
30.00	0.041	#####	#NUM!	260.95	0.00E+00	30	0.025	3	0.061	0.03	#NUM!	
31.00	0.076	0.24	#NUM!	10.92	0.00E+00	40	0.021	2.5	0.065	0.02	#DIV/0!	
32.00	0.075	0.41	2.00	12.81	0.00E+00	60	0.019	2	0.067	######	#DIV/0!	
33.00	0.08	0.23	-20.48	50.04	0.00E+00			#####	#####	######	#DIV/0!	
35.00	0.083	0.07	#NUM!	67.33	0.00E+00			#####	#####	######	#DIV/0!	
37.00	0.086	#####	#NUM!	529.75	0.00E+00			#####	#####	######	#DIV/0!	
40.00	0.084	#####	#NUM!	-325.62	0.00E+00			#####	#####	######	#DIV/0!	
45.00	0.081	#####	#NUM!	-317.61	0.00E+00			#####	#####	######	#DIV/0!	
50.00	0.082	#####	#NUM!	-317.61	0.00E+00			#####	#####	######	#DIV/0!	
60.00	0.082	#####	#NUM!	-317.61	0.00E+00							

C.1 Pumping Data at BH3-KNP

BH3-KNP				
Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	#NUM!	#NUM!	← Est. r_e	From r(e) sheet
Q (l/s) from pumping test =	0.5	0.00E+00	← S-late	← Change r_e
s_a (available drawdown), sigma_s = (enter)	0.1		← Sigma_s from risk	
Annual effective recharge (mm) =		0.09	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	60	0.086	End time and drawdown of test	
Average maximum derivative = (enter)	0.1	0.1	← Estimate of average of max deriv	
Average second derivative = (enter)	0.0	0.0	← Estimate of average second deriv	
Derivative at radial flow period = (enter)	#NUM!	#NUM!	← Read from derivative graph	
	T-early[m^2/d] =	#NUM!	Aqui. thick (m)	20
T and S estimates from derivatives	T-late [m^2/d] =	121.30	Est. S-late =	1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	1.10E-03	S-estimate could be wrong	

C.2 Basic FC Solution at BH3-KNP

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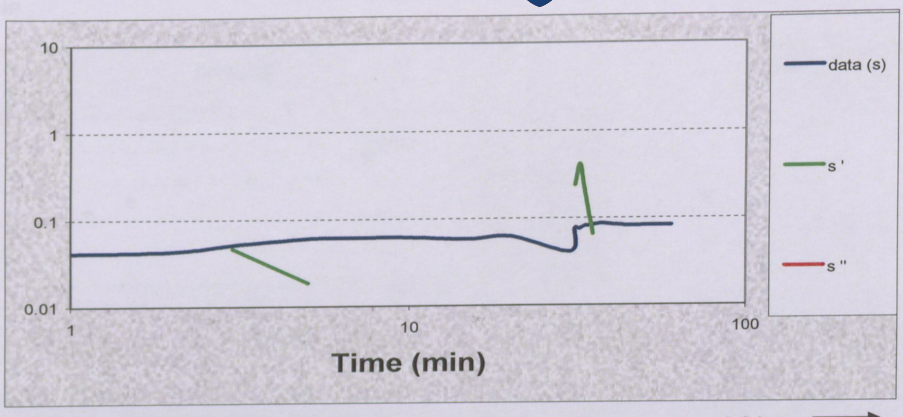
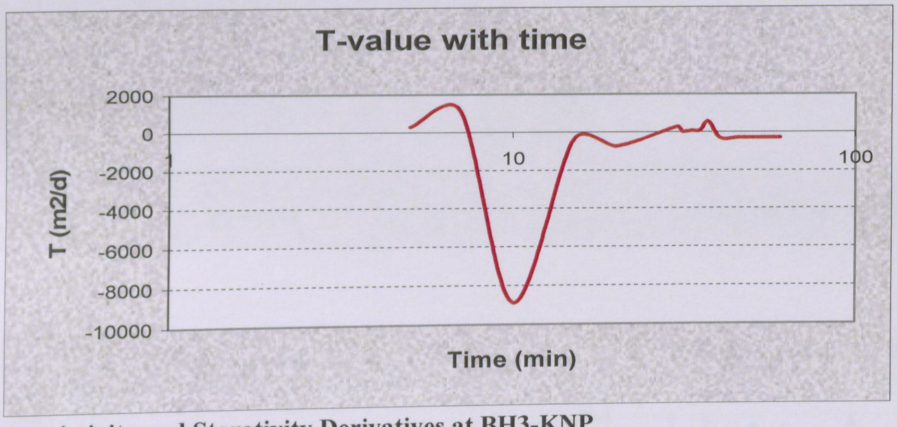


log derivative = 0.24



C.3 Transmissivity and Storativity Derivatives at BH3-KNP

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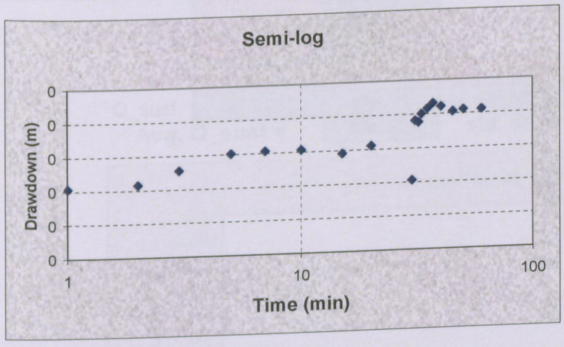

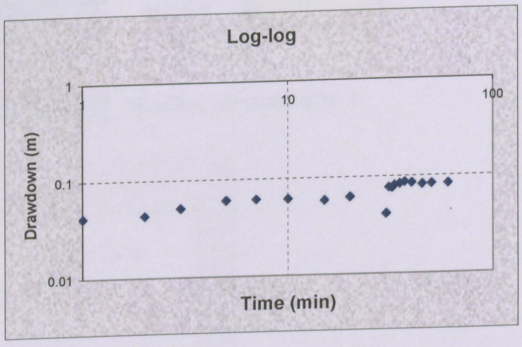

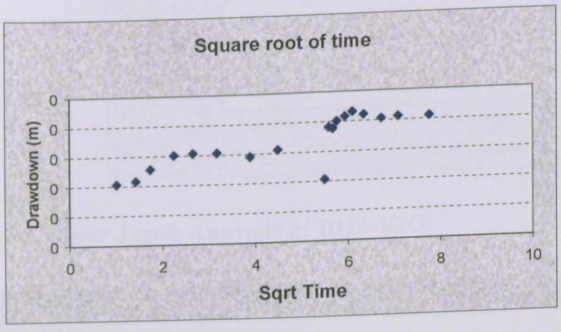

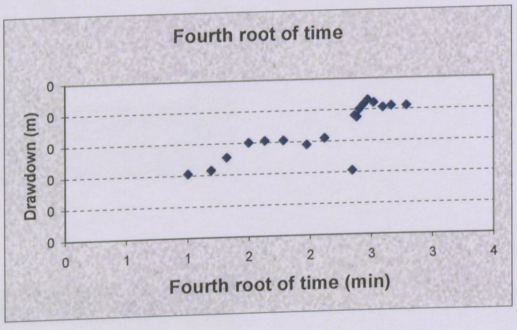

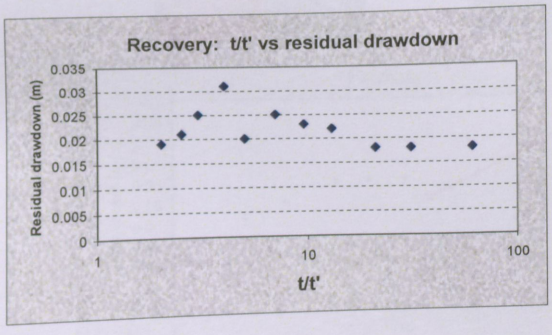

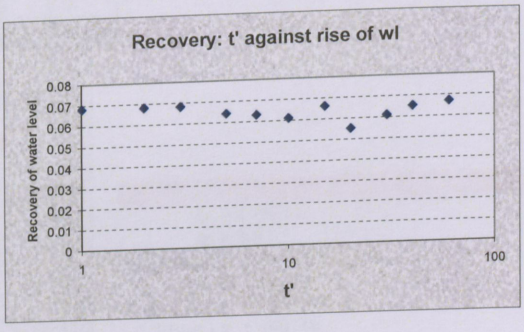

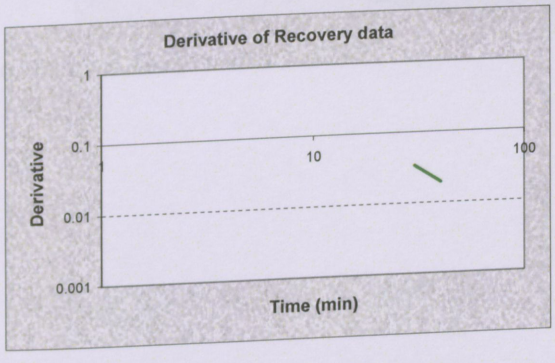

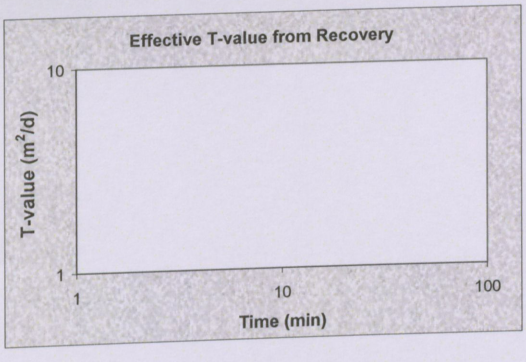

C.4 Diagnastic Plots at BH3-KNP

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Cooper-Jacob method

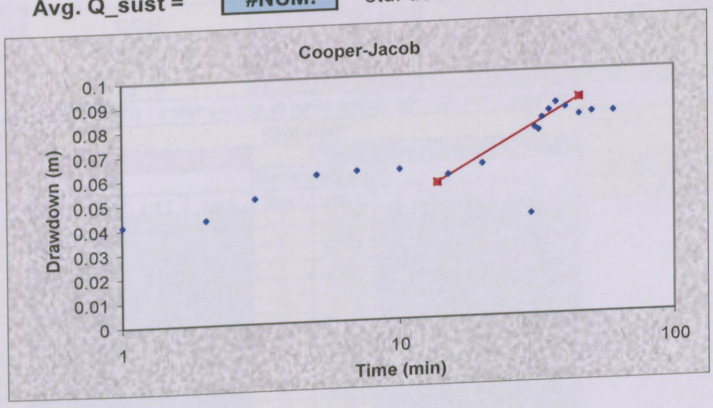
BH3-KNP

$T(m^2/d)$ =	123.9
S =	#NUM!

r_e (m)=	#NUM!
Q (l/s) =	0.5

No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	#NUM!	#NUM!	#NUM!
Avg. Q_sust =	**#NUM!**	std. dev =	#NUM!

including influence of bh's



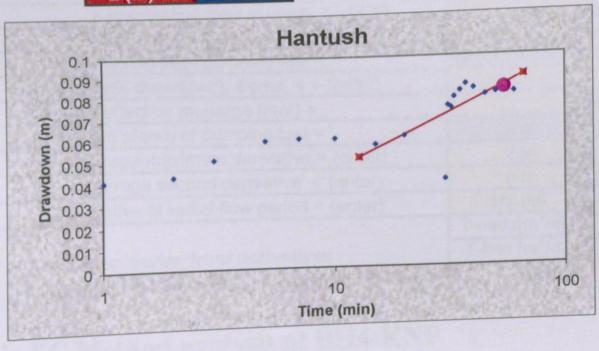
C.5 Cooper Jacob Analysis at BH3-KNP

Leaky Aquifer: Hantush Method

BH3-KNP

$T(m^2/d)$ =	118.0
S =	#NUM!
L (m) =	#NUM!

r_e (m)=	#NUM!
Q (l/s) =	0.5
C (d) =	#NUM!



