REPUBLIC OF BOTSWANA

Department of Water Affairs
Ministry of Minerals, Energy and Water Resources

Matsheng Groundwater Development Project

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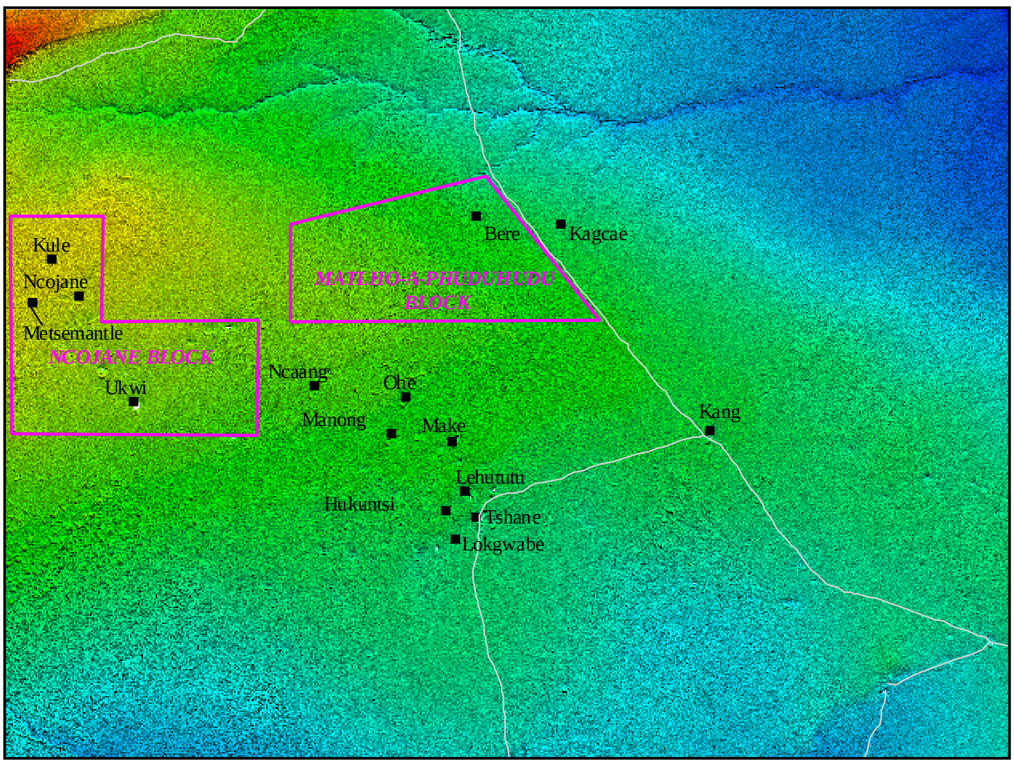

FINAL REPORT
VOLUME 2
HYDROGEOLOGICAL REPORT

MARCH 2008

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PREFACE

This report **Volume 2**, **Hydrogeological Report** of the Project Area, provides results of the exploration and Production phases. The activities in these phases included drilling, pumping tests, GPS surveys, groundwater level monitoring, recharge and resource assessment.

Drilling of exploration and monitoring boreholes during the Matsheng Project commenced on 19 May 2005 and was completed on 10 March 2006. Pumping tests were carried out over the period 12 October 2005 to 11 March 2006. Drilling and pump testing of Production boreholes started on 27 January 2007 and was completed on 17 October 2007.

The final reporting for this Project is as follows:

Volume No.	**Report Name**
	Executive Summary
Volume 1	Main Report
Volume 2	**Hydrogeological Report**
Volume 3A	Airborne and Ground Geophysics Report
Volume 3B	Transient Electromagnetic Sounding Data, Interpretation and Plots (Part 1 and 2)
Volume 3C	Downhole Geophysical Logging Report
Volume 4	Hydrochemistry and Environmental Isotopes
Volume 5	Groundwater Modelling
Volume 6	Preliminary Wellfield Design and Cost Estimates

SUMMARY

This Hydrogeological Report presents results of ground geophysical surveys, drilling, pumping tests, groundwater quality data, groundwater level monitoring and high precision GPS surveys data for the Matsheng Groundwater Development Project. In addition to the above, the report also includes the results of resource assessment and recharge dynamics.

Ground geophysical surveys consisting mainly of magnetic profiling and Time Domain Electromagnetic (TEM) soundings (200 x 200 m loop) together with limited horizontal loop electromagnetic profiling (HLEM) were conducted in the Ncojane Block, while in Matlhoaphuduhudu only TEM soundings (200 x 200 m loop) were conducted.

In general, ground magnetic profiling assisted in locating aeromagnetic and remote sensing data interpreted lineaments and faults, some of which have major effects on the aquifer geometry and water quality. Magnetic profiling was also very instrumental in locating some dolerite sills though not all the time due the horizontal and weathered nature of these dolerites.

HLEM profiling was found to be ineffective because a large portion of the project area is underlain by a thick sequence of conductive units overlying the target aquifer, except near Ncojane and Kule villages where Kalahari Beds, Mosolotsane and Kule Mudstones are thinner and more resistive.

TEM soundings combined with magnetic profiling were found to be the most effective methods for hydrogeological investigations in the project area and should constitute the only ground geophysical techniques employed for siting water supply boreholes in the area.

The main aquifer in the Ncojane Block is in the two sandstone units of the Ecca Group (Otshe Formation) which are separated from each other by mudstones, shales and siltstones. Water strike depths ranged from 154 m to 289 m with an average water strike depth of 209 m. Airlift yields in the two sandstone aquifers ranged from 22 to 127 m^3/hr. TDS values were of mostly between 168 mg/L to 1300 mg/L. Rest water levels for the Otshe sandstone aquifers in the Ncojane Block ranged from 85.40 m to 133.4 m below ground level.

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WRC Project Team deserves special thanks and appreciation for performing their duties with dedication, diligence and to high professional standards. The Personnel involved in the project included:

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WRC takes this opportunity to thank members of the Project Steering Committee particularly: Mr J. Ntsatsi, Mr N. Mbuli, Mr K. Setimela, Mr T. Setloboko representing the Department of Water Affairs; Mr Keakantse,from Ghanzi/CharlesHill Land Board, Dr. G. Tshoso, Mr C. Chilume, and Mr M. Keeletsang from Department of Geological Survey, Mr J. Monggae from GeoScience Consulting Services and Mr M. Madi from Hukuntsi Water Unit..

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We also take this opportunity to pay tribute to the late Mr. Flenner Linn, one of our team members, who passed away after a road accident in Zambia. May God rest his soul in peace.

Last but not least we would like to express our appreciation to the Ncojane Police, Marakanelo C. J. S. School Staff, and Ncojane Post Office Staff for giving us access to their communication devices whenever required.

Water Resources Consultants is most grateful to everyone else not mentioned here who assisted throughout the course of the project.

ACRONYMS AND ABBREVIATIONS

ACL	Analytical Compu Log
AIDS	Acquired Immune Deficiency Syndrome
AMSL	Above Mean Sea Level
AMT	Audio Magneto-Telluric
ART	Anti-retroviral Therapy
ASTER	Advance Space-borne Thermal Emission and Reflection Radiometer
BGL	Below Ground Level
BH	Borehole
CMB	Chloride Mass Balance
CSAMT	Controlled Source Audio Magneto-Telluric
DGS	Department of Geological Surveys
DWA	Department of Water Affairs
EC	Electrical Conductivity
FSD	Fracture Spatial Density
GS	Ground Surface
GCS	Geotechnical Consulting Services (Pty) Ltd.
HBC	Home Based Care
HIS	Hue- Intensity- Saturation
HLEM	Horizontal Loop Electromagnetic
Hz	Hertz (Unit of frequency)
JICA	Japan International Cooperation Agency
m	Meter
m atoc	Meter above top of casing
m bgl	Meter below ground level
m3/day	Meter cubic per day
m3/hr	Meter cubic per hour
mg/L	Milligram per litter
msec	Milli-seconds
MT	Magneto-Telluric
MRT	Mean Residence Time
NDVI	Normalised Difference Vegetation Index
NSAMT	Natural Source Audio Magneto-Telluric
PCIAC	Petro-Canada International Assistants Corporation
PMC	Percent Modern Carbon
PVC	Poly-Vinyl Chloride
RGB	Red- Green - Blue
PPK	Post Processing Kinematics
RTP	Reduce to Pole
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave Infra-Red
TB	Tuberculosis
TDEM/ TEM	Time-Domain Electromagnetic/ Transient Electromagnetic
TDS	Total Dissolved Solids
TIR	Thermal Infra-red
UTM	Universal Transverse Mercator
VES	Vertical Electrical Sounding
VNIR	Visible Near Infra-Red
WCS	Wellfield Consulting Services (Pty) Ltd.
WRC	Water Resources Consultants (Pty) Ltd.
µS/cm	Micro-Siemens per centimeters (Unit of EC)
Ω-m	Ohm-meter (Unit of resistivity)

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1 INTRODUCTION, PROJECT IMPLEMENTATION AND SCOPE OF THIS REPORT

1.1 INTRODUCTION

Water Resources Consultants (Pty) Ltd (WRC) was commissioned by the Department of Water Affairs (DWA) to execute the Matsheng Groundwater Development Project. The project activities were commenced on 1st of August 2004 and with field activities were completed to October 2007. The reporting phase was completed on February 2008. The project was initially scheduled to finish after 22 months in May 2006 but was later rescheduled to October 2006. Implementation of the production and resource evaluation phase (drilling and test pumping of 6 production boreholes and associated works) was however only completed on 17 October 2008 due to problems related to appointment of the drilling contractor for the production phase, mechanical breakdowns on rigs and support trucks and continuous abandoning of boreholes after unsuccessful fishing (4 boreholes were abandoned).

The primary goal of the Matsheng Groundwater Development Project is to locate and develop sufficient potable groundwater resources for supply to the demand centres of northern Kgalagadi District, particularly the primary demand centre comprising the Matsheng villages of Hukuntsi, Tshane, Lehututu and Lokgwabe, and demand centres located in central and southern Ghanzi District until year 2023.

1.2 LOCATION

The project area consists of two blocks, the Ncojane block and the Matlho-a-Phuduhudu Block, and is located in the western part of Botswana (**Figure 1**) within two administrative districts; Kgalagadi and Ghanzi. The Matlho-a-Phuduhudu Block is within the Ghanzi District while the Ncojane Block straddles both the Kgalagadi and Ghanzi Districts. Both blocks are located south of Ghanzi Township, west of the Trans-Kalahari Highway, and east of the Namibian boarder. The Trans-Kalahari Highway is the main access road into the project area. Bere, Hunhukwe, Lokalane, Ncaang and Monong villages/settlements are within or near Matlho-a-Phuduhudu Block, while Kule, Ncojane, Metsimantle, Metsimantsho, Ukwi and Ngwatle villages/settlements are located within Ncojane Block. The Matsheng villages, (comprising of Hukuntsi, Tshane, Lehututu and Lokgwabe and associated localities) are located approximately 120 to 150 km south of the Matlho-a-Phuduhudu Block and 150 to 200 km southeast of the Ncojane Block (**Figure 1**).

1.3 PROJECT IMPLEMENTATION

The Project implementation was designed under three main phases:

Phase 1: Inception Phase (*1 August to 22 November 2004*)
Phase 2: Exploration Phase (*Completed March 2006)*
Phase 3: Production and Resource Evaluation Phase *(May 2006 to February 2008)*

1.4 SCOPE OF THIS REPORT

This report provides a hydrogeological summary of the project area and includes the following:

- Drilling Results
- Pump Testing Results
- Water Chemistry Results
- High Precision GPS Surveys
- Groundwater level Monitoring
- Resources Assessment

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Figure 1 Project Area Location Map

2 GROUND GEOPHYSICS

2.1 OBJECTIVES

The objectives of the ground geophysical surveys were as follows;

- Locating/confirming structural features such as faults, lineaments and dolerite intrusions identified from aeromagnetic and remote sensing.
- Inferring subsurface lithological units and groundwater quality variations with depth.
- Siting of exploration monitoring and production boreholes.

2.1.1 DELINEATION OF STRUCTURAL FEATURES

Structurally two important issues had to be addressed, the possible presence of block faulting in the project area and the role of dolerite sills as hydraulic boundaries. Large scale block faulting has been interpreted throughout the Karoo basin in eastern Namibia, with offsets sufficient to isolate some aquifer units. In the project area, previous studies in the project area inferred that there was no block faulting in the Botswana portion of the basin, but if present it could have important implications on aquifer geometry, hydraulic properties, groundwater flow as well as quality. Aeromagnetic and remote sensing data interpretations carried out during the project indicated that some of the NE-SW and NW-SE trending faults in the project area parallel the structural trend of the Ghanzi–Chobe fold belt and the main Dyke swarm of eastern Botswana might affect the aquifer geometry and hydraulic characteristics of the aquifer units (**refer to Volume 3A**, **Airborne and Ground Geophysics Report).**

Also relevant to the possible aquifer boundaries are the extent and geometry of dolerite intrusions which are well developed towards the south and western parts of the Ncojane Block. For borehole siting, locating areas with significant dolerite intrusions was critical for three reasons;

1. Controlling drilling depths in such a way that boreholes are not sited in areas underlain by thick dolerite sills as this result, in deep boreholes and hence increased drilling costs
2. To determine the hydraulic role of these intrusions either as areas of increased hydraulic conductivity or as barriers to groundwater flow (aquifer compartmentalisation)
3. Evaluate their effect on groundwater quality

Accurate location of these structures on the ground (faults, lineaments dolerite dykes/sills) was therefore, one of the key objectives of the ground geophysical surveys. Drilling in the vicinity or away from these structures was important to verify and assess their hydrogeological role either as zones of enhanced groundwater potential (fracturing) or groundwater flow barriers.

2.1.2 INFERRING SUBSURFACE LITHOLOGICAL CONDITIONS

Aquifers in the project area are developed in sandstone units of the Lebung and Ecca Groups (Ntane and Otshe Formations). These two aquifers are separated from each other (if both are present) by argillaceous units of the Mosolotsane and Kule (Kwetla) Formations. In the absence of the Ntane Sandstone Formation, the Ecca aquifer is overlain by Kalahari Beds, Mosolotsane and Kule (Kwetla) Formations.

Based on the known stratigraphy of the project area and review of project and existing data, a typical resistivity sequence in an area underlain by Kalahari Beds, unsaturated Ntane Sandstone, Mosolotsane/Kule (Kwetla) Formations, Ecca and Upper Dwyka Formations **(Table 1)** in the Ncojane Block would be as follows;

Table 1 Resistivity Sequence in Ncojane Block

Layer 1	Resistive	Kalahari Beds/Unsaturated Mosolotsane/Kule (Kwetla) Mudstone Formations
Layer 2	Conductive	Mosolotsane/ Kule (Kwetla) Mudstone Formations
Layer 3	Resistive	Fresh Water Saturated Ecca Group Sandstone (Otshe)
Layer 4	Conductive	Saline Ecca Group Sandstone (Otshe) or Kobe Formations
Layer 5	Resistive	Upper Dwyka (quartzitic sandstones)

Within this sequence, dolerite intrusions will appear as zones of very high resistivity.

In the Matlho-a-Phuduhudu Block **(Table 2)**, because of the presence of saturated Ntane Sandstone Formation, a typical resistivity sequence would be as follows:

Table 2 Resistivity Sequence in the Matlho-a-Phuduhudu Block

Layer 1	Resistive Formation	Kalahari Beds/Unsaturated Ntane Sandstone
Layer 2	Moderately Resistive to Resistive Beds	Saturated Ntane Sandstone Formations
Layer 3	Conductive	Saline Mosolotsane/ Kule (Kwetla) Mudstone Formations
Layer 4	Resistive	Fresh Water Saturated Ecca Group Sandstone (Otshe)

.

2.2 SURVEY METHODOLOGY AND PARAMETERS

Ground geophysical surveys consisting mainly of magnetic profiling and Time Domain Electromagnetic (TEM) soundings (200 x 200 m loop) together with limited horizontal loop electromagnetic profiling (HLEM) were conducted in the project area as shown in **Figures 2 and 3**.

Magnetic profiling assisted in differentiating units underlain by dolerite intrusions (although flat and thick dolerite sills are not pronounced) from those without intrusions as well as locating the structural features interpreted from regional aeromagnetic and remote sensing data. The TEM soundings assisted in inferring subsurface lithologies and groundwater quality variations both laterally as well as vertically. During the surveys, the total magnetic field was recorded at station intervals of 20 m while TEM soundings along profile lines were conducted at station spacing of between 1 km (predominant) to 4km. A total of 291 (200x200 m loop size) TEM soundings were conducted along profile lines. In addition, 104 spot soundings were also conducted at various locations in order to assist in delineating the regional distribution of the different geological units (aquifers). Ten of these soundings were conducted using a loop size of 400x400m (ultra deep) while the rest were conducted using a loop size of 200x200 m. Horizontal Loop Electromagnetic (HLEM) profiling at 20 m intervals was carried out around Ncojane and Kule Villages and near Metsimantsho where this method was considered likely to provide useful information (thinner Kalahari) on vertical and sub-vertical structural features as well as geological contacts between different formations. HLEM was not applied during the production phase as it was not found effective during the exploration phase.

A summary of the equipment used is given in **Table 3.**

Table 3 Survey Method, Equipment and Survey Parameters

Survey Method	Equipment	Survey Parameters
Line Preparation	Garmin 12XL Hand Held GPS	Pegging at 20 m interval
Magnetic profiling	GEM GSM-19 and Geotron G5 total magnetic field magnetometers	Total magnetic field recording at 20 m station interval
HLEM Profiling	Apex maxmin I-10 and II EM units	Reading at 20m station interval using 200 m coil spacing at three frequencies 880, 1760 and 3520 Hz.
TEM Soundings	Geonics Protem D Receiver with TEM57 MK2 transmitter	In-loop soundings (200 x 200 m loop & 400x400) with 25, 6.25 and 2.5 Hz frequencies.

2.3 CALIBRATION SURVEYS AND DATA PROCESSING

2.3.1 CALIBRATION SURVEYS

Calibration surveys comprising of TEM soundings were conducted near six existing boreholes, BH8469, BH8470, BH8364, BH8363, BH8346 and BH8645 prior to conducting the surveys for the project. These surveys were conducted to correlate lithostratigraphic units and groundwater quality with resistivities obtained from TEM soundings inversions at known locations. All the boreholes where calibration surveys were conducted are tapping aquifers in Ecca and contain fresh groundwater with TDS values ranging between 500 and 900 mg/L. In the Ncojane Block, the Ntane Sandstone is absent and, therefore does not constitute an aquifer. Resistivity ranges of the main lithostratigraphic units as obtained from the calibration surveys are summarised in **Table 4.**

Table 4 Resistivity Range of Major Litho-Stratigraphic Units of the Project Area

Lithostratigraphic Unit	TEM Resistivity (Ω-m)
Kalahari Beds	11 – 90
Dolerite	40 – > 400
Mosolotsane Formation/Kule (Kwetla) Formation (saturated)	5 – 40 (mostly < 10)
Ecca Group (Fresh)	10– 70 (mostly 10 to 30)
Saline Ecca Group or Kobe	< 5

From **Table 4,** it can be observed that sandstones in the Ecca, which form the main aquifer units in the Ncojane Block, contain mostly fresh groundwater and are characterised by TEM resistivities ranging from of 10 to 70 Ω-m. However, the resistivity range of this unit is commonly observed to be between 10 to 30 Ω-m. The Mosolotsane and Kule (Kwetla) Formations have resistivities which are generally less than 10 Ω-m. Kalahari Beds are characterised by similar resistivities which range from 11 to about 90 Ω-m. The interpretations can be found in **Volume 3A**, **Airborne and Ground Geophysics Report.**

2.4 SURVEY RESULTS

An integrated interpretation of the acquired data was undertaken in conjunction with borehole information, geological and structural maps. The main objectives of the interpretation were:

- Verification of structural features and lineaments identified from aeromagnetic and remote sensing data interpretation
- Mapping of subsurface lithologies and inferring groundwater quality
- Correlation of the Geophysical Interpretations with drilling results

2.4.1 DRILLING SITES

There were a total 26 sites with 16 of these recommended for drilling of exploration boreholes and 10 for production drilling. These sites were selected in different geological and hydrogeological environments of the project area bearing in mind the principal objectives of this project which were;

- Delineation of structural features such as faults, lineaments and dolerite intrusions and evaluation of their hydrogeological significance as hydraulic barriers or areas with increased groundwater potential
- Inferring subsurface lithological units and groundwater quality variations with depth as well as spatially.

The surveys focused on the Ncojane Block, where the Ecca Group Sandstones (Otshe Formation) constitute the main aquifer units and the groundwater potential has not been extensively explored in previous projects.

To fully evaluate the groundwater potential of the different geological environments and the identified structures, drilling sites were selected based on different features such as:

- Structurally undisturbed areas which are characterised by uniform magnetic and or HLEM responses (where applicable) together with uniform resistivity layering on TEM sections.
- Structurally disturbed (fractured) areas which are characterised by magnetic and HLEM (where applicable) anomalies as well as discontinuities in the TEM resistivity sections coinciding with remote sensing and aeromagnetic data interpreted structures.

Based on the drilling data, some sites were moved from their original location to avoid drilling through thick Dolerite intrusions while some were moved to avoid drilling deeper boreholes in order to reach the main aquifer unit (Ecca, Otshe). Information from these drilled sites together with ground geophysical and borehole geophysical logging data interpretations are in **Volume 3A of the Project report**. A follow up geophysical survey conducted during the production phase was mainly used to refine known results and to collect more data in the area proposed for production wellfields. The basic criteria for production borehole siting was selecting areas underlain by a thick sequence of the Otshe Sandstone units which have proven to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block and with probable thin dolerite sill/dyke. Siting of production of boreholes in Matlhoaphuduhudu block involved review of hydrogeological data of existing boreholes and hence the central portion of the area was surveyed by conducting TEM sounding on the selected sites.

2.5 SUMMARY AND CONCLUSIONS

In general a good correlation between borehole lithology and TEM resistivities was observed, except at boreholes drilled between sounding points. At these locations dolerites were encountered where they were not expected due to the poor horizontal resolution of TEM data as well as the weathered nature of these dolerites. The TEM interpreted depths of the Otshe Formation which is the main aquifer in the Ncojane Block, correlates well with drilling and borehole geophysical logging results. At depths of more than 300 m however, TEM sounding have poor vertical resolution of the different lithological units, as sandstones and mudstones being encountered during drilling instead of the expected lithologies (dolerites). Only a few boreholes were drilled to these depths bearing in mind the poor vertical resolution of TEM data at these depths. At depth exceeding 300 m TEM smooth models provided critical information about the resistivity variation with depth for mapping saline and fresh water bearing aquifers.

Ground magnetic profiling assisted in locating aeromagnetic and remote sensing data encountered lineaments and faults, some of which have major effects on the aquifer geometry and water quality. Magnetic profiling was also instrumental in locating some dolerite sills though not always probably due the horizontal and weathered nature of these dolerites.

HLEM profiling was found to be ineffective because a large portion of the project area is underlain by thick conductive units overlying the target aquifer, except near Ncojane and Kule villages where Kalahari Beds, Mosolotsane and Kule Mudstones are thinner and more resistive.

TEM soundings together with magnetic profiling were found to be the most effective methods for hydrogeological investigations in the project area should constitute the only ground geophysical techniques employed for siting water supply boreholes in the area.

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Figure 2 Detailed Geophysical Plan in Ncojane Block

Figure 3 Detailed Geophysical Plan in Matlho-a-Phuduhudu Block

3 DRILLING, CONSTRUCTION & TEST PUMPING OF BOREHOLES

3.1 OVERVIEW

The drilling programme of the Matsheng Groundwater Development Project was carried out in two phases, the Exploration and Production Drilling Phases. The exploration drilling programme was divided into two Drilling Contracts, Batch 1 and Batch 2 while the production phase was carried out under a single drilling contract.

Drilling Contractors for the Exploration Phase were Nhabe Drilling and Pula Groundwater Developers while Notwane Drilling Company carried out drilling during the Production Phase.

3.1.1 EXPLORATION PHASE BATCH 1 CONTRACT

Under the Batch 1 contract, which was originally awarded to Nhabe Drilling, 15 boreholes were planned (10 exploration and 5 monitoring boreholes). Only 12 (8 exploration and 4 monitoring boreholes) were drilled due to deeper drilling depths than originally anticipated. During this contract there were numerous organisational and logistical problems with the contractor which ultimately resulted in them pulling out of the contract without completing a single borehole. This resulted in a delay of about 4.5 months (from 19 May 2005 to end September 2005). After Nhabe Drilling pulled out, the Batch 1 Contract was awarded to Pula Groundwater Developers who started their activities on 14 October 2005 and completed them on 10 March 2006. A total of 12 boreholes (4 monitoring and 8 exploration boreholes) were drilled. Three boreholes drilled under this contract were abandoned due to collapsing and the loss of a drilling bit. One existing borehole (BH929) was cleaned and converted into two nested piezometers to monitor Sandstones 1 and 2 of the Ecca aquifer.

3.1.2 EXPLORATION PHASE BATCH 2 CONTRACT

The Batch 2 Drilling Contract was awarded to Pula Groundwater Developers and similar to the Batch 1 contract it was also planned that a total of 15 boreholes would be drilled (10 exploration and 5 monitoring). Drilling under this contract was started on 23rd May 2005 and completed on 10 February 2006, four months after the planned completion date. This was again due to the incompetence of the drilling contractor. Under this contract, 12 new boreholes (8 monitoring and 4 exploration) were drilled using two drilling rigs. In addition to the 12 drilled boreholes, 5 existing boreholes were cleaned and one was deepened from a depth of 167 to 284 m.

3.1.3 PRODUCTION PHASE

Notwane Drilling Company who was awarded the Production Phase drilling contract, started their drilling operations on 27 January 2007 and completed their operations on 07 September 2007 after completing only 6 of the 10 planned production boreholes. Only 6 boreholes were drilled primarily as result of poor performance of the contractor and because the yield from the 6 completed boreholes were assessed to be sufficient to meet the projected year 2023 water demand for the Matsheng Villages as well as for the secondary demand centres.

3.1.4 DRILLING OBJECTIVES

Four types of boreholes, monitoring, exploration, test production and production boreholes were drilled during the Matsheng Groundwater Development Project. These boreholes were sited using ground geophysical techniques, remote sensing studies as well as aeromagnetic data interpretation. Borehole sites were selected in different geological and hydrogeological environments within the project area bearing in mind the principal objectives of the exploration and production drilling phases which included;

- Delineation of structural features such as faults, lineaments and dolerite intrusions and evaluation of their hydrogeological significance as hydraulic barriers or areas with increased groundwater potential,
- Evaluation of groundwater quality variation with depth as well as spatially.

- Determination of borehole yields.
- Determination of aquifer hydraulic parameters (e.g. transmissivity, storativity).
- Determination of the influence of faults and lineaments on aquifer geometry, aquifer yields and ground water quality.
- Generation of water level monitoring data for purposes of understanding the groundwater flow dynamics as well as for input into the numerical groundwater flow model and in addition monitoring seasonal water level fluctuations as well as long term water level trends.
- Understanding the influence of dolerite sills in water quality.
- Selection of optimal locations for the production wellfields.

To evaluate the groundwater potential of the different geological environments identified from remote sensing studies, aeromagnetic data interpretation and ground geophysical surveys, drilling sites were selected based on the following features :

- Structurally undisturbed areas characterised by uniform magnetic and or HLEM responses (where applicable) together with uniform resistivity layering on TEM sections
- Structurally disturbed (fractured) areas which are characterised by magnetic and HLEM (where applicable) anomalies as well as discontinuities in the TEM resistivity sections coinciding with remote sensing and aeromagnetic data interpreted structures
- Areas with dolerite sill intrusions characterised by short wavelength magnetic anomalies and high resistivities based on TEM sections

Production boreholes were drilled in areas which were considered to have the best groundwater potential in terms of yields, groundwater quality as well as those that had good potential for future wellfield expansion.

3.2 DRILLING PROGRAMME AND RESULTS

A total of 36 boreholes were completed during the Matsheng Groundwater Development Project amounting to total meterage of 9456 m. Borehole depths ranged from 201 to 444 m for exploration/test production and monitoring boreholes and from 244 to 263 m for production boreholes. These included 12 exploration boreholes, 2 test production boreholes, 6 production boreholes, 11 monitoring boreholes as well as 5 existing boreholes which were cleaned. In addition to the successfully completed boreholes, 7 boreholes were abandoned at different depths for various reasons.

In general, airlift yields measured over 90° V-notch weirs for monitoring boreholes ranged from 9 to 101 m^3/hr, for the exploration/test production boreholes the airlift yields ranged from 2 to 127 m^3/hr. For production boreholes airlift yields ranged from 44 to 78 m^3/hr. **Tables 6** and **7** provides a summary of the project's exploration, test production, monitoring and production boreholes respectively.

3.2.1 DRILLING METHODS EMPLOYED

The drilling and construction methods used for the different project borehole types are discussed below.

3.2.1.1 MONITORING BOREHOLES

Monitoring boreholes were drilled using an 8 inch diameter drilling bit using the down hole hammer (DTH) method to a depths of approximately 80 m after which 6.5 inch plain casings were installed and cement grouted. Drilling was then carried out using a 6.5 inch bit to the terminal depth. When drilling deep monitoring boreholes (more than 300m), a 10 inch drilling bit was used to drill through the Kalahari Beds (80m) which were then cased and cement grouted using 8 inch plain casings. Further drilling to the top of Ecca (~200) was achieved using an 8 inch bit and 6.5 inch casings were installed and cement grouted. A 6.5 inch bit was then used to drill to the terminal depth. However, in some boreholes a 6.25 inch tri-cone bit was used instead of the 6.5 inch DTH bit to overcome back pressure problems associated with high yielding water strikes particularly in the Ecca aquifer (Otshe Formation).

After completion of drilling, shallow (less than 300 m) monitoring boreholes were constructed with a 2 inch (50mm) PVC casing and screen assembly. Deep monitoring boreholes were constructed with 2.4 inch (60mm) reinforced PVC casings and screens. A Gravel pack consisting of 1.2 to 2.4 mm sub-rounded quartz grains was then tremied from the bottom of the hole to various depths above the top of the highest screened interval. The top 3m above the gravel pack was sealed off using bentonite and the remaining annulus was cement grouted to the surface. Monitoring boreholes were developed by blowing compressed air through a 1” airline using the PVC casing as an eductor pipe.

3.2.1.2 EXPLORATION AND TEST PRODUCTION BOREHOLES

Drilling of exploration boreholes was carried out with a 15 inch bit using the DTH drilling technique to depths of up to 80 m below ground level after which 12 inch plain casings were installed and cement grouted. A 12 inch DTH drilling bit was then used to continue drilling to depths of approximately 200 m after which 10 inch plain casings were installed and cement grouted. Drilling to the terminal depths was through a combination of 10 inch DTH bits and $9^{7/8}$ tricone bits. The tricone bits were used to overcome back pressure problems associated with high yielding water strikes in the Ecca aquifer (Otshe Formation). The exploration boreholes were completed with an assembly of 8 inch plain casing and factory slotted casings without gravel packing however one borehole (BH10214) was left as an open hole because of low airlift yield (<4 m^3/hr).

For test production boreholes, drilling was carried out using a 17.5 inch DTH bit to depths of about 10m after 15 inch casings were installed. Further drilling was through a 15 inch DTH bit to depths of about 140m after which a string of 12 inch casing was installed and cement grouted. Further drilling to the terminal depths were achieved by a 12 inch drilling bit using the DTH method. Tri-cone bits were used to overcome the back pressure problems. Test production boreholes were constructed with 6.5 inch steel casings and 6 inch Louvered screens or wire wrap screens (20 slot). Similar to monitoring boreholes, gravel pack was tremied from the bottom of the borehole to various depths above the highest screen interval for test production boreholes. The remaining annulus was cement grouted.

Borehole development was through airlift pumping for exploration boreholes while the test production boreholes were developed by both airlifting and air jetting techniques. Verticality and alignment tests were carried out in all exploration and test production boreholes.

It was initially planned that the exploration boreholes would be left as 10 inch open holes in the main aquifer zone (approximately below 200 m) but this plan was changed in the early stages of the exploration drilling programme due to collapsing problems. It was also realised that a completion diameter of 6.5 inch casings and screens limited the size of pumps during test pumping and 8 inch completion had to be utilised to cater for bigger pumps.

3.2.1.3 PRODUCTION BOREHOLES

Drilling of production boreholes was started a 17 inch drilling bit down to depths of about 70 m (Kalahari) after which 15 inch plain casings were installed and cement grouted. Drilling was then continued with a 15 inch bit to the top of the first sandstone unit of the Ecca (~190 to 200m) after which 12 inch plain casings were installed and cement grouted. Drilling to the terminal depth (244 to 263 m) of the borehole was through a combination of 12 inch bits as well as 12 inch tricone bits. The boreholes were constructed with 8 inch epoxy coated casings and screens and borehole development was through air lift pumping. Verticality and alignment tests were carried out to the top of the first screen in all production boreholes.

3.2.2 SUMMARY OF DRILLING RESULTS

A map showing borehole locations in the project area is given in **Figure 4** while a summary of drilling results for project boreholes is provided in **Tables 5** and **6**. Detailed descriptions of all project drilled boreholes including borehole logs, construction, water chemistry data and interpretation of pump testing data are given in **Appendix A.**

3.2.2.1 NCOJANE BLOCK

A total of 24 boreholes were drilled in the Ncojane Block, of which 5 were monitoring boreholes, 11 were exploration boreholes, 2 were test production boreholes and 6 were production boreholes. Seven other boreholes (one monitoring, two exploration and four production were drilled to different depths but were cement grouted and abandoned before completion. Replacement boreholes were drilled at the same location except at one production borehole site. In addition to the 24 drilled boreholes, one existing borehole BH9295 was also cleaned for retesting.

The main aquifer encountered during drilling in the Ncojane Block was in the two sandstone units of the Ecca Group (Otshe Formation) which are separated from each other by variably thick argillaceous units comprising of mudstone, shale siltstone and carbonaceous mudstone. Water strike depths ranged from 154 m to 289 m with an average water strike depth of 209 m. Airlift yields in the two sandstone aquifers ranged from 22 to 127 m^3/hr with TDS values falling mostly between 168 mg/L to 1300 mg/L. Rest water levels for the Otshe sandstone aquifers in the Ncojane Block range from 85.40 m to 133.4 m below ground level.

In addition to the predominantly fresh water aquifers found in the Otshe Formation sandstone units, saline aquifers were encountered in sandstone units of the underlying Kobe Formation particularly in the southern part of the Ncojane Block (**Figure 4**). At one site (BH10218 and BH10217) two monitoring boreholes, one screened in the Otshe Sandstone units and one in the saline Kobe sandstone indicated that the head of the shallow aquifer at 1146.44 m above mean sea level (BH10218), was higher than that of the underlying saline aquifer 1137.59 m amsl (BH10217). A detailed analysis of the Ecca aquifer including aquifer geometry, spatial variation of salinity (TDS) and groundwater flow directions is given in **Chapter 5** of this report.

Table 5 Summary of Project Boreholes

Table 6 Summary of Production Boreholes

Several boreholes intercepted aquifers in the basal sandstone units of the overlying Mosolotsane and Kule (Kwetla) Formations in the Ncojane Block (**Table 7**). These relatively shallow aquifers often contain groundwater with highly variable quality with TDS values ranging from 1807 mg/L to 12,350 mg/L and have the potential to contaminate the underlying aquifers of the Otshe sandstone if they are not properly sealed off. These water strikes were grouted before continuing drilling into the underlying Otshe Sandstone aquifers.

Table 7 Water Strikes, EC, TDS for Mosolotsane and Kule (Kwetla) Formation

BH No	Water Strike (m)	Aquifer	EC (μS/cm)	TDS (mg/L)
BH10212	144	Kule Basal Sandstone	5940	3861
BH10212	155	Kule Basal Sandstone	6950	4518
BH10222	150	Kule Basal Sandstone	2900	1885
BH10314	105	Mosolotsane	14230	9250
BH10314	116	Mosolotsane	18700	12155
BH10314	155	Kule Basal Sandstone	19000	12350
BH10315	156	Kule Mudstone	2780	1807
BH10315	177	Kule Basal Sandstone	3310	2152
BH10315	210	Kule Basal Sandstone	4330	2815

3.2.2.2 MATLHO-A-PHUDUHUDU BLOCK

A lot of exploration work was carried out in the Matlho-a-Phuduhudu Block during the Hunhukwe / Lokalane project and consequently only five monitoring boreholes were drilled in this block during the Matsheng Project. These boreholes were drilled at the sites of existing exploration boreholes to provide observation boreholes for estimation of the storativity values of the Ntane Sandstone during pump testing as well as providing water level head measurements (BH10225 and BH10317) for comparison with the underlying Ecca Group aquifer (Otshe Formation). In addition as drilling new monitoring (observation) boreholes, five existing boreholes were also cleaned during the project. One of these five boreholes was converted into a nested piezometer cluster (BH9297 and BH10320) to monitoring different levels of the Ecca aquifer while the rest of the boreholes were cleaned to allow pump testing with observation boreholes for purpose of calculating of the Ntane aquifer storativity values. A summary of the project boreholes in the Matlho-a-Phuduhudu Block is given in **Table 5**.

One existing borehole BH9293 terminated in the Kule Formation was deepened from 167 to 284m because the existing TEM interpretation (WCS 2001) indicated that drilling was stopped before intercepting the Ecca aquifer was intercepted. However a dolerite sill was intercepted at 239 m during drilling instead of the expected Ecca formation and the borehole was terminated 284 m in the dolerite.

As expected, the main aquifers in the Matlho-a-Phuduhudu Block are developed in the Ntane and Otshe Formations. Water strikes in the Ntane sandstone range from 143 to 244 m with TDS values ranging from 341 mg/L to 1829 mg/L. The rest water levels in the Ntane aquifer varied from 135.305 to 148.048 m below ground level. A comparative analysis of the groundwater head of the two main aquifers i.e. the Ntane and Ecca (Otshe) at BH10225 and BH10317 indicated that the head of the Ntane aquifer is higher than that of the Ecca. A detailed analysis of the Ntane sandstone aquifer, in corporating existing borehole data is given in **Chapter 5** of this Report. This analysis includes among others aquifer geometry, spatial variation of TDS and groundwater flow.

3.3 DISCUSSION OF DRILLING RESULTS

As indicated earlier, boreholes were sited and drilled in different geological/hydrogeological environments to enable a full evaluation of the potential of the aquifers in the project area particularly the Ecca in terms of borehole yields and groundwater quality. These environments included the following;

- Structurally undisturbed areas
- Structurally disturbed (fractured) areas
- Areas with dolerite sill intrusions

The drilling results are discussed below for each these environments.

3.3.1 STRUCTURALLY UNDISTURBED AREAS

Boreholes which were sited in structurally undisturbed areas include, BH10211, BH10215, BH10222, BH10228, BH10229, BH10314 and BH10316. Results from these boreholes (**Table 8, Figure 5**) indicate that the yield of the Ecca aquifer in these areas tends to be high. The majority of the borehole tested, at rates of between 40 to 95 m^3/hr with the exception of BH10229 and BH10222 which were tested had rates of 12 and 20 m^3/hr respectively, indicating that the Ecca aquifer occurs as a primary aquifer. TDS values for these boreholes range from 179 mg/L to 1210 mg/L. All boreholes with higher TDS values (BH10222, BH10229 and BH10314) had water strikes in the basal sandstones of the Kule (Kwetla) Formation in addition to water strikes in the main Otshe Sandstone aquifers. Elevated fluoride and sodium concentrations in the range 2.3 to 2.5 mg/L and 317 to 471 mg/L respectively (**Table 8**) were also found in these boreholes. Some boreholes, which were expected to intercept a thick sequence of coarse grained sandstone actually intercepted dolerite intrusions between the Ecca Group and the overlying Kule Formation (e.g. BH10228 and BH10211) but these dolerites did not seem to have any effect on the groundwater quality and yield (**Table 8**). Boreholes with higher fluoride, TDS and sodium values were mostly located southeast of aeromagnetic data interpreted fault F6 (**Figure 5**).

3.3.2 STRUCTURALLY DISTURBED AREAS

Two exploration boreholes, BH10214 and BH10216 were drilled close or within fault zones to evaluate the role of faulting on groundwater quality, lithology and borehole yields. These boreholes encountered multiple dolerite sill intrusions at different levels and contained groundwater with relatively high TDS with values of 1760 and 2016 mg/L. Fluoride and sodium concentrations for these two boreholes were also high with values of 3.5 to 2.3 mg/L and 746 to 648 mg/L respectively for these constituents. The Ecca lithology encountered in these boreholes was predominantly silty to fine grained sandstone, with minor medium to coarse grained sandstone. The tested yields of these two boreholes were 10 and 45 m^3/hr.

3.3.3 AREAS WITH DOLERITE INTRUSIONS

Some exploration boreholes were purposely sited in areas with interpreted dolerite sill intrusions for purposes of evaluating the role of these sills on groundwater quality while others intercepted dolerite sills in areas which were expected to be dolerite free. It was not always possible to distinguish dolerite free areas from areas with thick sandstones was that weathered dolerite has the same resistivity range as coarse sandstones and these flat lying sills were not picked by ground magnetic profiling. The boreholes which were deliberately sited in areas with dolerite intrusions were BH10214, BH10219, BH10212 and BH10216. Boreholes which were not expected to intercept dolerite sills were BH10228 and BH10211. Drilling results from this type of environment indicated that boreholes with multiple dolerite intrusions and saturated basal sandstone units of the Kule Formation tended to have groundwater with elevated fluoride and sodium levels (**Table 8**). These boreholes include BH10212, BH10214 and BH10216. If the dolerite intrusion is below the Kule basal sandstones it appears that the dolerite isolates the basal sandstone units from the underlying Otshe aquifer. When the dolerite intrusions were in areas where the Kule basal sandstone unit is unsaturated, the water quality was not affected probably indicating that the source of elevated constituents is basal Kule sandstone (BH10228 and BH10211).

Table 8 Yields, TDS, F and Na Concentrations for Boreholes in Different Environments

BH No	Tested Yield (m^3/hr)	Na (mg/L)	F (mg/L)	TDS (mg/L)	Environment	Remarks
BH 10212	12	315	1.8	845	Disturbed, Dolerite Expected	Multiple Dolerite intercepted, Kule Sandstone Saturated
BH 10214	10	746	3.5	2016	Disturbed, Dolerite Expected	Multiple Dolerite intercepted, Kule Sandstone Saturated
BH 10216	45	648	2.3	1760	Disturbed, Dolerite Expected	Multiple Dolerites intercepted, Kule Sandstone Saturated
BH 10219	95	326	1.8	794	Disturbed, Dolerite Expected	Single Dolerite Intercepted
BH 10228	93	81	0.59	397	Undisturbed	Unexpected dolerite intercepted below unsaturated Kule Formation
BH 10316	95	30	0.4	179	Undisturbed	Kule Unsaturated
BH10211	70	126	0.69	474	Undisturbed	Thin Dolerite intercepted/ Kule Unsaturated
BH10215	32	149	0.7	538	Undisturbed	Kule Unsaturated
BH10221	30	250	1.1	698	Disturbed	Unexpected dolerite intercepted. Kule Formation Unsaturated
BH10222	12	317	2.3	890	Undisturbed	Saturated Kule Sandstone above main aquifer
BH10229	20	317	2.3	870	Undisturbed	Some water Strikes in interlayered mudstones in Ecca aquifer
BH10314	40	471	2.5	1210	Undisturbed	Saturated Kule Sandstone above main aquifer

From the drilling results, it was concluded that areas with the best potential for wellfield development in terms of water quality and yield are areas underlain by undisturbed thick Ecca (Otshe Formation) aquifers with thin and unsaturated units of the overlying Mosolotsane and Kule formation or areas with dolerite intrusions between the Ecca and the overlying Kule basal sandstones. These areas are located to the northwest of fault F6 (Figure 4) and the Ncojane wellfield is located in such an area.

A detailed description of the structural control on aquifer geometry and spatial variation of groundwater quality is provided in **Chapter 5** of this Report.

3.3.4 VARIATION OF WATER QUALITY WITH DEPTH

Drilling results have shown that in some boreholes the conductivity decreases with depth. This occurred mostly in boreholes with water strikes in the basal sandstones of Mosolotsane and Kule (Kwetla) Formations in and a few boreholes with water strikes in the upper mudstone units of Otshe Formation. This trend clearly shows that these brackish or saline aquifers have to be properly sealed off to avoid contaminating the lower Ecca aquifers. The drilling water quality results of some boreholes with this trend are given **Table 9.** This trend was also noted during the Hunhukwe / Lokalane Project (WCS 2001).

Table 9 Variation of Drilling Water Quality with Depth

BH No	Water Strike (m)	Water Strike in	EC (μS/cm)	TDS (mg/L)
BH10229	183	(Otshe Mudstone 1)	5510	3,416
BH10229	198	Inter layered Mudstone in Sandstone 1	5970	3,701
BH10229	253	Otshe Mudstone 2	2080	1,290
BH10229	266	Otshe Mudstone 2	1775	1,101
BH10229	282	Otshe Sandstone 2	1503	932
BH10314	105	Mosolotsane Basal Sandstone	14230	8,823
BH10314	116	Mosolotsane Basal Sandstone	18700	11,594
BH10314	155	Kule Basal Sandstone	19000	11,780
BH10314	232	Otshe Mudstone 2	5040	3,125
BH10314	258	Otshe Mudstone 2	3700	2,294
BH10314	276	Otshe Sandstone 1	2800	1,736
BH10315	156	Kule Mudstone	2780	1,724
BH10315	177	Kule Basal Sandstone	3310	2,052
BH10315	210	Kule Basal Sandstone	4330	2,685
BH10315	250	Otshe Sandstone 1	890	552
BH9243	179	Mosolotsane Basal Sandstone	1486	921
BH9243	236	Otshe Sandstone 2	570	353
BH9243	248	Otshe Sandstone 2	420	260

Figure 4 Location of Production Boreholes

Figure 5 Integrated Base Map

3.4 SUMMARY AND CONCLUSIONS

Geophysical logging provided valuable information about the subsurface conditions of the project area, and supplemented information obtained during drilling and interpretation of TEM smooth model plots. Water inflow zones were also recognized in some boreholes, but generally they are difficult to infer from the geophysical logs probably indicating that the aquifers in the area are primary (not fractured). To best delineate contacts, a combination of electrical parameters, natural gamma and neutron logs are very useful since they complement each other.

From the review of existing logging data and interpretation of the logging data acquired during the project, it is can be concluded that:

- Natural gamma, resistivity and porosity together with the observed lithology provided very useful information on aquifers properties and assisted in interpretation of various lithological units
- Resistivity logs provide useful information on water quality variations with depth since a good correlation between groundwater electrical conductivity (EC), fluid conductivity, and formation resistivity was found.
- Water temperature was found to be very useful in identifying water inflow zones in only a limited number of cases mainly because of nature of the aquifer, however the water temperature logs picked the static water level in all the borehole.

3.5 PUMP TESTING PROJECT BOREHOLES

3.5.1 OVERVIEW

Pump testing of the exploration boreholes was carried out by Boreholes and Wells (Pty) Ltd Contractor with operations being carried between 12th October 2006 and 11th March 2007. A total of 17 boreholes were tested 14 of which are located in Ncojane Block and 3 located in the Matlho-a-Phuduhudu Block. Four of the 14 boreholes located tested boreholes tested in the Ncojane Block had observation boreholes while the three tested boreholes in the Matlho-a-Phuduhudu Block all had observation boreholes. All the tests in the Matlho-a-Phuduhudu Block were on boreholes which were previously tested during the Hunhukwe/Lokalane project and a repeat test was also carried out in one borehole in the Ncojane Block. These repeat tests were to allow for estimation of aquifer storativity values using data from observation boreholes which were not available during the Hunhukwe/Lokalane Project.

For the production phase, Geo-Civil Pty, Ltd was the appointed Contractor. Production phase pump testing activities commenced on 18th July 2007 and were completed on 18th October 2007. A total of 6 boreholes were tested out of which two had observation boreholes.

The location of the tested boreholes is given in **Figure 5**

3.5.2 OBJECTIVES OF PUMPING TESTS

Pumping tests were carried out to determine the yield potential, aquifer parameters, and performance characteristics of the completed boreholes. Groundwater samples were also collected for chemical and some isotope analysis tests for evaluation of compliance to drinking water quality standards (BOS32:2000), evaluation of groundwater types and recharge evaluation. The tests consisted of an initial calibration test, a step drawdown test (SDT), a constant rate test (CRT) and a recovery test.

3.5.3 METHODOLOGY

Water level data were collected manually from a fixed measuring point at the wellhead using an electric dipper. Measurements in the pumping borehole were taken through a PVC dipper access tube installed in the borehole. In monitoring (observation) boreholes measurements were also taken manually using an electric dipper. The discharge rate was measured using three methods: recording of the time required to fill a container of a known volume, using a manometer and an orifice plate, and a flow meter. Water level, discharge measurements and well head water chemistry analysis (temperature, electrical conductivity, pH and dissolved oxygen) were recorded on boreholes at specific times during the pumping tests. In observation boreholes only water level measurements were recorded.

Two boreholes tested in the Matlho-a-Phuduhudu Block had observation boreholes while for the Ncojane Block six boreholes had observation boreholes. The data from observation boreholes was used to calculate the aquifer storativity values in addition to the transmissivity values obtained from the rest of the boreholes.

3.5.3.1 TEST FORMAT

Calibration tests (15 minutes duration steps) were carried out to set up the pump testing equipment and to plan the pumping rates for the step drawdown tests. Step drawdown tests were conducted to evaluate the performance of the borehole in terms of the components of drawdown due to aquifer losses and well losses, and to select an optimal pumping rate for the constant rate test. Step drawdown tests normally consisted of 4 to 6 pumping steps with the discharge rates increased at the beginning of each step. The duration of each complete step of the step drawdown test was 100 minutes.

The duration of the CRT was usually 72 hours but in low yielding boreholes the duration was either 24 or 48 hours. In two boreholes, the duration of the tests were 51 and 60 hours due to mechanical breakdown of the pump testing unit. Four long duration tests were carried out with durations of 115, 120, 168 and 212 hours. The CRTs were immediately followed by recovery tests of 24 hours duration.

3.6 PUMPING TEST RESULTS

3.6.1 STEP DRAWDOWN TEST DATA ANALYSIS

Drawdown in a pumped borehole comprised of aquifer losses and well losses. The well losses are divided into linear and non-linear head losses. Step tests were carried out to determine the coefficients of aquifer and well losses, transmissivity as well as to decide the optimal discharge rates for the constant rate test.

Step drawdown pumping test data were analysed by preparing semi-logarithmic plots of time versus drawdown and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method in the computer programme StepMaster™. The Hantush-Bierschenk method was used to determine aquifer loss and well loss coefficients (B and C) and to predict the drawdown in a well at a specified pumping rate after a specified period of time (Δt). This method is suitable for confined, leaky, and unconfined aquifers pumped step-wise at increasing rates. The coefficients B (aquifer loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q.

An initial estimate of the transmissivity was also made from the step drawdown test data using the Eden-Hazel (1973) analytical method using the computer programme StepMaster™. In order to provide additional insights into the drawdown characteristics of the tested boreholes, specific capacities values at the end of each pumping step were also determined for each borehole.

3.6.2 STEP DRAWDOWN TEST RESULTS

The results of step drawdown test analysis for each borehole are summarised in **Tables 10** and **11** for the Ntane and Ecca Aquifers (Otshe) respectively. The results indicate that the specific capacities are generally inversely proportional to the pumping rate. However in some boreholes, an increasing trend in specific capacity values was observed, probably indicating that some degree of borehole development occurred during the step drawdown test. However, borehole leaky aquifers will have the same trend.

Step drawdown tests were carried out in three boreholes tapping the Ntane sandstone aquifer at discharge rates of between 10 to 6 m^3/hr (**Table 10**). Aquifer loss (B) values ranging between 5.82×10^{-3} to 8.62×10^{-3} (d/m^2) were obtained for the Ntane Aquifer while well loss coefficient (C) values of between -8.97×10^{-7} to 9.92×10^{-6} (d^2/m^5) were obtained. The transmissivity values calculated from the step drawdown data for the Ntane Sandstone aquifer ranges between 43 and 64 m^2/d.

Step drawdown tests were carried out in 20 boreholes completed in the Otshe sandstone aquifer (**Table 2**) at discharge rates of between 4 and 102 m^3/hr. For the Ecca aquifer, the B value ranged from 4.10×10^{-7} to 9.09×10^{-2} (d/m^2) and the C values ranged from -2.82×10^{-7} to 1.1×10^{-2} (d^2/m^5). Transmissivity values estimated from step drawdown test data for the Ecca (Otshe) aquifer range between 4 to 427 m^2/d.

The negative C value obtained in some boreholes may be attributed to some degree of borehole development, though leakage from overlying aquifers is also known to have the same effect. Example plots of step test data interpretations are presented in **Appendix A**

Table 10 Step Test Results for Ntane Aquifer

BH	Location	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
9237	Matlho-a-Phuduhudu	8.62E-03	9.92E-06	64.8	20.0	6.30	6.30	3.17
					30.0	5.20	11.50	2.61
					40.0	6.26	17.76	2.25
					50.0	6.52	24.28	2.06
9240	Matlho-a-Phuduhudu	8.35E-03	1.50E-06	43.4	20.0	4.12	4.12	4.85
					30.1	2.96	7.08	4.25
					41.4	3.10	10.18	4.07
					50.1	2.05	12.23	4.10
					62.21	3.06	15.29	4.07
9239	Matlho-a-Phuduhudu	5.82E-03	-8.97E-07	56.4	10.2	1.36	1.36	7.50
					20.3	1.47	2.83	7.17
					30.2	0.54	3.37	8.97
					40.3	1.36	4.73	8.53
					50.2	1.24	5.97	8.41

Table 11 Step Test Results for Ecca Aquifer

BH	Location	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
9295	Metsimantsho	3.82E-03	-2.82E-07	427.0	43.0	3.65	3.65	11.78
					65.0	1.66	5.31	12.24
					80.0	0.87	6.18	12.95
					102.0	1.56	7.74	13.18
10221	Ncojane Ranches	8.67E-02	6.63E-06	35.1	10.0	19.50	19.50	0.51
					15.0	15.00	34.50	0.43
					20.0	10.90	45.40	0.44
					30.0	17.70	63.10	0.48
		5.82E-02	6.57E-06	28.6	10.0	13.80	13.80	0.72
					15.0	8.55	22.35	0.67
					20.0	8.67	31.02	0.64
					25.0	6.01	37.03	0.68
					30.0	7.25	44.28	0.68
10211	Ncojane	1.99E-02	-1.07E-06	48.1	31.7	14.80	14.80	2.14
					42.9	3.51	18.31	2.34
					50.7	4.52	22.83	2.22
					60.4	4.22	27.05	2.23
					70.1	3.24	30.29	2.31
					80.1	3.87	34.16	2.34
10222	Ncojane	8.73E-02	1.10E-04	3.8	4.0	11.30	11.30	0.35
					7.0	2.96	14.26	0.49
					10.0	9.24	23.50	0.43
					13.0	17.90	41.40	0.31
					16.0	9.94	51.34	0.31
10228	Ncojane	1.37E-02	-7.79E-07	111.0	30.2	8.76	8.76	3.45
					45.5	7.09	15.85	2.87
					60.2	1.13	16.98	3.55
					75.3	6.11	23.09	3.26
					92.5	2.49	25.58	3.62
10229	Metsimantsho	9.09E-02	-3.19E-05	19.7	10.1	19.70	19.70	0.51
					14.1	8.74	28.44	0.50
					18.2	3.70	32.14	0.57
					22.2	7.60	39.74	0.56

Table 11 continued

BH	Location	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w ($m^3/hr/m$)
10314	Metsimantsho	4.61E-02	-1.93E-06	25	10	11.5	11.5	0.87
					20	8.69	20.19	0.99
					30	12.7	32.89	0.91
					40	8.18	41.07	0.97
					50	13.2	54.27	0.92
10215	Metsimantle	4.08E-02	4.78E-06	31	15.2	15.7	15.7	0.97
					21.3	6.48	22.18	0.96
					25.9	4.75	26.93	0.96
					30.2	3.91	30.84	0.98
					35.2	8.24	39.08	0.9
10315	Metsimantsho	9.10E-03	-6.20E-07	64	32.5	6.73	6.73	4.83
					45.3	2.38	9.11	4.97
					60.3	2.87	11.98	5.03
					70	1.41	13.39	5.23
10212	Metsimantsho	4.53E-02	6.47E-05	4	8	10.8	10.8	0.74
					12.1	7.83	18.63	0.65
					16.1	8.92	27.55	0.58
					20.1	11.7	39.25	0.51
					24.1	5.04	44.29	0.54
10216	Ukwi	2.10E-02	4.36E-06	15	20	11.5	11.5	1.74
					30	5.27	16.77	1.79
					40	7.4	24.17	1.65
					50	5.59	29.76	1.68
					61	12	41.76	1.46
10316	Metsimantle	1.49E-03	7.46E-08	300	25	0.943	0.943	26.51
					55	1.11	2.053	26.79
					75	0.732	2.785	26.93
					95	1.14	3.925	24.2
10219	Ukwi	1.98E-03	5.98E-08	48	31.3	14.8	14.8	2.11
					50.6	9.75	24.55	2.06
					72	8.76	33.31	2.16
					93	11.7	45.01	2.07
10402	Ncojane	1.30E-02	1.07E-06	75	25	7.68	7.68	3.26
					40	3.79	11.47	3.49
					55	2.66	14.13	3.89
					70	3.12	17.25	4.06
					77	5.39	22.64	3.4

Table 11 continued

BH	Location	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w ($m^3/hr/m$)
10404	Ncojane	1.54E-06	1.16E-02	82	30	9.23	9.23	3.25
					40	3.05	12.28	3.25
					50	4.45	16.73	2.98
					60	2.76	19.49	3.07
10405	Ncojane	4.10E-07	4.50E-03	194	30	3.3	3.3	9.09
					45	2.05	5.35	8.41
					60	2.56	7.91	7.58
					77	1.26	10.71	7.19
10407	Ncojane	2.97E-03	2.80E-06	73	30	3.01	3.01	9.97
					40	2.67	5.68	7.04
					50	3.56	9.24	5.41
					65	1.23	10.47	6.21
					77	4.32	14.79	5.21
10410	Ncojane	1.19E-02	4.40E-07	68	25	8.36	8.36	2.99
					40	2.15	10.51	3.81
					55	3.69	14.2	3.87
					70	5.39	19.59	3.57
					77	7.9	27.49	2.8
10411	Ncojane	1.06E-02	8.84E-07	61	20	6.86	6.86	2.92
					35	3	9.86	3.55
					50	3.66	13.52	3.7
					65	4.77	18.29	3.55
					78	5.36	23.65	3.3

3.6.3 CONSTANT RATE AND RECOVERY TEST DATA ANALYSIS

The CRT data were interpreted using the Theis, Cooper-Jacob, Hantush leaky (with storage in the confining layer) and Neuman unconfined analytical solutions using the computer programme "Aqtesolv". In pumping boreholes, these methods allowed for the calculation of transmissivity while in observation boreholes both storativity and transmissivity values were determined. The recovery data for all the boreholes were interpreted by the Theis recovery method. Transmissivity was the only parameter calculated by this method. The plots of interpreted data are in **Appendix A.**

In an ideal confined aquifer, the drawdown should form a straight line on a semi-log plot, however the early time is always distorted due to casing storage and skin effects and the early data was not interpreted. The results of the constant rate and recovery tests for all the boreholes in the project area are summarised in **Tables 12** and **13** for the Ntane and Ecca (Otshe) aquifers respectively.

Aquifer responses obtained from interpretation of pumping test data in conjunction with borehole lithological details ranged from unconfined with delayed yield, confined, confined leaky and confined with barrier boundary (**Appendix A)**. For the majority of boreholes, completed in the Ecca aquifer the aquifer response was confined while the Ntane aquifer displayed mostly unconfined with delayed yield and leaky confined behaviour. In boreholes which displayed barrier boundaries, the latter slope of the drawdown curve was not interpreted. However for production boreholes the transmissivity obtained from the latter stages of the drawdown curve was utilised in order to obtain the most conservative estimate of the long term abstraction rate.

3.6.4 NTANE SANDSTONE AQUIFER

Three observation boreholes were completed next to existing boreholes drilled during the Hunhukwe/Lokalane Project. Although step tests were carried out in all the three existing boreholes, constant rate tests were only completed in two of these. The third borehole (BH9239) could not be tested due to excessive sand pumping despite attempts to develop the borehole using a drilling rig. The discharge rates for the two boreholes, BH9240 and BH9237 were 56 and 48 m^3/hr respectively with durations of 48 and 120 hours (**Table 12**). Transmissivity values obtained from interpretation of project test pumping data ranged from 37 to 88 m^2/d while the storativity values ranged from $6.7x10^{-4}$ to $2.2x10^{-3}$.

For the two re-tested boreholes tapping the Ntane aquifer, one had a confined aquifer response and the other is unconfined with delayed yield. The majority of the boreholes tapping the Ntane were interpreted to be unconfined during the Hunhukwe / Lokalane Project, but re-interpretation of the data during the inception phase showed that most of the aquifer responses were semi-confined. It has to be pointed out that although the pumping durations during the Hunhukwe/Lokalane Project were very long, the drawdowns were small because of low pumping rates, which could have resulted in unreliable results.

Table 12 Summary of Constant Rate and Recover Tests, Ntane aquifer

BH No.	Total Drawdown (m)	Tested Dates	CRT Duration (hours)	Q (m^3/hr)	Pumping borehole		Obs. BH No	Observation boreholes		Aquifer type/ Response	
					T (m^2/d)			Pumping phase		Recovery phase	
					Pumping	Recovery		T (m^2/d)	S	T (m^2/d)	
9237	31.35	16/10/05 - 28/10/05	120	48	37	98	10223	62	6.7E-4	88	Semi Confined
9240	17.79	1/11/05 - 6/11/05	48	56	44	51	10225	51	2.2E-3	55	Unconfined with delayed yield

3.6.5 ECCA AQUIFER

Constant rate tests were completed in a total of 20 boreholes tapping the Ecca (Otshe) aquifer during the Matsheng Project including a previously tested borehole (BH9295). The discharge rates for these tests ranged from 10 to 95 m^3/hr and the test durations were mostly 72 hours. However, for one relatively low yielding borehole the test duration was 24 hrs and three boreholes had durations of 115, 212 and 168 hrs (**Table 13**). The pump intakes were between 150 and 180 m.

The transmissivity values obtained for the Ecca (Otshe) aquifer from project boreholes ranged from 3 to 474m^2/d (different interpretation methods) while the storativity values ranged from $1.00x10^{-4}$ to $4.05x10^{-6}$. The aquifer type interpreted from test pumping data is mostly confined with some boreholes showing confined leaky and confined with barrier responses.

Table 13 Summary of Constant Rate and Recover Tests, Ecca aquifer

BH No.	Total Drawdown (m)	CRT Duration (hours)	Q (m^3/hr)	Pumping borehole			Observation boreholes			
				Pumping Phase	Recovery Phase	Obs. BH No	Pumping T (m^2/d)	S	Rec T (m^2/d)	Aquifer Type
9295	8.62	212	91	408	440	10220	420	7.70E-04	398	Confined
10211	35.11	72	70	97	82	10210	66	3.25E-04	82	Confined-Leaky
10222	57.28	72	12	7	7	NA				Confined
10228	27.78	115	93	418	474	10227	537	4.05E-06	431	Confined
10229	44.23	72	20	21	15	NA				Confined
10314	51.52	72	40	35	33	NA				Confined
10215	42.01	72	32	40	40	NA				Confined
10221	58.49	72	30	23	23	NA				Confined
10315	12.1	72	55	127	151	NA				Confined
10212	57.51	48	12	5	3	NA				Confined with barrier
10216	41.3	75	45	30	27	NA				Confined
10316	5.47	72	95	404	372	NA				Confined
10219	52.81	51	95	51	44	10218	51	6.73E-04	40	Confined Leaky with storage
10214	57.62	24	10	3	3	NA				Confined
10402	20.64	72	70	150	111	10227	266	1.31E-04	259	Confined leaky with barrier boundary
						10228	251	1.31E-04	243	
10404	26.40	168	65	95	95	10210	75	1.00E-04	82	Confined leaky with storage
10405	12.55	72	75	162	172	NA				Confined leaky with barrier boundary
10407	21.55	60	65	147.5	143	NA				Confined leaky
10410	25.75	72	70	87	85	NA				Confined leaky with barrier boundary
10411	22.36	72	70	163	189	NA				Confined leaky with barrier boundary

A comparative analysis of all testing pumping data for boreholes completed in Ntane and Ecca (Otshe) aquifers indicates that the average transmissivity value for the Ntane aquifer is 43 m^2/d while the average value for the Ecca aquifer is 142 m^2/d. The average tested yield for the Ecca aquifer is also higher than of the Ntane aquifer at 59 m^3/hr and 44 m^3/hr respectively (**Table 14**).

Table 14 Aquifer Properties of Representative Boreholes Completed in the Two Main Aquifers of the Project Area

Ntane Sandstone Aquifer

BH No	Tested Yield (m^3/hr)	CRT Duration (days)	S	Average T (m^2/d)
9236	28	3		25
9237*	48	5	6.70E-04	68
9239	25	3		62
9238	8	4		6
9240	30	4		59
9240*	56	2	2.23E-04	48
9241	16	7		4
9297	52	9		68
Average	**44**			**43**

Ecca (Otshe) Aquifer

BH No	Tested Yield (m^3/hr)	CRT Duration (days)	S	Average T (m^2/d)
8469	33	3		20
8470	35	3		41
8346	48	3		122
8363	53	3		128
8364	45	3		116
9184	30	5		95
9243	31	1		32
9294	45	2		62
9295	53	7		654
9295*	91	9	7.70E-04	424
9298	20	7		18
10211	70	3	3.25E-04	90
10215	30	3		40
10216	45	3		29
10219	95	2	6.73E-04	47
10221	30	3		23
10228	93	5	4.05E-06	446
10229	20	3		18
10314	40	3		34
10315	55	3		139
10316	95	3		388
10402	70	3	1.31E-04	213
10404	65	7	1.00E-04	87
10405	75	3		167
10407	65	3		145
10410	70	3		86
10411	70	3		176
Average	**59**		**3.34E-04**	**142**

9295* Existing Borehole Re-tested during Matsheng project

3.7 RECOMMENDED ABSTRACTION RATES FOR THE PRODUCTION BOREHOLES

The recommended daily abstraction rates for the production boreholes were calculated based on the Cooper-Jacob approximation of the Theis Equation The Cooper-Jacob equation can be expressed as a follows;

$Q = 4\pi\ Ts/[2.3Log(2.25Tt/r^2S)]$

where:
Q = sustainable yield (m^3/day)
T= transmissivity (m^2/day)
s = available drawdown (m) {recommended pump intake-SWL}
t = pumping time (days)
r = radius of the borehole in (m)
S= storativity
It has to be noted that the yield calculated from the above equation is not very sensitive to the Log variables in the equation. However it is sensitive to transmissivity and available drawdown, therefore an accurate determination of these parameters is critical. The transmissivity was obtained from late time pumping testing data for each production borehole since most of these had negative boundaries and the storativity value was obtained from pumping boreholes with which had observation boreholes.

The recommended pump settings for all the production boreholes was set at 180 m which maximises the available drawdown, taken as the recommended pump intake minus the rest water level measured prior to pumping test.

A 20 year duration of continuous pumping was used in the calculation of the abstraction rates. By using long pumping durations it is believed (Kirchener and Van Tonder, 1995) that the influence of negative boundary conditions will be minimised. As it is not possible to predict what boundaries will be encountered beyond the duration of a pump test it is recommended that the pumping durations should be equal or longer than the anticipated period of no recharge.

The total daily abstraction from the 6 production boreholes of the Ncojane Wellfield is calculated as 9637 m^3/d which is more than the combined daily water demand of the Matsheng Villages and the Secondary Centres of 1655 m^3/d.

The daily abstraction rates obtained analytically were used in the numerical model to simulate wellfield abstraction. Numerical modelling results indicate that the wellfields should sustain the recommended yields, under a continuous pumping design for over 30 years.

It has to be noted that the daily abstraction rates are based on pumping test data which can not predict the pumping effects beyond the test duration and numerical modelling. It is therefore necessary that once the boreholes are brought into operation, regular water level and water quality monitoring is carried out to establish the maximum sustainable yield of each borehole. Long term sustainable abstraction rates can be sustainable yields can through systematic careful monitoring and analysis of the data. It is also paramount to monitor groundwater quality for compliance to the Botswana drinking water standards, BOS 32:2000 during operation of the wellfield The recommended daily abstraction rates for the production boreholes are presented in **Table 15.**

Table 15 Recommended Abstraction Rate Ncojane Wellfield

BH Number	Easting	Northing	Screened intervals (m)	Recommended Pump Intake (m)	Pre-CRT SWL (m)	Available drawdown (m)	Recommended drawdown (m)	*T (m^2/d)	S	Calculated yield (m^3/hr)	Tested yield (m^3/hr)	Recommended yield (m^3/hr)	Daily Abstraction 24 hrs pumping (m^3/d)
BH10402	441130	7435358	189 to 248	180	106.4	74	74	45	1.31E-04	64	70	64	1 542
BH10404	445760	7438700	205 to 226 & 236 to 245	180	108.33	72	72	94	1.31E-04	127	65	65	1 560
BH10405	442666	7436299	190 to 195 & 200 to 250	180	106.25	74	74	55	1.31E-04	78	75	75	1 800
BH10407	440170	7432108	198 to 243	180	103.65	76	76	46	1.31E-04	68	65	65	1 560
BH10410	442253	7428629	213 to 258	180	101.52	78	78	43	1.31E-04	66	70	66	1 574
BH10411	438645	7431005	211 to 261	180	103.6	76	76	45	1.31E-04	67	70	67	1 601
											Total	**402**	**9 637**

*T Later time transmissivity to allow for negative boundary

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4 DOWNHOLE GEOPHYSICAL LOGGING

4.1 OBJECTIVES OF LOGGING

The objectives of conducting borehole geophysical logging during the Matsheng Groundwater Development Project were as follows;

- To delineate and refine depths to contacts of the different stratigraphic units intercepted during drilling
- To correlate the lithology intercepted during drilling with the interpreted TEM smooth model layers
- To examine the water quality of the aquifer zones in the area
- To guide casing and screen placements to help in maximizing borehole yields
- To correlate the intercepted lithologies between boreholes to assist in delineating aquifer geometry

4.2 METHODOLOGY AND EQUIPMENT

During the exploration and production phases, borehole logging was conducted using the latest of Century's logging tools called System VI. It represents Century's sixth generation of logging equipment, and it is conceptually a peripheral device to the users desktop or laptop computer. All logging specific hardware/electronics are packaged into a single small box and connected to the user's computer via a standard Ethernet cable connection. System VI automatically identifies the connected logging probe and comes equipped with all software and hardware necessary to log, edit, process, interpret and print data.

Three downhole probes listed in **Table 16**, all allowing for measurements of several parameters, were used during the project's logging operations (exploration and production phases). Each sensor within the probe measures the appropriate parameter at the selected sampling interval which was 1 cm for this project.

Table 16 Logging Probes used During the Exploration Phase

Probe Number	Parameters measured
8074A	Diameter Calliper (3-arm)
8057A	Natural Gamma Neutron and neutron porosity Temperature and delta temp Point Resistance Self Potential Lateral Resistivity 16 inch Resistivity 64 inch Resistivity
9041A	Natural Gamma Fluid Resistivity Temperature and delta temp Point Resistance Self Potential Lateral Resistivity 16 inch Resistivity 64 inch Resistivity Fluid Conductivity

All geophysical logs were interpreted individually and interpretations concentrated on the identification of lithologic units and water quality in the logged boreholes. While each log carries some information about the traversed lithology, the use of multiple parameters (logs) improves the accuracy and the certainty of the interpretation, as the marker horizons may not always appear clearly on all lithological logs. The interpretation for each logged borehole is summarized is **Table 17** and more details are in ***Volume 3C; Down Hole Geophysics report.***

In the sandstone/siltstone/mudstone environment of the project area, the various logs were expected to respond in the following manner:

- Natural Gamma - increases with increasing clay content and very low in dolerites
- Neutron-Neutron - increasing neutron porosity with increasing silt content and water saturation.
- Resistivity - decreasing with increasing salt content, it is also generally high in fresh water sandstones and dolerites

4.2.1 DATA ACQUISITION AND QUALITY CONTROL

Data was obtained using three probes for all boreholes during the course of the project. All logging tools were run in the upward direction with the 8057A or the 9041A probes run as a first probe to record temperature in a relatively stable environment. Logging was performed at the recommended speed of 6 m/minute.

In order to provide the highest possible data quality and integrity of the collected data one existing borehole, BH8346, with known lithological information was chosen as a calibration borehole. This borehole was logged several times (4 times) during the course of the project. This calibration exercise was undertaken prior to, during and on completion of the exploration and production phases logging. All parameters remained within acceptable limits as no significant shifts were observed during the entire logging operations.

4.3 DATA PROCESSING AND INTERPRETATIONS

On completion of logging of each borehole, the raw unprocessed data was backed up to diskettes and converted to LAS format using the Analytical Compu Log (ACL) software, which accompanies the Portable Compu Log (PCL) logging software. The converted data was then imported into VIEWLOG (V1.0) software for interpretation purposes. Geophysical logging data interpretations were correlated with lithological information obtained from drilling chip samples. All the measured parameters (natural gamma, density, neutron, resistance, normal resistivity, fluid conductivity, and calliper) were utilized for the interpretation.

Table 17 Interpretation of the Logged Boreholes

Borehole Number	Depth Logged	Lithostratigraphic Interpretations						
		Base of Kalahari (m)	Base of Ntane (m)	Base of Mosolotsane (m)	Base of Beaufort (m)	Base of Ecca (Otshe) (m)	Top of ECCA (Upper Kobe) (m)	Dolerite (m)
BH10216	249.2	13	Absent	Absent	126	212	212	58-71 84-99 137-165
BH10212	198.08	27	Absent	107	159	196+		27-69, 121 -136
BH10215	249.77	15	Absent	Absent	106	226	226	Absent
BH10228	252.14	25	Absent	65	163	256+		119-159
BH10229	320	33	Absent	117	160	306	306	Absent
BH10315	282	37	Absent	153	209	300+		40-80
BH10314	300	20	Absent	120	157	292	292	Absent
BH10211	250.5	33	Absent	81	134	250+		160-165
BH10227	247.39	25	Absent	65	163	298	298	121-161
BH10220	226	64	Absent	77	129	253+		Absent
BH10221	295.28	42	Absent	81	235	327++		120 - 177
BH10222	282.8	30	Absent	127	166	290	290+	Absent
BH10214	318	37	Absent	Absent	55	246	246	55-144 313+
BH10219	297	14	Absent	Absent	71	290	290	68-149
BH10316	243	17	Absent	Absent	92	220	220	Absent
BH10317	349	93	202	216	289	347	Absent	345-349+
BH2412	87	20	87+					Absent
BH8346	163	27	Absent	69	109	163+		NE
BH6188	43	10	Absent	34+				34 - 43(+)
BH9218	365	37	Absent	120	231	365+		120 - 200, 231 - 242
BH7832	365	69	Absent	97	257	365+		257 - 267
BH7829	365	82		166	263	365+		
BH9297	365	148		277	365+			
BH7871	110	30	Absent	Absent	110+			
BH10402	265	25	Absent	65	127	264+		127 – 169
BH10404	250	33	Absent	81	144	250+		154 – 157
BH10405	257	47	Absent	86	169	257+		127 – 155
BH10407	251	55	Absent	91	118	246	246+	118 – 170 171 - 176
BH10410	265	60	Absent	88	135	265+		135 – 183
BH10411	262	50	Absent	77	119	262+		119 – 169

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5 HYDROGEOLOGICAL FRAME WORK

5.1 GEOLOGICAL BACKGROUND

The Proterozoic Okwa Basement Complex is the oldest rock unit in the project area, while the Karoo Supergroup constitutes the most important geologic unit in terms of groundwater resources potential in the project area. North-south trending Kalahari Line (approximately west of 22^{O} E), which is an ancient fault system intruded by basic igneous rocks (Smith 1984). In the north, the basin is bound by the northeast-southwest trending Tsau Fault. The Southwest Botswana Karoo basin extents southwards and westwards from Botswana into South Africa and Namibia respectively. Most of the bedrock geology within the project is obscured by unconsolidated Kalahari Beds sediments of variable thickness and lithologies and most of the bed geology and structure was interpreted from various data sets. This included aeromagnetic, ground geophysics, remote sensing, borehole geophysical logging and lithological details of boreholes drilled in the project area for different purposes including water and mineral exploration. **Figure 6** gives the geological disposition of the project area whilst **Table 18** and **Table 19** give the regional stratigraphy and the Karoo Stratigraphy respectively.

A description of the hydrogeological framework of the project area based on review of existing information and data collected during the exploration phase of the Matsheng Project is given in the following sections.

Table 18 Regional Stratigraphy *(after Carney, et al, 1994)*

Age	Supergroup	Group/Formation	Description
Cretaceous to Recent	Kalahari Beds		Unconsolidated sand, clay, and duricrusts
Cretaceous	Dolerite intrusions and dykes		Dolerite Dykes and sills
Carboniferous to Cretaceous	Karoo	Stormberg Lava	Basalt
		Lebung	Massive sandstone to sandstone/mudstone
		Ecca	Interlayered sandstone, siltstone, mudstone with carbonaceous mudstones and thin coals seams
		Dwyka	Tillite, mudstone and siltstone
Late Proterozoic		Nama	Conglomerate, sandstones and siltstones
Mid - Late Proterozoic	Damara	Ghanzi	Quartzites, arkoses and shales
		Kgwebe Fm.	Volcano-sedimentary units
		Okwa	Felsites and clastic sedimentary units
Early Proterozoic	Okwa Basement Complex		Granite, gneiss and felsite

Table 19 Karoo Stratigraphy of the Project Area *(from Smith, 1984; JICA, 2002)*

Group	Eastern Namibia	Botswana: West of 22º E Longitude (SW Karoo Basin)	Botswana: East of 22º E Longitude (Central Kalahari Karoo Basin)	Lithology	Age
Stormberg Lava	Kalkrand Basalt?	Stormberg Lava	Stormberg Lava		Triassic to Lower Cretaceous
Lebung	*absent*	Nakalatlou	Ntane Sandstone	Reddish to pink fine to medium grained sandstone	Permian to Triassic
		Dondong	Mosolotsane	Basal conglomeratic sandstone, greenish-yellow sandstone interbedded with red-brown siltstones, red-brown mudstone	
	Upper Reitmond		*Absent*		
Beaufort	Lower Reitmond	Kule	Kwetla	Basal fine grained sandstone (thin), dark grey mudstone/siltstone/shale purple grey reddish fine to medium sandstone (thin), grey, none carbonaceous purple-brown mudstone (main)	
Ecca	Auob	Otshe	Boritse	Coarsening upwards grey-brown to orange sandstone, micaceous at base and carbonaceous mudstone/siltstone and coal towards top	
				Thin fine grained dark grey sandstone, interbedded dark-grey siltstones/silty mudstone (Main)	
				Fine to medium grained sandstone (occasionally micaceous), overlain by occasionally micaceous dark grey/black mudstone with bands of dull coal	
				Interbedded light grey micaceous siltstone and dark grey mudstone with bright coal bands near top	
			Kweneng	Sequence of fine to medium grained sandstone interbedded with dark grey siltstone/mudstone, silty mudstone and occasionally pyrite reach at top	
				Coarsening upwards sequence of micaceous yellow, grey and brown sandstones, with micaceous siltstone, coarse grained pale grey arkosic sandstone near top	
	Mukorob	Upper Kobe	Bori	Dark grey silty mudstone with thin sandstone, grey micaceous siltstone with very thin coal bands at top	
	Nossob	Lower Kobe (Ncojane Sandstone)		From bottom dark grey siltstone, grey fining upwards sandstone, dark grey siltstone/carbonaceous mudstone	
Dwyka	Dwyka Group	Malogong Formation	Dukwi Formation	Predominantly Tillite with quartzite/granite clasts in sandstone matrix.	Carboniferous to Permian
		Khuis Formation		Purple mudstone rythmites/varvites with dropstones	
		Middlepits Formation		Purple siltstone and very fine sandstone	

5.2 HYDROGEOLOGICAL FRAMEWORK

The main aquifers in the project area are developed in the Karoo Supergroup sandstones (Ntane and Otshe Formations), with minor aquifers developed in the unconsolidated Kalahari Beds, Mosolotsane/Kule Formations and Dwyka Group.

5.2.1 NTANE SANDSTONE AQUIFER

The upper most formation of the Lebung Group, the Ntane Sandstone Formation, was established as one of the main aquifers during the Hunhukwe/Lokalane Project (WCS, 2001). This sandstone is however, limited to the eastern side of the project area in the Matlho-a-Phuduhudu Block while to the west, including the Ncojane Block, the Ntane has been removed through pre-Kalahari erosion.

Lithologically, the Ntane Sandstone consists primarily of red or pink, fine to medium grained sandstone. In the area where the Ntane Sandstone aquifer occurs (Matlho-a-Phuduhudu Block), no water strikes were recorded in the Kalahari Beds and only minor water strikes were recorded in the overlying Stormberg Lava where present. Water strikes range from 140 to 230 meters, while rest water levels range from 128 to 156 meters. Total dissolved solids (TDS) values for groundwater from the Ntane Sandstone aquifer ranges from 305 mg/L to 1918 mg/L. A hydrogeological summary for the Ntane aquifer in the project area giving details on aquifer geometry, aquifer hydraulic characteristics, groundwater flow, salinity distribution and compliance to drinking water standards based on data from previous projects as well as the Matsheng Project is discussed in the following sections of this report.

5.2.1.1 GEOMETRY

The Ntane Sandstone occurs in a roughly triangular pattern, thinning laterally to a point just east of the Ncojane Block in the west and widening eastward toward the Central Kalahari Karoo Basin (**Figure 5**). The depth to the top of Ntane sandstone increases from ~40 meters in the west to over 150 m in the east whilst the depth to its bottom increases from ~50 m west of Matlho-a-Phuduhudu Block to over 220 m in the east. **(Figure 7).** The thickness of the Ntane Sandstone in the project area ranges from 5 m (BH9292) to 115 m (BH9240). It attains its maximum thickness in the southeastern part of the Matlho-a-Phuduhudu Block **(Figure 8)** and thins toward the western, northern, and southern margins of this basin**.** The thickness of the Ntane Sandstone in the central part of the basin ranges between 80 to 115 meters **(Figure 9).**
In the north, the limit of the Ntane Sandstone aquifer coincides with a thin cover of basalt whilst the southern boundary occurs to the south of Hunhukwe Village where only the lower argillaceous Mosolotsane Formation is present (**Figure 5**). In the westernmost areas the sandstone is very thin and is eventually truncated by pre-Kalahari unconformity just west of the Ncojane ranches. The eastern boundary of the aquifer extends beyond the project area.

The Ntane Sandstone aquifer is largely overlain by Kalahari Beds except in the northern parts of the Matlho-a-Phuduhudu Block where it is overlain by preserved Stormberg Basalts. It is underlain by primarily argillaceous units of the Mosolotsane and Kule Formations. Data obtained from interpretation of borehole geophysical logging data for some boreholes drilled during both the Hunhukwe/Lokalane and Matsheng Projects relating to depth and thickness of Kalahari Beds and Lebung Group (Ntane and Mosolotsane Formations) is given in **Table 20.** The location of these boreholes can be seen in **Figure 4**.

Table 20 Depth and Thickness of Lebung Group Formations in Project Area.

		Kalahari Beds	LEBUNG GROUP					
			Ntane (Nakalatlou) Formation			Mosolotsane (Dondong) Formation		
Location	BH No	Kalahari Thickness	Ntane Top	Ntane Bottom	Ntane Thickness	Mosolotsane Top	Mosolotsane Bottom	Mosolotsane Thickness
MAP	9134	110	110	170	60	170	215	45
MAP	9236	105	105	180	75	180	210	30
MAP	9237	130	130	210	80	210	230	20
MAP	9238	120	120	170	50	170		
MAP	9239	135	135	230	95	230	260	30
MAP	9240	90	90	205	115	205	215	10
MAP	9241	130	130	178	48	178	220	42
MAP	9243	50	95	150	55	150	180	30
MAP	9244	95	95	125	30	125	190	65
MAP	9245	80	80	100	20	100	125	25
MAP	9291	130	130	165	35	165	190	25
MAP	9292	65	65	70	5	70	110	40
MAP	9293	100	100	140	40	140	160	20
MAP	9294	130	130	148	18	148	175	27
MAP	9297	150	150	230	80	230	260	30
MAP	9298	70	70	129	59	129	150	21
Hunhukwe	8545	70	70	105	35	105	190	85
Ncojane Ranges (MAP)	S8645	42	42	72	30	72	82	10
MAP	9097	78	78	111	33	111	137	26
MAP	9110	51	63	133	70			
MAP	9296	70	70	135	65	135	160	25
MAP	9044	150	150	205	55	205		
MAP	10317	93	93	202	109	202	216	14
MAP	10220	64	Absent	Absent	Absent	64	77	13
Ncojane	10221	42	Absent	Absent	Absent	42	81	39
Ncojane	10222	30	Absent	Absent	Absent	30	127	97
Ncojane	10227	25	Absent	Absent	Absent	25	65	40
Ncojane	10228	25	Absent	Absent	Absent	25	65	40
Ncojane	10211	33	Absent	Absent	Absent	33	81	88
Ncojane	10213	33	Absent	Absent	Absent	33	121	88
Ncojane	10214	37	Absent	Absent	Absent	Absent	Absent	Absent
Ncojane	10215	15	Absent	Absent	Absent	Absent	Absent	Absent
Ncojane	10216	13	Absent	Absent	Absent	Absent	Absent	Absent
Ncojane	10219	14	Absent	Absent	Absent	Absent	Absent	Absent
Ncojane	10229	33	Absent	Absent	Absent	33	117	84
Ncojane	10314	20	Absent	Absent	Absent	20	120	100
Ncojane	10212	27	Absent	Absent	Absent	27	107	80
Ncojane	10315	37	Absent	Absent	Absent	80	153	73
Ncojane	10402	25	Absent	Absent	Absent	25	65	40
Ncojane	10404	33	Absent	Absent	Absent	33	81	48
Ncojane	10405	47	Absent	Absent	Absent	47	86	39
Ncojane	10407	55	Absent	Absent	Absent	55	91	36
Ncojane	10410	60	Absent	Absent	Absent	60	88	28
Ncojane	10411	50	Absent	Absent	Absent	50	77	27

5.2.1.2 HYDRAULIC CHARACTERISTICS

Rest water levels in the Ntane Sandstone aquifer ranged between 128 to 156 meters and water strikes are between 141 and 220 meters. The Ntane Sandstone aquifer was previously interpreted to be fully unconfined (WCS, 2001), however, borehole logs and water level data suggest that it probably occurs as both an unconfined and semi-confined aquifer in the central portions of the basin, with many boreholes (i.e. BH9297) having rest water levels between 11 and 50 meters above the first water strikes. This indicates some degree of confinement in some areas (**Table 21**). The likelihood of at least the central portion the Ntane aquifer being semi-confined is also indicated in the hydrogeological cross section (**Figure 10**).

The interpreted Ntane aquifer response in existing pumping test data and existing boreholes re-tested during the current project is semi-confined to unconfined with delayed yield. However for purposes of groundwater exploitation, the Ntane aquifer was treated as an unconfined aquifer for most of its extent. Based on the assumption that for unconfined aquifers only the bottom third of the saturated thickness can be screened, the exploitable saturated thickness of the Ntane aquifer as presented in **Figure 11** indicates that only a small portion of the Ntane aquifer in the central part of the Ntane basin has potential for wellfield abstraction

Transmissivity values for the Ntane sandstone aquifer obtained from interpretation of existing data as well as data obtained during the current project ranges from 4 to 71 m^2/d with an average value of 43 m^2/d. The storativity values obtained from two observation boreholes, BH10223 and BH10225 are $6.70x10^{-4}$ to $2.20x10^{-3}$ respectively. Tested borehole yields range from 8 to 56 m^3/hr with average value of 44 m^3/hr (**Table 22**).