Move purple dot to steady state drawdown

sp =	0.04
tp =	8.3
e(r/L)*K0(r/L)=	1.817605
r/L =	0.232357
exp(-r/L) =	0.792663
K0(r/L) =	1.440749

C.6 Hantush Analysis at BH3-KNP

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D. BH4-KNP – Granite South

Country:	South Africa	Geology:	Granite
Region:	KNP	Depth of BH:	3[illegible] m
Owner:	CSIR	Water strikes:	N[illegible] water Strikes
X-coord:	31.30	Date of Test:	5-Nov-04
Y-coord:	23.19	Contractor:	D[illegible]partment of Water Affairs

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellov

Borehole: BH4-KNP — Other info:

Distance from Rest WL to main water strike (m) = — s_{max}= 11.07 — Recom. AD = 11.1

Q (l/s)= 0.04 — Recovery data — T (m²/d) : Logan eq. = 0.4

t (min)	s (m)	avg s'	avg s"	avg T	avg S	Time t'	Res_s	t/t'	Wl rise	s'	Rec_T
1.00	0.542					1	10.904	121	0.169		
2.00	0.799					2	10.81	61	0.263	0.36	
3.00	0.992	1.84	0.16			3	10.729	41	0.344	0.54	
5.00	1.521	1.87	0.43	0.35	0.00E+00	5	10.596	25	0.477	0.61	1.2
7.00	1.632	2.49	0.82	0.27	0.00E+00	7	10.505	18.14	0.568	0.45	1.6
10.00	2.056	3.49	0.97	0.18	0.00E+00	10	10.459	13	0.614	0.21	2.5
15.00	2.9	4.99	0.86	0.13	0.00E+00	15	10.436	9	0.637	0.18	2.8
20.00	3.674	6.54	0.72	0.09	0.00E+00	20	10.403	7	0.67	0.30	2.4
30.00	4.974	8.31	0.56	0.08	0.00E+00	30	10.345	5	0.728	0.35	1.8
40.00	6.105	9.79	0.41	0.06	0.00E+00	40	10.297	4	0.776	0.43	1.5
60.00	8.01	10.99	0.07	0.06	0.00E+00	60	10.217	3	0.856	0.54	1.2
70.00	8.982	10.82	-0.44	0.06	0.00E+00	90	10.107	2.333	0.966	0.68	#DIV/0!
80.00	9.424	9.92	-0.64	0.06	0.00E+00	120	10.012	2	1.061	######	#DIV/0!
90.00	9.97	9.20	#NUM!	0.06	0.00E+00			#####	#####	######	#DIV/0!
100.00	10.259	#####	#NUM!	0.06	0.00E+00			#####	#####	######	#DIV/0!
110.00	10.694	#####	#NUM!	0.06	0.00E+00			#####	#####	######	#DIV/0!
120.00	11.073	#####	#NUM!	0.06	0.00E+00			#####	#####	######	#DIV/0!

D.1 Pumping Data at BH4-KNP

FC-METHOD : Estimation of the sustainable yield of a borehole

BH4-KNP

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	#NUM!	#NUM! ← Est. r_e	From r(e) sheet	
Q (l/s) from pumping test =	0.04	0.00E+00 ← S-late	← Change r_e	
s_a (available drawdown), sigma_s = (enter)	11.1	← Sigma_s from risk		
Annual effective recharge (mm) =		11.07	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	120	11.073	End time and drawdown of test	
Average maximum derivative = (enter)	9.9	← 9.9	Estimate of average of max deriv	
Average second derivative = (enter)	0.0	← 0.0	Estimate of average second deriv	
Derivative at radial flow period = (enter)	#NUM!	← #NUM!	Read from derivative graph	
	T-early[m^2/d] =	#NUM!	Aqui. thick (m)	20
T and S estimates from derivatives	T-late [m^2/d] =	0.06	Est. S-late =	1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	1.10E-03	S-estimate could be wrong	

D.2 Basic FC Method analysis at BH4-KNP

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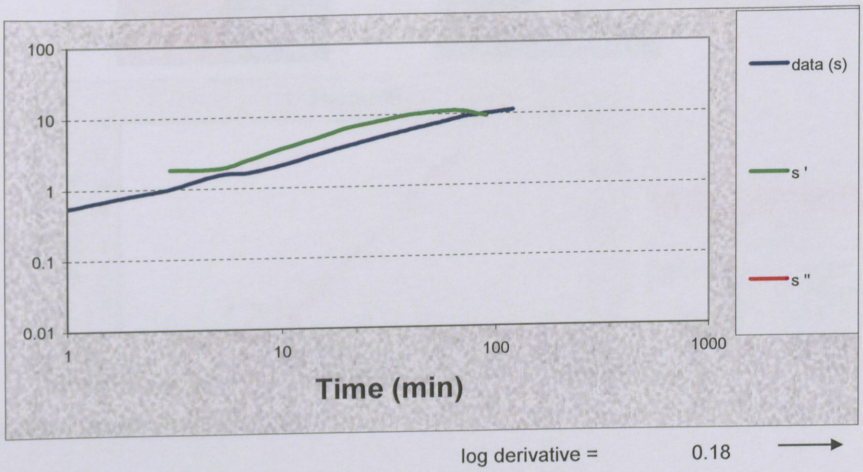
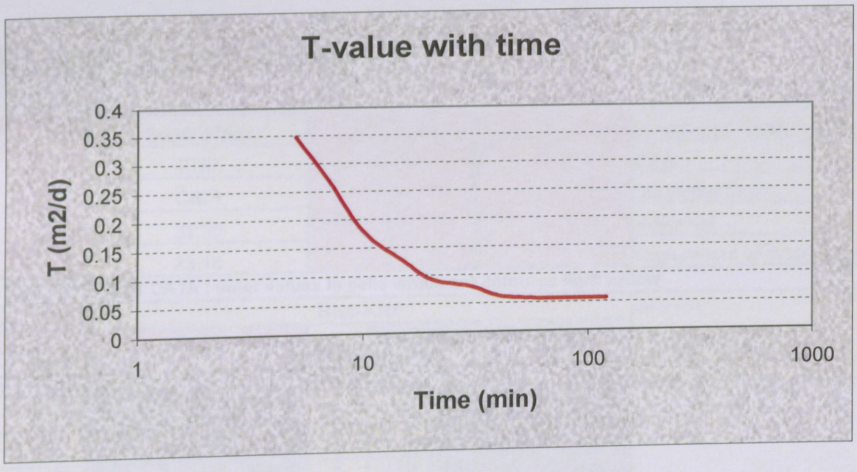


log derivative = 0.18 →



D.3 Derivative Plots for Storativity and Transmissivity at BH4-KNP

Cooper-Jacob method

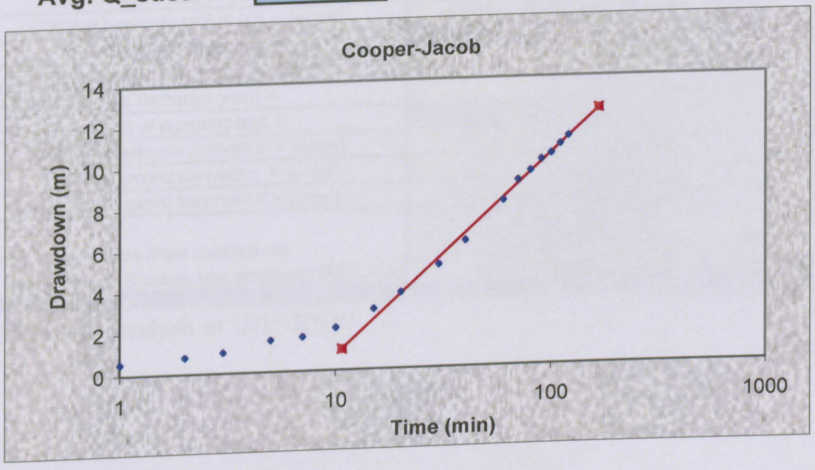
BH4-KNP

T(m^2/d) =	0.1	r_e (m)=	#NUM! →
S =	#NUM!	Q (l/s) =	0.04

	No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	#NUM!	#NUM!	#NUM!	#NUM!

including influence of bh's

Avg. Q_sust = #NUM! std. dev = #NUM!



D.4 Copper Jacob Analysis at BH4-KNP

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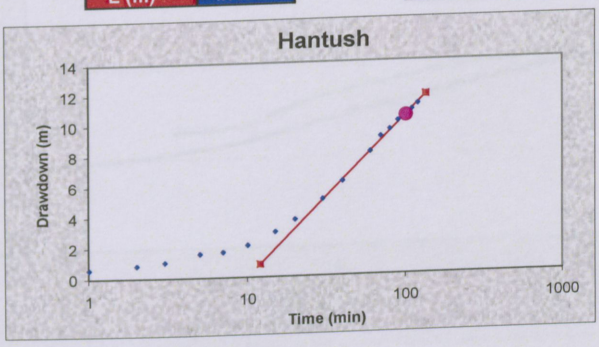
Leaky Aquifer: Hantush Method			
BH4-KNP			
T(m^2/d) =	0.0	r_e (m)=	#NUM!
S =	#NUM!	Q (l/s) =	0.04
L (m) =	#NUM!	C (d) =	#NUM!



Move purple dot to steady state drawdown

sp = 5.16
tp = 31.8
e(r/L)*K0(r/L)= 1.148587
r/L = 0.846883
exp(-r/L) = 0.428749
K0(r/L) = 0.492456

D.5 Hantush Analysis at BH4-KNP

E. BH5-KNP – Granite North

Country:	South Africa	Geology:	Weathered Gneiss / Granite
Region:	KNP	Depth of BH:	22 m
Owner:	CSIR	Water strikes:	No Water Strike
X-coord:	31.30	Date of Test:	4-Nov-04
Y-coord:	23.18	Contractor:	Department of Water Affairs

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Other info:

Borehole:	BH5-KNP											
Distance from Rest WL to main water strike (m) =					s_{max}=	11.82	Recom. AD =	11.8	T (m^2/d) : Logan eq.			
Q (l/s)=	0.06				Recovery data						0.5	
t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res_s	t/t'	WI rise	s'	Rec_T	
1.00	0.842					1	11.817	91	0			
2.00	0.977					2	11.882	46	-0.065	-0.14		
3.00	1.138	1.96	0.51			3	11.88	31	-0.063	-0.19		
5.00	1.485	2.23	0.78	0.44	0.00E+00	5	11.956	19	-0.139	0.05	#NUM!	
7.00	1.962	3.51	1.07	0.25	0.00E+00	7	11.849	13.86	-0.032	0.23	9.1	
10.00	2.678	5.12	0.92	0.18	0.00E+00	10	11.886	10	-0.069	0.10	5.2	
15.00	3.772	6.78	0.67	0.14	0.00E+00	15	11.818	7	-1E-03	0.27	5.8	
20.00	4.721	8.34	0.55	0.11	0.00E+00	20	11.808	5.5	0.009	0.16	4.4	
30.00	6.377	9.98	0.46	0.10	0.00E+00	30	11.77	4	0.047	0.23	4.4	
40.00	7.765	11.21	0.35	0.08	0.00E+00	40	11.738	3.25	0.079	0.27	3.5	
50.00	8.91	12.14	0.19	0.08	0.00E+00	50	11.711	2.8	0.106	0.33	2.9	
60.00	9.916	12.28	#NUM!	0.07	0.00E+00	60	11.68	2.5	0.137	0.42	2.3	
70.00	10.762	#####	#NUM!	0.07	0.00E+00	70	11.649	2.286	0.168	0.50	2.3	
80.00	11.493	#####	#NUM!	0.07	0.00E+00	80	11.617	2.125	0.2	0.32	#DIV/0!	
90.00	11.817	#####	#NUM!	0.07	0.00E+00	90	11.615	2	0.202	######	#DIV/0!	