Table 21 Hydrogeological Summary of Boreholes Completed in Ntane Sandstone

BH No.	Location	BH Depth (m)	WS (m bgl)	Screened Zones (mbgl)	RWL (m bgl)	Water Level Height above 1st WS (m)	Date	Airlift yield (m^3/h)	Tested Yield (m^3/h)	T (m^2/d)	TDS (mg/L)
9237	Near Bere	244	141	Open	129.628	11	26/01/06	8	48	57	616
9238	MAP	180	158	Open	136.39	22	11/10/05	3	8	7	546
9239*	MAP	276	152 & 220	149.37-167.46	135.99	16	26/01/06	13	25	56	1154
9240*	MAP	232	167	Open	134.78	32	27/01/06	7.5	30	35	316
9241	MAP	221	151	155-158	136.205	15	29/11/06	4.5	16	8	679
9297**	MAP	287	197	-	147.2	50	08/09/2004	30	50	46	305
7210	Lonetree	241	140, 167	157-163	128	12	05/03/93	25	-	-	-
9044	MAP	210	171 & 182	184-196	134	37	06/09/99	5	-	-	700
9236	MAP	295	167 & 201	174-177	156.191	11	12/02/06	7	28	25	326
10223***	Near Bere	215	143, 170, & 188	139.16 - 210.16	129.61	13	27/10/05	9	NA	88	859
10224***	MAP	240	182, 206 & 230	159-173.24 & 178.92 & 232.88	135.185	47	26/01/06	14	NA		1918
10225***	MAP	209	168 & 182	161.88-201.64	133.97	34	27/01/06	9	NA	55	358
10226***	MAP	201	162 & 174	173.34-193.12	147.16	15	12/02/06	8	NA	NA	333

Notes:
** borehole retested* **** Project Observation Borehole*

**** borehole was later deepened to 444 m**

Table 22 Summary of Hydraulic Parameters Representative Boreholes (Ntane Aquifer)

Ntane Sandstone Aquifer

Borehole Number	Tested Yield (m^3/hr)	Constant Rate Test Duration (days)	Storativity	Transmissivity (m^2/d)
9236	28	3		25
9237*	48	5	6.7E-4	68
9239	25	3		62
9238	8	4		6
9240	30	4		59
9240*	56	2	2.2E-4	48
9241	16	7		4
9297	52	9		68
Average	**44**			**43**

5.2.1.3 Groundwater Flow

Piezometric head in the Ntane aquifer (**Figure 10**) indicate that the general direction of ground flow is predominantly from west to east, with a north-easterly component in the central portion of the Matlho-a-Phuduhudu Block. Local flow variations occur in the southern part of this block with the flow patterns tending to a south-easterly direction. The general direction of groundwater flow follows the alignment of the Group 5 (W-E), Group 1 (NW-SE) and Group 3 (NE-SW) lineament directions obtained from Aster Imagery interpretation **(Figure 12)**. In terms of seasonal groundwater level fluctuations, the water levels in this aquifer are very flat to declining indicating that there is probably very negligible recharge to this aquifer.

5.2.1.4 Salinity Distribution

Groundwater in the central and western parts the Ntane Sub-basin is fresh with TDS values of between 200 and 650 mg/L with the lowest TDS found in the west associated with thin Kalahari cover (near BH9045). Towards the margins of the basin, particularly in the basalt sub-crop area in the north and the southern part of the Matlho-a-Phuduhudu Block, groundwater with relatively elevated TDS values (650 to 1000 mg/L) occurs (**Figure 13**). This trend is also observed in the sodium (Na) and chloride (Cl) distribution patterns (**Figures 14 and 15**), suggesting that recharge to the Ntane aquifer, if any occurs mainly in the west in areas with thinner Kalahari cover. Based on the distribution patterns of TDS, Na and Cl, only the central portion of the Ntane Sub-basin has the potential for long term abstraction as the areas toward the basin margins already have water quality which is close to and above the Class II limits for drinking water for TDS (1000 mg/L) and sodium (200 mg/L) respectively. Significant exploitable saturated thickness for the Ntane aquifer is also limited to a small area in the central portion of the basin as already discussed. A detailed discussion of the hydrochemistry of the Ntane sandstone aquifer is given in the ***Volume 4, Hydrochemistry, Environmental Isotopes, and Recharge Assessment***.

5.2.2 ECCA SANDSTONE AQUIFERS

Sandstones of the Otshe Formation, which underlie an extensive portion of the project area, constitute the main aquifer unit within the Ecca Group. In the Matlho-a-Phuduhudu block, recently drilled boreholes (DGS, 2001) could only penetrate the upper part of the Otshe Formation due to drilling difficulties indicating that an alternate drilling method might be required in order to penetrate the full aquifer thickness. The Otshe Formation consists of an alternating sequence of fine to coarse grained, clean sandstones separated by coals, carbonaceous mudstones, mudstones, shales and siltstones. Aquifers are primarily developed in the two sandstone units, (Sandstone 1 and Sandstone 2) which are separated from each other by varying thickness of mudstones, coals, carbonaceous mudstones, shales and siltstones. These argillaceous units are interbedded with thin sandstones. In the west (Ncojane Block) and northern western parts of Matlho-a-Phuduhudu Block, where the Otshe Formation sub-outcrops directly occur beneath relatively thin Kalahari Beds and Lebung/Beaufort Group rocks, water strikes are generally between to 154 to 290 metres below ground level with the majority of water strikes occurring around 211 m (Matlho-a-Phuduhudu block) where the Ecca underlies the Lebung Group. Water strike depths are over 390 m (bgl) in the central, eastern and southern parts of the Matlho-a-Phuduhudu block where the Otshe Formation occurs at much deeper depths, with correspondingly higher TDS values (**Table 23**). Borehole yields are variable and range between 20 to over 100 m^3/hr. Groundwater quality is portable in a broad area in the western and northern parts of the study area with TDS values of about 500 mg/l. some very high TDS values tend to increase dramatically (significantly (>6000 mg/l) were recorded in some boreholes to the south and southeast where the aquifer occurs at depths of over 390 m.

In addition to the two main sandstone aquifers, water strikes are also encountered in the two mudstone units of the Otshe Formation **(Table 24).** Groundwater quality in these mudstone units which are interlayered with thin sandstones is variable, but generally has relatively elevated TDS values compared to the two main sandstone units (TDS values range between 1065 to 6045 mg/L).

Table 23 Water Strikes, Yield, TDS Values for Ecca (Otshe) Aquifer

Block	BH No	Water Strike (m)	Aquifer	Airlift Yield (m^3/hr)	Field TDS (mg/L)
Ncojane	BH10211	199	SST 1	5	428
Ncojane	**BH10214	174	SST 1	4	2,319
Ncojane	BH10215	173	SST 1	4	986
Ncojane	BH10217	182	SST 1	16	808
Ncojane	BH10217	188	SST 1	17	767
Ncojane	BH10217	229	SST 1	23	817
Ncojane	BH10219	180	SST 1	30	866
Ncojane	BH10219	188	SST 1	13	818
Ncojane	BH10220	154	SST 1	16	713
Ncojane	BH10221	277	SST 1	46	620
Ncojane	BH10222	188	SST 1	27	2,604
Ncojane	BH10227	199	SST 1	93	403
Ncojane	BH10228	199	SST 1	93	403
Ncojane	BH10229	183	SST 1	7	3,416
Ncojane	*BH10229	198	SST 1	14	3,701
Ncojane	BH10315	250	SST 1	127	552
Ncojane	BH10316	162	SST 1	6	174
Ncojane	BH10316	174	SST 1	37	186
Ncojane	BH10402	198	SST 1	72	410
Ncojane	BH10404	198	SST 1	72	475
Ncojane	BH10404	225	SST 1	85	506
Ncojane	BH10405	193	SST 1	77	357
Ncojane	BH10405	206	SST 1	92	345
Ncojane	BH10410	201	SST 1	51	650
Ncojane	BH10411	202	SST 1	63	357
Ncojane	BH10211	224	SST 2	26	484
Ncojane	BH10212	223	SST 2	4	1,767
Ncojane	BH10212	249	SST 2	26	825
Ncojane	BH10215	203	SST 2	6	837
Ncojane	BH10215	215	SST 2	11	515
Ncojane	BH10217	275	SST 2	9	854
Ncojane	BH10220	210	SST 2	25	1,085
Ncojane	BH10222	289	SST 2	12	1,240
Ncojane	BH10229	282	SST 2	20	932
Ncojane	BH10407	205	SST 2	70	345
Ncojane	BH10407	232	SST 2	117	338
Ncojane	BH10410	226	SST 2	114	507
MAP	BH10317	307	SST 1	13	1,544
MAP	BH10317	328	SST 1	31	1,761
MAP	BH9294	208	SST 1	20	248
MAP	BH9298	200	SST 1	2	1,519
MAP	BH9298	215	SST 1	9	1,494
MAP	BH9243	236	SST 2	7	353
MAP	BH9243	248	SST 2	32	260

Notes

***BH10214 Silty Sandstone*

**BH10229 Water Strike in Interlayered Mudstone in Sandstone 1*

Water Strike Close to the Contact with Overlying Mudstone 1

SST 1 Otshe Sandstone 1(Ecca Group)

SST 1 Otshe Sandstone 2 (Ecca Group)

MAP Matlho-a-Phuduhudu

Table 24 Water Strikes, EC and TDS Values for Otshe Mudstones

Block	BH No	Water Strike (m)	Unit	Field TDS (mg/L)
Ncojane	BH10216	134	Mud 1	2021
Ncojane	BH10216	168	Mud 1	2034
Ncojane	BH10216	173	Mud 1	1668
Ncojane	BH10216	191	Mud 2	1829
Ncojane	BH10217	169	Mud 1	1600
Ncojane	BH10229	253	Mud 2	1290
Ncojane	BH10229	266	Mud 2	1101
Ncojane	BH10314	232	Mud 2	3125
Ncojane	BH10314	258	Mud 2	2294
MAP	BH9297	389	Mud 1	6014
MAP	BH9297	393	Mud 1	4458
MAP	BH9298	174	Mud 1	1065

Notes:

1. *Mud 1 Otshe Mudstone 1 (Ecca Group)*
2. *Mud 2 Otshe Mudstone 2 (Ecca Group)*
3. *MAP Matlho-a-Phuduhudu*

5.2.2.1 GEOMETRY

A west-southwest –east-northeast hydrogeological cross section and contour map to the top of the Ecca (Otshe Formation) Group based on borehole information from both existing and project boreholes are presented in **Figure 10**. The top Ecca Group (Otshe Formation), which is defined by a sequence of argillaceous units including mudstones, shales, carbonaceous mudstones and siltstone occurs at depths ranging from less than 100 metres in the northwestern part of the project area to over 370 m in the southeastern part (**Figure 16**). In the Ncojane Block, the Otshe Formation is found at depths of less than 100 to 160 metres (around Kule, Ncojane and Ukwi areas00 metres in the western and northern parts of the Matlho-a-Phuduhudu Block. The depth to the top of the Otshe Formation increases significantly towards the southeast, to depth in excess of 350 metres (B9297, BH7927 and BH8545) and appears to be related to down faulting across faults **F6**, and **F7** (**Figures 5)**.

The main aquifers in Ecca Group are developed in the two sandstone units of Otshe Formation which have been designated as Sandstone 1 (Aquifer 1) and Sandstone 2 (Aquifer 2) for ease of description. Both of these aquifers are comprised of fine, medium and coarse grained sandstones. These sandstones, particularly Sandstone 1 are often micaceous. **Table 25** summarises the depth and thickness of the Otshe Formation in the project area as interpreted from borehole geophysical logging data and lithological logs.

Sandstone 1 (Aquifer 1) generally occurs at depths ranging from 147 to 192 m in the Ncojane block, the western and northern parts of Matlho-a-Phuduhudu Block with the exception BH10221 and BH10315 where the sandstone was intercepted at 289 m and 245 m respectively. To the east of the project area, the depth to top of this aquifer increases significantly to over 390 m due to faulting across faults **F6** and **F7** (**Figure 10**). Sandstone 1 has a thickness ranging from 17 m to 50 m with an average thickness of 29 m.

Table 25 Depth of Different Lithological Units , Ecca Group

		Ecca Group														Post Karoo Dolerites								
		Otshe Formation												Kobe Form										
Block	BH No	Mud 1 Top	Mud 1 Bot	Mud 1 Thick	SST 1 Top	SST 1 Bot	SST1 Thick	Mud 2 Top	Mud 2 Bot	MUD 2 Thick	SST 2 Top	SST 2 Bot	SST 2 Thick	Mud 3 Top		Dol 1 Top	Dol 1 Bot	Dol 1 Thick	Dol 2 Top	Dol 2 Bot	Dol 2 Thick	Dol 3 Top	Dol 3 Bot	Dol 3 Thick
Ncojane	10220	129	147	18	147	180	33	180	206	26	206	>253		>253										
Ncojane	10221	235	289	54	289	>327	>38 m									122	176	54						
Ncojane	10222	166	181	15	181	215	34	215	253	38	253	>290		>290										
Ncojane	10227	163	192	29	192	210	18	210	226	16	226	298	72	298	>400	116	159	43						
Ncojane	10215	106	153	47	153	187	34	187	209	22	209	226	17	226										
Ncojane	10228	163	192	29	192	210	18	210	226	16	226	>256												
Ncojane	10211	134	192	58	192	209	17	209	220	11	220	>256				160	165	5						
Ncojane	10216	126	137	11	173	176	3	176	190	14	190	212	22	212		57	70	13	76	96	20	137	164	27
		164	173	9																				
Ncojane	10213	171	192	21	192	209	17	209	220	11	220	300	80	300	>350									
Ncojane	10229	160	179	19	179	225	46	225	276	51	276	306	30	306										
Ncojane	10314	157	176	19	176	196	20	196	269	73	269	292	23	292										
Ncojane	10217	145	181	36	181	231	50	231	257	26	257	290	33	290	>400	71	145	74						
Ncojane	10212	158	170	12	170	186	16	196	222	26	222	254	32			27	68	41	122	135	13			
Ncojane	10315	209	245	36	245	280	35	280	>300							37	71	34						
Ncojane	10214	143	163	20	163	200	37	200	230	30	230	246	16	246	313	55	143	88	313	>319				
Ncojane	10316	90	112	22	112	127	15	127	170	43	170	220	50	220	>250									
Ncojane	10219	148	181	33	181	231	50	231	257	26	257	290	33	290	>290	71	145	74						
Ncojane	8346			0																				
Ncojane	10402	169	192	23	192	226	34	226	243	17	243	>264				127	169	42						
Ncojane	10404	144	192	48	192	226	34	226	235	9	235	>250				154	157	3						
Ncojane	10405	169	193	24	193	218	25	218	224	6	224	>255				127	155	28						
Ncojane	10407	170	171	1	176	191	15	191	205	14	205	246	41	246	>249	118	170	52	171	176	5			
Ncojane	10410	183	196	13	196	202	6	202	225	23	225	>263				135	183	48						
Ncojane	10411	169	200	31	200	228	28	228	238	10	238	>260				119	169	50						
MAP	10317	289	301	12	301	329	28	329	347							347	>349							
MAP	9243	190	210	20	210	240	30	240	250	10	250	262	12	262	275									
MAP	9297	383	393	10	393	418	25	418	433	15	433	>444												
MAP	9298	177	197	20	197	220	23	220	240	20	240	270	30	270	290									
MAP	8545	368	391	23	391	420	29	420	451	31	451	468	17	468	480									
MAP	9294	200	207	7	207	>207																		
MAP	9244	290																						

This sandstone is overlain by a sequence of argillaceous units comprising of mudstones, shales, siltstones and carbonaceous mudstones with thickness ranging from 10 m to 72 m with an average thickness of ~ 30 m (**Table 25**). Interlayered within these argillaceous units, are relatively thin sandstones which are occasionally water bearing and usually contain groundwater with slightly elevated TDS values.

Underlying Otshe Sandstone 1 is an argillaceous unit (Mudstone 2) comprising predominantly of grey mudstone, black carbonaceous mudstone with occasional thin coal beds. The depth to the top of this unit varies between 176 m to 280 m (average 210 m) in the Ncojane and the western part of the Matlho-a-Phuduhudu Block. In the south east and eastern parts of the Matlho-a-Phuduhudu Block, the depth to the top of this unit is over 360 m due to faulting.

Mudstone 2 is in turn underlain by Sandstone 2 (Otshe Aquifer 2) which forms the second main aquifer unit of the Otshe Formation. This sandstone occurs at depths ranging from 192 m to 276 m in the Ncojane Block and the northern and western parts of the Matlho-a-Phuduhudu Block. East of faults **F6** and **F7**, this sandstone aquifer occurs at depths in excess of 430 m. The thickness of Sandstone 2 ranges from 12 to 80 m and is very similar to that of Sandstone 1 (**Table 25**). Its average thickness is 34 m.

The majority of boreholes in the project area have not penetrated the full thickness of the Ecca Formation, therefore the thickness of the Otshe aquifer is not well constrained. However, several boreholes have penetrated to the top of the overlying Kobe Formation and data from these boreholes indicate that the thickness of the Otshe Formation ranges from 48 m to 146 m with an average thickness of about 105 m **(Table 25).**

Several boreholes in the project area intercepted mudstone, shales coal, siltstones, a sandstones underlying Sandstone unit 2 belonging to the Kobe Formation (**Table 25**). These units were intercepted at depths ranging from 212 m to 468 m. Aquifers within the Kobe contain ground with variable quality ranging from fresh to saline. The saline Kobe aquifer was encountered in boreholes located southeast of fault **F6.** Water level data from a cluster of piezometers at the site of BH10217 (Kobe) and BH10218 (Otshe) completed in Kobe and Otshe Sandstone 1 (Aquifer 1) indicates that the head of the Otshe is higher than that of the Kobe i.e. groundwater head in vertically downwards.

The northern limit of the Ecca Aquifer (Otshe) aquifer in the project is defined by its truncation along the Ghanzi Ridge. To the south and east, it appears to be laterally continuous and extends beyond the project area, although it occurs at greater depths and is generally brackish. In the west, it forms an important aquifer in Namibia throughout it extent.

5.2.2.2 Aquifer Hydraulic Characteristics

Groundwater occurrence in the Otshe aquifer is under confined conditions with rest water levels rising between 27 and 318 m above the first water strikes (**Tables 26 and 27**). Rest water levels in the Otshe Sandstone aquifer range from 77 m to 153 m. The interpreted aquifer response from test pumping data of boreholes completed in Otshe Aquifer is confined. However, some boreholes also had semi-confined leaky responses and barrier boundary effects. Transmissivity values obtained for this aquifer range from 3 to 424 m^2/d with storativity values of between $2.4x10^{-4}$ to $9.2x10^{-4}$ which are typical values for confined aquifers (**Table 27**). Tested borehole yields ranged from 10 to 95 m^3/hr with an average of 48 m^3/hr. However, the tested yields from some existing boreholes are not considered representative as a lot of these boreholes were under pumped due to pump limitations. Considering yields from representative project boreholes an average tested yield of 61 m^3/hr is obtained (**Table 27**).

Table 26 Hydrogeological Summary Details of Ecca Aquifer (Existing Boreholes)

BH No.	Location	Borehole Depth (m)	Water Strike (m bgl)	Screened Zones (m bgl)	Rest Water Level (m bgl)	Water Level Rise above 1st Water Strike (Ecca)	Airlift Yield (m^3/h)	Tested Yield (m^3/h)	T (m^2/d)	TDS (mg/L)
8469	Kule	193	172	171-187.5	96.17	76	15	33	20	762
8470	Kule	211	150 & 201	149.5-155	93.84	56	20	35	41	973
9243	MAP Block	298	236 & 248	235-238	111.3	125	32	31	14	232
9244	MAP Block	298	298	-	153	145	43	18	18	2877
9294	MAP Block	284	168, 191 & 208	-	129.8	38	20	50	19	234
9297	MAP Block	444	380 & 393 (Mudstone)	-	149.2	231	36	25	23	4042
8545	MAP Block	500	393	-	134.8	258	51			5272
6342	Masetlheng	414	408-410	-	89.8	318	-	-	-	-
6161	Ncaang	336	275,306	-	100	175	25	-	-	-
8346	Ncojane	169	144-145	144-160.5	98.7	45	25	48	122	448
8363	Ncojane	181	159	158.5-175	111.02	48	25	53	128	538
8364	Ncojane	181	154	153-175	115.5	39	18	45	116	341
9217	Ngwatle	455	167, 193, 283 & 439	No screens	76.6	90	60	25	7	2066
9218	Ngwatle	449	157, 212, 250, 279, 356, 396, 435 & 440	437.9-449	83	74	70	30	9	2156
7755	Okwa Valley	319	187	187.5-204	123.5	64	8	-	-	-
7760	Okwa Valley	284	164	-	123	41	3	-	-	-
7763	Okwa Valley	244	236	-	99	137	25	-	-	-
7764	Okwa Valley	236	230	-	99	131	25	-	-	-
7826	Okwa Valley	210	190	-	122	88	5	-		-
9183	Ukwi	208	189	185.02-202.72	82.25	107	95	30	92	922
9184	Ukwi	203	137 & 183	182.32-199.32	83.7	43	66	30	100	936

Table 27 Hydrogeological Summary Details of the Ecca Aquifer (Project Boreholes)

BH No	Location	Borehole Depth (m)	Ecca Water Strikes (m)	Screened Zones (m bgl)	Rest Water Level (m bgl)	Water Level Rise above 1st Water Strike (Ecca)	Airlift Yield (m^3/h)	Tested Yield (m^3/hr)	Average T (m^2/d)	TDS
**BH9295	Ncojane Block	232	160 & 215	160 -195 & 211- 223	132.63	27.37	50	91	424	676
BH10221	Ncojane Block	327	277	276 - 299.2	98.72	178.28	12	30	23	698
BH10222	Ncojane Block	290	188 & 289	274.6-286	97.855	90.15	12	12	7	890
BH10227	Ncojane Block	300	199	190-250.9	106.50	92.50	101	Observation	431	
BH10210	Ncojane Block	250	195 & 218	192.83-244.07	109.45	85.55	25	Observation	398	
BH10215	Ncojane Block	250	173, 203 & 233	211.68-247.76	97.906	75.09	37	32	40	538
BH10228	Ncojane Block	256	199	211.68-247.76	106.60	58.40	74	93	446	397
BH10211	Ncojane Block	250	195 & 218	188.89-244	108.26	86.74	43	70	90	474
BH10216	Ncojane Block e	251	173, & 191	173.15-185.40	86.63	86.37	37	45	29	1760
BH10229	Ncojane Block	320	183, 198, 253, 266, 282 & 289	268.02-317	95.49	87.51	44	20	18	870
BH10314	Ncojane Block	300	232, 258, & 276	299.5-235.62 & 241.75-254	88.26	143.74	43	40	34	1210
BH10212	Ncojane Block	268	223, & 249	275.48-281.61 & 284.74-297	88.26	134.74	25	12	4	845
BH10315	Ncojane Block	287	250	248.31- 279	131.30	118.70	127	55	139	448
BH10218	Ncojane Block	290	172, 183, 189, & 213	175.80-246.67	85.65	97.35	59	Observation	40	
BH10214	Ncojane Block	324	170 & 300	Open	96.15	73.85	3	10	3	2016
BH10316	Ncojane Block	250	162 & 174	173.09 - 215.99	114.60	47.40	47	95	388	179
BH10317	MAP	348		371.642-374.487	144.37	162.63	44	NA		
BH10219	Ncojane Block	297	183,188, & 212	172.94 - 246.43	85.40	97.60	64	95	48	794
BH10402	Ncojane Block	257	198	189-248	106.9	91.1	72	70	213	358
BH10404	Ncojane Block	250	198 & 225	205-226 & 236-245	107.15	90.85	64	65	87	517
BH10405	Ncojane Block	255	193 & 206	190-195 & 200-250	109.20	83.8	78	75	167	351
BH10407	Ncojane Block	249	205 & 232	198 -243	104.37	100.64	70	65	145	351
BH10410	Ncojane Block	263	185, 201 & 226	213 -258	101.00	84	74	70	86	410
BH10411	Ncojane Block	263	202	211-261	103.6	98.4	44	70	176	364

Note Average T is from Recovery and Pumping Phase Data

5.2.2.3 Groundwater Flow

Groundwater flow for the Ecca (Otshe) aquifer as depicted on the piezometric head contour map (**Figure 17**) shows that groundwater flow is primarily from west to east with a northwest to southeast component in the southern part of the Ncojane Block. Several faults and lineaments were inferred from aeromagnetic and remote sensing data interpretation during the Inception Phase (Faults F4, F5, F6, & F6). Although Faults **F6** and **F7** have a significant impact on the depth to the top of the Otshe Formation, they seem to have limited impact if any on the groundwater flow. On the other hand faults, **F4** and **F5** seem to have little impact on the depth to the top of Ecca, but significant impact on the direction of groundwater flow with groundwater flow direction running parallel to their orientation (**Figure 17**). Regionally, the Ecca aquifer system is laterally continuous and groundwater flow is from Namibia, where sub-cropping conditions and saturated Kalahari Beds result in enhanced recharge.

5.2.2.4 Salinity Distribution

Overall, the total dissolved solids (TDS) values of groundwater from the Ecca (Otshe Sandstones 1 and 2) aquifer are less than 1000 mg/L except in the extreme south of the Ncojane Block (Ngwatle and Masetlheng) and the eastern parts of the Matlho-a-Phuduhudu Block. Salinity in the overlying Mosolotsane/Kule basal aquifers where present, is consistently high and these aquifers could act as sources of contamination for the underlying Otshe aquifers. It was found that most boreholes which had water strikes in the basal sandstone units of the Kule Formation had relatively elevated fluoride and sodium concentrations values even after these water strikes were grouted.

The regional distribution of TDS for the Ecca (**Figure 18**) indicates that salinity increases from the west to east and northwest to the southeast following the regional flow directions interpreted from the piezometric head. A sharp increase in salinity (TDS) southeast of faults **F6** and **F7** indicates that these structures play an important role in the salinity distribution of the Ecca. Also noticeable in this figure, is the distinctively low salinity region in the west and northwestern portions of the area (TDS less 1000 mg/L), suggesting that these areas are actively recharging or receiving active inflow from recharge areas to the west. In the project area, sodium and fluoride tended to exceed the Class II and Class III limits for drinking water. To evaluate the spatial distribution of these parameters, contour maps for these parameters are presented in **Figures 19** and **20**. **Figure 19** indicates that sodium was less than 400 mg/L (Class III limit) for a large part of the project area to the northwest of faults **F6** and **F7**, indicating that these structures play an important role in groundwater quality distribution of the Ecca (Otshe). The same trend is observed in the fluoride distribution pattern where concentrations of less than 1.5 mg/L were observed to the northwest of these faults. Of interest to note, is that the majority of boreholes which have low, TDS, sodium and fluoride values did not have any water strikes in the overlying Kule basal sandstones. This clearly shows that saturated Kule formations are the main source of poor quality water.

For groundwater development, areas with groundwater which falls within the drinking water specifications (Class II and Class III) have been targeted for wellfield development. A detailed discussion of the hydrochemistry of the project area aquifers is given in the ***Volume 5, Hydrochemistry, Environmental Isotopes, and Recharge Assessment***.

5.2.2.5 Kalahari Beds Aquifers

Aquifers are locally developed in the Kalahari Beds in the project area, although water quality (TDS) is extremely variable. The original water supply boreholes for the Matsheng Villages were developed in local Kalahari Beds Aquifers. Some of these production boreholes have since been decommissioned due to several factors including deteriorating water quality (mainly increases of nitrate), eccoli contamination, and declining yields. In adjacent Namibia (JICA 2002), Kalahari Beds aquifers are highly developed and account for greater abstraction (10 MCM/yr) than the underlying Ecca aquifers (5 MCM/yr). However in much of the project area, Kalahari Beds are unsaturated and where they are saturated the water quality is often saline.

5.2.3 COMPLIANCE TO DRINKING STANDARD

Groundwater samples were collected during the drilling and test pumping activities of the current project. The project samples were analysed at both the DWA laboratory in Gaborone as well as the CSIR laboratory in Stellenbosch.

Drinking water specifications for Botswana, (BOS 32:2000 standards) were established on 13 September 2000 and were made mandatory by the government with effect from 3 April 2003. The specification lists three Classes for drinking water requirements:

1. Class I (Ideal)
2. Class II (Acceptable) and
3. Class III (maximum allowable)

The results of chemical analysis of water samples from both project and existing boreholes are discussed as under in terms of compliance to drinking water standards.

5.2.3.1 Water Quality of Ntane Sandstone Aquifer

Chemical analysis results from boreholes tapping the Ntane Sandstone aquifer are given **Table 28.** The results indicate that most of the measured parameters in the Ntane aquifer are within the limits of the BOS32:2000 standards with the exception of a few parameters. Parameters that that exceed the limits are:

- TDS and EC in BH9239 with values 1154 mg/L and 2140 µS/cm respectively. These parameters exceed Class II limit but are within Class III limit.
- Sodium exceeds Class II standards in samples from three boreholes, (BH9239, BH9134 and BH9135) located in the south and northern margins of the Ntane Basin. In these boreholes sodium ranges between 222 and 370 mg/L and is within the Class III standard of 400 mg/L
- BH9239 with a chloride concentration of 378 mg/L exceeds the Class II limit but is within the Class III limit of 600 mg/L.

Most of the existing boreholes which are completed in Ntane Aquifer (Lokalane Project) were analysed when the BOS32:2000 standards were not in place, with the result that most of the parameters listed in this standard were not analysed. However two boreholes (BH9240 and BH9237) in the central portion of the basin were re-sampled during the current project and most of the BOS 32:2000 parameters were analysed for. Results from these boreholes indicate that the groundwater in this aquifer is within the Class II BOS32:2000 limits for drinking water (**Table 28**).

Table 28 Water Quality of the Ntane Aquifer

Major Constituents

BH No	Date	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	SO4 (mg/L)	Cl (mg/L)	HCO3 (mg/L)	NO3 (mg/L)	F (mg/L)	EC (μS/cm)	TDS (mg/L)
2211	09/08/04	7	58	67	11	15	35	340	1	0	660	422
5698	09/09/04	16	207	42	33	67	171	469	3	1	1380	883
7170	27-May-99	6	72	36	13	16	28	301	27	0	590	384
7172	30-May-00	11	68	37	12	14	23	267	26	0	570	371
9044	21-Jun-99	8	128	31	17	48	110	256	24	0	950	537
9134	09/09/04	17	224	34	27	83	171	456	1	1	1380	883
9135	09/09/04	17	222	35	27	67	175	390	3	1	1408	788
9237	02-Jun-00	16	157	40	21	68	105	343	5	0	1086	616
9238	30-May-00	13	125	45	21	76	38	404	8	<.05	915	546
9239	02-Jun-00	7	370	42	26	105	378	407	21	0	2140	1154
9240	18-Oct-00	6	60	24	20	5	16	281	27	<0.05	517	316
9241	11-May-00	10	200	50	11	56	93	438	16	1	1120	679
9297*	18-Sep-00	5	53	48	6	15	21	244	14	0	499	305
9237	26-Oct-05	25	163	39	29	64	103	416	0	0.17	1070	580
9240	11-May 05	20	39	46	20	7	15	297	27	0.09	1180	300
Class 2		60	200	150	70	250	200		45	1	1500	1000
Class 3		100	400	200	100	400	600		45	2	3100	2000

Minor Constituents

BH No	Date	Fe (mg/L)	Mn (mg/L)	CO_3 (mg/L)	As (mg/L)
2211	09/08/04	<0.05	<0.05		
5698	09/09/04	4.3	0.12		
7170	27-May-99				
7172	30-May-00			11.4	
9044	21-Jun-99	0.87	0.69	15	
9134	09/09/04	0.72	<0.05		
9135	09/09/04	0.5	0.02	35	
9237	02-Jun-00	0.08	<.1	0	
9238	30-May-00			0	
9239	02-Jun-00	0.32	<.1	0	
9240	18-Oct-00			0	
9241	11-May-00	0.32	<.1	0	
9297*	18-Sep-00	<0.1	<0.1	0	
9237	26-Oct-05	0.134	0	0	
9240	11-May 05	0.114	0	0	
Class 2		0.3	0.1		
Class 3		2	0.5		

Note, Constituent highlighted in grey exceeds the Class 2 limit (BOS32:2000)

5.2.3.2 WATER QUALITY OF THE ECCA (OTSHE) AQUIFER

The Otshe aquifer is well represented with regard to boreholes with analytical data, particularly in the Ncojane Block, with a total of 40 exploration and 6 production boreholes in the study area. This means that hydrochemical trends in the Otshe aquifer can be identified with a high degree of confidence. Furthermore, as set out in the description of the hydrogeologic framework the Otshe is essentially a confined aquifer. Hence a consistent hydrochemical evolution is expected along the flow path in the aquifer from the recharge area to the discharge area except for faults that may affect the groundwater flow in the aquifer by connecting it with either overlying or underlying aquifers.

In general the groundwater flow is primarily from the west to east with a northwest to southeast component in the southern part of the of the Ncojane Block which means that the hydrochemical evolution in the aquifer should take place in eastward or north-easterly direction

Overall, the total dissolved solids (TDS) values of groundwater from the Ecca (Otshe Sandstones 1 and 2) aquifer are less than 1000 mg/L except in the extreme south of the Ncojane Block (Ngwatle and Masetlheng) and the eastern parts of the Matlho-a-Phuduhudu Block. Salinity in the overlying Mosolotsane/Kule basal aquifers, where present is consistently high and these aquifers could act as sources of contamination for the underlying Otshe aquifers. It was found that most boreholes which had water strikes in the basal sandstone units of the Kule Formation had relatively elevated fluoride and sodium concentrations.

Regionally, the salinity increases from the west to east and northwest to the southeast following the regional flow directions interpreted from the piezometric head of the Ecca aquifer. A relatively sharp increase in salinity (TDS) southeast of faults **F6** and **F7** indicates that these structures play an important role in the salinity distribution of the Ecca (**Figure 18**), by either connecting it with overlying or underlying poor quality aquifers. Also noticeable in this figure, is the distinctively low salinity region in the west and northwestern portions of the area (TDS less 1000 mg/L). This suggests that these areas are actively recharging or receiving active inflow from recharge areas to the west. The possibility of active recharge to the Ecca in western parts is also indicated by water level monitoring data. In the project area, sodium and fluoride tend to exceed the Class II and Class III limits for drinking water. To evaluate the spatial distribution of these parameters, contour maps for these parameters are presented in **Figures 19** and **20**. **Figure 19** indicates that sodium is less than 400 mg/L (Class III limit) for a large part of the project area to the northwest of faults F6 and F7, again indicating that these structures play an important role in groundwater quality distribution of the of the Ecca (Otshe). The Tables showing Chemistry results for are presented in **Tables 29 and 30.**

The same trend is observed in the fluoride distribution pattern (**Figure 20**) where concentrations of less than 1.5 mg/L are observed to the northwest of these faults. Of interest to note, is that the majority of boreholes which have low TDS, sodium and fluoride values did not have any water strikes in the overlying Kule basal sandstones and also occur to the northwest of faults F6 and F7. This probably indicates that saturated Kule Formation acts as source of these ions in the groundwater.

Table 29 Groundwater Quality of Ecca Aquifer (Exploration boreholes)

Major Constituents

BH No	Date	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	NH4 as N (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity as CaCO3 mg/L	NO3 mg/L	F mg/L	EC (µS/cm)	TDS (mg/L)	Hardness as CaCO3 mg/L
10211	25-Nov-06	8.2	126	15	13	<0.1	20	59	262	17.14	0.69	740	474	90
10222	28-Nov-06	5	317	2.8	2.6	<0.1	44	103	550	<0.36	2.3	1390	890	18
10228	5-Dec-06	6	81	25	15	<0.1	13	41	211	16.05	0.59	620	397	126
10229	10-Dec-06	3	317	2.3	2.1	<0.1	43	88	547	<0.36	2.3	1360	870	14
10221	3-Feb-06	3.3	250	2.5	2.1	0.1	36	85	388	<0.36	1.1	1090	698	15
10215	28-Jan-06	10.1	149	17	13	<0.1	35	60	295	<0.36	0.7	840	538	96
10314	26-Jan-06	2.7	471	1.1	0.6	<0.1	76	115	744	<0.36	2.5	1890	1210	5
10214	10-Mar-06	3.5	746	3.2	3.3	0.1	326	418	682	<0.36	3.5	3150	2016	21
10316	21-Feb-06	3.5	30	20	5.9	<0.1	8.3	13	87	3.10	0.4	280	179	74
10219	3-Mar-06	1.7	326	1.6	1.1	<0.1	86	102	455	<0.36	1.8	1240	794	8.6
10212	11-Feb-06	2.9	315	2.4	2.1	<0.1	72	98	487	<0.36	1.8	1320	845	15
10216	19-Feb-06	4.4	648	4.9	3.6	<0.1	195	464	527	<0.36	2.3	2750	1760	27
10315	9-Feb-06	4.7	168	1.1	1.2	<0.1	19	41	290	<0.36	1.1	700	448	8
Class 2		50	200	150	70	1	250	200		45	1	1500	1000	200
Class 3		100	400	200	100	2	400	600		45	1.5	3100	2000	500

Minor Constituents

BH No	Sample Date	Al (mg/L)	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Ni (mg/L)	Zn (mg/L)	Cyanide as CN mg/L	pH (Lab) (20°C)
10211	25-Nov 06	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	0.11	<0.05	<0.05	<0.05	<0.05	<0.05	8
10222	28-Nov-06	0.61	<0.01	<0.005	<0.05	<0.05	<0.05	0.47	<0.05	<0.05	<0.05	<0.05	<0.05	8.4
10228	5-Dec-06	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	0.41	<0.05	<0.05	<0.05	<0.05	<0.05	7.4
10229	10-Dec-06	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	0.18	<0.05	<0.05	<0.05	<0.05	<0.05	8
10221	3-Feb-06	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	0.2	<0.05	<0.05	<0.05	<0.05	<0.05	7.3
10215	28-Jan-06	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	0.23	<0.05	<0.05	<0.05	<0.05	<0.05	7.3
10314	26-Jan-06	0.15	<0.01	<0.005	<0.05	<0.05	<0.05	0.16	<0.05	<0.05	<0.05	<0.05	<0.05	7.5
10214	10-Mar-06	<0.10	0.01	<0.005	<0.05	<0.05	<0.05	0.27	<0.05	<0.05	<0.05	0.08	<0.05	8.5
10316	21-Feb-06	<0.11	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.5
10219	3-Mar-06	<0.12	<0.01	<0.005	<0.05	<0.05	<0.05	2	<0.05	<0.05	<0.05	<0.05	<0.05	7.7
10212	11-Feb-06	<0.13	<0.01	<0.005	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	7.7
10216	19-Feb-06	<0.14	<0.01	<0.005	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	8
10315	9-Feb-06	<0.15	<0.01	<0.005	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	7.7
Class 2		0.2	0.01	0.003	0.05	0.5	1	0.3	0.01	0.1	0.02	5	0.07	5.5 - 9.5
Class 3		0.2	0.01	0.003	0.05	1	1	2	0.01	0.5	0.02	10	0	5.0 - 10

Note, Constituent highlighted in grey exceeds the Class 2 limit (BOS32:2000)

Table 30 Ground Water Quality of Production Borehole

Macro Constituents

BH No	Sample Date	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Nitrite as NO2 (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity as CaCO3 (mg/L)	Nitrate as NO3 mg/L	F mg/L	EC (mS/cm)	TDS (mg/L)	Hardness as CaCO3 mg/L
BH10402	23/9/07	7.3	88.2	25.9	19.3	<0.2	18.8	67.9	204	17.1	0.72	690	442	144
BH 10404	05/8/07	7.8	135.5	21.4	19.0	<0.05	33.0	112.5	208	17.1	0.59	840	538	132
BH10405	24/8/07	6.5	85.8	26.5	16.9	2.90	17.2	67.9	188	13.9	0.64	650	416	136
BH10407	05/9/07	8.3	139.5	22.7	19.7	<0.2	31.3	116.1	219	17.7	0.64	860	550	138
BH10410	16/9/07	7.5	112.0	21.8	16.3	<0.2	21.1	77.8	235	<0.2	0.69	720	461	122
BH10411	17/10/07	7.5	90.9	26.7	19.9	<0.2	19.5	62.5	215	17.6	0.6	690	442	148
Class I		25	100	80	30	3	200	100		45	0.70	700	450	20
Class II		50	200	150	70	3	250	200		45	1.00	1500	1000	200
Class III		100	400	200	100	3	400	600		45	1.5	3100	2000	500

Note Parameters Highlighted in grey exceeds the Class I Limit

Micro Constituents

BH No	Sample Date	Al (mg/L)	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Ni (mg/L)	Zn (mg/L)	Cyanide as CN mg/L	pH (Lab) (20°C)
BH10402	23/09/2007	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.80
BH10404	05/08/2007	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.80
BH10405	24/08/2007	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.60
BH10407	05/09/2007	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.70
BH10410	16/09/2007	0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.90
BH10411	17/10/2007	0.3	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	7.60
Class I		0.1	0.01	0.003	0.05	0.25	1	0.03	0.01	0.05	0.020	3	0.070	6.5-8.5
Class II		0.2	0.01	0.003	0.05	0.50	1	0.3	0.01	0.1	0.020	5	0.070	5.5 - 9.5
Class III		0.2	0.01	0.003	0.05	1	1	2	0.01	0.5	0.020	10	0.070	5.0 - 10

5.2.4 ROLE OF STRUCTURAL FEATURES

As indicated earlier, one of the objectives of exploration borehole drilling and testing was to evaluate the hydrogeological role of structural features such as faults, lineaments and dolerite sills. To fully evaluate the significance of these structures, exploration boreholes were sited on different hydrogeological/geological environments such as structurally disturbed/undisturbed areas and areas with dolerite intrusions. Based on analysis and evaluation of the results obtained the following conclusions have been made.

5.2.4.1 BOREHOLE YIELDS

Drilling results of exploration boreholes drilled in structurally undisturbed areas, (**Table 31**)**,** indicate that the yield of the Ecca aquifer in these areas tends to be high with the majority of them tested, at rates of between 40 to 95 m^3/hr indicating that the Ecca aquifer occurs as a primary aquifer. The TDS values for these boreholes ranges between 179 mg/L and 1210 mg/L. Boreholes with higher TDS values (BH10222, BH10229 and BH10314) also had water strikes in the basal sandstones of Kule (Kwetla) Formation and had elevated fluoride and sodium concentrations in the range 2.3 to 2.5 mg/L and 317 to 471 mg/L respectively (**Table 32**). In addition to these, some boreholes, which were expected to have thick sequences of coarse grained sandstone intercepted dolerite intrusions between the Ecca Group and the overlying Kule Formation (BH10228 and BH10211) but these dolerites did not seem to have any effect on the groundwater quality and yield. Boreholes with higher fluoride, TDS and sodium values are also located southeast of aeromagnetic data interpreted fault **F6**.

5.2.4.2 STRUCTURALLY DISTURBED AREAS

Two exploration boreholes, BH10214 and BH10216 were drilled close or within fault zones to evaluate the role of faulting on groundwater quality, lithology and borehole yields. These boreholes encountered multiple dolerite sill intrusions at different levels and have relatively high TDS groundwater with values of 1760 and 2016 mg/L. The fluoride and sodium contents for these two boreholes were also high with values of 3.5 to 2.3 mg/L and 746 to 648 mg/L respectively for these constituents. The Ecca lithology encountered in these boreholes was predominantly silty to fine grained sandstones, with minor medium to coarse grained sandstones. The tested yields of these two boreholes were 10 and 45 m^3/hr.

5.2.4.3 AREAS WITH DOLERITE INTRUSIONS

Some exploration boreholes were sited in areas with interpreted dolerite sill intrusions for purposes of evaluating the role of these sills on groundwater quality while others intercepted dolerite sills in areas which were expected to be dolerite free. The reason for not always being able to distinguish dolerite free areas from areas with thick sandstones was that weathered dolerite has the same resistivity range as coarse sandstones and these sills were not picked by ground magnetic profiling. Boreholes which were cited purposely in areas with dolerite intrusions were BH10214, BH10219, BH10212 and BH10216. Boreholes which were not expected to intercept dolerite sills were BH10228 and BH10211. Drilling results from this type of environment indicates that boreholes with multiple dolerite intrusions and saturated basal sandstone units of the Kule Formation tend to have groundwater with elevated fluoride and sodium levels regardless of the TDS value (**Table 31**). These boreholes include BH10212, BH10214 and BH10216. If the dolerite intrusion is below the Kule basal sandstones it appears that the dolerite sills isolate the basal sandstone units from the underlying Otshe aquifer and have no apparent effect on groundwater quality (BH10228 and BH10211).

Table 31 Yields, TDS, F and Na Concentrations for Boreholes in Different Environments

BH No	Tested Yield (m^3/hr)	Na (mg/L)	F (mg/L)	TDS (mg/L)	Environment	Remarks
BH 10212	12	315	1.8	845	Disturbed, Dolerite Expected	Multiple Dolerite intercepted, Kule Sandstone Saturated
BH 10214	10	746	3.5	2016	Disturbed, Dolerite Expected	Multiple Dolerite intercepted, Kule Sandstone Saturated
BH 10216	45	648	2.3	1760	Disturbed, Dolerite Expected	Multiple Dolerites intercepted, Kule Sandstone Saturated
BH 10219	95	326	1.8	794	Disturbed, Dolerite Expected	Single Dolerite Intercepted
BH 10228	93	81	0.59	397	Undisturbed	Unexpected dolerite intercepted below unsaturated Kule Formation
BH 10316	95	30	0.4	179	Undisturbed	Kule Unsaturated
BH10211	70	126	0.69	474	Undisturbed	Thin Dolerite intercepted/ Kule Unsaturated
BH10215	32	149	0.7	538	Undisturbed	Kule Unsaturated
BH10221	30	250	1.1	698	Undisturbed	Unexpected dolerite intercepted. Kule Formation Unsaturated
BH10222	12	317	2.3	890	Undisturbed	Saturated Kule Sandstone above main aquifer
BH10229	20	317	2.3	870	Undisturbed	Some water Strikes in interlayered mudstones in Ecca aquifer
BH10314	40	471	2.5	1210	Undisturbed	Saturated Kule Sandstone above main aquifer

5.2.4.4 Variation of Salinity with Depth

The drilling results have shown that in some boreholes the TDS, sodium fluoride and chloride concentrations reduces with depth. This was observed mostly in boreholes with water strikes in the basal sandstones of Mosolotsane and Kule (Kwetla) Formations and a few boreholes with water strikes in the upper mudstone units of Otshe Formation. This trend clearly shows that these brackish or saline water strikes should be properly sealed off to avoid contaminating the lower Ecca aquifers. Drilling samples water quality results of some boreholes with this trend are given **Table 32**. This trend was also noted during the Hunhukwe / Lokalane Project (WCS 2001).

Table 32 Variation of Water Quality with Depth

Borehole Number	Date Sampled	Type	Depth	EC (μS/cm)	TDS (mg/L)	Na mg/L	Cl mg/L	F mg/L	Aquifer
10212	3-Dec-05	Drilling	155	7530	4600	1474	3000	0	Kule Sandstone
10212	9-Dec-05	Drilling	223	3150	1838	695	580.9		MUD 2
10212	9-Dec-05	Drilling	249	1430	766	310.5	162	1.98	SST 2
10213	6-Jul-05	Drilling	198	730	406	126.15	53.99	0.65	SST 1
10213	6-Jul-05	Drilling	224	790	444	137.95	59.49	0.77	SST 2
10215	20-Oct-05	Drilling	173	1590	948	359.9	133.9	1.69	SST1
10215	20-Oct-05	Drilling	203	1350	796	263.8	118.1	1.46	MUD 2
10215	20-Oct-05	Drilling	215	830	484	182.9	63.36	0.99	SST 2
10215	21-Oct-05	Drilling	233	840	464	160.3	66.52	0.57	SST2
10218	19-Jan-06	Drilling	183	1270	792	313.4	114.7	1.65	SST 1
10218	19-Jan-06	Drilling	189	1240	786	306.5	102.8	1.58	SST 1
10218	19-Jan-06	Drilling	213	1240	720	323.6	106.46	1.3	SST 1
10219	9-Feb-06	Drilling	180	1270	878	307.2	109.49	0	MUD 1
10219	9-Feb-06	Drilling	188	1240	764	313.1	109.57	4.7	SST 1
10219	9-Feb-06	Drilling	212	1260	784	316.1	104.57	3.39	SST 1
10220	24-Jun-05	Drilling	145	1030	588	220.1	42.53	2.26	MUD 1
10220	16-Jun-05	Drilling	210	1520	892	292.5	131.2	1.56	SST 2
10221	28-Jul-05	Drilling	277	1170	616	248.2	99.2	1.01	SST 1
10222	16-Aug-05	Drilling	150	3630	2124	832.4	769.2	0	Kule Sandstone
10222	20-Aug-05	Drilling	188	5460	3376	1221.5	1302	0	SST1
10222	29-Aug-05	Drilling	289	1460	854	319.7	101.7	2.65	SST 2
10228	22-Oct-05	Drilling	165	620	318	82	45.17	0.48	MUD 1
10228	29-Oct-05	Drilling	199	630	322	86	44.7	0.5	SST 1
10315	5-Dec-05	Drilling	156	2990	1802	669.2	451.32	0	Kule Sandstone
10315	6-Dec-05	Drilling	177	3680	2118	809.5	653.56	2.06	Kule Sandstone
10315	8-Dec-05	Drilling	216	4170	2476	960	754.69	0	MUD 1
10315	14-Jan-06	Drilling	250	720	426	180.95	45.80	0.79	SST 1
10316	27-Jan-06	Drilling	162	290	168	41.29	13.51	0.3	SST 2
10316	27-Jan-06	Drilling	174	290	152	30.09	14.02	0.28	SST 2
10317	17-Feb-06	Drilling	307	2380	1504	612.2	389.87	0	SST 1
10317	17-Feb-06	Drilling	328	2640	1694	661.4	498.26	0	SST1
BOS 32:2000 Class II				1500	1000	200	200	1	
BOS 32:2000 Class III				3100	2000	400	600	1.5	

Notes:

MUD 1 Ecca Mudstone 1
SST 1 Ecca (Otshe Sandstone 1)
MUD 2 Ecca Mudstone 2
SST 2 Ecca (Otshe Sandstone 2)
Kule Sandstone (Beaufort Basal Sandstone)

Figure 6 Geological Map of the Project Area

Figure 7 Depth to Top of the Ntane Sandstone

Figure 8 Depth to Bottom of the Ntane Sandstone

Figure 9 Thickness of the Ntane Sandstone

Figure 10 West-Southwest –East Northeast Hydrogeological Cross-Section

Figure 11 Exploitable Saturated Thickness Ntane Sandstone

Figure 12 Piezometric Head Ntane Sandstone

Figure 13 TDS Distribution Ntane Sandstone

Figure 14 Sodium Distribution Ntane Sandstone

Figure 15 Chloride Distribution Ntane Sandstone

Figure 16 Depth to Top of Ecca Group

Figure 17 Piezometric Head Ecca (Otshe) Aquifer

Figure 18 TDS Distribution Ecca (Otshe) Aquifer

Figure 19 Sodium Distribution Ecca (Otshe) Aquifer

Figure 20 Fluoride Distribution Ecca (Otshe) Aquifer

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6 GPS SURVEYS

During the exploration phase high precision GPS surveys were carried out on project boreholes as well as on selected existing boreholes which are used for water level monitoring. These surveys were undertaken in February 2006 with a total of 28 boreholes surveyed both in the Ncojane and Matlho-a-Phuduhudu Blocks. In the Ncojane Block, 22 boreholes were surveyed while for the Matlho-a-Phuduhudu Block 6 boreholes were surveyed.

6.1 OBJECTIVES

The GPS surveys were carried out to locate and level project boreholes and selected existing boreholes to an accuracy of +/- 1 m in x, y and +/- 10 cm in z. The surveys included the elevation of the top of casing (measuring point), top of slab and ground level. Apart from providing accurate borehole positional data, these surveys also provided measuring point elevation control for the construction of piezometric maps and numerical groundwater models.

6.2 EQUIPMENT AND SURVEY METHODOLOGY USED

A Lieca SR530 dual frequency Real Time GPS system was used for the survey. This GPS system is a radio enabled differential GPS system which allows for both real time (RTK) and post-processing (PPK) surveys. The current survey was carried out in post processing mode due to distances between the survey points. In Post Processing (PPK) mode, data is collected independently by the base and rover receivers, and position calculations are performed later in the office. Since there is no communication between the rover and base receivers during data collection, adequacy of data cannot be checked and significantly more data has to be collected (thus longer occupation time) in order to ensure the desired quality of the survey.

During this survey, two sets of data were collected for most of the observation points using two different modes: one by using PPK “topo point” mode and another by PPK “Observed control point” mode. The data with the smallest ratios and root mean square (RMS) values was then selected for each survey point for final processing.

The survey data were projected onto the UTM co-ordinate system using the following parameters:

Co-ordinate system: UTM, Zone 34 K (18^{o} E to 24^{o} E)
Ellipsoid: Clarke 1880
Datum: Cape (South African)
Geoid model: EGM96

During the survey, the only existing benchmark in project area, (Matlho-a-Phuduhudu Block) of the Department of Surveying and Mapping (DSM) was used as a control point to tie in the surveyed points to the national grid of the DSM. Temporary control points were established where the baseline length (i.e. the distance between the rover and base station) was more than 10 km. The temporary control points were surveyed using the static method with an occupation time of one hour or more, depending on the baseline length. This survey was conducted by interchanging the position of the rover and base station with each other to check the configuration of the survey for any errors and whether the difference between the measured and actual (from DSM) position of the benchmark was within acceptable limits.

The quality of the GPS data survey was assessed through "internal" (i.e. derived only from GPS data) accuracy indices such as RMS (root mean square), vertical and horizontal precision, ratio or reference value. RMS provides a measure of confidence in GPS-derived positions (RMS is a radius of the error circle within which approximately 70% of position fixes are found).

The nominal accuracy of the GPS point position determination is as follows:

Horizontal
±10 mm + 2 ppm (parts per million) of baseline length, i.e. 1 mm per 1 km of distance between the base and the rover stations.

Vertical
±20 mm + 2 ppm (parts per million) of baseline length, i.e. 1 mm per 1 km of distance between the base and the rover.

For a baseline length of 10 km, the nominal accuracy of the GPS point position would be:
20 mm + (1x10) mm= 30 mm.

During the survey in the project area, the baseline length was always maintained below 10 km. Survey precision was randomly checked by occupying the same point during different phases of the survey.

The results of the GPS survey are presented in **Table 33**

Table 33 High Precision GPS Survey Results

BH No	Block	Easting	Northing	Ground Level Elevation (m msl)	Casing Elevation (m amsl)
BH10223	MAP	586358	7460350	1177.45	1178.4
BH10224	MAP	586902	7436518	1189.93	1190.91
BH10225	MAP	608914	7449809	1170.97	1171.81
BH10226	MAP	570319	7444055	1205.55	1206.44
BH9237	MAP	586367	7460348	1177.34	1177.77
BH9293	MAP	532473	7440719	1231.79	1232.27
BH10210	Ncojane	445827	7439007	1267.96	1268.92
BH10211	Ncojane	445818	7439004	1267.81	1268.8
BH10212	Ncojane	471357	7413720	1240.99	1242.08
BH10214	Ncojane	474333	7397979	1224.5	1225.41
BH10215	Ncojane	423550	7424116	1262.23	1262.68
BH10216	Ncojane	445843	7400347	1240.32	1241.04
BH10217	Ncojane	462926	7396725	1231.32	1232.14
BH10218	Ncojane	462941	7396727	1231.44	1232.09
BH10220	Ncojane	503298	7439428	1241.75	1242.74
BH10221	Ncojane	465933	7427586	1253.42	1254.04
BH10222	Ncojane	475982	7427299	1243.55	1244.47
BH10227	Ncojane	441140	7435377	1266.86	1267.63
BH10228	Ncojane	441134	7435388	1266.87	1267.56
BH10229	Ncojane	477486	7424731	1240.26	1240.99
BH10314	Ncojane	490310	7429080	1221.93	1222.66
BH10315	Ncojane	507682	7433985	1237.7	1238.59
BH6326	Ncojane	453660	7394892	1226.44	1226.9
BH8346	Ncojane	427452	7442568	1268.29	1268.5
BH8646	Ncojane	462708	7436128	1255.64	1255.85
BH9217	Ncojane	504418	7379165	1186.25	1186.72
BH9218	Ncojane	504513	7378617	1183.74	1184.27
BH9295	Ncojane	503305	7439434	1241.59	1242.15
BH10402	Ncojane	441127	7435359	1269.293	1270.601
BH10316	Ncojane	400854	7427984	1260.519	1261.413
BH10404	Ncojane	445806	7438994	1268.815	1270.062
BH10405	Ncojane	442715	7436590	1267.892	1269.014
BH10407	Ncojane	440212	7432266	1263.095	1264.401
BH10410	Ncojane	442582	7428919	1259.065	1259.826
BH10411	Ncojane	438640	7431015	1264.025	1265.041

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7 RECHARGE ASSESSMENT

Recharge in the project area (even if it occurs) is a difficult parameter to investigate, since it is highly variable both in time and space and is poorly quantified. This is largely due to limited data, particularly long term time series groundwater levels in this large, trans-boundary groundwater basin and to the lack of perception on the appropriate mechanism.

Previous recharge studies in the project area were confined to the Matlho-a-Phuduhudu Block, which includes the Hunhukwe/Lokalane Project (WCS, 2001), and the MSc theses of Chilume (2001) and Rahube (2003) who mainly used the data collected during the Hunhukwe/Lokalane. The methods used to estimate recharge in these studies included hydrograph analysis, radioactive and stable isotope studies, and the chloride mass balance together with numerical groundwater modelling. A common conclusion from all the recharge studies in and around the area is that, recharge is normally extremely low (0.01 to 0.4 mm/yr) with significant recharge occurring only during rare major rainfall events like that experienced during the 2000 and the 2005 rainy season.

In Namibia, recharge rates for Ecca aquifers of 0 to 0.85 mm/yr were estimated for average rainfall years and up to 18 mm/yr during the high rainfall event in 2000 (JICA, 2002).

7.1 OVERVIEW OF RECHARGE ESTIMATES IN THE PROJECT AREA

7.1.1 CHLORIDE MASS BALANCE (CMB)

This method was first used by Erikson and Kunakasem (1969). Chloride concentrations in groundwater reflect the degree to which chloride in precipitation is concentrated by evaporation. The input of chloride from precipitation and from dry deposition can be equated to the mass of chloride in groundwater. This concept provides a recharge calculation method that is applicable in those cases where chloride is conservative in the hydrogeologic systems and the mass of chloride lost by surface runoff, adsorption or reaction with mineral phases is considered insignificant. Knowing the total amount of chloride deposited annually (from precipitation and dry deposition), it is possible to calculate the amount of annual recharge to an aquifer. Wood and Sanford (1995) calculate the groundwater recharge flux, R, from the equation:

$$R = T_D/Cl_{gw} = PCl_{wd}/Cl_{gw} \qquad \text{equation (A)}$$

where:

- R = groundwater recharge flux (mm/a),
- T_D = total annual chloride deposition rate (mg/m^2/a)
- Cl_{gw} = chloride concentration in groundwater (mg/L),
- P = precipitation (mm/a) and
- Cl_{wd} = mean chloride content in precipitation (wet and dry deposition) (mg/L)

The chloride mass balance method was used extensively in Botswana during the GRES projects. Gieske (1992) and Selaolo (1998) produced chloride deposition maps of the country based on a limited number of rainfall collectors. It must be pointed out that the CMB method only provides an estimate of the micropore component of the total recharge. Macropore recharge, through outcrops and direct river recharge, will not be subject to evaporation losses and not show up by the CMB method. This is however hardly likely in the present project area due to the extensive Kalahari sand cover.

There are two ways of determining the parameter Cl_{wd} (chloride concentration of soil below the root zone or in groundwater). One method is to analyse the chloride content in soil moisture with depth. In general, chloride increases in soils with depth due to water removal by trees and by evaporation directly from the soil. From the depth at which the soil moisture is beyond the reach of trees, its chloride content will remain constant (Gieske 1992). In arid areas, the profile is frequently more complex, since many rainstorms do not penetrate deep into the soil cover (Gieske 1992, Wrabel 1999). The stable portion of chloride profile represents chloride content of groundwater that can be used in the above equation. The other method is to use the chloride concentration in groundwater directly. This is applicable in areas where the water table is deep enough to exclude the influence of water withdrawal by trees and where the chloride concentration of groundwater can be assumed to be unaffected by leaching of aquifer material. Sampling at the water table is ideal. In many cases the chloride content of groundwater within a locality is quite variable and some average value needs to be estimated. One way is to calculate the harmonic mean of the chloride contents of all the boreholes in the suitable area to calculate an average Cl_{gw} to use in the calculation. The equivalent method is to calculate recharge separately for each borehole and use the arithmetical mean to estimate the average of the area.

In the Matlho-a-Phuduhudu Block, recharge estimates using the chloride mass balance method ranged between 0.2 and 15 mm per year (WCS, 2001) which was based on the variable chloride content of the groundwater samples selected for calculation. This was based on Cl_{wd} which was 300mg/m^2/a. Later evaluations by Chilume (2001) and Rahube (2003) yielded recharge values in the same range In the Ncojane Block (Ncojane and Kule Villages), values of between 2.3 and 8.8 mm/yr were earlier derived (WRC, 1998), based on the presence of more low-level chloride abundances there.

The variable results from these studies highlight the problems inherent to this method. Firstly, in order to use this method, the chloride deposition rate (T_d in mg/m^2/yr), has to be known. The second problem with this method is the fundamental assumption that chloride is a conservative ion once it reaches the groundwater system. Chemistry data from the area indicate that this is not the case in some parts of the project area. Calculation of acceptable recharge rates based on the groundwater chloride content **does not prove** that recharge is actually occurring. The calculation merely indicates the micropore recharge rate if the vadose zone recharge were to be taking place over the presumed time scale.

7.1.2 STABLE ISOTOPES (DEUTERIUM AND ^{18}O)

Allison *et al*. (1984) developed an empirical method of estimating groundwater recharge from precipitation in semi-arid to arid regions in Australia with rainfall varying from 100 to 710 mm/yr and recharge rates of 1 to 140 mm/yr, and where a uniform sandy, unsaturated cover is usually present. Under these conditions, it was observed that ^{18}O-D (deuterium) analyses of groundwater plot below, but parallel to the local meteoric water line. This is interpreted to be the result of mixing of infiltrating rainwater with soil moisture that has undergone some evaporation in the unsaturated zone. If recharge conditions remain uniform through time, the groundwater ^{18}O and deuterium data would plot along a line parallel to, but displaced from, the local meteoric water line. The extent of this displacement is proportional to the evaporative enrichment of infiltrating water in the upper layers of the soil and dilution by recharging groundwater.

For a uniform soil, it has been shown empirically that the enrichment in ^{18}O and deuterium is related to the recharge by the following equation (Allison et al, 1984):

$$\Delta\delta D = \frac{C}{\sqrt{R}} \qquad \text{equation (B)}$$

where:

$\Delta\delta D$ is the displacement of δD
C is 22 (constant)
R is mean annual recharge mm/a

Recharge values estimated in this manner are generally more accurate in areas with low recharge, typically less than 10 mm/yr (Selaolo, 1998). The assumption of this method is that recharge occurs in un-vegetated (barren) soils. Nevertheless this method appears to give acceptable results in Botswana (Selaolo, 1998). This method also excludes macro-pore recharge and the effects of soil moisture withdrawal by trees and therefore provides a minimum recharge estimate for the appropriate timescale (decades to centuries).

The method requires that a local meteoric rainfall line (^{18}O-D relation) be available. In arid regions this requires quite a few years of samples in order to be certain that the data set is representative of the actual rainfall that is recharging. Groundwater samples that are to be used for this comparison need to be obtained from those parts of the aquifer that are likely to be recharge regions (up gradient of the flow path, low chloride, high ^{14}C, thin sand cover). In that respect the requirements are similar to that of the chloride method.

7.1.3 TRITIUM AND RADIOCARBON

The presence of tritium (^{3}H) and radiocarbon (^{14}C) above about 80 pmc, are both indicative of recent (post 1960AD) recharge. In a qualitative sense they are therefore recharge indicators and are frequently used as such. In low-flow situations where reliable samples can be obtained from well-defined depths, ^{14}C and tritium profiles can indicate vertical flow rates which can be equated with recharge rates. This is however not applicable in the present study area where the water table is quite deep and a large amount of the recent recharge, if such exists, is contained in the unsaturated zone.

In cases where the water flow pattern is understood, a simplified application of ^{14}C interpretation can be made. The mean residence time (MRT) of water in the aquifer can be calculated from (Gieske 1995):

$$MRT = 8267*\ln(A_o/A) \qquad \text{equation (D)}$$

valid for a confined aquifer, or

$$MRT=8267/(A_o/A - 1) \qquad \text{equation(E)}$$

valid for an unconfined aquifer
where A_0 is the initial 14C content of the water, and
A is the measured 14C content of the water

MRT of the water can then be used to derive a long-term recharge quantity from:

$$R = pH/MRT \qquad \text{equation (F)}$$

where p = total porosity of the aquifer, and
H = depth of the saturated water column of the aquifer.

Rahube (2003) has used this method to calculate recharge values of water in the Lokalane/Ncojane basin and produced recharge values of 0.04 to 0.2 for the Ecca and 0.6 to 2.5 for the Ntane. It is however not clear what values for p and H were used and whether the water quantities in the unsaturated zone were taken into account. The advantage of the method is that it handles the long-term recharge and encompasses the total recharge over the time span of the MRT. The disadvantage is that it includes a number of assumptions which are difficult to test in these large study areas.

7.2 RECHARGE EVALUATION FROM PROJECT DATA

7.2.1 GROUNDWATER NUMERICAL MODELLING

In order to estimate recharge values from the numerical groundwater model, it was assumed that the aquifer transmissivity is better known than the recharge. Recharge values required to produce the observed water levels were then calibrated with the numerical model. Recharge values obtained for the Ecca aquifer based on modelling ranged between 0.15 mm/yr to 0.63 mm/.

The value of recharge obtained through numerical modelling is uncertain because it depends on aquifer transmissivities used. However the estimated recharge values are considered good as lower bound values. An estimate of was obtained can be obtained from the head variations after rainfall events. For example, water level rise of 150 mm to 250 mm was observed between November 2005 and February 2006 (Piezometers BH6342 and BH10220). With a storage coefficient of about 0.01 this would mean that there was a recharge of 1.5 to 2.5 mm over a time frame of about 4 months or a recharge for the whole year of 0.5 to 0.8 mm/yr if no further recharge occurred. The interval spanned by these values includes the calibrated estimate of recharge of 0.63 mm/yr obtained in zone 2 (where the two piezometers lie)

7.2.2 Rainwater Sampling

The deuterium-offset and the CMB methods both require long-term chemistry and isotope data of rainfall from localities in or close to the study area. The earlier work did not provide much rainfall data that were thought to be of value for the present project. The sample network of rainfall collectors that were used in the GRES projects (Gieske 1992, Selaolo 1998) has a sparse coverage of the western part of the country: Only the two year (1988/90) data from Tshane can potentially be applicable to this project. Sampling of rainfall for ^{18}O, D and Cl determination was therefore included in the Matsheng project to fill this data gap.

Five pairs of cumulative rain collectors were set up. Cumulative rain collectors are fairly simple devices that can be set up unattended for a full rainy season and yield suitable representative rainfall samples. The samplers were deployed at five localities; at the same sites as the recording rain gauges that were deployed for the project (**Figure 21**). The samplers were supplied by the CSIR and consist of 1 metre long PVC tubes into which the rainfall is collected while it is covered with oil to prevent evaporation. The oil layer ensures that the samples that are retrieved in this way are a representation of the cumulative rainfall during the sampling period (Weaver & Talma 2004) suitable for chemical and isotope determination. When these samplers are set up for long enough periods, then the dry deposition ends up in the sample as well and the water sample therefore represents the total salt deposition for that period. Pairs of samplers were set up in order to identify contamination of the samples. Rainwater samples were collected for two periods that covered the period February 2005 to February 2006.

Table 34 Analysis Results for Rainwater samples

Locality	Rainfall amount	Chloride	Nitrate	Phosphate	Sulphate	$\delta^{18}O$	δD	Cl input
	mm	mg/l	mg/l (as NO3)	mg/l (as PO4)	mg/l (as SO4)	‰SMOW	‰SMOW	mg/m²
Period: February to June 2005								
Ukwi primary school	155	1.12	<0.05	<0.05	2.64	-1.7	-1	173
Ukwi west rain gauge	232	0.38	<0.05	<0.05	1.14	-3.0	-10	88
Ncaang primary school	147	0.46	<0.05	0.16	1.44	-1.4	2	68
Ncojane ranches	221	0.73	3.52*	<0.05	2.01	-1.6	-1	163
Ncojane CJSS	126	0.87	<0.05	<0.05	2.06	-1.4	-2	110
Period: June 2005 to February 2006								
Ukwi primary school	298	0.45	0.95	0.23	1.02	-8.0	-51	135
Ukwi west rain gauge	512	1.70*	0.72	0.22	0.93	-6.5	-41	872*
Ncaang primary school	131**	0.32	0.82	0.21	1.03	-6.5	-37	42**
Ncojane ranches	741	0.25	0.70	0.24	1.06	-6.3	-39	199
Ncojane CJSS	502	0.21	1.11	0.15	0.76	-6.2	-38	105

** contaminated samples*

*** Recorder not working for period Dec 05 to Feb 2006, rainfall data shown is for October & November 05*

The (short) winter samples show a fairly clear consistent chemical content. The usual contamination indicators (P and N) are generally low and the chloride values of the pairs are consistent. The summer samples have lower Cl but are more contaminated. Contaminated analyses were ignored and data from the remaining data pairs averaged to obtain acceptable chemical contents for each period (**Table 34**). The resulting chloride levels of rainfall range between 0.21 and 1.12 mg/L with lower values during the rainy season (**Table 34**). The chloride contents from the five stations showed acceptable patterns for each season when compared with the rainfall (**Figure 22**). One can see the dilution effect of concentration by increased rainfall and the higher concentrations during the drier seasons. This relation was used to interpolate one contaminated Cl. These Cl values are consistent with other values obtained throughout Botswana (Gieske 1992) and Namibia (Wrabel 1999) but may vary from year to year (Selaolo 1998). Chloride contents <1 mg/L were found by Wrabel (1999) in Namibia generally in the later part of summer. On that basis the chloride values presented here are likely to be minimum values and acceptable for processing.

Table 35 Chloride deposition details for the period Feb 2005 - Feb 2006

Site	Rainfall amount mm	Total Cl deposition $mg/m^2/y$	Mean rainfall chloride mg/L	^{18}O input ‰SMOW	D input ‰SMOW
Ukwi primary school	453	308	0.68	-5.9	-34
Ukwi west rain gauge	744	237	0.32	-5.4	-31
Ncaang primary school	447*	164	0.37	-4.8	-25
Ncojane ranches	962	362	0.38	-5.2	-30
Ncojane CJSS	628	214	0.34	-5.2	-31
Average	**647**	**257 s,d. =87**	**0.42**	**-5.3**	**-30**

**447* estimated rainfall includes data gap between Dec 2005 and February 2006

The chloride depositions for the five stations represent a complete calendar year and the average annual chloride deposition rate calculated for the five stations of 257 $mg/m^2/yr$ (**Table 35**) is comparable with annual data obtained by from studies. A value of 300$mg/m^2/yr$ was earlier used for the Lokalane area (WCS 2001) based on contour maps by Selaolo (1998). The 1988/90 value obtained from Tshane (302 $mg/m^2/yr$) fits in with this pattern and compares quite favourably; given that it is known that such values can vary 20%-30% from year to year (Gieske 1992) and 33% within the present study area.

^{18}O and deuterium for the first low rainfall are high (more positive) (**Table 34**). Those from the wetter second period, in contrast, show significantly lower ^{18}O and deuterium content (**Figure 23**). The local meteoric water line (LMWL) for these two seasons was calculated from the regression through all the analyses and result in the general relation:

$$\delta D = 7.86*\delta^{18}O + 11.7 \text{‰} \qquad \text{equation(C)}$$

The slope of this regression line (7.86) is quite close to the global meteoric water line (slope 8.0, Figure B) that was established for coastal stations worldwide (Gat 2005). These are all good samples, since they cluster close together and represent long-term (many months) average rainfall. To what extent this one year's data is representative of a long-term mean, remains open. The two samples that were analysed during the Lokalane project in 2000 (WCS 2001) are merely single storm samples and therefore less representative (**Figure 23**).

Selaolo (1998) has given a summary of the LMWL's analysed at various stations and years throughout Botswana and shown that most of the slope values for local rainfall data sets range between 5.6 and 7.5. This makes the present data set with its slope of nearly 8 quite exceptional. The reason must be sought in the exceptional conditions that prevailed during the months of 2005/2006 rainfall season when total rainfalls of triple the normal rainfall were observed (962 mm for Ncojane compared to the long-term mean of 250). It is known that exceptionally high rainfalls produce anomalous stable isotope patterns (Gat 2005, EI 1997) and it is a reasonable explanation to assume that the high rainfalls during the project period prevented the rain from evaporating during and just after rainfall thereby retaining the original slope 8 in the resulting infiltrating water.

It can be argued that if recharge in the arid zone is only produced by such exceptional rain events and not by the 'regular' annual rainfall, then the isotope characteristics of these exceptional ones should be used for recharge determination by the D-off-set method and not those produced from normal years.

7.2.3 Chloride Mass Balance

As is shown by the ^{14}C data (**Table 37**), the Ntane sandstone which is saturated only in the eastern part, has the youngest water and represents the best examples of recent recharge. However, no new boreholes were drilled in this area during the present project and no new chemical analyses of groundwater are therefore available. The data from the previous study around Lokalane (WCS 2001) can however be used. In this study CMB calculations were made on the basis of a chloride deposition rate of 300 mg/m^2/yr (data obtained during 2005/6 at the five rainfall stations of the present project averaged at 257). Chloride concentrations from 20 boreholes (20 to 1448 mg/L) in the Ntane were used (**Figure 24**) and produced a range of recharge estimates between 0.2 and 15 mm/yr, with an average of 6 mm/yr. Given the limited distribution of low chloride boreholes, it seems likely that recharge is localised and that it only occurs in some areas but then at rates greater than 5mm/yr.

Effective application of the CMB recharge method requires chloride values of groundwater in the soil moisture below the root zone, or in groundwater at the water table not too far below the root zone, in order to minimize the possibility that additional sources of chloride be intercepted. The new groundwater data obtained in the present project for the Ecca (Otshe) aquifer represent deep water of great age (>11 000years, see **Table 37**). CMB calculation of the project groundwater vis-à-vis the present rainfall in the project area is subject to considerable doubt since:

1. the present day chloride deposition rate is unlikely to be applicable to recharge events that occurred 10 000 to 30 000 years ago when conditions were certainly much different;
2. the chloride content at the first water strikes during drilling in the Ecca (134 + metre) could well have changed during its long passage down to these levels as is suggested by the chloride variation in groundwater.

Nevertheless, such a calculation can indicate some ball-park number of recharge: where it may occur. The chloride chemistry map of the Otshe (Figure 20 of the hydrochemistry section) indicates low Cl values in the west and north-western part of the project area. The minimum chloride value of 8 mg/L (BH 3016) represents a recharge rate of 38 mm/a. The harmonic mean of all the chloride values in the Ecca of 58 mg/L indicates a recharge rate of 5 mm/a. The true value of recharge, in those areas where recharge has occurred in the past would then be somewhere between 5 and 38 mm/yr.

7.2.4 Stable Isotopes (^2H and ^{18}O)

Results of stable isotope analysis for the groundwater samples obtained during the present project are shown in **Table 36**. Overall the stable isotope ($\delta^{13}C$, $\delta^{18}O$ and δD) data are quite similar throughout the aquifer, suggesting that no separate water bodies are involved within the subdivisions of the Ecca. Vertically the water properties are quite uniform: $\delta^{18}O$ in those boreholes where multiple water strikes were encountered is constant within ± 0.2% with no evident vertical trend. The exception is the deepest sample from BH10217 (335 m deep) taken from the Kobe aquifer, below the Otshe sandstone.

The distribution of ^{18}O in the groundwater throughout the study area tends to show more negative values in the west (**Figure 25**). The combination of ^{18}O and deuterium (**Figure 26**) gives a different pattern for the samples from the present investigation (along an evaporated line with a slope of 3.8) than for those of the 2000 project in the east (along the GMWL).

Recharge calculation by the deuterium offset method described earlier was done using the local meteoric water line established by Selaolo (1998): $\delta D = 6.7*\delta^{18}O + 8.3$ ‰. This has been established over a longer time span and the annual averages established for 2005/6 in the present study area fit the curve quite well (**Figure 26**).

The four available δD, $\delta^{18}O$ pairs from the Ntane data of the 2000 project (**see Figure 26**) yield recharge rates of 8, 10, 14 and 16 (mean 12) mm/a. The data for the Ecca are more difficult to interpret. As was the case with the CMB approach, there is the problem of using present day rainfall data to apply to groundwater that was recharged many thousands of years ago (well within the Pleistocene). It is known that the stable isotope composition of Pleistocene groundwater (and its rainfall) was certainly different from the Holocene (Stute & Talma 1996, Kulongoski & Hilton 2004).

No reliable recharge values can therefore be obtained from these old samples

Table 36 Isotope Results from the present Project

Borehole	Date	Water Strike Depth/ Screen Zone Aquifer	Aquifer	Detail	$\delta^{18}O$ ‰SMOW	δD ‰SMOW	Tritium TU	^{14}C pmc	^{13}C ‰PDB	Chloride mg/L
BH 10211	24-11-05	188.89-244	SST 1/2	CRT 48hrs	-7.3	-50				59
BH 10212	11-02-06	275 .48-281.61 & 284.74-297	SST2	CRT 48hrs	-7.5	-52		2.8 ± 0.4	-13.9	98
BH 10214	10-03-06	174 & 300	Open in SST1, SST2 & Kobe	CRT 72hrs	-7.1	-50		3.7 ± 0.1	-16.3	418
BH 10215	28-01-06	211.68-247.76	SST 1/Mud 2	CRT 72hrs	-7.7	-52		<1.2	-12.8	60
BH 10216	08-11-05	134	Mud 1	Strike 1	-6.7	-49	0.0 ± 0.1			
BH 10216	08-11-05	168	Mud 1	Strike 2	-7	-48				
BH 10216	14-11-05	173	Mud 1	Strike 3	-6.7	-48				
BH 10216	16-11-05	191	Mud 2	Strike 4	-6.6	-45				
BH 10216	19-02-06	173.15 – 185.40	SST1 & Mud 2	CRT 75hrs	-7.6	-52		1.0 ± 0.1	-12.7	464
BH 10217	25-11-05	169	Mud 1	Strike 1	-7.2	-49	0.0 ± 0.1			
BH 10217	25-11-05	182	SST 1	Strike 2	-7	-48				
BH 10217	25-11-05	188	SST 1	Strike 3	-7.4	-50				
BH 10217	26-11-05	229	SST 1	Strike 4	-7.2	-49				
BH 10217	28-11-05	275	SST 2	Strike 5	-7.3	-49				
BH 10217	05-12-05	335		Strike 6	-5.6	-45				
BH 10219	03-03-06	172.94-246.43	SST 1	CRT 51hrs	-7.3	-52		1.7 ± 0.2	-14.3	102
BH 10221	03-02-06	276-299.20	SST 1	CRT 72hrs	-7.5	-52		1.1 ± 0.1	-13.5	85
BH 10222	28-11-05	274.60-286.00	SST 1/2	CRT 72hrs	-7.1	-51				103
BH 10228	05-12-05	191.00-250.90	SST 1	CRT 115hrs	-6.5	-47	0.0 ± 0.1	1.6 ± 1.5	-8.3	41

BH 10229	15-11-05	183	SST 1	Strike 1	-7	-48	0.0 ± 0.1	0.0 ± 1.5	-12.1	
BH 10229	16-11-05	198	SST 1	Strike 2	-6.8	-48	0.0 ± 0.1			
BH 10229	21-11-05	253	Mud 2	Strike 3	-6.8	-48				
BH 10229	21-11-05	266	Mud 2	Strike 4	-6.9	-49				
BH 10229	21-11-05	282	SST 2	Strike 5	-7.1	-50				
BH 10229	21-11-05	289		Strike 6	-7.2	-49				
BH 10229	10-12-05	268.02-317.00		CRT 72hrs	-7.2	-50				88
BH 10314	26-01-06	173.15-185.4 & 191.52-216	MOS/KBSST/Mud2	CRT 72hrs	-7.2	-50		<0.5	-14.0	115
BH 10315	09-02-06	248.31-279	KWMud/KBSST/SST1	CRT 72hrs	-6.7	-45		<1.8	-12.2	41
BH 10316	21-02-06	173.09-215.99	SST 1	CRT 72hrs	-6.6	-45		6.5 ± 0.1	-12.9	13

7.2.5 TRITIUM AND CARBON 14

A limited number of samples were collected for tritium and ^{14}C (radiocarbon) analysis from the newly drilled boreholes: all in the Ecca. Tritium measurements were also obtained from the first water strikes of the three boreholes 10216, 10217 and 10229 as well as a few others that could conceivably contain some recent water. In none of the samples was any tritium detected **(Table 36).** This agrees with the observation during the Lokalane project when the only three boreholes from the Ecca for which tritium was measured, all showed zero (WCS 2001).

Radiocarbon data were obtained from some of the boreholes that were drilled in the course of this project (**Table 36**). Most of them showed negligible ^{14}C content (<2 pmc). This quantity represents a model age in excess of 28 000 years and this low level can very well be due to contamination during sample handling. The values in the range of 2-7 pmc must indicate real quantities that correspond to model ages in the 19 000 to 30 000 year age range (**Table 37**). This does not necessary imply that all the water is of that age: it is also likely that this water contains a small amount of younger water added to water of a greater age.

During the Lokalane project four samples from the Ecca in the north-eastern part of the present study area showed ^{14}C contents of 4 to 14 pmc (**Figure 27**). These boreholes are located much closer to the Ntane where ^{14}C contents between 21 and 58 were found (**Table 37**). This suggests that either there is recharge to the Ecca in the north eastern part of the present study area or there is connection between the Ntane and Ecca aquifer in this area.

Carbonate addition that will reduce the ^{14}C content of groundwater has been estimated from alkalinity increases underground. The average alkalinity of water from the Ntane sandstone in this area as analysed in 2000, is 304 mg/L (WCS 2001); that of the Ecca samples of the present and 2000 project average at 405 mg/L. An average worst case scenario of dead-carbonate addition to the Ecca groundwater would therefore be an extra 33% and has been accounted for in the calculation of MRT of the groundwater in Table **24**. The age calculations show that the Ntane water is of Holocene age (<11 600 years) while the Ecca groundwater is Pleistocene recharge (> 11 400 years

Table 37 Listing of ^{14}C Data and Derived Ages for the Project Area

Borehole	Year	Depth /Screen Zone	Aquifer	^{14}C pmc	^{13}C ‰PDB	MRT years
BH 8547	2000	Unknown?	Mosolotsane/Kwetla	57.6 ± 0.5	-9.5	3 200
BH 9237 WS1	2000	Unknown?	Ntane	39.2 ± 0.4	-8.4	6 400
BH 9237 T.P	2000	Unknown?	Ntane	28.4 ± 0.4	-9.8	9 100
BH 9297	2000	Unknown?	Ntane	20.9 ± 0.4	-9.0	11 600
BH 7755	2000	Unknown?	Ecca	14.2 ± 0.3	-13.4	11 400
BH 7752	2000	Unknown?	Ecca	9.0 ± 0.3	-14.0	15 900
BH 10316	2006	173.1-216.0	Ecca	6.5 ± 0.1	-12.9	18 800
BH 9297	2000	? Unknown?	Ecca	4.1 ± 0.2	-10.4	21 700
BH 7760	2000	Unknown??	Ecca	3.7 ± 0.4	-10.5	22 600
BH 10214	2006	170	Ecca	3.7 ± 0.1	-16.3	22 600
BH 10212	2006	275 .5-281.6 & 284.7-297.0	Ecca	2.8 ± 0.4	-13.9	24 900
BH 10219	2006	172.9-246.4	Ecca	1.7 ± 0.2	-14.3	29 000
BH 10228	2005	191.0-250.9	Ecca	1.6 ± 1.5	-8.3	29 500
BH 10221	2006	276.0-299.2	Ecca	1.1 ± 0.1	-13.5	32 600
BH 10216	2006	?	Ecca	1.0 ± 0.1	-12.7	33 400
BH 10315	2006	248.3-279.0	Kwetla/Ecca	<1.8	-12.2	>28 000
BH 10229	2005	183	Ecca	<1.5	-12.1	>30 000
BH 10215	2006	211.7-247.8	Ecca	<1.2	-12.8	>32 000
BH 10314	2006	173.1-185.4 & 191.5-216.0	Mosolotsane/Kwetla	<0.5	-14.0	>39 000

Mean residence time (MRT) calculations are based on an initial ^{14}C content of 85pmc for the Ntane and 56 (=85*⅔) for the Ecca samples.

Recharge rates based on the ^{14}C content of groundwater have the advantage that they show the integrated values that are suitable for water balance calculations. This is in contrast to the rates determined by CMB and D-offset methods which describe the localised recharge rates and are insensitive to those areas where no recharge is actually occurring.

The calculations shown in Table **38** all use a porosity of 20% based on data from neutron porosity logging data from the current project, WCS (2001) and JICA (2002). The thickness of the aquifer is the difference between the water level depth and bottom of the aquifer The results are presented for both the confined and unconfined flow models. Since the aquifers in the study area are most likely a combination of these types one can set the acceptable range of recharge values by this method somewhere between the two models.

The data show that only a single Ntane borehole (BH 8547) reflects a high recharge (5-6 mm/yr). All of the other boreholes listed in Table 38 show recharge values from 1.5 mm/yr to nil. This range seems independent of the actual ^{14}C content (0 – 21 pmc) and indicates a good internal consistency. Even the samples with ^{14}C content less than 2 pmc fit the pattern.

Table 38 Calculation of Recharge from the ^{14}C Content of Groundwater

Sample	^{14}C pmc	Porosity %	Thickness m	Recharge mm/yr		Aquifer type
				confined model	unconfined model	
BH 8547	57.6	20%	100	6.2	5.1	NTANE
BH 9297	20.9	20%	83	1.4	0.7	NTANE
BH 7755	14.2	20%	100	1.4	0.5	ECCA
BH 7752	9	20%	100	1.1	0.3	ECCA
BH10316	6.5	20%	105.4	1.0	0.2	Ecca
BH10214	3.7	20%	149.85	1.2	0.2	Ecca & Kobe
BH10212	2.8	20%	165.74	1.2	0.1	Ecca
BH10315	1.8	20%	168.7	1.1	0.1	Ecca
BH10219	1.7	20%	204.6	1.3	0.1	Ecca
BH10228	1.6	20%	191.4	1.2	0.1	Ecca
BH10215	1.2	20%	128.09	0.7	0.0	Ecca
BH10221	1.1	20%	228.28	1.3	0.1	Ecca
BH10216	1	20%	125.37	0.7	0.0	E
BH10314	0.5	20%	203.74	1.0	0.0	MOS/KBSST/Mud2

7.3 CONCLUSIONS FROM ISOTOPES

- Total chloride deposition (both wet and dry precipitation) in the study area for the twelve month period from February 2005 to February 2006 for five sites ranged between 164 and 362 mg/m2. The summer of 2005/6 was an exceptionally high rainfall season. Nevertheless the deposition rates measured for that season are comparable with the 300 mg/m2/a determined in other years in this part of the country.
- Rainfall 18O and deuterium (2H) values for the 2005/6 rainy season (derived from cumulative rainfall collectors) are located along the Global Meteoric Water Line and fairly close to the Local water Line established for Lobatse between 1991 and 1995.
- The chemistry and isotope data of samples that were collected at different depths in Ecca boreholes during drilling, do not provide any evidence of vertical recharge.
- The oxygen-18 and deuterium content of Ecca groundwater is fairly uniform with a slight decrease towards the western part of the study area. There are no evident differences between SST1 and SST2.

- Groundwater in the Ecca within the project area represents recharge of 11 000 years and older (to beyond 30 000 years). There is no local evidence of recharge to the Ecca other than a single borehole (BH10316) with the highest ^{14}C content and the lowest chloride level. Any further search for recharge evidence should be directed towards the area with the lowest chloride levels and shallowest water table (western).
- Groundwater in the Ntane located in the north-east of the project area is of Holocene origin (age <11 000 years). Low chloride and high ^{14}C indicate that active recharge may still be taking place. The absence of tritium in the groundwater, however, implies that the bomb-tritium signal may still be located in the unsaturated zone here. Tritium and chloride profiling of the soils in this area might therefore be profitable.
- Recharge knowledge of the Ntane aquifer is based on the results of samples collected in 2000, since the present project did not sample there. The CMB and D offset methods both indicated a range of recharge values from 18 mm/yr to lower with a mean around 6 mm/yr. Both these methods indicate the recharge rate only for localised areas where recharge actually occurs.
- The recharge calculation for the Ntane using ^{14}C is based on only the two samples for which both borehole details and ^{14}C analyses are known (BH8547&9297). These yield rates of 6 and 1 mm/yr and therefore covers the range of the other methods. It is therefore likely that active recharge occurs in the Ntane, though it is low and very localised.
- In the Ecca (Otshe) the CMB method becomes less certain due to the great age of the groundwater and the likelihood of chloride uptake in the aquifer. Based on the assumption of the present chloride input, the borehole with the lowest chloride content shows a recharge of 38 mm/a and the others progressively smaller; with a mean of 5 mm/yr. As in the Ntane, this probably means that at some time localised recharge of this magnitude occurred here.
- The D-offset method of recharge determination could not be applied to the Ecca, since the small δD difference is very susceptible to the actual rain input values. It is also seems that evaporation enrichment of the Ecca groundwater has occurred some time in the past.
- The ^{14}C method of recharge determination in the Ecca (Otshe) yields fairly consistent numbers in the range of 0.7 to 1.4 mm/yr for the confined model. The absence of younger water and the hydrological observations in this aquifer indicate that the confined model is more applicable here. ^{14}C recharge calculations done in this manner yield the regional recharge (including areas of zero recharge) and can therefore be used for water balance calculations.
- Future recharge investigations should be directed to mapping the area of low chloride water, investigating its flow pattern and its isotopic content. The question of lateral inflow from the west and north needs exploration beyond the boundary of the present project. Soil moisture investigations in very selected areas may be useful.
- The great age of this water body and its low replenishment rate necessitates great caution in its future exploitation

7.4 GROUNDWATER MONITORING ANALYSIS

Water level monitoring was initiated at the start of this project in November 2004 in order to understand following;

- Groundwater flow systems
- Assessment of long term groundwater level trends,
- Delineation of groundwater flow directions,
- Evaluation of the groundwater head relationships between different aquifers (both laterally as well as vertically) and generating groundwater level data for input into numerical groundwater models.

In this section water level responses in the project are discussed.

A number of boreholes within and around the in vicinity of the project area were monitored by WRC and the Department of Geological Surveys (DGS). The DGS monitored boreholes in the Matlho-a-Phuduhudu Block (MAP) are equipped with diver data loggers and a barometric pressure logger is installed in BH9044 to compensate for barometric pressure fluctuations. Monitoring of these boreholes was initiated in September 1999. There is however a problem with the diver data obtained from DGS in that there is no continuity of the water levels after each down loading period and this data was not used for water level trend analysis (**Figure 5.**). In addition to the boreholes monitored with data loggers, the DGS also manually monitors 8 other boreholes located along the Okwa River Valley and the Matsheng Villages (**Table 39**).

Table 39 Boreholes Monitored by DGS

BH No.	Location	Easting	Northing	Aquifer	SWL (mbgl)	Remarks
7167	MAP Block	627215	7448697	Ntane	131.12*	Lokalane Data Logger,
7752	MAP Block	542651	7480153	Ecca	105*	Lokalane Data Logger
7826	North central	479319	7476847	Ecca	120*	Lokalane Data Logger
9044	MAP Block (ADAS Station)	588027	7446659	Ntane	131.41*	Lokalane Data Logger
9045	Ncojane Ranches	504756	7455359	Mosolotsane	133.3*	Lokalane Data Logger
7761	Okwa Valley	525669	7493170	Ecca	105.32	Manually monitored
7763	Okwa Valley	560105	7496069	Ecca	99.2	Manually monitored
7764	Okwa Valley	560119	7496035	Ecca	98.6	Manually monitored
7768	Okwa Valley	525669	7493170	Ecca	114.33	Manually monitored
4237	Matsheng Villages	583187	7356026	Kalahari	17.8	Manually monitored
7868	Matsheng Villages	579344	7346881	Kalahari	11.52	Manually monitored
7872	Matsheng Villages	580299	7335804	Kalahari	17.1	Manually monitored
7889	Matsheng Villages	579270	7333595	Kalahari	15.55	Manually monitored

A total of 43 boreholes are monitored by WRC out which 11 are equipped with pressure transducers and barometric pressure logger is installed in BH8346 to compensate for barometric pressure fluctuations. Monitoring with pressure transducers was initiated in November 2004 whilst manual monitoring of selected existing boreholes was started in March 2005 **(Appendix B).** These boreholes are located in both the Ncojane and Matlho-a-Phuduhudu Blocks. The project boreholes equipped with pressure transducers are shown in **Table 40** and a complete list of boreholes recommended for water level monitoring is given in **Table 41.**

In groundwater projects, it is important to have rainfall data for correlation with water level trends. This is achieved by correlating rainfall events with water level fluctuations. Long term rainfall data from 1975 to 2004/2005 is available from Gantsi Township and the villages of Tshane and Ncojane. During the Hunhukwe/Lokalane Project, five rain gauges were installed in the Matlho-a-Phuduhudu Block while under the Matsheng Project five rain gauges were installed mainly in the Ncojane Block.

Table 40 List of Project Boreholes Monitored with Transducers

BH No.	Location	Easting	Northing	Aquifer	Approx. SWL (mbgl)	Remarks
6342	Masetlheng	485971	7376597	Otshe	64.342	Transducer monitored since Dec 2004
8346	Ncojane	427458	7442545	Otshe	93.691	Transducer monitored since Jan 2005
8646	Ncojane Ranches	462698	7436099	Otshe	103.36	Transducer monitored since Dec 2004
10316	Ncojane West			Otshe	115.102	Transducer monitored since May 2006 ,transducer not working since Mar 2007 and replaced by transducer from BH9241 in Nov 2007
9244	MAP Block	607706	7420856	Otshe	152.868	Transducer monitored since Dec 2004, stopped working in Oct 07
9295*	Metsimantsho	503310	7439415	Otshe	132.728	Transducer monitored between Dec 2004 and Sep 2005. Transducer moved to BH10220 (monitoring) in 7 Nov 05
9297	MAP Block	570320	7444043	Otshe	153.055	Transducer monitored between Nov 2004 and Feb 2006 & it was re installed on May 2006
9240*	MAP Block	608896	7449821	Ntane	134.78	Transducer monitored between March and October 2005. Transducer moved to BH10225 (monitoring) in Nov 2005.
10220	Metsimantsho	503304	7439407	Otshe	133.40	Transducer monitored since Nov 2005
9294*	MAP Block	516232	7457410	Otshe	129.365	Transducer monitored since March 2005 till May 2006 and moved to BH10226 in May 2006
9298*	MAP Block	577042	7478359	Otshe	110.97	Transducer monitored since March 2005 till May 2006 and moved to 10317
8545*	Hunhukwe	562009	7408307	Otshe	126.8	Transducer monitored since September 2005 till May 2006 and moved to BH10320 in May 2006
10225	MAP Block	608900	7449809	Ntane	135.36	Transducer monitored since Dec 2005
10320	MAP Block	570320	7444043	Otshe	153.02	Transducer monitored since May 2006
10226	MAP Block	570320	7444055	Ntane	147.98	Transducer monitored since May 2006
10317	MAP Block	608875	7449516	Otshe	145.99	Transducer monitored since May 2006
9241*	MAP Block	542780	7460881	Ntane	136.06	Transducer monitored since Nov 2004 and moved to BH10316 in Nov 2007

**Transducers moved to another location*

1. All transducer Batteries Should be Changed every 6 months BH 9244 **
2. Manual Monitoring should be every 2 months
3. All transducers should be down loaded every 2 months
4. All raingauges are working, their batteries should be changed every 11 months
5. All raingauge batteries were replaced in OCTOBER 2007
6. 9244** Transducer not functioning needs repairs
7. Transducer batteries should be changed every 6 months, last battery change date August 2007
8. Monitoring network was handed to DWA in January 2008
9. MAP = Matlho-a-Phuduhudu

Table 41 Boreholes Recommended for Water Level Monitoring (Manual and Transducers)

BH No.	Easting	Northing	Transducer Installation Date	Casing Elevation (m amsl)	Block	Comments
9135	589441	7473110		1151.30	MAP	
8545	562002	7408323		1249.00	MAP	
9237	586371	7460347		1177.77	MAP	
9239	586905	7436509		1192.00	MAP	
9240	608903	7449807		1173.00	MAP	
9291	593058	7420962		1186.00	MAP	
9217	504420	7379146		1186.72	Ncojane	
9244**	607710	7420857	12 September 2004	1182.00	MAP	Not working
9297	570325	7444044	29 November 2004	1201.00	MAP	
8646	462698	7436099	05 May 2005	1255.85	Ncojane	
8346	427458	7442545	22 January 2005	1268.50	Ncojane	Barotroll installed in the same borehole
9295	503310	7439415		1242.15	Ncojane	
9218	504517	7378596		1184.27	Ncojane	
6342	485971	7376597	10 December 2004		Ncojane	
10210	445827	7439007		1268.92	Ncojane	
10211	445818	7439004		1268.80	Ncojane	
10212	471357	7413720		1242.08	Ncojane	
10214	474333	7397979		1225.41	Ncojane	
10215	423550	7424116		1262.68	Ncojane	
10216	445843	7400347		1241.04	Ncojane	
10217	462926	7396725		1232.14	Ncojane	
10218	462941	7396727		1232.09	Ncojane	
10219	462945	7396707		1232.09	Ncojane	
10220	503298	7439428	07 November 2005	1242.74	Ncojane	
10221	465933	7427586		1254.04	Ncojane	
10222	475982	7427299		1244.47	Ncojane	
10223	586358	7460350		1178.40	MAP	
10224	586902	7436518		1190.91	MAP	
10225	608914	7449809	05 December 2005	1171.81	MAP	
10226	570319	7444055	12 May 2006	1206.44	MAP	
10227	441140	7435377		1267.63	Ncojane	
10228	441134	7435388		1267.56	Ncojane	
10229	477486	7424731		1240.99	Ncojane	
10314	490310	7429080		1222.66	Ncojane	
10315	507682	7433985		1238.59	Ncojane	
10316	400854	7427983	11 May 2006 (Original)	1261.41	Ncojane	Replaced Original transducer by the one from 9241 on 02-11-07
10317	608900	7449809	13 May 2006		MAP	
10320	570325	7444044	12 May 2006	1201.00	MAP	
10402	441130	7435358		1270.60	Ncojane	Production Borehole
10404	445760	7438700		1270.06	Ncojane	Production Borehole
10405	442666	7436299		1269.01	Ncojane	Production Borehole
10407	440170	7432108		1264.40	Ncojane	Production Borehole
10410	442531	7428629		1259.83	Ncojane	Production Borehole
10411	438640	7431014		1265.04	Ncojane	Production Borehole

7.5 WATER LEVEL TRENDS

7.5.1 KALAHARI BEDS

Data is available for four boreholes completed in the Kalahari aquifer. Four of these boreholes are located in the Hukuntsi area (Matsheng villages) and are monitored by DGS. Data from these boreholes dates from 1999 to July 2005. The other Kalahari monitoring borehole is located in Ukwi (BH6326) and monitoring of this borehole commenced November 2004. The Kalahari aquifer is mostly saline and was not targeted in this project.

Two boreholes completed in Kalahari beds (Matsheng Villages) BH4237 and BH7868 recorded water level rises after the high rainfall events of the 1999/2000 rain fall season (**Figure 30**). The other two boreholes, BH7872 and BH7889 showed only groundwater recession despite the recorded rainfalls. After the 1999/2000 rainfall season no water level rises were observed in all the four boreholes monitoring the Kalahari Beds in the Matsheng Villages, indicating that only rainfall events with a certain magnitude actually results in groundwater recharge. The magnitude of water level rises in borehole which had response was between 0.5 and 1 m. Relatively high water levels were maintained in BH4237 and BH7868 through out 2001 and 2002, with the recession trend only starting in 2003. The recession trends in boreholes monitoring Kalahari Beds are probably driven by evapotranspiration. The variable responses to rainfall events in a relatively small area of the Kalahari Beds aquifer indicate that recharge is heterogeneous.

Similar to Kalahari Beds aquifers in the Matsheng area, the project monitored borehole (BH6326) located near Ukwi pan did not show any response to 2004/2005 and 2005/2006 rainfall seasons (**Figure 31**). The water levels in this borehole are stable compared to the Matsheng boreholes indicating that there is little or no evapotranspiration in this area probably because of the highly saline groundwater in this borehole.

7.5.2 NTANE AQUIFER

A total of 4 boreholes are currently being monitored by pressure transducers. Two boreholes are monitored by WRC while others are monitored by the DGS **(Tables 39 and 40).** Data from the DGS monitored boreholes date as far back as 1999 but there is problem with the recent data as it lacked continuity with the old data after each down loading session **(Figure 32)**. As a result only data collected by WRC is discussed here.

These boreholes were selected to represent the central, northern, southern margins of the Ntane Sub-basin. In general water level trends in this aquifer are flat to declining with very little evidence for active recharge. The magnitude of water level rises in this aquifer are very small probably because of its unconfined nature or possibly because it is the least actively recharged aquifer in the project.

7.5.3 ECCA (OTSHE) AQUIFER

A total of 9 boreholes tapping the Ecca aquifer are monitored with pressure transducers by WRC (**Table 40).** Some 2 additional boreholes are monitored by DGS in the Matlho-a-Phuduhudu Block as well as four along the Okwa valley **(Table 39).** The DGS monitored boreholes have a relatively long (from 1999) monitoring record. Manual monitoring of boreholes tapping Otshe aquifer was also conducted by WRC and DGS. A list of

Water levels in boreholes monitoring Ecca (Otshe) aquifer show a range of responses from stable, continuously rising and receding trends throughout the monitoring period. These trends are illustrated in hydrographs given in **Figures 37** to **39**.

BH8346 recorded continuously rising water levels since inception of monitoring in January 2005 with the water level having risen by 2.62 m by September 2007 (**Figure 37**). BH8646, which had similar trend to BH8346 at the beginning of the monitoring period in December 2004, is now showing a receding to stable water level trend since December 2006. Another borehole also tapping the Ecca aquifer, BH10220 has similar response to the other two boreholes (BH8646 and BH8346) i.e. continuously rising water levels though of a smaller magnitude since November 2005 until a slightly declining to stable trend is observed from September 2007. Seasonal rises of between 0.14 to 2.62 m were recorded through out the 3 year monitoring period (**Figure 39**). In terms of the hydraulic head between the two sandstone units of the Ecca, Sandstone 1 and 2, groundwater level monitoring data at a location in the Matlho-a-Phuduhudu block indicates that the head difference between the 2 sandstones is very little with sandstone 2 having slightly higher head than sandstone 1.

Water levels for the Ecca aquifer show seasonal rises which usually occur around October to June as well as continuous rises. This could reflect that local rainfall events as well as long term regional inflow are recharging this aquifer. Some of the observed water level rises may in fact be a response to the high rainfall events of 1999/2000 season and can not be preferential recharge along fault planes or dolerite intrusions as the trend is not affected by local rainfall events.

7.5.4 Summary of Water Level Trends

Water level monitoring data indicates that the Ecca aquifer, particularly in Ncojane block is actively recharging probably through both regional inflow and local rainfall events.

Qualitatively, the magnitude of recharge responses for the Ecca (Otshe) and the Ntane aquifers are different, with the Ecca (Otshe) responses generally larger. This may relate to the confined nature of Ecca and the semi confined to unconfined nature of Ntane where for a given recharge quantum, water levels will rise less in an unconfined aquifer than in a confined aquifer. It may also reflect an actual greater amount of recharge to Ecca aquifers, which in the west tend to have thinner Kalahari overburden and is reportedly exposed in Namibia. Water level rises of 0.14 m to 2.62 were recorded through out the monitoring period.

Monitoring of the groundwater levels to establish the long term trends of the aquifers in the project area is essential. The monitoring network initiated during the project was handed over to DWA in January 2008 and DWA is encouraged to continue with manual and as well as transducer monitoring (**Table 41**) to ensure availability of data for updating of the numerical model in future.

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Figure 21 Location of Monitored Boreholes and Rain Gauges/Collectors

Figure 22 Chloride concentrations of rainfall samples collected in the cumulative rainfall samplers

Figure 23 Plot of deuterium against ^{18}O of Rainwater Samples Collected During the present project

Figure 24 Distribution of chloride values in the two main aquifers of the project area[1]

Figure 25 Distribution of ^{18}O in the Study Area[2]

Figure 26 Plot of ^{18}O and deuterium in the present study area[3]

Figure 27 Distribution of ^{14}C content through the study area: based on the Present Project Data & WCS 2000[4]

Figure 28 Chloride Distribution, Ecca

Figure 29 Hydrographs for Kalahari Beds aquifer (Matsheng Villages)

Figure 30 Hydrograph for Kalahari Beds aquifer in BH6326, Ukwi.

Figure 31 Water Level Data, BH9045 (DGS Diver Monitored), Matlho-a-Phuduhudu

Figure 32 Hydrographs Central Ntane Sub-Basin, Matlho-a-Phuduhudu

Figure 33 Ntane Hydrographs, Northern Margins of the Ntane Sub-Basin

Figure 34 Ntane Hydrographs, Southern Margins of the Ntane Sub-Basin

Figure 35 Hydrographs of the Otshe aquifer (Okwa Valley)

Figure 36 Continuously Rising Water Levels Otshe aquifer, BH8346 (Ncojane)

Figure 37 Hydrograph of the Otshe Sandstones 1 and 2 aquifer (Matlho-a-Phuduhudu)

Figure 38 Typical Hydrographs of the Otshe aquifer in the Ncojane Block)

8 RESOURCE ASSESSMENT

The groundwater resources in the two exploration blocks (Ncojane and Matlhoaphuduhudu) were evaluated both analytically and using numerical modelling. The analytical methodology was employed to provide an estimate of the total groundwater reserves as well as the "extractable" portion of these reserves. The numerical model was utilised to understand the dynamics of the hydrogeological system under natural conditions as well as during wellfield abstraction. Using the numerical model, wellfield scenarios were evaluated to assess the sustainable abstraction rates.

8.1 RESOURCE ASSESSMENT METHODOLOGY

The Ecca aquifer has been broadly divided into two compartments by fault **F6**. This fault exerts major control on both the depth to top of the Otshe aquifer as well as groundwater quality. Groundwater which falls within acceptable Class II limits occurs in the compartment located northwest of fault **F6**, while some parameters such sodium, TDS and fluoride exceeded the Class II limit to the southeast of this fault. For the resource assessment for Ecca aquifer only the area falling northwest of fault F6 was considered.

For the Ntane sandstone, only areas where third of the saturated thickness is more than 20m were considered as possible areas for wellfield development. This is because for unconfined aquifers, only the bottom third of the aquifer can be screened to allow for dewatering. These areas are referred to as potential wellfield areas (PWA).

The methodology employed in assessing the water resources of the exploration areas consists largely of a volumetric estimation. The volumetric estimation incorporated aquifer area and thickness, and calculation of matrix volume and aquifer storage. These were combined to provide an assessment of the total groundwater reserves of each PWA. The other criterion used was that the potential wellfield area had to be located in an area where groundwater quality is within drinking water standards. The distance from the potential wellfield to the demand centres as well as the need for future wellfield expansions was also taken into consideration while selecting the final wellfield areas.

8.1.1 AQUIFER AREA AND THICKNESS

Accurate estimates of aquifer area and thickness are crucial in assessing the total groundwater resources for any given aquifer system. The aquifer thickness was obtained from interpretation of borehole geophysical logging data, drilling data and ground geophysical data sets and the physical boundaries (aquifer area), using existing geological mapping data and drilling data.

For the Ecca aquifer, the saturated thickness was assumed to be the depth to the top of first unit of the Otshe Formation (Sandstone 1) minus the rest water level (available drawdown). The saturated thickness was taken as an average of all the boreholes located northwest of fault **F6**. The saturated thickness for the Ntane Aquifer was taken as 1/3 of the saturated thickness to allow for dewatering of a part of the aquifer during abstraction. Only areas where 1/3 of the saturated thickness exceeded 20 m were considered as potential wellfield areas.

8.1.2 SATURATED MATRIX VOLUME, AQUIFER STORAGE AND RESERVES

The Matrix Volume (R), for each potential wellfield area, was calculated based on the following equation

R = Aquifer Area*Aquifer thickness
Ecca aquifer, Thickness = Depth to Top Sandstone 1 –Rest water Level (Confined aquifer)
Ntane aquifer Thickness = 1/3 of saturated thickness (unconfined)

This method of estimating aquifer reserves is conservative and should provide an underestimate of the volumes of water in storage. Based on these assumptions the total reserves (TR) for each Potential Wellfield Area were calculated as follows:

$TR = RxS_{av}$
Where,
R = matrix volume
Sav= average storage coefficient
The storage coefficient (S_{av}) value was taken as the average of pumping test data derived values for each aquifer.

Under wellfield abstraction, only a part of these reserves can ever be practically exploited (exploitable resource versus total resource). The reasons for this include:

- Some water will remain trapped in the aquifer matrix
- Pockets of air will form and isolated patches of water will remain in the aquifer and will not be easily extracted

Most of these parameters are difficult to determine with any degree of accuracy and a value of 20% was used to estimate the extractable resources (ER) as follows.

ER = TR*.20

8.1.3 Resource Quantification

The groundwater resources of the PWAs were determined based on the calculated total reserves (TR) and extractable reserves (ER). A comparison of the total reserves in each PWA indicates that the Ecca aquifer has the highest total reserves of 158 MCM in storage compared with the Ntane aquifer which has a total of approximately 40 MCM in storage (**Table 42**).

Table 42 Summary of Groundwater Resources Assessment for the PWAs

Aquifer	Surface Area m^2	Aquifer Thickness (m)	Saturated Matrix Volume (m^3)	Average S	Total Reserves (m^3)	Extractable Reserves, m^3	Average Q (m^3/hr)	Average Q/s (m^2/hr)	Average T (m^2/d)
Ecca Aquifer (Otshe), Ncojane Block	4,391,115,829	81	307,378,108,012	4.43E-04	157,566,409	31,513,282	54	5	137
Ntane Aquifer	1,126,898,090	25	28,172,452,251	1.44E-03	40,427,469	8,085,494	33	3	52

8.2 Potential Wellfield Area Comparison

There were two main components of the resource assessment in each PWA; a quantitative evaluation of the total and extractable volumes of groundwater in PWA and a comparative analysis of the two aquifer systems under consideration based on series of key hydraulic parameters. The main inputs to the volumetric assessment were aquifer area, aquifer thickness, calculated volumes of groundwater in storage and extractable volumes. The key hydraulic parameters that were considered for comparative analysis of the two aquifers were:

- Borehole Yield Characteristics (Average Yields)
- Borehole and Aquifer Productivity Characteristics (Specific Capacity and Transmissivity)
- Recharge Potential
- Extractable Reserves

In addition to these, the water quality, environmental considerations and the potential for future wellfield expansion were taken into consideration while selection the final wellfield area location.

8.2.1 BOREHOLE YIELD CHARACTERISTICS

The borehole yield characteristics of each potential wellfield area were analysed by collating constant rate test yields from project and existing boreholes for each aquifer system. The mean yield was derived by averaging the tested yield from all the boreholes in each area. The results show that the Ecca (Otshe aquifer) has the highest average yield of 54 m^3/hr compared to the Ntane aquifer where an average yield of 33 m^3/hr was obtained.

8.2.2 BOREHOLE AND AQUIFER PRODUCTIVITY CHARACTERISTICS

Borehole and aquifer productivity characteristics of each potential wellfield area were evaluated by collating pump testing data from project and existing boreholes. Parameters which were collated were specific capacity and transmissivity.

The Specific Capacity (Q/s) of a borehole is its yield (Q) per unit drawdown (s). This parameter provides a useful measure of the productivity of a borehole and an aquifer. If the aquifer is large and has good transmissivity and storage characteristics, relatively large Q/s values will result from high yields and small drawdowns. A specific capacity of 5 m^2/hr was obtained for the Ecca (Otshe) aquifer compared to a value of 3 m^2/hr for the Ntane aquifer (**Table 42**).

Aquifer Transmissivity (T) is a measure of the rate of groundwater flow through an aquifer, and also the productivity of an aquifer. The mean T value was calculated from all tested boreholes (project and existing) for each area under consideration. A comparison of the two aquifers again indicates that the Ecca aquifer (Otshe) has higher average T values compared to the Ntane aquifer where values of 137 m^2/d and 52 m^2/d were obtained respectively for Ecca and Ntane aquifers.

8.2.3 RECHARGE POTENTIAL

The actual recharge potential of each potential wellfield area is difficult to quantify, although considerable qualitative understanding of recharge dynamics of the two aquifers under consideration has resulted from the project. Water level monitoring data indicates that recharge is occurring to the Ecca (Otshe) while there is very little evidence for active recharge to the Ntane aquifer based on available monitoring data. Most of the Ntane aquifer monitoring boreholes indicates declining water levels, and pumping will probably accelerate the reduction of the saturated thickness, possibly resulting in wellfield failure.

8.2.4 POTENTIAL FOR FUTURE WELLFIELD EXPANSION

The fact that the potential wellfield area for the Ntane aquifer is limited in aerial extent implies that the area has limited potential for future wellfield expansion if the water quality deteriorates with time and borehole yields fail. Pumping might also induce poor quality groundwater from the margins of the basin as these areas have relatively poor quality groundwater.

8.2.5 EXPLOITABLE RESERVES

The exploitable reserves were taken as 20% of the total volumes of groundwater in storage for each potential wellfield area. Exploitable reserves in the Ecca aquifer were calculated as 32 MCM while for the Ntane aquifer, an estimate of 8 MCM was obtained.

8.2.6 POTENTIAL ENVIRONMENTAL IMPACTS

The Matlho-a-Phuduhudu Block, where the Ntane aquifer is developed, is located in an area identified as a possible wildlife migratory corridor between the Transfrontier Park and the Central Kalahari Game Reserve. Developing a wellfield in this area might have some impacts on wild life migration patterns. The water levels in the Ntane aquifer are declining due to the evapotranspiration effects and operating a wellfield will accelerate the water level decline, and might have some effects on the vegetation.

8.3 SUMMARY

The comparative analysis of the two aquifers indicates that the Ecca aquifer has the highest potential aquifer in terms of groundwater development and wellfield was developed in this aquifer shown in **Figure 39**. Numerical groundwater modelling indicates that the wellfield can sustain abstraction rates of approximately 10,000 m^3/d for a period of up to 30 years. The potential for the Ntane aquifer to sustain large scale wellfield abstraction has been evaluated as limited and it is not considered as viable long term solution for sustainable water supply in the project area.

Figure 39 Location of the Ncojane Wellfield and other Potential Wellfield Areas

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9 BIBLIOGRAPHY

JICA, 2002: The Groundwater Potential Evaluation and Management Plan in the Southeast Kalahari (Stampriet) Artesian Basin in the Republic of Namibia, Final Report submitted to the Department of Water Affairs, Namibia

Kirchner, J., Tredoux, G., Wierenga, A., and Christelis, G., 2002: Applying environmental isotopes to a Hydrogeological model of the Stampriet Artesian Basin. IAEA regional model project RAF/8/029. Department of Water Affairs, Windhoek.

Renshaw, C.E., 1998: Sample bias and the scaling of hydraulic conductivity in fractured rock. Geophysical Research Letters, **25**, 121-124.

Resources Services, 2001: Tsabong Groundwater Investigation Assessment and Development. Final Report. Department of Water Affairs. Gaborone. Botswana.

Reynolds J.M., 1997: An Introductory to Applied and Environmental Geophysics

Selaolo, E.T., 1998: Tracer Studies and Groundwater Recharge Assessment in the Eastern Fringe of the Botswana Kalahari: The Letlhakeng-Botlhapatlou Area. Ph.D. Thesis. Free University of Amsterdam

Smith, 1984: The Lithostratigraphy of the Karoo Supergroup in Botswana – DGS bulletin 26, Botswana.

Tredoux, G., Cave. L. C., & Engelbrecht, J. F. P., 2000: In-Situ measurements of physico-chemical parameters down a borehole as a tool for resource evaluation, Groundwater: Past Achievements and Future Challenges, A. A. Balkema/Rotterdam/ Brookfield. P667.

Verhagen, B. Th., Bredenkamp, D.B., and Botha, L.J., 2001: Hydrogeological and isotopic assessment of the response of a fractured multi-layered aquifer to long term abstraction in a semi-arid environment. Water Research Commission, Report 565/1/01. ISBN 1 86845 710 9. Pretoria. 42p.

Verhagen, B. T., Mazor, E., & Sellschop, J. P. F., 1974: Radiocarbon and Tritium evidence for direct recharge to groundwater in the Northern Kalahari, Nature, 249:643-644

Verhagen, B. T., 1985: Isotope hydrology of ground waters of the Kalahari, Gordonia. Trans geol soc S Afr 88 (3):517-522.

Wellfield Consulting Services (WCS), 2003: Werda- Mabutsane- Sekoma TGLP Groundwater Survey. Final Report (Volume 1). Department of Geological Survey, Lobatse, Botswana.

Wellfield Consulting Services (WCS), 2001: Hunhukwe/Lokalane Groundwater Survey Project (TB 10/2/1/98-99), Wellfield Consulting Services, Final Report submitted to the Department of Geological Survey, Lobatse, Botswana.

Wellfield Consulting Services (WCS), 1996: Matsheng Area Groundwater Investigation (TB 10/2/12/92-93), Wellfield Interconsult, Revised Final Report submitted to the Department of Geological Survey, Lobatse, Botswana.

Weaver, J.M.C., and Talma, A.S., 2002: Cumulative rainfall collectors – a tool for assessing groundwater recharge. Conference: Tales of a hidden treasure; Somerset West, 16 Sept. 2002. Groundwater Division, Western Cape.

Wood, W.W., and Sanford, W.E., 1995: Chemical and isotopic methods for quantifying ground-water recharge in a regional, semi-arid environment. Ground Water 33(3) 458-468.

Wrabel, J., 1999: Determination of groundwater recharge in a semi-arid area in Namibia with the chloride mass balance method in German). PhD thesis. University of Wurzburg.

Water Resources Consultant (WRC), 1998: Groundwater Development in Ncojane and Kule Villages, Ghanzi District. Final Report submitted to the Department of Water Affairs, Gaborone, Botswana.

Table 5 Summary of Project Exporation Boreholes

BH No	UTM Coordinates		Block	Drilled Dates	Borehole Type	Drilled Depth	Water Strike, Yield, EC	Screened Interval		Completed Meterage (Casing & Screens)	Logged Meterage (N, T, C, NG, RS)	SWL	Elevation of MP	SWL	Date of SWL Measurement	Final Airlift Yield	Tested Yield	Final EC
	Easting (m)	Northing (m)				(m)	(m, m3/h, mS/cm)	From (m)	To (m)		(m)	(m bmp)	(m asl)	(m asl)		(m3/hr)	(m3/hr)	(µS/cm)
**BH9295	503305	7439434	MAP	23 - 24 May 2005	E	232	140, Minor, 1540 160, 6.5, 1000 185, 9.5, 1030 215, 35, 510	160.00	195.00	232.00	NL	132.73	1242.15	1109.42	29-Jan-06	50.0	91.0	1180
*BH9293	532473	7440719	MAP	27 - 28 May 2005	E	284	Dry				130							
BH10220	503298	7439428	MAP	31 May - 24 June 2005	M	232	145, 5.2, 1150 210, 25, 1750	155.11 211.82	194.81 223.15	226.00	226	133.40	1242.74	1109.34	29-Jan-06	25.1		1520
BH10221	465933	7427586	Ncojane	27 June - 11 September 2005	e	327	277, 46, 1000	276.00	299.20	302.20	293	101.74	1254.04	1152.30	12-Sep-05	12.2	30.0	1090
BH10222	475982	7427299	Ncojane	2 - 29 August 2005	e	290	150, 7, 2900 188, 27, 4200 289, 12, 2000	274.60	286.00	289.00	286	97.86	1244.47	1146.62	03-Feb-06	12.3	12.0	1390
**BH9237	586367	7460348	MAP	16 - 20 February 2000	E	244	158, 5.4, 1150 185, 2.9, 1220 244, 0.9, 1280	Open		67.70	NL	129.63	1177.77	1048.14	26-Jan-06	10.5	48.0	1140
BH10223	586358	7460350	MAP	14-19 September 05	M	215	143, 1.64, 1175 170, 4.48, 1228 188, 3.08, 1264	139.16	210.16	212.16	NL	130.31	1178.40	1048.10	19-Sep-05	9.0		1170
BH10227	441140	7435377	Ncojane	17 September - 31 October 2005	M	300	126, Minor 165, 7.7, 1100, 199, 93.3, 650	190.00	250.90	253.90	NL	106.00	1267.63	1161.63	30-Nov-05	101.0		620
BH10224	586902	7436518	MAP	21 September - 19 October 05	M	240	182, 7.5, 3450 206, 3.5, 3150 230, 2, 2950	159.04 178.92	173.24 232.88	235.88	NL	136.17	1190.91	1054.75	24-Jan-06	13.6		2390
**BH9240	608900	7449809	MAP	21-Oct-05	E	244	167, 2.9, 280 185 3.7, 440 200, 3.9, 380 208, 5.3, 460	Open		83.00	NL	134.78	1173.00	1038.22	27-Jan-06	15.9	55.5	560
BH10225	608914	7449809	MAP	22 - 29 October 2005	M	209	168, 4.14, 626 182, 4.5, 560	161.88	201.64	204.48	NL	135.36	1171.81	1036.45	27-Jan-06	8.6		550
BH10210	445827	7439007	Ncojane	14 - 27 October 2005	M	250	60, Minor 195, 22, 700 218, 3, 790	192.83	244.07	247.00	NL	107.64	1268.92	1161.28	27-Oct-05	25.0		830
BH10215	423550	7424116	Ncojane	12 - 27 October 2005	E	250	173, 3.5, 3250 203, 5.5, 2500 215, 11, 2200 233, 10, 2300	211.68	247.76	250.00	NL	97.91	1262.68	1164.77	06-Feb-06	36.6	32.0	840
BH10228	441134	7435388	Ncojane	15 - 31 October 2005	E	256	126, Minor 165, 7.7, 1100, 199, 93.3, 650	191.00	250.90	253.90	NL	107.40	1267.56	1160.16	31-Oct-05	73.6	93.0	620
BH10211	445818	7439004	Ncojane	27 October 2005 -	E	257	60, Minor 199.5, 25, 690, 224, 26.3, 780	188.89	244.00	247.00	248	107.46	1268.8	1161.34	11-Nov-05	43.0	70.0	740
BH10216	445843	7400347	Ncojane	29 October - 19 November 2005	E	251	134, 4.4, 3260, 168, 4.4, 3280, 173, 5.4, 2690, 191, 22.4, 2950	173.15 191.52	185.40 216.00	219.00	248	86.63	1241.04	1154.41	14-Feb-06	51.0	45.0	2750
BH10226	570319	7444055	MAP	31 October - 7 November 2005	M	201	162 Minor 174, 6.6, 564	173.24	193.12	195.96	NL	148.05	1206.44	1058.39	12-Feb-06	8.0		513
BH10229	477486	7424731	Ncojane	5 November to 25 November 2005	E	320	183, 6.5, 5510, 198, 13.5, 5970 253, 4.4, 2080 266, 4.7, 1775, 282, 20.3, 1503 289, 18.6, 1460	268.02	317.00	320.00	317	95.49	1240.99	1145.50	30-Jan-06	43.6	20.2	1360
BH10314	490310	7429080	Ncojane	13 November - 8 December 2005	E	300	105, Minor, 14230 116, 4.5, 18700 152, 7.8, 18600 155, 17.3, 19000, 232, 9.2, 5040 258, 6.8, 3700, 276, 20.8, 2800	275.48 284.74	281.61 297.00	300	252.8	88.26	1222.66	1134.4	1-Feb-06	42.9	40.0	1890
BH10217	462926	7396725	Ncojane	21 November - 14 December 2005	M	400	169, 4.4, 2580 182, 15.6, 1304 188, 16.6, 1237 229, 22.9, 1318 275, 9.1, 1377 338, 14.4, 13500 371, 6.1, 12760	371.64	374.49	377.33	399.5	94.02	1232.14	1138.12	14-Dec-05	10.5		12570
**BH9239	586815	7436504	MAP	10-Dec-05	E	276	160, 6.5, 1000 215,51,1830	149.00 209.00	167.00 276.00	276.00	NL	136.00	1192.00	1056.00	26-Jan-06	9.2	NA	2430
BH10212	471357	7413720	Ncojane	28 November 2005 - 17 January 2006	E	268	144, Minor, 5940 155, 6.5, 6950 223, 4.4, 2850 249, 26, 1330	229.5 241.75	235.62 254	257	198.02	88.26	1242.08	1153.82	01-Feb-06	25.0	12.0	1320
BH10315	507682	7433985	Ncojane	28 November 2005 - 24 January 2006	E	287	156, 7.68, 2780 177, 47.65, 3310 210, 41.85, 4330 250, 126.96, 890	248.31	279	282	282	130.89	1238.59	1107.7	24-Jan-06	127.0	55.0	700
BH10218	462941	7396727	Ncojane	21 November - 14 December 2005	M	290	172, 4.4, 2480 183, 32.17, 1360 189, 14.5, 1295 213, 8.35, 1325	175.8	246.67	249.67	NL	84.02	1232.09	1148.07	26-Jan-06	59.4		1445
BH10316	400854	7427983	Ncojane	21 January - 10 February 2006	E	250	162, 6, 280 174, 37.2, 300	173.09	215.99	218.99	226	115.23			10-Feb-06	46.5	95.0	280
BH10214	474333	7397979	Ncojane	20 January - 16 February 2006	E	324	170, 4.4, 3740 300, 2.8, 1800	Open		89	324	101.2	1225.41	1124.21	16-Feb-06	2.8	10.0	3150
BH10219	462945	7396707	Ncojane	27 January - 17 February 2006	E	296	170, 4, 2460 182, 30.39, 1396 188, 13.07, 1320 212, 15.96, 1340	172.94	246.43	249.43	296	86.72			17-Feb-06	63.8	95.0	1240
BH10317	608900	7449809	MAP	31 January - 28 February 2006	M	349	170, 2.86, 560 181, 7.7, 510 199, 12.31, 520 307, 12.65, 2490 328, 30.98, 840	321.55	324.3	327	349	144.37			06-Mar-06	43.6		2840
BH9297**	573156	7444406	MAP	6 June - 21 August 2000	M	444	197, 0.14, 480, 210, 7.36, 420 240, 12.5, 470 257, 10.5, 520, 393, 30, 5180 411, 33, 4670 417, 5.5, 4640, 429, 9.8, 4540	433.75	436.59	439.49	373.22	153.83			10-Mar-06	9.2		1280
BH10320								397.76	400.56	403.46		126.83						

Notes:

1. MP - Measuring Point
2. M - Monitoring Piezometer, 2 inch completion
3. E - Exploration Borehole, 8" Plain and slotted casings
4. TP - Test production borehole, 6.5" casings and screens
5. N - Neutron
6. T - Temperature log
7. C - Calliper log
8. NG - Natural Gamma
9. RS - Resistivity
10. NL- Not logged
11. *BH9293, an existing borehole deepened
12. **BH9295, an existing borehole cleaned
13. ***BH10213, borehole cement grouted and abandoned
14. NA - Not applicable

Table 6 Summary of Production Boreholes

BH No	UTM Coordinates		Location	Drilled Dates	Borehole Type	Drilled Depth	Water Strike, Yield, EC	Screened Interval		Completed Meterage (Casing & Screens)	Logged Meterage (N, T, C, NG, RS)	SWL	Elevation of MP	SWL	Date of SWL Measurement	Final Airlift Yield	Tested Yield	Final EC
	Easting (m)	Northing (m)				(m)	(m, m3/h, mS/cm)	From (m)	To (m)		(m)	(m bmp)	(m asl)	(m asl)		(m3/hr)	(m3/hr)	(µS/cm)
BH10402	441130	7435358	Ncojane	27 Jan-23 March 2007	P	257	167, 4.5, 1050 198, 72.32, 630	189.00	248.00	253.00	257	106.90	1270.60	1163.70	19-Mar-07	53	70	550
BH10403	445764	7438705	Ncojane	20 Jan - 03 April 2007		69		Borehole is abandoned, cement grouted and was replaced by BH10404.			NL							
BH10404	445760	7438700	Ncojane	03 March - 27 April 2007	P	250	198, 72, 730 225, 85, 778	205.00 236.00	226.00 245.00	250.00	250	107.15	1270.06	1162.91	25-Mar-07	64	65	795
BH10405	442666	7436299	Ncojane	15 March - 8 May 2007	P	255	161, 10, 960 193, 77, 550 206, 530, 92	190.00 200.00	195.00 250.00	255.00	255	109.20	1269.01	1159.81	25-Mar-07	78	75	540
BH10406	444840	7435850	Ncojane	28 April-13 May 2007	P	197	172, 4, 960	Borehole was abandoned			NIL							
BH10407	440170	7432108	Ncojane	10 May - 6 June 2007	P	249	205, 70.38, 530, 232, 117, 520	198.00	243.00	246.00	249	104.375	1264.40	1160.03	09-Jun-07	70	65	540
BH10408	440220	7432250	Ncojane	18 - 31 May 2007	P	144	Dry	Borehole is abandoned, cement grouted and was replaced by BH10411.										
BH10409	444840	7435850	Ncojane	22 - 24 May 2007		20	Dry	This borehole was started as the replacement borehole for BH10406, but was abandoned as well										
BH10410	442253	7428629	Ncojane	07 June -23 July 2007	P	263	185, 9.06, 1003 201, 51.21, 1000 226, 780, 113.58	213.00	258.00	263.00	263	101.00	1259.83	1158.83	04-Aug-07	74	70	630
BH10411	438645	7431005	Ncojane	27 July -07 September 2007	P	263	168, 2.9, 1190 202, 63, 550	211.00	261.00	266.00	266	103.60	1265.04	1161.44	11-Sep-07	44	70	560

P = Production

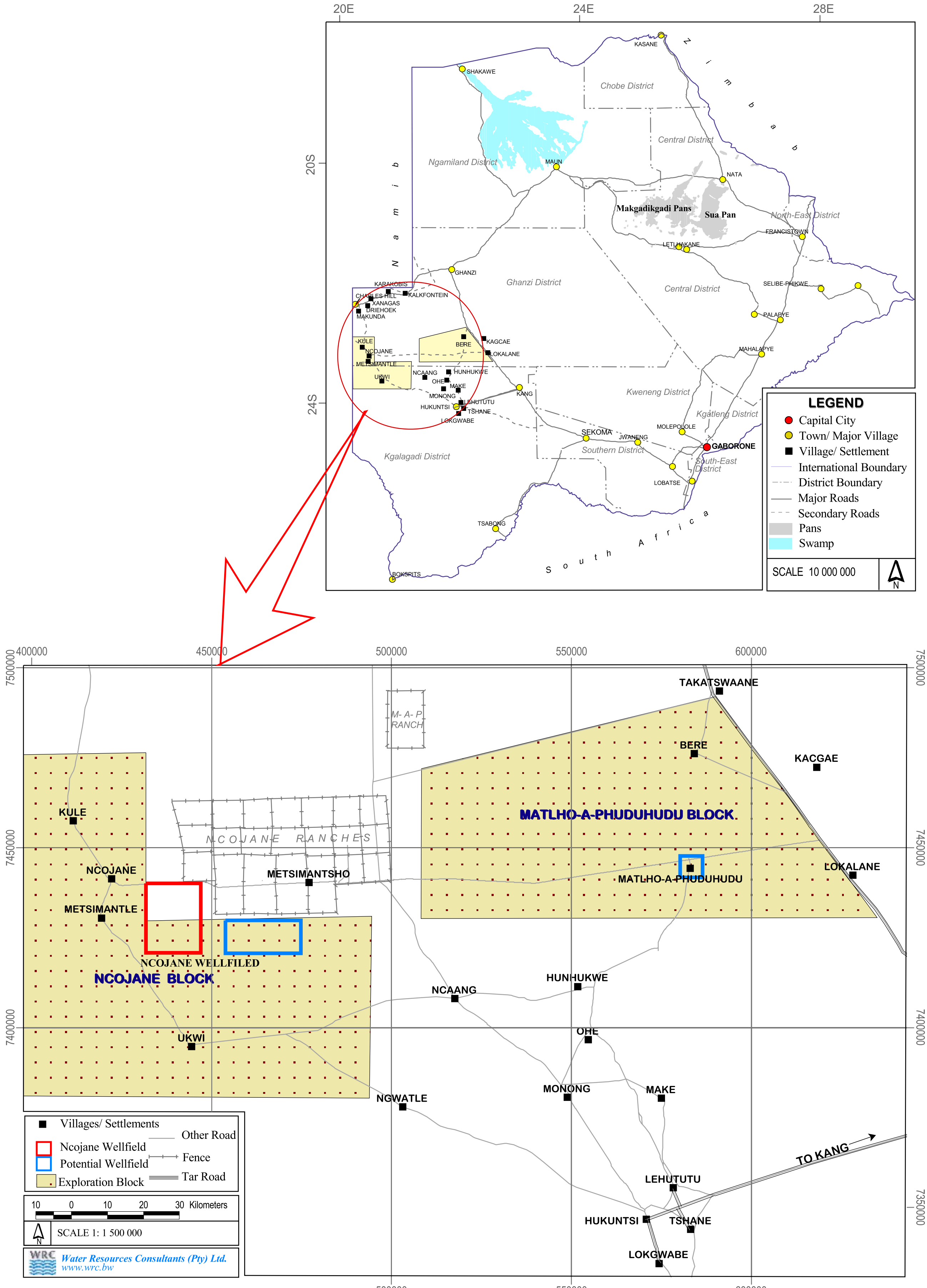
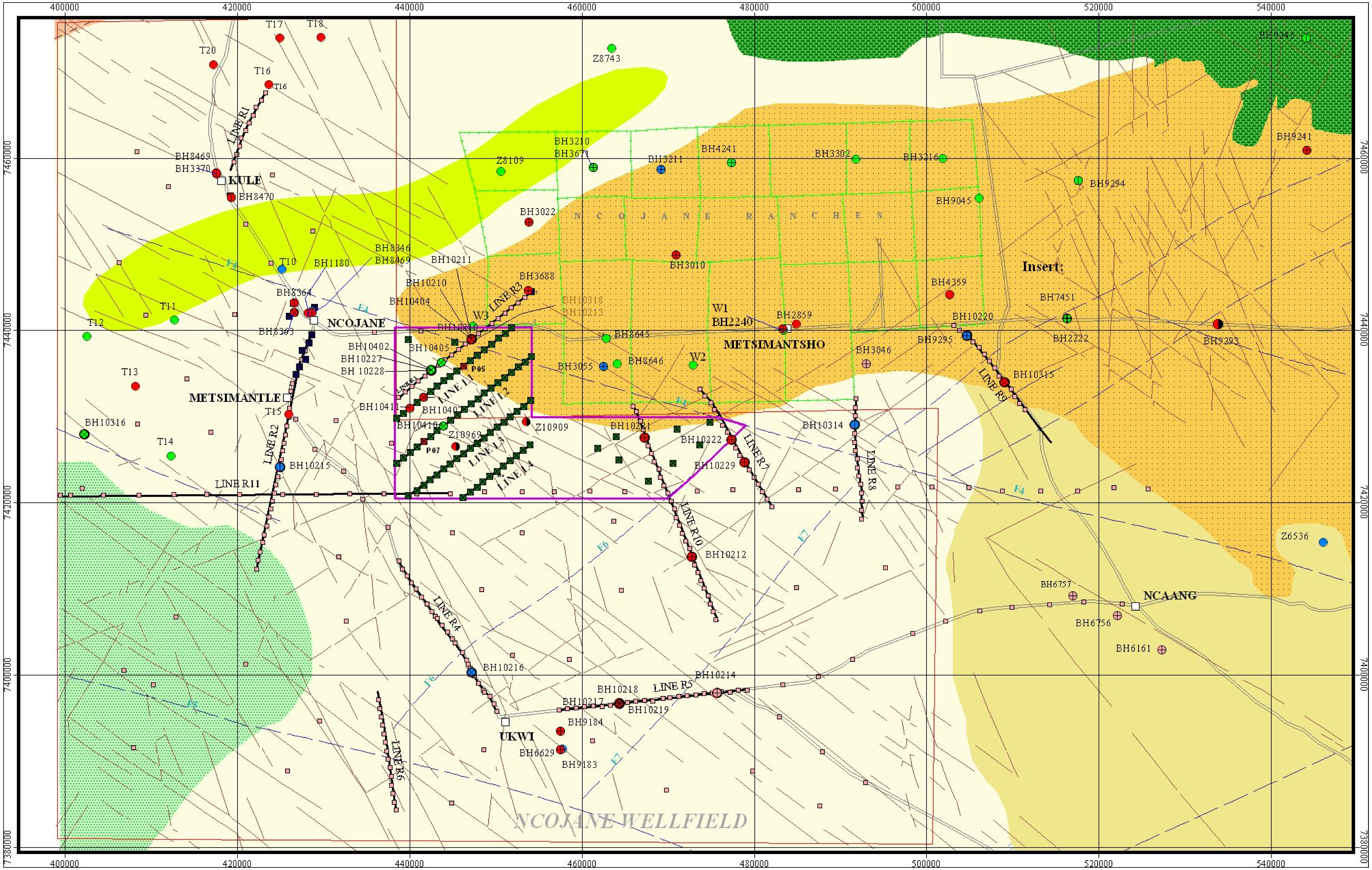


Figure 1 : Project Area Location Map



LEGEND

- Post Karoo Dolerites
- Stormberg Basalts
- Ntane Formation
- Mosolotsane Formation
- Ecca Group
- Ngwako Pan Formation
- Undifferentiated Ghanzi

LEBUNG GROUP

KAROO SUPERGROUP

- Recommeded Production Drilling Sites
- TEM Soundings (Exploration)
- TEM Soundings Production
- Calibration Soundings
- Calibration Soundings
- Possible Boundary (Remote Sensing)
- F6 Lineaments from Aeromag
- Lineaments from Remote Sensing
- LINE R8 Profile Lines Surveyed
- Welfield Area
- Fence
- Road
- Villages/ Settlements

Boreholes:

- TDS <= 450 (mg/L)
- TDS: 450 - 1000 (mg/L)
- TDS:1000 - 2000 (mg/L)
- TDS >=2000 (mg/L)
- Yield > 50 cubic meter/ hr
- Yield : 30 - 50 cubic meter/ hr
- Yield < 30 cubic meter/ hr

(Yield data not available for all BH)

- Private Borehole

T10, Private Boreholes Without Numbers

SCALE 1: 175,000

Coordinate System: UTM Zone 34S

Datum: Cape, Spheroid: Clarke 1880

3 0 3 6 Kilometers

N

Source: Geological Map Botswana- 1999, Dept. of Geological Survey(DGS), Hunhukwe/ Lokalane Groundwater Survey Project, 2001, DGS.

Figure 2:

Detailed Geophysical Survey Plan in Ncojane Block

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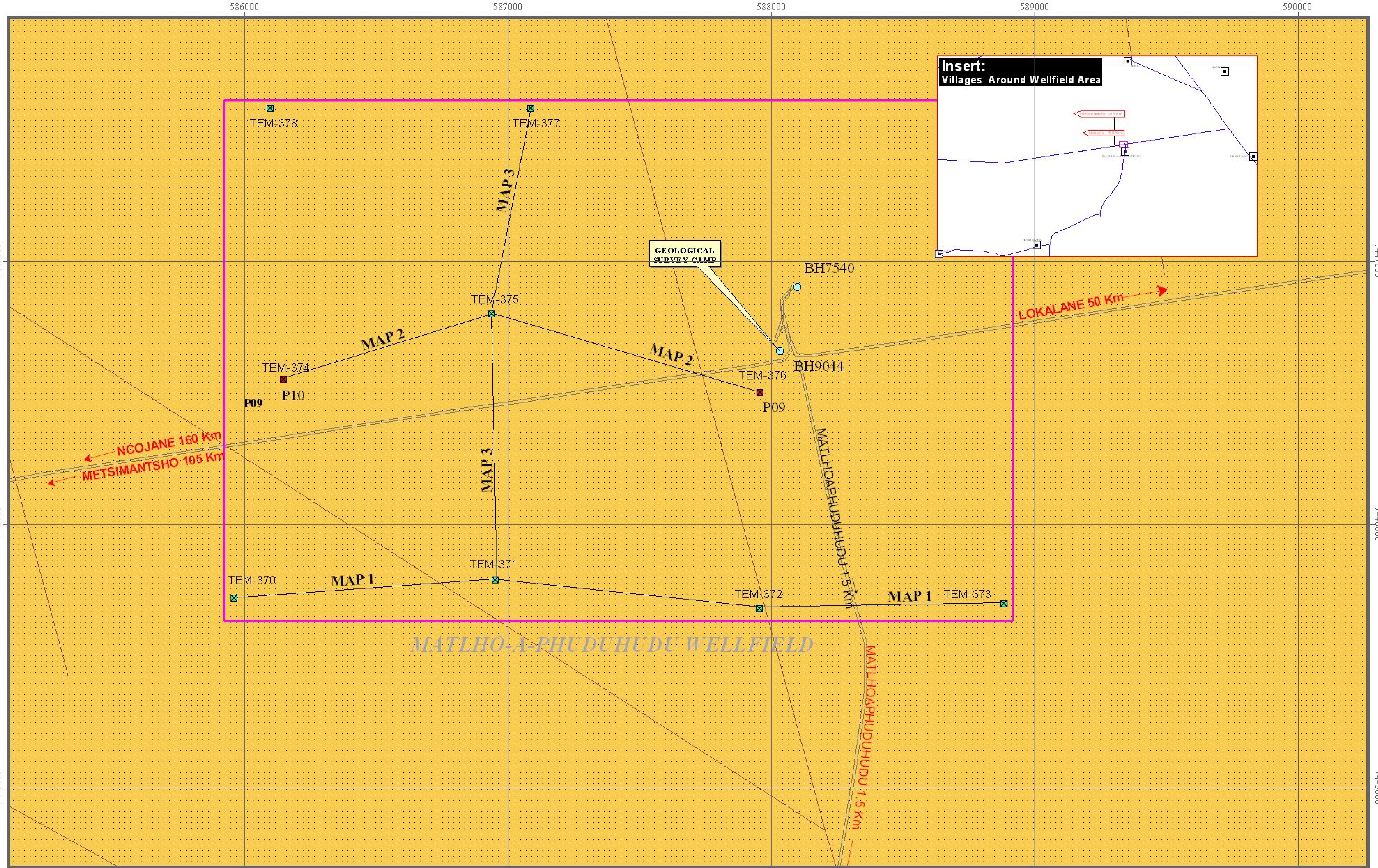

LEGEND

Ntane Formation] Karoo Super Group

Wellfirled Area

Lineaments from Remote Sensing

Road

Existing Boreholes:

TDS <= 1000 (mg/L)

330 TEM Soundings Production

P09 Recommended Production Drilling Site

SCALE 1: 15,000
Coordinate System: UTM Zone 34S
Datum: Cape, Spheroid: Clarke 1880

N

100 0 100 200 300 400 Meters

Source: Geological Map Botswana- 1999, Dept. of Geological Survey (DGS), Botswana and Hunhukwe/ Lokalane Groundwater Survey Project, 2001, DGS.

Figure 3: Detailed Geophyiscal Survey Plan (Matlhoa-phuduhudu Block)

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Figure 4 : Location of Production Boreholes

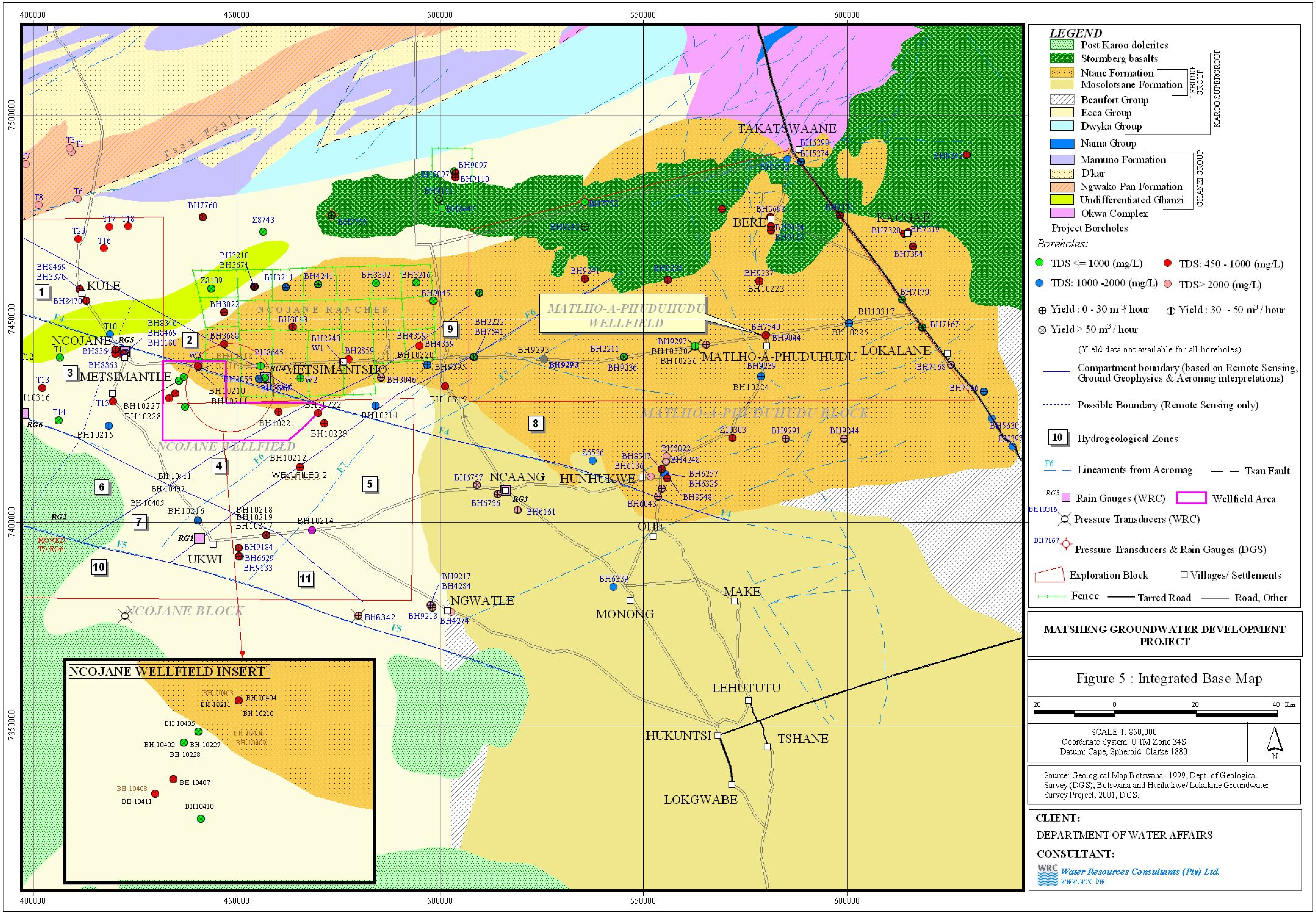

Figure 5 : Integrated Base Map

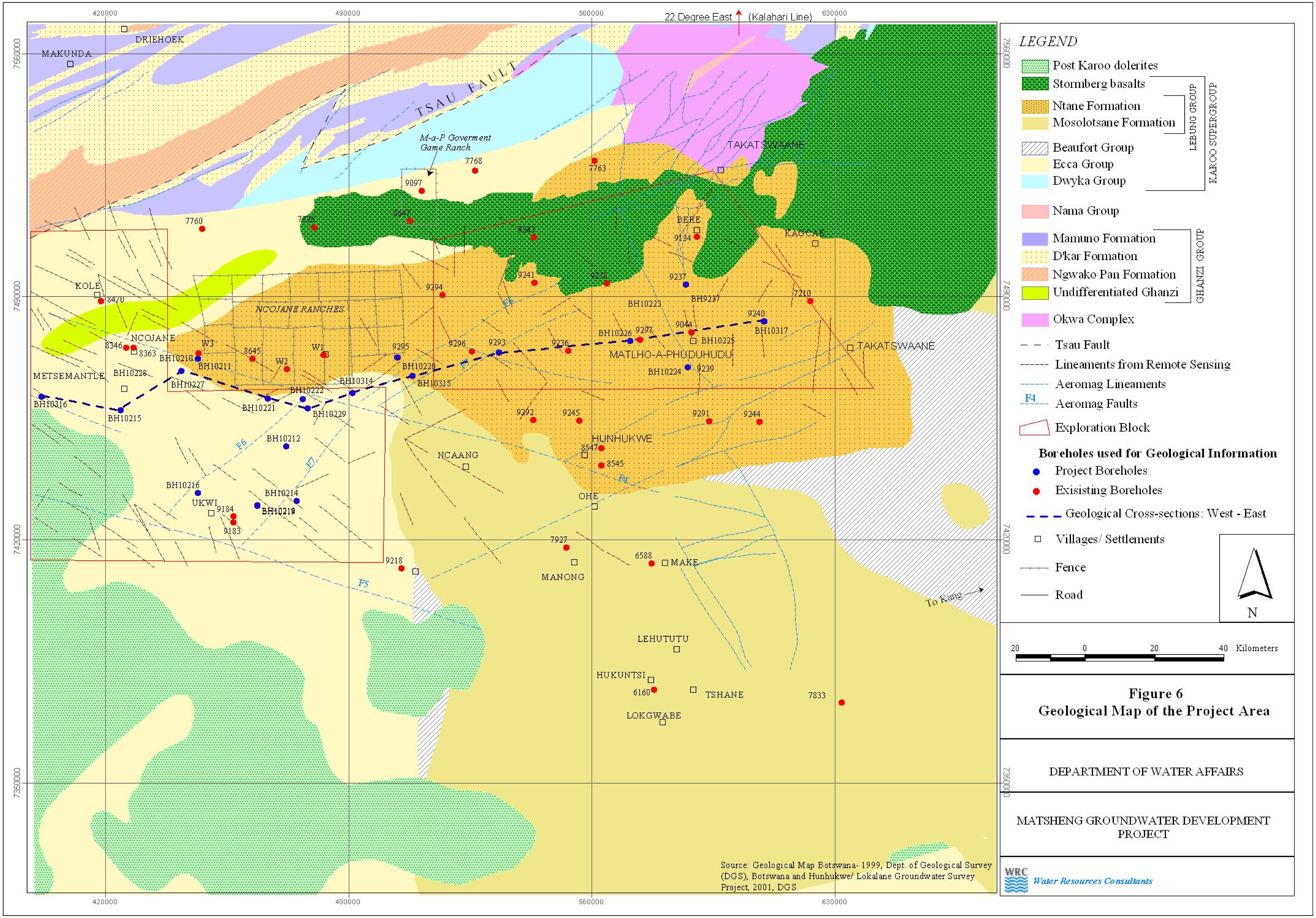

Figure 6
Geological Map of the Project Area

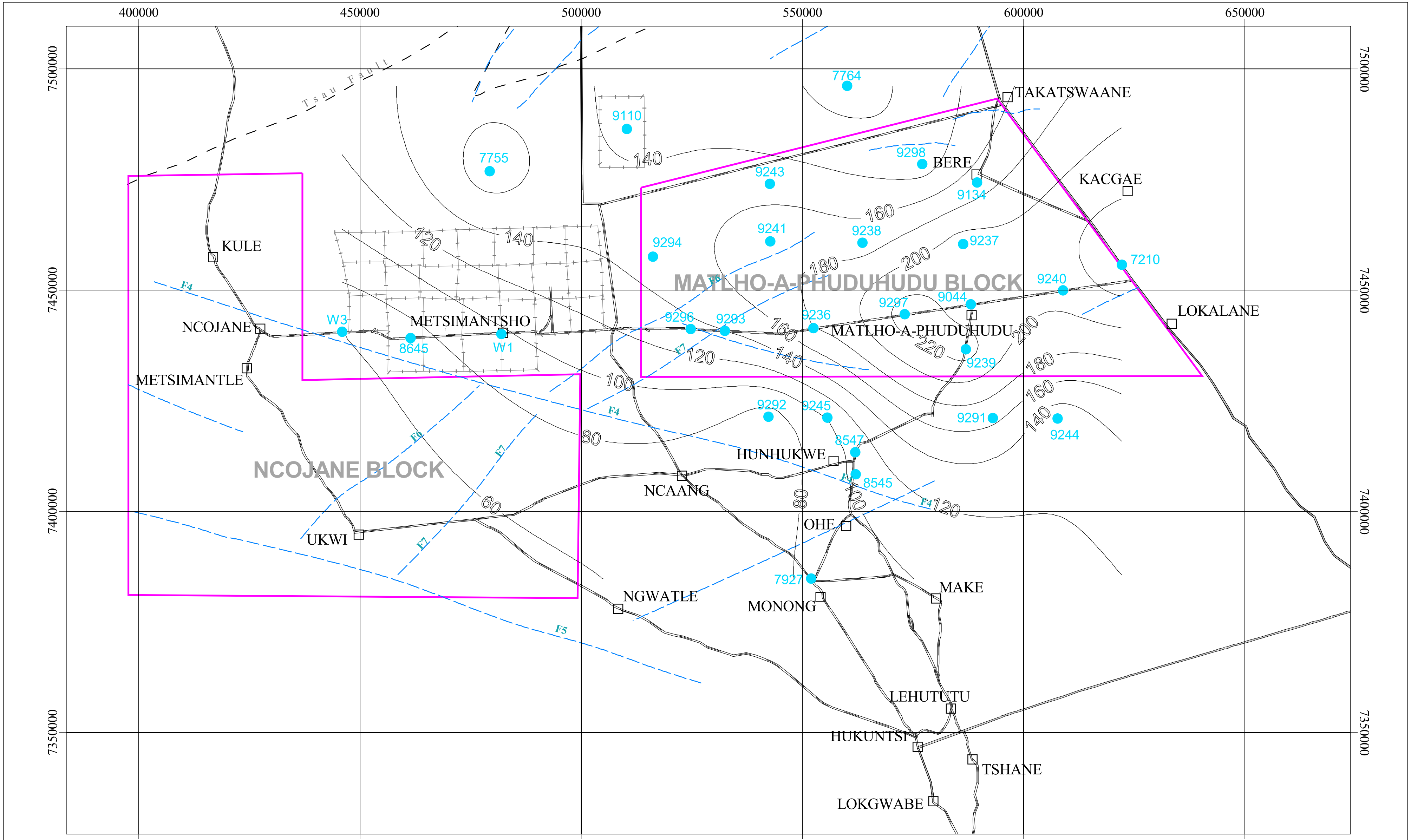

Figure 8
Depth To Bottom of the Ntane Sandstone

Scale 1:1 200 000

20 0 20 40 Kilometers

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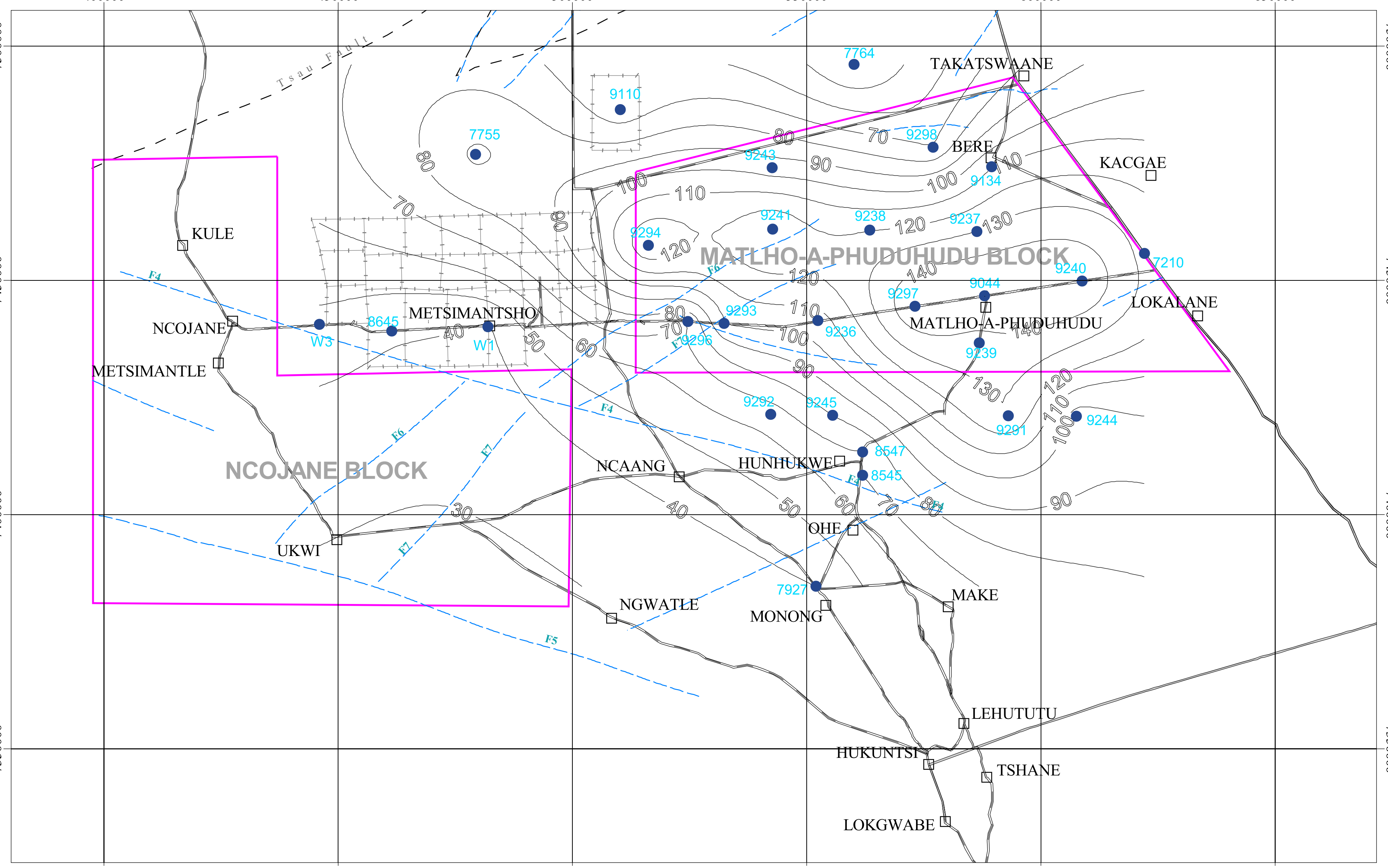

LEGEND

Lineaments from Aeromag

F6 Aeromag Fualt

Exploration Block

Villages/ Settlements

Tsau Fault

Farm Boundary

9292 Boreholes used for contouring

30 Depth(m)

Tarred Road

Other Roads

Figure 7
Depth to Top of the Ntane Sandstone

Scale 1:1 200 000

20 0 20 40 Kilometers

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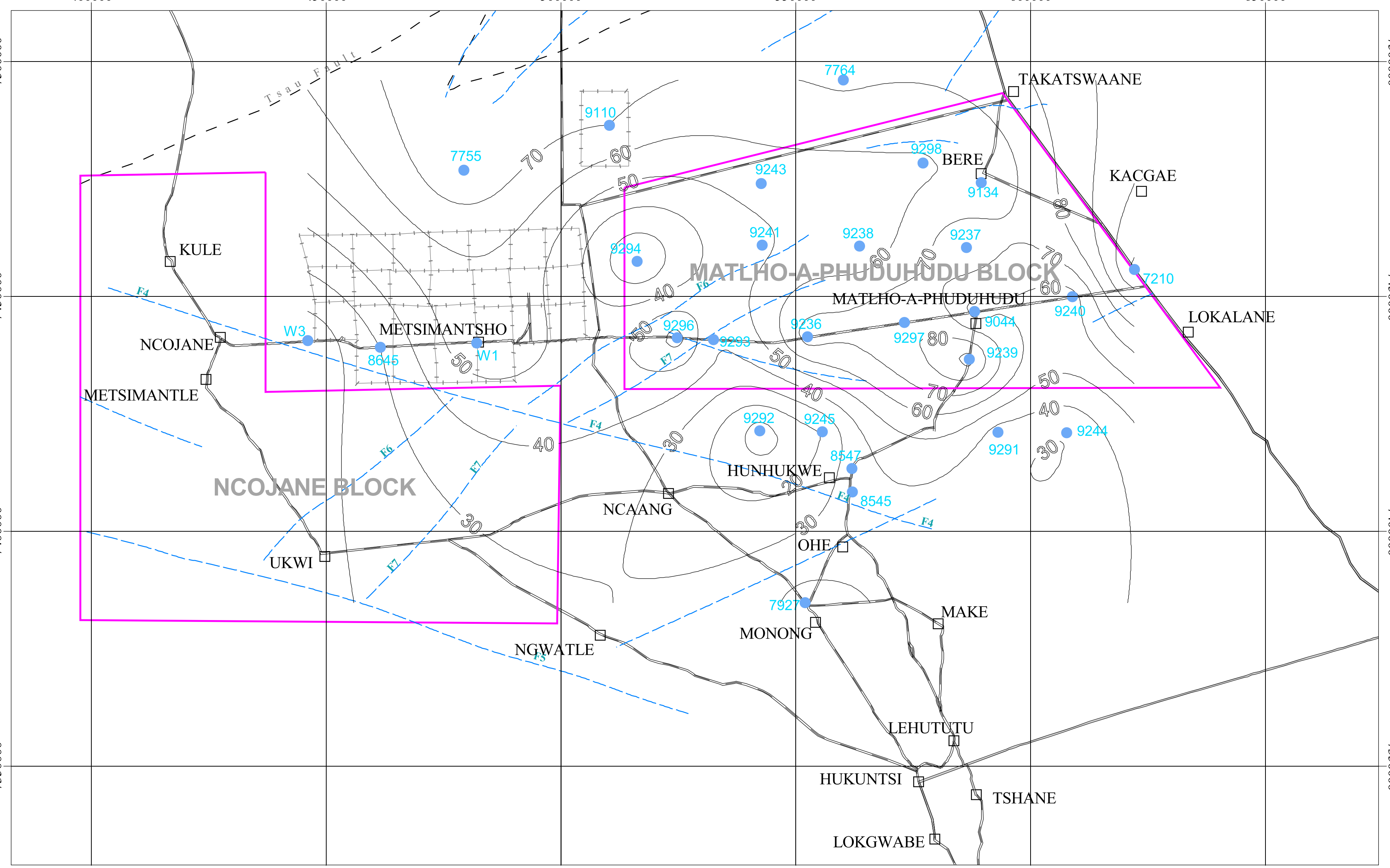

LEGEND

- Lineaments from Aeromag
- F6 Aeromag Fualt
- Exploration Block
- Villages/ Settlements
- Tsau Fault
- Farm Boundary
- 9110 Boreholes used for contouring
- 30 Thickness(m)
- Tarred Road
- Other Roads

Figure 9:
Thickness of the Ntane Sandstone

Scale 1:1 200 000

20 0 20 40 Kilometers

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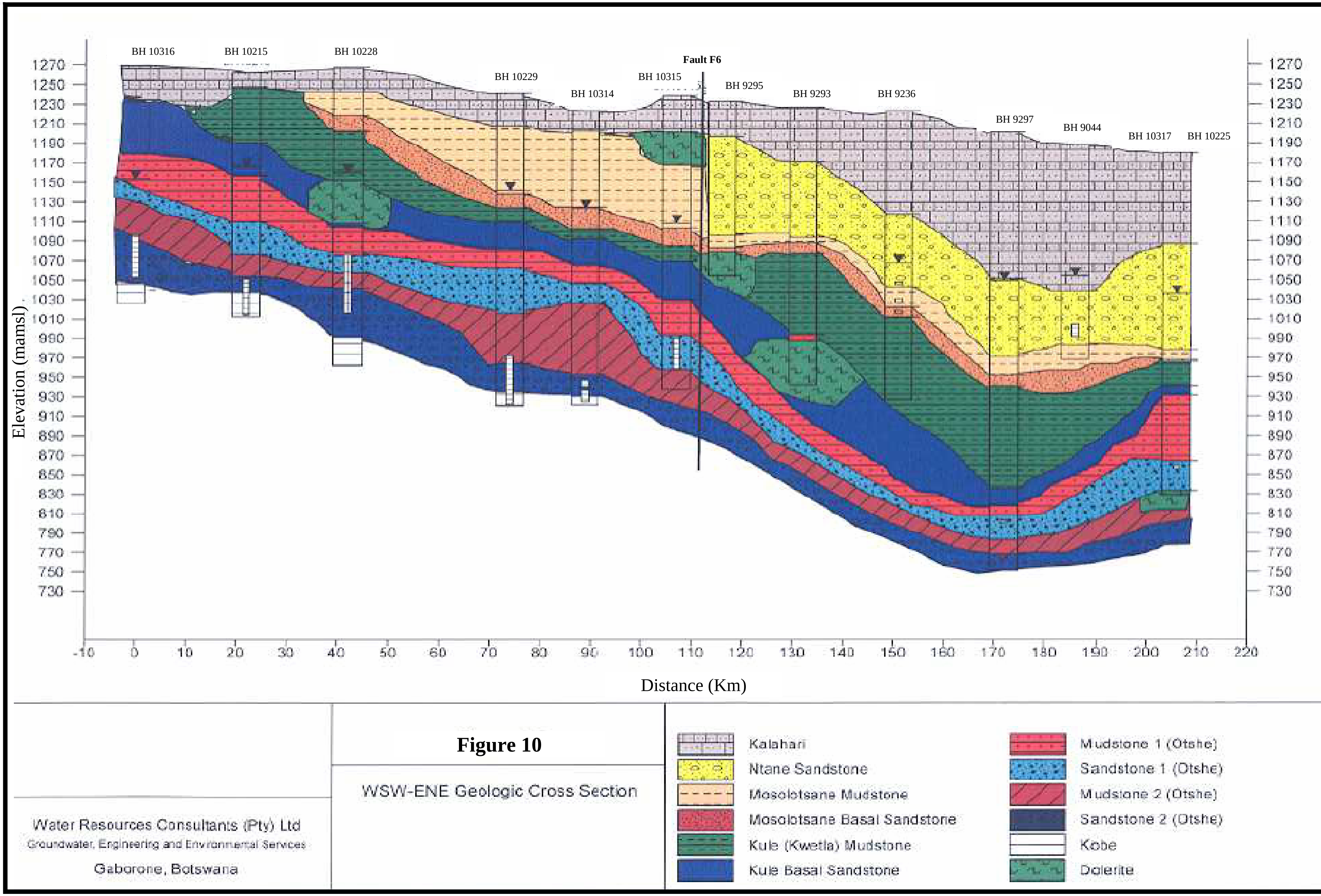
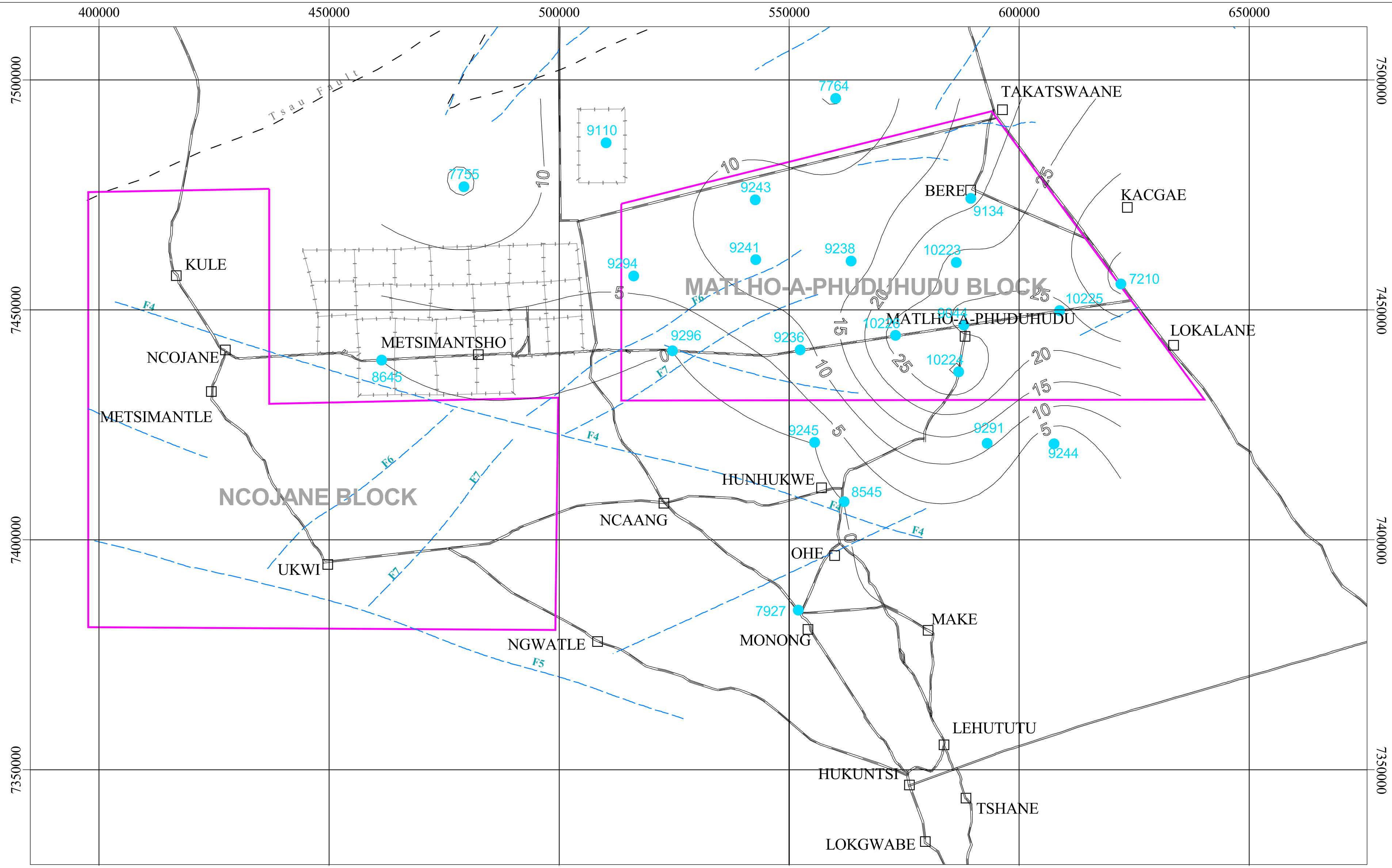


Figure 10

WSW-ENE Geologic Cross Section



LEGEND

Lineaments from Aeromag — F6 Aeromag Fualt

Exploration Block — Villages/ Settlements — Tsau Fault

Farm Boundary — 9110 Boreholes used for contouring

5 Exploitable Thickness(m) — Tarred Road — Other Roads

Figure 11:
Exploitable Saturated Thickness
Ntane Sandstone

Scale 1:1 200 000

20 0 20 40 Kilometers

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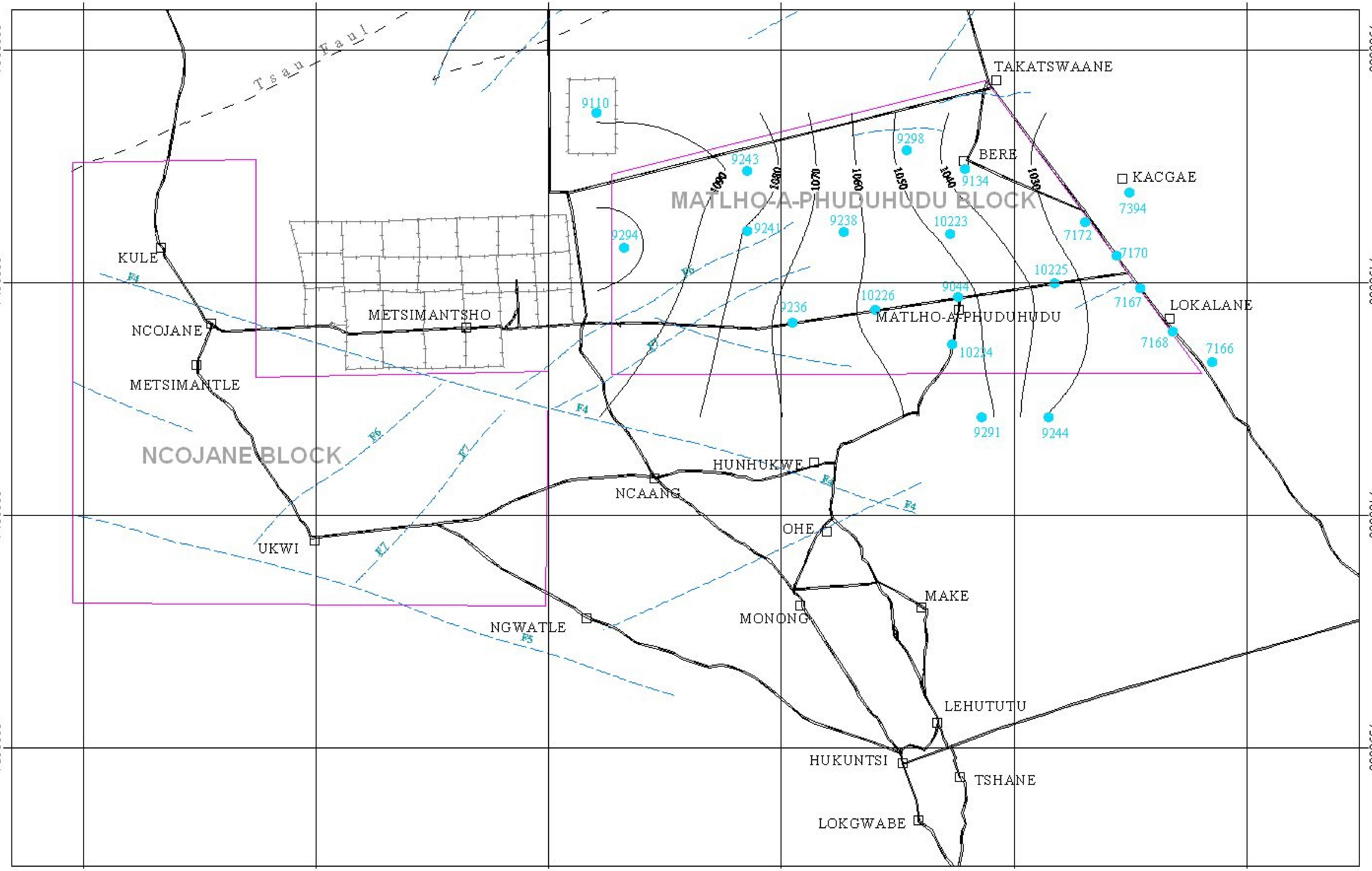

LEGEND

Lineaments from Aeromag

F6 Aeromag Fualt

Exploration Block

Villages/ Settlements

Tsau Fault

Farm Boundary

9110 Boreholes used for contouring

1090 Saturated Thickness(m)

Tarred Road

Other Roads

Figure 12:
Piezometric Head Ntane Sandstone

Scale 1:1 200 000

20 0 20 40 Kilometers

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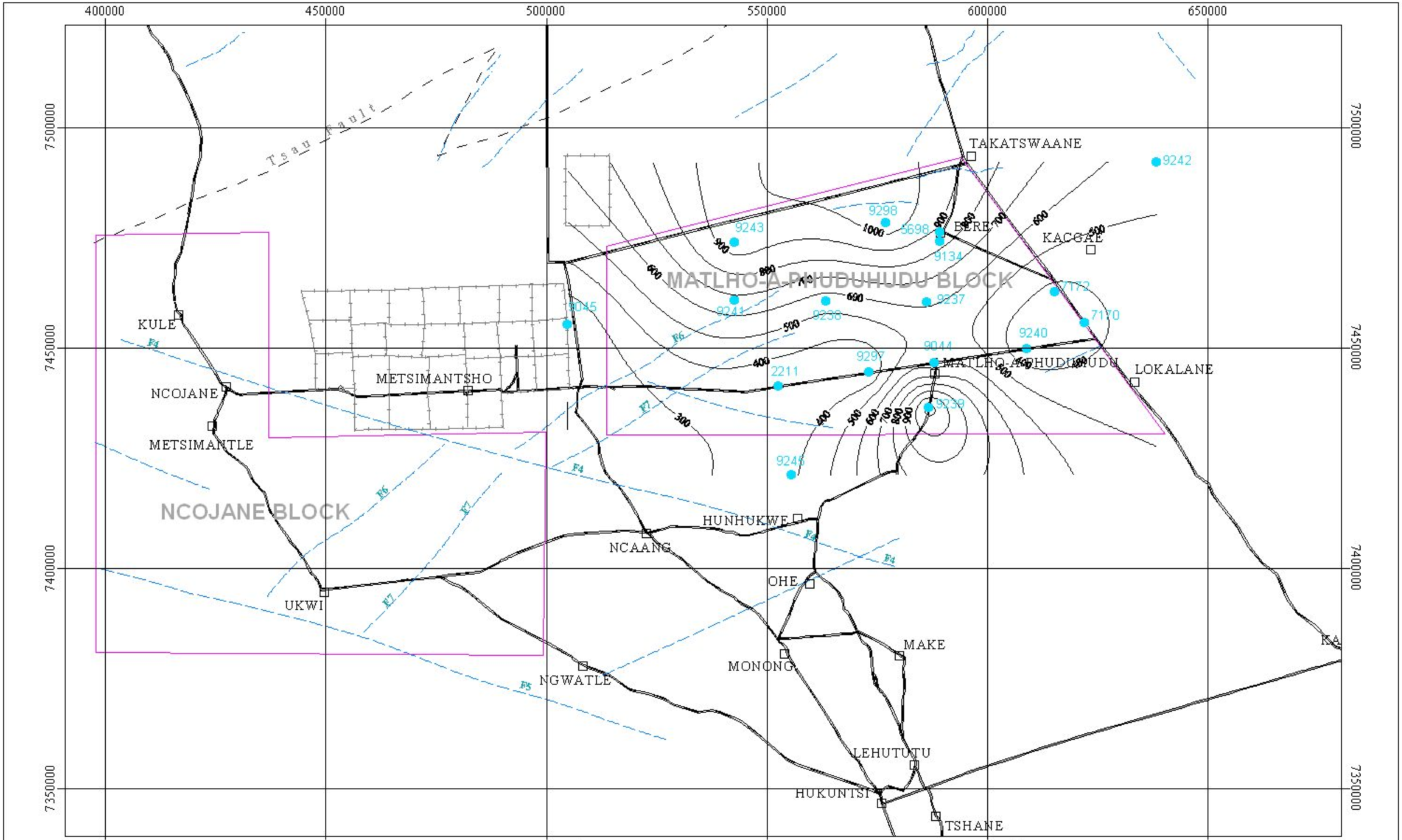

LEGEND

- Lineaments from Aeromag
- F6 Aeromag Fualt
- Exploration Block
- Villages/ Settlements
- Tsau Fault
- Farm Boundary
- 9243 Boreholes used for contouring
- 300 Saturated Thickness(m)
- Tarred Road
- Other Roads