E.1 Pumping Data at BH5-KNP

FC-METHOD : Estimation of the sustainable yield of a borehole			
BH5-KNP			
Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes
Effective borehole radius (r_e) = (enter)	#NUM!	#NUM! ← Est. r_e	From r(e) sheet
Q (l/s) from pumping test =	0.06	0.00E+00 ← S-late	Change r_e
s_a (available drawdown), sigma_s = (enter)	11.8	← Sigma_s from risk	
Annual effective recharge (mm) =		11.82	s_available working drawdown(m)
t(end) and s(end) of pumping test =	90	11.817	End time and drawdown of test
Average maximum derivative = (enter)	0.0	0.0 ←	Estimate of average of max deriv
Average second derivative = (enter)	0.0	0.0 ←	Estimate of average second deriv
Derivative at radial flow period = (enter)	#NUM!	#NUM! ←	Read from derivative graph
	T-early[m^2/d] =	#NUM!	Aqui. thick (m) 20
T and S estimates from derivatives	T-late [m^2/d] =	#DIV/0!	Est. S-late = 1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	1.10E-03	S-estimate could be wrong

E.2 Basic FC Method analysis at BH5-KNP

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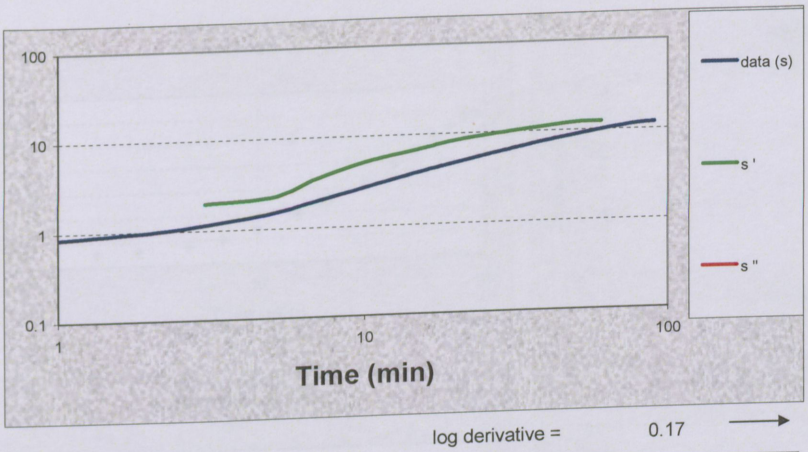
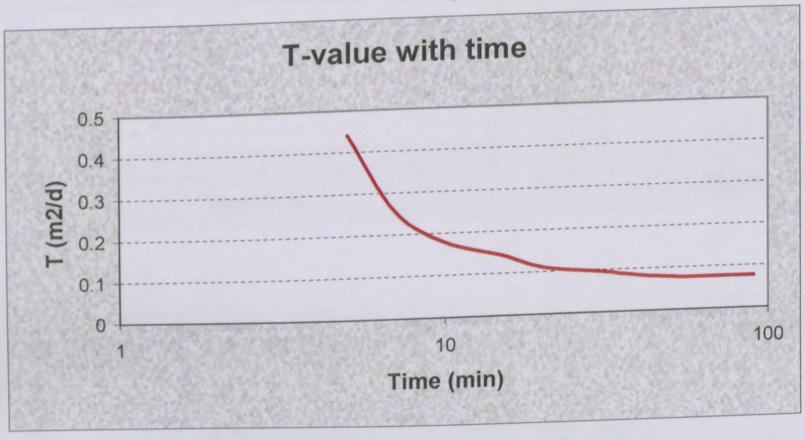


log derivative = 0.17



E.3Derivative Plots for Storativity and Transmissivity at BH5-KNP

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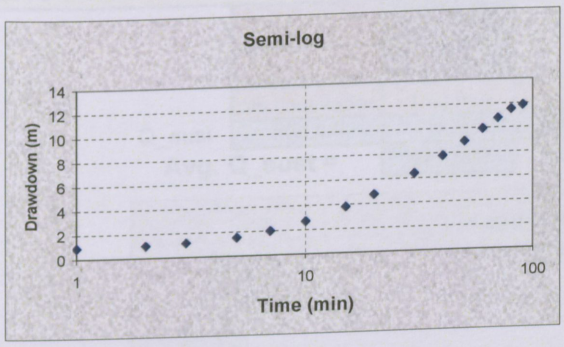
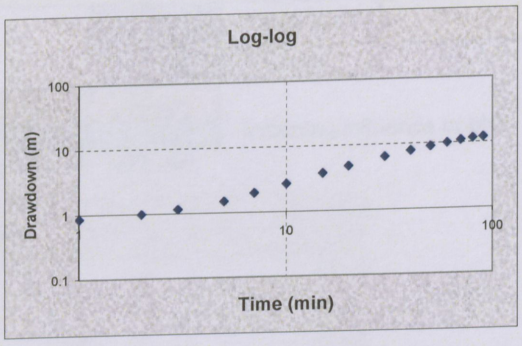
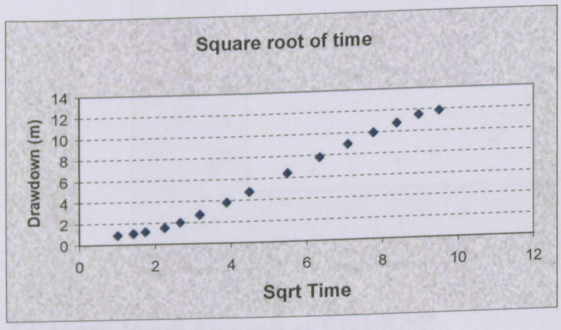
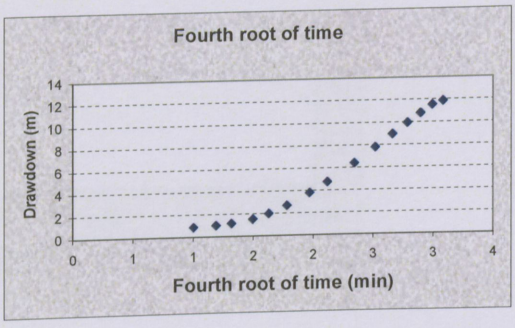
DIAGNOSTIC PLOTS

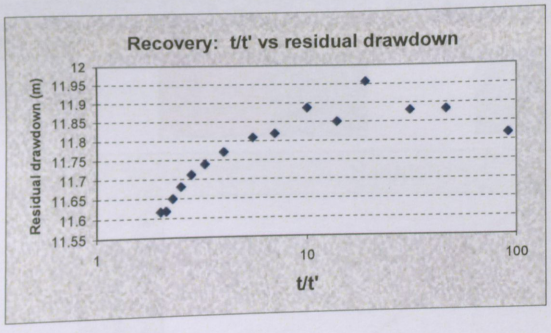
BH5-KNP

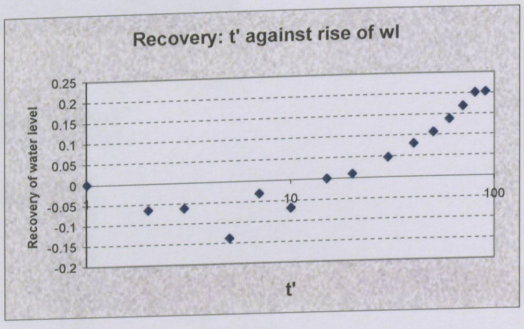


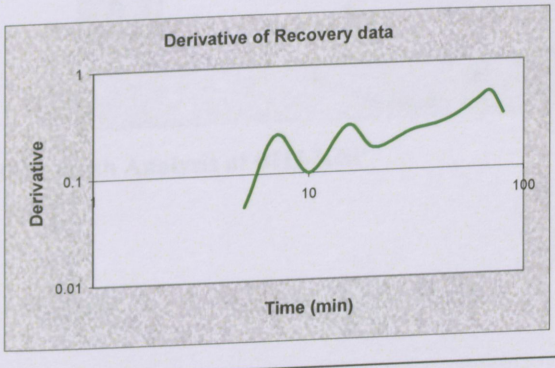












E.4Diagoastic Plots at BH5-KNP

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Cooper-Jacob method

BH5-KNP

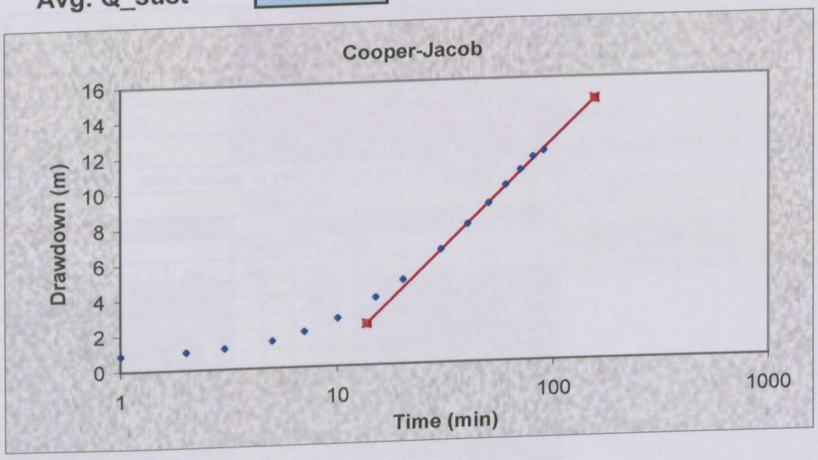
$T(m^2/d)$ =	0.1
S =	#NUM!

r_e (m)=	#NUM! →
Q (l/s) =	0.06

	No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	#NUM!	#NUM!	#NUM!	#NUM!

including influence of bh's

Avg. Q_sust = #NUM! std. dev = #NUM!



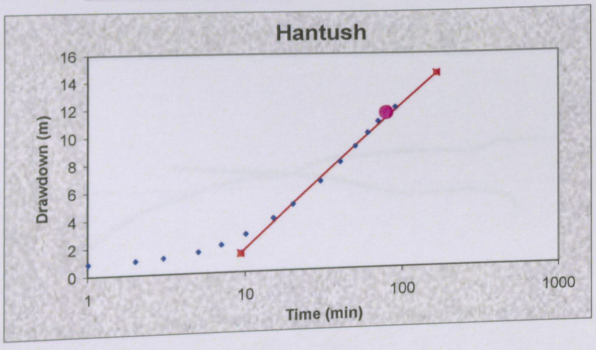
E.5 Cooper Jacob Analysis at BH5-KNP

Leaky Aquifer: Hantush Method

BH5-KNP

$T(m^2/d)$ =	0.0
S =	#NUM!
L (m) =	#NUM!

r_e (m)=	#NUM! →
Q (l/s) =	0.06
C (d) =	#NUM!