Figure 13:
TDS Distribution Ntane Sandstone

Scale 1:1 200 000

20 0 20 40 Kilometers

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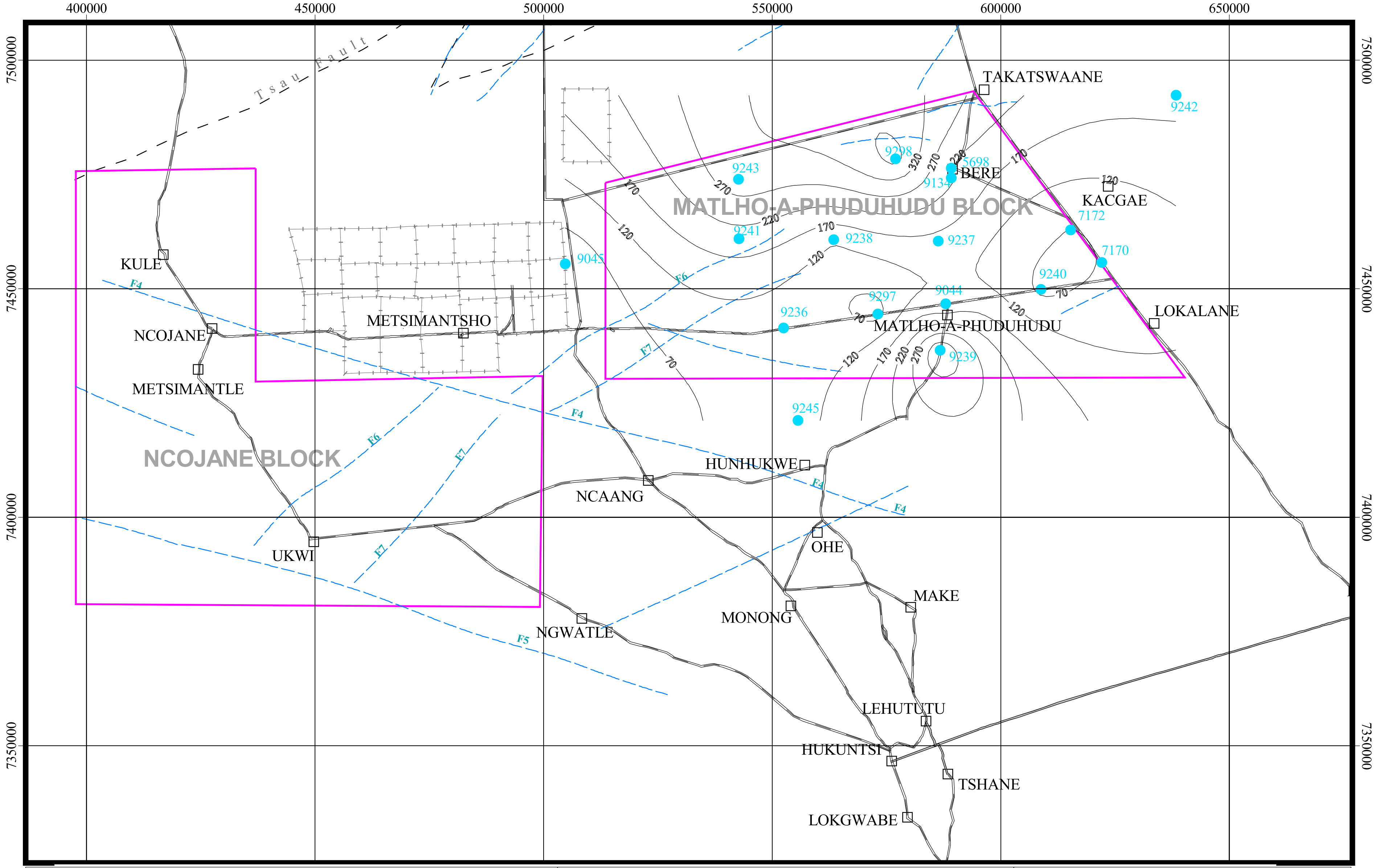

LEGEND

Lineaments from Aeromag

F6 Aeromag Fualt

Exploration Block

Villages/ Settlements

Tsau Fault

Farm Boundary

9245 Boreholes used for contouring

120 Saturated Thickness(m)

Tarred Road

Other Roads

Sodium Distribution Ntane Sandstone

Scale 1:1 200 000

20 0 20 40 Kilometers

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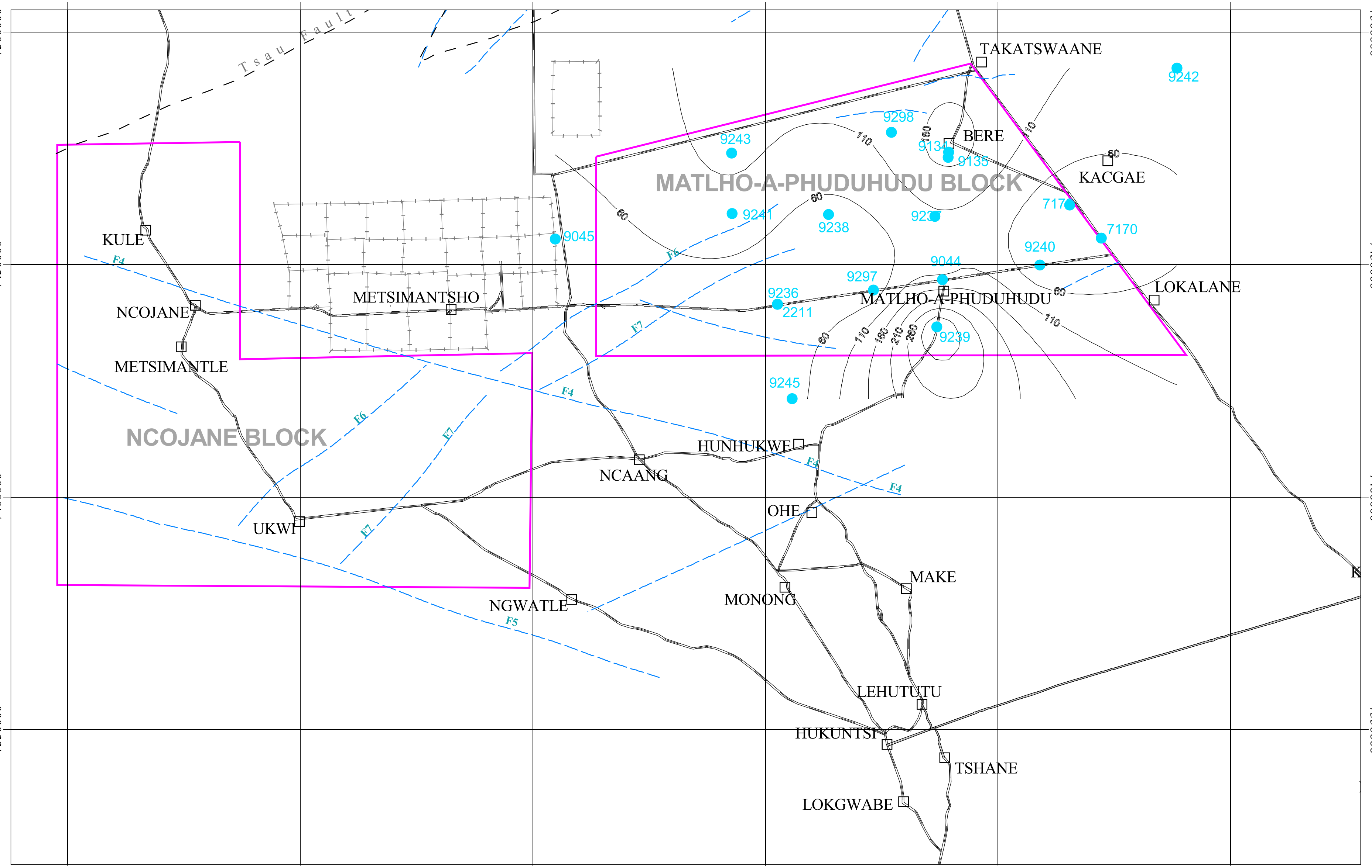
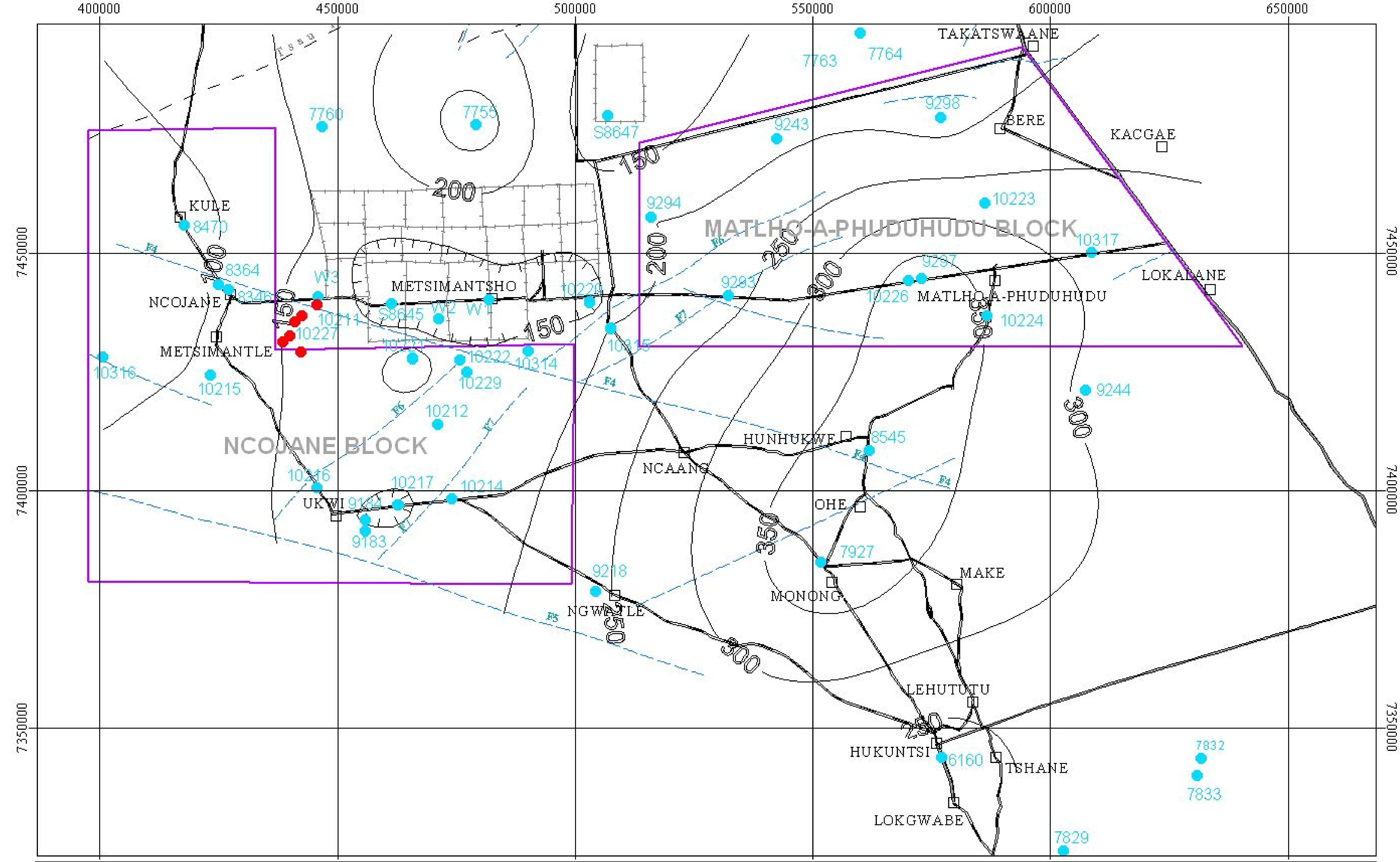


LEGEND Lineaments from Aeromag; F6 Aeromag Fualt Exploration Block; Villages/ Settlements; Tsau Fault Farm Boundary; 9245 Boreholes used for contouring 60 Saturated Thickness(m); Tarred Road; Other Roads	**Chloride Distribution Ntane Sandstone** **Scale 1:1 200 000** 20 0 20 40 Kilometers	MATSHENG GROUNDWATER DEVELOPMENT PROJECT CLIENT: DEPARTMENT OF WATER AFFAIRS CONSULTANT: WRC *Water Resources Consultants (Pty) Ltd.* *www.wrc.bw*



LEGEND

- Lineaments from Aeromag
- F6 Aeromag Fualt
- Exploration Block
- Villages/ Settlements
- Tsau Fault
- Farm Boundary
- 150 Depth(m)
- 7755 Boreholes used for contouring
- Production Boreholes
- Tarred Road
- Other Roads

Figure 16: Depth to Top of Ecca Group

20 0 20 40 Kilometers

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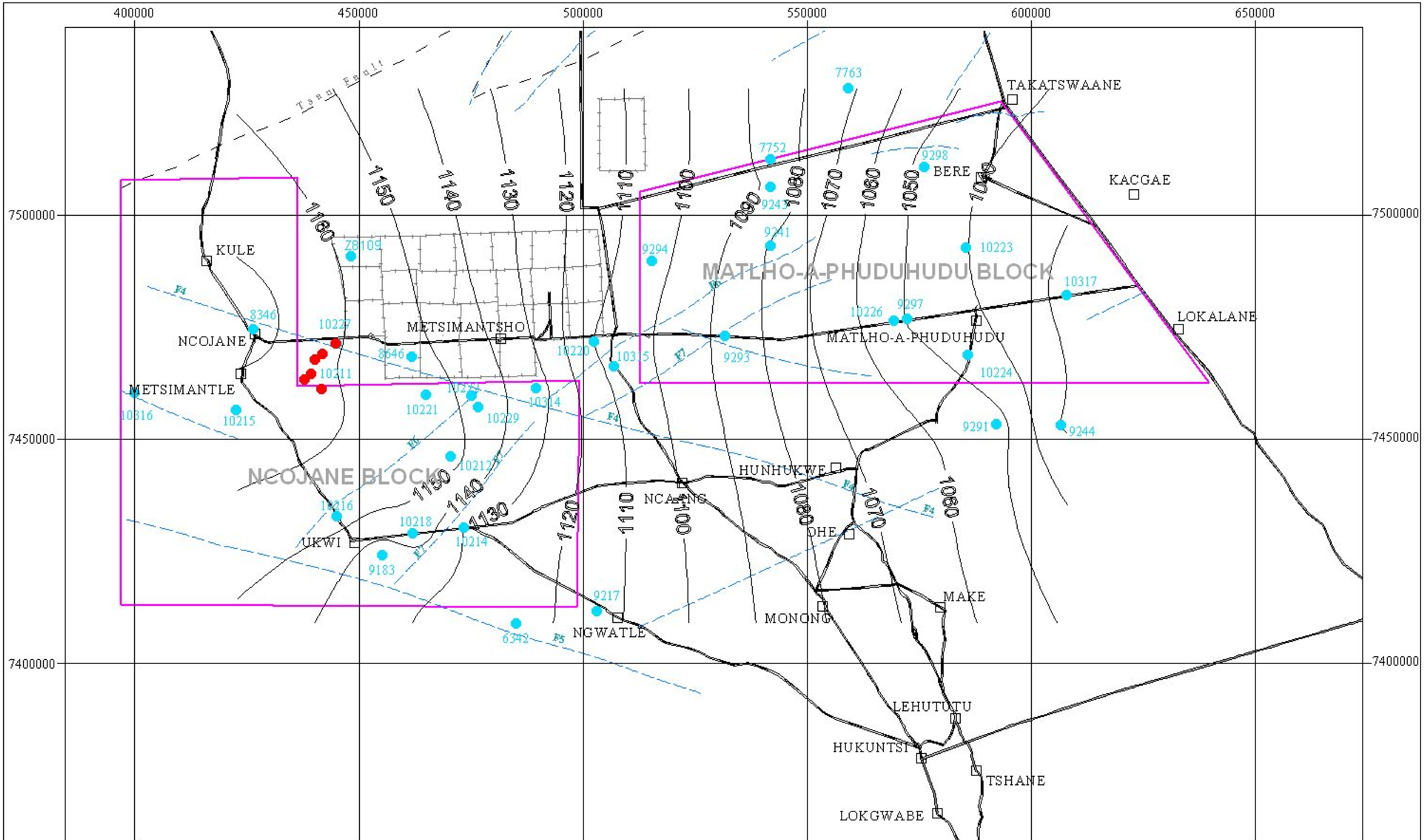

LEGEND

- Lineaments from Aeromag
- F6 Aeromag Fualt
- Exploration Block
- Villages/ Settlements
- Tsau Fault
- Farm Boundary
- 9217 Boreholes used for contouring
- 1130 Piozometric Head (masl)
- Production Boreholes
- *masl - Meters above sea level*
- Tarred Road
- Other Roads

Figure 17:
Piezometric Head Ecca (Otshe) Aquifer

20 0 20 40 Kilometers

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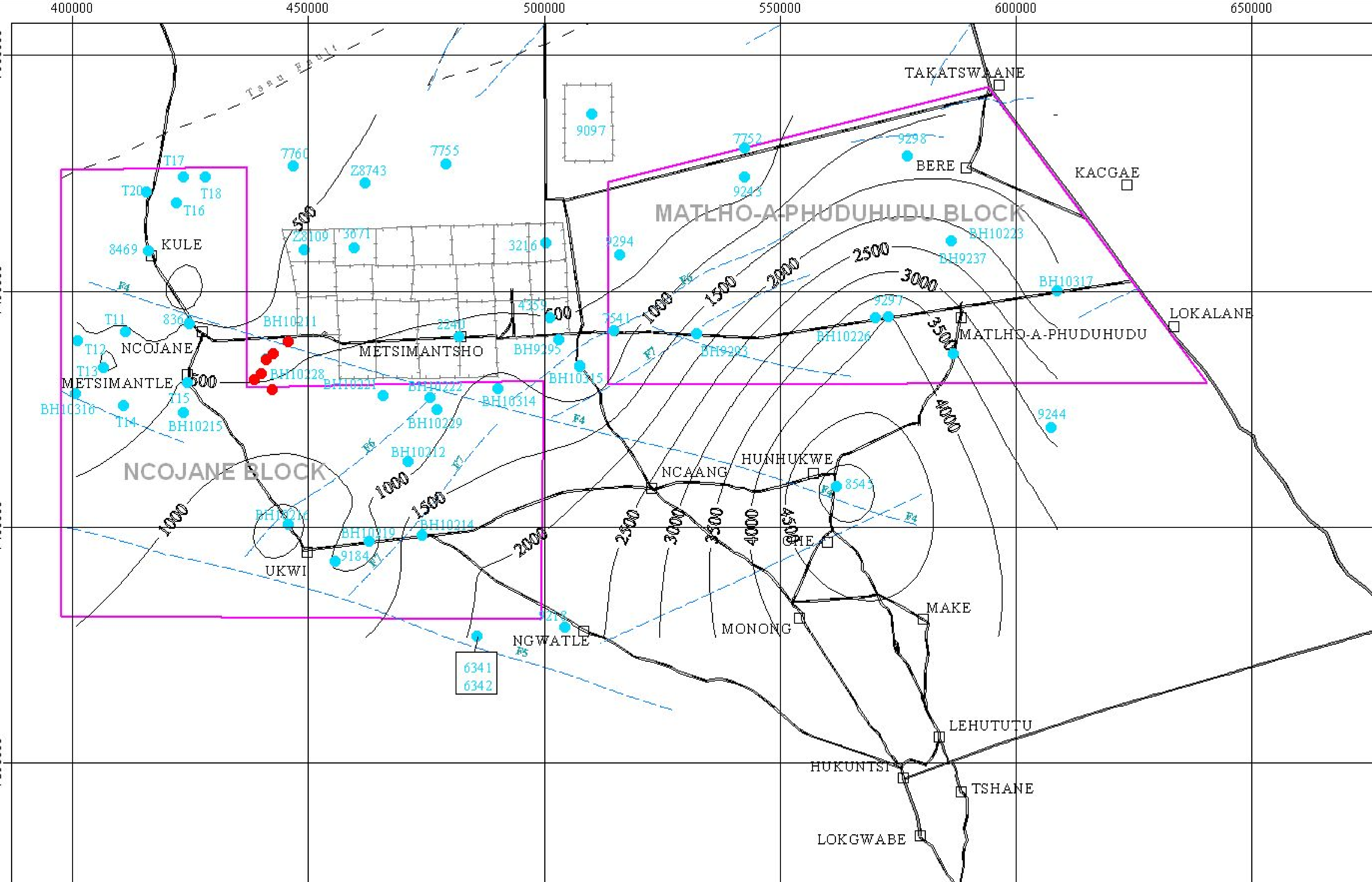

LEGEND	
Lineaments from Aeromag	F6 Aeromag Fualt
Exploration Block	Villages/ Settlements
Tsau Fault	Farm Boundary
9218 Boreholes used for contouring	1000 TDS Value(mg/L)
Production Boreholes	Tarred Road
Other Roads	

Figure 18:
TDS Distribution Ecca (Otshe) Aquifer

20 0 20 40 Kilometers

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CONSULTANT:
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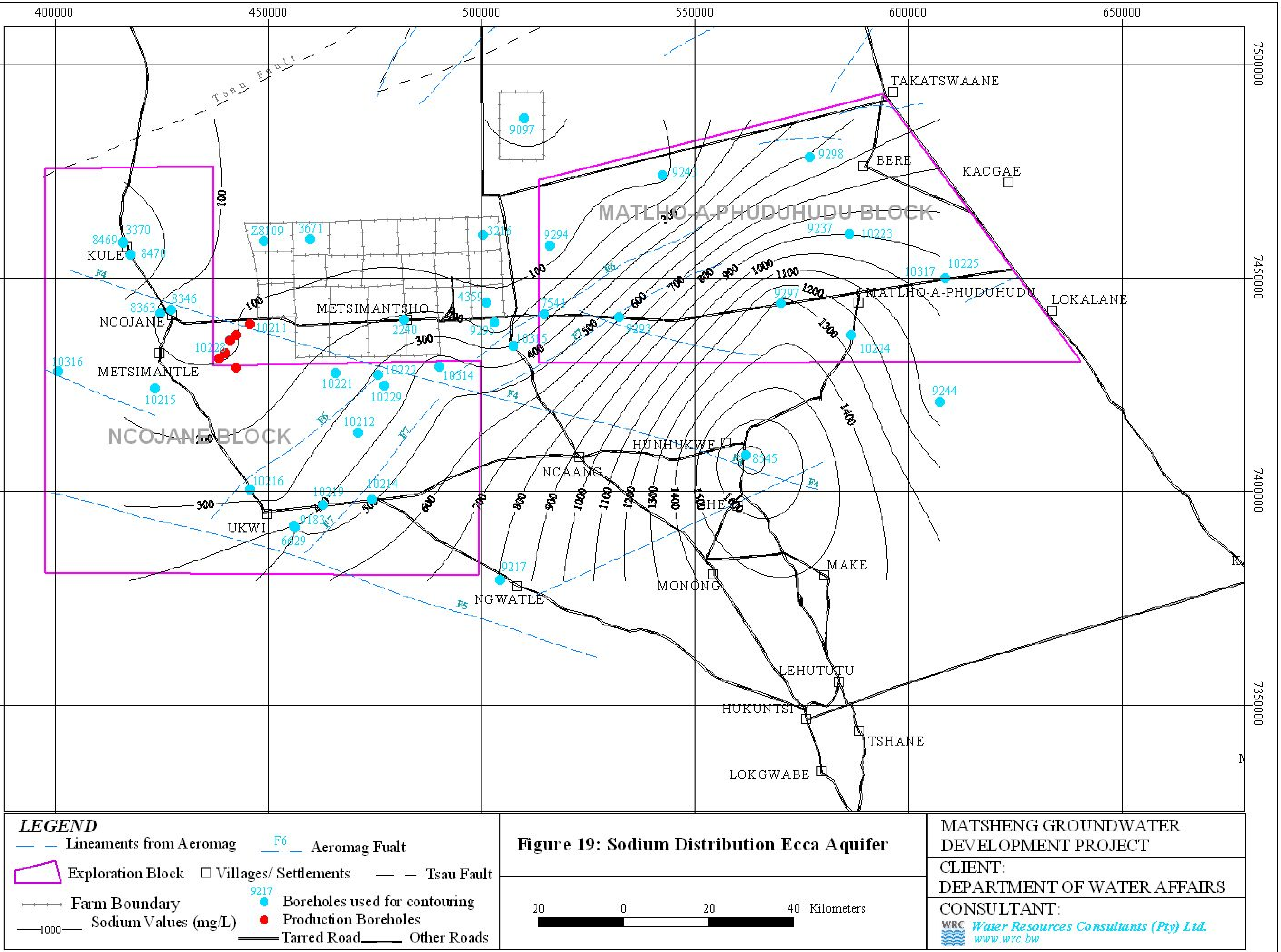

Figure 19: Sodium Distribution Ecca Aquifer

MATSHENG GROUNDWATER DEVELOPMENT PROJECT

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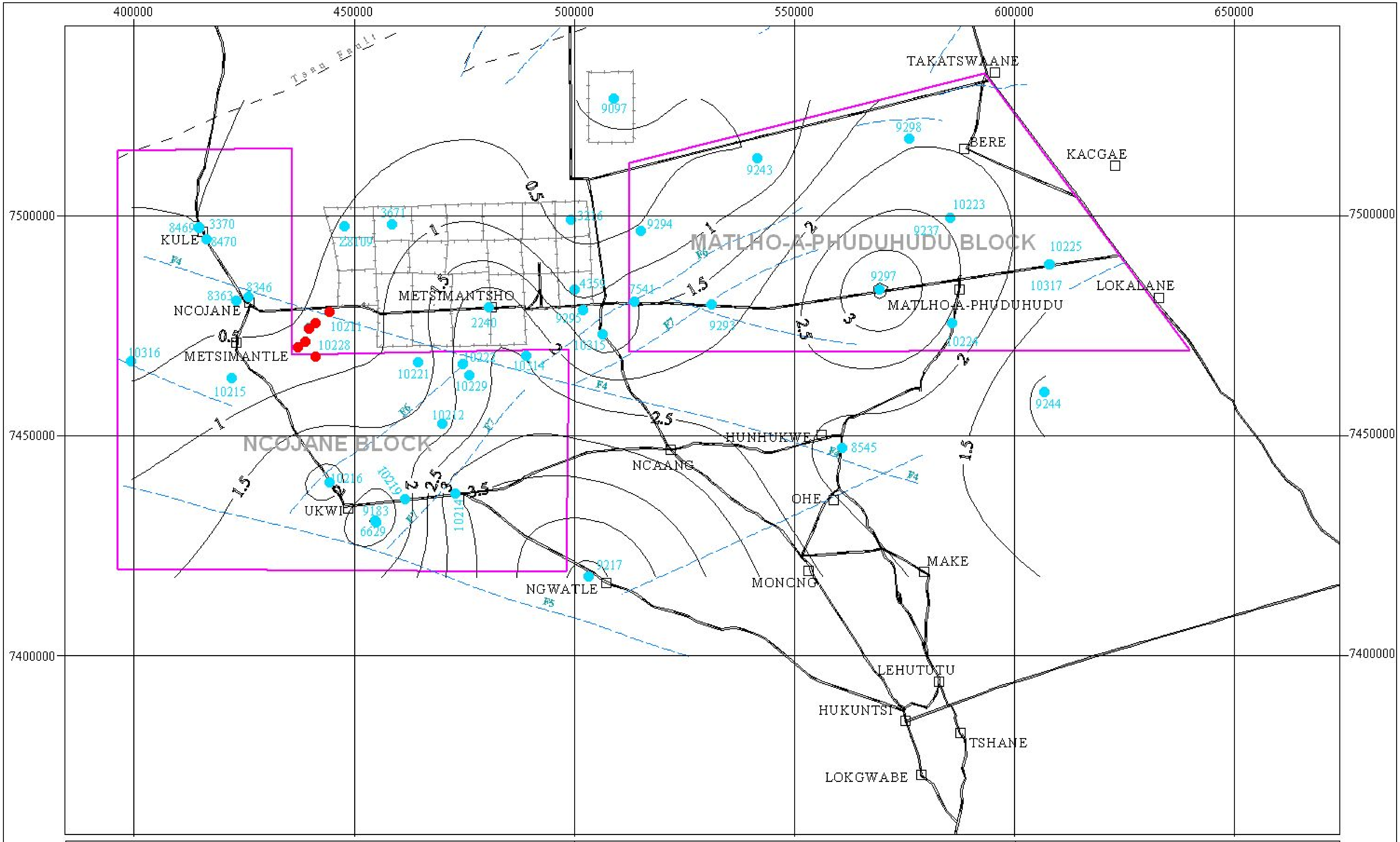
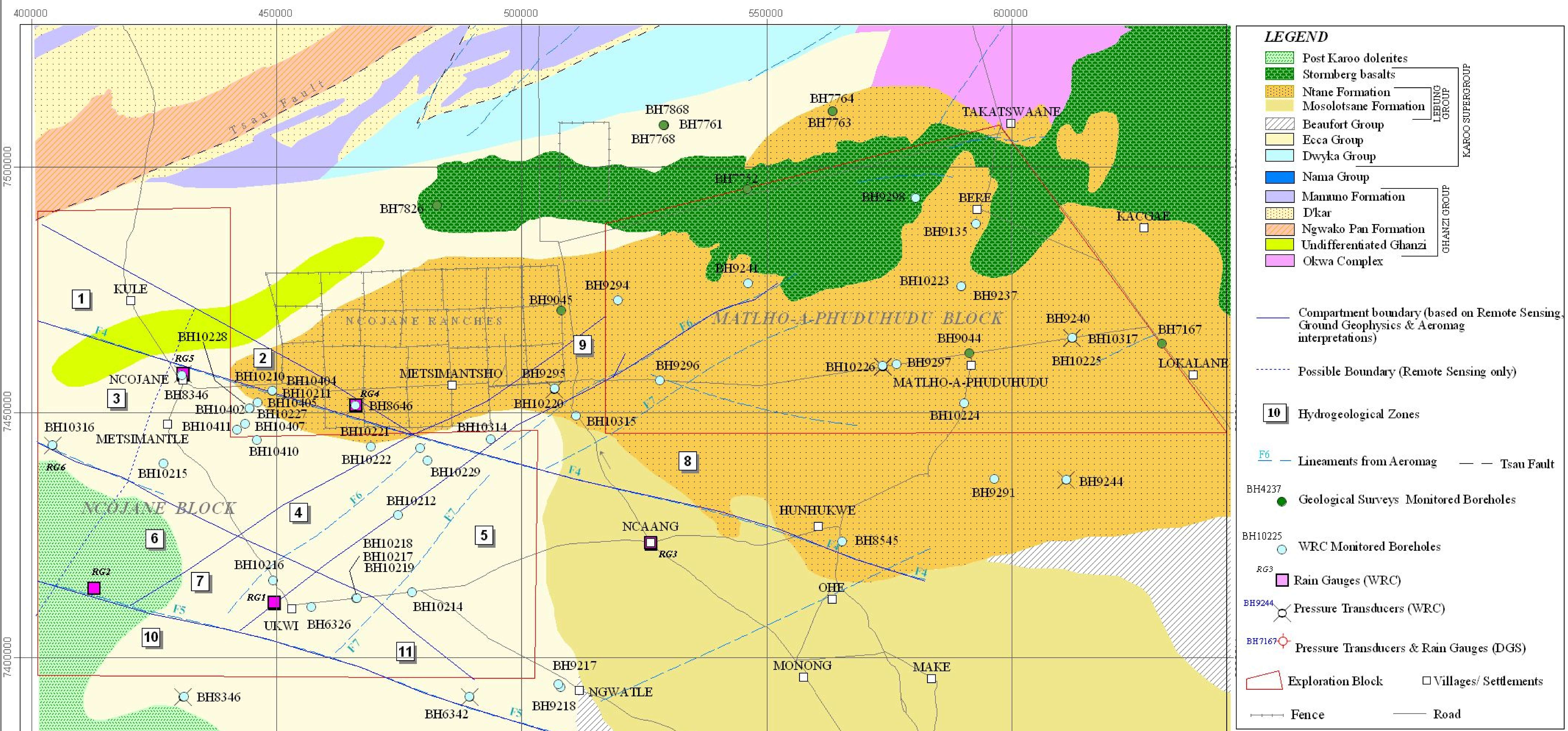


Figure 20: Fluoride Distribution Ecca (Otshe) Aquifer



MATSHENG GROUNDWATER DEVELOPMENT PROJECT

Figure 21:

Location of Monitored Boreholes and Rainguages

20 0 20 40 Km

Coordinate System: UTM Zone 34S
Datum: Cape, Spheroid: Clarke 1880

N

Source: Geological Map Botswana - 1999, Dept. of Geological Survey (DGS), Botswana and Hunhukwe/ Lokalane Groundwater Survey Project, 2001, DGS.

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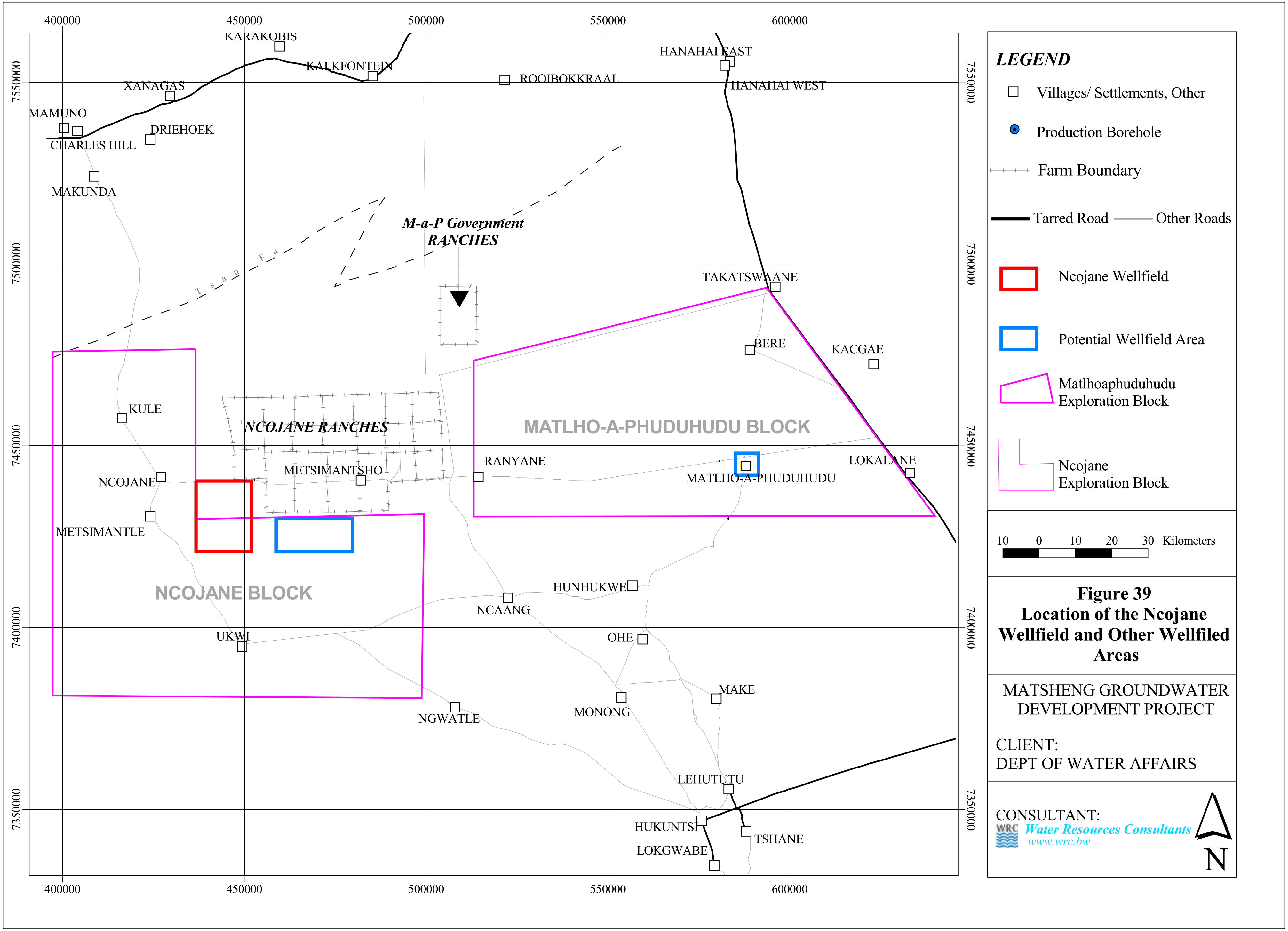

Figure 39
Location of the Ncojane Wellfield and Other Wellfiled Areas

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LIST OF TABLES

LIST OF FIGURES

1 BH9237

BH9237 is an exploration borehole drilled during the Hunhukwe / Lokalane project. It is located in the Matlho-a-Phuduhudu Block, about 20 km south of Bere and almost 200km east of Ncojane. This borehole was pump tested during the Hunhukwe / Lokalane project at a discharge rate of 52 m^3/h for 6.4 days and it had a total drawdown of 32.76m.

During the Matsheng Groundwater Project, a monitoring piezometer BH10223 was drilled next to BH9237 to allow for the estimation of the Ntane Sandstone aquifer storativity for input into the numerical model. The monitoring piezometer will also allow for accurate head measurement of the Ntane aquifer.

1.1 DRILLING RESULTS

This borehole was drilled through various lithologies including fine grained sands, silcrete, fine grained sandstones, siltstones and mudstones **(Figure 1-1).** Drilling was started using a 10 inch drilling bit to a depth of 67 m after which 8 inch casings were installed. Drilling was continued to the terminal depth of 244 m using an 8 inch drilling bit.

During drilling of this borehole, three water strikes were encountered. The depths, conductivities and yields (measured on a 90^O V-notch weir) for the water strikes are as follows:

1. 141m, 1080 µS/cm, 2 m^3/h
2. 158m, 1150 µS/cm, 3.4 m^3/h
3. 185m, 1220 µS/cm, 4.9 m^3/h

After development, the final yield was 10.5m^3/hr, the pH was 8.8 and the electrical conductivity was 1230 µS/cm. This borehole was left open from 67 m down to 244m.

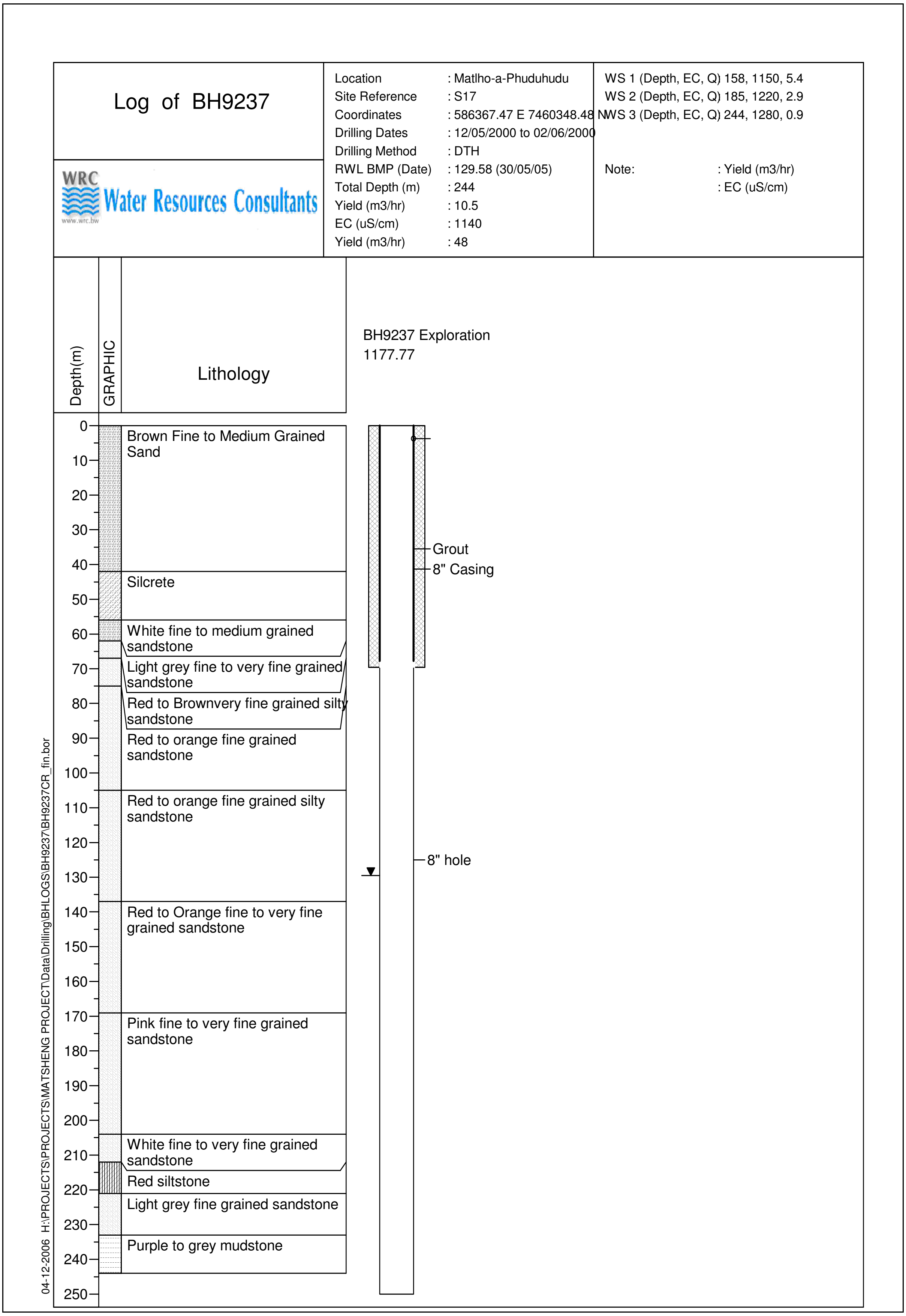

Figure 1-1 Log of BH9237

1.2 PUMP TESTING RESULTS

Borehole BH9237 was tested between 16 and 27 October 2005. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.44 m above ground level (agl) and the pump intake was set at 168.5 m below ground level. Summary details for the pumping test activities are given in **Table 1-1**. The collected data is presented in **Tables 1-6 to 1-11.**

Table 1-1 Summary of Pumping Test Data BH9237

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	4.35	20
	2	15	8.25	30
	3	15	14.56	40
	4	15	24.19	50
	5	15	32.27	61
Step Test	1	100	6.11	20
	2	100	11.76	30
	3	100	18.52	40
	4	100	25.98	50
	5	10	35.47	60.5
Constant Rate	1	7200	31.35	48
Recovery	1	1440	0.78	0

1.2.1 Step Drawdown Test

The step drawdown test was carried out on 17 October 2005. The static water level before the start of the test was 129.52 m bmp. The step drawdown test consisted of 4 steps of 100 minutes duration. The discharge rates were 20, 30, 40 and 50m^3/hr for steps 1 to 4 respectively. A fifth step at a discharge rate of 60.5 m3/hr lasted only 10 minutes before reaching the pump intake.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test data using this method is presented in **Figure 1.2**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 1-3**. The Transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 65 m^2/d (**Figure 1-4**). The results of the step test data interpretation are given in **Table 1-2**.

Table 1-2 Results of Step Test Analysis BH9237

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
9237	8.62×10^{-3}	9.92×10^{-06}	65	20	6.3	6.3	3.17
				30	5.2	11.5	2.61
				40	6.26	17.76	2.25
				50	6.5	24.26	2.06

The duration for the constant rate test of this borehole lasted for 5 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 1-2**) to estimate the expected total drawdown after 5 days of pumping. It was found out that a discharge rate of 48 m^3/hr was ideal for this borehole.

1.2.2 Constant Rate Test Data Interpretation

The constant rate test (CRT) was carried out between 22 and 27 October 2005 at a discharge rate of 48 m^3/hr. This was followed by recovery monitoring for 24 hrs. The Theis (1935) and the Cooper-Jacob (1946) analytical solutions were used to interpret the data using the computer programme "Aqtesolv". The calculated transmissivity (T) values by these methods are 46.5 and 47 m^2/d respectively. The recovery data was analysed using the Theis recovery solution using the computer programme "Aqtesolv". The calculated T value is 97m^2/d. These results are summarised in **Table 1-3** and the interpreted data is presented in **Figures 1-5** to **1-7**.

Table 1-3 Summary of Constant Rate and Recovery Tests Results.

BH No.	CRT Duration (hours)	Q (m^3/d)	Pumping borehole T (m^2/d)		Obs. BH No.	Observation borehole			Aquifer type
						Pumping phase		Recovery phase	
			Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
9237	120	1152	a) 46.5 b) 47	d) 97	10223	b) 58 c) 53	b) 7.3E-4 c) 3.5E-2	d) 88	Confined

Notes:
Interpretation Techniques
a) Theis
b) Cooper-Jacob
c) Neuman (Unconfined)
d) Theis Modified Recovery

1.2.2.1 Observation Borehole

The monitoring borehole, BH10223 located 10.1m from the pumping borehole (BH9237) was monitored during pump testing. This monitoring borehole is screened between 139 to 210.16m and the total drawdown at the end of test was 10.01m.

The pump testing data was interpreted using the Neuman Unconfined and the Cooper-Jacob (1946) analytical solutions using the computer programme "Aqtesolv". The transmissivity (T) values obtained by these two analytical solutions are 53 and 58 m^2/d respectively. The recovery data was analysed using the Theis recovery method and the T value was obtained as 88 m^2/d. Results are summarised in **Table 1-3** and the interpreted data is presented in **Figures 1-8** to **1-10.**

1.2.2.2 Aquifer Type interpreted

The interpretation of the pump testing data indicates that the aquifer type is confined.

1.3 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none acidified) were collected and submitted to the DWA Lab in Gaborone for basic chemical analysis while the other samples collected were submitted to the CSIR laboratory (Stellenbosch, South Africa) for analysis of most of the BOS 32:2000 listed determinants. The results of the DWA laboratory analysis are shown in **Table 1-4** and those for the CSIR analysis are shown in **Table 1-5**. The results from the analyses show that all the analysed parameters are within the Class II BOS32:2000 standards.

The well head chemical analysis at the end of pumping for temperature, EC and pH are 27.4 ^{o}C, 1050 µS/cm and 7.44 respectively.

.

Table 1-4 Chemistry Results from the DWA Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	HCO_3	NO_3	F	Fe	Mn	EC	pH	TDS
BH9237	25.3	162.9	39.4	29.2	64.4	102.51	415.7	0	0.17	0.13	0	1070	7.28	580
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units

Table 1-5 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH9237	19	161	42	23	68	107	323	2.4	0.4	<0.05	<0.05	1140	8	730
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH9237	<0.1	197	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

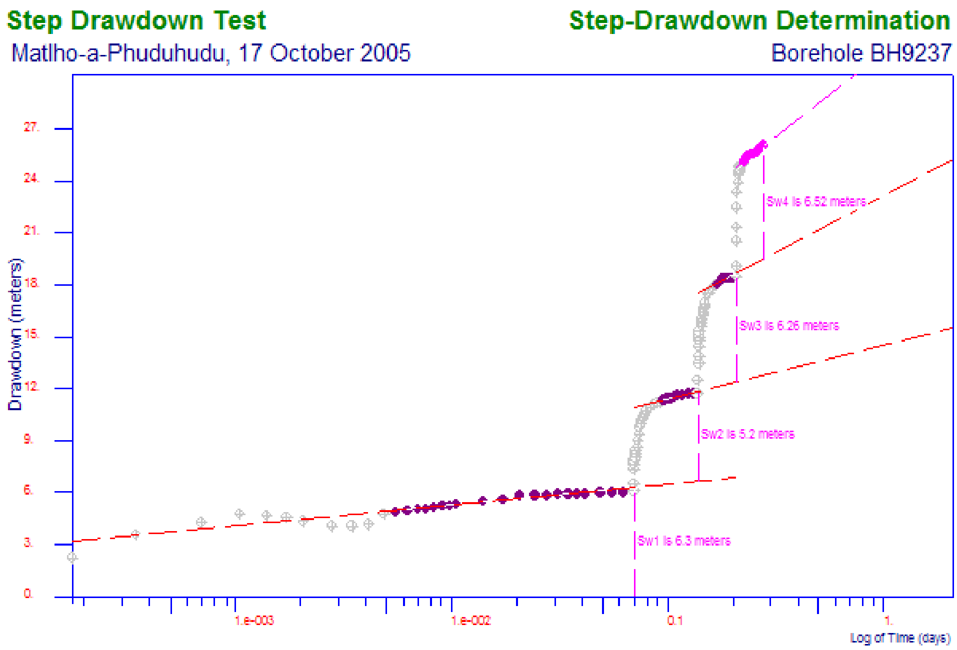

Figure 1-2 Pumping Testing Results for BH9237:Step Drawdown Test – Hantush-Bierschenk (semi log)

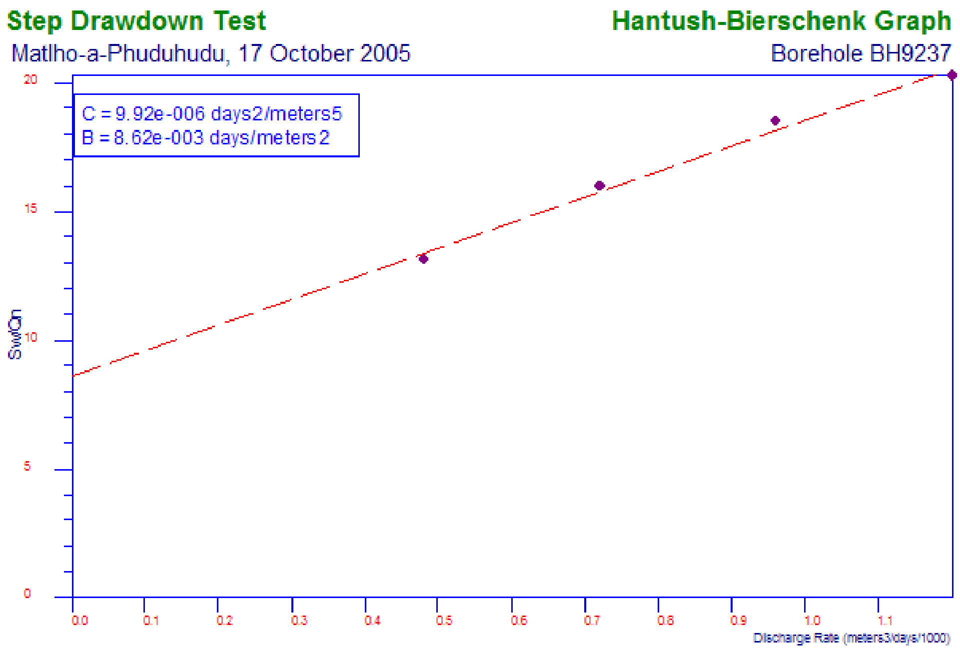

Figure 1-3 Pumping Test Results for BH9237: Step Drawdown Test – Hantush-Bierschenk

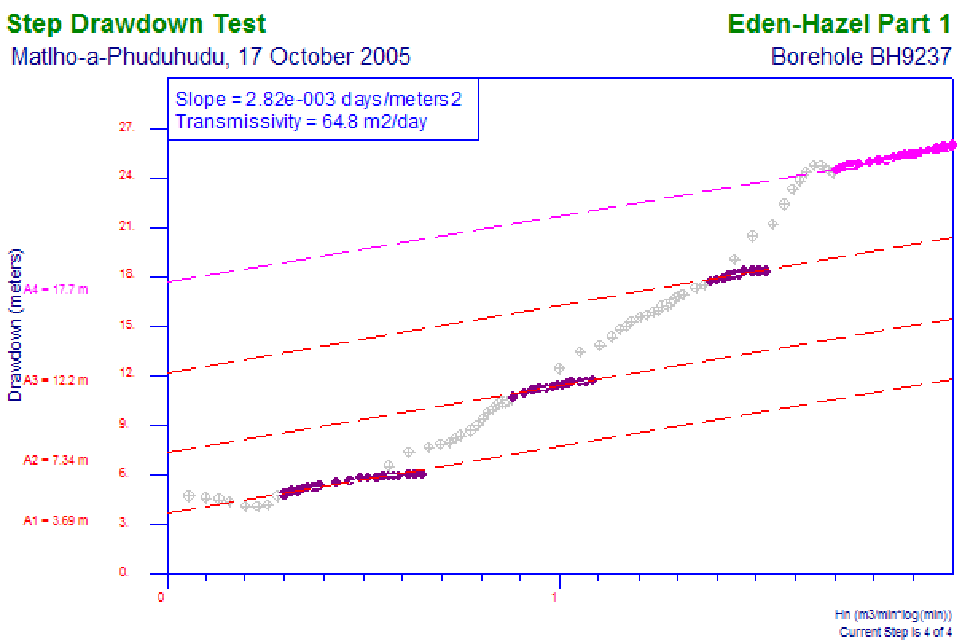

Figure 1-4 Pumping Test Results for BH9237: Step Drawdown Test – Eden-Hazel (Part 1)

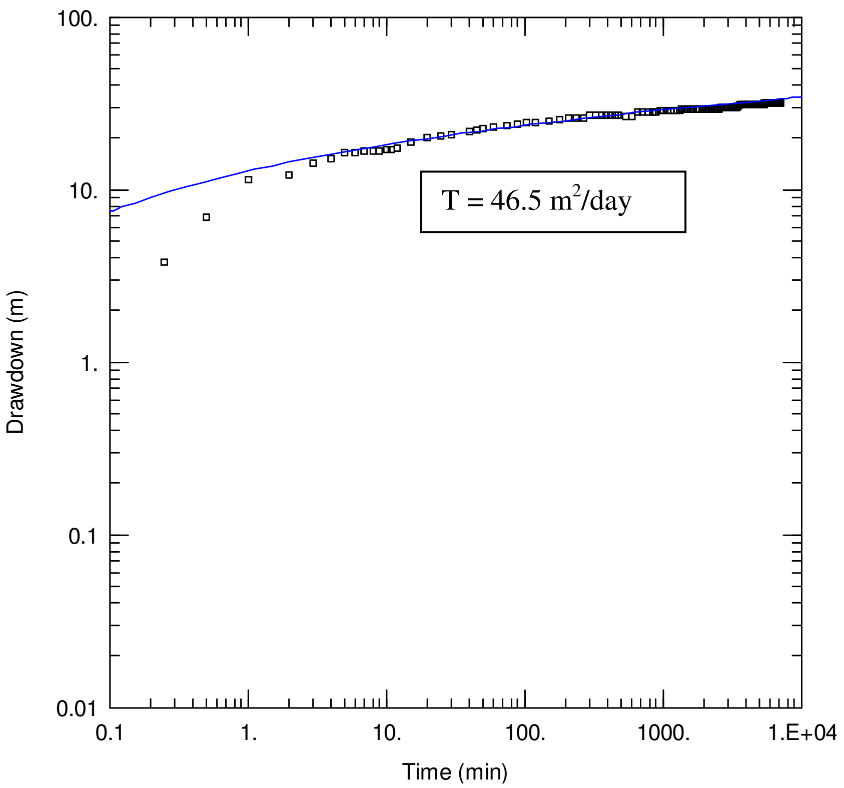

Figure 1-5 Pumping Test Results for BH9237: Theis Solution

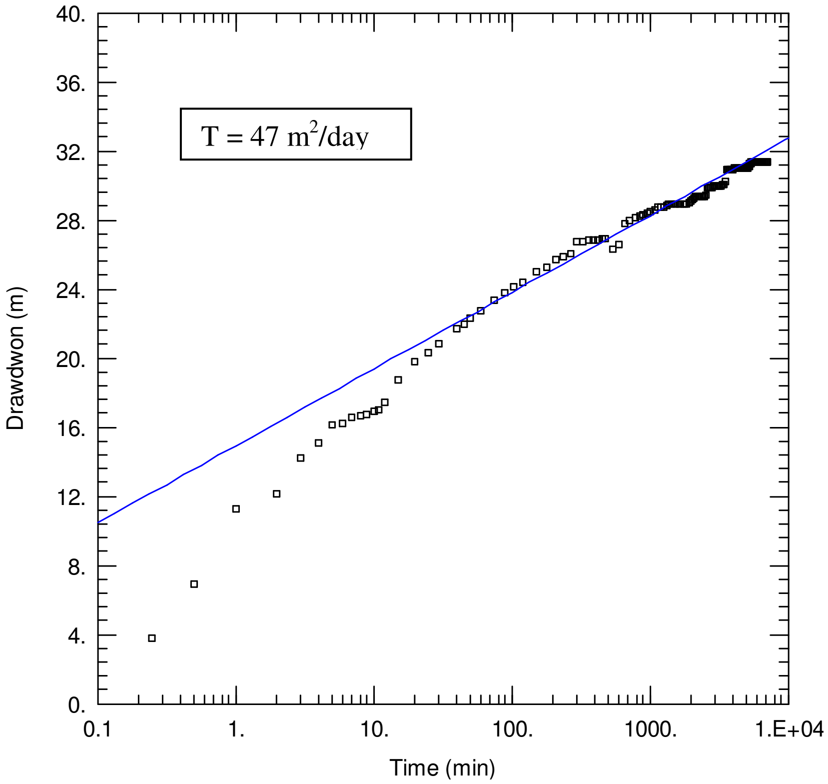

Figure 1-6 Pumping Test Results for BH9237: CRT Cooper Jacob Solution

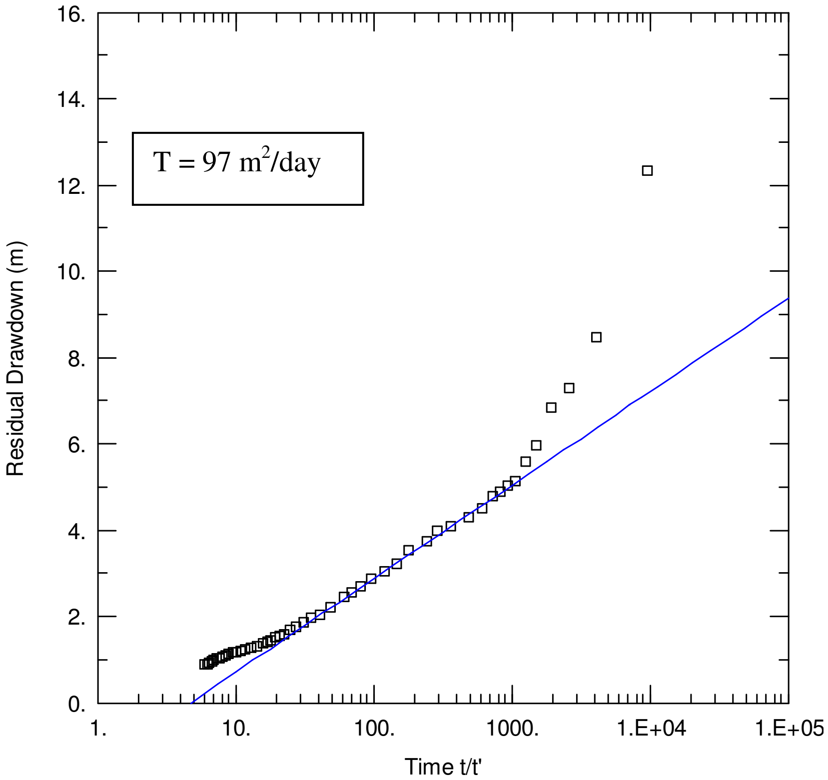

Figure 1-7 Pumping Test Results for BH9237: Theis Recovery Solution

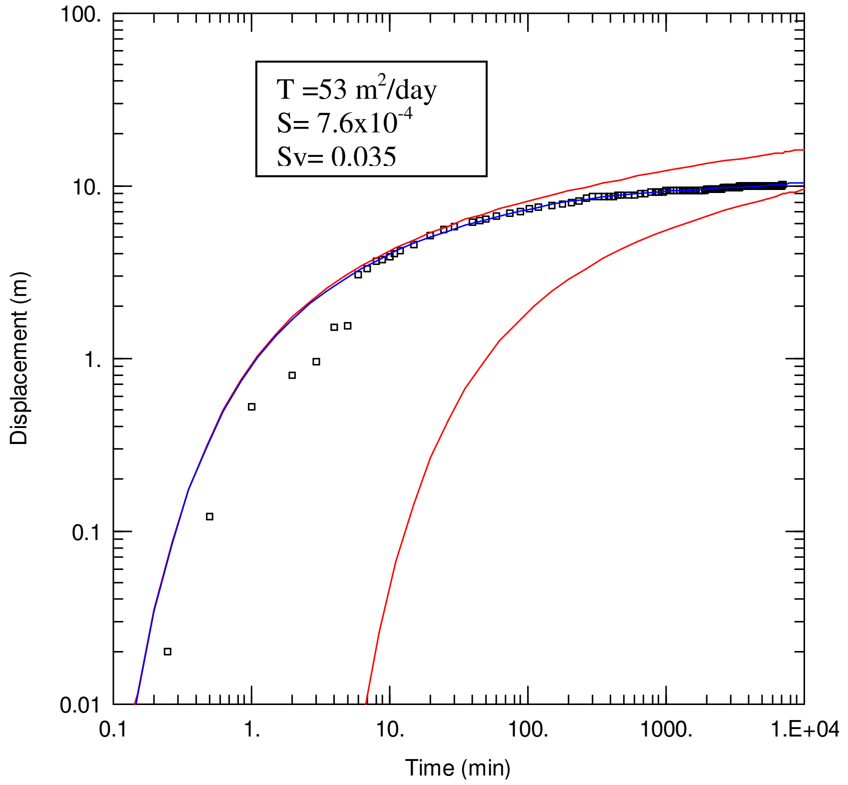

Figure 1-8 Pumping Test Results for BH10223: CRT Neuman Solution

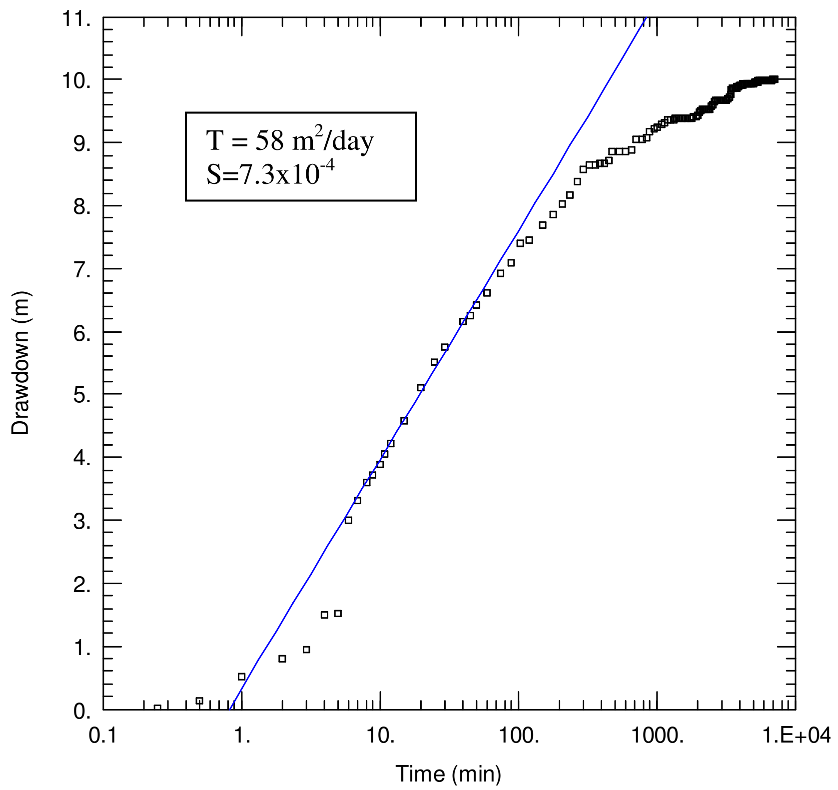

Figure 1-9 Pumping Test Results for BH10223: CRT Cooper Jacob Solution

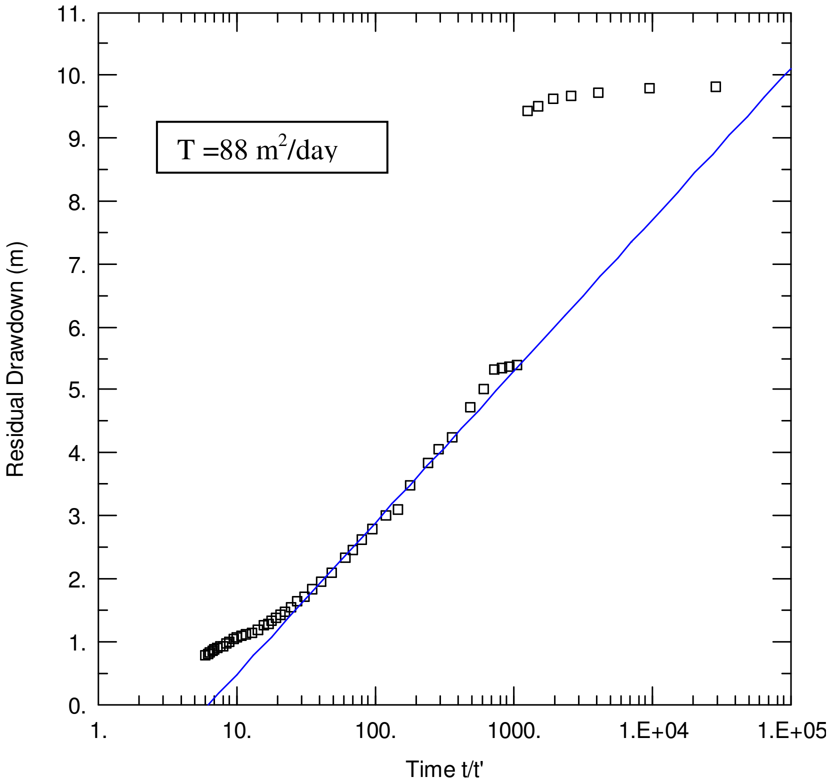

Figure 1-10 Pumping Test Results for BH10223: Theis Recovery Solution

Table 1-6 Calibration Test Data – BH9237

Official BH No.:	9237	District:	Ghanzi
Date of test commencement:	16.10.2005	Location:	MAP
Time of test commencement	12.00	BH depth (m):	244
Date of test completion:	16.10.05	Screen Interval (m):	Open
Time of test completion	13.15hrs	Depth of pump intake (m):	168.5m
Method of water level measurement:	dipper	Static water level before test (m):	129.50
Casing diameter (mm)	Open	Water strike (m) 141, 158, 185 and 244	
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	586372	Northing	7460371

STEPNo. 1						STEPNo. 2					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments
0.25	130.00	0.50				0.25	134.47	4.97			
0.5	130.40	0.90				0.5	134.92	5.42			
1	130.86	1.36				1	135.44	5.94	13.60	26.47	
1.5	132.48	2.98				1.5	135.71	6.21			
2	133.20	3.70				2	136.02	6.52	11.94	30.15	
2.5	133.28	3.78				2.5	136.28	6.78			
3	133.28	3.78				3	136.45	6.95	11.95	30.13	
4	132.88	3.38				4	136.70	7.20	12.00	30.00	
5	132.40	2.90				5	136.90	7.40	11.88	30.30	
6	132.15	2.65				6	137.02	7.52	11.90	30.25	
7	132.07	2.57				7	137.20	7.70	11.97	30.08	
8	132.10	2.60				8	137.29	7.79	11.98	30.05	
9	132.12	2.62			adj	9	137.37	7.87	11.99	30.03	
10	133.03	3.53	17.90	20.11		10	137.46	7.96	11.98	30.05	
11	133.35	3.85	18.00	20.00		11	137.54	8.04	11.97	30.08	
12	133.48	3.98	17.98	20.02		12	137.61	8.11	11.99	30.03	
15	133.85	4.35	17.90	20.11		15	137.75	8.25	11.95	30.13	

STEP No. 3						STEPNo. 4					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	Pumping Rate (m^3/hr)	Comments
0.25	137.89	8.39				0.25	145.83	16.33			
0.5	138.04	8.54				0.5	146.47	16.97			
1	138.34	8.84	18.44	39.05		1	148.71	19.21	13.84	52.02	
1.5	138.94	9.44				1.5	149.47	19.97			
2	139.06	9.56	17.99	40.02		2	149.84	20.34	14.60	49.32	
2.5	139.87	10.37				2.5	150.35	20.85			
3	140.50	11.00	18.00	40.00		3	150.66	21.16	14.28	50.42	
4	141.38	11.88	17.95	40.11		4	151.26	21.76	14.19	50.74	
5	141.96	12.46	17.98	40.04		5	151.65	22.15	14.33	50.24	
6	142.37	12.87	17.96	40.09		6	151.99	22.49	14.40	50.00	
7	142.59	13.09	17.95	40.11		7	152.39	22.89	14.35	50.17	
8	142.87	13.37	18.00	40.00		8	152.60	23.10	14.32	50.28	
9	143.16	13.66	17.98	40.04		9	152.87	23.37	14.28	50.42	
10	143.40	13.90	17.95	40.11		10	153.05	23.55	14.35	50.17	
11	143.53	14.03	17.90	40.22		11	153.27	23.77	14.40	50.00	
12	143.70	14.20	17.97	40.07		12	153.43	23.93	14.38	50.07	
15	144.06	14.56	17.95	40.11		15	153.69	24.19	14.35	50.17	

Official BH No.:	9237	District:	Ghanzi
Date of test commencement:	16.10.2005	Location:	MAP
Time of test commencement	12.00	BH depth (m):	244
Date of test completion:	16.10.05	Screen Interval (m):	
Time of test completion	13.15hrs	Depth of pump intake (m):	168.5m
Method of water level measurement:	dipper	Static water level before test (m):	129.50
Casing diameter (mm)		Water strike	
Orifice plate diameter		Delivery pipe diameter	102mm
Latitude		Longitude	

STEPNo. 5 STEPNo. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments
0.25	154.43	24.93				0.25					
0.5	155.65	26.15				0.5					
1	157.29	27.79	17.50	61.71		1					
1.5	158.06	28.56				1.5					
2	158.65	29.15	17.49	61.75		2					
2.5	159.05	29.55				2.5					
3	159.46	29.96	18.00	60.00		3					
4	159.84	30.34	17.90	60.34		4					
5	160.08	30.58	17.88	60.40		5					
6	160.36	30.86	17.94	60.20		6					
7	160.60	31.10	17.98	60.07		7					
8	160.79	31.29	17.54	61.57		8					
9	161.02	31.52	17.60	61.36		9					
10	161.12	31.62	17.55	61.54		10					
11	161.30	31.80	17.63	61.26		11					
12	161.45	31.95	17.60	61.36		12					
15	161.77	32.27	17.55	61.54		15					

Table 1-7 Step Drawdown Test Data – BH9237

Official BH No.:	9237	District:	Ghanzi
Date of test commencement:	17.10.2005	Location:	MAP
Time of test Commencement:	0700hrs	BH depth (m):	244
Date of test completion:	17.10.2005	Screens(m) Open	
Time of test Completion:	0700 hrs	Depth to pump intake (m)	168.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	10223	Height of MP above ground:	0.44
Distance to OB. BH (m)	10.1	Static water level before test (m):	129.52
Casing diameter (mm)	203	Water strike (m) 141, 158, 185 & 244	
Orifice plate diameter	4 inch	Delivery pipe diameter	102mm
Easting	586372	Northing	7460371

STEP No. 1 STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments
0.25	131.82	2.30				0.25	136.03	6.51			
0.5	133.12	3.60				0.5	136.95	7.43			
1	133.84	4.32				1	137.15	7.63	26.42	27.25	
1.5	134.26	4.74				1.5	137.42	7.90			
2	134.19	4.67				2	137.55	8.03	25.14	28.64	
2.5	134.08	4.56				2.5	137.77	8.25			
3	133.91	4.39				3	137.93	8.41			
4	133.59	4.07	19.84	18.15		4	138.17	8.65	24.66	29.20	
5	133.59	4.07	17.99	20.01		5	138.53	9.01	24.15	29.81	
6	133.72	4.20	17.76	20.27	adj	6	138.92	9.40	24.10	29.88	
7	134.27	4.75	17.99	20.01		7	139.31	9.79	24.34	29.58	
8	134.40	4.88	17.96	20.04		8	139.51	9.99	24.15	29.81	
9	134.51	4.99	17.98	20.02		9	139.69	10.17	24.30	29.63	

10	134.60	5.08	17.99	20.01		10	139.80	10.28	24.34	29.58	
11	134.63	5.11	18.00	20.00		11	139.91	10.39	24.31	29.62	
12	134.72	5.20	17.98	20.02		12	139.98	10.46	24.25	29.69	
13	134.77	5.25	17.95	20.06		13	140.09	10.57	23.95	30.06	
14	134.80	5.28	17.97	20.03		14	140.17	10.65	23.81	30.24	
15	134.88	5.36	17.96	20.04		15	140.24	10.72	23.90	30.13	
20	135.09	5.57	17.95	20.06		20	140.48	10.96	23.99	30.01	
25	135.21	5.69	17.99	20.01		25	140.63	11.11	23.95	30.06	
30	135.34	5.82	18.00	20.00		30	140.77	11.25	23.86	30.18	
35	135.34	5.82	17.96	20.04		35	140.80	11.28	23.94	30.08	
40	135.40	5.88	17.98	20.02		40	140.90	11.38	23.89	30.14	
45	135.45	5.93	17.97	20.03		45	140.93	11.41	23.97	30.04	
50	135.48	5.96	17.99	20.01		50	140.97	11.45	23.88	30.15	
55	135.49	5.97	17.98	20.02		55	141.07	11.55	23.94	30.08	
60	135.50	5.98	17.96	20.04		60	141.12	11.60	23.87	30.16	
70	135.54	6.02	17.95	20.06		70	141.17	11.65	23.91	30.11	
80	135.57	6.05	17.99	20.01		80	141.21	11.69	23.86	30.18	
90	135.59	6.07	18.00	20.00		90	141.28	11.76	23.97	30.04	
100	135.63	6.11	17.97	20.03		100	141.28	11.76	23.86	30.18	

Official BH No.:	9237	District:	Ghanzi
Date of test commencement:	17.10.2005	Location:	MAP
Time of test Commencement:	0700hrs	BH depth (m):	244
Date of test completion:	17.10.2005	Screens(m) Open	
Time of test Completion:	0700 hrs	Depth to pump intake (m)	168.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	10223	Height of MP above ground:	0.44
Distance to OB. BH (m)	10.1	Static water level before test (m):	129.52
Casing diameter (mm)	203	Water strike (m)	141, 158, 185 & 244
Orifice plate diameter	4 inch	Delivery pipe diameter	102mm
Easting	586372	Northing	7460371

STEPNo. 3 | STEPNo. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments
0.25	142.00	12.48				0.25	148.58	19.06			
0.5	142.99	13.47				0.5	149.99	20.47			
1	143.41	13.89	18.44	39.05		1	150.75	21.23	33.97	52.99	
1.5	143.95	14.43				1.5	151.93	22.41			
2	144.30	14.78				2	152.82	23.30	36.41	49.44	
2.5	144.54	15.02				2.5	153.40	23.88			
3	144.79	15.27	17.18	41.91		3	153.92	24.40	36.21	49.71	
4	145.08	15.56	18.28	39.39		4	154.27	24.75	36.39	49.46	adj rpm
5	145.27	15.75	17.95	40.11		5	154.27	24.75	36.35	49.52	
6	145.45	15.93	17.98	40.04		6	153.97	24.45	35.90	50.14	
7	145.58	16.06	17.90	40.22		7	153.90	24.38	35.99	50.01	
8	145.73	16.21	17.89	40.25		8	153.97	24.45	36.08	49.89	
9	145.87	16.35	17.95	40.11		9	154.07	24.55	35.99	50.01	
10	145.98	16.46	17.99	40.02		10	154.15	24.63	36.40	49.45	
11	146.13	16.61	17.89	40.25		11	154.24	24.72	36.15	49.79	
12	146.23	16.71	17.99	40.02		12	154.28	24.76	36.19	49.74	
13	146.35	16.83	18.00	40.00		13	154.28	24.76	36.05	49.93	
14	146.43	16.91	17.97	40.07		14	154.32	24.80	36.46	49.37	
15	146.47	16.95	17.95	40.11		15	154.35	24.83	36.40	49.45	
20	146.90	17.38	17.99	40.02		20	154.48	24.96	35.99	50.01	
25	147.06	17.54	18.00	40.00		25	154.55	25.03	36.03	49.96	
30	147.25	17.73	17.95	40.11		30	154.63	25.11	36.05	49.93	
35	147.35	17.83	17.99	40.02		35	154.80	25.28	36.00	50.00	
40	147.51	17.99	17.89	40.25		40	154.89	25.37	35.99	50.01	
45	147.55	18.03	17.95	40.11		45	154.98	25.46	36.01	49.99	
50	147.63	18.11	17.96	40.09		50	155.02	25.50	36.04	49.94	
55	147.71	18.19	17.98	40.04		55	155.04	25.52	35.94	50.08	
60	147.88	18.36	17.97	40.07		60	155.05	25.53	36.03	49.96	
70	147.91	18.39	17.99	40.02		70	155.15	25.63	35.98	50.03	
80	147.91	18.39	17.96	40.09		80	155.25	25.73	36.00	50.00	
90	147.91	18.39	17.99	40.02		90	155.39	25.87	35.98	50.03	
100	148.04	18.52	18.00	40.00		100	155.50	25.98	35.99	50.01	

Official BH No.:	9237	District:	Ghanzi	
Date of test commencement:	17.10.2005	Location:	MAP	
Time of test Commencement:	0700hrs	BH depth (m):	244	
Date of test completion:	17.10.2005	Screens(m)	Open	
Time of test Completion:	0700 hrs	Depth to pump intake (m)	168.5	
Method of water level measurement:	dipper	Description of MP:	top of dipper tubing	
Observation Bh No.:	10223	Height of MP above ground:	0.44	
Distance to OB. BH (m)	10.1	Static water level before test (m):	129.52	
Casing diameter (mm)	203	Water strike (m)	141, 158, 185 & 244	
Orifice plate diameter	4 inch	Delivery pipe diameter	102mm	
Easting	586372	Northing	7460371	

STEPNo. 5 STEPNo. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments
0.25	156.69	27.17				0.25					
0.5	158.51	28.99				0.5					
1	160.34	30.82	29.25	61.54		1					
1.5	161.59	32.07				1.5					
2	162.36	32.84	29.47	61.08		2					
2.5	163.02	33.50				2.5					
3	163.21	33.69	29.57	60.87		3					
4	163.60	34.08	29.60	60.81		4					
5	163.81	34.29	29.55	60.91		5					
6	163.90	34.38	29.60	60.81		6					
7	164.15	34.63	29.59	60.83		7					
8	164.21	34.69	29.90	60.20		8					
9	164.97	35.45	29.89	60.22		9					
10	164.99	35.47	29.77	60.46		10					
11						11					
12						12					
13						13					
14						14					
15						15					
20						20					
25						25					
30						30					
35						35					
40						40					
45						45					
50						50					
55						55					
60						60					
70						70					
80						80					
90						90					
100						100					

Table 1-8 Constant Rate Test Data – BH9237

Official BH NO :	9237	District :	Ghanzi
Date of test commencement :	22/10/05	Location :	MAP
Time of test commencement :	1100hrs	BH depth(m) :	244
Date of test completion	27/10/05	Screen Interval (m)	Open
Time of test completion :	1100hrs	Depth of pump intake (m) :	168.5
Method of water level measurement	dipper	Description of MP	Top of Dipper tube
OB BH NO:	10223	Height of MP above ground(m) :	0.44
Distance ob BH r (m)	10.1	Static Water level before test(m) :	129.8
Casing diameter (mm)	203	Water strike	141, 158, 185, & 244
Orifice plate diameter	4 inch	Delivery pipe diameter	102mm
Easting	586372	Northing	7460371

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500L	$Q(m^3/h)$	Temp (^0C)	EC (us/cm)	pH	Manometer (cm)/DO
	0.25	133.56	3.76						Flowmeter Reading
	0.5	136.75	6.95						
	1	141.10	11.30						
	2	141.97	12.17						
	3	143.98	14.18						
	4	144.93	15.13						
	5	145.97	16.17	35.14	51.22				
	6	146.03	16.23	37.15	48.45				
	7	146.38	16.58	37.76	47.67				
	8	146.44	16.64	37.16	48.44				
	9	146.55	16.75	37.41	48.12				
	10	146.69	16.89	37.40	48.13				
	11	146.83	17.03	37.47	48.04				
	12	147.25	17.45	37.57	47.91				
	15	148.57	18.77	37.50	48.00	28.1	1050	7.84	30
	20	149.60	19.80	37.43	48.09	28	1040	7.81	30
	25	150.09	20.29	37.46	48.05	27.8	1040	7.83	30
	30	150.63	20.83	37.64	47.82	28.4	1040	7.84	30
	40	151.49	21.69	37.53	47.96	29	1050	7.84	30
	45	151.80	22.00	37.93	47.46	29.1	1040	7.84	30
	50	152.10	22.30	37.86	47.54	29	1040	7.83	30
	60	152.58	22.78	37.54	47.95	29.5	1030	7.82	30
	75	153.17	23.37	37.81	47.61	30	1020	7.82	30
	90	153.58	23.78	37.41	48.12	30	1030	7.83	30
	105	153.96	24.16	37.65	47.81	30.2	1050	7.35	30
	120	154.23	24.43	37.95	47.43	29.8	1060	7.39	30
	150	154.78	24.98	37.78	47.64	30.5	1040	7.41	30
	180	155.02	25.22	37.15	48.45	30.4	1030	7.46	30
	210	155.48	25.68	37.50	48.00	30.1	1040	7.39	30
	240	155.64	25.84	37.40	48.13	30.2	1050	7.41	30
	270	155.82	26.02	37.48	48.03	30.1	1040	7.83	30
	300	156.51	26.71	37.75	47.68	29.1	1090	7.48	30
	330	156.54	26.74	37.51	47.99	29.0	1070	7.47	30
	360	156.60	26.80	37.43	48.09	28.9	1060	7.46	30
	390	156.63	26.83	37.61	47.86	28.7	1050	7.45	30
	420	156.65	26.85	37.40	48.13	28.7	1050	7.46	30
	450	156.67	26.87	37.39	48.14	28.5	1060	7.47	30
	480	156.70	26.90	37.57	47.91	27.9	1040	7.41	30
	540	156.12	26.32	37.43	48.09	28	1020	7.47	30
	600	156.38	26.58	37.16	48.44	28.6	1040	7.49	30
	660	157.62	27.82	37.41	48.12	28.6	1050	7.74	30
	720	157.76	27.96	37.33	48.22	28.7	1070	7.72	30
	780	157.91	28.11	37.38	48.15	28.6	1060	7.73	30
	840	157.99	28.19	37.40	48.13	28.7	1040	7.63	30
	900	158.09	28.29	37.43	48.09	28.9	1050	7.65	30
	960	158.20	28.40	37.21	48.37	28.4	1070	7.68	30
	1020	158.24	28.44	37.34	48.21	29.2	1040	7.76	30
	1080	158.36	28.56	37.41	48.12	29.1	1050	7.74	30
	1140	158.52	28.72	37.38	48.15	29.3	1060	7.51	30
	1200	158.54	28.74	37.49	48.01	29.1	1040	7.51	30
	1260	158.58	28.78	37.48	48.03	29.2	1070	7.40	30
	1320	158.59	28.79	37.53	47.96	28	1030	7.52	30
	1380	158.70	28.90	37.34	48.21	28	1040	7.52	30
	1440	158.70	28.90	37.57	47.91	29.1	1020	7.50	30
	1500	158.70	28.90	37.31	48.24	30.0	1030	7.51	30
	1560	158.70	28.90	37.44	48.08	30.3	1040	7.54	30
	1620	158.70	28.90	37.33	48.22	30.2	1050	7.48	30
	1680	158.70	28.90	37.60	47.87	30.1	1040	7.47	30

	1740	158.70	28.90	37.55	47.94	29.9	1050	7.46	30
	1800	158.70	28.90	37.31	48.24	29.7	1090	7.50	30
	1860	158.70	28.90	37.47	48.04	28	1060	7.49	30
	1920	158.78	28.98	37.65	47.81	28.8	1010	7.52	30
	1980	158.88	29.08	37.54	47.95	27.9	1030	7.51	30
	2040	159.00	29.20	37.49	48.01	27.7	1030	7.53	30
	2100	159.06	29.26	37.61	47.86	27.5	1040	7.54	30
	2160	159.12	29.32	37.49	48.01	27.1	1050	7.81	30
	2220	159.12	29.32	37.35	48.19	27.8	1090	7.80	30
	2280	159.12	29.32	37.40	48.13	27.1	1080	7.81	30
	2340	159.15	29.35	37.42	48.10	27.2	1070	7.83	30
	2400	159.15	29.35	37.43	48.09	27.4	1060	7.86	30
	2460	159.18	29.38	37.44	48.08	27.3	1030	7.82	30
	2520	159.18	29.38	37.41	48.12	27.1	1050	7.51	30
	2580	159.23	29.43	37.40	48.13	28.4	1040	7.61	30
	2640	159.67	29.87	37.50	48.00	28.6	1050	7.64	30
	2700	159.70	29.90	37.41	48.12	27.2	1070	7.73	30
	2760	159.70	29.90	37.53	47.96	27.1	1020	7.74	30
	2820	159.70	29.90	37.44	48.08	27.2	1020	7.73	30
	2880	159.78	29.98	37.54	47.95	27.6	1010	7.41	DO - 4.0mg/l
	2940	159.78	29.98	37.38	48.15	30	1010	7.38	30
	3000	159.79	29.99	37.41	48.12	29.2	1080	7.30	30
	3060	159.79	29.99	37.50	48.00	29.1	1060	7.31	30
	3120	159.79	29.99	37.43	48.09	29.2	1050	7.32	30
	3180	159.79	29.99	37.53	47.96	29.1	1020	7.30	30
	3240	159.79	29.99	37.53	47.96	29.8	1090	7.36	30
	3300	159.79	29.99	37.57	47.91	28.9	1100	7.38	30
	3360	159.82	30.02	37.47	48.04	27.8	1100	7.44	30
	3420	159.86	30.06	37.46	48.05	27.6	1090	7.62	30
	3480	159.88	30.08	37.49	48.01	28.2	1080	7.60	30
	3540	160.01	30.21	37.47	48.04	28.4	1090	7.74	30
	3600	160.75	30.95	37.35	48.19	28.1	1050	7.73	30
	3660	160.75	30.95	37.51	47.99	27.9	1040	7.75	30
	3720	160.75	30.95	37.61	47.86	27.7	1050	7.70	30
	3780	160.75	30.95	37.39	48.14	26.9	1040	7.44	30
	3840	160.75	30.95	37.43	48.09	26.8	1050	7.45	30
	3900	160.75	30.95	37.48	48.03	26.9	1030	7.73	30
	3960	160.75	30.95	37.50	48.00	26.8	1040	7.72	30
	4020	160.75	30.95	37.41	48.12	27.1	1060	7.45	30
	4080	160.77	30.97	37.60	47.87	28.1	1140	7.44	30
	4140	160.77	30.97	37.48	48.03	27.9	1090	7.43	30
	4200	160.78	30.98	37.51	47.99	29.6	1110	7.45	30
	4260	160.78	30.98	37.50	48.00	28.6	1090	7.54	30
	4320	160.80	31.00	37.48	48.03	30.2	1080	7.64	DO 4.2mg/l
	4380	160.80	31.00	37.51	47.99	30.1	1090	7.72	30
	4440	160.80	31.00	37.41	48.12	30.2	1080	7.69	30
	4500	160.80	31.00	37.50	48.00	30.1	1050	7.47	30
	4560	160.80	31.00	37.38	48.15	29.9	1030	7.40	30
	4620	160.80	31.00	37.43	48.09	30.2	1060	7.48	30
	4680	160.80	31.00	37.41	48.12	30.1	1030	7.48	30
	4740	160.80	31.00	37.48	48.03	30.1	1040	7.41	30
	4800	160.80	31.00	37.50	48.00	30.0	1060	7.41	30
	4860	160.80	31.00	37.46	48.05	30.1	1040	7.40	30
	4920	160.80	31.00	37.44	48.08	30.1	1030	7.40	30
	4980	160.80	31.00	37.46	48.05	30.2	1060	7.61	30
	5040	160.80	31.00	37.50	48.00	30.1	1080	7.49	30
	5100	160.83	31.03	37.46	48.05	30.4	1090	7.46	30
	5160	160.86	31.06	37.50	48.00	30.2	1080	7.56	30
	5220	160.93	31.13	37.46	48.05	30.4	1090	7.33	30
	5280	160.98	31.18	37.38	48.15	29.5	1060	7.55	30
	5340	161.02	31.22	37.41	48.12	27.5	1050	7.49	30
	5400	161.04	31.24	37.55	47.94	27.4	1040	7.54	30
	5460	161.15	31.35	37.33	48.22	27.1	1040	7.57	30
	5520	161.15	31.35	37.45	48.06	28.5	1030	7.59	30
	5580	161.15	31.35	37.59	47.89	29.5	1070	7.48	30
	5640	161.15	31.35	37.39	48.14	29.7	1060	7.45	30
	5700	161.15	31.35	37.56	47.92	29.8	1050	7.47	30
	5760	161.15	31.35	37.46	48.05	29.9	1040	7.45	30
	5820	161.15	31.35	37.50	48.00	30.6	1060	7.43	DO 4.0mg/l
	5880	161.15	31.35	37.46	48.05	30.5	1050	7.44	30
	5940	161.15	31.35	37.41	48.12	29.9	1030	7.42	30
	6000	161.15	31.35	37.38	48.15	30.0	1040	7.45	30
	6060	161.15	31.35	37.56	47.92	29.8	1030	7.41	30
	6120	161.15	31.35	37.55	47.94	29.5	1090	7.47	30
	6180	161.15	31.35	37.50	48.00	28.9	1080	7.45	30

	6240	161.15	31.35	37.33	48.22	28.1	1060	7.41	30
	6300	161.15	31.35	37.45	48.06	28.9	1050	7.43	30
	6360	161.15	31.35	37.39	48.14	28.7	1040	7.44	30
	6420	161.15	31.35	37.18	48.41	27.1	1060	7.47	30
	6480	161.15	31.35	37.45	48.06	28.2	1080	7.47	30
	6540	161.15	31.35	37.48	48.03	28.1	1060	7.43	30
	6600	161.15	31.35	37.50	48.00	28.2	1040	7.43	30
	6660	161.15	31.35	37.33	48.22	28.1	1060	7.41	30
	6720	161.15	31.35	37.42	48.10	28.4	1080	7.43	30
	6780	161.15	31.35	37.50	48.00	29.1	1090	7.44	30
	6840	161.15	31.35	37.48	48.03	28.6	1060	7.34	30
	6900	161.15	31.35	37.55	47.94	28.5	1050	7.41	30
	6960	161.15	31.35	37.56	47.92	28.4	1030	7.43	30
	7020	161.15	31.35	37.39	48.14	26.9	1040	7.48	30
	7080	161.15	31.35	37.41	48.12	27.0	1040	7.45	30
	7140	161.15	31.35	37.50	48.00	27.1	1050	7.43	Flowmeter - 0034332.03
	7200	161.15	31.35	37.45	48.06	27.4	1050	7.44	DO - 4.0mg/l

Table 1-9 Recovery Test Data – BH9237

Official BH NO :	9237	District :	Ghanzi
Date of test commencement :	27.10.05	Location :	Matloaphuduphudu
Time of test commencement :	1100hrs	BH depth(m) :	244
Date of test completion	28.10.05	Screen Int (m)	Open
Time of test completion :	1100hrs	Depth of pump intake (m) :	168.5
Method of water level measurement:	dipper	Description of MP	top of dippetubing
OB. BH. No.:	10223	Height of MP above ground(m) :	0.44
Dist.to Ob Bh:	10.1	Static Water level before test(m) :	129.8
Casing diameter (mm)	Open	Water strike (m)	141, 158, 185, & 244
Orifice plate diameter	4 inch	Delivery pipe diameter	102mm
Easting	586372	Northing	7460371

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	161.15	31.35
	0.25	160.66	30.86
	0.5	154.95	25.15
	1	142.14	12.34
	2	138.28	8.48
	3	137.09	7.29
	4	136.63	6.83
	5	135.76	5.96
	6	135.40	5.60
	7	134.93	5.13
	8	134.83	5.03
	9	134.70	4.90
	10	134.57	4.77
	12	134.32	4.52
	15	134.08	4.28
	20	133.88	4.08
	25	133.77	3.97
	30	133.55	3.75
	40	133.33	3.53
	50	133.02	3.22
	60	132.86	3.06
	75	132.67	2.87
	90	132.48	2.68
	105	132.34	2.54
	120	132.25	2.45

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	132.00	2.20
	180	131.85	2.05
	210	131.76	1.96
	240	131.65	1.85
	270	131.56	1.76
	300	131.47	1.67
	330	131.40	1.60
	360	131.36	1.56
	390	131.30	1.50
	420	131.24	1.44
	450	131.22	1.42
	480	131.18	1.38
	540	131.12	1.32
	600	131.06	1.26
	660	131.02	1.22
	720	131.00	1.20
	780	130.98	1.18
	840	130.96	1.16
	900	130.93	1.13
	960	130.90	1.10
	1020	130.86	1.06
	1080	130.84	1.04
	1140	130.82	1.02
	1200	130.80	1.00
	1260	130.77	0.97
	1320	130.72	0.92
	1380	130.69	0.89
	1440	130.67	0.87

Table 1-10 Observation Borehole Data – BH10223 (CRT)

Official BH NO : Observation hole	10223	District :	Ghanzi
Date of test commencement :	22/10	Location :	MAP
Time of test commencement :	1100hrs	BH depth(m) :	215
Date of test completion	27/10/05	Screen Interval (m)	139 to 210.16
Time of test completion :	1100hrs	Depth of pump intake (m) :	N/A
Method of water level measurement	dipper	Description of MP	top of casing
Pumping BH NO:	9237	Height of MP above ground(m) :	0.97
Distance to pumping BH (m)	10.1	Static Water level before test(m) :	
Casing diameter (mm)	203	Water strike(m)	143, 170 & 188
Orifice plate diameter	4 inch	Delivery pipe diameter	N/A
Easting	586372	Northing	7460371

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill	Q(m^3/h)	Temp (^{0}C)	EC (us/cm)	pH	Comments
	0.25	130.60	0.02						
	0.5	130.70	0.12						
	1	131.10	0.52						
	2	131.37	0.79						
	3	131.53	0.95						
	4	132.08	1.50						
	5	132.11	1.53						
	6	133.59	3.01						
	7	133.90	3.32						
	8	134.19	3.61						
	9	134.30	3.72						
	10	134.47	3.89						
	11	134.64	4.06						
	12	134.79	4.21						
	15	135.15	4.57						
	20	135.69	5.11						
	25	136.10	5.52						
	30	136.32	5.74						
	40	136.73	6.15						
	45	136.84	6.26						
	50	137.00	6.42						
	60	137.20	6.62						
	75	137.51	6.93						
	90	137.68	7.10						
	105	137.98	7.40						
	120	138.03	7.45						
	150	138.28	7.70						
	180	138.43	7.85						
	210	138.60	8.02						
	240	138.74	8.16						
	270	138.95	8.37						
	300	139.15	8.57						
	330	139.23	8.65						
	360	139.23	8.65						
	390	139.24	8.66						
	420	139.25	8.67						
	450	139.29	8.71						
	480	139.44	8.86						
	540	139.44	8.86						
	600	139.44	8.86						
	660	139.47	8.89						
	720	139.62	9.04						
	780	139.64	9.06						
	840	139.66	9.08						
	900	139.74	9.16						
	960	139.79	9.21						
	1020	139.83	9.25						
	1080	139.86	9.28						
	1140	139.89	9.31						
	1200	139.94	9.36						
	1260	139.94	9.36						
	1320	139.94	9.36						
	1380	139.96	9.38						
	1440	139.97	9.39						
	1500	139.97	9.39						
	1560	139.97	9.39						
	1620	139.97	9.39						
	1680	139.97	9.39						
	1740	139.97	9.39						
	1800	139.97	9.39						
	1860	139.98	9.40						
	1920	139.99	9.41						
	1980	140.02	9.44						
	2040	140.05	9.47						
	2100	140.08	9.50						
	2160	140.10	9.52						
	2220	140.10	9.52						
	2280	140.10	9.52						
	2340	140.11	9.53						
	2400	140.12	9.54						
	2460	140.12	9.54						
	2520	140.15	9.57						

	2580	140.17	9.59							
	2640	140.23	9.65							
	2700	140.25	9.67							
	2760	140.25	9.67							
	2820	140.26	9.68							
	2880	140.26	9.68							
	2940	140.26	9.68							
	3000	140.26	9.68							
	3060	140.26	9.68							
	3120	140.26	9.68							
	3180	140.26	9.68							
	3240	140.26	9.68							
	3300	140.28	9.70							
	3360	140.31	9.73							
	3420	140.35	9.77							
	3480	140.41	9.83							
	3540	140.44	9.86							
	3600	140.45	9.87							
	3660	140.45	9.87							
	3720	140.45	9.87							
	3780	140.45	9.87							
	3840	140.46	9.88							
	3900	140.46	9.88							
	3960	140.46	9.88							
	4020	140.48	9.90							
	4080	140.48	9.90							
	4140	140.50	9.92							
	4200	140.50	9.92							
	4260	140.51	9.93							
	4320	140.51	9.93							
	4380	140.51	9.93							
	4440	140.51	9.93							
	4500	140.51	9.93							
	4560	140.51	9.93							
	4620	140.51	9.93							
	4680	140.51	9.93							
	4740	140.51	9.93							
	4800	140.51	9.93							
	4860	140.51	9.93							
	4920	140.51	9.93							
	4980	140.52	9.94							
	5040	140.52	9.94							
	5100	140.53	9.95							
	5160	140.53	9.95							
	5220	140.53	9.95							
	5280	140.53	9.95							
	5340	140.53	9.95							
	5400	140.53	9.95							
	5460	140.57	9.99							
	5520	140.57	9.99							
	5580	140.57	9.99							
	5640	140.57	9.99							
	5700	140.57	9.99							
	5760	140.57	9.99							
	5820	140.57	9.99							
	5880	140.57	9.99							
	5940	140.57	9.99							
	6000	140.57	9.99							
	6060	140.57	9.99							
	6120	140.57	9.99							
	6180	140.57	9.99							
	6240	140.57	9.99							
	6300	140.57	9.99							
	6360	140.57	9.99							
	6420	140.57	9.99							
	6480	140.57	9.99							
	6540	140.57	9.99							
	6600	140.57	9.99							
	6660	140.57	9.99							
	6720	140.57	9.99							
	6780	140.57	9.99							
	6840	140.57	9.99							
	6900	140.58	10.00							
	6960	140.58	10.00							
	7020	140.59	10.01							

	7080	140.59	10.01						
	7140	140.59	10.01						

Table 1-11 Observation Borehole Data – BH10223 (Recovery Data)

Official BH NO :	10223	District :	Ghanzi
Date of test commencement :	27.10.05	Location :	Matloaphuduphudu
Time of test commencement :	1100hrs	BH depth(m) :	215
Date of test completion	28.10.05	Screen Int (m)	139 to 210.16
Time of test completion :	1100hrs	Depth of pump intake (m) :	n/a
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	10223	Height of MP above ground(m) :	0.97
Dist.to pumping Bh:	10.1	Static Water level before test(m) :	130.58
Casing diameter (mm)	203	Water strike	143, 170 & 188
Orifice plate diameter	n/a	Delivery pipe diameter	n/a
Easting	586372	Northing	7460371

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	140.59	10.01
	0.25	140.44	9.86
	0.5	140.40	9.82
	1	140.37	9.79
	2	140.30	9.72
	3	140.25	9.67
	4	140.20	9.62
	5	140.09	9.51
	6	140.01	9.43
	7	135.97	5.39
	8	135.95	5.37
	9	135.93	5.35
	10	135.91	5.33
	12	135.60	5.02
	15	135.30	4.72
	20	134.83	4.25
	25	134.63	4.05
	30	134.41	3.83
	40	134.06	3.48
	50	133.68	3.10
	60	133.57	2.99
	75	133.36	2.78
	90	133.19	2.61
	105	133.03	2.45
	120	132.90	2.32

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	132.67	2.09
	180	132.52	1.94
	210	132.40	1.82
	240	132.30	1.72
	270	132.21	1.63
	300	132.12	1.54
	330	132.06	1.48
	360	132.00	1.42
	390	131.95	1.37
	420	131.90	1.32
	450	131.87	1.29
	480	131.83	1.25
	540	131.77	1.19
	600	131.72	1.14
	660	131.70	1.12
	720	131.68	1.10
	780	131.65	1.07
	840	131.62	1.04
	900	131.58	1.00
	960	131.55	0.97
	1020	131.51	0.93
	1080	131.50	0.92
	1140	131.48	0.90
	1200	131.45	0.87
	1260	131.42	0.84
	1320	131.40	0.82
	1380	131.38	0.80
	1440	131.36	0.78

2 BH10223

BH10223 with siting reference of **S17** is a monitoring borehole (observation piezometer) for the existing borehole (BH9237) which was drilled during the Hunhukwe/ Lokalane Project. It is located in the Matlho-a-Phuduhudu Block. Drilling at this site commenced on 14 September 2005 and was completed on 19 September 2005. The drilled depth of this piezometer is 215m.