Move purple dot to steady state drawdown

sp =	5.70
tp =	24.5
e(r/L)*K0(r/L)=	1.250954
r/L =	0.665809
exp(-r/L) =	0.513858
K0(r/L) =	0.642812

E.6 Hantush Analysis at BH5-KNP

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F. BH6-KNP – Shingwedzi Tributary

Country:	RSA	Geology:	Alluvium
Region:	KNP	Depth of BH:	18
Owner:	CSIR	Water strikes:	
X-coord:	31.29	Date of Test:	4-Nov-04
Y-coord:	23.18	Contractor:	Department of Water Affairs

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Other info:

Borehole: BH6-KNP

Distance from Rest WL to main water strike (m) =

s_{max}= 0.21 Recom. AD = 0.2

T (m^2/d) : Logan eq. 177.4

Q (l/s)= 0.3533

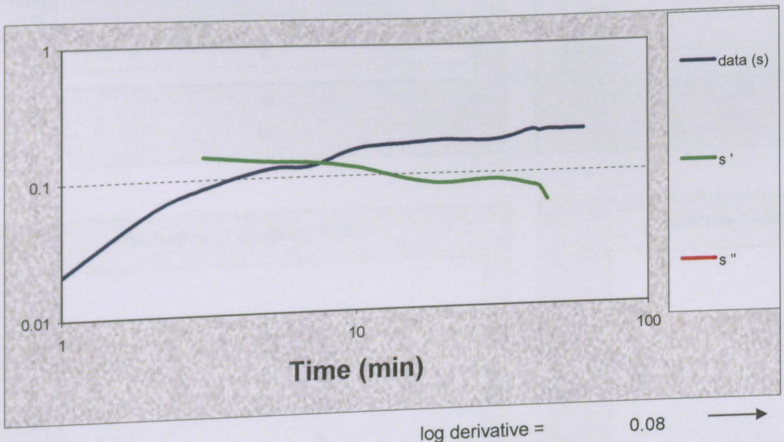
Recovery data

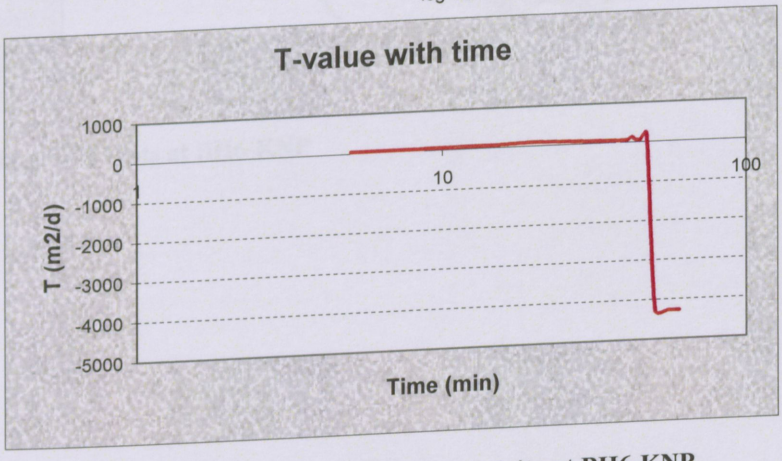
t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res_s	t/t'	WI rise	s'	Rec_T
1.00	0.021					1	0.044	61	0.166		
2.00	0.059					2	0.038	31	0.172	0.02	
3.00	0.085	0.15	-0.18			3	0.034	21	0.176	0.06	
5.00	0.116	0.13	-0.15	42.60	0.00E+00	5	0.014	13	0.196	0.07	#NUM!
7.00	0.12	0.13	-0.19	43.39	0.00E+00	7	0.009	9.571	0.201	0.00	#NUM!
10.00	0.159	0.12	-0.46	45.36	0.00E+00	10	0.014	7	0.196	-0.02	#NUM!
15.00	0.171	0.09	-0.42	58.21	0.00E+00	15	0.017	5	0.193	0.01	#NUM!
20.00	0.179	0.08	-0.02	86.63	0.00E+00	20	0.012	4	0.198	0.00	#NUM!
30.00	0.177	0.09	-0.12	58.94	0.00E+00	30	0.016	3	0.194	-0.06	#NUM!
40.00	0.21	0.08	-2.08	50.00	0.00E+00	40	0.03	2.5	0.18	0.01	#DIV/0!
42.00	0.204	0.08	0.71	121.03	0.00E+00	60	0.016	2	0.194	######	#DIV/0!
43.00	0.205	0.07	-3.20	65.23	0.00E+00			#####	#####	######	#DIV/0!
45.00	0.209	0.06	#NUM!	59.43	0.00E+00			#####	#####	######	#DIV/0!
47.00	0.21	#####	#NUM!	208.40	0.00E+00			#####	#####	######	#DIV/0!
50.00	0.208	#####	#NUM!	-4284.72	0.00E+00			#####	#####	######	#DIV/0!
55.00	0.21	#####	#NUM!	-4284.72	0.00E+00			#####	#####	######	#DIV/0!
60.00	0.209	#####	#NUM!	-4284.72	0.00E+00						

F.1 Pumping Data at BH6-KNP

DERIVATIVE PLOTS AND T- AND S - VALUES

BH6-KNP





F.2 Derivative Plots for Storativity and Transmissivity at BH6-KNP

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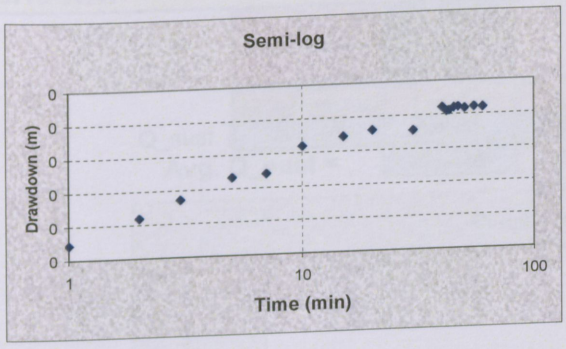

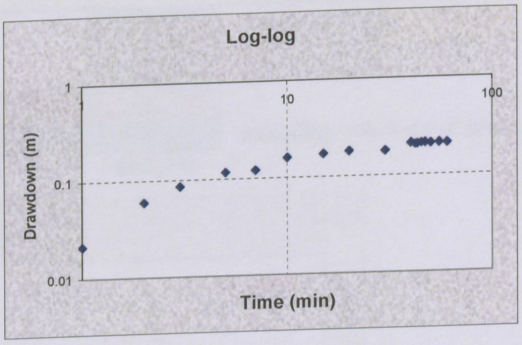

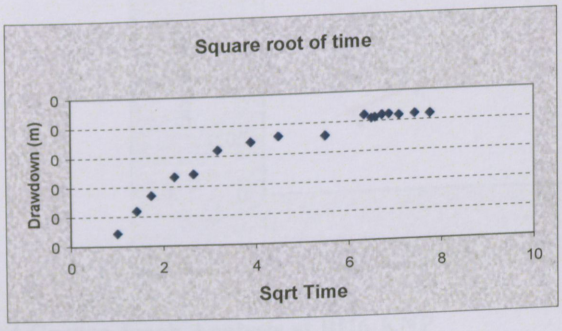

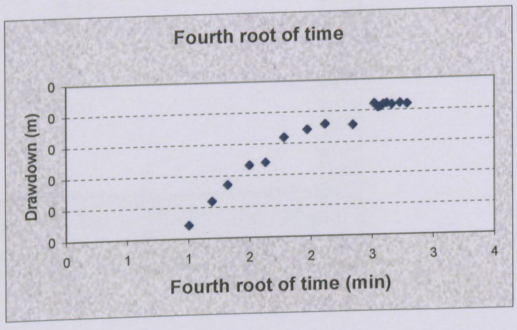

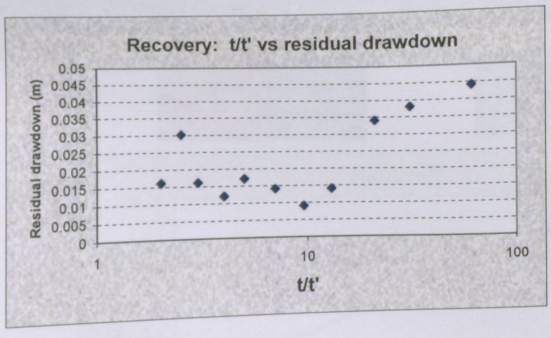

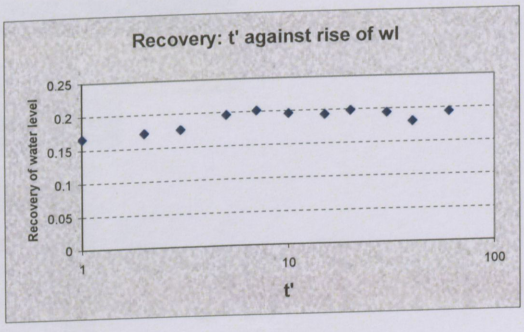

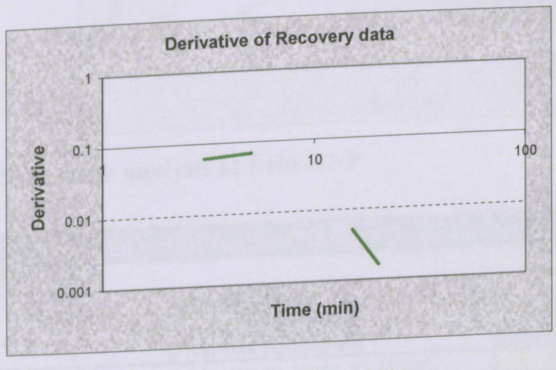

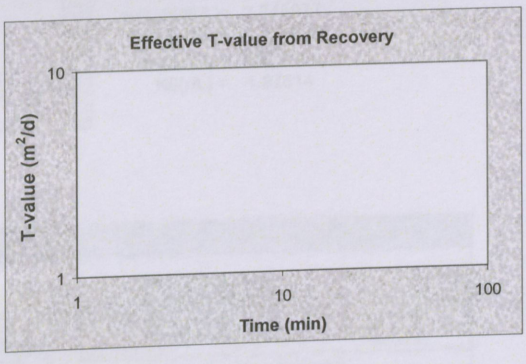

F.3 Diagnostic Plots at BH6-KNP

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Cooper-Jacob method

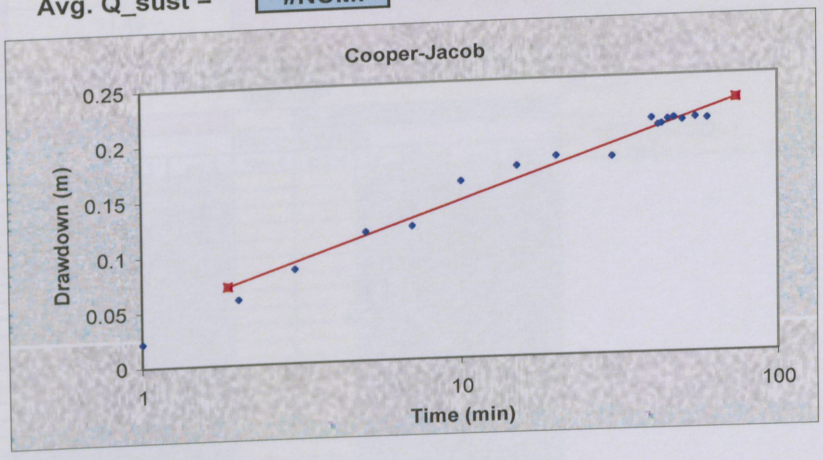
BH6-KNP

$T(m^2/d)$ =	57.4
S =	#NUM!

r_e (m)=	#NUM!
Q (l/s) =	0.35333333

No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	#NUM!	#NUM!	#NUM!
Avg. Q_sust =	#NUM!	std. dev =	#NUM!

including influence of bh's



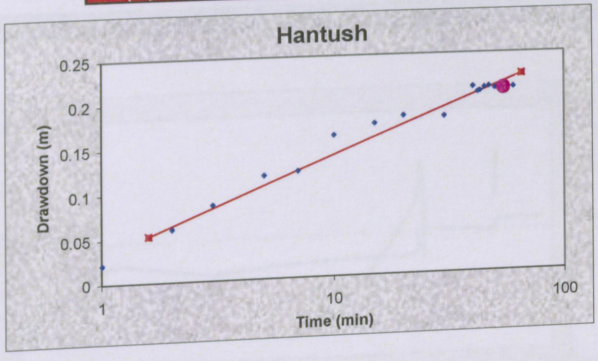
F.4 Cooper Jacob Analysis at BH6-KNP

Leaky Aquifer: Hantush Method

BH6-KNP

$T(m^2/d)$ =	46.2
S =	#NUM!
L (m) =	#NUM!

r_e (m)=	#NUM!
Q (l/s) =	0.35333333
C (d) =	#NUM!