2.1 SITING CRITERIA AND DRILLING OBJECTIVES

This monitoring borehole was drilled at the site of existing borehole BH9237 to allow for the estimation of the storativity of the Ntane aquifer. It will also allow for the accurate hydraulic head measurement of the Ntane aquifer at this location.

2.2 DRILLING RESULTS

This borehole was drilled through various lithologies including fine grained sand, silcrete, calcrete, and fine to medium grained sandstones (**Figure 2-1**). Drilling of BH10223 was carried out with a 10 inch drilling bit using the DTH drilling technique down to a depth of 16 m bgl and installation of 8 inch plain casings and drilling was continued to a depth of 124m using an 8 inch bit. 6.5 inch plain casings were installed to a depth of 124m and cement grouted. Drilling to the terminal depth of 215m was carried out using a 6.5 inch drilling bit.

After drilling, 2 inch PVC casing (interval 0 to 139 m bgl and 210.16 to 212.16 m bgl.) and screens (interval 139 to 210.16 m bgl) assembly was installed into the borehole. Gravel pack, comprising of sub-rounded gravel, was tremied down from 119 to 215 m bgl. A bentonite seal was placed from 119 to 116 m and the remaining annulus was cement grouted to surface (116 to 0 m).

During drilling of this borehole, three water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the three water strikes are as follows;

1. (143m, 1175 µS/cm, 1.64m^3/hr)
2. (170m, 1228 µS/cm, 4.48 m^3/hr)
3. (188m, 1264 µS/cm, 1.82 m^3/hr)

The final estimated yield determined using a 90^{o} V-notch weir was 8 m^3/hr while the electrical conductivity was measured as 1244 µS/cm. Borehole development was through airlift pumping using 1.5 inch air line. The borehole was finally capped and a cement slab was constructed. The borehole details are shown in **Figure 2-1**.

Water samples collected at completion of borehole development was submitted to the DWA laboratory for chemical analysis. The laboratory results are presented in **Table 2-1**.

Table 2-1 Drilling Chemistry results (DWA)

BHNo	Depth	pH	TDS	Ca	Mg	Na	K	Cl	SO_4	NO_3	F	CO_3	HCO_3	Mn	Fe
10223	215	7.49	632	41.65	28.45	175.85	27.85	153.6	69.15	10.13	0.25	0	350.45	0	0.067
BOS 32:2000 Class II		5.5-9.5	1000	150	70	200	50	200	250	45	1	200	250	1	3
BOS 32:2000 Class III		5.0 - 10.0	2000	200	100	400	100	600	400	45	1.5	600	400	5	20

Note: Parameters in mg/l

2.3 PUMP TESTING RESULTS

This borehole was used as an observation borehole during pump testing of BH9237 and the pump testing results are discussed in Chapter 1.

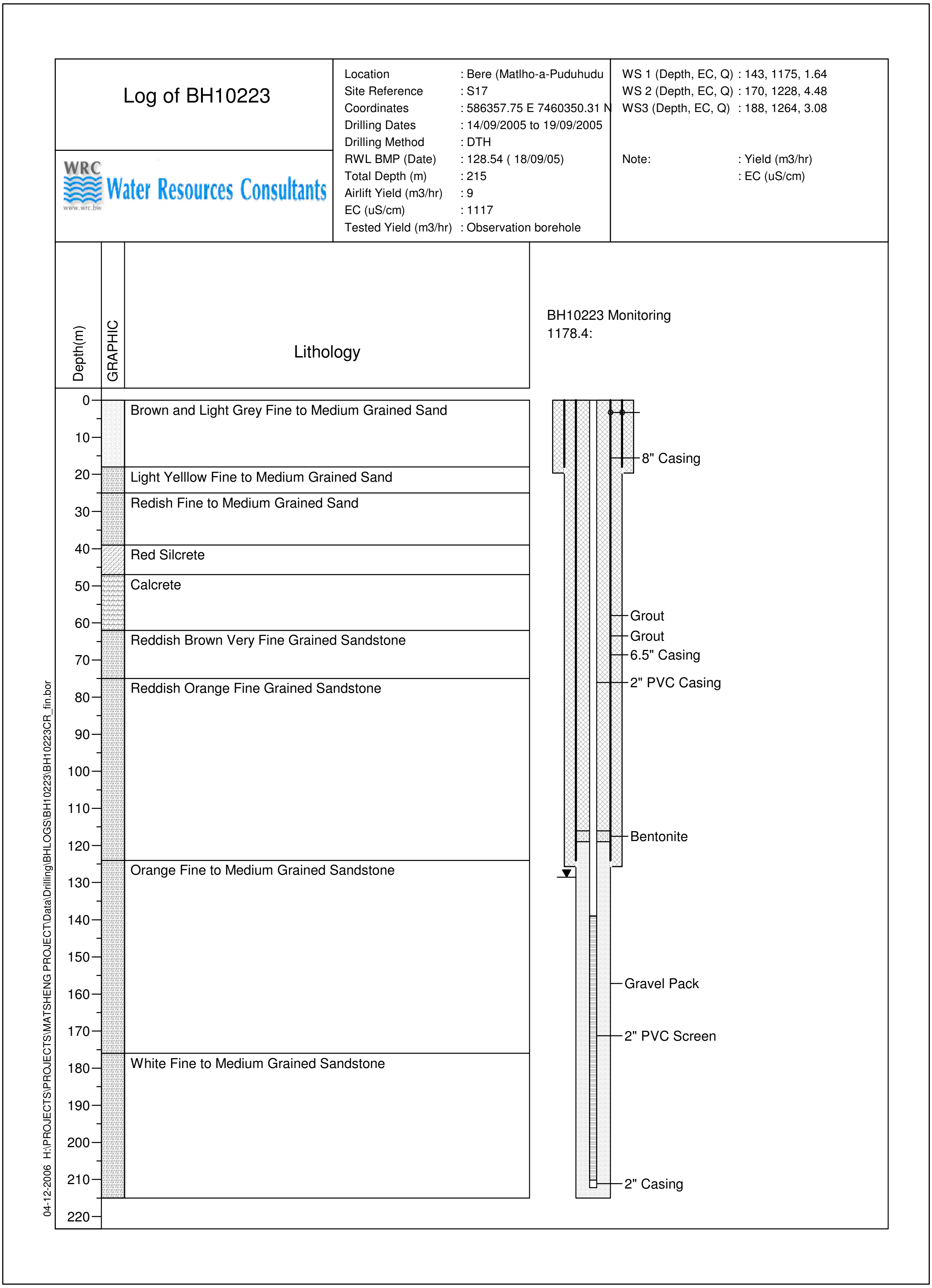

Figure 2-1 Log of BH10223

3 BH9239

BH9239 is an exploration borehole drilled during the Hunhukwe / Lokalane project. It is located in the Matlho-a-Phuduhudu Block, about 60 km south of Bere and is about 180km east of Ncojane. This borehole was pump tested during the Hunhukwe / Lokalane project at a discharge rate of 25 m^3/h for 3.1 days and it had a total drawdown of 5.83m.

During the Matsheng Groundwater Project, a monitoring piezometer BH10224 was drilled next to BH9239 to allow for the estimation of the Ntane Sandstone aquifer storativity for input into the numerical model. The monitoring piezometer will also allow for accurate head measurement of Ntane aquifer.

3.1 DRILLING RESULTS

This borehole was drilled through various lithologies including fine grained sands, silcrete, fine to medium grained sandstones and siltstone (**Figure 3-1**). Drilling was started using a 15 inch drilling bit to a depth of 70 m after which a 10 inch casing was installed. Drilling was continued to the terminal depth of 232m using a 12 inch drilling bit.

During drilling of this borehole, three water strikes were encountered. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows:

1. 152m, 1990 µS/cm, 2.85 m^3/h
2. 166m, 1930 µS/cm, 2 m^3/h
3. 220m, 2390 µS/cm, 10.5 m^3/h

After development, the final yield was 9.2 m^3/hr the pH was 8.8 and the electrical conductivity was 1280 µS/cm.

The borehole was constructed using 6.5 inch plain and slotted casings due to the collapsing problems. The plain casings were installed between 0160 m to 149m and 167 to 209m and the slotted zones were between 149 m to 167m and 209 to 276m.

A summary of the borehole details is presented in **Figure 3-1**.

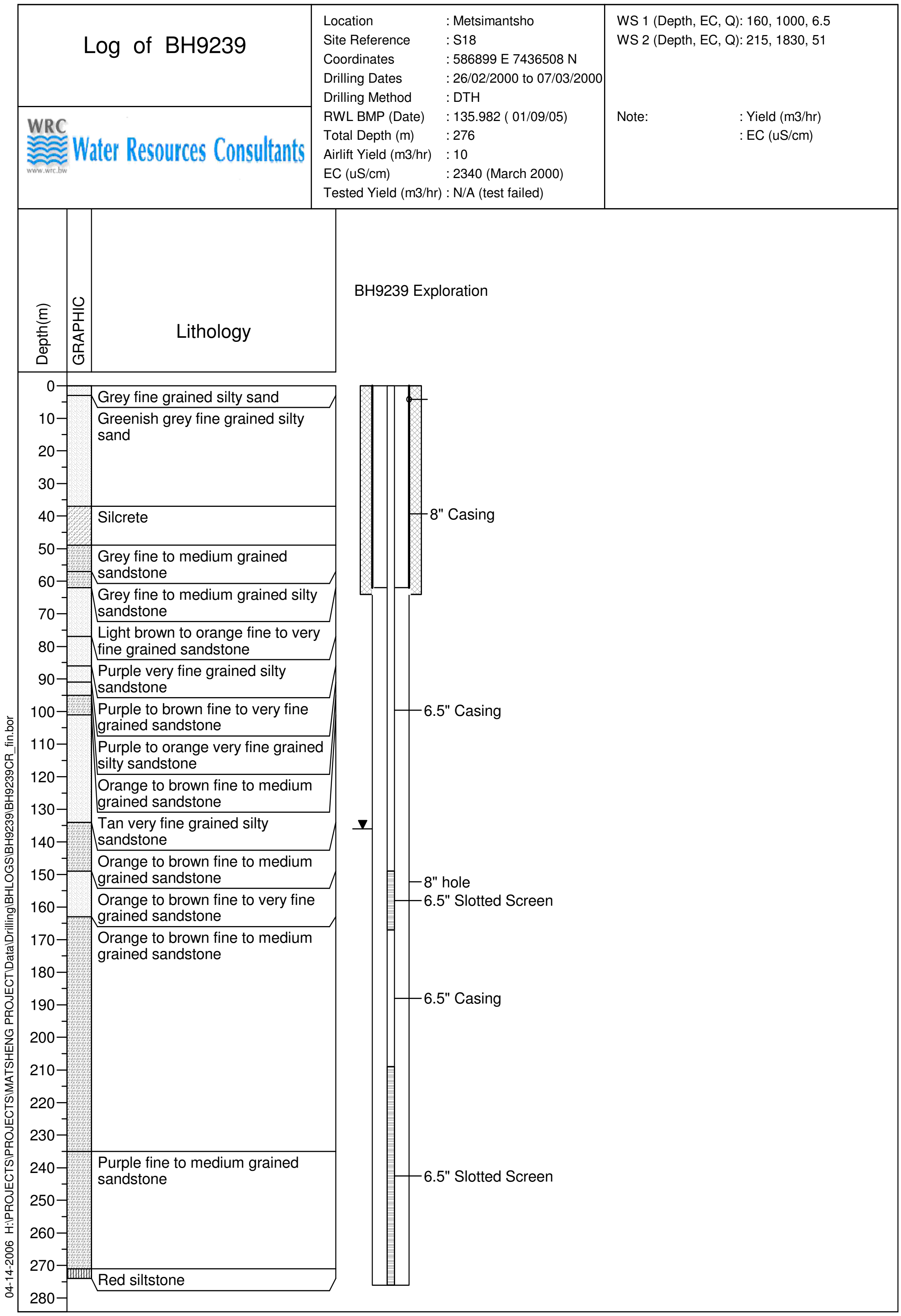

Figure 3-1 Log of BH9239

3.2 PUMP TESTING RESULTS

A pumping test was attempted in November 2005 but had to be abandoned because of sand pumping and it was decided to repeat the test after the borehole was cleaned by a drilling contractor. It has to be pointed out that this borehole has slotted casings between 149 to 167m and 209 and 276m.

Borehole BH9239 was re-tested between 24 and 28 February 2006. The tests carried out were calibration and step drawdown only. This was because there was a lot of sand coming out at the discharge point during pumping. The measuring point was 0.44 m above ground level (agl) and the pump intake was set at 168.5 m below ground level. There was a breakdown of the pump shaft at the beginning of the 6th calibration step and the pump intake was lowered to 148m. The measuring point for the second installation was 0.48 m above ground level (agl). Summary details for the pumping test activities are given in **Table 3-1**. The collected test pumping data is presented in **Tables 3-3 to 3-5.**

Table 3-1 Summary of Pumping Test Data BH9239

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	1.02	9.6
	2	15	1.74	15.2
	3	15	2.52	25.1
	4	15	4.56	35.3
	5	15	6.16	45.7
	1	15	0.46	10.1
	2	15	1.88	20.3
	3	15	2.34	30.2
	4	15	3.81	40.6
	5	15	5.25	50
	6	15	6.86	59
Step Test	1	100	1.35	10
	2	100	2.98	20.2
	3	100	4.32	30.2
	4	100	6.22	40.3
	5	10	8.29	50.2

3.2.1 Step Drawdown Test

The step drawdown test was carried out on 28 February 2006. The static water level before the start of the test was 135.64 m bmp. The step drawdown test consisted of 5 steps of 100 minutes duration. The discharge rates were 10.2, 20.3, 30.2, 40.3 and 50.2 m^3/hr for steps 1 to 5 respectively.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test data using this method is presented in **Figure 3-2**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 3-3**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 56.4 m^2/d (**Figure 3.4**). The results of the step test data interpretation are given in **Table 3-2**.

Table 3-2 Results of Step Test Analysis BH9239

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
9239	5.82E-03	-8.97E-07	56.4	10.2	1.36	1.36	7.50
				20.3	1.47	2.83	7.17
				30.2	0.54	3.37	8.97
				40.3	1.36	4.73	8.53
				50.2	1.24	5.97	8.41

The planned duration for the constant rate test of this borehole was 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 3-2**) to estimate the expected total drawdown after 5 days of pumping. It was found out that a discharge rate of 35 m^3/hr was ideal for this borehole.

3.2.2 Constant Rate Test

A constant rate test at a discharge of 35 m^3/hr was attempted on 1 March 2006 but there was a breakdown of the pump shaft at the beginning of the test. This was because of sand pumping and it was therefore decided that there would be no further pump testing in this borehole.

When this borehole was tested during the Hunhukwe / Lokalane project (pump intake of 171.5), sand pumping was also reported.

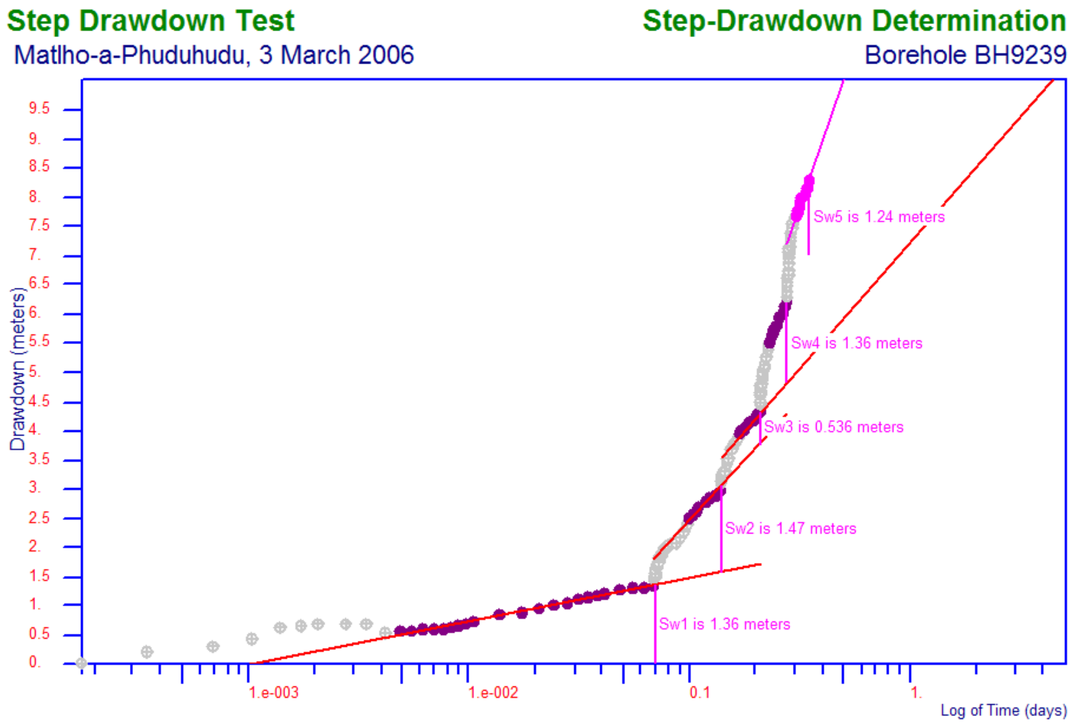

Figure 3-2 Pumping Test Results for BH9239: Step Drawdown Test – Hantush-Bierschenk (semi-log)

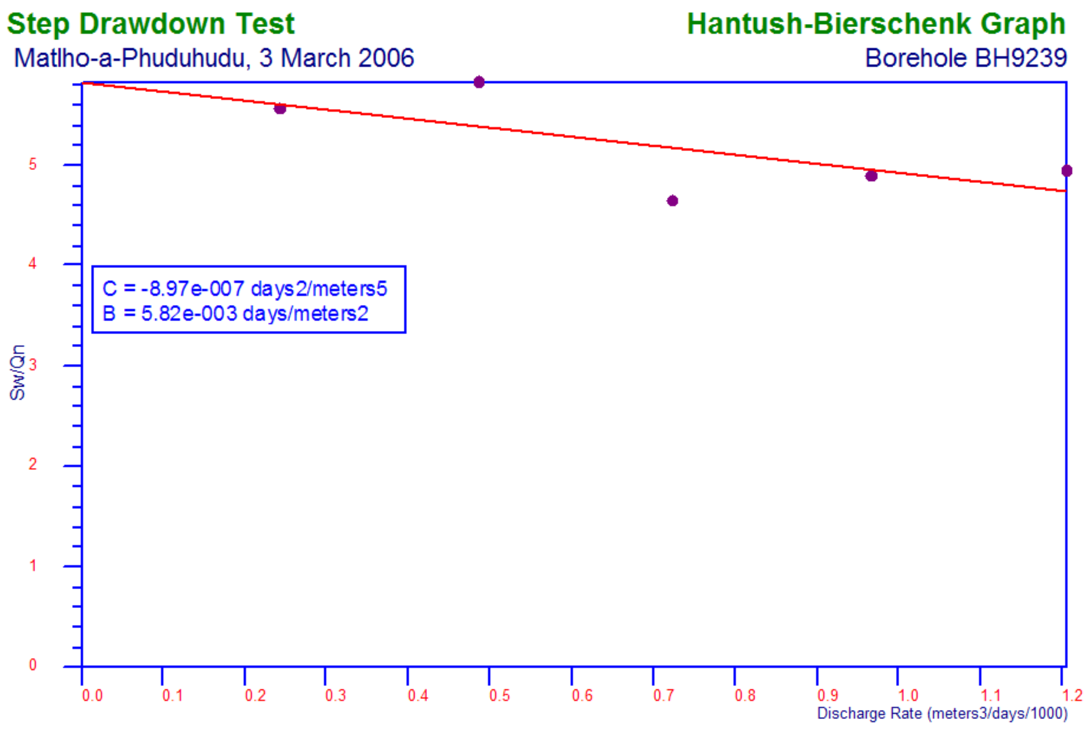

Figure 3-3 Pumping Test Results for BH9239: Step Drawdown Test – Hantush-Bierschenk

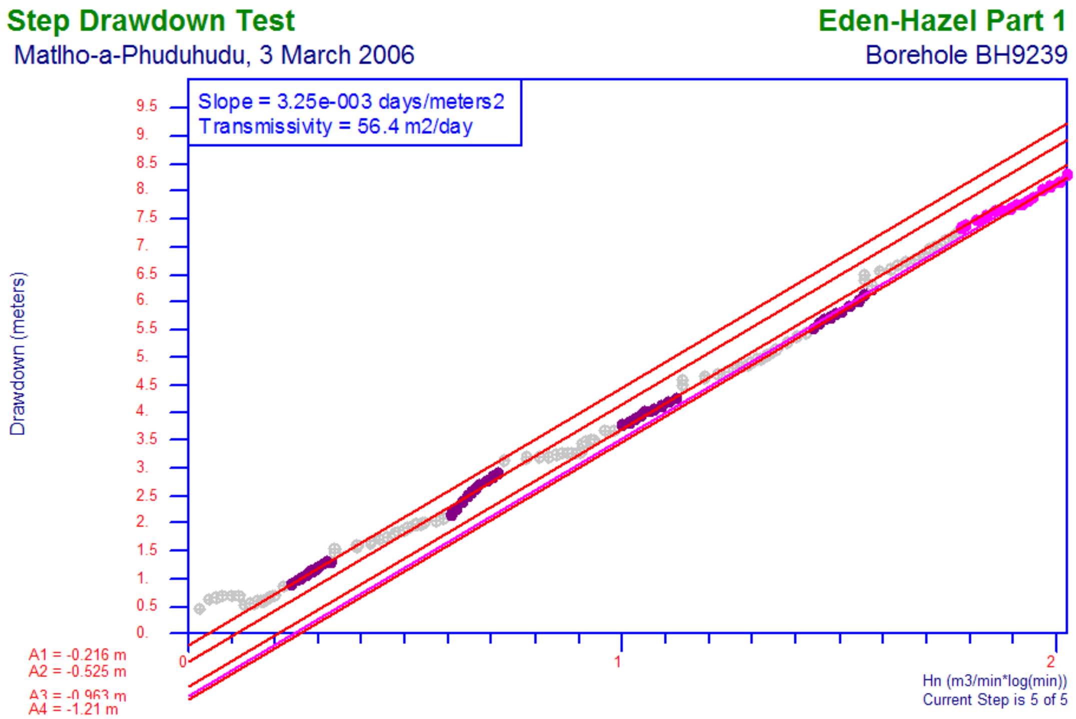

Figure 3-4 Pumping Test Results for BH9239: Step Drawdown Test – Eden-Hazel (Part 1)

Table 3-3 Calibration Test Data – BH9239

Official BH No.:	9239	District:	Ghanzi
Date of test commencement:	24.02.06	Location:	Matlhoaphuduhudu
Time of test commencement	1415hrs	BH depth (m):	276
Date of test completion:	24.02.06	Screen Interval (m):	149 to 167 and 209 to 276
Time of test completion	1530hrs	Depth of pump intake (m):	168.5
Method of water level measurement:	dipper	Static water level before test (m):	135.65
Casing diameter (mm)	203.2	Water strike	160 and 215 m
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	586815	Northing	7436504

STEP No. 1 / STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	136.00	0.35				0.25	136.78	1.13			
0.5	136.05	0.40				0.5	136.79	1.14			
1	136.15	0.50				1	136.83	1.18	11.46	15.71	
1.5	136.17	0.52				1.5	136.87	1.22			
2	136.21	0.56				2	136.91	1.26	11.85	15.19	
2.5	136.23	0.58				2.5	136.94	1.29			
3	136.26	0.61				3	136.94	1.29	11.75	15.32	
4	136.34	0.69				4	137.03	1.38	12.00	15.00	
5	136.39	0.74				5	137.07	1.42	11.92	15.10	
6	136.42	0.77	20.44	8.81		6	137.12	1.47	11.97	15.04	
7	136.45	0.80	22.50	8.00		7	137.15	1.50	11.88	15.15	
8	136.50	0.85	18.35	9.81		8	137.19	1.54	11.75	15.32	
9	136.54	0.89	18.00	10.00		9	137.22	1.57	11.92	15.10	
10	136.59	0.94	17.94	10.03		10	137.27	1.62	11.91	15.11	
11	136.63	0.98	17.87	10.07		11	137.30	1.65	11.88	15.15	
12	136.63	0.98	17.97	10.02		12	137.33	1.68	11.82	15.23	
15	136.67	1.02	18.00	10.00		15	137.39	1.74	11.93	15.09	

STEP No. 3 / STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments
0.25	137.55	1.90				0.25	138.30	2.65			
0.5	137.61	1.96				0.5	138.42	2.77			
1	137.68	2.03	12.59	28.59		1	138.48	2.83	8.75	41.14	
1.5	137.71	2.06				1.5	138.55	2.90			
2	137.76	2.11	12.75	28.24		2	138.65	3.00	10.75	33.49	
2.5	137.80	2.15			adj	2.5	138.67	3.02			
3	137.83	2.18	14.22	25.32		3	138.71	3.06	10.20	35.29	
4	137.87	2.22	14.30	25.17		4	138.81	3.16	10.22	35.23	
5	137.92	2.27	14.29	25.19		5	138.90	3.25	10.28	35.02	
6	137.96	2.31	14.35	25.09		6	139.04	3.39	10.20	35.29	
7	137.98	2.33	14.28	25.21		7	139.13	3.48	10.19	35.33	
8	138.02	2.37	14.40	25.00		8	139.23	3.58	10.18	35.36	
9	138.05	2.40	14.32	25.14		9	139.44	3.79	10.17	35.40	
10	138.07	2.42	14.39	25.02		10	139.65	4.00	10.15	35.47	
11	138.09	2.44	14.27	25.23		11	139.83	4.18	10.22	35.23	
12	138.13	2.48	14.40	25.00		12	140.00	4.35	10.20	35.29	
15	138.17	2.52	14.32	25.14		15	140.21	4.56	10.28	35.02	

Official BH No.:	9239	District:	Ghanzi
Date of test commencement:	24.02.06	Location:	MAP
Time of test commencement	1415hrs	BH depth (m):	276
Date of test completion:	24.02.06	Screen Interval (m):	149 to 167 and 209 to 276
Time of test completion	1530hrs	Depth of pump intake (m):	168.5
Method of water level measurement:	dipper	Static water level before test (m):	135.65
Casing diameter (mm)	203.2	Water strike	160 and 215
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	586815	Northing	7436504

STEP No.	5					STEPNo.	6				
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	140.45	4.80				0.25	shafting				
0.5	140.49	4.84				0.5	break				
1	140.56	4.91	11.50	46.96		1	due to sand				
1.5	140.61	4.96				1.5					
2	140.72	5.07	12.00	45.00		2					
2.5	140.81	5.16				2.5					
3	140.91	5.26	11.78	45.84		3					
4	141.10	5.45	11.37	47.49		4					
5	141.25	5.60	11.69	46.19		5					
6	141.34	5.69	11.99	45.04		6					
7	141.39	5.74	12.00	45.00		7					
8	141.53	5.88	11.82	45.69		8					
9	141.61	5.96	11.79	45.80		9					
10	141.67	6.02	11.82	45.69		10					
11	141.76	6.11	11.90	45.38		11					
12	141.78	6.13	11.84	45.61		12					

Table 3-4 Calibration Test Data – BH9239

Official BH No.:	9239	District :	Ghanzi
Date of test commencement:	27.02.06	Location:	MAP
Time of test commencement	1200hrs	BH depth (m):	276
Date of test completion:	27.02.06	Screen Interval (m):	149 to 167 and 209 to 276
Time of test completion	1330hrs	Depth of pump intake (m):	148
Method of water level measurement:	dipper	Static water level before test (m):	135.64
Casing diameter (mm)	203	Water strike	160 and 215 m
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	586815	Northing	7436504

STENo. 1						STEPNo. 2					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	135.71	0.07				0.25	136.37	0.73			
0.5	135.91	0.27				0.5	136.39	0.75			
1	135.95	0.31				1	136.40	0.76	12.58	14.31	
1.5	135.95	0.31				1.5	136.41	0.77			adj
2	135.95	0.31				2	136.52	0.88	9.53	18.89	
2.5	135.95	0.31				2.5	136.65	1.01			
3	135.96	0.32				3	136.73	1.09	9.68	18.60	adj
4	135.99	0.35				4	136.92	1.28	8.70	20.69	
5	135.99	0.35				5	136.99	1.35	8.97	20.07	
6	135.99	0.35				6	137.08	1.44	8.78	20.50	
7	135.99	0.35	17.71	10.16		7	137.17	1.53	8.71	20.67	
8	135.99	0.35	17.61	10.22		8	137.24	1.60	8.75	20.57	
9	135.99	0.35	17.94	10.03		9	137.24	1.60	8.92	20.18	
10	136.00	0.36	17.88	10.07		10	137.28	1.64	8.94	20.13	
11	136.03	0.39	17.99	10.01		11	137.36	1.72	8.81	20.43	
12	136.04	0.40	17.69	10.18		12	137.40	1.76	8.93	20.16	
15	136.10	0.46	17.92	10.04		15	137.52	1.88	8.94	20.13	

STEP No. 3						STEP No. 4					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments
0.25	137.65	2.01				0.25	138.26	2.62			
0.5	137.67	2.03				0.5	138.33	2.69			
1	137.67	2.03	11.88	30.30		1	138.36	2.72	9.38	38.38	
1.5	137.71	2.07				1.5	138.39	2.75			
2	137.74	2.10	11.85	30.38		2	138.47	2.83	9.60	37.50	
2.5	137.75	2.11				2.5	138.51	2.87			
3	137.75	2.11	11.81	30.48		3	138.52	2.88	8.93	40.31	
4	137.76	2.12	12.00	30.00		4	138.60	2.96	8.97	40.13	
5	137.76	2.12	11.96	30.10		5	138.66	3.02	9.00	40.00	
6	137.76	2.12	11.94	30.15		6	138.74	3.10	8.38	42.96	
7	137.76	2.12	11.96	30.10		7	138.80	3.16	8.94	40.27	
8	137.78	2.14	11.89	30.28		8	138.83	3.19	8.79	40.96	
9	137.80	2.16	11.90	30.25		9	138.90	3.26	8.88	40.54	
10	137.82	2.18	11.97	30.08		10	139.09	3.45	8.93	40.31	
11	137.83	2.19	11.88	30.30		11	139.11	3.47	8.97	40.13	
12	137.89	2.25	11.81	30.48		12	139.19	3.55	8.88	40.54	
15	137.98	2.34	11.96	30.10		15	139.45	3.81	8.99	40.04	

Official BH No.:	9239	District:	Ghanzi
Date of test commencement:	27.02.06	Location:	Matlhoaphuduhudu
Time of test commencement	1200hrs	BH depth (m):	276
Date of test completion:	27.02.06	Screen Interval (m):	149 to 167 and 209 to 276
Time of test completion	1330hrs	Depth of pump intake (m):	148
Method of water level measurement:	dipper	Static water level before test (m):	135.64
Casing diameter (mm)	203	Water strike	160 and 215 m
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	586815	Northing	7436504

STEP No. 5						STEP No. 6					
TIME (min)	Depth to WL	Drawdown (m)	Time to fill	P Rate (m^3/hr	Comments	TIME	Depth to WL	Drawdown (m)	Time to fill	P Rate (m^3/hr	Comments

	(m)		150L	)		(min)	(m)		200L	)	
0.25	139.57	3.93				0.25	140.99	5.35			
0.5	139.68	4.04				0.5	141.11	5.47			
1	139.71	4.07	12.19	44.30		1	141.24	5.60	13.20	54.55	
1.5	139.82	4.18			adj	1.5	141.35	5.71			
2	139.91	4.27	12.20	44.26		2	141.40	5.76	12.34	58.35	
2.5	139.99	4.35				2.5	141.46	5.82			
3	140.08	4.44	11.00	49.09		3	141.51	5.87	12.00	60.00	
4	140.19	4.55	10.97	49.23		4	141.59	5.95	12.15	59.26	
5	140.29	4.65	10.74	50.28		5	141.39	5.75	12.40	58.06	
6	140.37	4.73	10.78	50.09		6	141.49	5.85	12.50	57.60	
7	140.41	4.77	10.69	50.51		7	141.76	6.12	12.00	60.00	
8	140.44	4.80	10.70	50.47		8	141.93	6.29	12.15	59.26	
9	140.49	4.85	10.80	50.00		9	142.05	6.41	12.25	58.78	
10	140.57	4.93	10.79	50.05		10	142.10	6.46	12.20	59.02	
11	140.65	5.01	10.76	50.19		11	142.16	6.52	12.34	58.35	
12	140.71	5.07	10.77	50.14		12	142.24	6.60	12.15	59.26	
15	140.89	5.25	10.78	50.09		15	142.50	6.86	12.18	59.11	

Table 3-5 Step Drawdown Test Data – BH9239

Official BH No.:	9239	District:	Ghanzi
Date of test commencement:	28.2.06	Location:	Matlhoaphuduhudu
Time of test Commencement:	0800hrs	BH depth (m):	276
Date of test completion:	28.02.06	Screens(m)	149 to 167 and 209 to 276
Time of test Completion:	1620hrs	Depth to pump intake (m)	148
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.48
Distance to OB. BH (m)	n/a	Static water level before test (m):	135.64
Casing diameter (mm)	203	Water strike	160 and 215 m
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	586815	Northing	7436504

STEP No. 1 STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments
0.25	135.67	0.03				0.25	137.10	1.46			
0.5	135.85	0.21				0.5	137.12	1.48			
1	135.95	0.31				1	137.17	1.53	8.69	20.71	
1.5	136.09	0.45				1.5	137.21	1.57			
2	136.27	0.63				2	137.25	1.61	8.74	20.59	
2.5	136.30	0.66				2.5	137.28	1.64			
3	136.34	0.70				3	137.32	1.68	8.90	20.22	
4	136.34	0.70			adj	4	137.36	1.72	8.74	20.59	
5	136.34	0.70	14.42	12.48		5	137.40	1.76	8.64	20.83	
6	136.18	0.54	15.04	11.97	sand	6	137.46	1.82	8.96	20.09	
7	136.19	0.55	15.47	11.64		7	137.49	1.85	8.81	20.43	
8	136.21	0.57	19.57	9.20		8	137.53	1.89	8.95	20.11	
9	136.24	0.60	19.00	9.47		9	137.54	1.90	8.94	20.13	
10	136.25	0.61	18.94	9.50		10	137.58	1.94	8.89	20.25	
11	136.25	0.61	18.00	10.00		11	137.62	1.98	8.96	20.09	
12	136.28	0.64	17.95	10.03		12	137.63	1.99	8.95	20.11	
13	136.29	0.65	17.96	10.02		13	137.63	1.99	8.98	20.04	
14	136.32	0.68	17.78	10.12		14	137.65	2.01	8.87	20.29	
15	136.35	0.71	17.86	10.08		15	137.67	2.03	8.99	20.02	
20	136.49	0.85	17.89	10.06		20	137.70	2.06	8.97	20.07	
25	136.54	0.90	17.94	10.03		25	137.72	2.08	8.91	20.20	
30	136.59	0.95	17.86	10.08		30	137.80	2.16	8.90	20.22	
35	136.65	1.01	17.91	10.05		35	137.91	2.27	8.95	20.11	
40	136.70	1.06	17.83	10.10		40	138.02	2.38	8.87	20.29	
45	136.76	1.12	17.99	10.01		45	138.13	2.49	8.93	20.16	
50	136.77	1.13	17.96	10.02		50	138.21	2.57	8.86	20.32	
55	136.82	1.18	17.85	10.08		55	138.27	2.63	8.98	20.04	
60	136.84	1.20	17.92	10.04		60	138.33	2.69	8.74	20.59	
70	136.91	1.27	17.83	10.10		70	138.41	2.77	8.81	20.43	
80	136.93	1.29	17.97	10.02		80	138.48	2.84	8.99	20.02	
90	136.95	1.31	17.98	10.01		90	138.53	2.89	8.86	20.32	
100	136.99	1.35	17.89	10.06		100	138.62	2.98	8.95	20.11	

Official BH No.:	9239	District:	Ghanzi
Date of test commencement:	28.2.06	Location:	Matlhoaphuduhudu
Time of test Commencement:	0800hrs	BH depth (m):	276
Date of test completion:	28.02.06	Screens(m)	149 to 167 and 209 to 276
Time of test Completion:	1620hrs	Depth to pump intake (m)	148
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.48
Distance to OB. BH (m)	n/a	Static water level before test (m):	135.64
Casing diameter (mm)	203	Water strike	160 and 215 m
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	586815	Northing	7436504

STEP No. 3 STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	138.74	3.10				0.25	140.08	4.44			
0.5	138.77	3.13				0.5	140.14	4.50			
1	138.79	3.15	12.01	29.98		1	140.25	4.61	9.82	36.66	
1.5	138.80	3.16				1.5	140.27	4.63			
2	138.83	3.19	11.91	30.23		2	140.30	4.66	8.94	40.27	
2.5	138.84	3.20				2.5	140.32	4.68			
3	138.84	3.20	11.78	30.56		3	140.33	4.69	8.88	40.54	
4	138.84	3.20	11.94	30.15	adj	4	140.38	4.74	9.44	38.14	
5	138.87	3.23	11.82	30.46		5	140.43	4.79	8.94	40.27	
6	138.92	3.28	11.97	30.08	sand	6	140.46	4.82	8.99	40.04	
7	138.92	3.28	11.97	30.08		7	140.51	4.87	9.00	40.00	
8	138.92	3.28	11.80	30.51		8	140.55	4.91	8.93	40.31	
9	138.92	3.28	11.96	30.10		9	140.59	4.95	8.94	40.27	
10	138.92	3.28	11.99	30.03		10	140.61	4.97	8.99	40.04	
11	139.08	3.44	11.92	30.20		11	140.65	5.01	8.89	40.49	
12	139.13	3.49	11.98	30.05		12	140.69	5.05	8.90	40.45	
13	139.15	3.51	11.86	30.35		13	140.72	5.08	8.92	40.36	
14	139.15	3.51	11.94	30.15		14	140.74	5.10	8.88	40.54	
15	139.15	3.51	11.79	30.53		15	140.77	5.13	8.97	40.13	
20	139.31	3.67	11.99	30.03		20	140.91	5.27	8.87	40.59	
25	139.33	3.69	12.00	30.00		25	141.01	5.37	8.94	40.27	
30	139.41	3.77	11.98	30.05		30	141.09	5.45	8.89	40.49	
35	139.46	3.82	11.94	30.15		35	141.15	5.51	8.95	40.22	
40	139.51	3.87	11.97	30.08		40	141.25	5.61	8.88	40.54	
45	139.58	3.94	11.96	30.10		45	141.33	5.69	8.94	40.27	
50	139.64	4.00	11.99	30.03		50	141.35	5.71	8.85	40.68	
55	139.64	4.00	11.98	30.05		55	141.41	5.77	8.89	40.49	
60	139.70	4.06	11.99	30.03		60	141.44	5.80	8.97	40.13	
70	139.76	4.12	12.00	30.00		70	141.57	5.93	8.90	40.45	
80	139.81	4.17	11.94	30.15		80	141.04	5.40	8.87	40.59	
90	139.89	4.25	11.97	30.08		90	141.75	6.11	8.95	40.22	
100	139.96	4.32	12.00	30.00		100	141.86	6.22	8.90	40.45	

Official BH No.:	9239	District:	Ghanzi
Date of test commencement:	28.2.06	Location:	MAP
Time of test Commencement:	0800hrs	BH depth (m):	276
Date of test completion:	28.02.06	Screens(m)	149 to 167 and 209 to 276
Time of test Completion:	1620hrs	Depth to pump intake (m)	148
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.48
Distance to OB. BH (m)	n/a	Static water level before test (m):	135.64
Casing diameter (mm)	203	Water strike	160 and 215 m
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	586815	Northing	7436504

STEP No. 5 — STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	141.92	6.28				0.25					
0.5	142.03	6.39				0.5					
1	142.12	6.48	12.59	42.89		1					
1.5	142.19	6.55				1.5					
2	142.25	6.61	12.90	41.86	adj	2					
2.5	142.31	6.67				2.5					
3	142.37	6.73	11.00	49.09		3					
4	142.39	6.75	10.76	50.19		4					
5	142.49	6.85	10.69	50.51		5					
6	142.60	6.96	10.75	50.23		6					
7	142.65	7.01	10.65	50.70		7					
8	142.69	7.05	10.78	50.09		8					
9	142.73	7.09	10.76	50.19		9					
10	142.76	7.12	10.75	50.23		10					
11	142.81	7.17	10.79	50.05		11					
12	142.89	7.25	10.80	50.00		12					
13	142.94	7.30	10.75	50.23		13					
14	142.97	7.33	10.73	50.33		14					
15	143.02	7.38	10.80	50.00		15					
20	143.11	7.47	10.69	50.51		20					
25	143.17	7.53	10.76	50.19		25					
30	143.27	7.63	10.68	50.56		30					
35	143.28	7.64	10.69	50.51		35					
40	143.31	7.67	10.70	50.47		40					
45	143.37	7.73	10.75	50.23		45					
50	143.40	7.76	10.73	50.33		50					
55	143.46	7.82	10.74	50.28		55					
60	143.53	7.89	10.76	50.19		60					
70	143.64	8.00	10.80	50.00		70					
80	143.71	8.07	10.78	50.09		80					
90	143.80	8.16	10.75	50.23		90					
100	143.93	8.29	10.74	50.28		100					

Official BH No.:	9239	District:	Ghanzi
Date of test commencement:	28.2.06	Location:	MAP
Time of test Commencement:	0800hrs	BH depth (m):	276
Date of test completion:	28.02.06	Screens(m)	149 to 167 and 209 to 276
Time of test Completion:	1620hrs	Depth to pump intake (m)	148
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.48
Distance to OB. BH (m)	n/a	Static water level before test (m):	135.64
Casing diameter (mm)	203	Water strike	160 and 215 m
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	586815	Northing	7436504

STEP No. 5 STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	141.92	6.28				0.25					
0.5	142.03	6.39				0.5					
1	142.12	6.48	12.59	42.89		1					
1.5	142.19	6.55				1.5					
2	142.25	6.61	12.90	41.86	adj	2					
2.5	142.31	6.67				2.5					
3	142.37	6.73	11.00	49.09		3					
4	142.39	6.75	10.76	50.19		4					
5	142.49	6.85	10.69	50.51		5					
6	142.60	6.96	10.75	50.23		6					
7	142.65	7.01	10.65	50.70		7					
8	142.69	7.05	10.78	50.09		8					
9	142.73	7.09	10.76	50.19		9					
10	142.76	7.12	10.75	50.23		10					
11	142.81	7.17	10.79	50.05		11					
12	142.89	7.25	10.80	50.00		12					
13	142.94	7.30	10.75	50.23		13					
14	142.97	7.33	10.73	50.33		14					
15	143.02	7.38	10.80	50.00		15					
20	143.11	7.47	10.69	50.51		20					
25	143.17	7.53	10.76	50.19		25					
30	143.27	7.63	10.68	50.56		30					
35	143.28	7.64	10.69	50.51		35					
40	143.31	7.67	10.70	50.47		40					
45	143.37	7.73	10.75	50.23		45					
50	143.40	7.76	10.73	50.33		50					
55	143.46	7.82	10.74	50.28		55					
60	143.53	7.89	10.76	50.19		60					
70	143.64	8.00	10.80	50.00		70					
80	143.71	8.07	10.78	50.09		80					
90	143.80	8.16	10.75	50.23		90					
100	143.93	8.29	10.74	50.28		100					

4 BH10224

BH10224 with siting reference of **S18** is an observation piezometer for the existing borehole (BH9239) drilled during the Hunhukwe/ Lokalane Project. It is located in the Matlho-a-Phuduhudu Block. Drilling at this site commenced on 21 September and was completed on 19 October 2005. The drilled depth of this piezometer is 240m.

4.1 SITING CRITERIA AND DRILLING OBJECTIVES

This piezometer was drilled at the site of existing borehole BH9239 to allow for the estimation of the storativity of the Ntane aquifer. It will also allow for the accurate hydraulic head measurement of the Ntane aquifer at this locality. However this borehole was not utilised in the estimation of storativity, during pumping of BH9239 because no constant rate test was carried out due to sand pumping.

4.2 DRILLING RESULTS

The borehole was drilled through various lithologies including fine grained sand, silcrete, calcrete, very fine grained silty sandstone and fine to medium grained sandstones (**Figure 4-1**). Drilling of BH10224 was carried out with a 10 inch drilling bit using the DTH drilling technique down to a depth of 56 m bgl after which 8 inch casings were installed and grouted. Drilling was continued to a depth of 130m using an 8 inch bit. 6.5 inch plain casings were installed to a depth of 130 m and cement grouted. Drilling to the terminal depth of 240 m was carried out using a 6.5 inch drilling bit..

During drilling of this borehole, three water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the three water strikes are as follows;

1. (182m, 3450 µS/cm, 7.5m^3/hr)
2. (206m, 3150 µS/cm, 3.5 m^3/hr)
3. (230m, 2950 µS/cm, 2 m^3/hr)

The final borehole blow-out yield was 13.6 m^3/hr and the electrical conductivity was 2950 µS/cm. One sample was collected at the end of development and was submitted to the DWA lab for basic chemical analysis. The result is presented in **Table 4-1.**

Table 4-1 Drilling Chemistry result (DWA)

BHNo	Depth	pH	TDS	Ca	Mg	Na	K	Cl	SO_4	NO_3	F	CO_3	HCO_3	Mn	Fe
10224	230	11.01	1162	44.7	6.4	379.2	25.7	371.63	103.7	11.89	0	296.6	0.00	0	0.05
BOS 32:2000 Class II		5.5-9.5	1000	150	70	200	50	200	250	45	1	200	250	1	3
BOS 32:2000 Class III		5.0 - 10.0	2000	200	100	400	100	600	400	45	1.5	600	400	5	20

Note: Parameters in mg/l

This piezometer was constructed using 2 inch PVC plain casing and screens. The plain casings were installed between 0 to 159.04m, 173.24 to 178.92 and 232.88 to 235.88m. The screens were installed between 159.04 to 173.24m and 178.92 to 232.88m. After lowering the casing and screen assembly, gravel pack was installed from 240 to 139m. A bentonite seal was installed from 136 to 139m and the remaining annulus was cement grouted to the surface. After development, the final yield and electrical conductivity were 14 m^3/hr and 2950 µS/cm respectively.

The borehole details are shown in **Figure 4-1.**

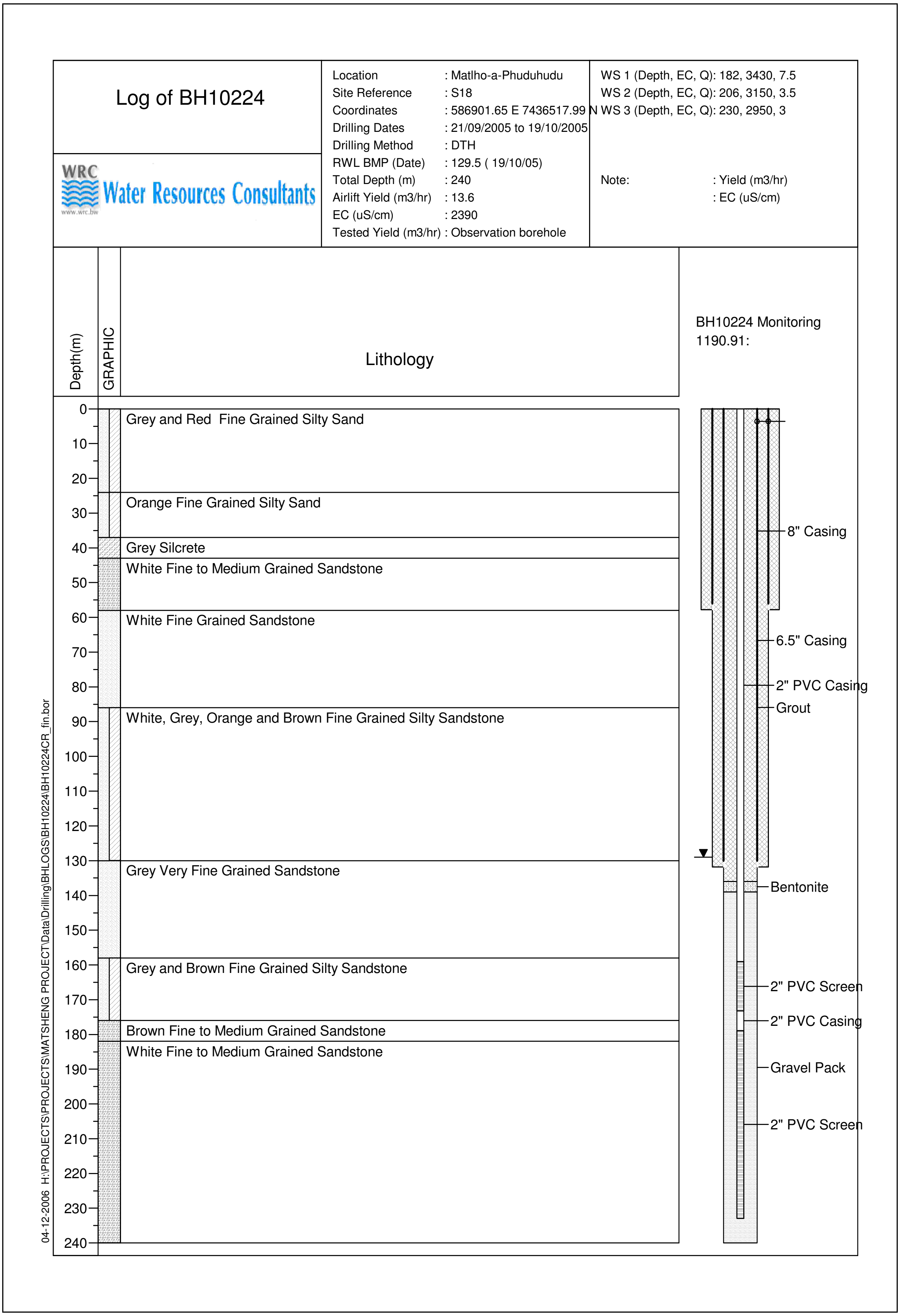

Figure 4-1 Log of BH10224

5 BH9240

BH9240 is an exploration borehole drilled during the Hunhukwe / Lokalane project. It is located in the Matlho-a-Phuduhudu Block, about 190 km east of Ncojane. This borehole was pump tested during the Hunhukwe / Lokalane project at a discharge rate of 30 m^3/hr for 4.2 days and the total drawdown was 10.1m.

During the Matsheng Groundwater Project, an observation borehole, BH10225 was drilled next to BH9240 (about 12.6 m) to allow for the estimation of the Ntane aquifer storativity for input into the numerical model.

5.1 DRILLING RESULTS

This borehole was drilled through various lithologies including fine grained sand, silcrete, siltstones, mudstones and fine to medium grained sandstones (**Figure 5-1**). Drilling was started using a 12 inch drilling bit to a depth of 6.1 m and was changed to an 10inch bit to drill to 83m. An assembly of 10 inch plain casings were installed and grouted to 83 and drilling to the terminal depth of 232m was achieved with an 8 inch bit. The borehole was left open from 83 to 232 m.

During drilling of this borehole, four water strikes were encountered. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows:

1. 167m, 280 µS/cm, 2.85 m^3/h
2. 185m, 440 µS/cm, 3.65 m^3/h
3. 200m, 380 µS/cm, 3.85 m^3/h
4. 208m, 460 µS/cm, 5.25 m^3/h

The final airlift yield after development was 16 m^3/hr with an electrical conductivity of 530 µS/cm and the water level was 134.7 m. This borehole is open hole after installation of 8 inch plain casings to 83m. A summary of the borehole details is in **Figure 5-1**.

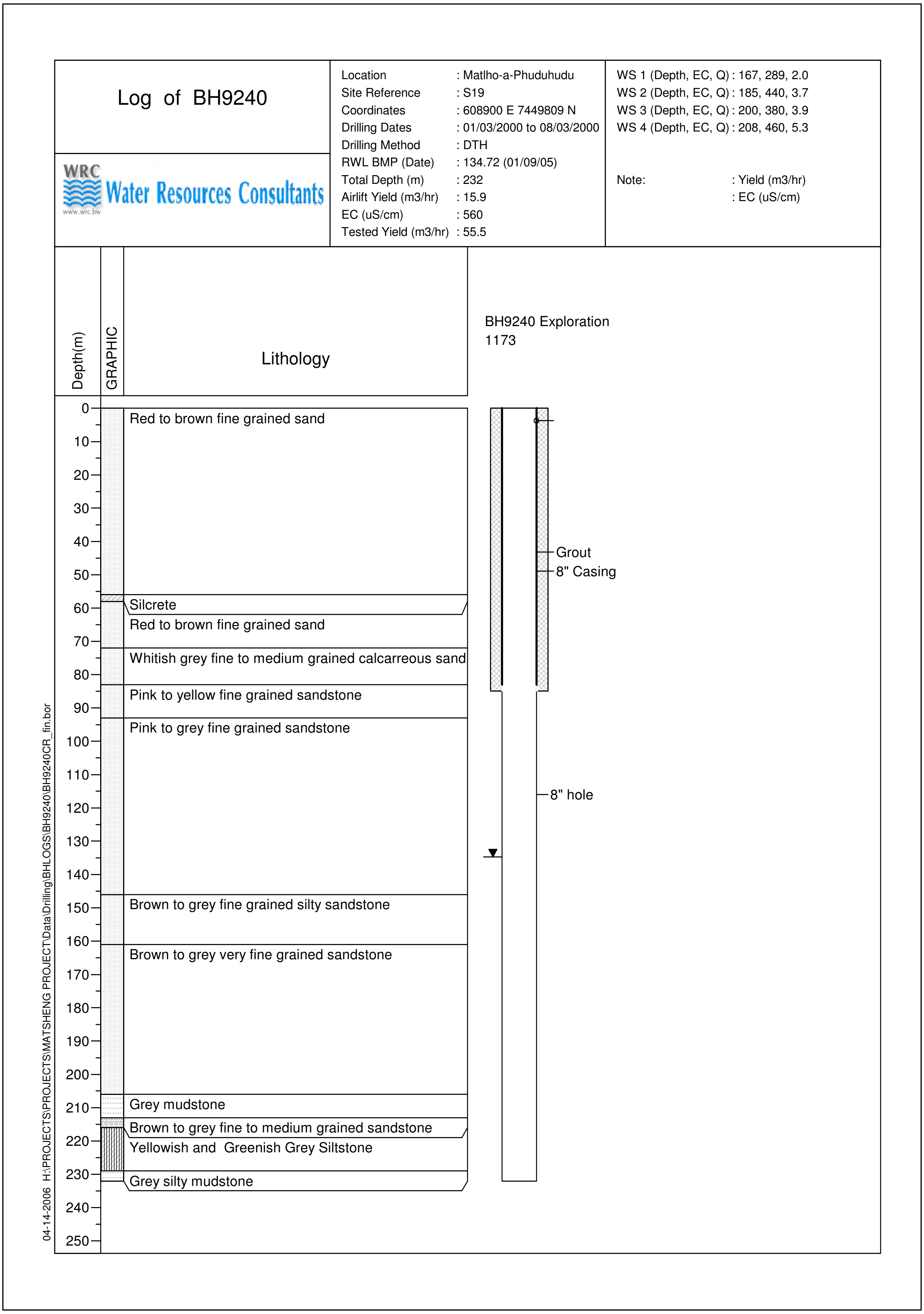

Figure 5-1 Log of BH9240

5.2 PUMP TESTING RESULTS

BH9240 was tested between 1 and 6 November 2005 and the tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.46 m above ground level (agl) and the pump intake was set at 168.5 m below ground level. Summary details for the pumping test activities at BH9240 are given in **Table 5-1**.

Table 5-1 Summary of Pumping Test Data BH9240

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	1.6	10
	2	15	4.2	20
	3	15	5.95	30
	4	15	9.37	45
	5	10	13.94	63
Step Test	1	100	4.23	20
	2	100	7.47	30
	3	100	11.72	40
	4	100	14.69	50
	5	100	18.61	60
Constant Rate	1	2880	17.79	55.5
Recovery*	1	1440	0.15*	0

Note. 0.15* Residual Drawdown

5.2.1 Step Drawdown Test

The step drawdown test (SDT) was carried out on 2 November 2005. The static water level before the start of the test was 134.86 m bmp. The step drawdown test consisted of 5 steps of 100 minutes duration. The discharge rates were 20, 30, 40, 50 and 60 m^3/hr for steps 1 to 5 respectively and the total drawdown at the end of the step drawdown test was 18.61 m.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test data using this method is presented in **Figure 5-2**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 5-3**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 44 m^2/d (**Figure 5-4**). The results of the step test data interpretation are given in **Table 5-2**.

Table 5-2 Results of Step Test Analysis BH9240

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
9240	8.35E-03	1.5E-06	44	20	4.12	4.12	4.85
				30	2.96	7.08	4.24
				40	3.10	10.18	3.93
				50	2.05	12.23	4.09
				60	3.06	15.29	3.92

The planned duration for the constant rate test of this borehole is 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 5-2**) to estimate the expected total drawdown after 5 days of pumping. It was found out that a discharge rate of 55 m^3/hr was ideal for this borehole.

5.2.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 3 and 5 November 2005 at a discharge rate of 55.5 m^3/hr and the total drawdown after 48 hrs of pumping was 17.79 m. The CRT test was followed by a 24 hr recovery monitoring period at the end of which the residual drawdown was 0.15 m. Data from the pumping period was interpreted through the Cooper-Jacob (1946) analytical solution using the computer programme "Aqtesolv" and the transmissivity (T) value obtained was 44 m^2/d. The recovery data was analysed using the Theis recovery solution and the T value obtained was 51 m^2/d. The interpretation results are summarised in **Table 5-3** and the interpreted data is presented in **Figures 5-5** and **5-6**.

Table 5-3 Summary of Constant Rate and Recovery Tests BH9240

BH No.	CRT Duration (hours)	Q (m^3/d)	Pumping borehole T (m^2/d)		Obs. BH No.	Observation borehole			Aquifer type
						Pumping phase		Recovery phase	
			Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
9240	48	1332	b) 44	d) 51	10225	b) 57 c) 45	b) 2.09E-3 c) 2.34E-3	d) 55	Unconfined with delayed Yield

Notes:
Interpretation Techniques
a) Theis
b) Cooper-Jacob
c) Neuman (Unconfined)
d) Theis Modified Recovery

5.2.2.1 Observation Borehole

The water level response was monitored in an observation borehole (BH10225) located 12.60 m away from BH9240 (pumped borehole). This observation borehole is screened between 161.88 to 201.64 m bgl and the total drawdown at the end of the pumping was 9.33 m.

Various analytical solutions (Theis, Cooper-Jacob, Hantush Leaky, Neuman Unconfined) were applied to the pumping test data from this observation borehole using the computer programme "Aqtesolv" and the best fit was obtained based on the Neuman unconfined solution in addition to the standard Cooper-Jacob interpretation. The transmissivity (T) values obtained by these two analytical solutions are 45 and 57 m^2/d respectively while the storativity values were 2.34×10^{-3} and 2.09×10^{-3} respectively. The recovery data was analysed using the Theis recovery method and the T value was obtained as 55 m^2/d. The results are summarised in **Table 5-3** and the interpreted data is presented in **Figures 5-7 to 5-9.**

5.2.2.2 Aquifer Type Interpreted

After evaluation of various analytical solutions and based on the lithological conditions at this site, the pump testing data particularly from the observation borehole (**Figure 5-7**) indicates that aquifer type is unconfined with delayed yield.

5.3 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none acidified) were collected for chemical analysis. Some of the collected samples were submitted to the DWA Lab for basic chemical analysis while other samples were submitted to the CSIR laboratory, Stellenbosch, South Africa for BOS 32:2000 compliance. The results of the DWA laboratory analysis are shown in **Table 5-4** and for the CSIR analysis are shown in **Table 5-5**.

The results from the two analyses show that all the analysed parameters are within the Class II BOS32:2000 standards.
The results from the two analyses show that all the analysed parameters are within the Class II BOS32:2000 standards.

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC) and pH were 27.1 °C, 550 µS/cm and 7.70 respectively.

The results from the two analyses show that all the analysed parameters are within the Class II BOS32:2000 standards.

Table 5-4 Chemistry Results from the DWA Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	HCO_3	NO_3	F	Fe	Mn	EC	pH	TDS
BH9240	6.34	39.08	45.8	20.3	7.41	14.48	297.05	26.63	0.09	0.11	0	560	6.76	300
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in µS/cm
All units are in mg/L except pH, which has no units

Table 5-5 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH9240	5.3	41	47	20	3.9	14	239	7.2	0.14	0.18	<0.05	560	7.9	358
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH9240	<0.1	200	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in µS/cm
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

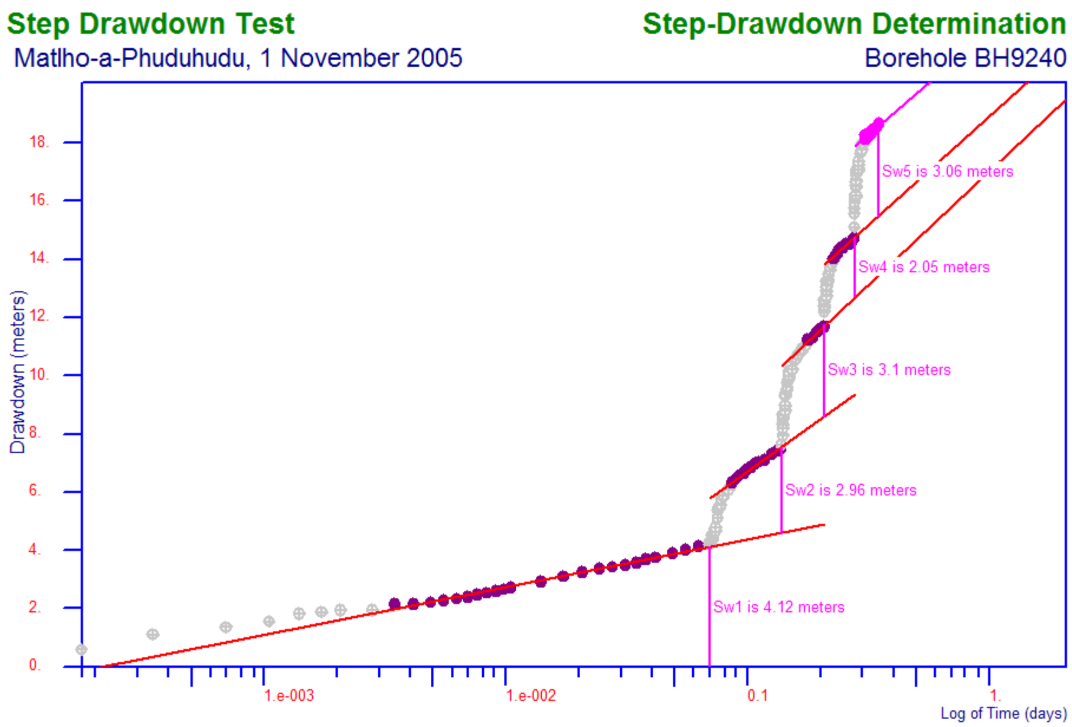

Figure 5-2 Pumping Test Results for BH9240: Step Drawdown Test – Hantush-Bierschenk (semi-log)

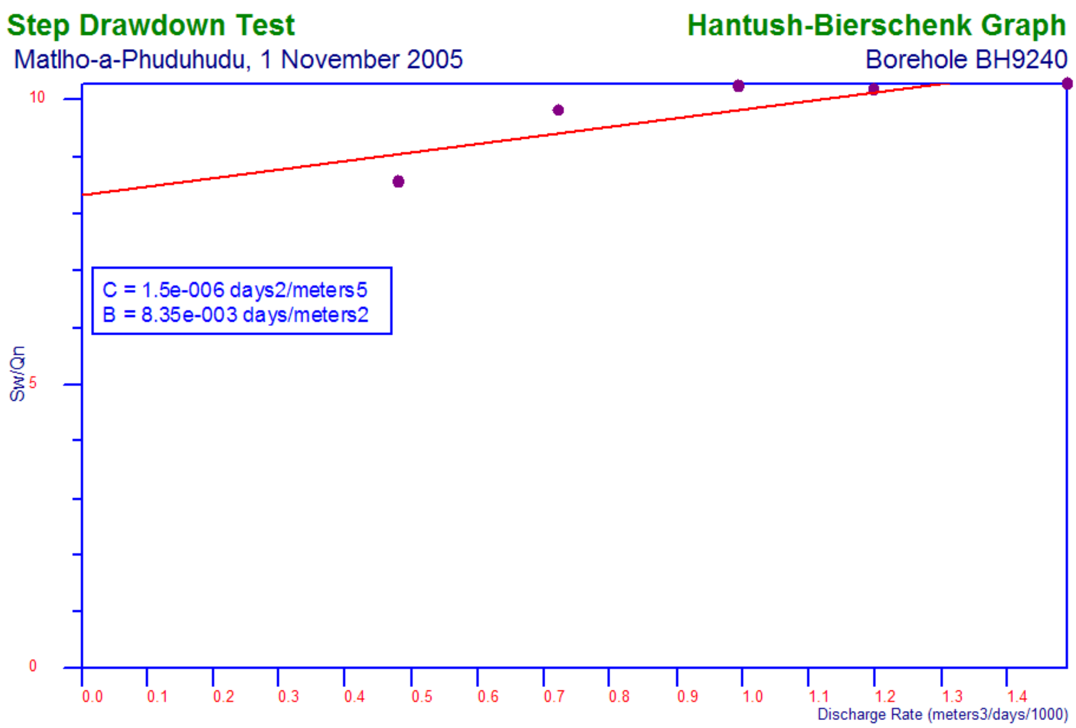

Figure 5-3 Pumping Test Results for BH9240: Step Drawdown Test – Hantush-Bierschenk

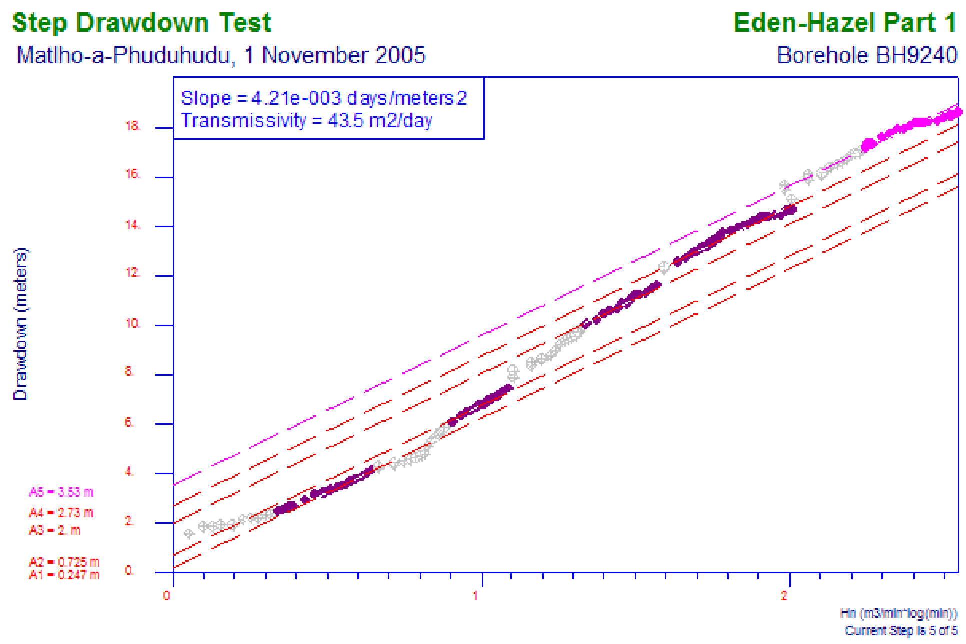

Figure 5-4 Pumping Test Results for BH9240: Step Drawdown Test – Eden-Hazel (Part 1)

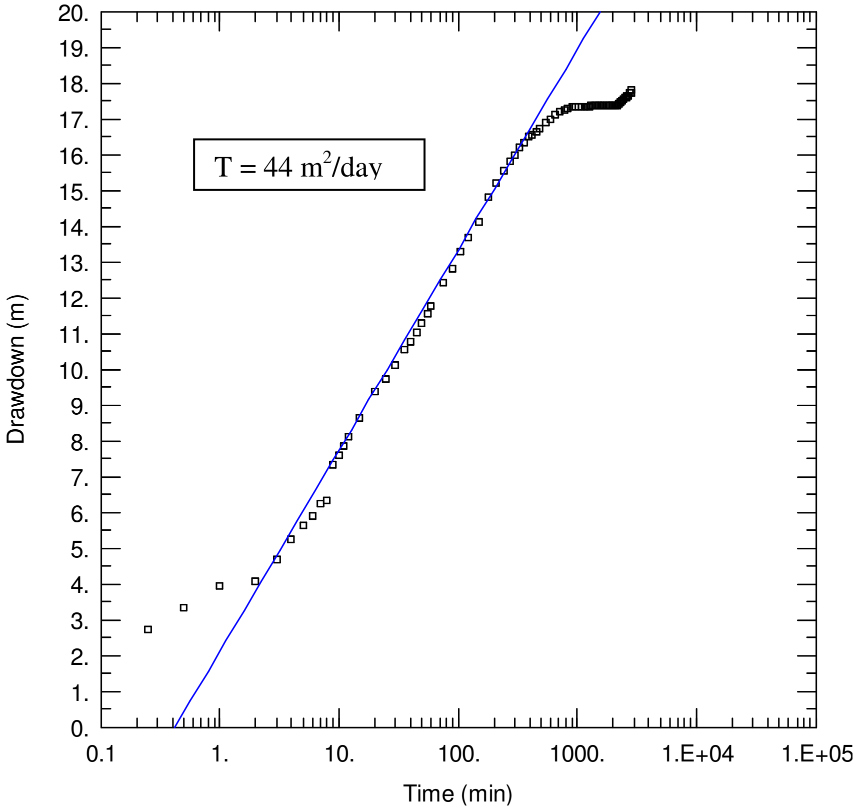

Figure 5-5 Pumping Test Results for BH9240: CRT Cooper- Jacob Solution

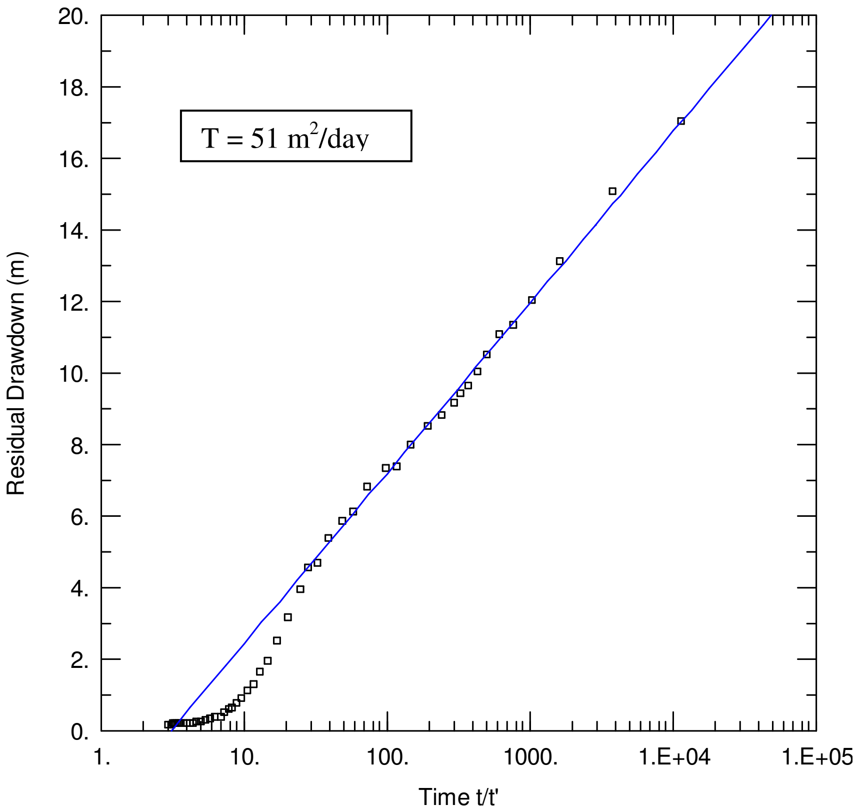

Figure 5-6 Pumping Test Results for BH9240: Theis Recovery Solution

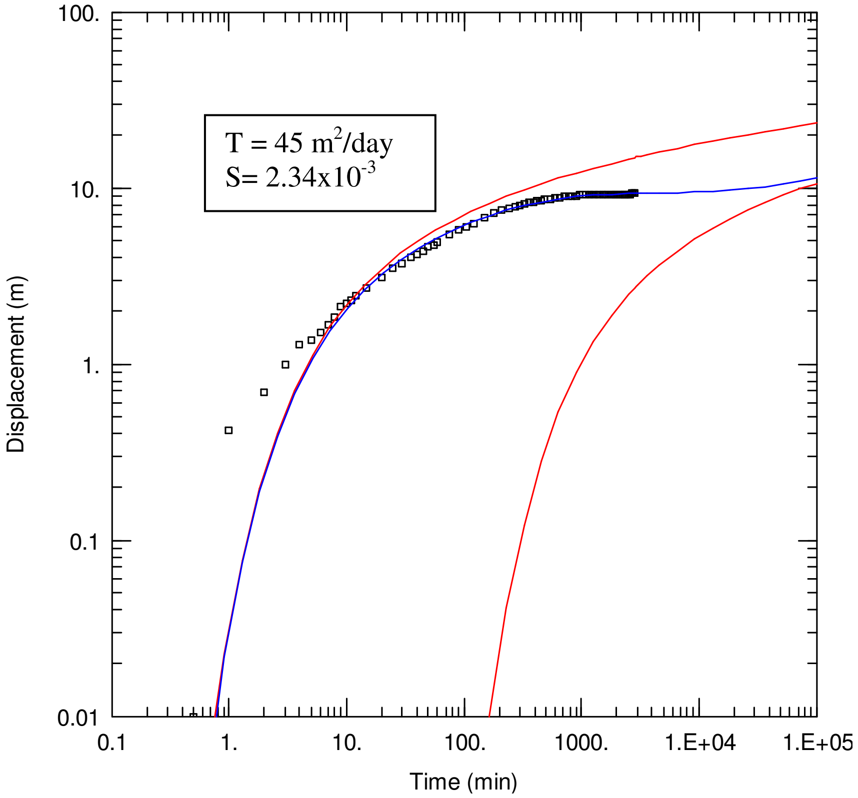

Figure 5-7 Pumping Test Results for BH10225: Neuman (Unconfined) Solution

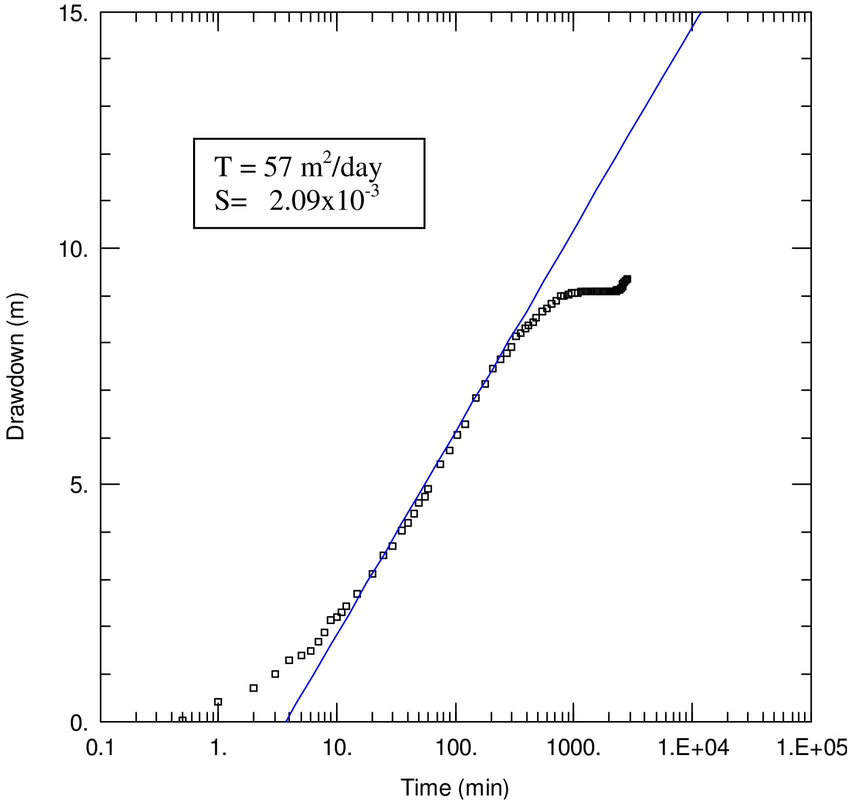

Figure 5-8 Pumping Test Results for BH10225: Cooper-Jacob Solution

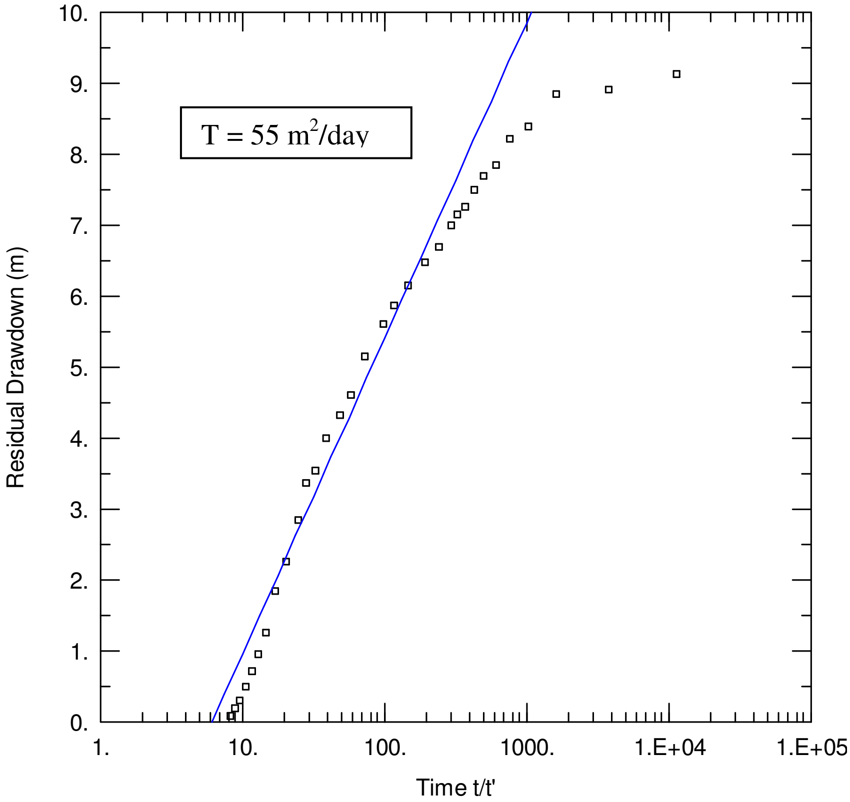

Figure 5-9 Pumping Test Results for BH10225: Theis Recovery Solution

6 BH10225

BH10225 with siting reference of **S19** is an observation piezometer for the existing borehole (BH9240) drilled during the Hunhukwe/ Lokalane Project. This borehole is also at the site of BH10317 drilled during the Matsheng project and completed in the Ecca aquifer. It is located in the Matlho-a-Phuduhudu Block. Drilling at this site commenced on 22 October and was completed on 29 October 2005. The drilled depth of this piezometer is 209m.

6.1 SITING CRITERIA AND DRILLING OBJECTIVES

This piezometer was drilled at the site of existing borehole BH9240 to allow for the estimation of the storativity of the Ntane aquifer. It will also allow for an accurate determination of the hydraulic head difference between the Ntane Sandstone and Ecca aquifers at this locality. It will also allow for comparison of the heads of the Ntane and the Ecca aquifers at the same locality.

6.2 DRILLING RESULTS

The borehole was drilled through various lithologies including fine grained sand, silcrete, calcrete, very fine grained silty sandstone and fine grained sandstones (**Figure 6-1**). Drilling of BH10225 was carried out with a 10 inch drilling bit using the DTH drilling technique down to a depth of 52 m bgl and 8 inch casings were installed at the same time as drilling to 52 m because of collapsing problems. Drilling was continued to a depth of 124m using an 8 inch bit. 6.5 inch plain casings were installed to a depth of 124m and cement grouted. Drilling to the terminal depth of 209 m was carried out using a 6.5 inch drilling bit.

During drilling of this borehole, two water strikes were encountered. The depths, conductivities and yields (measured on a 90^O V-notch weir) for the two water strikes are as follows;

1. (168m, 626 µS/cm, 4.14m^3/hr)
2. (182m, 560 µS/cm, 4.5 m^3/hr)

Water samples were collected at both water strikes for basic chemical analysis and were to the DWA lab. The results are presented in **Table 6-1.**

Table 6-1 Drilling Chemistry results (DWA)

BHNo	Depth	pH	TDS	Ca	Mg	Na	K	Cl	SO_4	NO_3	F	CO_3	HCO_3	Mn	Fe
10225	170	7.85	296	52.86	22.24	39.26	7.48	14.82	8.89	32.11	0	0	301.77	0	0.09
10225	209	7.79	280	25.1	12.3	68.6	7.68	14.39	8.79	27.45	0.17	0	268.24	0	0.1
BOS 32:2000 Class II		5.5-9.5	1000	150	70	200	50	200	250	45	1	200	250	1	3
BOS 32:2000 Class III		5.0 - 10.0	2000	200	100	400	100	600	400	45	1.5	600	400	5	20

Note: Parameters in mg/l

This borehole was constructed as a piezometer utilising 2 inch PVC casings and screens. Plain casings were installed between 0 to 161.88m and 201.64 to 204.48m while the screens were installed between 161.88 and 201.64m, representing a zone of 39.76m. The annulus between the PVC casing and the 6.5 inch hole was gravel packed from 209 to a depth of 135 m and a 3m bentonite seal was installed between 135 and 138m. The rest of the annular space was cement grouted to the surface and the piezometer was developed using the air lifting method. The final yield and electrical conductivity after development were 9 m^3/hr and 550 µS/cm respectively. The water level was measures as 133.81 m bgl on 29 October 2005.

The borehole details are summarised in **Figure 6-1.**

6.2.1 Pump Testing Results

This borehole was used as an observation borehole during pump testing of BH9240 and the pump testing results are discussed in chapter 5.

6.2.2 Comparison of Hydraulic heads

From the water levels data, the head of the Ntane aquifer (BH9240 andBH10225) is higher than that of the Ecca aquifer (BH10317). There is therefore the likelihood that the Ntane aquifer can recharge the Ecca.

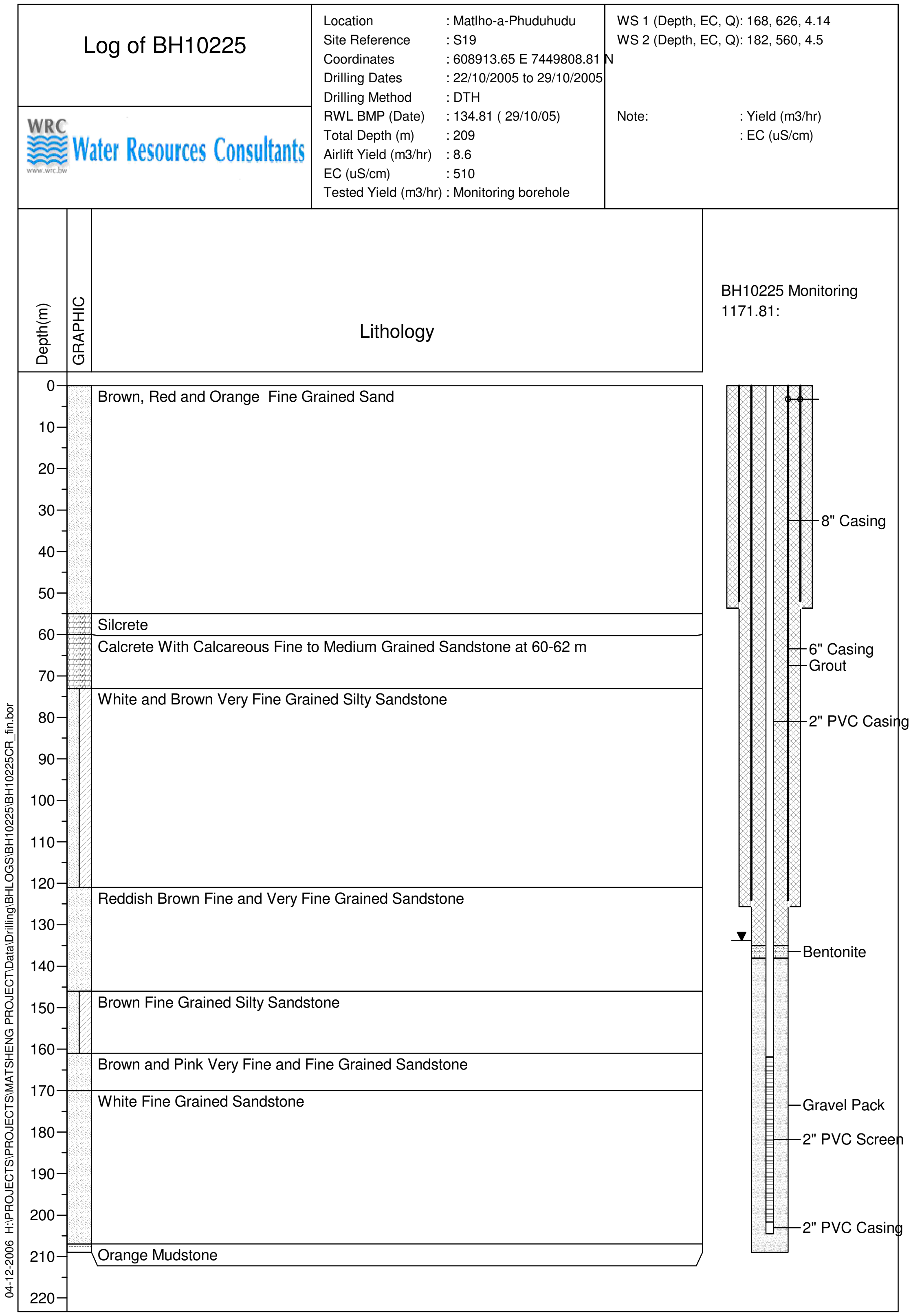

Figure 6-1 Log of BH10225

7 BH10317

BH10317 with siting reference of **S19** is a monitoring borehole (piezometer) drilled at the site of existing borehole BH9240 drilled during the Hunhukwe / Lokalane Project. It is also at the site of BH10225 drilled during the Matsheng Project. It is located in the Matlho-a-Phuduhudu Block. This borehole was drilled between 31 January and 28 February 2006.

7.1 SITING CRITERIA AND DRILLING OBJECTIVES

This monitoring borehole is drilled to explore the Ecca aquifer at this locality. It will also provide accurate groundwater head data and allow for comparison of the Ecca and Ntane (BH9240 and BH10225) heads at the same locality.

7.2 DRILLING RESULTS

Various lithologies including fine to medium grained sands, silcrete, fine grained sandstone, mudstones, siltstones, fine to course grained micaceous sandstones and dolerite were intercepted during drilling of this borehole (**Figure 7-1**). Drilling was carried out with a 10 inch bit using the DTH drilling technique from 0 to 131 m bgl and 8 inch plain casings were installed and cement grouted. From 131 to 256 m, drilling was carried out using an 8 inch drilling bit and a 6.5 inch bit was used to drill from 256 to 311m. A 6.25 inch tri-cone bit was used to drill from 311m to the terminal depth of 349m.

During drilling of this borehole, five water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the four water strikes are as follows;

1. (170m, 5940 µS/cm, 2.86 m^3/hr)
2. (181m, 6950 µS/cm, 7.7 m^3/hr)
3. (199m, 2850 µS/cm, 12.31 m^3/hr)
4. (307m, 1330 µS/cm, 12.65 m^3/hr)
5. (328m, 2840 µS/cm, 30.98 m^3/hr)

Water samples were collected at different water strikes and after borehole development. The samples collected were submitted to the DWA laboratory for chemical analysis and the laboratory analysis are presented in **Table 7-1**. The top three water strikes were sealed off to allow further drilling into the Ecca aquifer and the cumulative yield at the end of drilling before installation of the casing and screens assembly was 30.98 m^3/hr.

able 7-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10317	170	7.64	322	34.08	27.79	36.49	6.48	15.37	6.34	35.42	0	0	271.05	0.25	4.66	Ntane
10317	181	7.26	306	43.05	17.63	54.04	6.15	12.44	5.12	9.13	0	0	318.59	0.08	2.78	Ntane
10317	199	7.07	356	33.01	11.78	64.45	4.73	17.66	7.79	21.43	0		266.57	0.03	3.30	Ntane
10317	307	7.78	1504	15.35	5.26	612.2	4.535	389.87	328.99	0	0	0	711.98	0.78	16.12	SST 1
10317	328	7.67	1694	24.90	6.36	661.4	4.595	498.26	366.47	0	0	0	746.12	0.00	6.70	SST1
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

The borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 349m, **Figure 7-2**. The borehole assembly was constructed using 2 inch PVC casings and screens. The 2.4 inch plain casings were installed between 0 to 321.55 m and 324.3 to 327 m while the screens were between 321.55 to 324.30m.

The static water level measured on 6 March 2006 was 144.37 m bgl. The borehole was capped and a cement slab was constructed. The borehole details are summarised in **Figure 7-1**.

7.2.1 Pump Testing Results

This borehole was drilled after the pump testing of BH9240 and as such was not used as an observation borehole.

7.2.2 Comparison of Hydraulic heads

From the water levels data, the head of the Ntane aquifer (BH9240 and BH10225) is higher than that of the Ecca aquifer (BH10317). There is therefore the likelihood that the Ntane aquifer can recharge the Ecca.

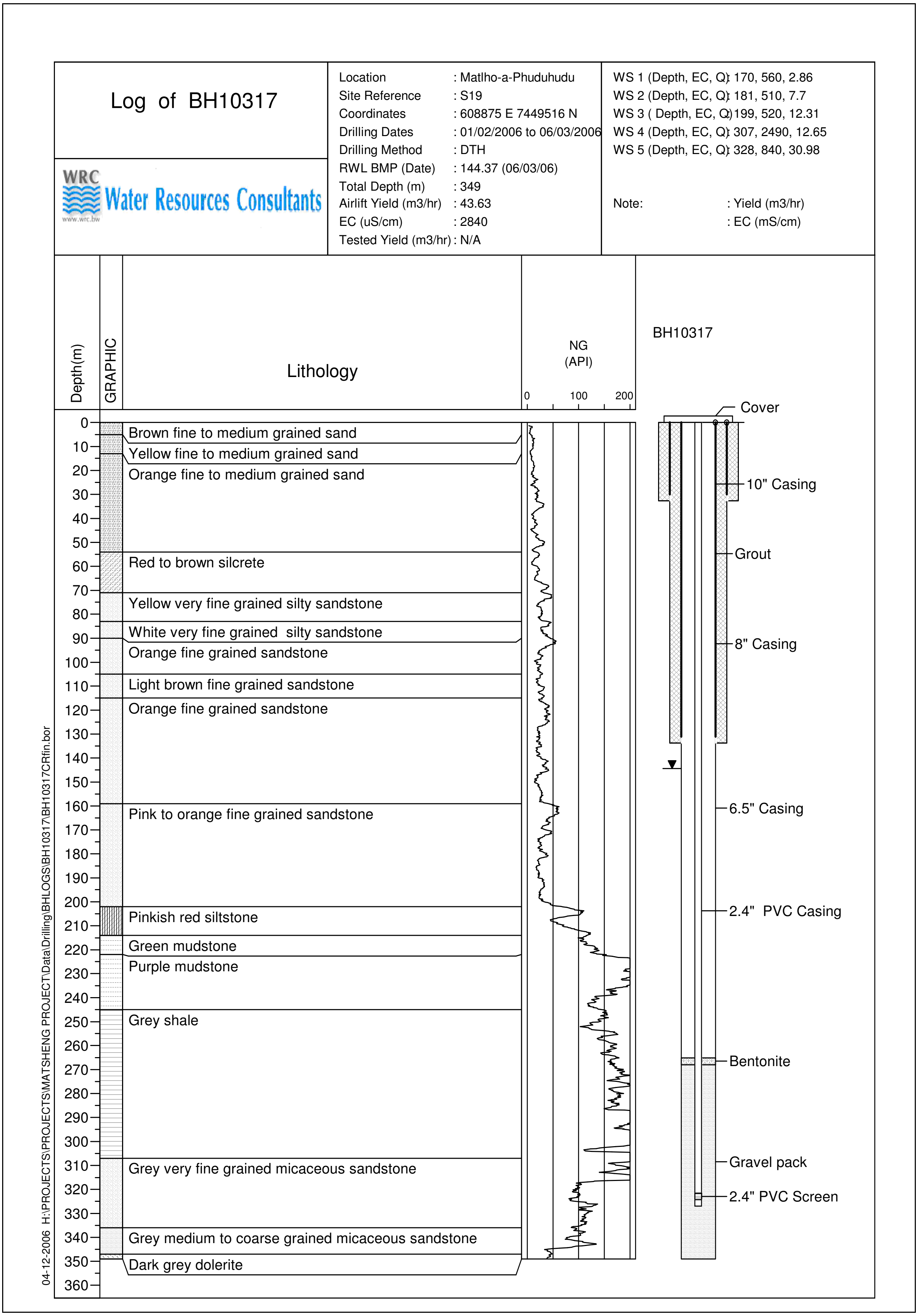

Figure 7-1 Log of BH10317

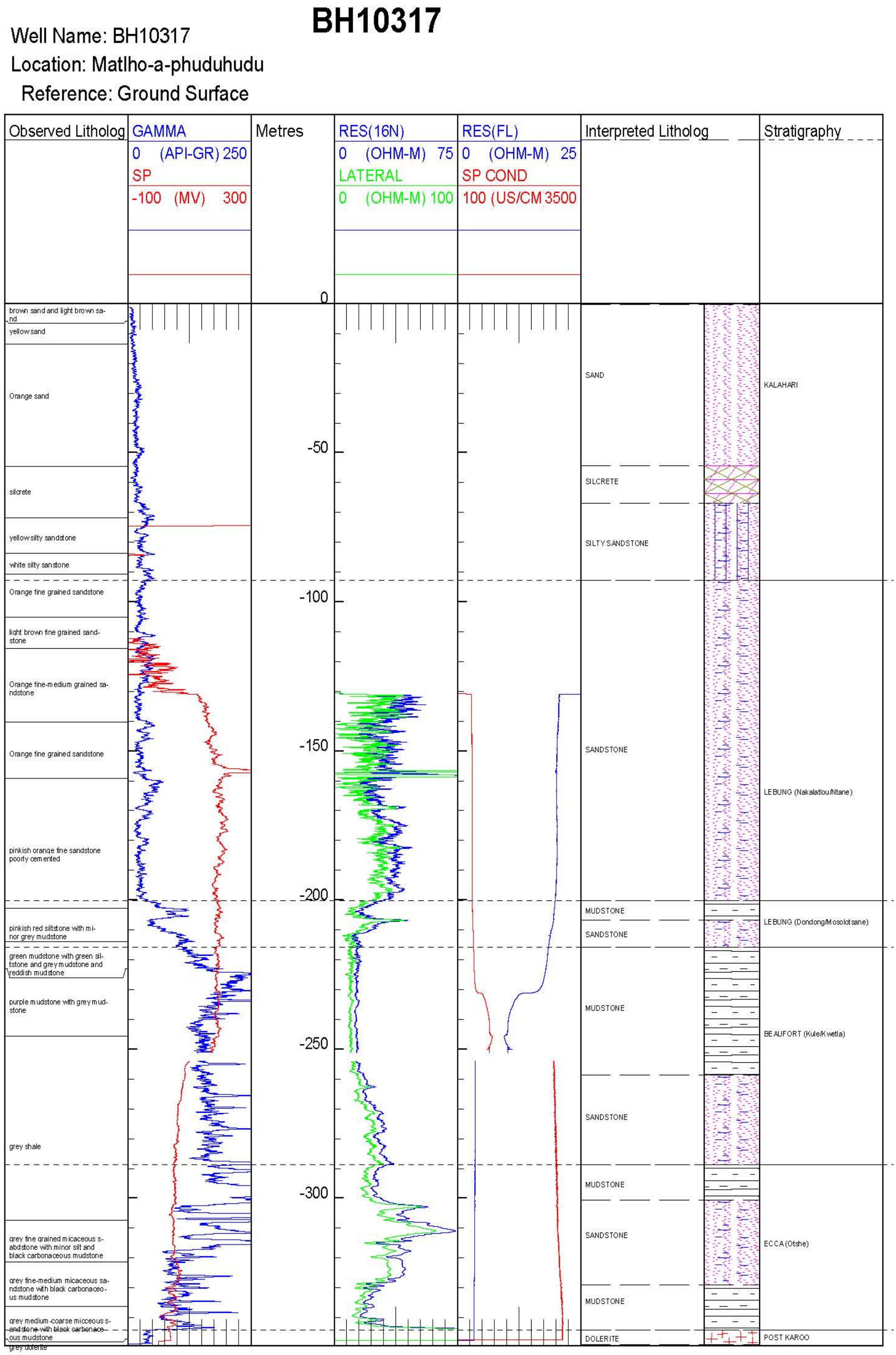

Figure 7-2 Geophysical log of BH10317

8 BH9293

Borehole BH9293 with siting reference of **S16** is an existing borehole which was drilled during the Hunhukwe / Lokalane project. It is located in the Matlho-a-Phuduhudu Block, and is about 110km east of Ncojane. The borehole was drilled to the terminal depth of 167m in the Kule Mudstone Formation. This borehole is cased with 8 inch plain casing to a depth of 66 m and left open hole to the bottom. During the Matsheng Project, this borehole was deepened from 167m to 284m.

8.1 SITING CRITERIA AND DRILLING OBJECTIVES

The existing TEM from Hunhukwe / Lokalane project showed that BH9293 was stopped before it intercepted the Ecca sandstones. This borehole was planned to be deepened to a depth of 420m to explore the Ecca aquifer. This borehole will also allow for measuring the head of the Ecca aquifer at this locality and to determine the yield potential.

8.2 DRILLING RESULTS

This borehole was drilled through various lithologies including fine grained sand, silcrete, conglomerate, mudstones, fine to medium grained sandstones and dolerite (**Figure 8-1**). Drilling was started using a 10 inch drilling bit to a depth of 66 m and 8 inch plain casings were cement grouted into place. Drilling was continued to a depth 167m using 8 inch bit.

The borehole was cleaned in the depth zone 147 to 167 m where it was found to have collapsed. Drilling was then carried out from 167 to 284 m with an 8 inch drilling bit. The borehole was drilled through mudstones from 167 m to 239 m where a dolerite sill was intercepted. Drilling was stopped at a depth of 284m in dolerite. It was realised that the dolerite sills have very similar resistivities to the Ecca sandstone and hence borehole was terminating at 284m after re-interpretation of the TEM data for BH9293 indicated that the dolerite is continuous to a depth of 400m.

There were no water strikes encountered during drilling of BH9293 and the borehole was capped. The borehole details are shown in **Figure 8-1.**

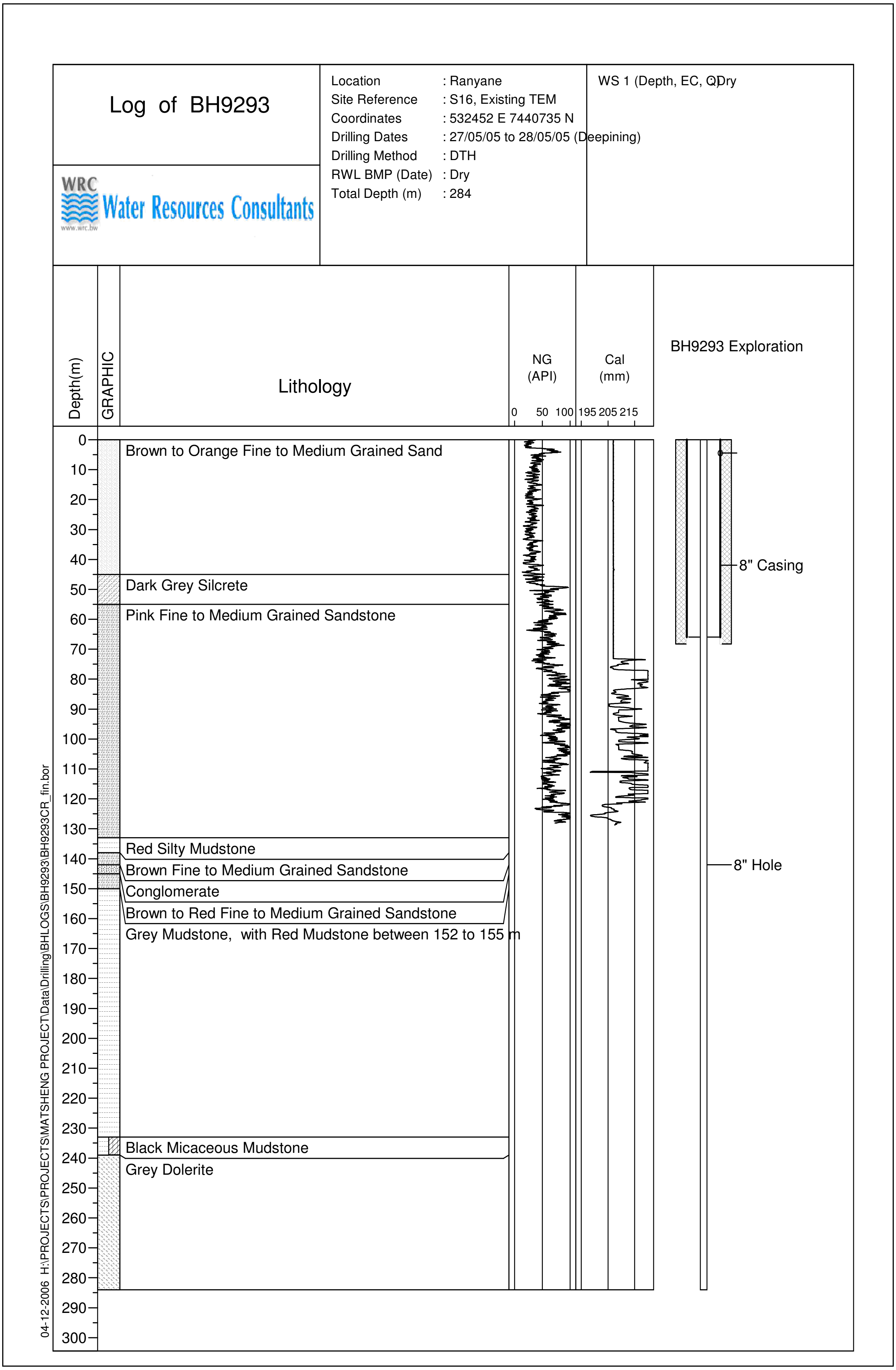

Figure 8-1 Log of BH9293

9 BH9295

BH9295 is an exploration borehole drilled during the Hunhukwe / Lokalane project. It is located about 80 km from Ncojane on the road from Metsimantsho to Ncaang. This borehole was pump tested during the Hunhukwe / Lokalane project at a discharge rate of 53 m^3/h for 7 days and it had a total drawdown of 4.75m.

During the Matsheng Groundwater Project, a monitoring piezometer BH10220 was drilled next to BH9295 to allow for the estimation of the Ecca aquifer storativity and for accurate hydraulic head measurement of the Ecca aquifer.

9.1 DRILLING RESULTS

This borehole was drilled through various lithologies including fine grained sand, shales and fine, grained sandstones. Drilling was started using a 15 inch drilling bit to a depth of 70 m after which a 10 inch casing was installed. Drilling was continued to the terminal depth of 232m using a 12 inch drilling bit.

During drilling of this borehole, three water strikes were encountered. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows:

1. 140m, Unmeasurable
2. 160m, 1000 µS/cm, 6.5 m^3/h
3. 215m, 510 µS/cm, 44.5 m^3/h

The borehole was constructed using 8 inch plain and slotted casings. The plain casings were installed between 0 to 160 m, 195 to 211m and 223 m to 232 m and the slotted zones were between 160 m to 195m and 211 to 223m. After construction and development, the final airlift yield was 12 m^3/hr whilst the electrical conductivity was 1670 µS/cm and the water level was 102.72 m.

The borehole summary and lithology are presented in **Figure 9-1**.

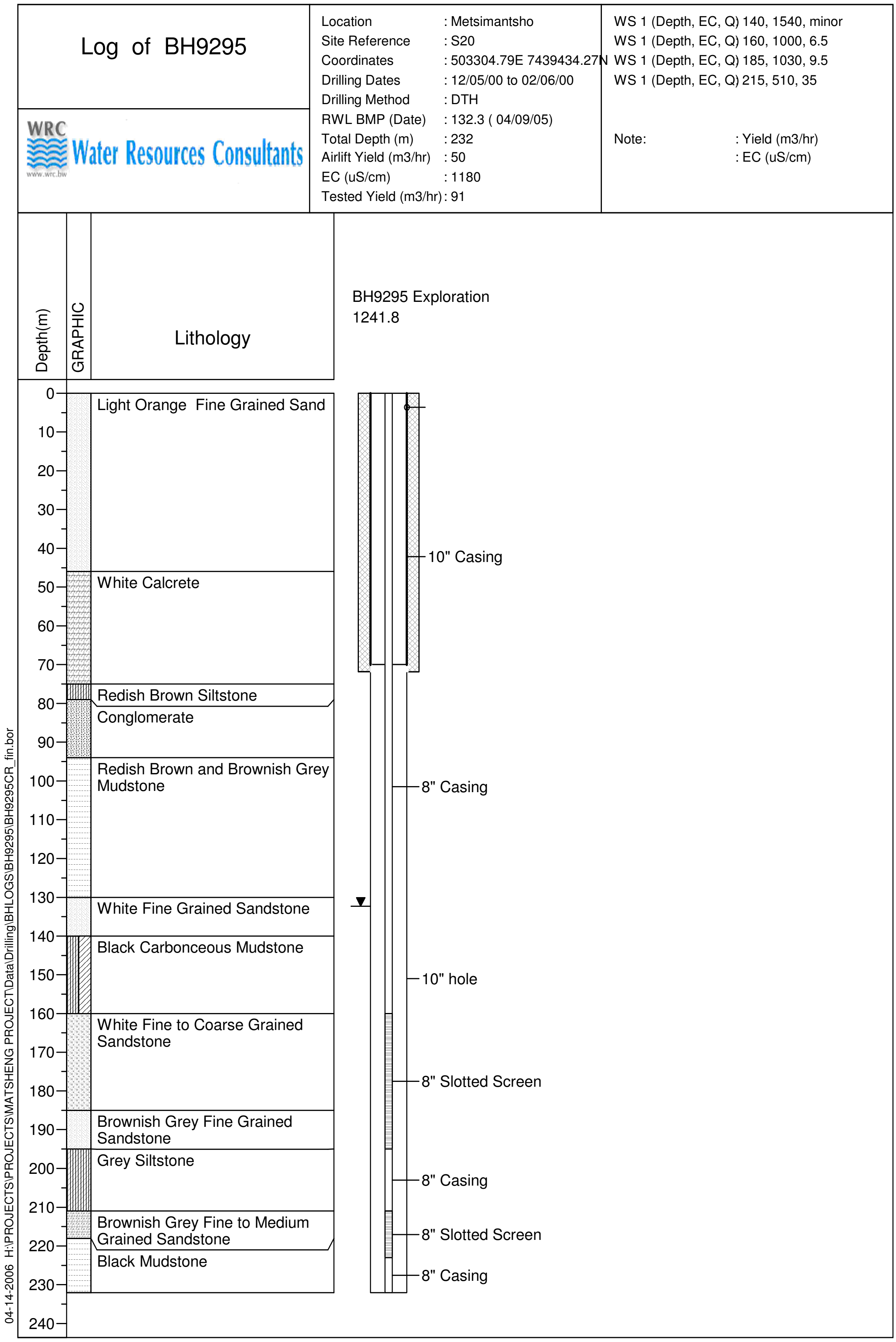

Figure 9-1 Log of BH9295

9.2 PUMP TESTING RESULTS

Borehole BH9295 was tested between 12 and 24 September 2005. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.59 m agl and the pump intake was set at 155 m bmp. The summary results for the pumping test activities are given in **Table 9-1.**

Table 9-1 Summary of Pumping Test Data BH9295

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	2.23	25
	2	15	3.94	51
	3	15	5.28	73
	4	10	7.36	100
Step Test	1	100	3.68	43
	2	100	5.35	65
	3	100	6.43	80
	4	100	8.14	102
Constant Rate	1	12720	8.62	91
Recovery	1	1440	1.08	0

9.2.1 Step Drawdown Test

The step test was carried out on 13 September 2005. The static water level before the start of the test was 132.75 m bmp. The step drawdown test consisted of 4 steps of 100 minutes duration. The discharge rates were 43, 65, 80 and 102 m^3/hr for steps 1 to 4 respectively.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test data using this method is presented in **Figure 9-2**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 9-3**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 44 m^2/d, (**Figure 9-4**). The results of the step test data interpretation are given in **Table 9-2**.

The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 427 m^2/d. The results are tabulated in **Table 9-2**.

Table 9-2 Results of Step Test Analysis

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
9295	3.82E-02	-2.82E-07	427	43	3.65	3.65	11.78
				65	1.66	5.31	12.24
				80	0.868	6.178	12.95
				102	1.56	7.738	13.18

9.2.2 Constant Rate and Recovery Tests

The constant rate test was carried out between 14 and 23 September 2005 at a discharge rate of 91 m^3/hr. The duration of the CRT was planned to be 10080 minutes, but there was a problem with the pump after 12720 minutes of pumping. This was followed by recovery monitoring for 24 hrs. The Theis (1935) and the Cooper-Jacob (1946) analytical solutions were used to interpret the data using the computer programme "Aqtesolv". The calculated transmissivity (T) values are 416 and 400 m^2/d. The recovery data was analysed using the Theis recovery solution using the computer programme

"Aqtesolv". The calculated T value is 440 m^2/d. These results are summarised in **Table 9-3** and the interpreted data is presented in **Figures 9-5 to 9-7**.

Table 9-3 Summary of Constant Rate and Recovery Tests Results.

BH No.	CRT Duration (hours)	Q (m^3/d)	Pumping borehole T (m^2/d)		Obs. BH No.	Observation borehole Pumping phase		Observation borehole Recovery phase	Aquifer type
			Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
9295	212	2184	a) 416 b) 400	d) 440	10220	a) 399 b) 440	a) 9.2E-4 b) 6.2E-4	d) 398	Confined

Notes:
Interpretation Techniques
- *a) Theis*
- *b) Cooper-Jacob*
- *c) Hantush Leaky (with no aquitard storage)*
- *d) Theis Modified Recovery*

9.2.2.1 Observation Borehole

The observation piezometer, BH10220 is located 10.2m from the pumping borehole was monitored during testing of BH9295. This piezometer is screened between 155.11 – 194.81 m and 211.82 – 223.15 m bgl. The total drawdown at the end of pumping was 5.1 m.

The pump testing data was interpreted using the Theis (1935) and the Cooper-Jacob (1946) analytical solutions in the computer programme "Aqtesolv". The transmissivity (T) values obtained by these two analytical solutions are 399 and 440 m^2/d respectively while the storativity values were $9.2x10^{-4}$ and $6.2\ x10^{-4}$ respectively. The recovery data was analysed using the Theis recovery method and the T value was obtained 398m^2/d. The results are summarised in **Table 9-3** and the interpreted data is presented in **Figures 9-8 to 9-10.**

9.2.2.2 Aquifer Type Interpreted

The interpretation of the pump testing data indicates that the aquifer type is confined.

9.3 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. The samples collected during the test were submitted to the DWA laboratory in Gaborone.

The well head chemistry at the end of pumping for temperature, EC and pH were 25.4 ^oC, 1020 µS/cm and 7.94 respectively. The lab analyses for the water samples collected at the end of the test are shown in **Table 9-4**. This result shows that for the analysed parameters, sodium and fluoride exceeds the BOS32:2000 standards and so the water has to be treated before it can be safe for human consumption. These parameters are highlighted in grey in **Table 9-4**. The fluoride content also exceeds the Class III standards, the maximum permissible level for potable water.

Table 9-4 Chemistry Results from the DWA Laboratory.

	K	Na	Ca	Mg	SO_4	Cl	HCO_3 (Calc)	NO_3	F	Fe	Mn	EC	pH	TDS
BH9295	43.4	242.6	16.2	17.05	48.4	71.7	595.17	0	1.78	0.04	0	1180	7.22	676
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 *is calculated from alkalinity*

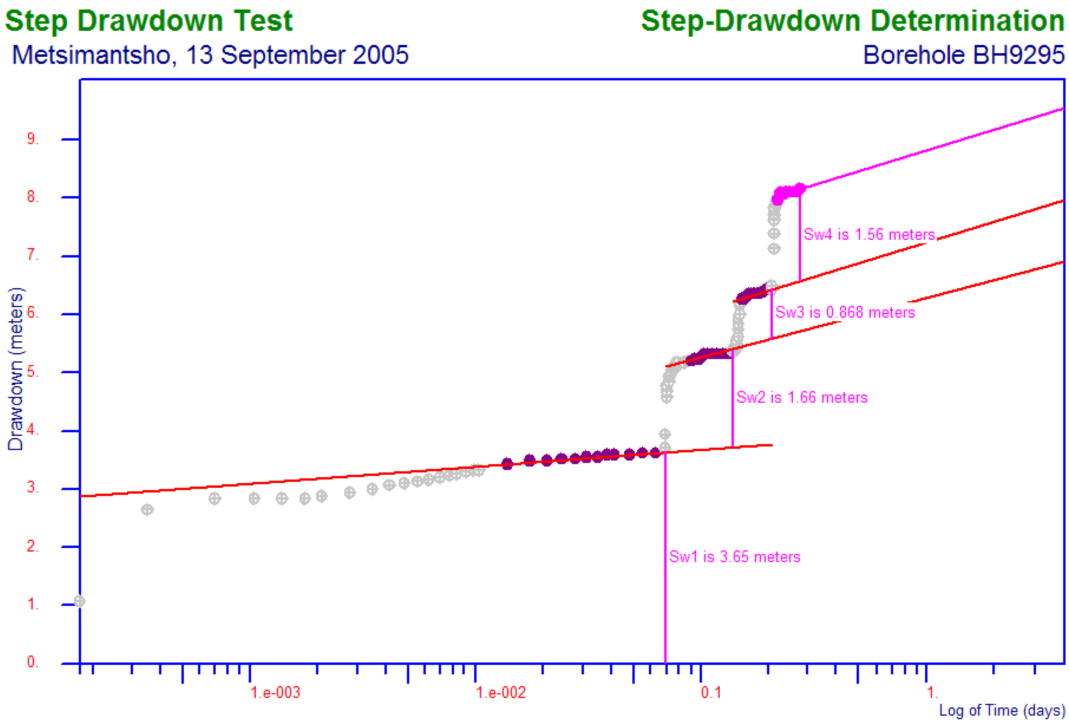

Figure 9-2 Pumping Test Results for BH9295: Step Drawdown Test – Hantush-Bierschenk (semi-log)

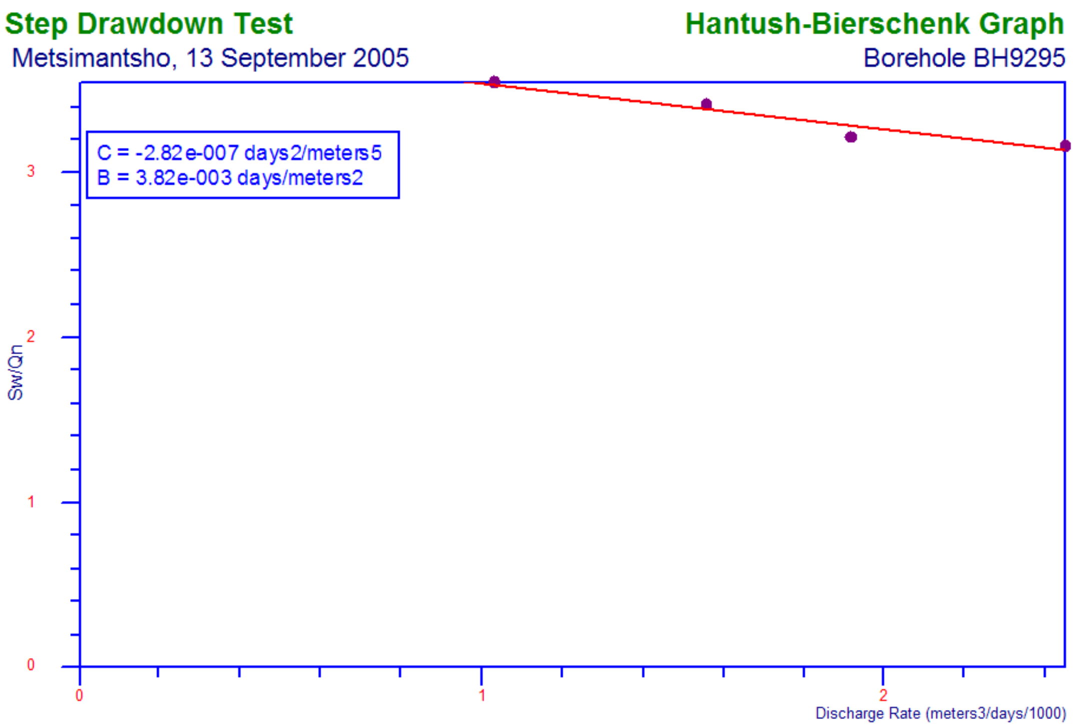

Figure 9-3 Pumping Test Results for BH9295: Step Drawdown Test – Hantush-Bierschenk

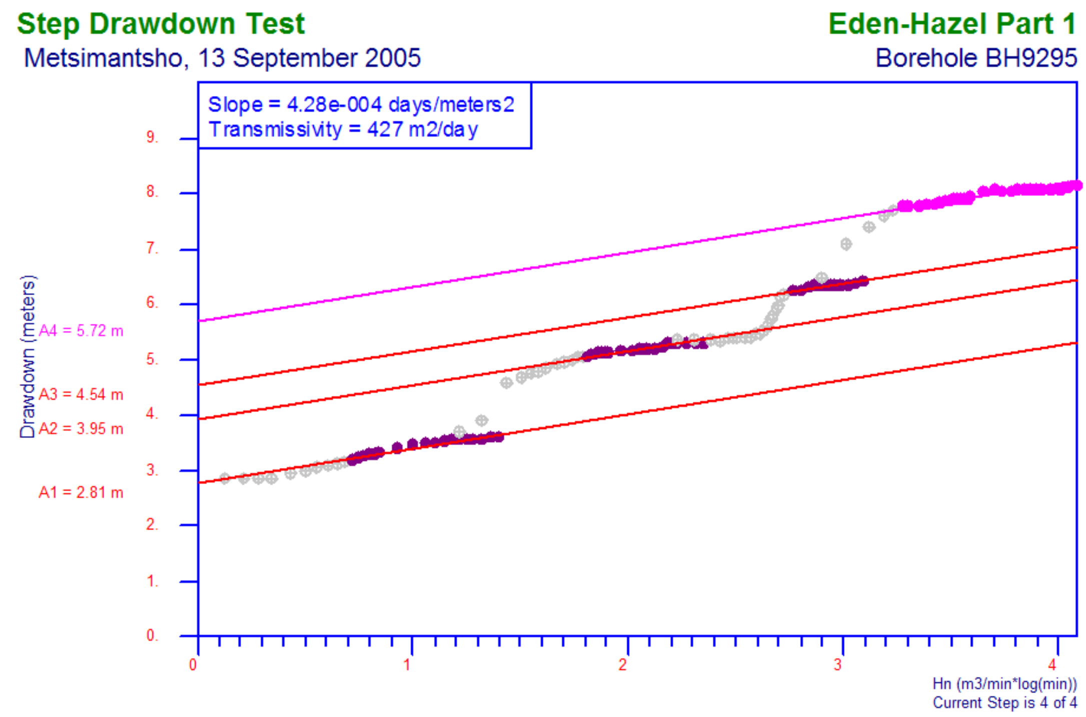

Figure 9-4 Pumping Test Results for BH9295: Step Drawdown Test – Eden-Hazel (Part 1)

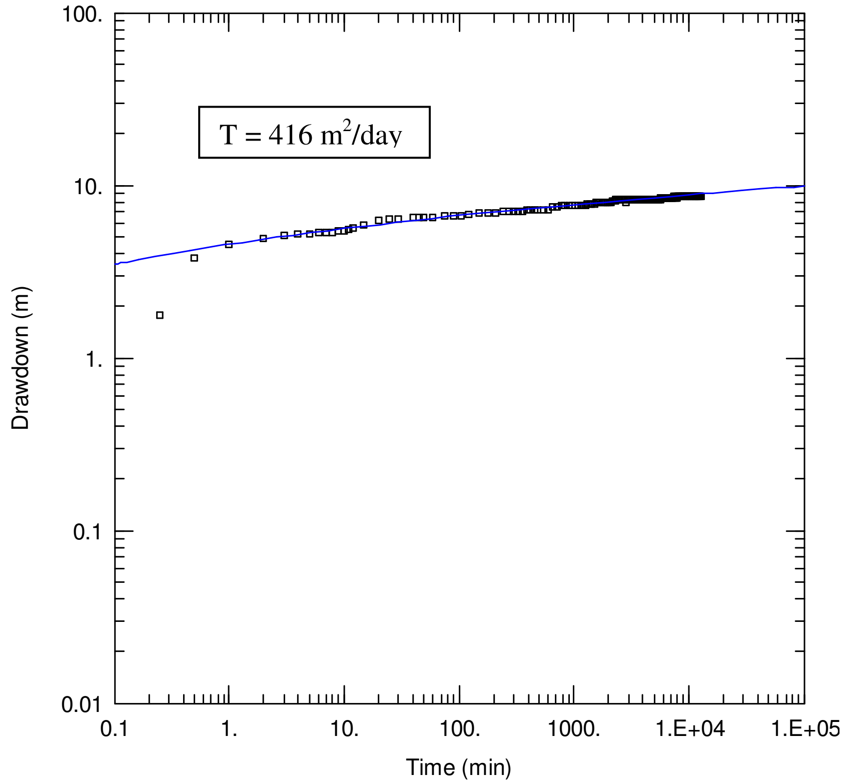

Figure 9-5 Pumping Test Results for BH9295: CRT Theis Solution

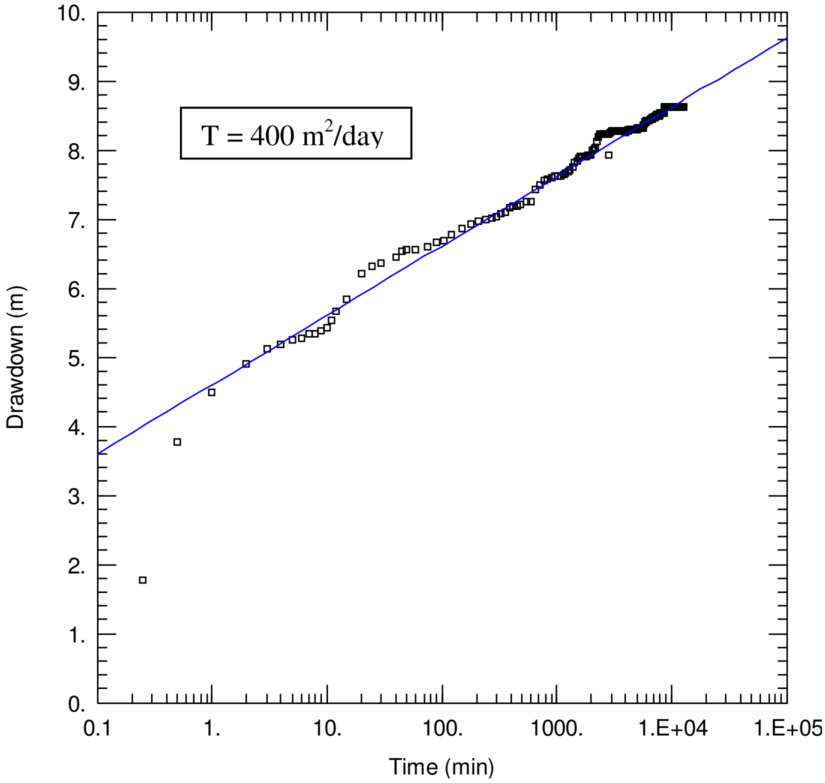

Figure 9-6 Pumping Test Results for BH9295: CRT Cooper Jacob Solution

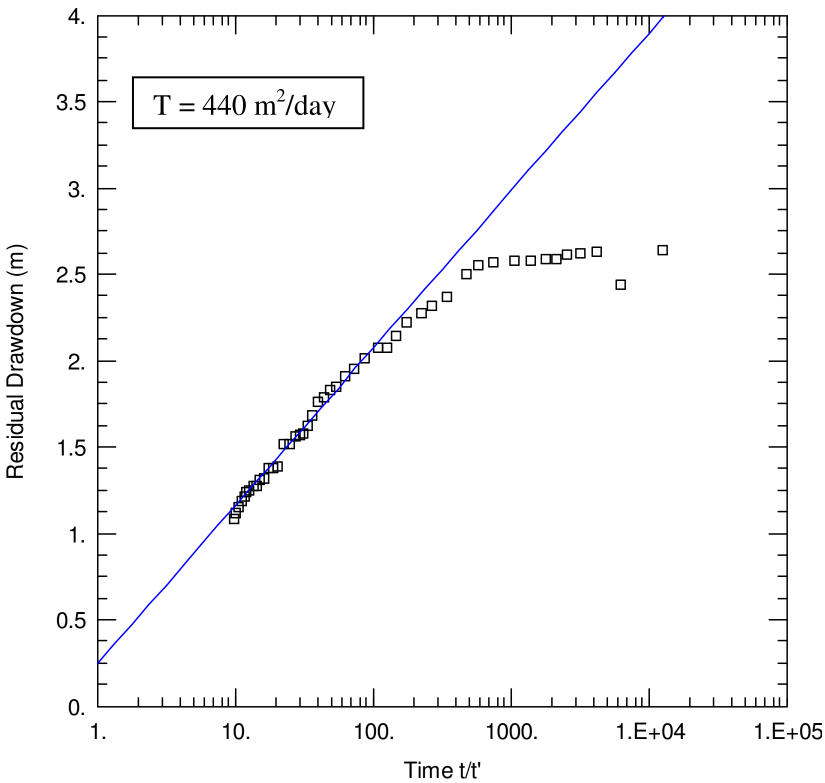

Figure 9-7 Pumping Test Results for BH9295: Theis Recovery Solution

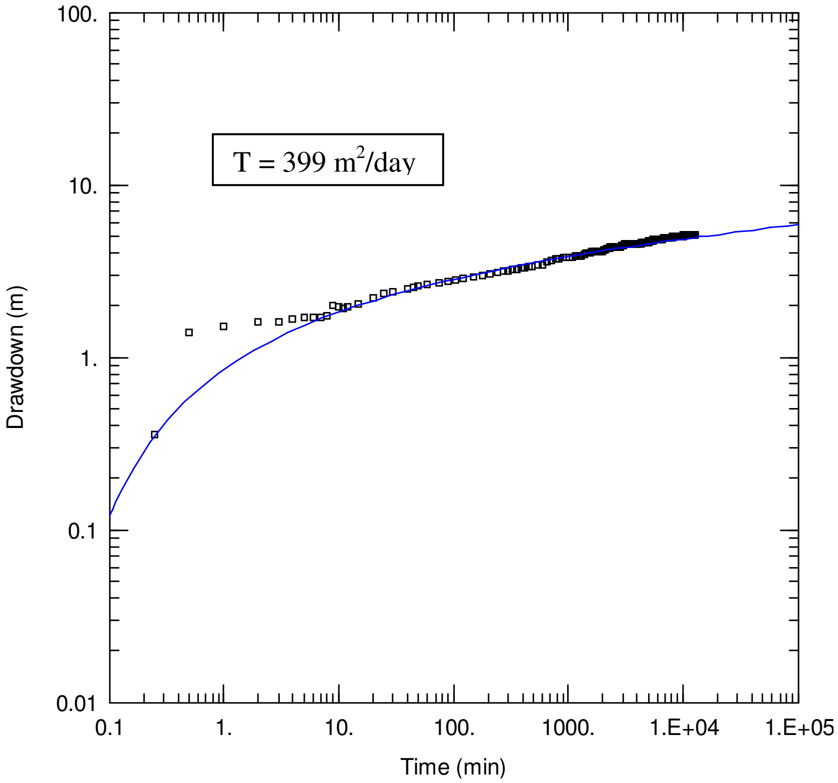

Figure 9-8 Pumping Test Results for BH10220: CRT Theis Solution

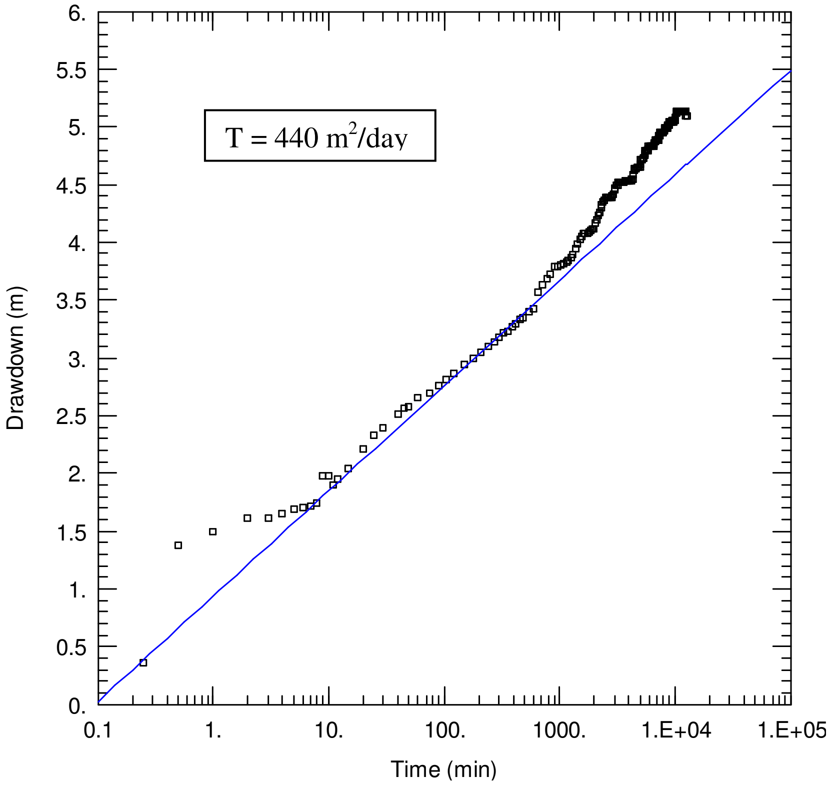

Figure 9-9 Pumping Test Results for BH10220: CRT Cooper-Jacob Solution

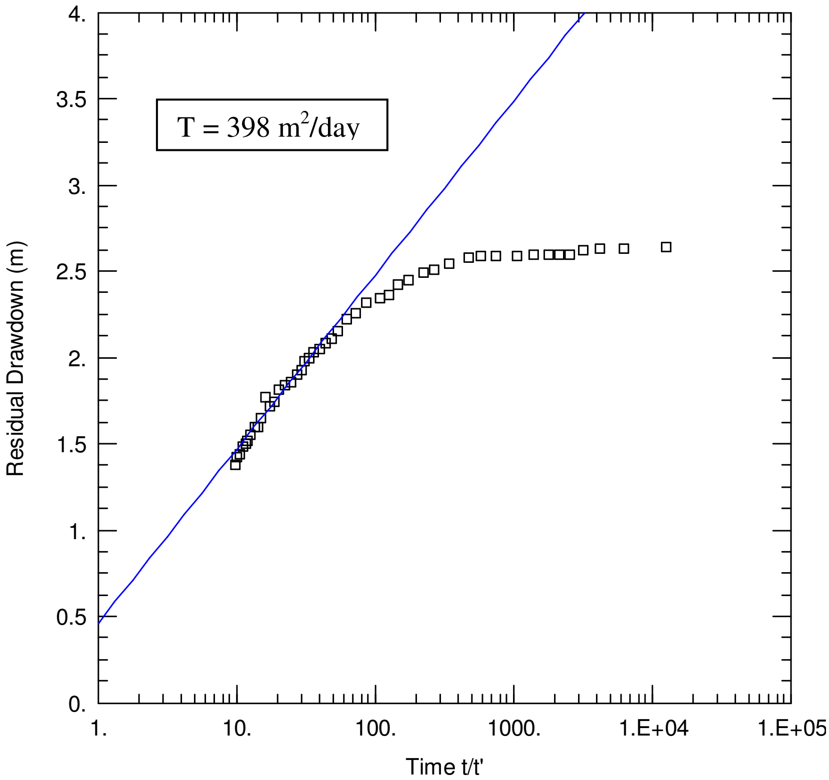

Figure 9-10 Pumping Test Results for BH10220: Theis Recovery Solution

10 BH10220

Borehole BH10220 with siting reference **S20** is an observation borehole (piezometer) for the existing borehole BH9295. It is located about 80 km from Ncojane on the road from Metsimantsho to Ncaang. Drilling at this site commenced on 31 May 2005 and was completed on 24 June 2005. The drilled depth of this borehole is 232m which is the same as for BH9295.

10.1 SITING CRITERIA AND DRILLING OBJECTIVES

This borehole was drilled at the site of existing borehole BH9295 drilled during the Hunhukwe / Lokalane project to allow for the estimation of the storativity of the Ecca aquifer during pump testing. It will also allow for the accurate hydraulic head measurement of the Ecca aquifer at this locality.

10.2 DRILLING RESULTS

The borehole was drilled through various lithologies including fine grained sand, calcrete, silcrete, conglomerate, mudstones, shales and fine, medium and coarse grained sandstones (**Figure 10-1**). Drilling of BH10220 was carried out with a 6.5 inch bit using the DTH drilling technique down to a depth of 117m bgl. During drilling, the borehole collapsed and the whole drilling string got stuck at 117 m. To recover the equipment and to drill further, the hole was reamed using a 10 inch drilling bit to a depth of 36m and 8 inch casings were installed. From 36 to 117 m, the hole was reamed with an 8 inch bit. Drilling was then continued from 117 m to 123 m with the 8 inch drilling bit after which 6.5 inch casing were installed. Drilling to the terminal depth of 232 m was carried out by a 6 inch drilling bit.

After completion of drilling, the borehole was geophysical logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, calliper, neutron and temperature probes. The borehole geophysical log is presented in **Figure 10-2.**

After logging, a 2 inch PVC casing and screen (interval 155.11 to 194.81 m bgl and 211.82 to 223.15 m bgl) assembly was installed into the borehole. Gravel pack, comprising of sub-rounded gravel, was tremied down from 130 to 232 m bgl. A bentonite seal was placed from 130 to 127 m. From 127 to 97 m, the borehole was cement grouted from 97 to 20 m. The borehole was backed filled up to last 20m below surface with the remaining annulus cement grouted (20 to 0 m).

During drilling of this borehole, two water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows;

1. (145m, 1150 µS/cm, 6 m^3/hr)
2. (210m, 1750 µS/cm, 19 m^3/hr)

Borehole development was through airlift pumping using 1.5 inch air line for a total of 5 hrs and the final yield and conductivity were 6 m^3/hr and 1750 µS/cm. Water samples were collected at the two water strikes (145 and 210 m) were submitted to the DWA laboratory for chemical analysis. The results are shown in **Table 10-1.**

Table 10-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10220	145	8.2	588	11.78	10.98	220.1	39.2	42.53	36.33	3.82	2.26	0	587.79	0.00	0.10	MUD 1
10220	210	7.98	892	7.11	17.56	292.5	27.7	131.17	83.88	0	1.56	0	602.46	0.00	0.11	SST 2
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

Note:

The borehole was finally capped and a cement slab was constructed. The borehole lithology and details are shown in **Figure 10-1.**

Log of BH10220

Water Resources Consultants

Location	: Near Ncojane
Site Reference	: S20
Coordinates	: 503297.7 E 7439427.6 N
Drilling Dates	: 31/05/2005 to 24/06/2005
Drilling Method	: DTH
RWL BMP (Date)	: 132.98 (24/06/05)
Total Depth (m)	: 232
Airlift Yield (m3/hr)	: 25.1
EC (uS/cm)	: 1520
Tested Yield (m3/hr)	: Observation borehole

WS 1 (Depth, EC, Q) : 145, 1150, 5.2
WS 2 (Depth, EC, Q) : 210, 1750, 25

Note: : Yield (m3/hr)
: EC (uS/cm)

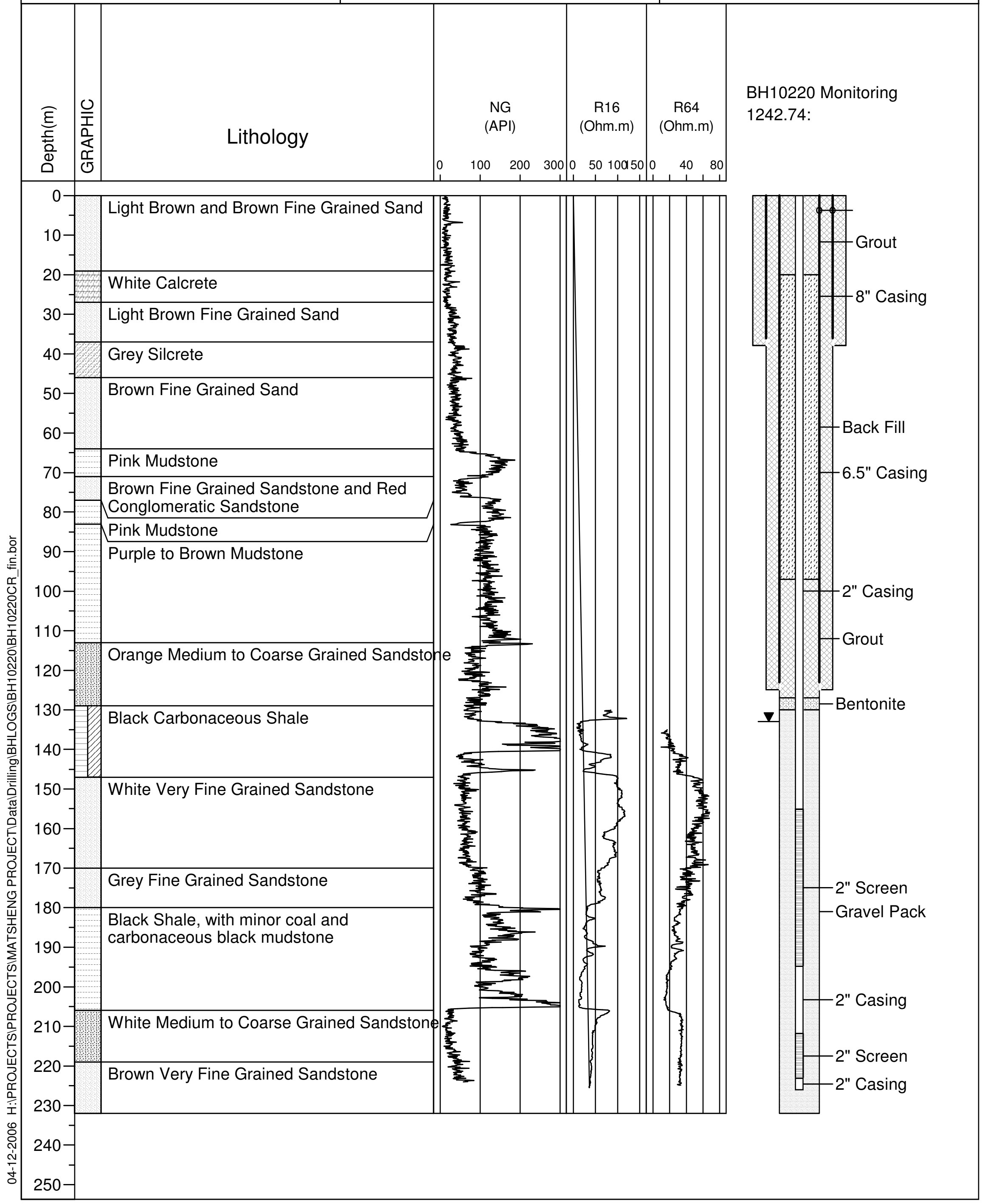

Figure 10-1 Log of BH10220

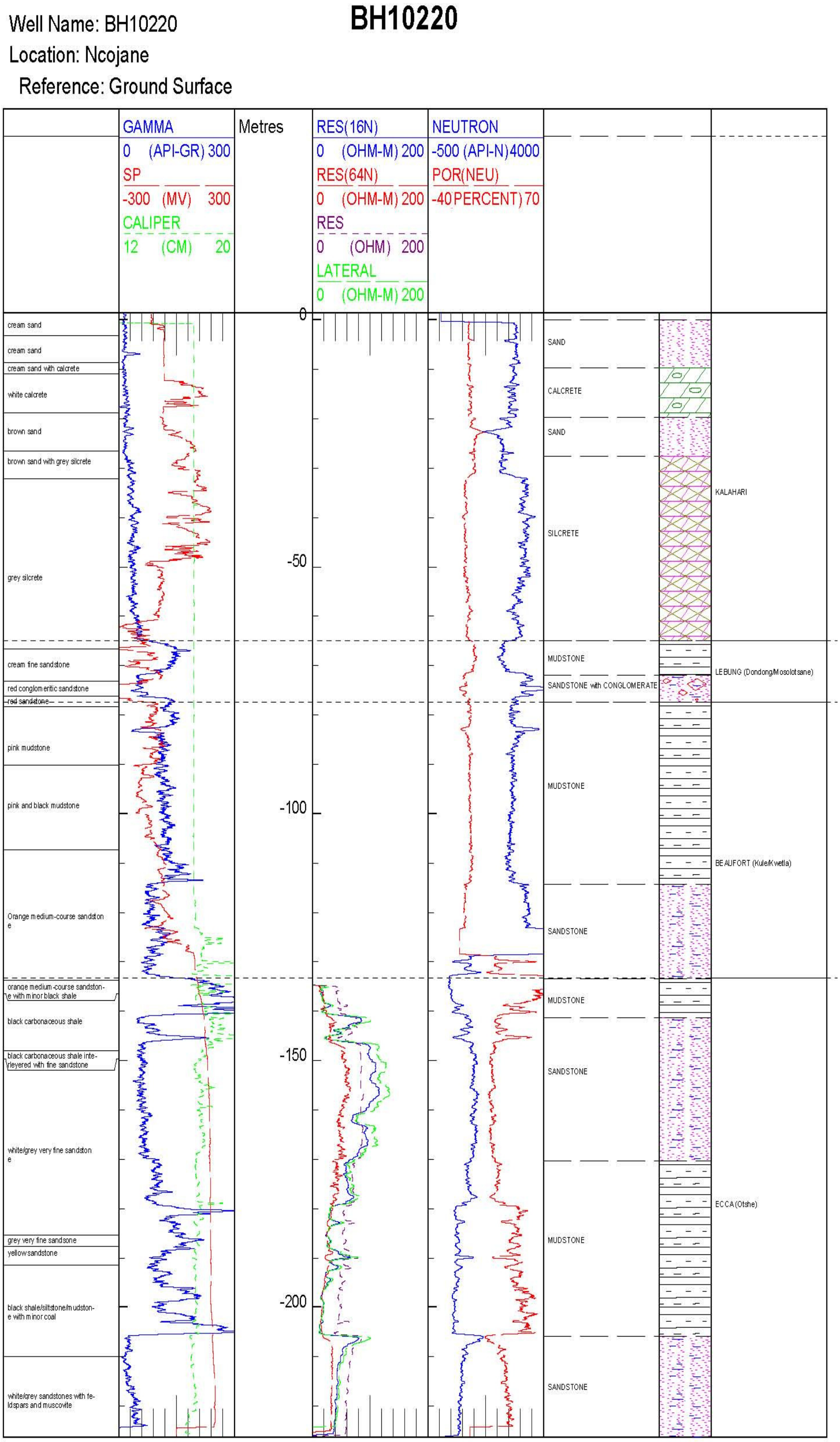

Figure 10-2 Geophysical log of BH10220

10.3 WATER CHEMISTRY RESULTS

A set of water samples (acidified and none) were collected for major ion chemistry analysis for each water strike and the samples were submitted to the DWA laboratory in Gaborone. The laboratory analysis for the second water strike is shown in **Table 10-2**. This result shows that for the analysed parameters, sodium, fluoride and conductivity exceeds the BOS32:2000 standards and so the water has to be treated before it can be safe for human consumption. These parameters are highlighted in grey in **Table 10-2**. The fluoride content also exceeds the Class III standards.

10.3.1 Pump Testing Results

This borehole was used as an observation borehole during pump testing of BH9295 and the pump testing results are discussed in chapter 9.

Table 10-2 Chemistry Results from the DWA Laboratory.

	K	Na	Ca	Mg	SO_4	Cl	HCO_3 (Calc)	NO_3	F	Fe	Mn	EC	pH	TDS
BH10220	27.7	292.5	7.11	17.56	83.88	131.2	602.46	0	1.56	0.11	0	1520	7.98	892
Class II	50	200	150	70	250	200	250	45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600	400	45	1.5	2	0.5	3100	5 - 10	2000

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

11 BH9297

BH9297 is an exploration borehole drilled during the Hunhukwe / Lokalane project and was converted to monitoring boreholes during the Matsheng Project. It is located in the Matlho-a-Phuduhudu Block, about 150 km east of Ncojane along the cattle route trek. This borehole was initially completed at a depth of 287m in the Ntane aquifer with a yield, electrical conductivity and water level of 30.5 m^3/h, 550 µS/cm and 147.2m respectively. The borehole was pump tested at a discharge rate of 52 m^3/h for 9.25 days and it had a total drawdown of 16.62m. It was later deepened to a depth of 444m to explore the Ecca aquifer also in the Hunhukwe / Lokalane project. The air lift yield and conductivity of the Ecca aquifer were 78.3 m^3/h and 4540 µS/cm. The Ecca aquifer was pump tested at a discharge rate of 25 m^3/h for 5.5 days and it had a total drawdown of 12.79m.

11.1 SITING CRITERIA AND DRILLING OBJECTIVES

This existing borehole was converted into two monitoring boreholes, BH9297 and BH10320 tapping different sandstone units of the Ecca aquifer. It will generate the groundwater head of the different sandstone units of the Ecca aquifer at the same locality and hence will allow for the comparisons of their heads.

11.2 DRILLING RESULTS

This borehole was drilled through various lithologies including fine grained sands, silcrete, fine to medium grained sandstones, mudstones, fine to medium micaceous sandstones, siltstone and dolerite (**Figure 11-1**). Drilling was started using a 15 inch drilling bit to a depth of 76 m after which a 12 inch casing was installed and grouted. A 12 inch drilling bit was used to drill to a depth of 287m in the Ntane aquifer. After completing a pumping test (obtaining hydraulic parameters of the Ntane aquifer), 10 inch plain casing were installed in the borehole to allow for the deepening of the borehole into the Ecca aquifer. A 10 inch bit was used to drill from 287 to 403m and an 8 inch bit was used to drill from 403 to 404m. A 6.5 inch bit was used to drill from 404 to the terminal depth of 444m.

During drilling of this borehole, nine water strikes were encountered. The depths, conductivities and yields (measured on a 90^O V-notch weir) for the water strikes are as follows:

1. 197m, 480 µS/cm, 0.14 m^3/h
2. 210m, 420 µS/cm, 7.36 m^3/h
3. 240m, 470 µS/cm, 12.5 m^3/h
4. 257m, 520 µS/cm, 10.5 m^3/h
5. 389m, 7120 µS/cm, Not measurable
6. 393m, 5180 µS/cm, 30.0 m^3/h
7. 411m, 4670 µS/cm, 33.3 m^3/h
8. 417m, 4640 µS/cm, 5.5 m^3/h
9. 429m, 4540µS/cm, 9.8 m^3/h

After development at 287m, the yield was 9.2 m^3/hr, the pH was 8.8 and the electrical conductivity was 1280 µS/cm. A final yield of 9.2 m^3/hr, pH of 8.8 and the electrical conductivity of 1280 µS/cm were obtained at the completion of borehole development at 444m depth. The borehole was left open from 287 to 444m.

During the Matsheng Project, this borehole had collapsed from 300m to 444m and was cleaned to the bottom. A 2.4 inch PVC casing and screen (screen interval 433.75 to 436.59 m bgl) assembly was installed into the borehole to tap the lower Otshe sandstone unit of the Ecca aquifer. Gravel pack, comprising of sub-rounded gravel, was tremied down from 406.18 to 444 m bgl. A bentonite seal was placed from 403.46 to 406.18m to allow for the construction of the shallower monitoring borehole, BH10320.

11.2.1 Comparison of Hydraulic heads

The water level data shows that the heads of the two Otshe sandstone units (Ecca aquifer) are equal.

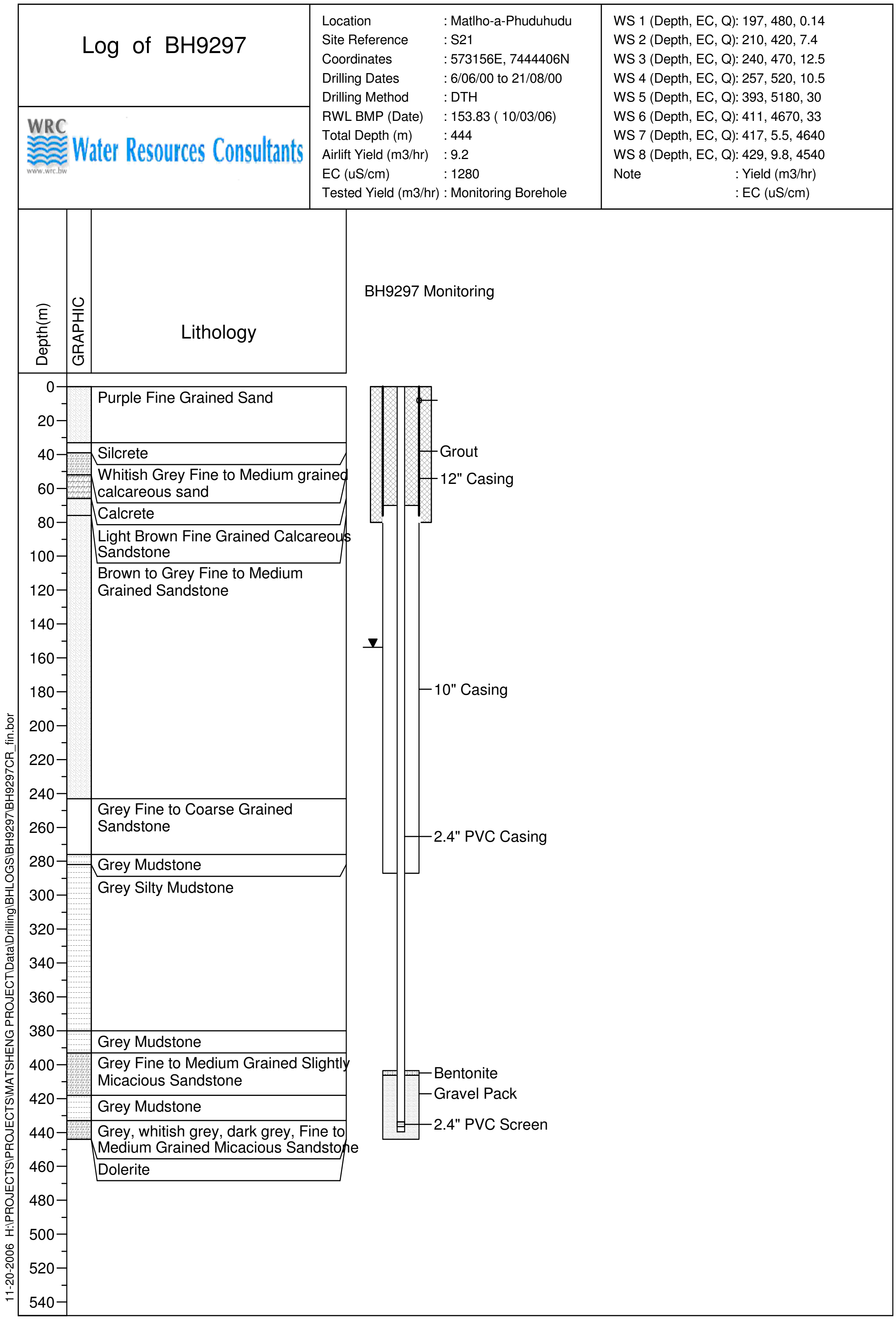

Figure 11-1 Log of BH9297

12 BH10320

BH10320 is a second monitoring borehole constructed in existing borehole BH9297 which was drilled during the Hunhukwe / Lokalane project. It is located in the Matlho-a-Phuduhudu Block, about 150 km east of Ncojane along the cattle route trek. BH9297 was drilled to a depth of 444m and was converted to monitoring boreholes in the Matsheng project.

12.1 SITING CRITERIA AND DRILLING OBJECTIVES

This monitoring borehole was completed in the upper Otshe sandstone unit and will generate water level data for this aquifer unit. It will allow for comparison of the groundwater heads from two Otshe sandstone units at the same location.

12.2 DRILLING RESULTS

Borehole BH9297 was drilled through various lithologies including fine grained sands, silcrete, fine to medium grained sandstones, mudstones, fine to medium micaceous sandstones, siltstone and dolerite (**Figure 12-1**). Drilling was started using a 15 inch drilling bit to a depth of 76 m after which a 12 inch casing was installed and grouted. A 12 inch drilling bit was used to drill to a depth of 287m in the Ntane aquifer.

After completing a pumping test (obtaining hydraulic parameters of the Ntane aquifer), 10 inch plain casing were installed in the borehole to allow for the deepening of the borehole into the Ecca aquifer. After installing the 10 inch casings, a 10 inch bit was used to drill from 287 to 403m and an 8 inch bit was used to drill from 403 to 404m. A 6.5 inch bit was used to drill from 404 to the terminal depth of 444m. During drilling of this borehole, nine water strikes were encountered. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows:

1. 197m, 480 µS/cm, 0.14 m^3/h
2. 210m, 420 µS/cm, 7.36 m^3/h
3. 240m, 470 µS/cm, 12.5 m^3/h
4. 257m, 520 µS/cm, 10.5 m^3/h
5. 389m, 7120 µS/cm, Not measurable
6. 393m, 5180 µS/cm, 30.0 m^3/h
7. 411m, 4670 µS/cm, 33.3 m^3/h
8. 417m, 4640 µS/cm, 5.5 m^3/h
9. 429m, 4540µS/cm, 9.8 m^3/h

After development at 287m, the yield was 9.2 m^3/hr, the pH was 8.8 and the electrical conductivity was 1280 µS/cm. A final yield of 9.2 m^3/hr, pH of 8.8 and the electrical conductivity of 1280 µS/cm were obtained at the completion of borehole development at 444m depth. The borehole was left open from 287 to 444m.

During the Matsheng Project, this borehole collapsed from 300m to 444m and was cleaned to the bottom. After successfully installing 2.4 inch reinforced PVC casings and screens in the deeper monitoring borehole BH9297 (screen interval 433.75 to 436.59 m bgl), the shallower monitoring borehole BH10320 was constructed. A 2.4 inch PVC casing and screen (screen interval 397.76 to 400.56 m bgl) assembly was installed into the borehole to tap the upper Otshe sandstone unit of the Ecca aquifer. Gravel pack, comprising of sub-rounded gravel, was tremied down from 367.76 to 403.46 m bgl. A bentonite seal was placed from 365.76 to 367.76m and the borehole was cement grouted from the ground surface to 365.76m.

12.2.1 Comparison of Hydraulic heads

The water level data shows that the heads of the two Otshe sandstone units (Ecca aquifer) are equal.

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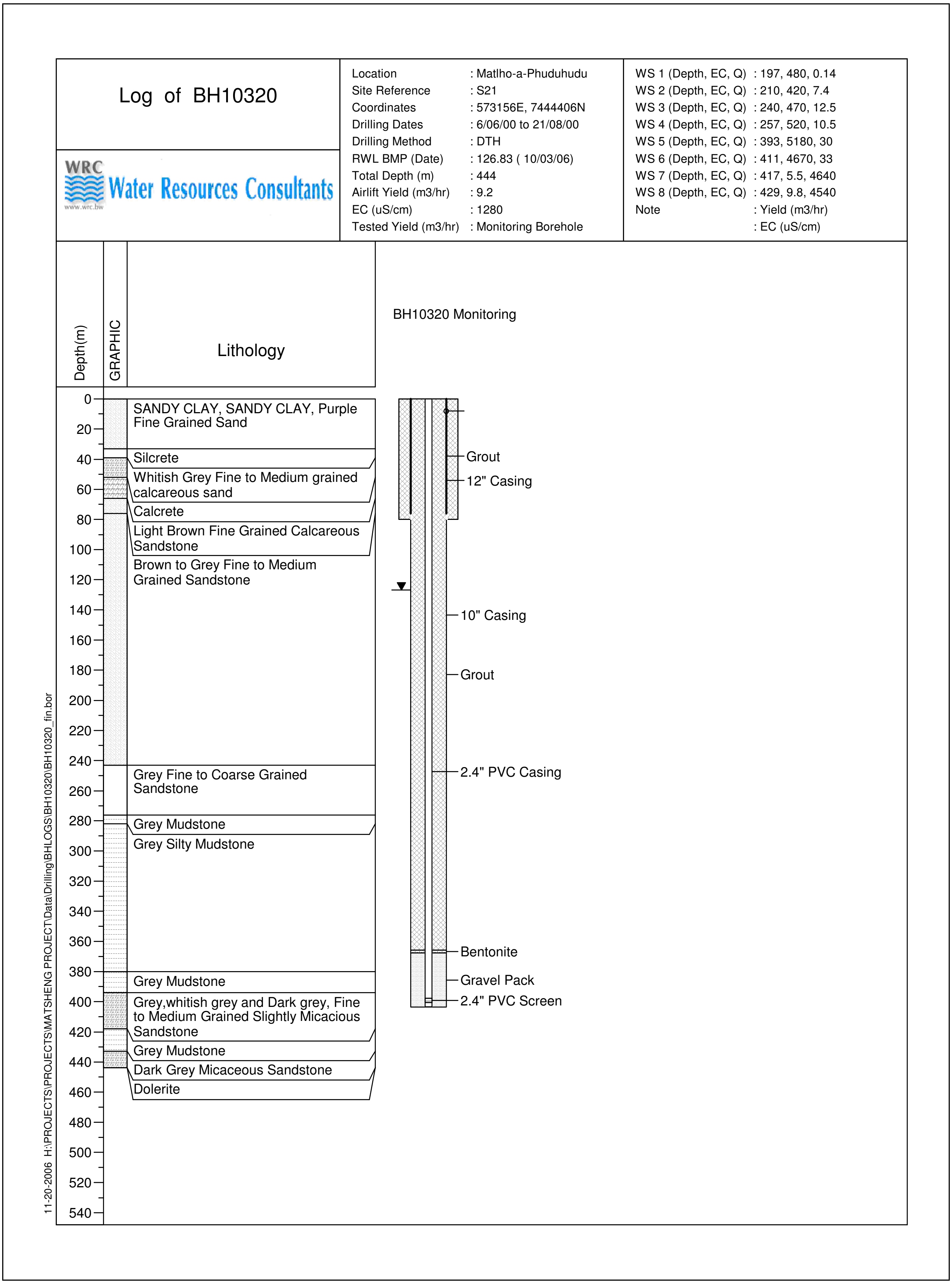

Figure 12-1 Log of BH10320

13 BH10226

BH10226 with siting reference **S21** is an observation borehole drilled near existing borehole BH9297, to allow measurement of the head difference between the Ntane Sandstone Aquifer and Ecca aquifer at this site. It is located in the Matlho-a-Phuduhudu Block, about 150km east of Ncojane along the cattle route trek. Drilling at this site commenced on 31 October 2005 and was completed on 7 November 2005. The drilled depth of this piezometer is 201m.

13.1 SITING CRITERIA AND DRILLING OBJECTIVES

This observation borehole (piezometer) was drilled at the site of existing borehole BH9297 drilled during the Hunhukwe / Lokalane project to allow accurate head measurement of the Ntane aquifer to allow for comparison of the hydraulic heads of the Ntane and Ecca aquifers.

13.2 DRILLING RESULTS

This monitoring borehole was drilled through various lithologies including fine grained sand, calcrete, silcrete, and fine and medium grained sandstones (**Figure 13-1**). Drilling of BH10226 was carried out with an 8 inch bit to a depth of 123m bgl after which 6.5 inch plain casings were installed and cement grouted. Further drilling to the terminal depth of 201m was achieved using a 6.5 inch bit.

During drilling of this borehole, two water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the two water strikes are as follows;

1. (162m, not measurable)
2. (174m, 564 µS/cm, 6.6m^3/hr)

The borehole was developed by airlift pumping using 1.5 inch air line for 1 hour and the final electrical conductivity and yield were 513 µS/cm and 8 m^3/hr respectively.

Final borehole construction was through installation of 2 inch PVC casings and screens (screened interval 173.24 to 193.12 m bgl) assembly. Gravel pack, comprising of sub-rounded gravel, was tremied down from 152 to 201 m bgl. A bentonite seal was placed from 149 to 152 m and the remaining annulus was cement grouted (149 to 0 m). The rest water level was 146. 79 m below ground level, measured on 7 November 2005.

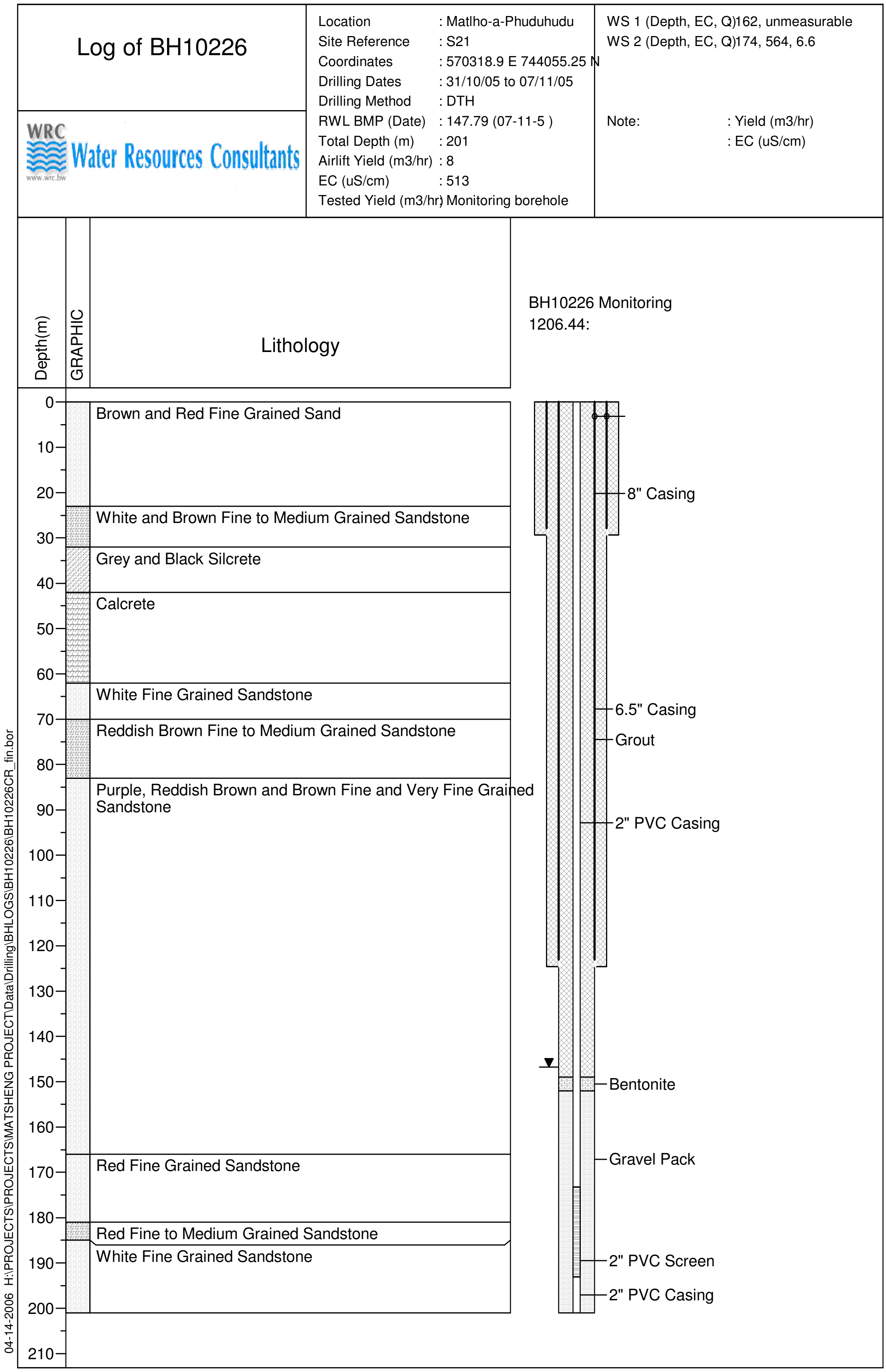

Figure 13-1 Log of BH10226

14 BH10211

BH10211, an exploration borehole with a siting reference of **S4,** line R3, peg 9000m, TEM 63, was drilled to explore the Ecca aquifer northeast of fault **F4**. This exploration borehole is located about 20 km east of Ncojane Village 2 km off (south) to the gravel road leading to Metsimantsho village. Drilling of this borehole commenced on 27 October 2005 and was completed on 11 November 2005. The total drilled depth for this borehole is 250 m.

14.1 SITING CRITERIA AND DRILLING OBJECTIVES

This exploration borehole was drilled 10.6 m from monitoring borehole BH10210 to allow for the calculation of the hydraulic properties (Transmissivity and storativity) of the Ecca aquifer at this site.

14.2 DRILLING RESULTS

Various lithologies including fine grained sand, silcrete, mudstones, coal and fine to medium grained sandstones were intercepted by this exploration borehole (**Figure 14-1**). Drilling was carried out with a 15 inch bit using the DTH drilling technique from 0 to 80 m bgl after which 12 inch plain casings were installed and cement grouted. From 80 m to 201 m drilling was carried out using a 12 inch drilling bit after which 10 inch casings were installed and grouted. From 201m to the terminal depth of 250 m, drilling was accomplished with $9^{7/8}$ tri-cone bit.

During drilling of this borehole, two water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the two water strikes are as follows;

1. (199m, 690 µS/cm, 25m^3/hr)
2. (224m, 800 µS/cm, 26 m^3/hr)

The cumulative yield at the end of drilling before installation of casings was 51 m^3/hr.

After completion of drilling, the borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, caliper, neutron and temperature probes to a depth of 248m. It should be noted that during logging, the only portion of the borehole which was open was from 201 to 250 m. After logging, 8 inch steel casing and slotted screen (interval 188.89 to 244 m bgl) assembly was installed.

The borehole was developed using the air jetting method for 4.5 hours and the yield was measured as 43 m^3/hr and the electrical conductivity was 800 µS/cm. The rest water level was measured as 106.56 m bgl on 11 November 2005.