Move purple dot to steady state drawdown

sp = 0.10
tp = 4.9
e(r/L)*K0(r/L)= 2.245977
r/L = 0.127995
exp(-r/L) = 0.879858
K0(r/L) = 1.97614

F.5 Hantush analysis at BH6-KNP

FC-METHOD : Estimation of the sustainable yield of a borehole

BH6-KNP

Extrapolation time in years = (enter)		0	Extrapol.time in minutes
Effective borehole radius (r_e) = (enter)	#NUM!	#NUM!	Est. r_e / From r(e) sheet
Q (l/s) from pumping test =	0.353333333	0.00E+00	S-late / Change r_e
s_a (available drawdown), sigma_s = (enter)	0.2		Sigma_s from risk
Annual effective recharge (mm) =		0.21	s_available working drawdown(m)
t(end) and s(end) of pumping test =	60	0.21	End time and drawdown of test
Average maximum derivative = (enter)	0.1	0.1	Estimate of average of max deriv
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv
Derivative at radial flow period = (enter)	#NUM!	#NUM!	Read from derivative graph
	T-early[m^2/d] =	#NUM!	Aqui. thick (m) 20
T and S estimates from derivatives	T-late [m^2/d] =	93.14	Est. S-late = 1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	1.10E-03	S-estimate could be wrong

F.6 Basic FC Analysis at BH6-KNP

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G. BH7-KNP –Shingwedzi Bridge West

Country:	South Africa	Geology:	Alluvial Aquifer
Region:	KNP	Depth of BH:	22 m
Owner:	CSIR	Water strikes:	14 m
X-coord:	31.42	Date of Test:	6-Nov-04
Y-coord:	23.09	Contractor:	DWAF (Pretoria)

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Other info:

Borehole: BH7-KNP

s_{max}= 0.124 Recom. AD = 0.1

Distance from Rest WL to main water strike (m) =

T (m^2/d) : Logan eq. 437.8

Q (l/s)= 0.515

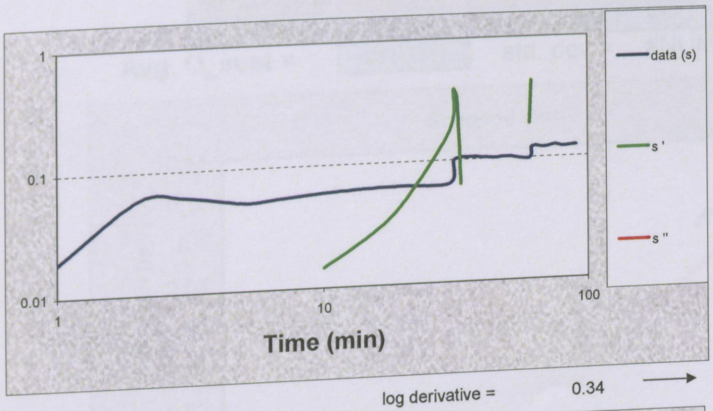
Recovery data

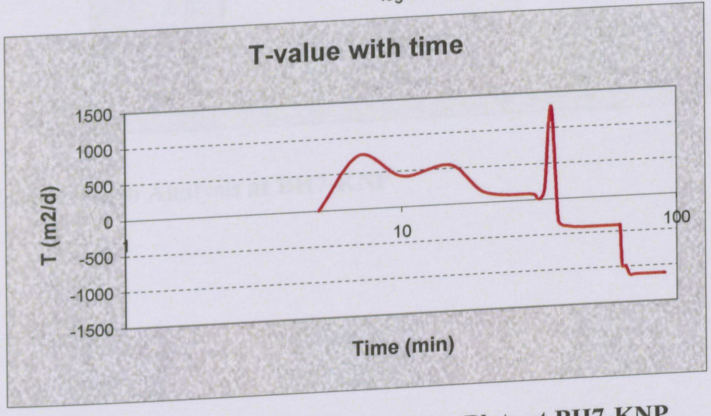
t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res_s	t/t'	Wl rise	s'	Rec_T
1.00	0.019							#####	#####		
2.00	0.059							#####	#####	#####	
3.00	0.06	#####	#NUM!					#####	#####	#####	#DIV/0!
5.00	0.052	#####	#NUM!	0.00	0.00E+00			#####	#####	#####	#DIV/0!
7.00	0.055	#####	#NUM!	746.13	0.00E+00			#####	#####	#####	#DIV/0!
10.00	0.059	0.01	#NUM!	425.21	0.00E+00			#####	#####	#####	#DIV/0!
15.00	0.062	0.03	1.56	545.74	0.00E+00			#####	#####	#####	#DIV/0!
20.00	0.063	0.05	2.77	134.93	0.00E+00			#####	#####	#####	#DIV/0!
30.00	0.064	0.17	11.26	73.97	0.00E+00			#####	#####	#####	#DIV/0!
31.00	0.098	0.38	-3.05	10.26	0.00E+00			#####	#####	#####	#DIV/0!
32.00	0.102	0.32	-20.95	13.14	0.00E+00			#####	#####	#####	#DIV/0!
33.00	0.104	0.06	#NUM!	127.55	0.00E+00			#####	#####	#####	#DIV/0!
35.00	0.104	#####	#NUM!	1295.87	0.00E+00			#####	#####	#####	#DIV/0!
37.00	0.104	#####	#NUM!	-318.00	0.00E+00			#####	#####	#####	#DIV/0!
40.00	0.102	#####	#NUM!	-394.93	0.00E+00			#####	#####	#####	#DIV/0!
45.00	0.101	#####	#NUM!	-416.46	0.00E+00			#####	#####	#####	#DIV/0!
50.00	0.102	#####	#NUM!	-416.46	0.00E+00			#####	#####	#####	#DIV/0!
60.00	0.098	0.19	#NUM!	-416.46	0.00E+00			#####	#####	#####	#DIV/0!
61.00	0.12	0.43	#NUM!	-416.46	0.00E+00			#####	#####	#####	#DIV/0!
62.00	0.122	#####	#NUM!	-416.46	0.00E+00			#####	#####	#####	#DIV/0!
63.00	0.123	#####	#NUM!	-995.45	0.00E+00			#####	#####	#####	#DIV/0!
65.00	0.122	#####	#NUM!	-995.45	0.00E+00			#####	#####	#####	#DIV/0!
67.00	0.12	#####	#NUM!	-1115.49	0.00E+00			#####	#####	#####	#DIV/0!
70.00	0.121	#####	#NUM!	-1115.49	0.00E+00			#####	#####	#####	#DIV/0!
75.00	0.124	#####	#NUM!	-1115.49	0.00E+00			#####	#####	#####	#DIV/0!
80.00	0.121	#####	#NUM!	-1115.49	0.00E+00			#####	#####	#####	#DIV/0!
90.00	0.123	#####	#NUM!	-1115.49	0.00E+00			#####	#####	#####	#DIV/0!

G.1Pumping Data at Bh6-KNP

DERIVATIVE PLOTS AND T- AND S - VALUES

BH7-KNP





G.2 Derivative Storativity and Transmissivity Plots at BH7-KNP

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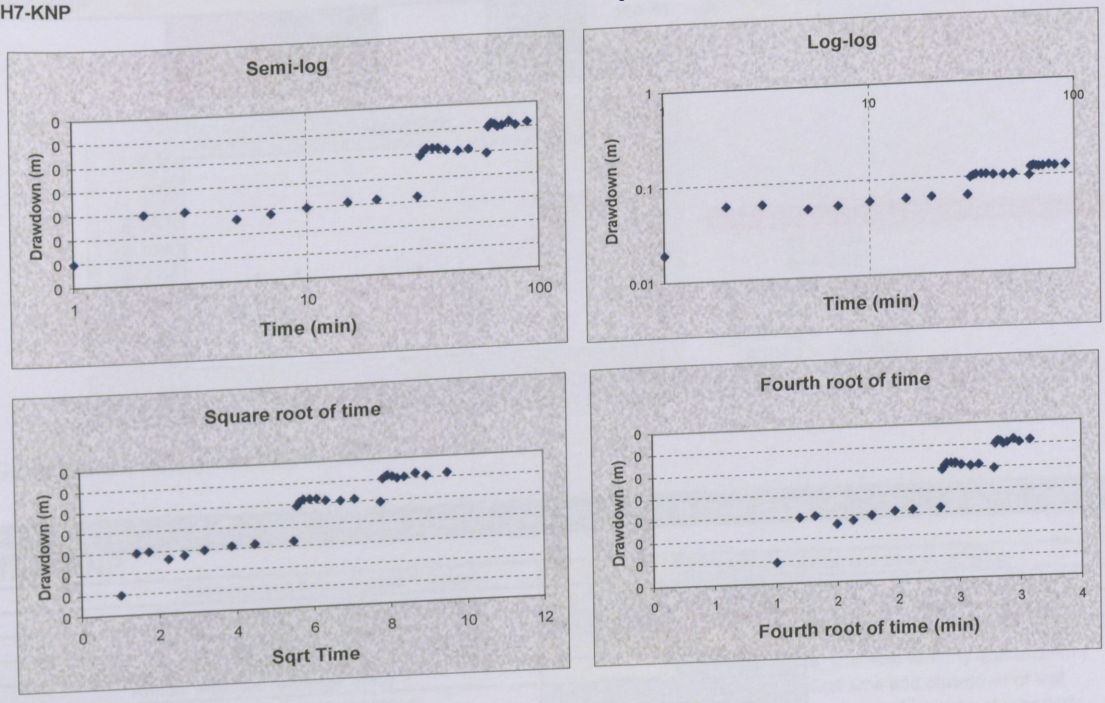
DIAGNOSTIC PLOTS

BH7-KNP



G.3 Diagnostic Plots at BH7-KNP

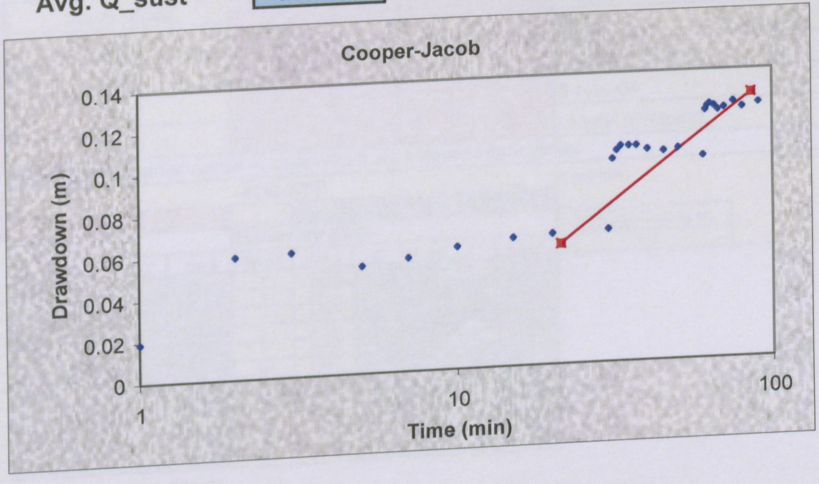
Cooper-Jacob method

BH7-KNP

$T(m^2/d)$ =	70.3	r_e (m)=	#NUM!
S =	#NUM!	Q (l/s) =	0.515

No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	#NUM!	#NUM!	#NUM!
Avg. Q_sust =	#NUM!	std. dev =	#NUM!

including influence of bh's



G.4Cooper Jacob Analysis at BH7-KNP

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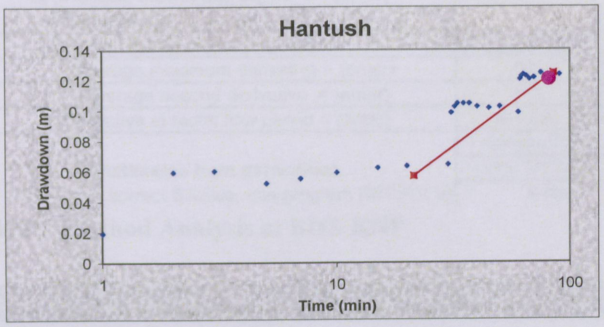
Leaky Aquifer: Hantush Method			
BH7-KNP			
T(m^2/d) =	35.7	r_e (m)=	#NUM!
S =	#NUM!	Q (l/s) =	0.515
L (m) =	#NUM!	C (d) =	#NUM!