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

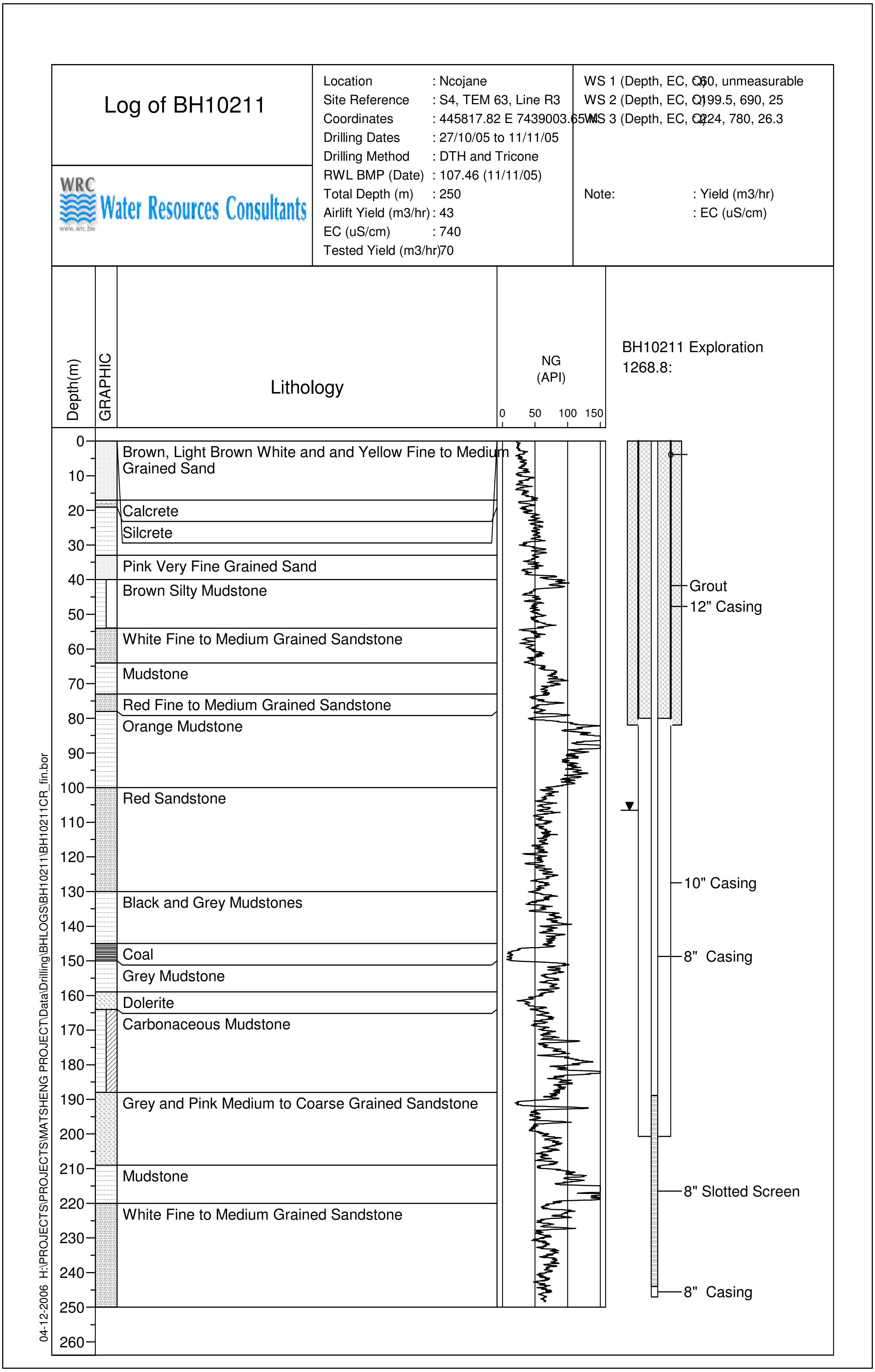

Figure 14-1 Log of BH10211

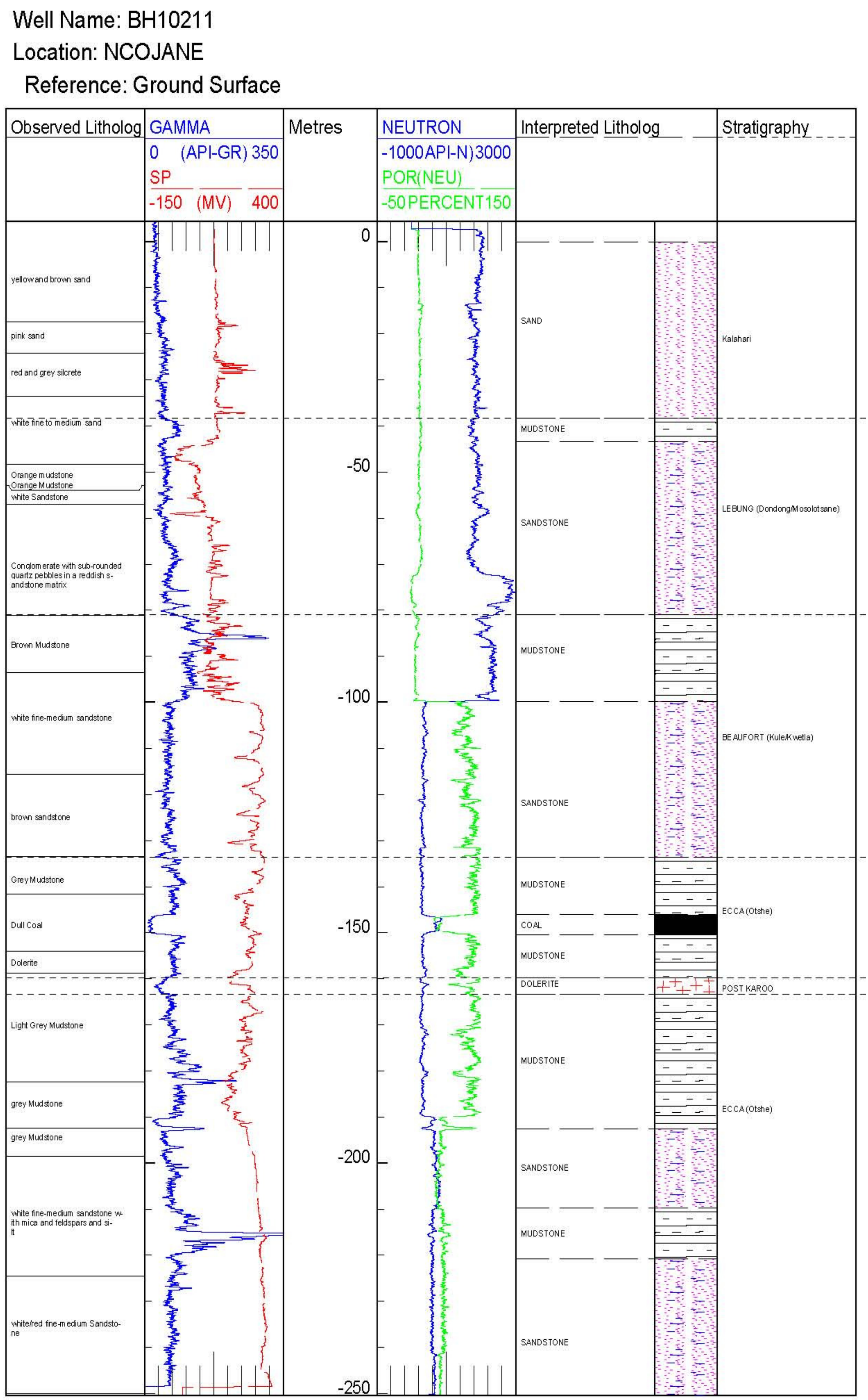

Figure 14-2 Geophysical log of BH10211

14.3 PUMP TESTING RESULTS

Borehole BH10211 was tested between 19 and 26 November 2005. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.9 m above ground level (agl) and the pump intake was set at 150 m below ground level. Summary details for the pumping test activities are given in **Table 14-1**. The collected pump testing data is presented in **Tables 14-5 to 14-9.**

Table 14-1 Summary of Pumping Test Data BH10211

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	5.92	20
	2	15	11.52	32
	3	15	17.59	44
	4	15	21.91	52
	5	15	26.52	62
	6	15	31.51	72
	7	15	36.46	82
Step Test	1	100	14.81	31
	2	100	19.31	43
	3	100	24.33	50
	4	100	29.41	60
	5	100	33.49	72.5
	6	100	38.5	80
Constant Rate	1	4320	35.11	70
Recovery	1	1440	1.76*	0

Note. 1.76 Residual Drawdown*

14.3.1 Step Drawdown Test

The step drawdown test was carried out on 21 November 2005. The static water level before the start of the test was 108.4 m bmp. The step drawdown test consisted of 6 steps of 100 minutes duration at discharge rates of 31.7, 42.9, 50.7, 60.4, 70.1 and 80.1 m^3/hr for steps 1 to 6 respectively, **Table 14-2**.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test using this method is plotted in **Figure14-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 14-4**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 19.7 m^2/d, **Figure-14-5**.

The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 48 m^2/d. The results are tabulated in **Table 14-2**.

Table 14-2 Results of Step Test Analysis BH10211

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10211	1.99E-02	-1.07E-6	48.1	31.7	14.80	14.80	2.1
				42.9	3.51	18.31	2.3
				50.7	4.52	22.83	2.2
				60.4	4.22	27.05	2.2
				70.1	3.24	30.29	2.3
				80.1	3.87	34.16	2.3

The planned duration for the constant rate test of this borehole was 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slope of the semi-logarithmic plot of drawdown versus time (**Figure14-3**) to estimate the expected total drawdown after 3 days of pumping at different pumping rates. It was found out that the discharge rate of 70m^3/hr is ideal for this borehole.

14.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 22 and 25 November 2005 at a discharge rate of 70 m^3/hr and the total drawdown after 72 hrs of pumping was 35.11 m. The CRT test was followed by a 24 hr recovery monitoring period at the end of which the residual drawdown was 1.76 m. Data from the pumping borehole was interpreted using the Theis, Cooper-Jacob (1946) and Hatush Leaky analytical solutions using the computer programme "Aqtesolv". Transmissivity (T) values obtained by these three analytical solutions were 100, 100 and 90 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 82 m^2/d was obtained. The interpretation results are summarised in **Table 14-3** and the interpreted data is presented in **Figures 14-6** to **14-9**.

Table 14-3 Summary of Constant Rate and Recovery Tests BH10211

BH No.	CRT Duration (hours)	Q (m^3/d)	Pumping borehole T (m^2/d)		Obs. BH No.	Observation borehole			Aquifer type
						Pumping phase		Recovery phase	
			Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
10211	4320	1680	a) 100 b) 100 c) 90	d) 82	10210	a) 63 b) 87 c) 48	a) 4.4x10^{-4} c) 2.4x10^{-4}	d) 82	Confined Leaky

Notes:
Interpretation Techniques
a) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

14.3.2.1 Observation Borehole

The water level response was monitored in an observation borehole (BH10210) located 10 m away from BH10211 (pumped borehole). This observation borehole is screened between 192.83 to 244.7 m bgl and the total drawdown in this borehole at the end of pumping (72 hrs) was 22.84 m.

Various analytical solutions (Theis, Cooper-Jacob, Hantush Leaky,) were applied to the pumping test data from this observation borehole using the computer programme "Aqtesolv" and the best fit was obtained based on the Theis and Hantush Leaky solutions in addition to the Cooper-Jacob interpretation. The transmissivity (T) values obtained by these three analytical solutions are 63, 48 and 87 m^2/d respectively while the storativity values calculated from the Theis and Hatush Leaky solutions4.4x10^{-4} and 2.4x10^{-4} respectively. The recovery data was analysed using the Theis recovery method and the T value was obtained as 82 m^2/d. The results are summarised in **Table 14-4** and the interpreted data is presented in **Figures 14-10 to 14-14.**

14.3.2.2 Aquifer Type interpreted

The pump testing data particularly from the observation borehole (BH10210) indicates that the aquifer type is confined leaky.

14.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. In addition to these, another sample collected were submitted for stable isotope analysis at the CSIR laboratory in Pretoria, South Africa **.** The well head chemical analysis at the end of pumping for temperature, EC and pH are 27.4 ^{o}C, 1050 µS/cm and

7.44 respectively. The results of the CSIR laboratory analysis are shown in **Table 14-4**. The results show that all the analysed parameters are within the Class II BOS32:2000 standards.

Table 14-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10211	8.2	126	15	13	20	59	262	4.7	0.69	0.11	<0.05	740	8	474
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10211	<0.1	90	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

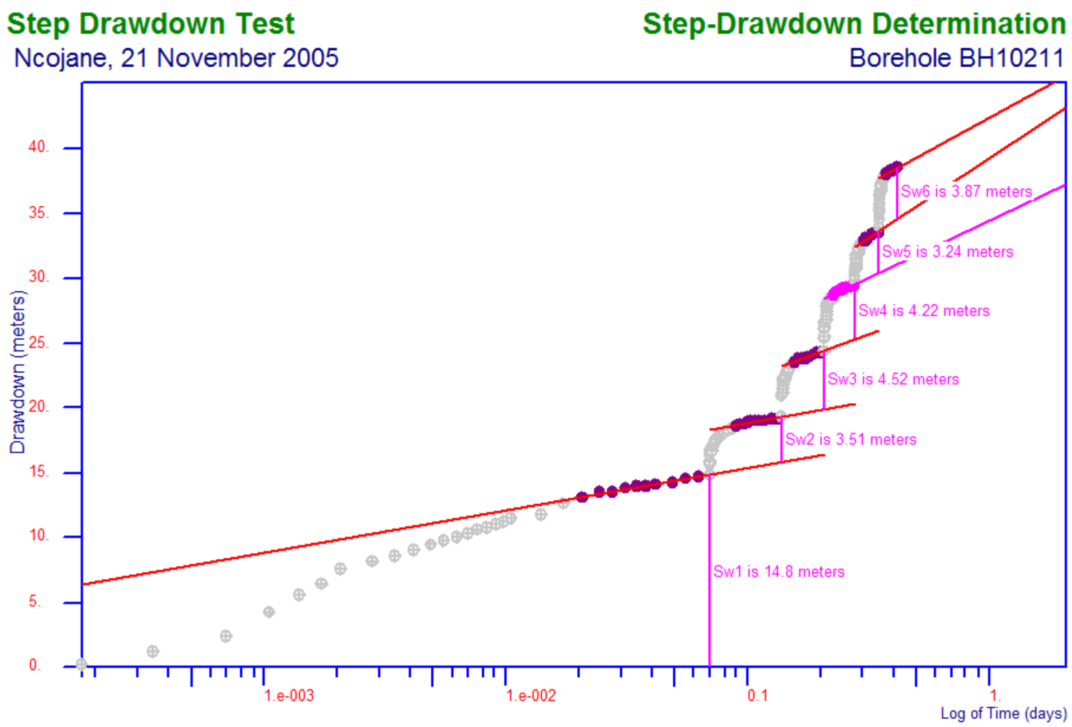

Figure 14-3 Pumping Test Results for BH10211: Step Drawdown Test – Hantush-Bierschenk (semi-log)

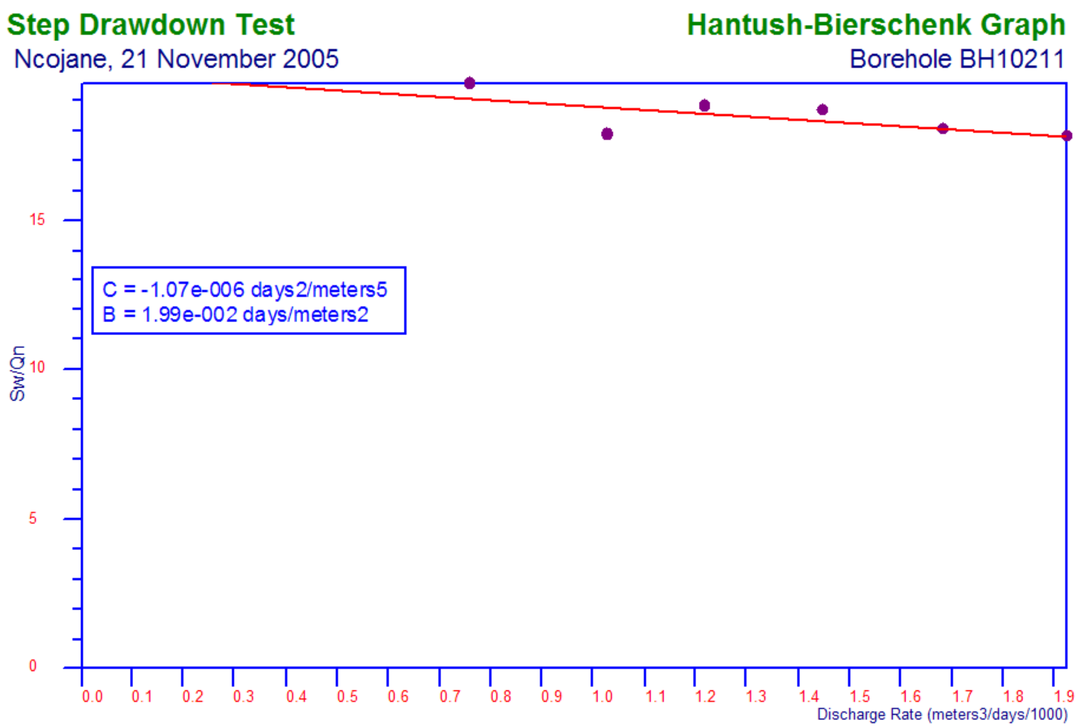

Figure 14-4 Pumping Test Results for BH10211: Step Drawdown Test – Hantush-Bierschenk

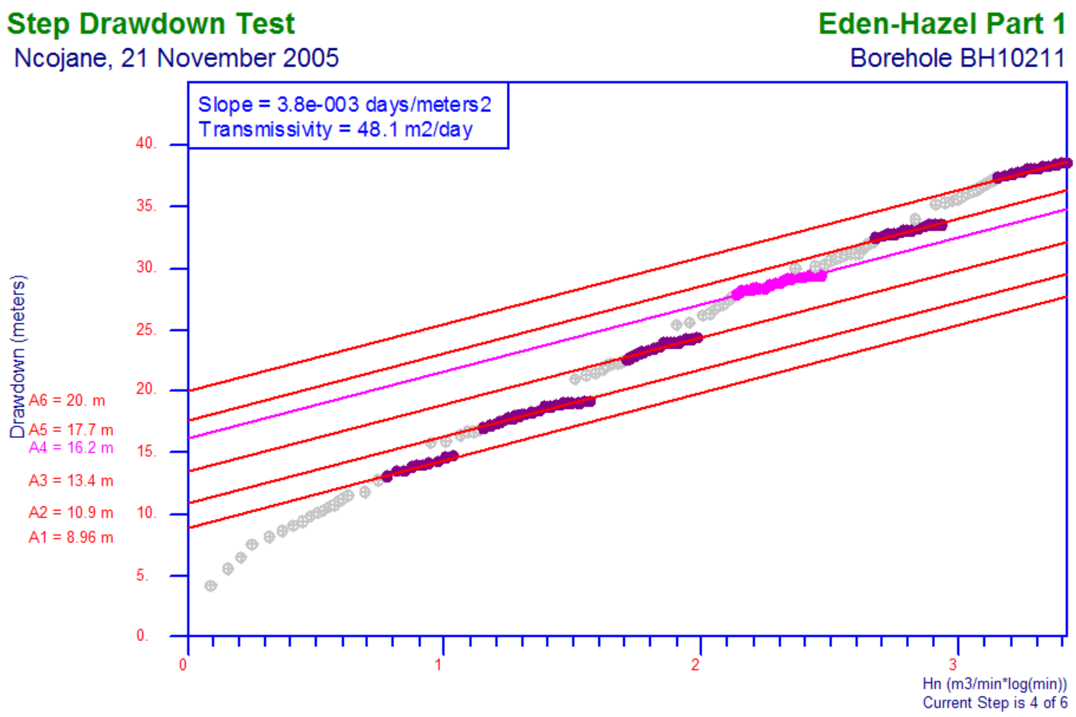

Figure 14-5 Pumping Test Results for BH10211: Step Drawdown Test – Eden-Hazel (Part 1)

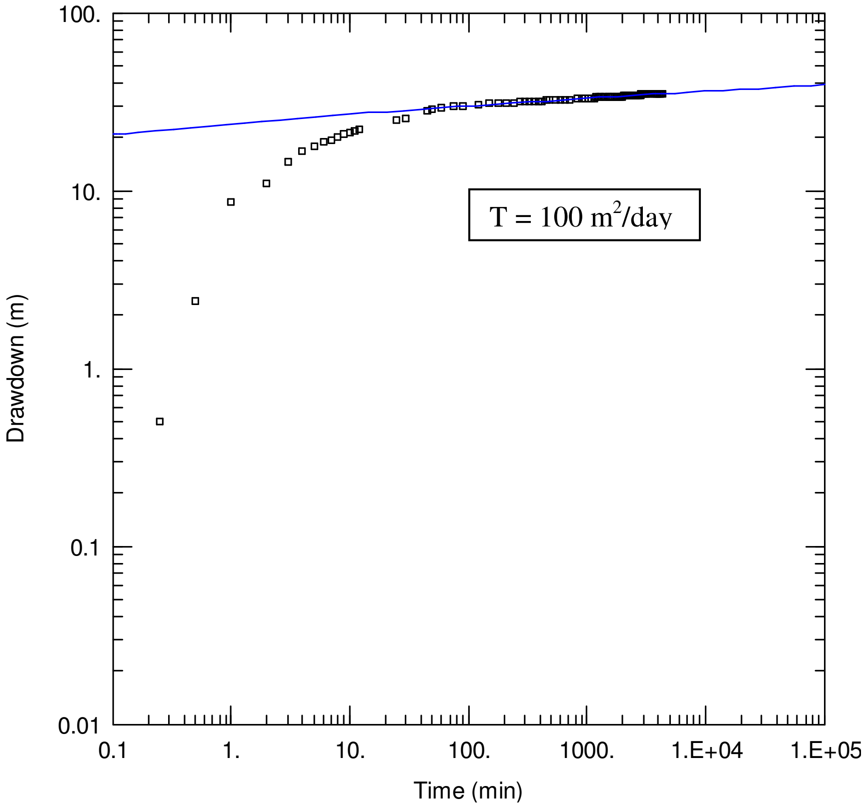

Figure 14-6 Pumping Test Results for BH10211: Theis Solution

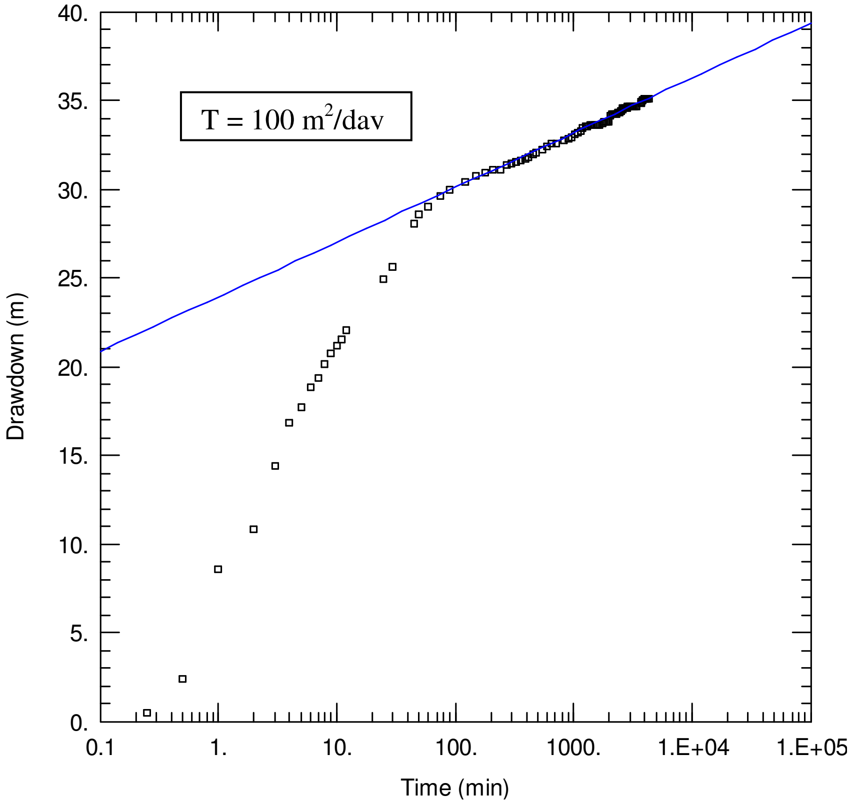

Figure 14-7 Pumping Test Results for BH10211: CRT Cooper Jacob Solution

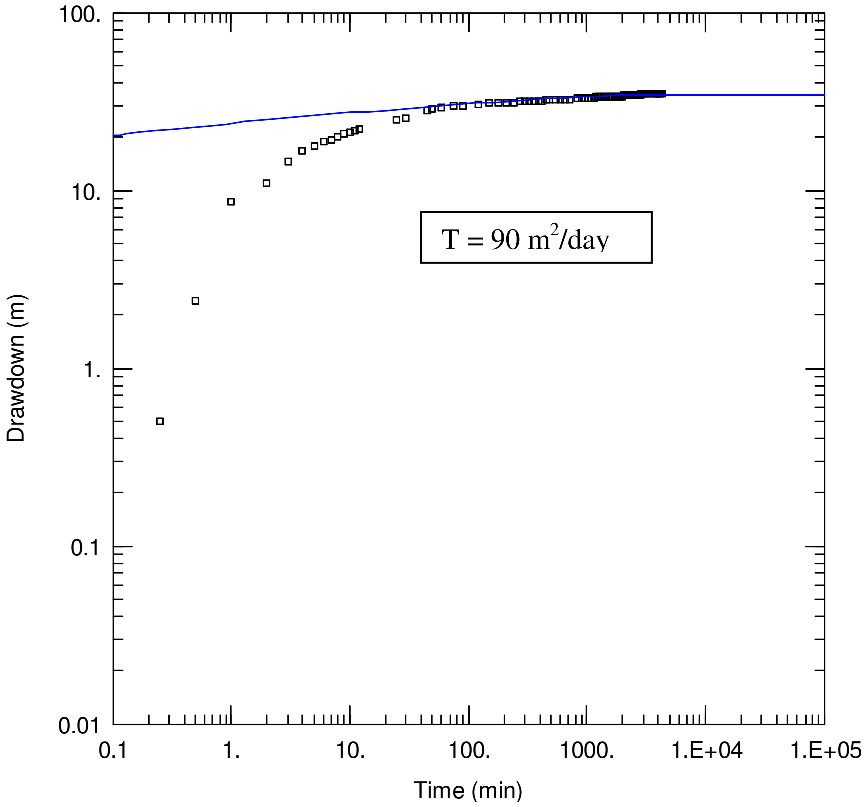

Figure 14-8 Pumping Test Results for BH10211: Hantush Leaky (no Aquitard Storage)

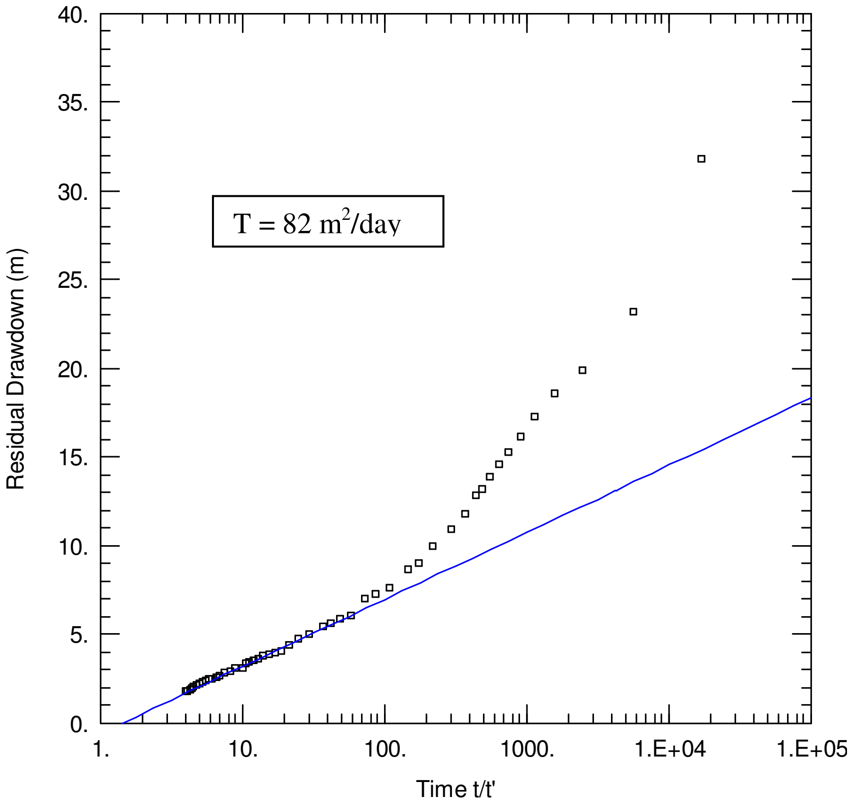

Figure 14-9 Pumping Test Results for BH10211: Theis Recovery Solution

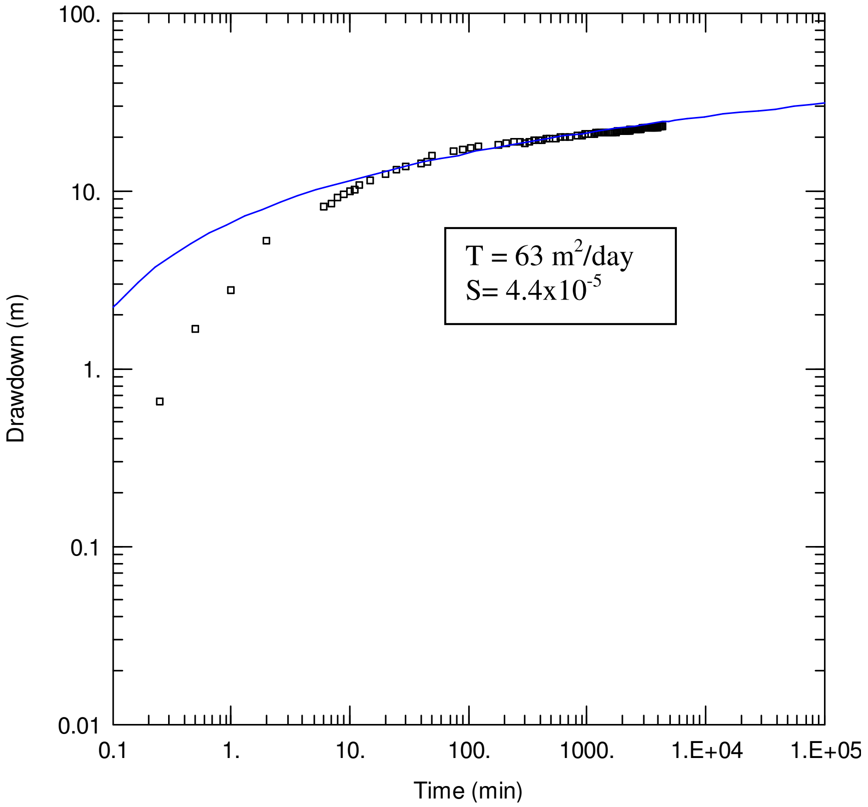

Figure 14-10 Pumping Test Results for BH10210: Theis Confined Solution

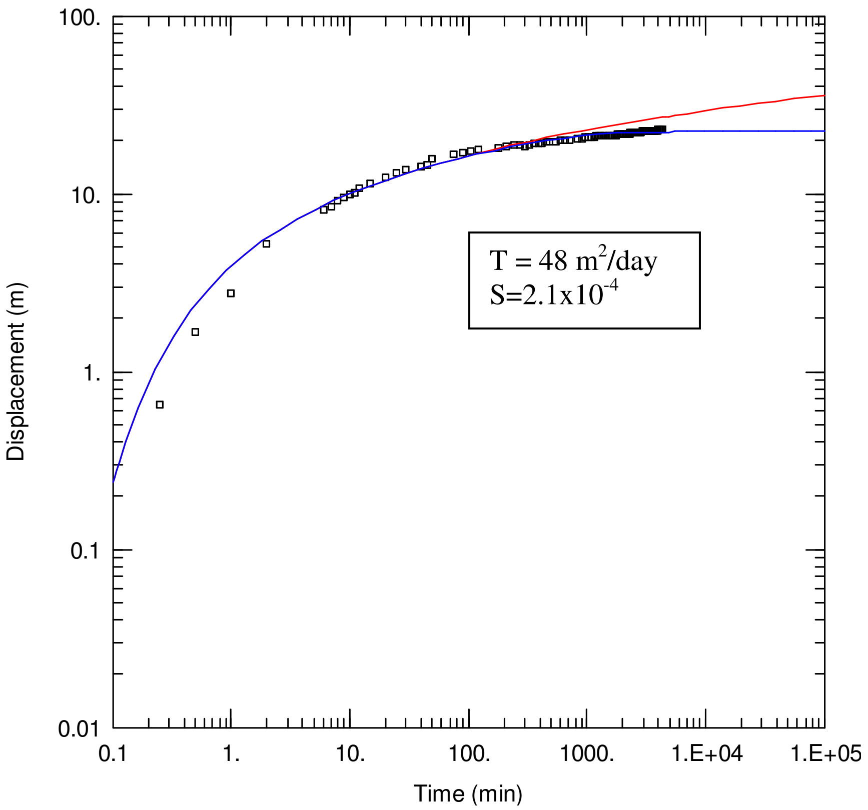

Figure 14-11 Pumping Test Results for BH10210: Hantush Leaky (No Aquitard Storage)

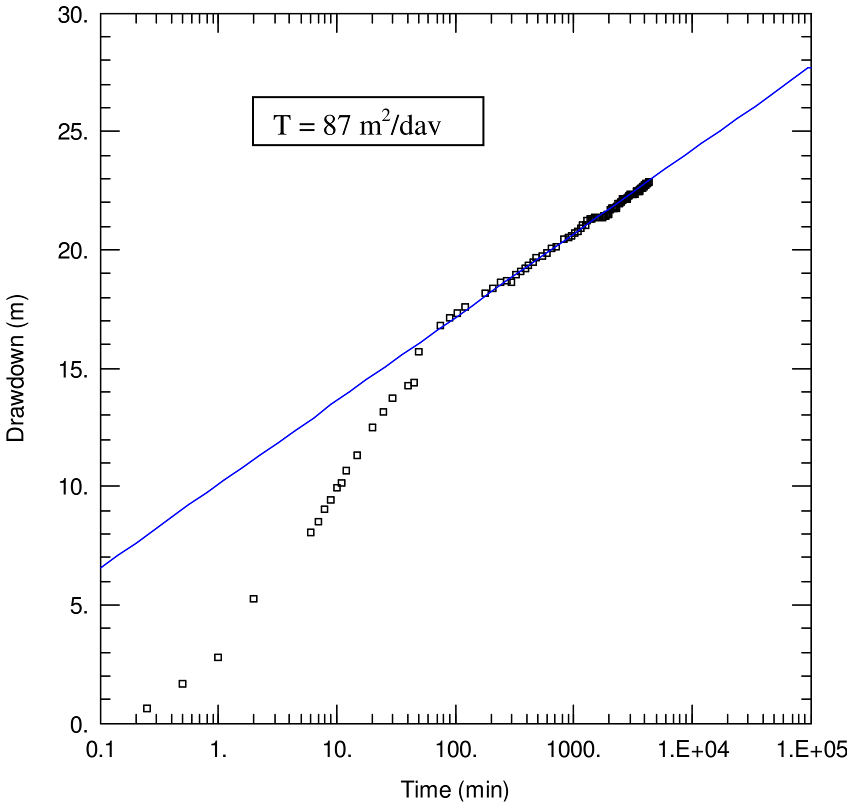

Figure 14-12 Pumping Test Results for BH10210: CRT Cooper Jacob Solution

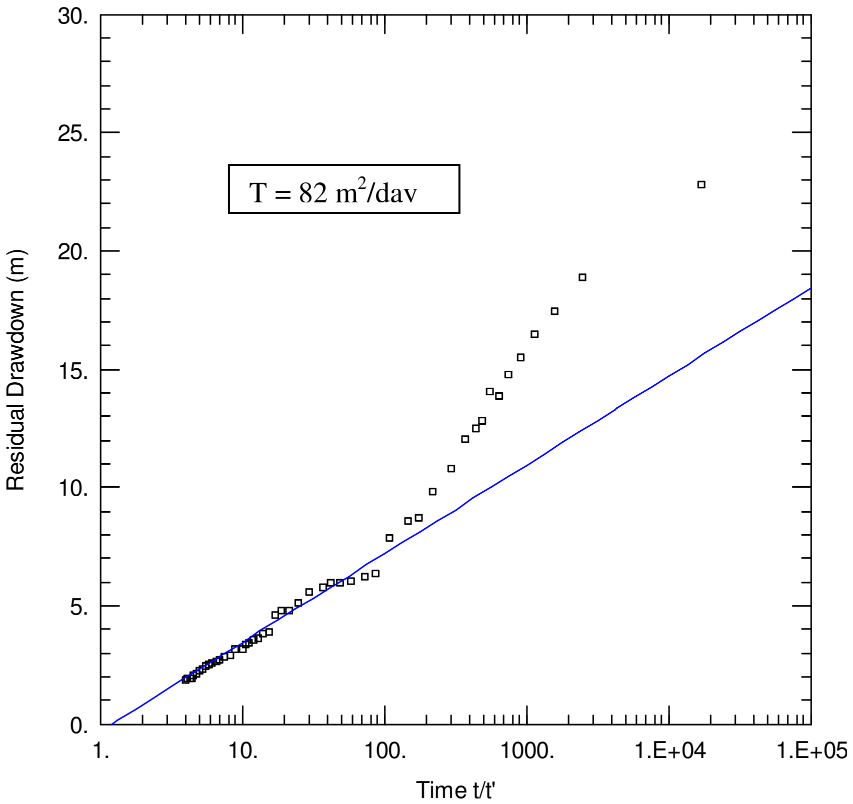

Figure 14-13 Pumping Test Results for BH10210: Theis Recovery Solution

Table 14-5 Calibration Test Data – BH10211

Official BH No.:	10211	District:	Ghanzi
Date of test commencement:	18.11.05	Location:	Ncojane
Time of test commencement		BH depth (m):	250
Date of test completion:	18.11.05	Screen Interval (m):	188.89 - 244
Time of test completion		Depth of pump intake (m):	150
Method of water level measurement:	dipper	Static water level before test (m):	108.26
Casing diameter (mm)	203	Water strike	199.5 and 224 m
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	445822	Northing	7438983

STEPNo. 1 / STEPNo. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	108.57	0.31				0.25	114.48	6.22			
0.5	109.26	1.00				0.5	114.98	6.72			
1	109.77	1.51				1	115.21	6.95			
1.5	110.06	1.80				1.5	116.03	7.77			
2	110.11	1.85				2	116.30	8.04	22.48	32.03	
2.5	110.24	1.98			adj	2.5	116.66	8.40			
3	110.58	2.32				3	117.18	8.92	22.64	31.80	
4	110.69	2.43			adj	4	117.62	9.36	22.75	31.65	
5	111.98	3.72				5	118.02	9.76	22.97	31.35	
6	111.61	3.35	36.02	19.99		6	118.26	10.00	22.68	31.75	
7	112.20	3.94				7	118.60	10.34	22.56	31.91	
8	112.67	4.41				8	118.79	10.53	22.42	32.11	
9	113.06	4.80	37.46	19.22		9	118.93	10.67	22.49	32.01	
10	113.35	5.09				10	119.15	10.89	23.02	31.28	
11	113.54	5.28				11	119.23	10.97	22.74	31.66	
12	113.73	5.47	36.28	19.85		12	119.35	11.09	21.68	33.21	
15	114.18	5.92				15	119.78	11.52	22.37	32.19	

STEPNo. 3 / STEPNo. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 400L	Pumping Rate (m^3/hr)	Comments
0.25	121.50	13.24				0.25	126.90	18.64			
0.5	125.48	17.22				0.5	127.15	18.89			
1	124.85	16.59	16.02	44.94	adj	1	127.59	19.33	27.44	52.48	
1.5	124.19	15.93				1.5	127.83	19.57			
2	124.01	15.75	14.22	50.63		2	128.14	19.88	26.12	55.13	
2.5	124.03	15.77			adj	2.5	128.32	20.06			
3	124.08	15.82	16.78	42.91		3	128.59	20.33	27.45	52.46	
4	124.34	16.08	15.41	46.72		4	128.72	20.46	27.94	51.54	
5	124.55	16.29	16.12	44.67		5	128.94	20.68	27.58	52.21	
6	124.74	16.48	16.23	44.36		6	129.00	20.74	28.68	50.21	
7	124.90	16.64	16.13	44.64		7	129.17	20.91	28.47	50.58	
8	125.30	17.04	16.16	44.55		8	129.30	21.04	27.58	52.21	
9	125.50	17.24	16.53	43.56		9	129.60	21.34	28.10	51.25	
10	125.50	17.24	15.81	45.54		10	129.70	21.44	28.64	50.28	
11	125.50	17.24	16.28	44.23		11	129.85	21.59	28.48	50.56	
12	125.50	17.24	16.49	43.66		12	129.97	21.71	27.33	52.69	
15	125.85	17.59	16.26	44.28		15	130.17	21.91	28.41	50.69	

Table 14-6 Step Drawdown Test Data – BH10211

Official BH No.:	10211	District:	Ghanzi
Date of test commencement:	21.11.2005	Location:	Ncojane
Time of test Commencement:	0700hrs	BH depth (m):	250
Date of test completion:	21.11.2005	Screens(m)	188.89 - 244
Time of test Completion:	1900hrs	Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	10210	Height of MP above ground:	1.25
Distance to OB. BH (m)	10	Static water level before test (m):	108.4
Casing diameter (mm)	203	Water strike	199.5 and 224 m
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	445822	Northing	7438983

STEP No. 3						STEP No. 4					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 400L	P. Rate (m^3/hr)	Comments
0.25	129.33	20.93				0.25	133.80	25.40			
0.5	129.67	21.27				0.5	133.98	25.58			
1	129.88	21.48	13.64	52.79		1	134.50	26.10			
1.5	130.11	21.71			adj	1.5	134.64	26.24			adj
2	130.46	22.06	13.48	53.41		2	135.01	26.61	22.96	62.72	
2.5	130.56	22.16				2.5	135.25	26.85			
3	130.56	22.16	13.62	52.86		3	135.52	27.12	23.68	60.81	
4	130.62	22.22	13.78	52.25		4	135.80	27.40	23.77	60.58	
5	130.72	22.32	14.39	50.03		5	136.06	27.66	23.72	60.71	
6	130.87	22.47	14.32	50.28		6	136.26	27.86	23.94	60.15	
7	130.97	22.57	14.27	50.46		7	136.44	28.04	23.98	60.05	
8	131.05	22.65	14.31	50.31		8	136.47	28.07	23.74	60.66	
9	131.15	22.75	14.33	50.24		9	136.50	28.10	23.80	60.50	
10	131.21	22.81	14.37	50.10		10	136.53	28.13	23.79	60.53	
11	131.28	22.88	14.36	50.14		11	136.57	28.17	23.88	60.30	
12	131.40	23.00	14.33	50.24		12	136.60	28.20	23.85	60.38	
13	131.41	23.01	14.35	50.17		13	136.66	28.26	23.74	60.66	
14	131.47	23.07	14.38	50.07		14	136.72	28.32	23.86	60.35	
15	131.51	23.11	14.27	50.46		15	136.75	28.35	23.90	60.25	
20	131.71	23.31	14.38	50.07		20	136.75	28.35	23.94	60.15	
25	131.88	23.48	14.33	50.24		25	137.07	28.67	23.99	60.03	
30	132.02	23.62	14.36	50.14		30	137.15	28.75	23.90	60.25	
35	132.20	23.80	14.30	50.35		35	137.20	28.80	23.92	60.20	
40	132.21	23.81	14.34	50.21		40	137.35	28.95	23.88	60.30	
45	132.24	23.84	14.35	50.17		45	137.42	29.02	23.91	60.23	
50	132.26	23.86	14.36	50.14		50	137.46	29.06	23.93	60.18	
55	132.34	23.94	14.33	50.24		55	137.55	29.15	23.94	60.15	
60	132.40	24.00	14.31	50.31		60	137.59	29.19	23.99	60.03	
70	132.55	24.15	14.32	50.28		70	137.68	29.28	23.86	60.35	
80	132.61	24.21	14.35	50.17		80	137.72	29.32	23.90	60.25	
90	132.67	24.27	14.28	50.42		90	137.80	29.40	23.87	60.33	
100	132.73	24.33	14.33	50.24		100	137.81	29.41	23.84	60.40	

Official BH No.:	10211	District:	Ghanzi
Date of test commencement:	21.11.2005	Location:	Ncojane
Time of test Commencement:	0700hrs	BH depth (m):	250
Date of test completion:	21.11.2005	Screens(m)	188.89 - 244
Time of test Completion:	1900hrs	Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	10210	Height of MP above ground:	1.25
Distance to OB. BH (m)	10	Static water level before test (m):	108.4
Casing diameter (mm)	203	Water strike	199.5 and 224 m
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	445822	Northing	7438983

STEP No. 5 | STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments
0.25	138.22	29.82				0.25	142.93	34.53			
0.5	138.34	29.94				0.5	143.36	34.96			
1	138.50	30.10	26.28	68.49		1	143.49	35.09	21.84	82.42	
1.5	138.64	30.24			adj	1.5	143.68	35.28			
2	138.94	30.54	24.69	72.90		2	143.80	35.40	22.48	80.07	
2.5	139.04	30.64				2.5	144.09	35.69			
3	139.14	30.74	24.86	72.41		3	144.14	35.74	22.50	80.00	
4	139.31	30.91	24.89	72.32		4	144.47	36.07	22.56	79.79	
5	139.45	31.05	24.87	72.38		5	144.70	36.30	22.61	79.61	
6	139.52	31.12	24.88	72.35		6	144.84	36.44	22.46	80.14	
7	139.60	31.20	24.48	73.53		7	144.91	36.51	22.44	80.21	
8	139.66	31.26	24.90	72.29		8	145.06	36.66	22.52	79.93	
9	139.90	31.50	24.36	73.89		9	145.19	36.79	22.64	79.51	
10	140.09	31.69	24.72	72.82		10	145.32	36.92	22.51	79.96	
11	140.24	31.84	24.64	73.05		11	145.39	36.99	22.45	80.18	
12	140.40	32.00	24.72	72.82		12	145.55	37.15	22.53	79.89	
13	140.44	32.04	24.68	72.93		13	145.58	37.18	22.47	80.11	
14	140.49	32.09	24.78	72.64		14	145.64	37.24	22.45	80.18	
15	140.54	32.14	24.82	72.52		15	145.70	37.30	22.48	80.07	
20	140.80	32.40	24.49	73.50		20	145.91	37.51	22.54	79.86	
25	140.96	32.56	24.47	73.56		25	146.00	37.60	22.48	80.07	
30	141.08	32.68	24.96	72.12		30	146.11	37.71	22.50	80.00	
35	141.14	32.74	24.88	72.35		35	146.19	37.79	22.63	79.54	
40	141.29	32.89	24.90	72.29		40	146.45	38.05	22.40	80.36	
45	141.37	32.97	24.95	72.14		45	146.46	38.06	22.45	80.18	
50	141.44	33.04	24.97	72.09		50	146.50	38.10	22.43	80.25	
55	141.46	33.06	24.96	72.12		55	146.52	38.12	22.40	80.36	
60	141.53	33.13	24.88	72.35		60	146.60	38.20	22.44	80.21	
70	141.65	33.25	24.77	72.67		70	146.67	38.27	22.47	80.11	
80	141.79	33.39	24.90	72.29		80	146.75	38.35	22.46	80.14	
90	141.89	33.49	24.89	72.32		90	146.85	38.45	22.42	80.29	
100	141.89	33.49	24.97	72.09		100	146.90	38.50	22.48	80.07	

Official BH No.:	10211	District:	Ghanzi
Date of test commencement:	21.11.2005	Location:	Ncojane
Time of test Commencement:	0700hrs	BH depth (m):	250
Date of test completion:	21.11.2005	Screens(m)	188.89 - 244
Time of test Completion:	1900hrs	Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	10210	Height of MP above ground:	1.25
Distance to OB. BH (m)	10	Static water level before test (m):	108.4
Casing diameter (mm)	203	Water strike	199.5 and 224 m
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	445822	Northing	7438983

STEP No. 5 | STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments
0.25	138.22	29.82				0.25	142.93	34.53			
0.5	138.34	29.94				0.5	143.36	34.96			
1	138.50	30.10	26.28	68.49		1	143.49	35.09	21.84	82.42	
1.5	138.64	30.24			adj	1.5	143.68	35.28			
2	138.94	30.54	24.69	72.90		2	143.80	35.40	22.48	80.07	
2.5	139.04	30.64				2.5	144.09	35.69			
3	139.14	30.74	24.86	72.41		3	144.14	35.74	22.50	80.00	
4	139.31	30.91	24.89	72.32		4	144.47	36.07	22.56	79.79	
5	139.45	31.05	24.87	72.38		5	144.70	36.30	22.61	79.61	
6	139.52	31.12	24.88	72.35		6	144.84	36.44	22.46	80.14	
7	139.60	31.20	24.48	73.53		7	144.91	36.51	22.44	80.21	
8	139.66	31.26	24.90	72.29		8	145.06	36.66	22.52	79.93	
9	139.90	31.50	24.36	73.89		9	145.19	36.79	22.64	79.51	
10	140.09	31.69	24.72	72.82		10	145.32	36.92	22.51	79.96	
11	140.24	31.84	24.64	73.05		11	145.39	36.99	22.45	80.18	
12	140.40	32.00	24.72	72.82		12	145.55	37.15	22.53	79.89	
13	140.44	32.04	24.68	72.93		13	145.58	37.18	22.47	80.11	
14	140.49	32.09	24.78	72.64		14	145.64	37.24	22.45	80.18	
15	140.54	32.14	24.82	72.52		15	145.70	37.30	22.48	80.07	
20	140.80	32.40	24.49	73.50		20	145.91	37.51	22.54	79.86	
25	140.96	32.56	24.47	73.56		25	146.00	37.60	22.48	80.07	
30	141.08	32.68	24.96	72.12		30	146.11	37.71	22.50	80.00	
35	141.14	32.74	24.88	72.35		35	146.19	37.79	22.63	79.54	
40	141.29	32.89	24.90	72.29		40	146.45	38.05	22.40	80.36	
45	141.37	32.97	24.95	72.14		45	146.46	38.06	22.45	80.18	
50	141.44	33.04	24.97	72.09		50	146.50	38.10	22.43	80.25	
55	141.46	33.06	24.96	72.12		55	146.52	38.12	22.40	80.36	
60	141.53	33.13	24.88	72.35		60	146.60	38.20	22.44	80.21	
70	141.65	33.25	24.77	72.67		70	146.67	38.27	22.47	80.11	
80	141.79	33.39	24.90	72.29		80	146.75	38.35	22.46	80.14	
90	141.89	33.49	24.89	72.32		90	146.85	38.45	22.42	80.29	
100	141.89	33.49	24.97	72.09		100	146.90	38.50	22.48	80.07	

Official BH NO :	10211	District :	Ghanzi
Date of test commencement :	22.11.2005	Location :	Ncojane
Time of test commencement :	0900hrs	BH depth(m) :	250
Date of test completion	25.11.2005	Screen Interval (m)	188.89 - 244
Time of test completion :	0900hrs	Depth of pump intake (m) :	150m
Method of water level measurement	electrical dipper	Description of MP	top of dipper tubing
OB BH NO:	10210	Height of MP above ground(m) :	0.75m
Distance ob BH r (m)	10	Static Water level before test(m) :	109.10
Casing diameter (mm)	203	Water strike	199.5 and 224 m
Orifice plate diameter	4"	Delivery pipe diameter	102mm
Easting	445822	Northing	7438983

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500l	Q(m^3/h)	Temp (^{0}C)	EC (µs/Cm)	pH	Manometer (cm) /DO
	0.25	109.60	0.50						
	0.5	111.50	2.40						
	1	117.66	8.56						
	2	119.95	10.85	25.55	70.45				
	3	123.90	14.80	25.60	70.31				
	4	125.90	16.80	25.54	70.48				
	5	126.80	17.70	25.66	70.15				
	6	127.89	18.79	25.51	70.56				
	7	128.42	19.32	25.48	70.64				
	8	129.22	20.12	25.55	70.45				
	9	129.81	20.71	25.64	70.20				
	10	130.27	21.17	25.61	70.29				
	11	130.56	21.46	25.54	70.48				
	12	131.13	22.03	25.55	70.45				
	15	131.95	22.85	25.53	70.51				
	20	133.10	24.00	25.64	70.20				
	25	133.98	24.88	25.61	70.29	29.1	820	7.56	25
	30	134.66	25.56	25.63	70.23	29.1	820	7.57	25
	40	135.78	26.68	25.66	70.15	29.0	820	7.57	25
	45	137.12	28.02	25.65	70.18	29.2	820	7.57	25
	50	137.68	28.58	25.62	70.26	29.2	820	7.57	25
	60	138.14	29.04	25.64	70.20	29.4	820	7.57	25
	75	138.67	29.57	25.60	70.31	29.4	820	7.57	25
	90	139.02	29.92	25.63	70.23	29.4	820	7.57	25
	105	139.37	30.27	25.64	70.20	29.4	820	7.57	25
	120	139.53	30.43	25.62	70.26	29.6	850	7.77	25
	150	139.86	30.76	25.60	70.31	29.6	850	7.77	25
	180	140.01	30.91	25.60	70.31	29.6	850	7.77	25
	210	140.15	31.05	25.56	70.42	29.7	820	7.66	25
	240	140.23	31.13	25.62	70.26	29.7	820	7.66	25
	270	140.43	31.33	25.63	70.23	29.8	830	7.66	25
	300	140.55	31.45	25.56	70.42	30.6	780	7.68	25
	330	140.62	31.52	25.65	70.18	30.4	780	7.68	25
	360	140.74	31.64	25.70	70.04	30.4	780	7.68	25
	390	140.80	31.70	25.54	70.48	30.2	780	7.68	25
	420	140.89	31.79	25.62	70.26	29.3	860	7.73	25
	450	141.10	32.00	25.68	70.09	29.2	840	7.70	25
	480	141.15	32.05	25.63	70.23	29.1	840	7.70	25
	540	141.34	32.24	25.69	70.07	29.5	820	7.66	25
	600	141.47	32.37	25.61	70.29	28.9	850	7.74	24
	660	141.63	32.53	25.68	70.09	28.9	860	7.77	25
	720	141.65	32.55	25.63	70.23	28.9	870	7.78	25
	780	141.66	32.56	25.60	70.31	29.0	880	7.76	25
	840	141.82	32.72	25.58	70.37	27.8	880	7.77	25
	900	141.91	32.81	25.66	70.15	27.6	860	7.78	25
	960	142.04	32.94	25.64	70.20	27.4	870	7.77	25
	1020	142.18	33.08	25.58	70.37	27.4	880	7.79	25
	1080	142.26	33.16	25.70	70.04	27.2	820	7.76	25
	1140	142.33	33.23	25.61	70.29	27.1	860	7.75	25
	1200	142.53	33.43	25.63	70.23	27.5	870	7.73	25
	1260	142.58	33.48	25.67	70.12	27.3	880	7.71	25

	1320	142.61	33.51	25.69	70.07	27.7	860	7.70	25
	1380	142.63	33.53	25.62	70.26	27.9	840	7.69	DO2 3.25
	1440	142.63	33.53	25.64	70.20	28.2	870	7.71	25
	1500	142.70	33.60	25.66	70.15	29.5	820	7.73	25
	1560	142.73	33.63	25.60	70.31	30.0	820	7.77	25
	1620	142.74	33.64	25.68	70.09	30.3	770	7.70	25
	1680	142.75	33.65	25.58	70.37	30.0	780	7.74	25
	1740	142.79	33.69	25.62	70.26	30.1	840	7.76	25
	1800	142.85	33.75	25.70	70.04	29.8	820	7.77	25
	1860	142.88	33.78	25.66	70.15	29.5	830	7.76	25
	1920	142.88	33.78	25.62	70.26	29.4	790	7.73	25
	1980	142.89	33.79	25.70	70.04	29.1	820	7.73	25
	2040	143.27	34.17	25.67	70.12	29.4	840	7.77	25
	2100	143.28	34.18	25.58	70.37	29.3	860	7.76	25
	2160	143.29	34.19	25.66	70.15	29.6	840	7.73	25
	2220	143.29	34.19	25.70	70.04	29.7	860	7.79	25
	2280	143.30	34.20	25.65	70.18	29.6	840	7.78	25
	2340	143.31	34.21	25.60	70.31	29.8	880	7.74	25
	2400	143.39	34.29	25.69	70.07	29.5	870	7.77	25
	2460	143.43	34.33	25.62	70.26	29.0	880	7.74	25
	2520	143.49	34.39	25.68	70.09	29.3	820	7.76	25
	2580	143.55	34.45	25.63	70.23	29.0	840	7.77	25
	2640	143.64	34.54	25.66	70.15	29.4	830	7.77	25
	2700	143.64	34.54	25.69	70.07	29.3	840	7.76	25
	2760	143.68	34.58	25.62	70.26	29.1	830	7.76	25
	2820	143.70	34.60	25.61	70.29	29.4	880	7.75	25
	2880	143.72	34.62	25.66	70.15	29.3	870	7.74	25
	2940	143.74	34.64	25.68	70.09	29.5	770	7.86	25
	3000	143.77	34.67	25.70	70.04	29.6	840	7.77	25
	3060	143.77	34.67	25.58	70.37	29.8	770	7.86	25
	3120	143.77	34.67	25.70	70.04	29.8	840	7.84	25
	3180	143.77	34.67	25.60	70.31	29.9	860	7.88	25
	3240	143.77	34.67	25.66	70.15	29.8	840	7.77	25
	3300	143.77	34.67	25.65	70.18	29.7	860	7.88	25
	3360	143.79	34.69	25.63	70.23	29.6	840	7.77	25
	3420	143.80	34.70	25.70	70.04	29.4	860	7.88	25
	3480	143.83	34.73	25.58	70.37	29.3	840	7.74	25
	3540	143.87	34.77	25.71	70.01	29.2	880	7.77	25
	3600	143.88	34.78	25.66	70.15	29.1	870	7.74	25
	3660	143.89	34.79	25.68	70.09	29.0	770	7.88	25
	3720	143.94	34.84	25.60	70.31	29.0	820	7.74	25
	3780	143.99	34.89	25.62	70.26	29.0	840	7.77	25
	3840	144.05	34.95	25.65	70.18	29.0	770	7.72	25
	3900	144.10	35.00	25.60	70.31	28.9	840	7.77	25
	3960	144.12	35.02	25.62	70.26	28.9	760	7.77	25
	4020	144.15	35.05	25.68	70.09	28.9	740	7.84	25
	4080	144.15	35.05	25.67	70.12	28.7	730	7.81	25
	4140	144.15	35.05	25.62	70.26	28.6	740	7.84	25
	4200	144.16	35.06	25.68	70.09	28.5	730	7.80	25
	4260	144.16	35.06	25.69	70.07	28.5	720	7.81	25
	4320	144.21	35.11	25.69	70.07	28.5	710	7.80	25

Table 14-7 Recovery Test Data – BH10211

Official BH NO :	10211	District :	Ghanzi
Date of test commencement :	25.11.05	Location :	Ncojane
Time of test commencement :	0900hrs	BH depth(m) :	250
Date of test completion	26.11.05	Screen Int (m)	188.89 - 244
Time of test completion :	0900hrs	Depth of pump intake (m) :	150
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	10210	Height of MP above ground(m) :	0.75
Dist.to Ob Bh:	10	Static Water level before test(m) :	109.1
Casing diameter (mm)	203	Water strike	199.5 and 224 m
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	445822	Northing	7438983

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	144.21	35.11
	0.25	143.90	34.80
	0.5	140.88	31.78
	1	132.28	23.18
	2	128.97	19.87
	3	127.69	18.59
	4	126.32	17.22
	5	125.25	16.15
	6	124.56	15.46
	7	123.69	14.59
	8	122.96	13.86
	9	122.27	13.17
	10	121.90	12.80
	12	120.84	11.74
	15	120.05	10.95
	20	119.05	9.95
	25	118.10	9.00
	30	117.79	8.69
	40	116.74	7.64
	50	116.35	7.25
	60	116.12	7.02
	75	115.14	6.04
	90	114.96	5.86
	105	114.75	5.65
	120	114.55	5.45

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	114.07	4.97
	180	113.87	4.77
	210	113.48	4.38
	240	113.15	4.05
	270	113.02	3.92
	300	112.96	3.86
	330	112.90	3.80
	360	112.74	3.64
	390	112.62	3.52
	420	112.50	3.40
	450	112.41	3.31
	480	112.29	3.19
	540	112.16	3.06
	600	112.00	2.90
	660	111.94	2.84
	720	111.79	2.69
	780	111.70	2.60
	840	111.62	2.52
	900	111.56	2.46
	960	111.49	2.39
	1020	111.37	2.27
	1080	111.28	2.18
	1140	111.19	2.09
	1200	111.12	2.02
	1260	111.05	1.95
	1320	110.99	1.89
	1380	110.91	1.81
	1440	110.88	1.78

Table 14-8 Observation Borehole Data – BH10210

Official BH NO :	10210	District :	Ghanzi
Date of test commencement :	22.11.05	Location :	Ncojane
Time of test commencement :	0900hrs	BH depth(m) :	250
Date of test completion	25.11.05	Screen Interval (m)	192.83 - 244.07
Time of test completion :	0900hrs	Depth of pump intake (m) :	NA
Method of water level measurement	dipper	Description of MP	top of dipper tubing
Pumping BH NO:	10211	Height of MP above ground(m) :	0.25m
Distance to Pumping BH r (m)	10	Static Water level before test(m) :	109.45
Casing diameter (mm)	50	Water strike	195.22 and 218
Orifice plate diameter	NA	Delivery pipe diameter	NA
Easting	445830	Northing	7439010

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500l	$Q(m^3/h)$	Temp (^0C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO
	0.25	110.10	0.65						
	0.5	111.13	1.68						
	1	112.19	2.74						
	2	114.68	5.23						
	3	114.87	5.42						
	4	114.89	5.44						
	5	114.92	5.47						
	6	117.53	8.08						
	7	117.98	8.53						
	8	118.50	9.05						
	9	118.88	9.43						
	10	119.41	9.96						
	11	119.56	10.11						
	12	120.13	10.68						
	15	120.78	11.33						
	20	121.91	12.46						
	25	122.58	13.13						
	30	123.15	13.70						
	40	123.73	14.28						
	45	123.80	14.35						
	50	125.16	15.71						
	60	125.63	16.18						
	75	126.23	16.78						
	90	126.54	17.09						
	105	126.78	17.33						
	120	127.01	17.56						
	150	127.45	18.00						
	180	127.60	18.15						
	210	127.83	18.38						
	240	128.10	18.65						
	270	128.16	18.71						
	300	128.35	18.90						
	330	128.42	18.97						
	360	128.54	19.09						
	390	128.65	19.20						
	420	128.77	19.32						
	450	128.89	19.44						
	480	129.10	19.65						
	540	129.18	19.73						
	600	129.33	19.88						
	660	129.50	20.05						
	720	129.54	20.09						
	780	129.62	20.17						
	840	129.82	20.37						
	900	129.97	20.52						
	960	130.04	20.59						
	1020	130.17	20.72						
	1080	130.23	20.78						
	1140	130.33	20.88						
	1200	130.45	21.00						
	1260	130.50	21.05						
	1320	130.70	21.25						
	1380	130.73	21.28						
	1440	130.74	21.29						
	1500	130.80	21.35						
	1560	130.80	21.35						
	1620	130.80	21.35						

	1680	130.80	21.35						
	1740	130.81	21.36						
	1800	130.87	21.42						
	1860	130.90	21.45						
	1920	130.93	21.48						
	1980	130.96	21.51						
	2040	131.18	21.73						
	2100	131.20	21.75						
	2160	131.20	21.75						
	2220	131.20	21.75						
	2280	131.22	21.77						
	2340	131.29	21.84						
	2400	131.38	21.93						
	2460	131.42	21.97						
	2520	131.46	22.01						
	2580	131.52	22.07						
	2640	131.59	22.14						
	2700	131.59	22.14						
	2760	131.61	22.16						
	2820	131.62	22.17						
	2880	131.63	22.18						
	2940	131.73	22.28						
	3000	131.77	22.32						
	3060	131.77	22.32						
	3120	131.77	22.32						
	3180	131.77	22.32						
	3240	131.77	22.32						
	3300	131.77	22.32						
	3360	131.90	22.45						
	3420	131.91	22.46						
	3480	131.90	22.45						
	3540	131.90	22.45						
	3600	131.94	22.49						
	3660	131.98	22.53						
	3720	132.03	22.58						
	3780	132.05	22.60						
	3840	132.08	22.63						
	3900	132.11	22.66						
	3960	132.14	22.69						
	4020	132.18	22.73						
	4080	132.21	22.76						
	4140	132.22	22.77						
	4200	132.23	22.78						
	4260	132.39	22.94						
	4320	132.44	22.99						

Table 14-9 Observation Borehole Data – BH10210 (Recovery Test)

Official BH NO :	10210	District :	Ghanzi
Date of test commencement :	25.11.05	Location :	Ncojane
Time of test commencement :	0900hrs	BH depth(m) :	250
Date of test completion	26.11.05	Screen Int (m)	192.83 - 244.07
Time of test completion :	0900hrs	Depth of pump intake (m) :	n/a
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
Pumping BH. No.:	10211	Height of MP above ground(m) :	0.95
Dist.to Pumping Bh:	10	Static Water level before test(m) :	109.45
Casing diameter (mm)	50	Water strike	195.22 and 218
Orifice plate diameter	NA	Delivery pipe diameter	NA
Easting	445830	Northing	7439010

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	132.44	22.99
	0.25	132.25	22.80
	0.5	132.25	22.80
	1	132.20	22.75
	2	128.30	18.85
	3	126.87	17.42
	4	125.95	16.50
	5	124.94	15.49
	6	124.22	14.77
	7	123.29	13.84
	8	122.53	13.08
	9	122.24	12.79
	10	121.92	12.47
	12	121.50	12.05
	15	120.24	10.79
	20	119.26	9.81
	25	118.55	9.10
	30	118.02	8.57
	40	117.32	7.87
	50	115.99	6.54
	60	115.66	6.21
	75	115.48	6.03
	90	115.39	5.94
	105	115.19	5.74
	120	115.00	5.55

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	114.57	5.12
	180	114.27	4.82
	210	114.04	4.59
	240	113.25	3.80
	270	113.50	4.05
	300	113.36	3.91
	330	113.28	3.83
	360	113.06	3.61
	390	112.98	3.53
	420	112.90	3.45
	450	112.78	3.33
	480	112.61	3.16
	540	112.52	3.07
	600	112.38	2.93
	660	112.26	2.81
	720	112.14	2.69
	780	112.08	2.63
	840	112.00	2.55
	900	111.94	2.49
	960	111.86	2.41
	1020	111.79	2.34
	1080	111.68	2.23
	1140	111.57	2.12
	1200	111.49	2.04
	1260	111.40	1.95
	1320	111.38	1.93
	1380	111.37	1.92
	1440	111.24	1.79

15 BH10210

BH10210 is a monitoring piezometer with siting reference **S4**, line R3, peg 9000m and TEM 63 and was drilled to explore the Ecca aquifer northeast of fault **F4**. This piezometer will also allow for the determination of the storativity of the Ecca aquifer during the pump testing of the test production borehole (BH10211) at this site. The initial borehole drilled at this site was abandoned (grouted to surface) because the contractor could not salvage it. This was because the borehole was left open for a long time and it collapsed below 146 m. This borehole is located about 20 km east of Ncojane Village. Drilling operations at this site commenced on 12 October and was completed on 27 October 2005.

15.1 SITING CRITERIA AND DRILLING OBJECTIVES

This piezometer was drilled to explore the potential of Ecca aquifer near or to the east of fault F4, and will also provide aquifer hydraulic data (transmissivity and storativity) for the Ecca as well as providing water level data.

15.2 DRILLING RESULTS

The borehole was drilled through various lithologies including fine grained sand, calcrete, mudstones, dolerite, coal and fine to medium grained micaceous sandstone and fine to medium grained sandstones (**Figure 15-1**). Drilling of BH10210 was carried out with a 10 inch bit using the DTH drilling technique down to a depth of 80m bgl after which 8 inch plain casings were installed and grouted. Drilling between 80 to 195m was accomplished using an 8 inch drilling bit after which 6.5 inch casings were installed and grouted. Drilling was by a 6.5 inch DTH bit to depth of 219 m after which a 6.25 tricone bit was utilised to complete the borehole to the terminal depth of 250 m due to back pressure problems.

During drilling of this borehole, three water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the three water strikes are as follows;

1. (60m, Unmeasurable)
2. (195m, 700 µS/cm, 22 m^3/hr)
3. (218m, 790 µS/cm, 3 m^3/hr)

The cumulative yield at the end of drilling was 25m^3/hr and the electrical conductivity was 800µS/cm

After completion of drilling, the borehole was constructed using 2 inch plain PVC casings and screens. The 2 inch plain casings were installed between 0 to 192.83m and 244.07 to 247m and the screens were installed between 192.83 and 244.07m, representing a zone of 51.24m. The annulus between 2 inch assembly and the 6.5 inch hole was gravel packed from 182.83m to 250m. A 3m thick bentonite seal was installed between 179.83m and 182.83m after which the remaining annulus was cement grouted to the surface. A short duration development was carried out and the static water level after borehole was completed was 108.26 m bgl.

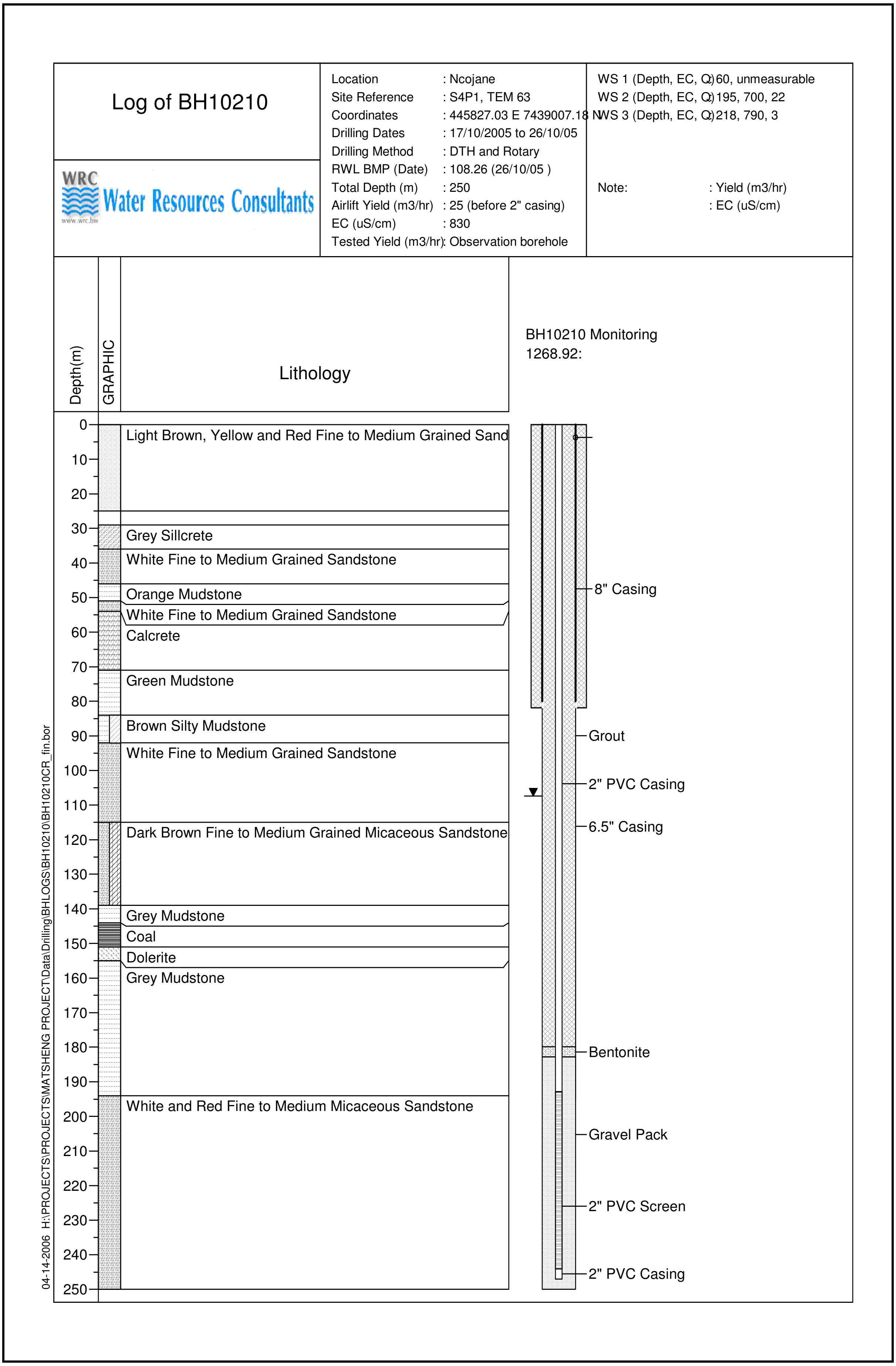

Figure 15-1 Log of BH10210

16 BH10212

BH10212 is an exploration borehole with a siting reference **S15,** line R10, peg 19 000m and TEM 140. It is located about 40 km south-west of Metsimantsho Village. Drilling of this borehole commenced on 27 November 2005 and was completed on 17 January 2006 at a depth of 268 m.

16.1 SITING CRITERIA AND DRILLING OBJECTIVES

This exploration borehole was drilled to explore the relatively undisturbed Ecca aquifer near fault **F6** and to assess Ecca aquifer overlain by dolerite. It will also generate water level data in this locality.

16.2 DRILLING RESULTS

Various lithologies including fine grained sands, dolerite, mudstones, siltstones and fine to medium grained sandstones were intercepted during drilling of this exploration borehole (**Figure 16-1**). Drilling was carried out with a 15 inch bit using the DTH drilling technique from 0 to 74 m bgl and 12 inch plain casings were installed and cement grouted. From 74 to 200 m, drilling was carried out using a 12 inch drilling bit after which 10 inch casings were installed and cement grouted. A 10 inch DTH bit was used to drill from 200 m to the terminal depth of 268 m.

During drilling of this borehole, four water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^O V-notch weir) for the four water strikes are as follows;

1. (144m, 5940 µS/cm, Not measurable)
2. (155m, 6950 µS/cm, 7 m^3/hr)
3. (223m, 2850 µS/cm, 4 m^3/hr)
4. (249m, 1330 µS/cm, 26 m^3/hr)

The top two water strikes were sealed off due to their saline nature and the cumulative yield at the end of drilling before installation of the casing and screens assembly was 25 m^3/hr.

The borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 252.8m but has to be re-logged (natural gamma) due to the poor data quality caused by probe malfunctioning. The borehole was constructed using 8 inch steel casings and factory slotted screen (intervals 229.495 to 235.62 m bgl and 241.75 to 254 m bgl) assembly.

The borehole was developed using the air lifting method for 3 hours and the final airlift yield measured on 90^o V-Notch weir was 25m^3/hr and the electrical conductivity was 1220µS/cm. The static water level was 102.67 m bgl, measured on 17 January 2006. Water samples were collected at different water strikes during drilling of BH10212. The samples collected at the water strikes were submitted to the DWA laboratory for chemical analysis and results are shown on **Table 16-1**.

Table 16-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10212	155	7.5	4600	109.00	126.5	1474	220	2999.51	873.89	53.99	0		541.55	0.05	0.08	KuleSST
10212	223	8.14	1838	17.74	12.91	695	6.69	580.93	514.45				613.66	0.03	0.08	MUD 2
10212	249	7.81	766	8.90	2.73	310.5	2.703	162.01	76.81	10.78	1.98	0	573.68	0.00	5.33	SST 2
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

After successfully carrying out the verticality and alignment tests, the borehole was capped and a cement slab was constructed.

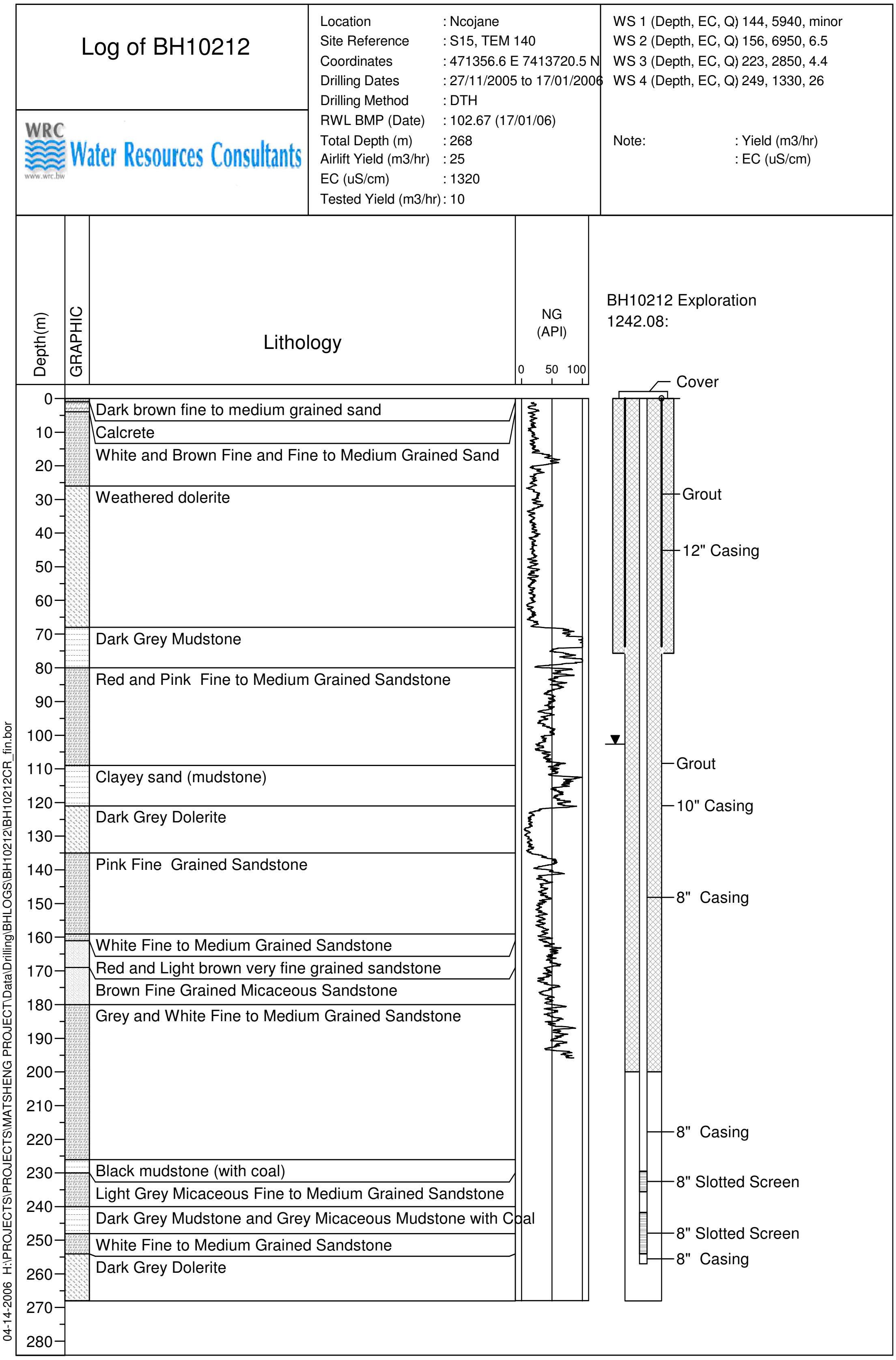

Figure 16-1 Log of BH10212

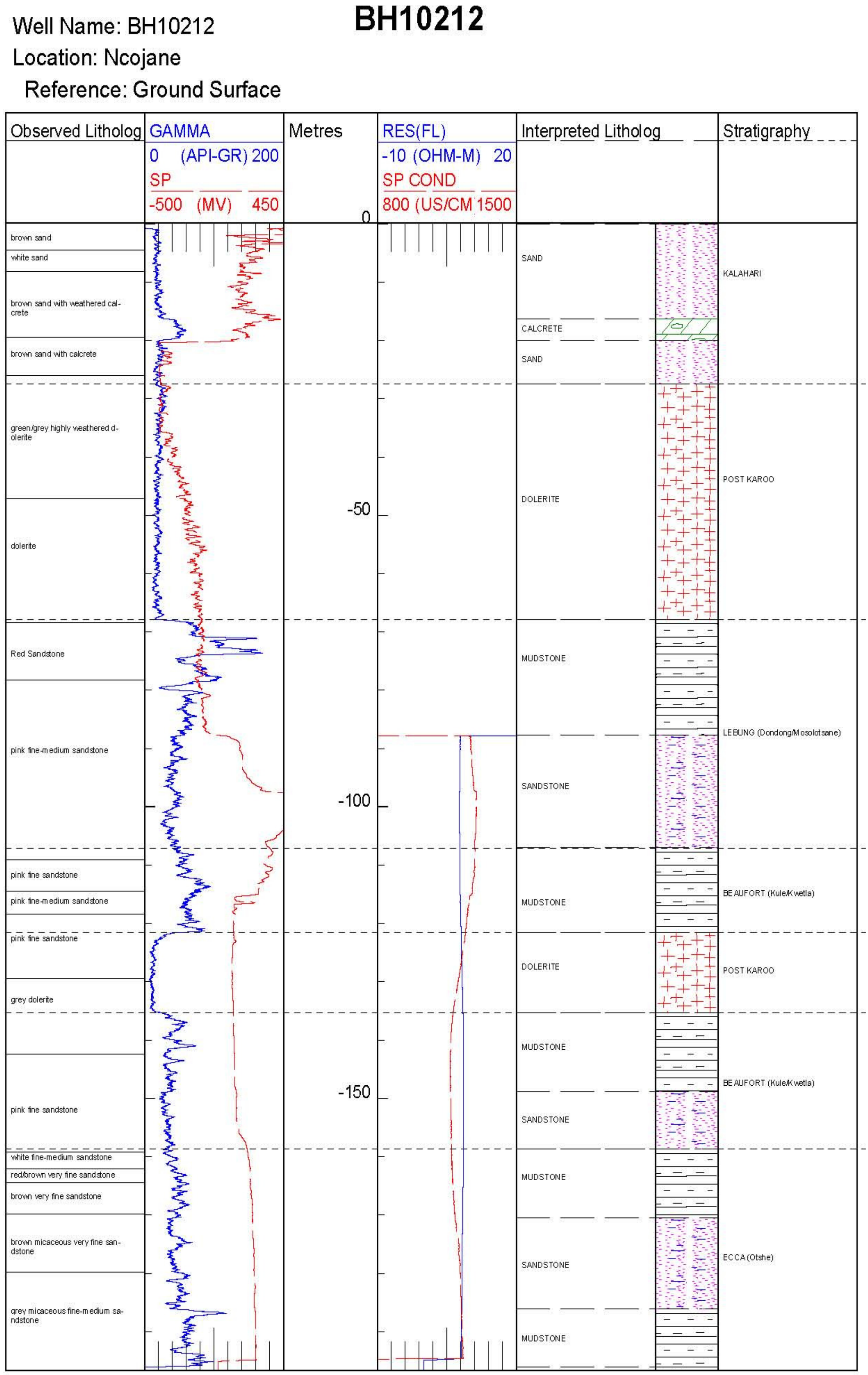

Figure 16-2 Geophysical log of BH10212

16.3 PUMP TESTING RESULTS

Borehole BH10212 was pump tested between 6 and 12 February 2006. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.36 m above ground level (agl) and the pump intake was set at 168.5 m below ground level. The summary details for the pumping test are given in **Table 16-2**. The collected pump testing data is presented in **Tables 16-5 to 16-9.**

Table 16-2 Summary of Pumping Test Data BH10212

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	7.64	8.7
	2	15	17.88	16.1
	3	15	29.41	24.1
	4	15	47.59	35.4
	5	15	60.67	45.3
	6	9	77.59	59.7
Step Test	1	100	15.92	10.1
	2	100	41.65	20.4
	3	100	59.49	25.1
	4	60	70.38	30.2
	1	100	11.12	8
	2	100	20.13	12.1
	3	100	32.97	16.1
	4	100	48.90	20.1
	5	100	60.28	24.1
Constant Rate	1	2880	57.51	12
Recovery*	1	1440	1.68	0

Note. 1.68 Residual Drawdown*

16.3.1 Step Drawdown Test

An initial step drawdown test was carried out on 7 February 2006. The static water level before the start of the test was 94.3 m bmp. The step drawdown test consisted of 3 steps of 100 minutes duration at discharge rates of 10.1, 20.4 and 25.1 m^3/hr, respectively for steps 1 to 3. A fourth step at 24 m^3/hr lasted for 60 minutes only and it was decided to repeat the step test in order to get the requisite 4 steps. The step test was repeated on 8 February 2006 and the static water level before the start of this test was 102.56 m bmp. The step drawdown test consisted of 5 steps of 100 minutes duration at discharge rates of 8, 12.1, 16.1, 20.1 and 24.1 m^3/hr, respectively for steps 1 to 5.

The data for the second step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test data using this method is plotted in **Figure 16-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q (**Figure 16.4**). The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 25 m^2/d (**Figure 16-5**). The interpreted step data is summarised in **Table 16-3**.

Table 16-3 Results of Step Test Analysis BH10212

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10215	4.08E-02	4.78E-06	30.8	15.2	15.70	15.70	0.97
				21.3	6.48	22.18	0.96
				25.9	4.75	26.93	0.96
				30.2	3.91	30.84	0.98
				35.2	8.24	39.08	0.90

The planned duration for the constant rate test of this borehole was 2 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 16-3**) to estimate the expected total drawdown after 3 days of pumping. A discharge rate of 12 m^3/hr was selected as an optimal rate for the CRT because at higher rates the slopes were very steep due to the close proximity of fault **F6**.

16.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 9 and 11 February 2006 at a discharge rate of 12m^3/hr and the total drawdown after 48 hrs of pumping was 57.51 m. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 1.68 m.

Data from this borehole was interpreted using the Theis and Cooper-Jacob (1946) analytical solutions using the computer programme "Aqtesolv". Transmissivity (T) value obtained by these two analytical solutions was 5 m^2/d. The recovery data was analysed using the Theis recovery solution and a T value of 3 m^2/d was obtained. The interpretation of the results are summarised in **Table 16-4** and the interpreted data is presented in **Figures 16-6 to 16-8**.

There is an apparent impermeable barrier interpreted in the CRT data after 100 minutes of pumping, **Figure 16-6**. This barrier is probably caused by fault **F6** which is close to BH10212.

Table 16-4 Summary of Constant Rate and Recovery Tests BH10212

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10212	48	288	a) 4.8 b) 4.7	d) 3.3	Confined

Notes:
Interpretation Techniques
a) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

16.3.2.1 Aquifer Type interpreted

The aquifer type determined from the pump testing interpretation is confined.

16.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis, for most of the BOS 32:2000 listed determinants. In addition to these, some samples collected were submitted for stable and radioactive (^{14}C) isotope analysis at the CSIR laboratory in Pretoria, South Africa

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), pH and dissolved oxygen are 28.9 ^{o}C, 1290 µS/cm, 8.4 and 1.65 mg/L respectively. The results of the CSIR laboratory analysis are shown in **Table 16-5**.

The results show that all the analysed parameters are within the Class II BOS32:2000 standards.