Move purple dot to steady state drawdown	
sp =	0.06
tp =	23.0
e(r/L)*K0(r/L)=	1.224622
r/L =	0.706941
exp(-r/L) =	0.49315
K0(r/L) =	0.603923

G.5 Hantush Analysis at BH7-KNP

FC-METHOD : Estimation of the sustainable yield of a borehole				
BH7-KNP				
Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	#NUM!	#NUM!	Est. r_e	From r(e) sheet
Q (l/s) from pumping test =	0.515	0.00E+00	S-late	Change r_e
s_a (available drawdown), sigma_s = (enter)	0.1		Sigma_s from risk	
Annual effective recharge (mm) =		0.12	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	90	0.124	End time and drawdown of test	
Average maximum derivative = (enter)	0.4	0.4	Estimate of average of max deriv	
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv	
Derivative at radial flow period = (enter)	#NUM!	#NUM!	Read from derivative graph	
	T-early[m^2/d] =	#NUM!	Aqui. thick (m)	20
T and S estimates from derivatives	T-late [m^2/d] =	19.07	Est. S-late =	1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	1.10E-03	S-estimate could be wrong	

G.6 Basic FC Method Analysis at BH7-KNP

H. BH8-KNP – Bare Patches

Country:	South Africa	Geology:	Clayey, and Granite
Region:	KNP	Depth of BH:	18 m
Owner:	CSIR	Water strikes:	No water Strikes
X-coord:	31.27	Date of Test:	5-Nov-04
Y-coord:	23.19	Contractor:	DWAF (Pretoria)

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:	BH8-KNP									Other info:
Distance from Rest WL to main water strike (m) =					s_{max}=	6.688	Recom. AD =	6.7		
Q (l/s)=	0.061				Recovery data					T (m^2/d) : Logan eq.
t (min)	s (m)	avg s'	avg s"	avg T	avg S	Time t'	Res_s	t/t'	WI rise	s'	Rec_T	1.0
1.00	0.556					1	6.652	46	0.036			
2.00	0.434					2	6.417	23.5	0.271	0.84		
3.00	0.834	1.43	0.46			3	6.247	16	0.441	0.76		
5.00	1.006	1.64	0.68	0.58	0.00E+00	5	6.11	10	0.578	0.57	1.5	
7.00	1.288	2.38	0.90	0.42	0.00E+00	7	6.037	7.429	0.651	0.61	1.4	
10.00	1.729	3.25	0.92	0.27	0.00E+00	10	5.927	5.5	0.761	0.94	#NUM!	
15.00	2.482	4.63	0.94	0.23	0.00E+00	15	5.727	4	0.961	-1.60	#NUM!	
20.00	3.205	6.46	#NUM!	0.15	0.00E+00	20	6.465	3.25	0.223	2.02	#NUM!	
30.00	3.661	#####	#NUM!	0.10	0.00E+00	30	5.224	2.5	1.464	5.35	0.4	
40.00	6.624	#####	#NUM!	0.10	0.00E+00	40	4.89	2.125	1.798	1.64	#DIV/0!	
45.00	6.688	#####	#NUM!	0.10	0.00E+00	60	4.716	1.75	1.972	######	#DIV/0!	

H.1 Pumping Data at BH8-KNP

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FC-METHOD : Estimation of the sustainable yield of a borehole

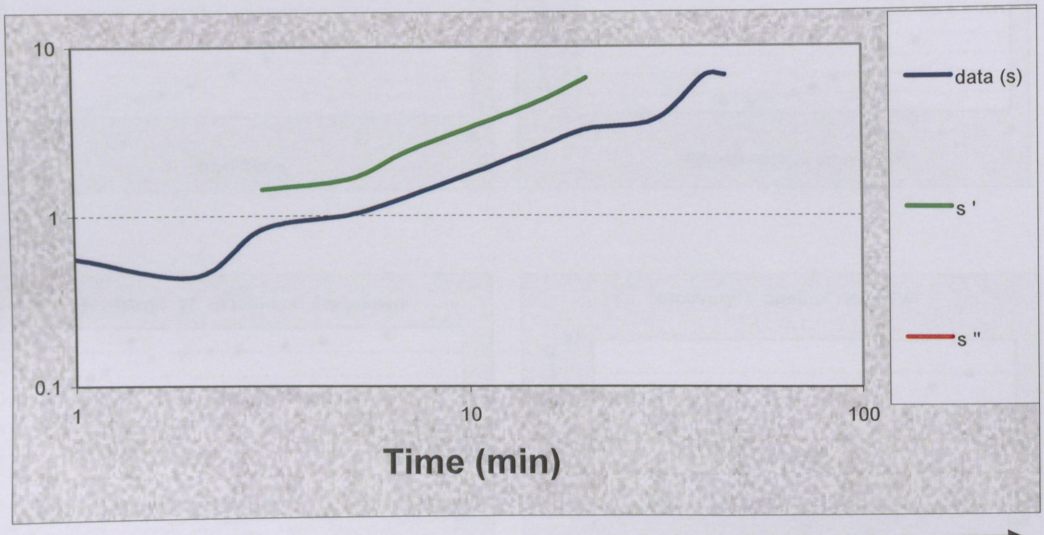
BH8-KNP

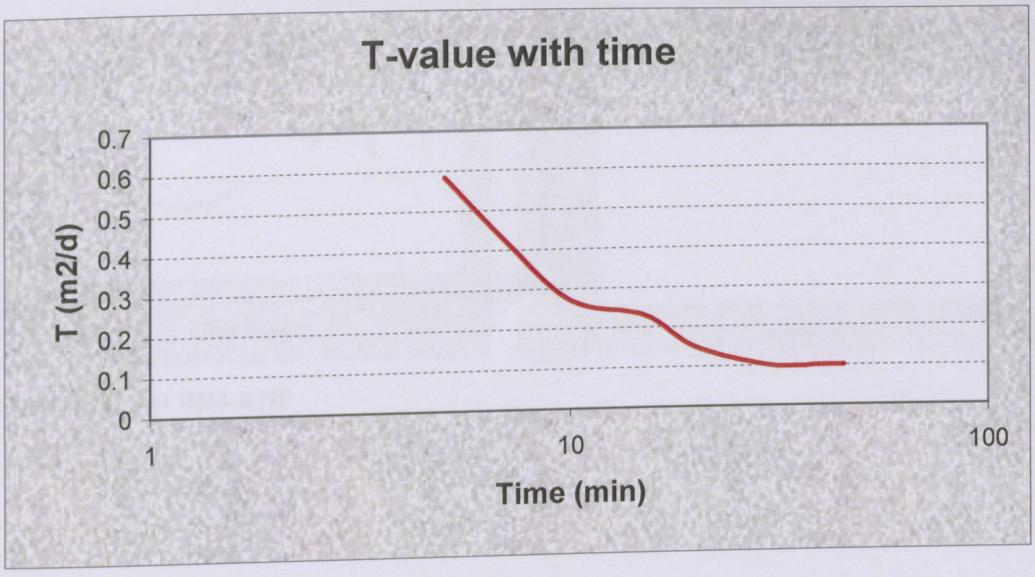
Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	#NUM!	#NUM!	← Est. r_e	From r(e) sheet
Q (l/s) from pumping test =	0.061	0.00E+00	← S-late	← Change r_e
s_a (available drawdown), sigma_s = (enter)	6.7		← Sigma_s from risk	
Annual effective recharge (mm) =		6.69	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	45	6.688	End time and drawdown of test	
Average maximum derivative = (enter)	0.0	0.0	← Estimate of average of max deriv	
Average second derivative = (enter)	0.0	0.0	← Estimate of average second deriv	
Derivative at radial flow period = (enter)	#NUM!	#NUM!	← Read from derivative graph	
	T-early[m^2/d] =	#NUM!	Aqui. thick (m)	20
T and S estimates from derivatives	T-late [m^2/d] =	#DIV/0!	Est. S-late =	1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	1.10E-03	S-estimate could be wrong	

H.2 Basic FC Method Analysis at BH8-KNP

DERIVATIVE PLOTS AND T- AND S - VALUES

BH8-KNP





H.3 Derivative Storativity and Transmissivity Plots at BH8-KNP

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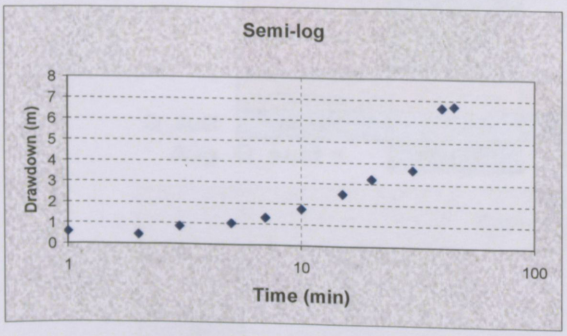

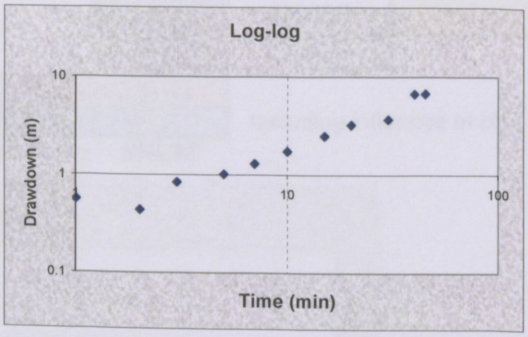

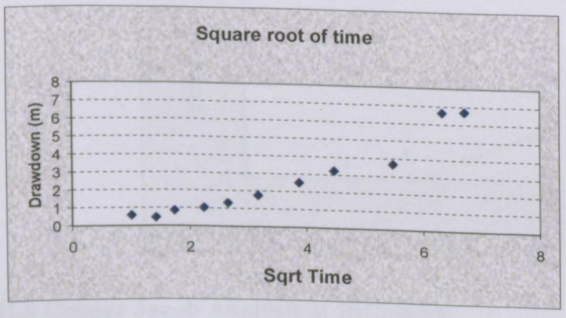

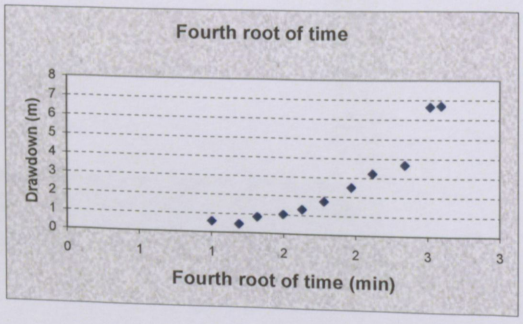

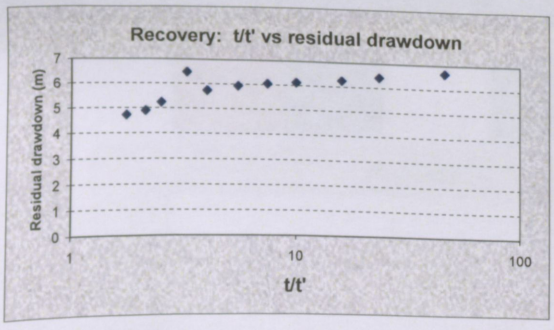

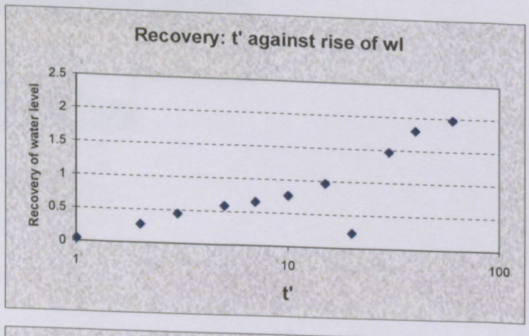

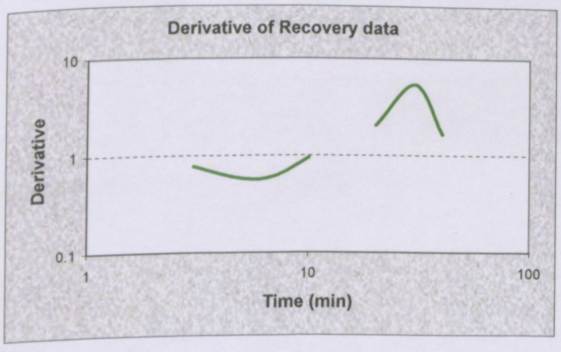

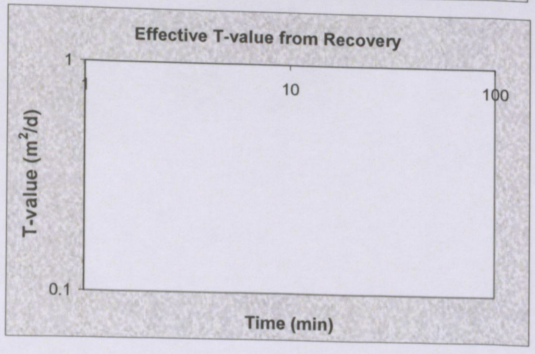

H.4 Derivative Plots at BH8-KNP

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Cooper-Jacob method

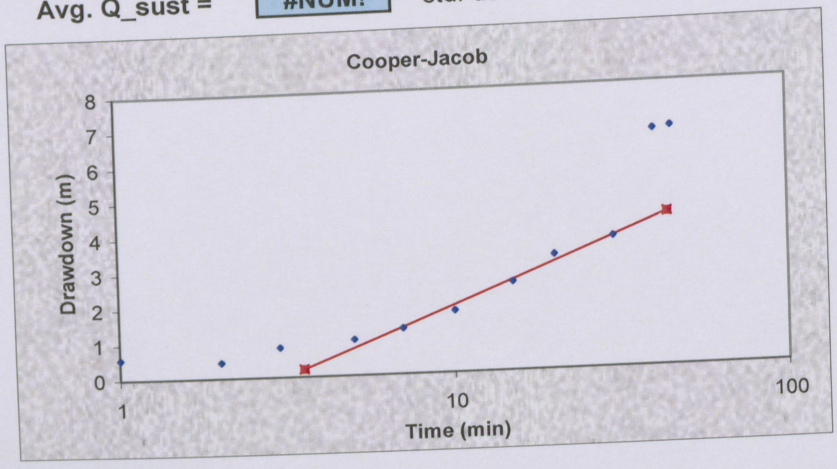
BH8-KNP

$T(m^2/d)$ =	0.3
S =	#NUM!

r_e (m)=	#NUM!
Q (l/s) =	0.061

No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	#NUM!	#NUM!	#NUM!
Avg. Q_sust =	#NUM!	std. dev =	#NUM!

including influence of bh's



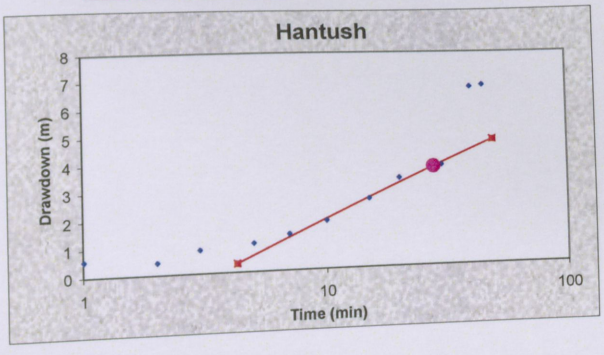
H.5 Cooper Jacob Analysis at BH8-KNP

Leaky Aquifer: Hantush Method

BH8-KNP

$T(m^2/d)$ =	0.1
S =	#NUM!
L (m) =	#NUM!

r_e (m)=	#NUM!
Q (l/s) =	0.061
C (d) =	#NUM!



Move purple dot to steady state drawdown

sp =	1.80
tp =	10.0
e(r/L)*K0(r/L)=	1.020558
r/L =	1.181529
exp(-r/L) =	0.306809
K0(r/L) =	0.313117

H.6 Hantush Analysis at BH8-KNP

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APPENDIX 3: FIGURES

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Figure 3.1.1: Mphongolo Site geophysical transverse and location of BH1-KNP

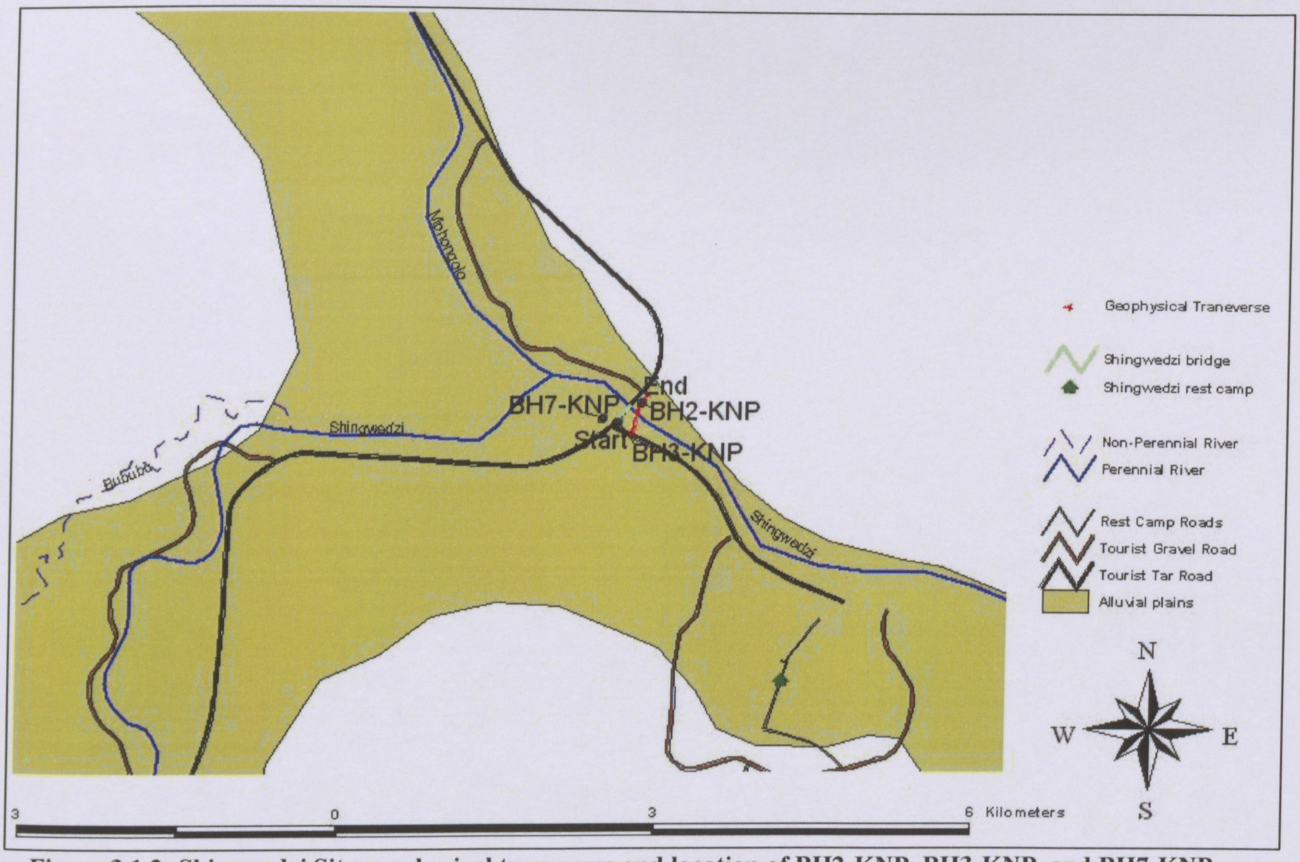

Figure 3.1.2: Shingwedzi Site geophysical transverse and location of BH2-KNP, BH3-KNP, and BH7-KNP

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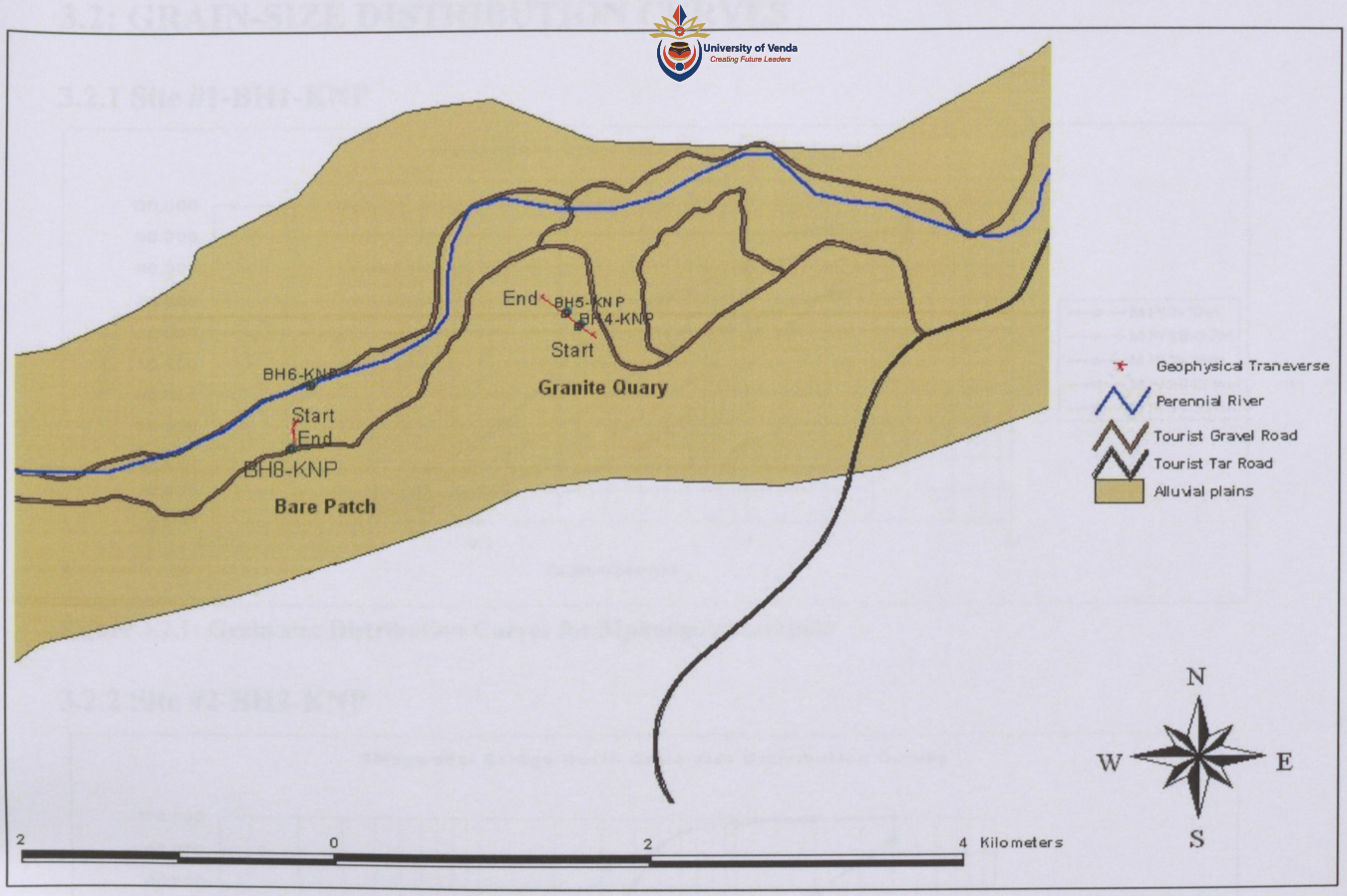

Figure 3.1.3: Granite Quarry and Bare Patch Site geophysical transverse and location of BH4-KNP, BH5-KNP, BH6-KNP, and BH8-KNP

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3.2: GRAIN-SIZE DISTRIBUTION CURVES

3.2.1 Site #1-BH1-KNP

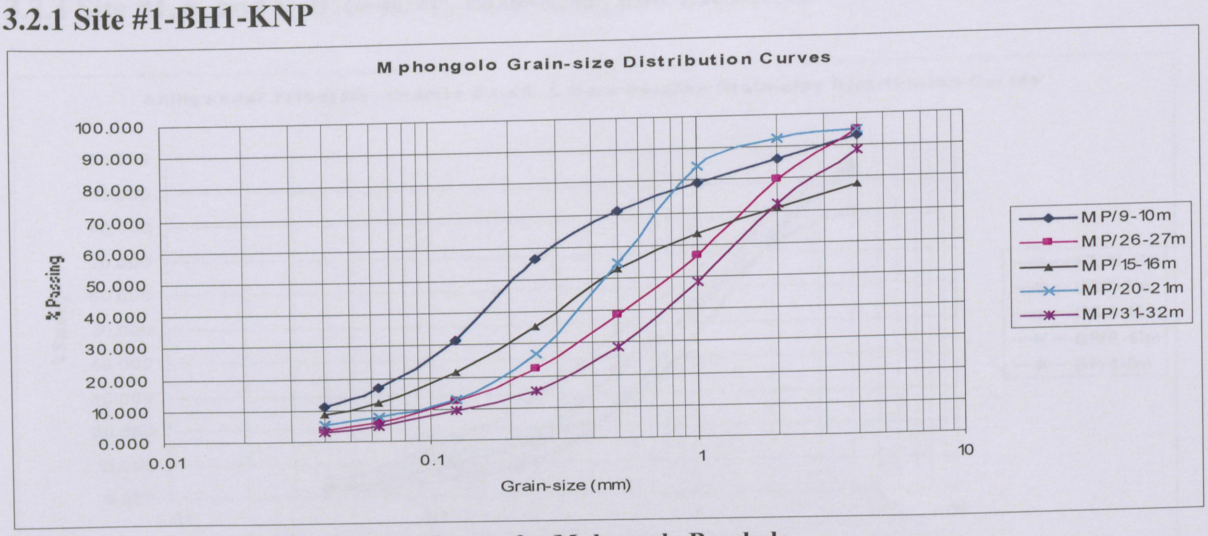

Figure 3.2.1: Grain size Distribution Curves for Mphongolo Borehole

3.2.2 Site #2-BH2-KNP

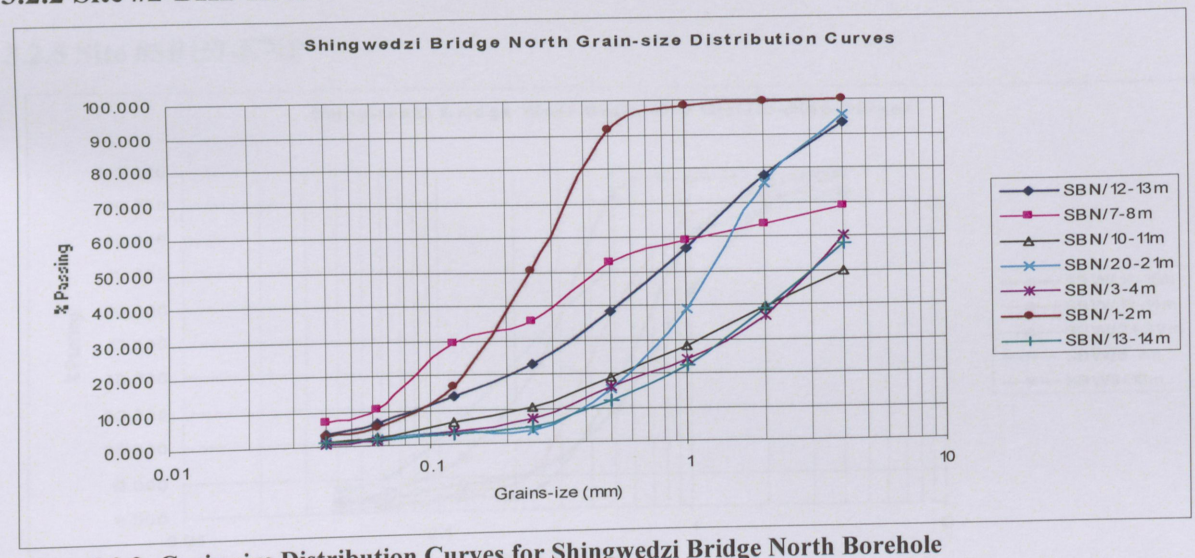

Figure 3.2.2: Grain size Distribution Curves for Shingwedzi Bridge North Borehole

3.2.3 Site#3 - BH3-KNP

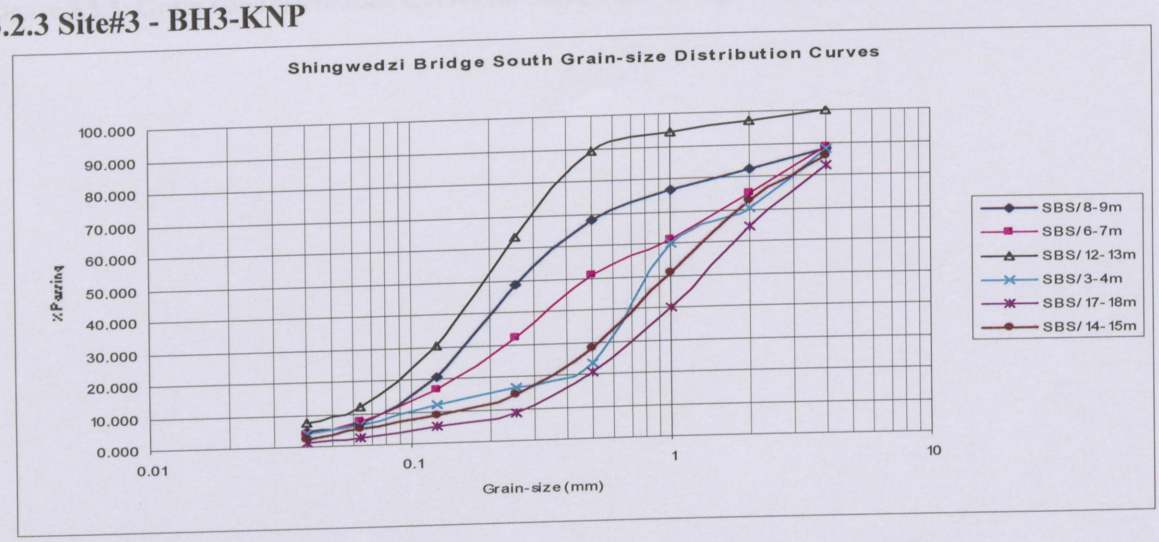

Figure 3.2.3: Grain size Distribution Curves for Shingwedzi Bridge South Borehole

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3.2.4 Site #4, 6, and 8 -BH4-KNP, BH6-KNP, and BH8-KNP

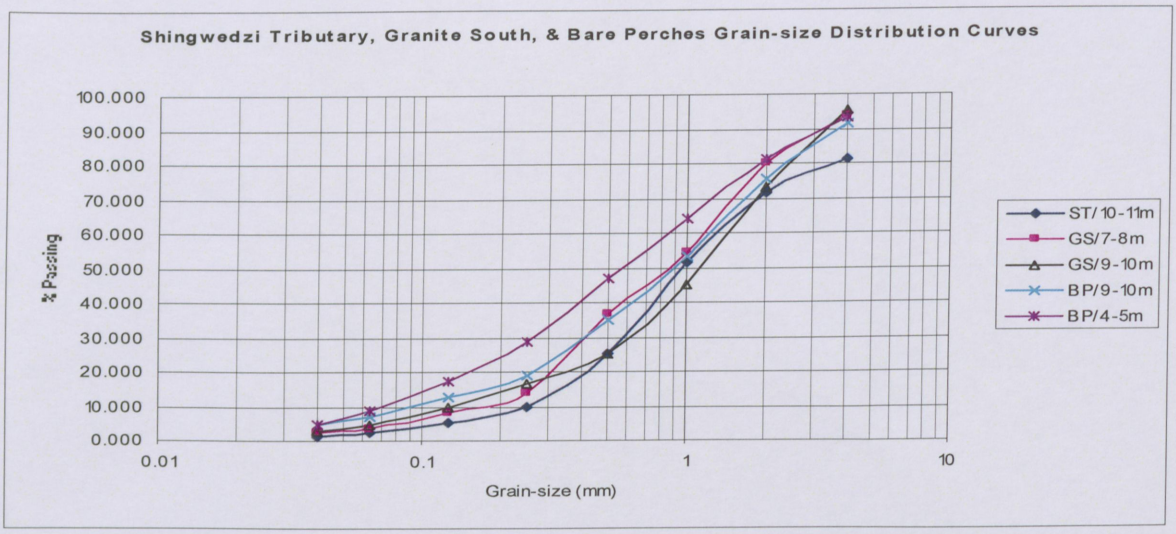

Figure 3.2.4: Grain size Distribution Curves for Granite South Borehole

3.2.5 Site #5BH7-KNP

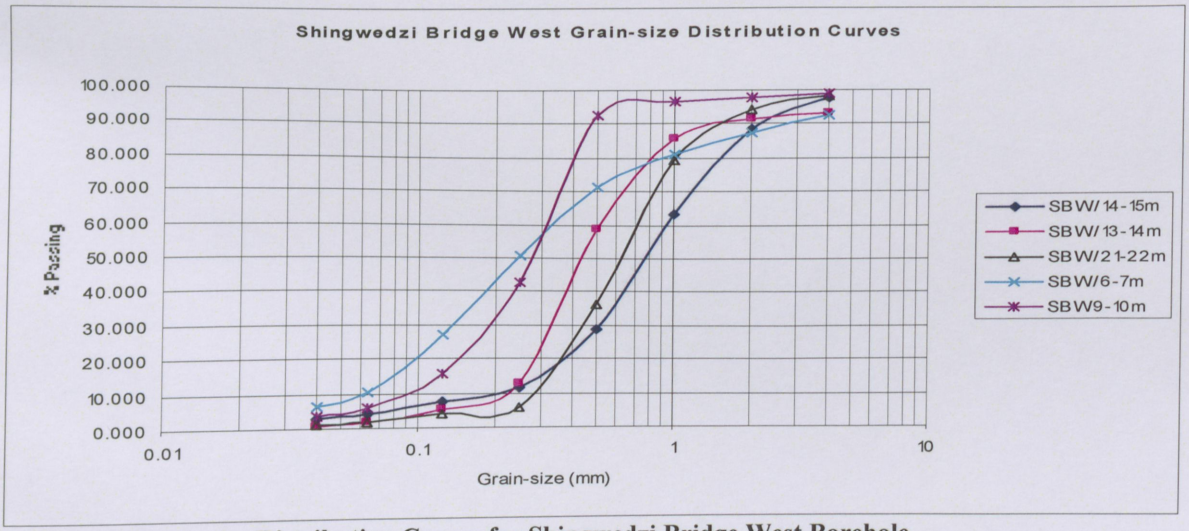

Figure 3.2.5: Grain size Distribution Curves for Shingwedzi Bridge West Borehole

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