Table 16-5 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10212	2.9	315	2.4	2.1	72	98	487	<0.1	1.8	0.07	<0.05	1320	7.7	845
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10212	<0.1	15	<0.13	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

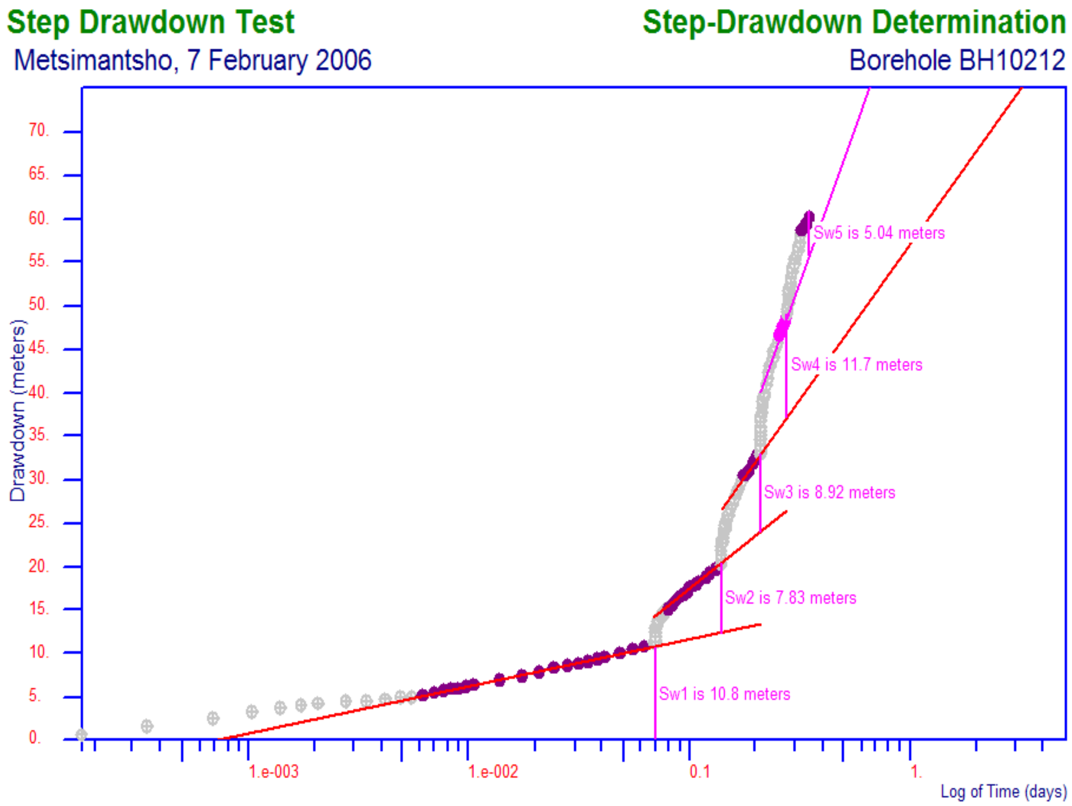

Figure 16-3 Pumping Test Results for BH10212: Step Drawdown Test - Hantush-Bierschenk (semi-log)

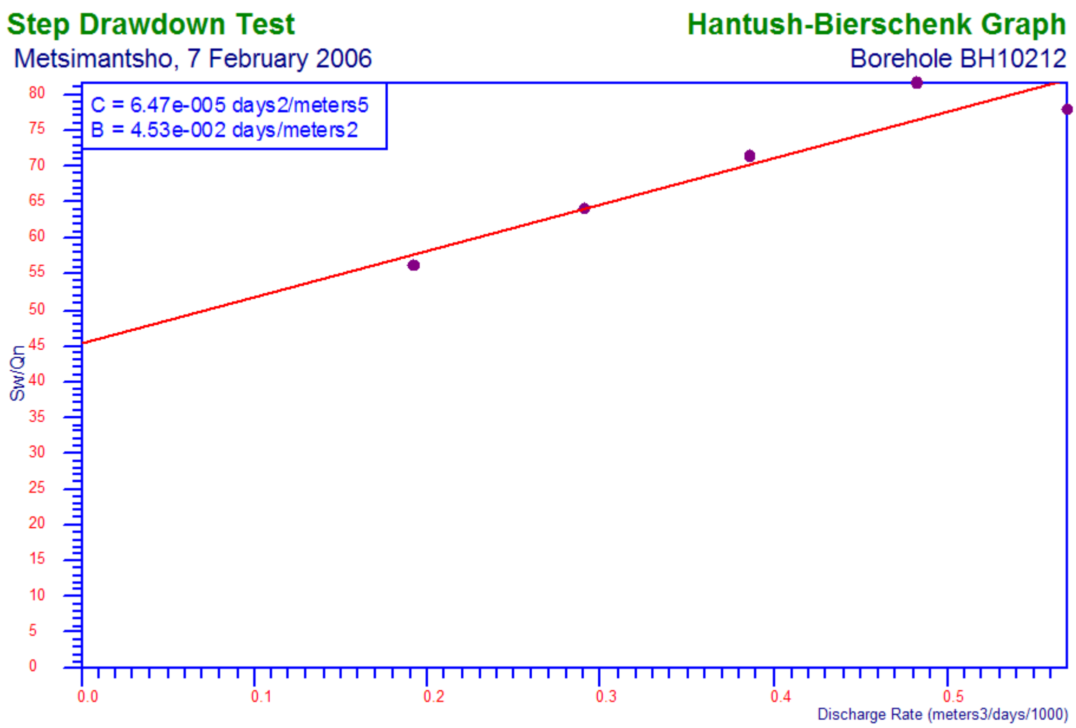

Figure 16-4 Pumping Test Results for BH10212: Step Drawdown Test – Hantush-Bierschenk

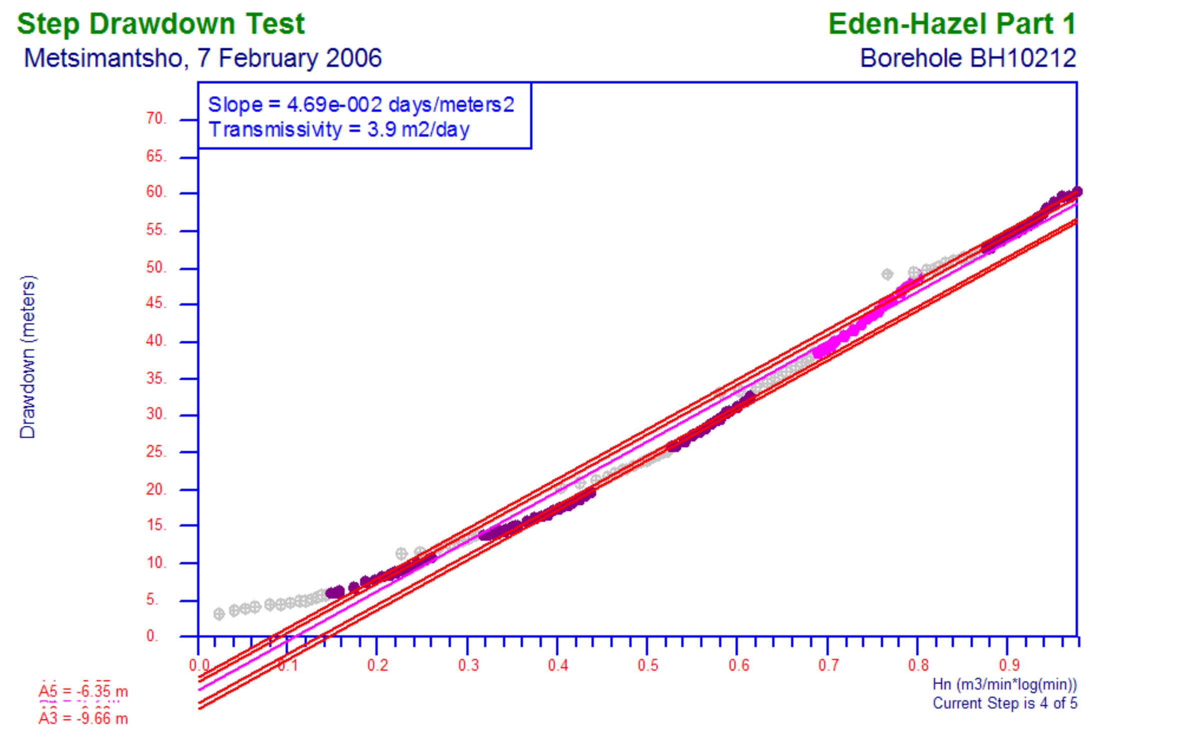

Figure 16-5 Pumping Test Results for BH10212: Step Drawdown Test – Eden-Hazel (Part 1)

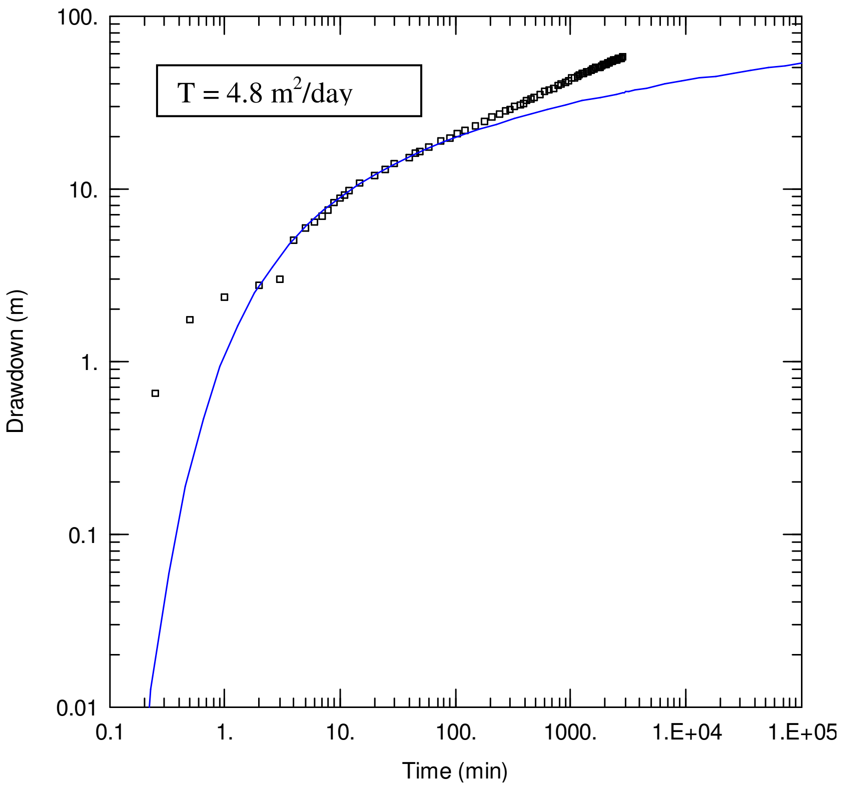

Figure 16-6 Pumping Test Results for BH10212: Theis Solution

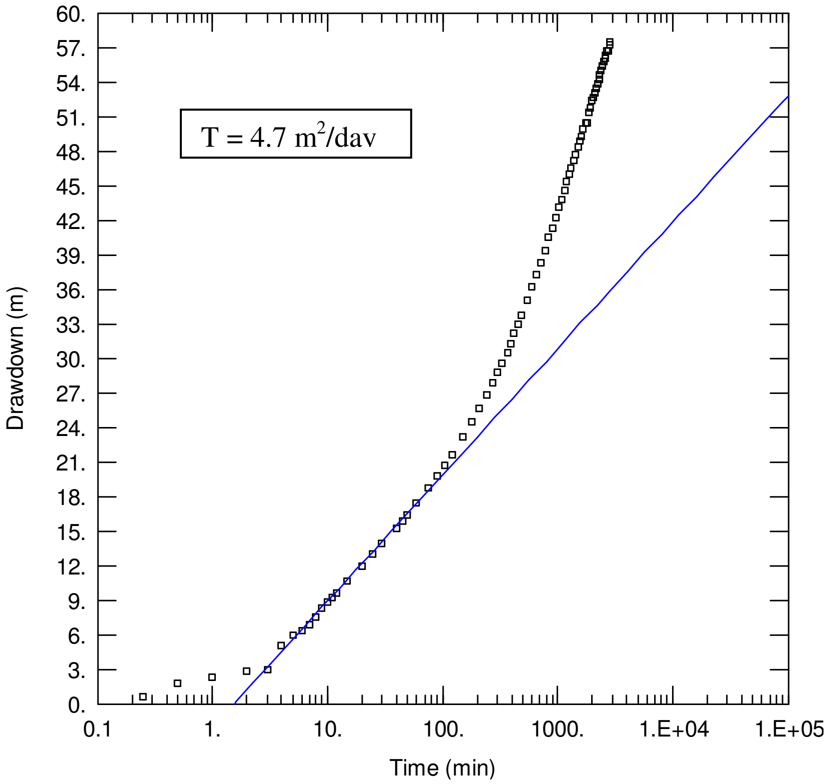

Figure 16-7 Pumping Test Results for BH10212: CRT Cooper Jacob Solution

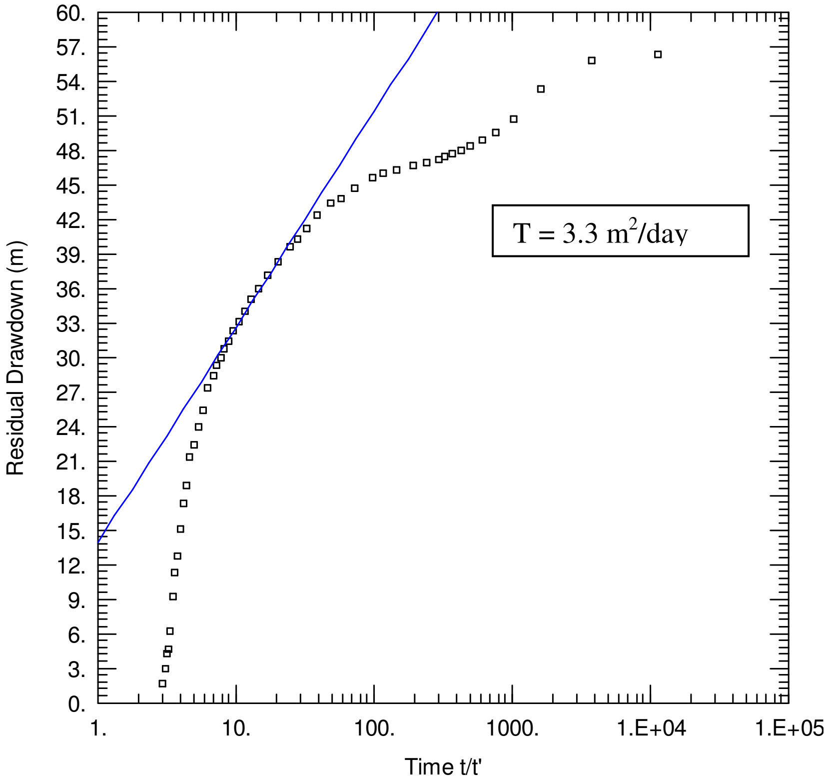

Figure 16-8 Pumping Test Results for BH10212: Theis Recovery Solution

Table 16-6 Calibration Test Data – BH10212

Official BH No.:	10212	District:	Kgalagadi
Date of test commencement:	06.02.06	Location:	Ukhwi
Time of test commencement	2045hrs	BH depth (m):	268
Date of test completion:	06.02.06	Screen Interval (m):	229.5 to 235.62 & 241.75 to 254
Time of test completion	2209hrs	Depth of pump intake (m):	168.5
Method of water level measurement:	dipper	Static water level before test (m):	87.80
Casing diameter (mm)	203.2	Water strike	144, 155, 223 & 249
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	471352	Northing	7413710

STEPNo. 1

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	87.91	0.11			
0.5	89.09	1.29			
1	89.25	1.45			
1.5	90.22	2.42			
2	91.30	3.50			
2.5	92.08	4.28			
3	92.63	4.83			
4	93.05	5.25			
5	93.49	5.69			
6	93.99	6.19			
7	94.08	6.28	18.81	9.57	
8	94.21	6.41	20.75	8.67	
9	94.44	6.64	20.91	8.61	
10	94.36	6.56	20.94	8.60	
11	94.76	6.96	20.97	8.58	
12	94.93	7.13	21.00	8.57	
15	95.44	7.64	21.10	8.53	

STEPNo. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	95.66	7.86			
0.5	95.72	7.92			
1	96.55	8.75	10.97	16.41	
1.5	97.75	9.95			
2	98.61	10.81	11.24	16.01	
2.5	99.31	11.51			
3	100.03	12.23	10.98	16.39	
4	100.98	13.18	11.25	16.00	
5	101.72	13.92	11.15	16.14	
6	102.39	14.59	11.20	16.07	
7	102.87	15.07	11.22	16.04	
8	103.31	15.51	11.17	16.11	
9	103.74	15.94	11.19	16.09	
10	104.15	16.35	11.15	16.14	
11	104.53	16.73	11.10	16.22	
12	104.83	17.03	11.16	16.13	
15	105.68	17.88	11.20	16.07	

STEP No. 3

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	Pumping Rate (m^3/hr)	Comments
0.25	105.97	18.17			
0.5	106.18	18.38			
1	107.52	19.72	7.82	23.02	
1.5	108.57	20.77			
2	109.34	21.54	7.50	24.00	
2.5	110.12	22.32			
3	111.14	23.34	7.41	24.29	
4	112.49	24.69	7.46	24.13	
5	113.14	25.34	7.39	24.36	
6	113.45	25.65	7.48	24.06	
7	113.93	26.13	7.43	24.23	
8	114.58	26.78	7.45	24.16	
9	114.78	26.98	7.47	24.10	
10	115.30	27.50	7.46	24.13	
11	115.55	27.75	7.42	24.26	
12	116.18	28.38	7.45	24.16	
15	117.21	29.41	7.46	24.13	

STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments
0.25	117.52	29.72			
0.5	118.24	30.44			
1	120.58	32.78	9.99	36.04	
1.5	122.03	34.23			
2	123.31	35.51	10.13	35.54	
2.5	124.32	36.52			
3	125.45	37.65	10.18	35.36	
4	126.88	39.08	10.24	35.16	
5	128.07	40.27	10.15	35.47	
6	129.05	41.25	10.19	35.33	
7	129.97	42.17	10.25	35.12	
8	130.75	42.95	10.20	35.29	
9	131.48	43.68	10.23	35.19	
10	132.27	44.47	10.24	35.16	
11	132.85	45.05	10.15	35.47	
12	133.59	45.79	10.24	35.16	
15	135.39	47.59	10.19	35.33	

Official BH No.:	10212	District:	Kgalagadi
Date of test commencement:	06.02.06	Location:	Ukhwi
Time of test commencement	2045hrs	BH depth (m):	268
Date of test completion:	06.02.06	Screen Interval (m):	229.5 to 235.62 & 241.75 to 254
Time of test completion	2209hrs	Depth of pump intake (m):	168.5
Method of water level measurement:	electrical dipper	Static water level before test (m):	87.80
Casing diameter (mm)	203.2	Water strike	144, 155, 223 & 249
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	471352	Northing	7413710

STEP No. 5						STEP No. 6					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	135.86	48.06				0.25	148.89	61.09			
0.5	136.00	48.20				0.5	149.56	61.76			
1	136.69	48.89	11.56	46.71		1	151.09	63.29	12.43	57.92	
1.5	137.88	50.08				1.5	153.04	65.24			
2	138.66	50.86	12.00	45.00		2	155.01	67.21	12.28	58.63	
2.5	139.36	51.56				2.5	156.11	68.31			
3	140.09	52.29	11.94	45.23		3	157.43	69.63	12.09	59.55	
4	141.03	53.23	11.95	45.19		4	159.51	71.71	11.99	60.05	
5	142.10	54.30	11.89	45.42		5	161.24	73.44	11.95	60.25	
6	142.94	55.14	11.96	45.15		6	162.39	74.59	11.97	60.15	
7	143.69	55.89	11.99	45.04		7	163.34	75.54	11.95	60.25	
8	144.41	56.61	11.97	45.11		8	164.32	76.52	11.89	60.56	
9	145.07	57.27	11.90	45.38		9	165.39	77.59	11.94	60.30	
10	145.70	57.90	11.93	45.26		10	suction				
11	146.36	58.56	11.92	45.30		11					
12	146.89	59.09	11.95	45.19		12					
15	148.47	60.67	11.94	45.23		15					

Official BH No.:	10212	District:	Kgalagadi
Date of test commencement:	06.02.06	Location:	Ukhwi
Time of test commencement	2045hrs	BH depth (m):	268
Date of test completion:	06.02.06	Screen Interval (m):	229.5 to 235.62 & 241.75 to 254
Time of test completion	2209hrs	Depth of pump intake (m):	168.5
Method of water level measurement: electrical	dipper	Static water level before test (m):	87.80
Casing diameter (mm)	203.2	Water strike	144, 155, 223 & 249
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	471352	Northing	7413710

STEPNo. 5 | STEPNo. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	135.86	48.06				0.25	148.89	61.09			
0.5	136.00	48.20				0.5	149.56	61.76			
1	136.69	48.89	11.56	46.71		1	151.09	63.29	12.43	57.92	
1.5	137.88	50.08				1.5	153.04	65.24			
2	138.66	50.86	12.00	45.00		2	155.01	67.21	12.28	58.63	
2.5	139.36	51.56				2.5	156.11	68.31			
3	140.09	52.29	11.94	45.23		3	157.43	69.63	12.09	59.55	
4	141.03	53.23	11.95	45.19		4	159.51	71.71	11.99	60.05	
5	142.10	54.30	11.89	45.42		5	161.24	73.44	11.95	60.25	
6	142.94	55.14	11.96	45.15		6	162.39	74.59	11.97	60.15	
7	143.69	55.89	11.99	45.04		7	163.34	75.54	11.95	60.25	
8	144.41	56.61	11.97	45.11		8	164.32	76.52	11.89	60.56	
9	145.07	57.27	11.90	45.38		9	165.39	77.59	11.94	60.30	
10	145.70	57.90	11.93	45.26		10	suction				
11	146.36	58.56	11.92	45.30		11					
12	146.89	59.09	11.95	45.19		12					
15	148.47	60.67	11.94	45.23		15					

Table 16-7 Step Drawdown Test Data - BH10212

Official BH No.:	10212	District:	Kgalagadi
Date of test commencement:	07.2.2006	Location:	Ukhwi
Time of test Commencement:	0700hrs	BH depth (m):	268
Date of test completion:	07.2..2006	Screens(m)	229.5 to 235.62 & 241.75 to 254
Time of test Completion:	1300hrs	Depth to pump intake (m)	168.5
Method of water level measurement:	electrical dipper	Description of MP:	Top of casing
Observation Bh No.:	n/a	Height of MP above ground:	0.36
Distance to OB. BH (m)	n/a	Static water level before test (m):	94.3
Casing diameter (mm)	203	Water strike	144, 155, 223 & 249
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	471352	Northing	7413710

STEP No. 1						STEP No. 2					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments
0.25	95.00	0.70				0.25	110.30	16.00			
0.5	96.31	2.01				0.5	110.65	16.35			
1	97.64	3.34				1	110.78	16.48	8.07	22.30	
1.5	98.21	3.91				1.5	112.54	18.24			
2	99.02	4.72				2	113.94	19.64	8.04	22.39	
2.5	99.45	5.15				2.5	115.08	20.78			
3	99.78	5.48				3	115.87	21.57	8.37	21.51	
4	100.34	6.04	16.50	10.91		4	116.97	22.67	8.92	20.18	
5	100.63	6.33	16.99	10.59		5	118.03	23.73	8.78	20.50	
6	100.96	6.66	16.94	10.63		6	118.75	24.45	8.92	20.18	
7	101.28	6.98	17.74	10.15		7	119.45	25.15	8.88	20.27	
8	101.61	7.31	17.89	10.06		8	119.95	25.65	8.81	20.43	
9	101.89	7.59	17.90	10.06		9	120.48	26.18	8.78	20.50	
10	102.16	7.86	17.91	10.05		10	120.86	26.56	8.89	20.25	
11	102.38	8.08	17.86	10.08		11	121.31	27.01	8.94	20.13	
12	102.75	8.45	17.93	10.04		12	121.75	27.45	8.96	20.09	
13	102.96	8.66	17.89	10.06		13	122.09	27.79	8.99	20.02	
14	103.04	8.74	17.87	10.07		14	122.45	28.15	8.90	20.22	
15	103.21	8.91	17.98	10.01		15	122.78	28.48	8.93	20.16	
20	104.05	9.75	17.85	10.08		20	124.34	30.04	8.97	20.07	
25	104.78	10.48	17.90	10.06		25	125.50	31.20	8.89	20.25	
30	105.38	11.08	17.94	10.03		30	126.48	32.18	8.96	20.09	
35	105.91	11.61	17.89	10.06		35	127.43	33.13	8.94	20.13	
40	106.51	12.21	17.88	10.07		40	128.41	34.11	8.98	20.04	
45	106.89	12.59	17.96	10.02		45	129.31	35.01	8.87	20.29	
50	107.24	12.94	17.99	10.01		50	129.90	35.60	8.95	20.11	
55	107.65	13.35	17.94	10.03		55	130.70	36.40	8.92	20.18	
60	108.01	13.71	17.90	10.06		60	131.34	37.04	8.93	20.16	
70	108.63	14.33	17.99	10.01		70	132.84	38.54	8.95	20.11	
80	109.15	14.85	17.98	10.01		80	133.91	39.61	8.92	20.18	
90	109.72	15.42	17.93	10.04		90	134.97	40.67	8.93	20.16	
100	110.22	15.92	17.90	10.06		100	135.95	41.65	8.99	20.02	

Table 16-8 Constant Rate Test Data – BH10212

Official BH NO :	10212	District :	Kgalagadi
Date of test commencement :	9.2.06	Location :	Ukhwi
Time of test commencement :	1300hrs	BH depth(m) :	268
Date of test completion	11.02.06	Screen Interval (m)	229.5 to 235.62 & 241.75 to 254
Time of test completion :	1300hrs	Depth of pump intake (m) :	168.5m
Method of water level measurement	dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.36
Distance ob BH r (m)	n/a	Static Water level before test(m) :	106.70
Casing diameter (mm)	203.2	Water strike	144, 155, 223 & 249
Orifice plate diameter	4"	Delivery pipe diameter	4"
Easting	471352	Northing	7413710

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 50l	Q(m^3/h)	Temp (^{0}C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO
	0.25	107.35	0.65						Flowmeter 175482
	0.5	108.44	1.74						
	1	109.02	2.32						
	2	109.47	2.77						
	3	109.67	2.97						
	4	111.76	5.06	15.00	12.00				
	5	112.60	5.90	14.94	12.05				
	6	113.05	6.35	14.85	12.12				
	7	113.57	6.87	15.00	12.00				
	8	114.25	7.55	14.79	12.17				
	9	114.98	8.28	14.98	12.02				
	10	115.47	8.77	14.93	12.06				
	11	115.89	9.19	14.81	12.15				
	12	116.33	9.63	14.90	12.08				
	15	117.32	10.62	14.94	12.05	30.5	1180	8.41	10
	20	118.63	11.93	14.87	12.10	29.2	1350	8.51	10
	25	119.64	12.94	14.92	12.06	29.3	1190	8.53	10
	30	120.53	13.83	14.94	12.05	28.2	1240	8.56	10
	40	121.92	15.22	14.89	12.09	28.8	1220	8.56	10
	45	122.57	15.87	14.78	12.18	29.6	1240	8.55	10
	50	123.04	16.34	14.75	12.20	29.5	1230	8.57	10
	60	124.05	17.35	14.97	12.02	29.1	1240	8.52	10
	75	125.38	18.68	14.83	12.14	29.8	1210	8.53	10
	90	126.42	19.72	14.95	12.04	29.9	1190	8.52	10
	105	127.39	20.69	14.79	12.17	29.9	1210	8.43	10
	120	128.28	21.58	14.99	12.01	29.8	1210	8.45	10
	150	129.84	23.14	14.86	12.11	29.9	1180	8.46	10
	180	131.15	24.45	14.77	12.19	29.7	1220	8.51	10
	210	132.35	25.65	14.81	12.15	29.5	1210	8.52	10
	240	133.44	26.74	14.96	12.03	29.7	1190	8.46	10
	270	134.50	27.80	14.84	12.13	29.8	1210	8.42	10
	300	135.45	28.75	14.95	12.04	28.8	1210	8.56	10
	330	136.28	29.58	14.72	12.23	28.2	1230	8.57	10
	360	137.19	30.49	14.96	12.03	27.7	1220	8.54	10
	390	137.98	31.28	14.87	12.10	27.5	1210	8.55	10

	420	138.83	32.13	14.99	12.01	27.4	1220	8.53	10
	450	139.65	32.95	14.75	12.20	27.3	1220	8.54	10
	480	140.41	33.71	14.86	12.11	27.0	1210	8.55	10
	540	141.67	34.97	14.97	12.02	27.1	1210	8.53	10
	600	142.87	36.17	14.81	12.15	27.1	1220	8.57	10
	660	143.91	37.21	14.90	12.08	27.4	1220	8.61	10
	720	144.92	38.22	14.96	12.03	27.6	1210	8.59	10
	780	145.99	39.29	14.93	12.06	28.4	1220	8.60	10
	840	147.18	40.48	14.96	12.03	27.9	1200	8.59	10
	900	147.99	41.29	14.94	12.05	28.4	1200	8.46	10
	960	148.92	42.22	14.96	12.03	27.3	1210	8.44	10
	1020	149.87	43.17	14.99	12.01	27.4	1200	8.49	10
	1080	150.44	43.74	14.96	12.03	27.6	1210	8.46	10
	1140	151.27	44.57	14.90	12.08	27.6	1200	8.47	10
	1200	152.05	45.35	14.99	12.01	27.6	1230	8.59	10
	1260	152.68	45.98	14.96	12.03	27.4	1220	8.61	10
	1320	153.24	46.54	14.94	12.05	28.4	1250	8.56	10
	1380	153.87	47.17	14.98	12.02	28.2	1220	8.46	10
	1440	154.36	47.66	14.99	12.01	28.4	1230	8.48	DO = 1.60mg/l
	1500	155.02	48.32	14.98	12.02	28.2	1250	8.42	10
	1560	155.58	48.88	14.96	12.03	29.2	1230	8.40	10
	1620	155.98	49.28	14.99	12.01	28.4	1210	8.46	10
	1680	156.65	49.95	14.99	12.01	27.9	1220	8.50	10
	1740	157.06	50.36	14.97	12.02	28.6	1200	8.32	10
	1800	157.72	51.02	14.95	12.04	28.4	1230	8.45	10
	1860	158.03	51.33	14.96	12.03	27.7	1210	8.55	10
	1920	158.44	51.74	14.97	12.02	26.9	1240	8.61	10
	1980	159.04	52.34	14.96	12.03	25.7	1250	8.69	10
	2040	159.36	52.66	14.87	12.10	25.6	1240	8.67	10
	2100	159.76	53.06	14.94	12.05	25.7	1260	8.68	10
	2160	160.15	53.45	14.99	12.01	25.5	1250	8.66	10
	2220	160.56	53.86	14.81	12.15	25.6	1230	8.65	10
	2280	160.95	54.25	14.93	12.06	25.7	1210	8.63	10
	2340	161.27	54.57	14.99	12.01	26.1	1220	8.61	10
	2400	161.70	55.00	14.98	12.02	26.7	1210	8.60	10
	2460	162.02	55.32	14.85	12.12	27.2	1220	8.62	10
	2520	162.49	55.79	14.89	12.09	26.0	1240	8.64	10
	2580	162.70	56.00	14.94	12.05	27.0	1260	8.63	10
	2640	163.00	56.30	14.85	12.12	27.7	1270	8.66	10
	2700	163.32	56.62	14.86	12.11	28.7	1250	8.55	10
	2760	163.66	56.96	14.89	12.09	29.6	1240	8.36	10
	2820	163.92	57.22	14.94	12.05	29.4	1330	8.50	10

Table 16-9 Recovery Test Data – BH10212

Official BH NO :	10212	District :	Kgalagadi
Date of test commencement :	11.2.2006	Location :	Ukhwi
Time of test commencement :	1300hrs	BH depth(m) :	268
Date of test completion	12.2.2006	Screen Int (m)	229.5 to 235.62 & 241.75 to 254
Time of test completion :	1300hrs	Depth of pump intake (m) :	168.5
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	n/a	Height of MP above ground(m) :	0.36
Dist.to Pumping Bh:	n/a	Static Water level before test(m) :	106.7
Casing diameter (mm)	203	Water strike	144, 155, 223 & 249
Orifice plate diameter		Delivery pipe diameter	
Easting	471352	Northing	7413710

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	164.21	57.51
	0.25	163.50	56.80
	0.5	162.95	56.25
	1	162.40	55.70
	2	160.01	53.31
	3	157.40	50.70
	4	156.14	49.44
	5	155.51	48.81
	6	155.03	48.33
	7	154.65	47.95
	8	154.35	47.65
	9	154.10	47.40
	10	153.83	47.13
	12	153.58	46.88
	15	153.34	46.64
	20	152.95	46.25
	25	152.63	45.93
	30	152.29	45.59
	40	151.43	44.73
	50	150.40	43.70
	60	150.01	43.31
	75	149.05	42.35
	90	147.87	41.17
	105	147.00	40.30
	120	146.27	39.57

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	145.03	38.33
	180	143.80	37.10
	210	142.68	35.98
	240	147.70	41.00
	270	140.65	33.95
	300	139.74	33.04
	330	138.99	32.29
	360	138.07	31.37
	390	137.38	30.68
	420	136.69	29.99
	450	136.00	29.30
	480	135.10	28.40
	540	133.99	27.29
	600	132.04	25.34
	660	130.69	23.99
	720	129.01	22.31
	780	127.99	21.29
	840	125.54	18.84
	900	123.92	17.22
	960	121.78	15.08
	1020	119.47	12.77
	1080	117.96	11.26
	1140	115.92	9.22
	1200	112.94	6.24
	1260	111.37	4.67
	1320	110.88	4.18
	1380	109.63	2.93
	1440	108.39	1.69

17 BH10213

Abandoned borehole BH10213 was a monitoring piezometer with siting reference **S4**, line R3, peg 9000m and TEM 63 and was drilled to explore the Ecca aquifer northeast of fault **F4.** It was also drilled to allow for the determination of the storativity of the Ecca aquifer during pump testing of the test production borehole (BH10211) at this site. The site was abandoned (grouted to surface) because the contractor could not salvage it. This was because the borehole was left open for a long time and it collapsed below 146 m. The abandoned borehole is located about 20 km east of Ncojane village. Drilling operations at this site commenced on 19 May and was abandoned on 30 June 2005.

17.1 SITING CRITERIA AND DRILLING OBJECTIVES

. This piezometer was going to explore the potential of Ecca aquifer near or to the east of fault F4, and will have also provided aquifer hydraulic data (transmissivity and storativity) for the Ecca as well as providing water level data.

18 BH10214

BH10214 with siting reference **S7,** Line **R5** and Peg 18500m is an exploration borehole drilled to explore the Ecca aquifer close to a fault zone interpreted from TDEM sounding data. It is located about 26km south of Ukwi along the road to Hukuntsi. This borehole was drilled between 20 January and 16 February 2006 to the terminal depth of 324m.

18.1 SITING CRITERIA AND DRILLING OBJECTIVES

This exploration borehole was drilled to explore the Ecca aquifer close to the apparent fault zone of fault F7 as per the TDEM interpretation. It will also generate groundwater head for this locality.

18.2 DRILLING RESULTS

This borehole was drilled through various lithologies including fine grained sands, silcretes, mudstones, dolerite and fine and medium grained sandstones (**Figure 18-1**). Drilling of BH10214 was carried out with a 15 inch bit to a depth of 89 m bgl after which 12 inch plain casings were installed and cement grouted. Drilling to a depth of 261m was achieved using a 12 inch bit and a 10 inch bit was used to drill from 261m to the terminal depth of 324m.

Two water strikes were encountered during drilling of this borehole. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows:

1. (170 m, 3740 µS/cm, 4.5 m^3/hr)
2. 300 m, 1800 µS/cm, 2.8m^3/hr)

The static water level measured on 16 February was 101.2 m bgl.

The borehole was geophysically logged and was left open due to its relatively low yield and stable formation **(Figure 18-2).**

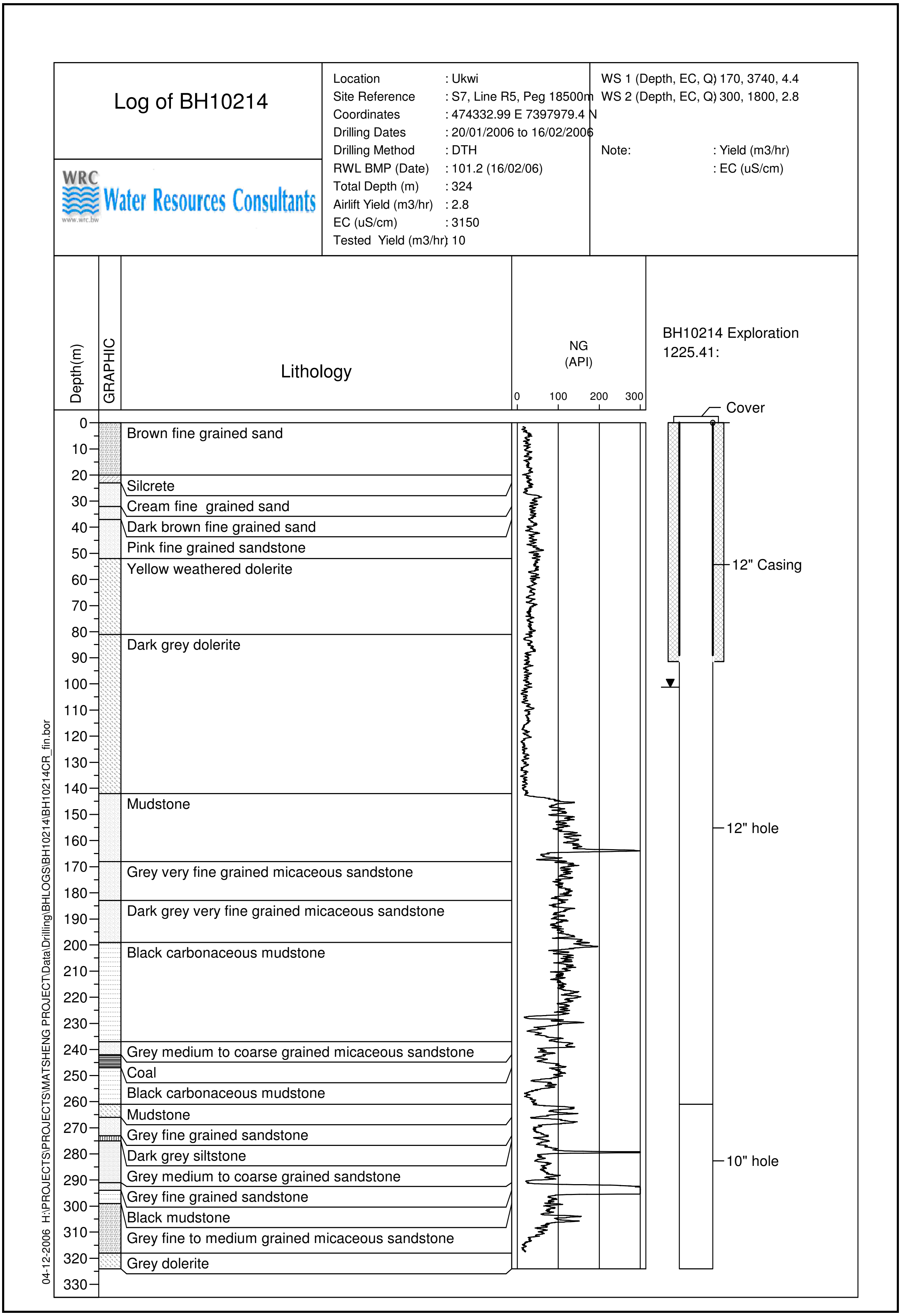

Figure 18-1 Log of BH10214

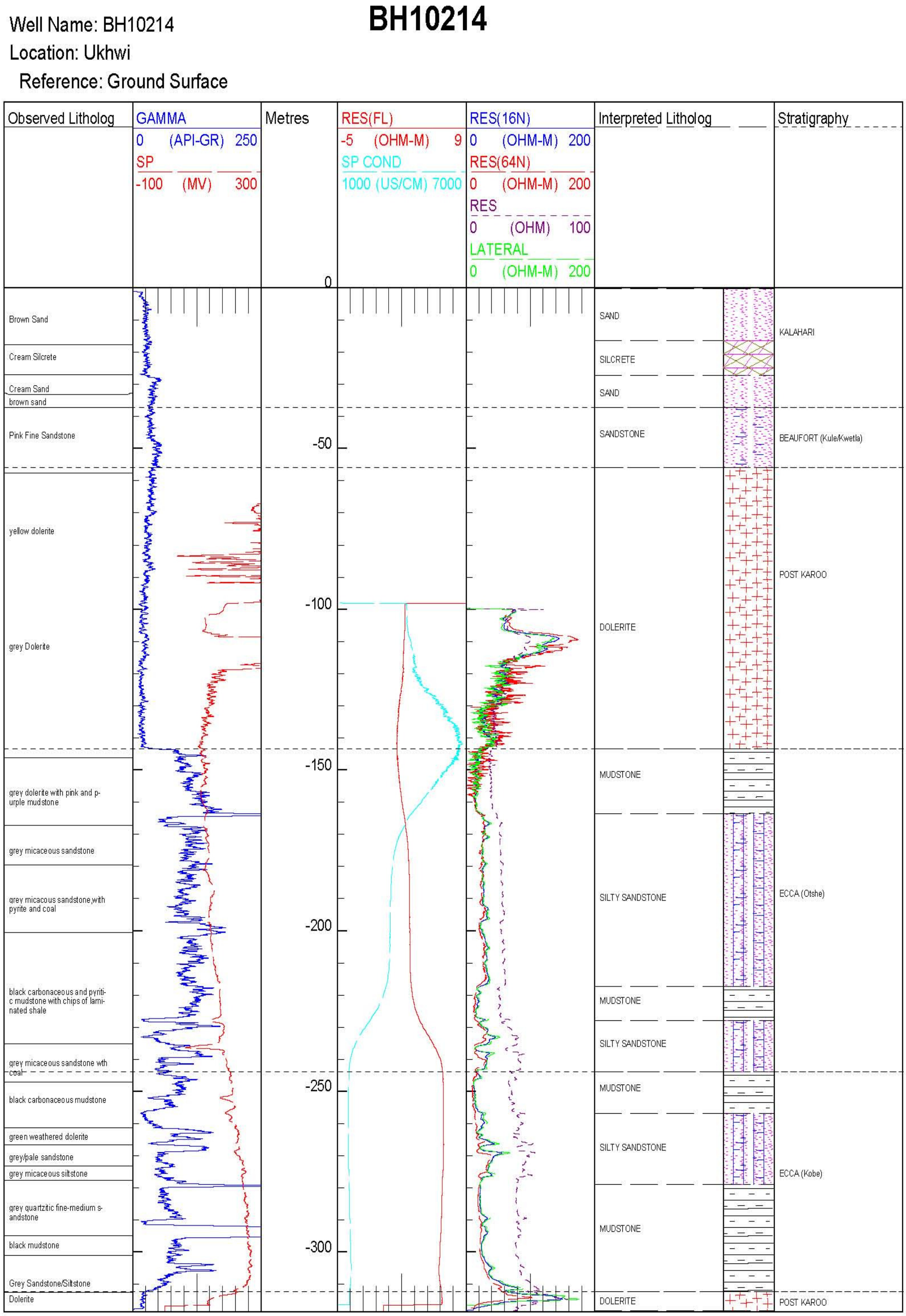

Figure 18-2 Geophysical log of BH10214

18.3 PUMP TESTING RESULTS

BH10214 was tested between 8 and 11 March 2006 and the tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.35 m above ground level (agl) and the pump intake was set at 180.5 m below ground level. Summary details for the pumping test activities at BH10216 are given in **Table 18-1**. The collected pump tsting data is presented in **Tables 18-5 to 18-8.**

Table 18-1 Summary of Pumping Test Data BH10214

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	3.18	2
	2	15	11.33	4.8
	3	15	21.5	8.9
	4	15	31.8	12
	5	15	43.5	16.2
	6	15	54.12	20
	7	15	71.1	28.8
	8	15	83.93	35.1
Step Test	1	100	17.95	5
	2	100	36.24	10
	3	100	56.33	15.1
	4	100	78.75	20
Constant Rate	1	1440	57.62	10
Recovery*	1	1440	3.19	0

Note.3.19 Residual Drawdown*

18.3.1 Step Drawdown Test

A step drawdown test (SDT) was carried out on 8 March 2006. The static water level before the start of the test was 99 m bmp. The step drawdown test consisted of 4 steps of 100 minutes duration. The discharge rates were 5, 10, 15.1 and 20 m^3/hr, respectively for steps 1 to 4.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test using this method is plotted in **Figure 18-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 18-4**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 2.6 m^2/d, **Figure 18-5**.

The results for the step test interpretation are tabulated in **Table 18-2**.

Table 18-2 Results of Step Test Analysis BH10214

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10215	1.56E-01	-4.08E-05	2.6	5.0	18.500	18.500	0.27
				10.0	15.80	34.300	0.29
				15.1	15.600	49.900	0.30
				20.0	17.30	67.200	0.30

The planned duration of the constant rate test for this borehole is 1 day and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slope of the semi-logarithmic plot of drawdown versus time (**Figure 18-3**) to estimate expected total drawdown after 1 days of pumping. It was interpreted that a discharge rate of 10 m^3/hr is ideal for this borehole.

18.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 9 and 10 March 2006 at a discharge rate of 10 m^3/hr and the total drawdown after 24 hrs of pumping was 57.62 m. The CRT test was followed by a 24 hr recovery monitoring period at the end of which the residual drawdown was 3.19 m. Data from the pumping period was interpreted using the Theis and the Cooper-Jacob (1946) analytical solution using the computer programme “Aqtesolv” and the transmissivity (T) values obtained were 2.3 and 2.7 m^2/d. The recovery data was analysed using the Theis recovery solution and the T value computed was 2.6 m^2/d. The interpretation of the results are summarised in **Table 18-3** and the interpreted data is presented in **Figures 18-6** to **18-8**.

Table 18-3 Summary of Constant Rate and Recovery Tests BH10214

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10214	24	240	a) 2.3 b) 2.7	d) 2.6	Confined

Notes:
<u>Interpretation Techniques</u>
a) Theis
b) Cooper-Jacob
c) Neuman (Unconfined)
d) Theis Modified Recovery

18.3.2.1 <u>Aquifer Type interpreted</u>

The aquifer type determined from the pump testing interpretation is confined.

18.4 WATER CHEMISTRY RESULTS

A set of water samples (acidified and none) were collected at the end of the CRT for chemical analysis. The samples were submitted to the CSIR laboratory in Stellenbosch, South Africa for chemical analysis of most of the BOS 32:2000 listed determinants. The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), pH and dissolved oxygen are 29.5 ^{o}C, 830 µS/cm 7.73 and 4.25 mg/L respectively.

Table 18-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10214	3.5	746	3.2	3.3	326	418	487	<0.1	3.5	0.27	<0.05	3150	8.5	2016
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10214	0.1	21	<0.10	0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

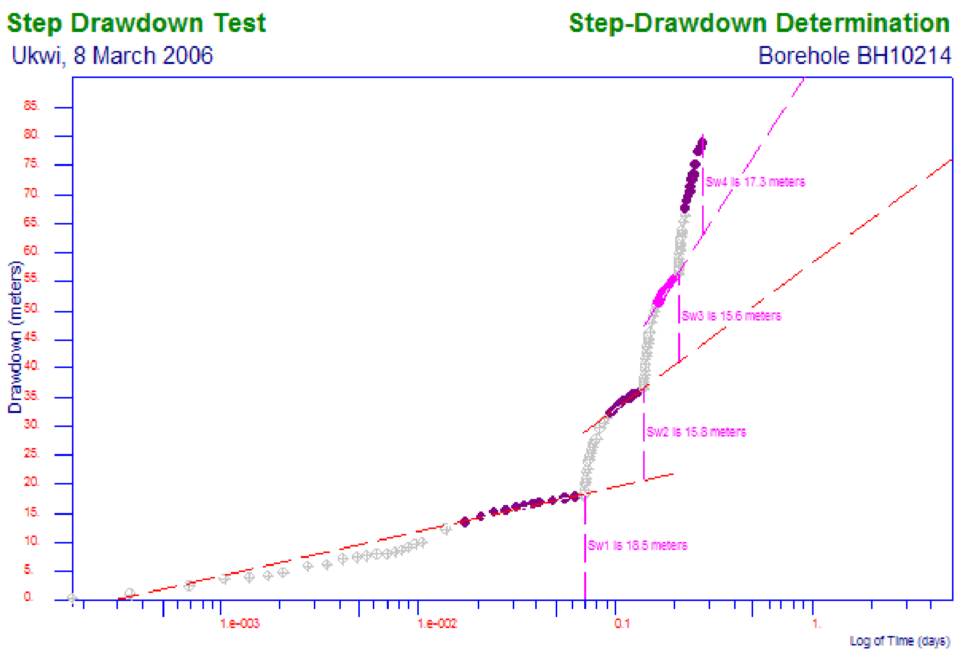

Figure 18-3 Pumping Test Results for BH10214: Step Drawdown Test – Hantush-Bierschenk (semi-log)

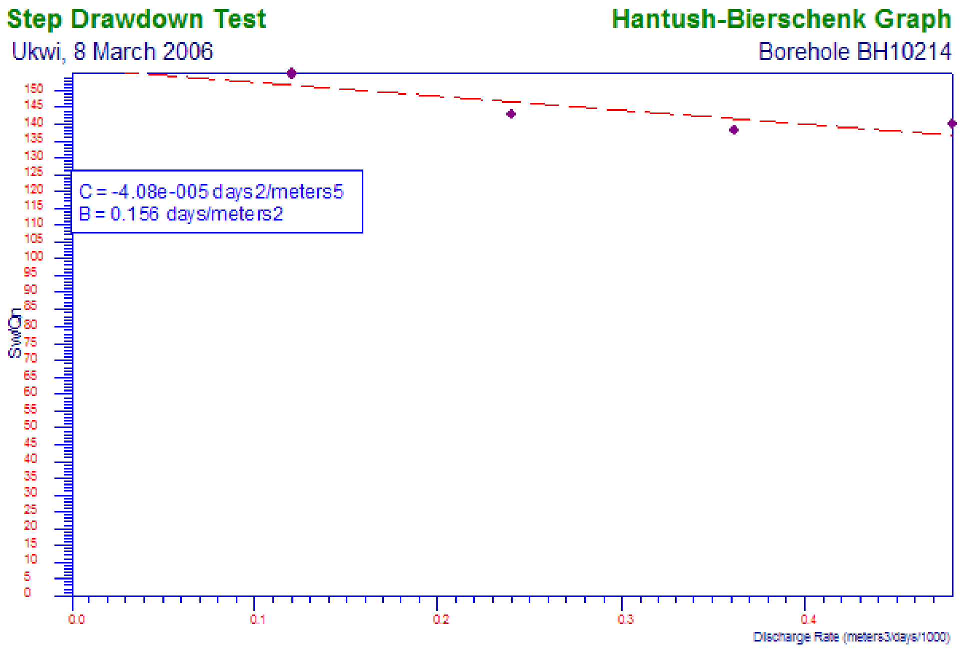

Figure 18-4 Pumping Test Results for BH10214: Step Drawdown Test – Hantush-Bierschenk

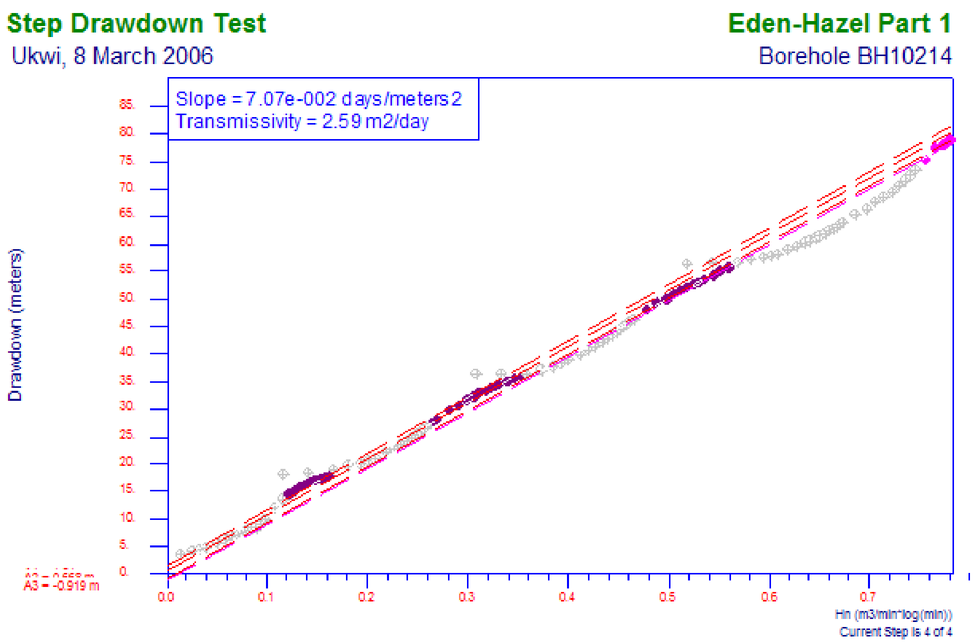

Figure 18-5 Pumping Test Results for BH10214: Step Drawdown Test – Eden-Hazel (Part 1)

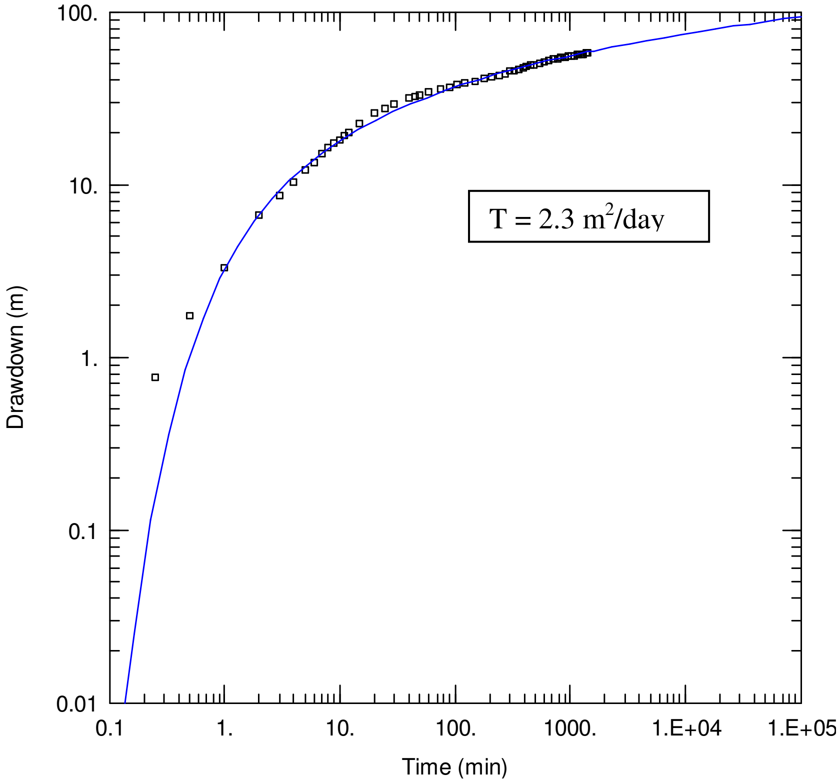

Figure 18-6 Pumping Test Results for BH10214: CRT Theis Solution

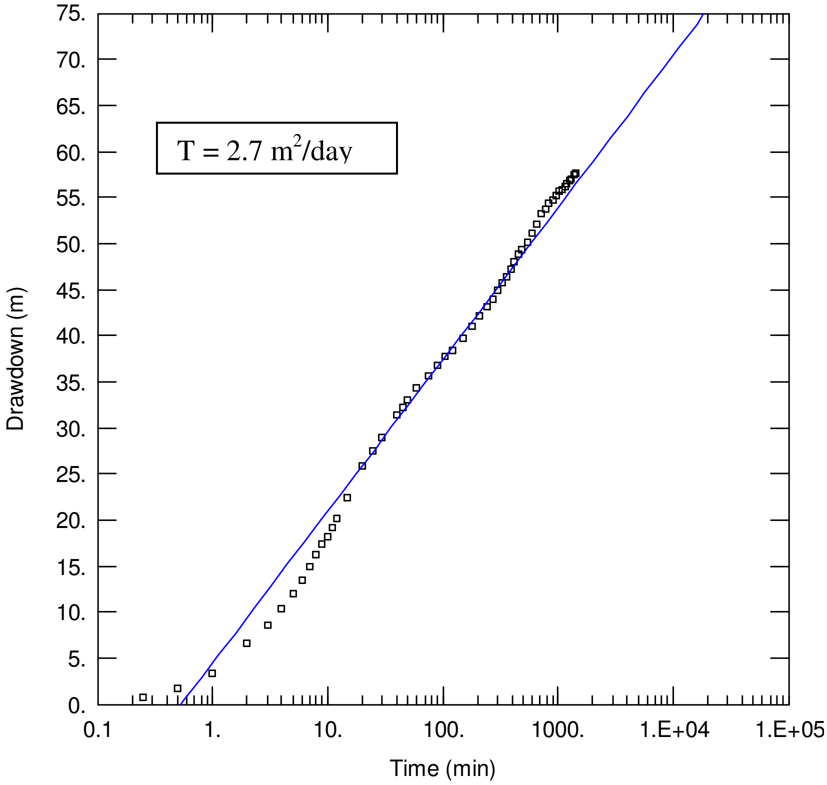

Figure 18-7 Pumping Test Results for BH10214: CRT Cooper- Jacob Solution

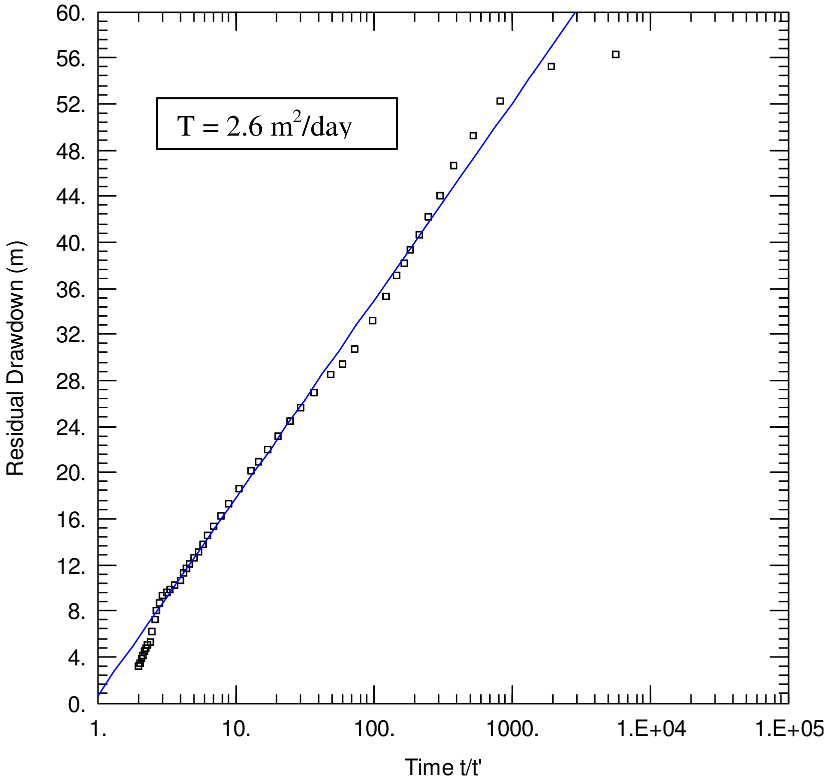

Figure 18-8 Pumping Test Results for BH10214: Theis Recovery Solution

Table 18-5 Calibration Test Data – BH10214

Official BH No.:	10214	District:	Kgalagadi
Date of test commencement:	08.03.06	Location:	Ukhwi
Time of test commencement	0945hrs	BH depth (m):	324
Date of test completion:	08.03.06	Screen Interval (m)	n/a
Time of test completion	113hrs	Depth of pump intake (m):	180.8
Method of water level measurement:	dipper	Static water level before test (m):	93.30
Casing diameter (mm)	8"	Water strike	170m
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Latitude	474336	Longitude	7397956

STEPNo. 1						STEP No. 2					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments
0.25	93.68	0.38				0.25	96.66	3.36			
0.5	93.72	0.42				0.5	96.86	3.56			
1	93.98	0.68				1	97.20	3.90			
1.5	94.24	0.94				1.5	97.61	4.31			
2	94.53	1.23				2	98.14	4.84	71.41	5.04	
2.5	94.72	1.42				2.5	98.52	5.22			
3	94.98	1.68				3	98.93	5.63	71.45	5.04	
4	95.04	1.74				4	99.52	6.22	71.50	5.03	
5	95.50	2.20				5	100.24	6.94	72.91	4.94	
6	95.82	2.52	no water			6	100.90	7.60	73.04	4.93	
7	95.96	2.66	est yield 2m3/hr			7	101.41	8.11	73.50	4.90	
8	96.15	2.85				8	101.93	8.63	73.88	4.87	
9	96.20	2.90				9	102.40	9.10	74.93	4.80	
10	96.27	2.97				10	102.82	9.52	74.79	4.81	
11	96.32	3.02				11	103.20	9.90	74.85	4.81	
12	96.38	3.08				12	103.60	10.30	74.90	4.81	
15	96.54	3.24				15	104.63	11.33	74.85	4.81	

STEP No. 3						STEP No. 4					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments
0.25	104.76	11.46				0.25	114.96	21.66			
0.5	104.78	11.48				0.5	114.99	21.69			
1	104.91	11.61	40.44	8.90		1	115.45	22.15	29.28	12.30	
1.5	105.04	11.74				1.5	115.98	22.68			
2	105.32	12.02	40.49	8.89		2	116.54	23.24	29.41	12.24	
2.5	105.96	12.66				2.5	117.05	23.75			
3	106.32	13.02	40.46	8.90		3	117.60	24.30	29.31	12.28	
4	107.34	14.04	40.40	8.91		4	118.55	25.25	29.56	12.18	
5	108.37	15.07	40.30	8.93		5	119.43	26.13	29.60	12.16	
6	109.48	16.18	40.39	8.91		6	120.27	26.97	29.68	12.13	
7	110.06	16.76	40.75	8.83		7	121.14	27.84	29.97	12.01	
8	110.91	17.61	40.49	8.89		8	121.55	28.25	29.75	12.10	
9	111.58	18.28	40.55	8.88		9	122.29	28.99	29.31	12.28	
10	112.22	18.92	40.39	8.91		10	122.83	29.53	29.68	12.13	
11	112.82	19.52	40.75	8.83		11	123.29	29.99	29.97	12.01	
12	113.45	20.15	40.49	8.89		12	123.85	30.55	29.90	12.04	
15	114.80	21.50	40.30	8.93		15	125.10	31.80	29.68	12.13	

Official BH No.:	10214	District	Kgalagadi
Date of test commencement:	08.03.06	Location:	Ukhwi
Time of test commencement	0945hrs	BH depth (m):	324
Date of test completion:	08.03.06	Screen Interval	n/a
Time of test completion	113hrs	Depth of pump intake (m):	180.8
Method of water level measurement:	dipper	Static water level before test (m):	93.30
Casing diameter (mm)	8"	Water strike	170m
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Latitude	474336	Longitude	7397956

STEPN. 5						STEPNo. 6					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments
0.25	125.32	32.02				0.25	136.96	43.66			
0.5	125.62	32.32				0.5	137.14	43.84			
1	126.40	33.10	21.78	16.53		1	137.73	44.43	19.53	18.43	
1.5	127.85	34.55				1.5	137.78	44.48	19.41	18.55	
2	128.45	35.15	22.01	16.36		2	138.55	45.25	17.94	20.07	adj
2.5	128.64	35.34				2.5	138.92	45.62			
3	129.50	36.20	22.08	16.30		3	139.35	46.05	17.81	20.21	
4	130.46	37.16	22.00	16.36		4	140.32	47.02	17.90	20.11	
5	131.30	38.00	22.12	16.27		5	141.30	48.00	18.00	20.00	
6	131.81	38.51	22.18	16.23		6	142.08	48.78	17.94	20.07	
7	132.15	38.85	22.08	16.30		7	142.62	49.32	17.99	20.01	
8	133.00	39.70	22.10	16.29		8	143.68	50.38	17.89	20.12	
9	133.53	40.23	22.12	16.27		9	144.37	51.07	17.95	20.06	
10	134.16	40.86	22.00	16.36		10	144.87	51.57	18.00	20.00	
11	134.75	41.45	22.10	16.29		11	145.45	52.15	17.94	20.07	
12	135.35	42.05	22.18	16.23		12	145.98	52.68	17.81	20.21	
15	136.80	43.50	22.20	16.22		15	147.42	54.12	17.91	20.10	

STEPN 7						STEP No. 8					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	Pumping Rate (m^3/hr)	Comments
0.25	147.66	54.36				0.25	164.50	71.20			
0.5	147.92	54.62				0.5	164.60	71.30			
1	148.92	55.62	12.97	27.76		1	164.70	71.40	20.30	35.47	
1.5	149.77	56.47				1.5	164.80	71.50			
2	150.66	57.36	12.61	28.55		2	166.38	73.08	20.57	35.00	
2.5	151.38	58.08				2.5	167.00	73.70			
3	152.20	58.90	12.57	28.64		3	167.80	74.50	20.56	35.02	
4	153.55	60.25	12.53	28.73		4	170.38	77.08	20.53	35.07	
5	155.08	61.78	12.50	28.80		5	173.61	80.31	20.57	35.00	
6	156.41	63.11	12.55	28.69		6	175.90	82.60	20.55	35.04	
7	157.74	64.44	12.51	28.78		7	177.23	83.93	20.49	35.14	
8	158.70	65.40	12.50	28.80		8	suction				
9	159.90	66.60	12.57	28.64		9					
10	160.75	67.45	12.55	28.69		10					
11	161.76	68.46	12.49	28.82		11					
12	162.38	69.08	12.54	28.71		12					
15	164.40	71.10	12.50	28.80		15					

Table 18-6 Step Drawdown Test Data – BH10214

Official BH No.:	10214	District:	Kgalagadi
Date of test commencement:	8.3.06	Location:	Ukhwi
Time of test Commencement:	1330hrs	BH depth (m):	324
Date of test completion:	8.3.06	Screens(m)	n/a
Time of test Completion:	2000hrs	Depth to pump intake (m)	180.8
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.35
Distance to OB. BH (m)	n/a	Static water level before test (m):	99
Casing diameter (mm)	203	Water strike	170m
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Latitude	474336	Longitude	7397956

STEP No. 1 STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	99.38	0.38				0.25	117.17	18.17			
0.5	100.05	1.05				0.5	117.40	18.40			
1	101.43	2.43				1	117.97	18.97	35.72	10.08	
1.5	102.64	3.64				1.5	118.70	19.70			
2	103.00	4.00				2	119.02	20.02	35.38	10.18	
2.5	103.31	4.31				2.5	119.47	20.47			
3	103.74	4.74				3	120.05	21.05	35.90	10.03	
4	104.79	5.79				4	121.00	22.00	35.85	10.04	
5	105.35	6.35				5	121.80	22.80	35.78	10.06	
6	106.07	7.07				6	122.78	23.78	35.89	10.03	
7	106.32	7.32				7	123.24	24.24	35.72	10.08	
8	106.62	7.62	71.88	5.01		8	123.88	24.88	35.95	10.01	
9	106.88	7.88	69.98	5.14		9	124.39	25.39	35.92	10.02	
10	107.10	8.10	70.68	5.09		10	124.88	25.88	35.85	10.04	
11	107.33	8.33	71.11	5.06		11	125.41	26.41	35.79	10.06	
12	107.49	8.49	71.41	5.04		12	125.93	26.93	35.88	10.03	
13	108.13	9.13	71.69	5.02		13	126.30	27.30	35.81	10.05	
14	108.58	9.58	71.55	5.03		14	126.66	27.66	35.86	10.04	
15	109.05	10.05	71.88	5.01		15	126.98	27.98	35.95	10.01	
20	111.17	12.17	70.32	5.12		20	128.63	29.63	35.90	10.03	
25	112.58	13.58	71.22	5.05		25	129.65	30.65	35.89	10.03	
30	113.37	14.37	70.11	5.13		30	130.52	31.52	35.81	10.05	
35	114.06	15.06	70.77	5.09		35	131.19	32.19	35.90	10.03	
40	114.62	15.62	72.00	5.00		40	131.70	32.70	36.00	10.00	
45	115.05	16.05	71.12	5.06		45	132.15	33.15	35.89	10.03	
50	115.34	16.34	71.69	5.02		50	132.59	33.59	35.90	10.03	
55	115.61	16.61	71.10	5.06		55	132.92	33.92	35.88	10.03	
60	115.83	16.83	71.80	5.01		60	133.25	34.25	35.86	10.04	
70	116.21	17.21	71.77	5.02		70	133.83	34.83	35.72	10.08	
80	116.54	17.54	71.11	5.06		80	134.40	35.40	35.81	10.05	
90	116.73	17.73	71.55	5.03		90	134.79	35.79	35.90	10.03	
100	116.95	17.95	71.88	5.01		100	135.24	36.24	35.85	10.04	

Official BH No.:	10214	District:	Kgalagadi
Date of test commencement:	8.3.06	Location:	Ukhwi
Time of test Commencement:	1330hrs	BH depth (m):	324
Date of test completion:	8.3.06	Screens(m)	n/a
Time of test Completion:	2000hrs	Depth to pump intake (m)	180.8
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.35
Distance to OB. BH (m)	n/a	Static water level before test (m):	99
Casing diameter (mm)	203	Water strike	170m
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Latitude	474336	Longitude	7397956

STEP No. 3 STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	135.48	36.48				0.25	155.43	56.43			
0.5	135.52	36.52				0.5	155.53	56.53			
1	135.59	36.59	24.07	14.96		1	155.74	56.74	17.78	20.25	
1.5	136.14	37.14				1.5	156.07	57.07			
2	136.70	37.70	24.01	14.99		2	156.51	57.51	17.83	20.19	
2.5	137.38	38.38				2.5	156.92	57.92			
3	137.91	38.91	24.00	15.00		3	157.20	58.20	17.75	20.28	
4	138.92	39.92	23.96	15.03		4	157.90	58.90	17.88	20.13	
5	139.74	40.74	23.89	15.07		5	158.66	59.66	18.00	20.00	
6	140.45	41.45	23.95	15.03		6	159.31	60.31	17.92	20.09	
7	141.21	42.21	23.85	15.09		7	159.62	60.62	17.97	20.03	
8	141.80	42.80	23.89	15.07		8	160.07	61.07	17.90	20.11	
9	142.48	43.48	24.00	15.00		9	160.47	61.47	18.00	20.00	
10	142.98	43.98	23.90	15.06		10	160.91	61.91	17.93	20.08	
11	143.54	44.54	23.96	15.03		11	161.36	62.36	17.90	20.11	
12	143.95	44.95	23.89	15.07		12	161.77	62.77	17.88	20.13	
13	144.40	45.40	23.89	15.07		13	162.13	63.13	17.97	20.03	
14	144.82	45.82	24.00	15.00		14	162.46	63.46	17.92	20.09	
15	145.20	46.20	23.90	15.06		15	162.85	63.85	17.99	20.01	
20	146.91	47.91	24.85	14.49		20	164.34	65.34	17.88	20.13	
25	148.16	49.16	24.00	15.00		25	165.50	66.50	17.90	20.11	
30	148.98	49.98	24.00	15.00		30	166.56	67.56	17.97	20.03	
35	149.79	50.79	23.89	15.07		35	167.59	68.59	17.88	20.13	
40	150.44	51.44	23.85	15.09		40	168.55	69.55	18.00	20.00	
45	151.03	52.03	23.90	15.06		45	169.48	70.48	17.98	20.02	
50	151.62	52.62	24.00	15.00		50	170.41	71.41	17.90	20.11	
55	152.04	53.04	23.90	15.06		55	171.39	72.39	17.88	20.13	
60	152.47	53.47	23.96	15.03		60	172.33	73.33	17.92	20.09	
70	153.27	54.27	23.85	15.09		70	174.20	75.20	17.90	20.11	
80	154.02	55.02	23.89	15.07		80	176.28	77.28	18.00	20.00	
90	154.75	55.75	24.00	15.00		90	177.77	78.77	17.89	20.12	
100	155.33	56.33	23.85	15.09		100	suction				

Table 18-7 Constant Rate Test Data – BH10214

Official BH NO :	10214	District :	Kgalagadi
Date of test commencement :	9.3.06	Location :	Ukhwi
Time of test commencement :	1500hrs	BH depth(m) :	324
Date of test completion	9.3.06	Screen Interval (m)	n/a
Time of test completion :	1500hrs	Depth of pump intake (m) :	180.8
Method of water level measurement	dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.35
Distance ob BH r (m)	n/a	Static Water level before test(m) :	96.15
Casing diameter (mm)	203	Water strike	170m
Orifice plate diameter	4"	Delivery pipe diameter	102mm
Latitude	474336	Longitude	7397956

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 100l	$Q(m^3/h)$	Temp (^0C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO
	0.25	96.92	0.77						
	0.5	97.88	1.73						
	1	99.45	3.30						
	2	102.74	6.59						
	3	104.76	8.61						
	4	106.52	10.37	37.69	9.55				
	5	108.15	12.00	36.28	9.92				
	6	109.63	13.48	35.88	10.03				
	7	111.14	14.99	35.87	10.04				
	8	112.35	16.20	35.59	10.12				
	9	113.47	17.32	35.78	10.06				
	10	114.38	18.23	35.59	10.12				
	11	115.30	19.15	35.66	10.10				
	12	116.22	20.07	35.69	10.09				
	15	118.55	22.40	35.78	10.06	28.8	1720	8.61	
	20	121.92	25.77	35.90	10.03	28.0	1780	8.66	
	25	123.67	27.52	35.72	10.08	27.5	1810	8.68	
	30	125.13	28.98	35.59	10.12	27.3	1780	8.72	
	40	127.59	31.44	35.87	10.04	28.0	1730	8.70	
	45	128.42	32.27	35.59	10.12	27.7	1730	8.71	
	50	129.17	33.02	35.79	10.06	27.2	1730	8.75	
	60	130.40	34.25	35.87	10.04	27.7	1710	8.75	
	75	131.79	35.64	35.87	10.04	28.2	1700	8.75	
	90	132.87	36.72	35.84	10.04	27.9	1720	8.78	
	105	133.86	37.71	35.87	10.04	27.3	1780	8.79	
	120	134.54	38.39	35.78	10.06	27.4	1750	8.79	
	150	135.86	39.71	35.87	10.04	27.3	1790	8.74	
	180	137.15	41.00	35.90	10.03	27.0	1840	8.79	
	210	138.24	42.09	35.88	10.03	26.4	1920	8.77	
	240	139.22	43.07	35.90	10.03	25.9	2040	8.77	
	270	140.13	43.98	35.86	10.04	25.7	2040	8.77	
	300	141.06	44.91	35.91	10.03	26.4	2250	8.72	
	330	141.83	45.68	35.87	10.04	26.1	2350	8.71	
	360	142.53	46.38	35.90	10.03	26.0	2360	8.70	
	390	143.30	47.15	35.86	10.04	26.0	2360	8.63	
	420	144.10	47.95	35.88	10.03	25.3	2710	8.63	
	450	144.94	48.79	35.84	10.04	25.8	2810	8.63	
	480	145.40	49.25	35.90	10.03	24.7	2720	8.60	
	540	146.34	50.19	35.85	10.04	24.0	2730	8.63	
	600	147.28	51.13	35.91	10.03	24.5	2740	8.63	
	660	148.26	52.11	35.87	10.04	24.3	2730	8.63	
	720	149.34	53.19	35.90	10.03	24.1	2740	8.60	

	780	149.83	53.68	36.00	10.00	24.3	2700	8.63	
	840	150.48	54.33	35.87	10.04	24.5	2680	8.61	
	900	150.89	54.74	35.95	10.01	24.3	2730	8.66	
	960	151.39	55.24	35.88	10.03	24.2	2670	8.68	
	1020	151.89	55.74	36.00	10.00	25.1	2890	8.55	
	1080	152.07	55.92	35.84	10.04	27.2	2880	8.46	
	1140	152.27	56.12	35.47	10.15	27.7	3030	8.42	
	1200	152.59	56.44	35.88	10.03	27.6	3030	8.46	
	1260	152.90	56.75	35.90	10.03	27.8	3030	8.48	
	1320	153.17	57.02	35.87	10.04	28.0	2920	8.42	
	1380	153.69	57.54	35.90	10.03	28.4	2930	8.42	
	1440	153.77	57.62	35.88	10.03	28.2	2930	8.44	

Table 18-8 Recovery Test Data – BH10214

Official BH NO :	10214	District :	Kgalagadi
Date of test commencement :	9.3.06	Location :	Ukhwi
Time of test commencement :	1500hrs	BH depth(m) :	324
Date of test completion	9.3.06	Screen Int (m)	n/a
Time of test completion :	1500hrs	Depth of pump intake (m) :	180.8
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	n/a	Height of MP above ground(m) :	0.35
Dist.to Pumping Bh:	n/a	Static Water level before test(m) :	96.15
Casing diameter (mm)	203	Water strike	170m
Orifice plate diameter	4"	Delivery pipe diameter	102mm
Latitude	474336	Longitude	7397956

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	153.77	57.62
	0.25	153.28	57.13
	0.5	152.43	56.28
	1	151.39	55.24
	2	148.34	52.19
	3	145.33	49.18
	4	142.78	46.63
	5	140.18	44.03
	6	138.32	42.17
	7	136.84	40.69
	8	135.50	39.35
	9	134.36	38.21
	10	133.26	37.11
	12	131.41	35.26
	15	129.32	33.17
	20	126.82	30.67
	25	125.56	29.41
	30	124.60	28.45
	40	123.06	26.91
	50	121.84	25.69
	60	120.55	24.40
	75	119.24	23.09
	90	118.12	21.97
	105	117.05	20.90
	120	116.25	20.10

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	114.78	18.63
	180	113.44	17.29
	210	112.40	16.25
	240	111.50	15.35
	270	110.65	14.50
	300	109.96	13.81
	330	109.30	13.15
	360	108.75	12.60
	390	108.26	12.11
	420	107.81	11.66
	450	107.42	11.27
	480	106.80	10.65
	540	106.35	10.20
	600	106.04	9.89
	660	105.73	9.58
	720	105.44	9.29
	780	104.82	8.67
	840	104.14	7.99
	900	103.41	7.26
	960	102.36	6.21
	1020	101.40	5.25
	1080	101.23	5.08
	1140	100.93	4.78
	1200	100.63	4.48
	1260	100.29	4.14
	1320	100.04	3.89
	1380	99.62	3.47
	1440	99.34	3.19

19 BH10215

BH10215 is an exploration borehole with a siting reference of **S2**, Line R2, Peg 16000m at TEM 18. This borehole was drilled to explore the full sequence of the Ecca aquifer and its potential at this locality. This site was moved from TEM 10 to avoid drilling through a thick sequence of dolerite as per the re-interpretation of the TEM data and available drilling results. This borehole is located about 20km south west of Ncojane. Drilling operations at this site commenced on 12 October and was completed on 27 October 2005.

19.1 SITING CRITERIA AND DRILLING OBJECTIVES

This borehole was drilled to explore the relatively undisturbed Ecca aquifer to the south west of Ncojane near the boundary of compartment 4 and 6. It will also provide water level data for Ecca in the western part of the Ncojane Block.

19.2 DRILLING RESULTS

The borehole was drilled through various lithologies including fine grained sand, calcrete, mudstones, fine to medium grained micaceous sandstone and medium to coarse grained sandstones (**Figure 19-1**). Drilling of BH10215 was carried out with a 15 inch bit using the DTH drilling technique down to a depth of 52m bgl after which 12 inch plain casings were installed and grouted. Drilling between 52 to 107m was accomplished using a 12 inch drilling bit after which 10 inch casing were installed. A 10 inch drilling bit was used to drill from 107 to the terminal depth of 250m. The borehole was geophysically logged to the depth of250m **(Figure 18-2).**

During drilling of this borehole, four water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the four water strikes are as follows;

1. (173m, 3250 µS/cm, 3.5m^3/hr)
2. (203m, 2500 µS/cm, 5.5 m^3/hr)
3. (215m, 2200 µS/cm, 11 m^3/hr)
4. (233m, 2300 µS/cm, 10 m^3/hr)

The cumulative yield at the end of drilling was 30 m^3/hr and the electrical conductivity was 2210 µS/cm. Water samples were collected at the four water strikes and were submitted to the DWA laboratory for chemical analysis. The results are presented in **Table 19-1.**

Table 19-1 Drilling chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10215	173	7.48	948	9.64	10.83	359.9	6.15	133.89	158.89	0	1.69	0	581.74	0.03	5.52	SST1
10215	203	7.53	796	6.81	7.86	263.8	56.3	118.14	118.36	0	1.46	0	496.70	0.00	0.15	MUD 2
10215	215	7.97	484	3.85	4.79	182.9	32.3	63.36	37.17	29.95	0.99	0	393.91	0.00	0.13	SST 2
10215	233	7.75	464	11.48	11.57	160.3	52.4	66.52	34.92	23.39	0.57	0	364.79	0.00	0.07	SST2
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

After completion of drilling, the borehole was constructed using 8 inch plain and factory slotted casings. The 8 inch plain casings were installed between 0 to 211.68m and 247.76 to 250m while the slotted casings were installed between 211.68 and 247.76m. No gravel pack was installed in the borehole. Borehole development was by air jetting for 4.67 hours and the final airlift yield after borehole was 37 m^3/hr and the electrical conductivity was measured as 2210 µS/cm.

After development, verticality and alignment tests were carried out successfully to top of the slotted casings (211 m). The static water level was 97.38 m bgl on 31 October 2005.

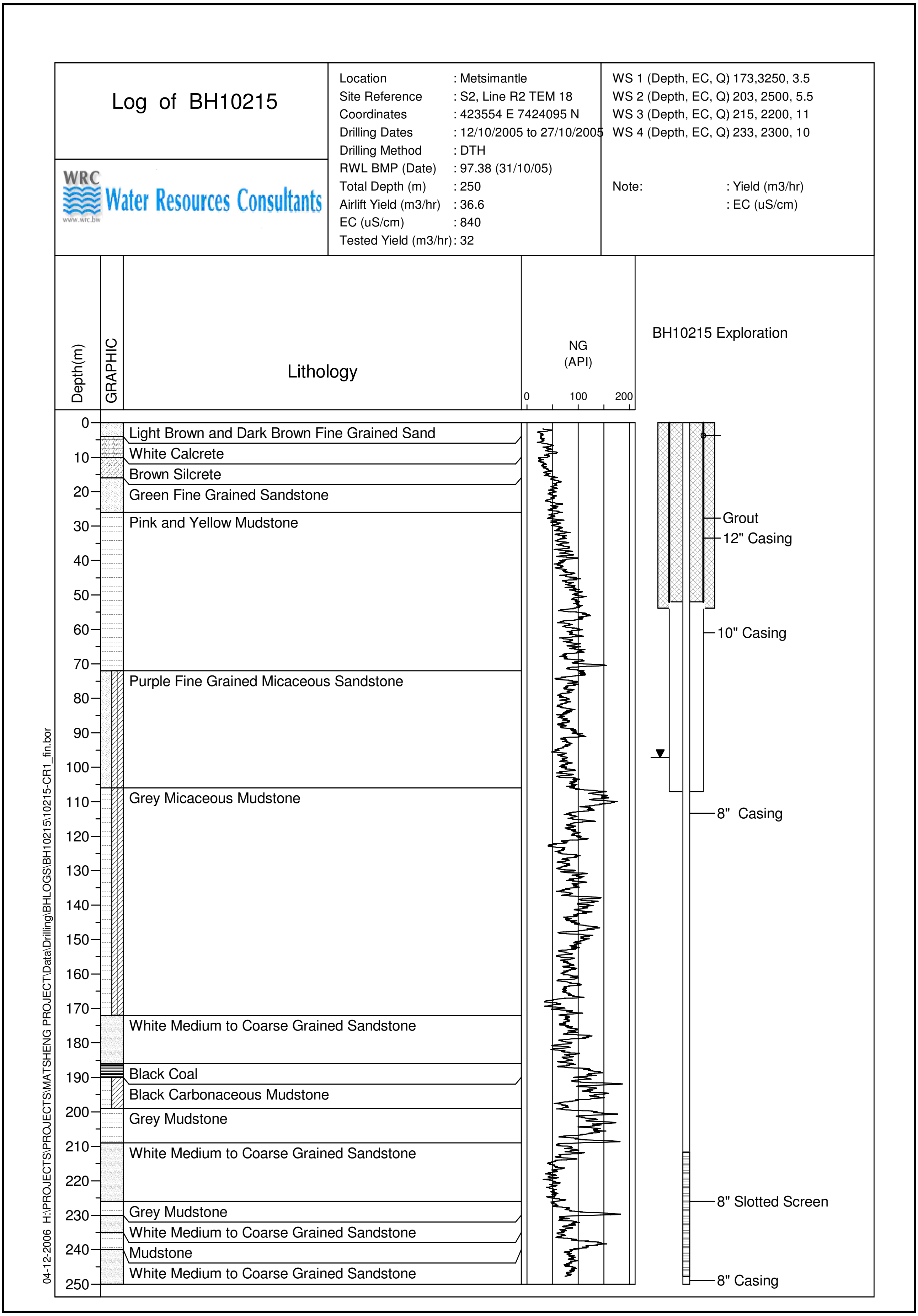

Figure 19-1 Log of BH10215

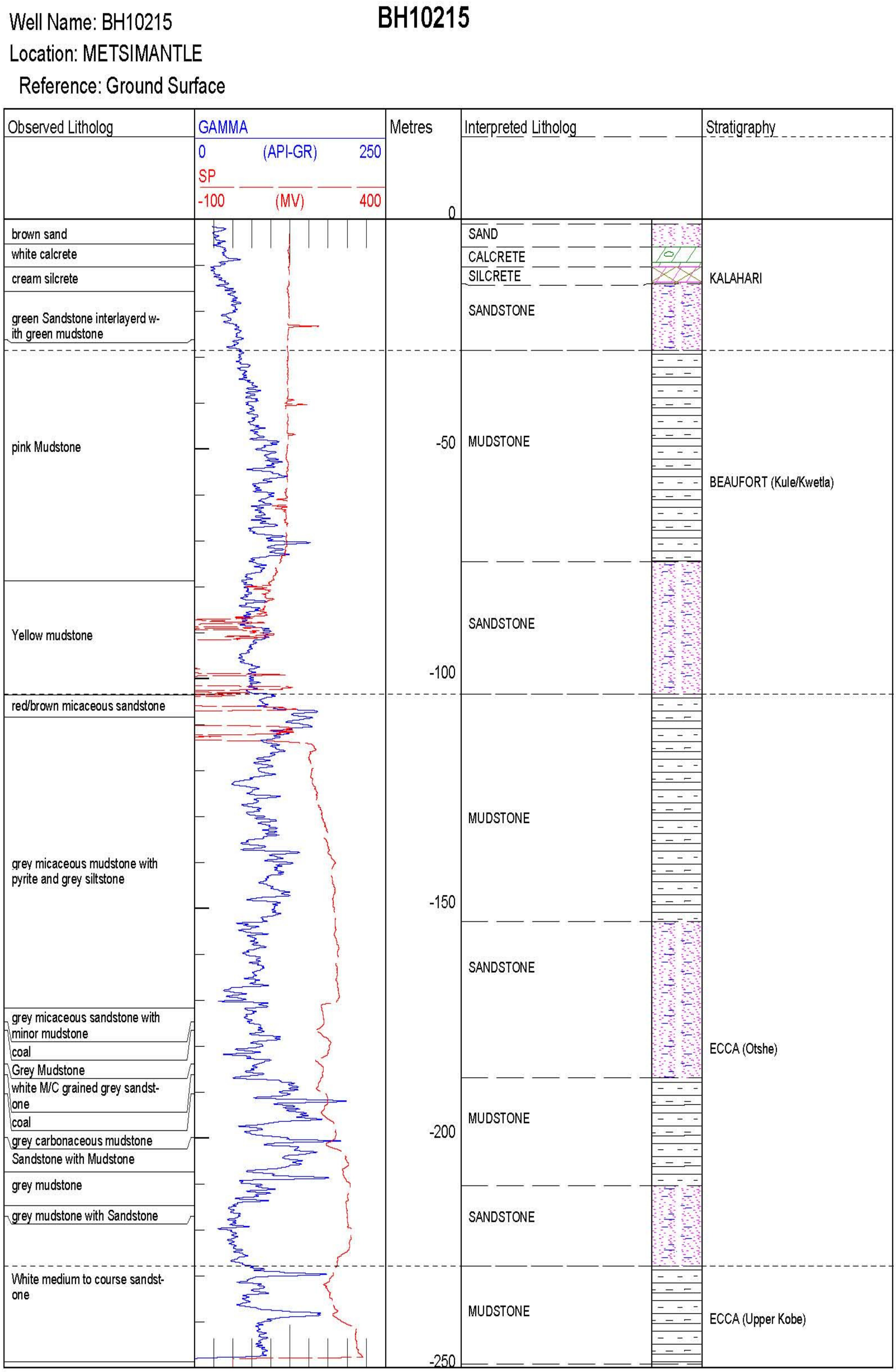

Figure 19-2 Geophysical log of BH10215

19.3 Pump Testing Results

BH10215 was tested between 23 and 29 January 2006 and the tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.51 m above ground level (agl) and the pump intake was set at 150.8 m below ground level. Summary details for the pumping test activities at BH10215 are given in **Table 19-2**. The collected pump testing data is presented in **Tables 19-5 to 19-9.**

Table 19-2 Summary of Pumping Test Data BH10215

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	18.22	20.3
	2	15	30.8	30.3
	3	3	44.75	40
Step Test	1	100	15.65	15.2
	2	100	22.65	21.3
	3	100	28.23	25.8
	4	100	32.98	30
	5	100	41.98	35
Constant Rate	1	4320	42.01	32
Recovery*	1	1440	0.71	0

Note.0.71 Residual Drawdown*

19.3.1 Step Drawdown Test

The step drawdown test (SDT) was carried out on 24 January 2006. The static water level before the start of the test was 98.25 m bmp. The step drawdown test consisted of 5 steps of 100 minutes duration. The discharge rates were 15.2, 21.3, 25.8, 30 and 35 m^3/hr, respectively for steps 1 to 5.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test using this method is plotted in **Figure 19-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 19-4**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 111 m^2/d, **Figure 19-5**.

The results for the step test interpretation are tabulated in **Table 19-2**.

Table 19-3 Results of Step Test Analysis BH10215

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10215	4.08E-02	4.78E-06	30.8	15.2	15.70	15.70	0.97
				21.3	6.48	22.18	0.96
				25.9	4.75	26.93	0.96
				30.2	3.91	30.84	0.98
				35.2	8.24	39.08	0.90

The planned duration of the constant rate test for this borehole is 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slope of the semi-logarithmic plot of drawdown versus time (**Figure 19-3**) to estimate expected total drawdown after 3 days of pumping.

19.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 25 and 28 January 2006 at a discharge rate of 32 m^3/hr and the total drawdown after 72 hrs of pumping was 42.01 m. The CRT test was followed by a 24 hr recovery monitoring period at the end of which the residual drawdown was 0.71 m. Data from the pumping period was interpreted using the Theis and the Cooper-Jacob (1946) analytical solution using the computer programme "Aqtesolv" and the transmissivity (T) values obtained were 39.1 and 40.1 m^2/d. The recovery data was analysed using the Theis recovery solution and the T value computed was 39.8 m^2/d. The interpretation of the results are summarised in **Table 19-4** and the interpreted data is presented in **Figures 19-6** to **19-8**.

Table 19-4 Summary of Constant Rate and Recovery Tests BH10215

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10215	72	725	a) 39.1 b) 40.1	d) 39.8	Confined

Notes:
Interpretation Techniques
a) Theis *c) Neuman (Unconfined)*
b) Cooper-Jacob *d) Theis Modified Recovery*

19.3.2.1 Aquifer Type interpreted

The aquifer type determined from the pump testing interpretation is confined.

19.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples were submitted to the CSIR laboratory in Stellenbosch, South Africa for most of the BOS 32:2000 listed determinants. The results of CSIR are presented in **Table 19-5**. The other samples collected at 72 hrs were submitted for both stable and unstable isotope analysis at the CSIR laboratory in Pretoria, South Africa **.**

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), pH and dissolved oxygen are 29.5 ^{o}C, 830 µS/cm, 7.73 and 4.25 mg/L respectively. The EC was improving during the CRT and the conductivity after 15 minutes of pumping was 2910 µS/cm. During the step test, the conductivity also improved from 5870 µS/cm at the end of the first step was to 2770 µS/cm by the end of the fifth step. This variation of conductivity shows the contribution of the upper saline water strikes that were not sealed off during drilling.

Table 19-5 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10215	10.1	149	17	13	35	60	295	0.15	0.7	0.23	<0.05	840	7.3	538
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10215	<0.1	96	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

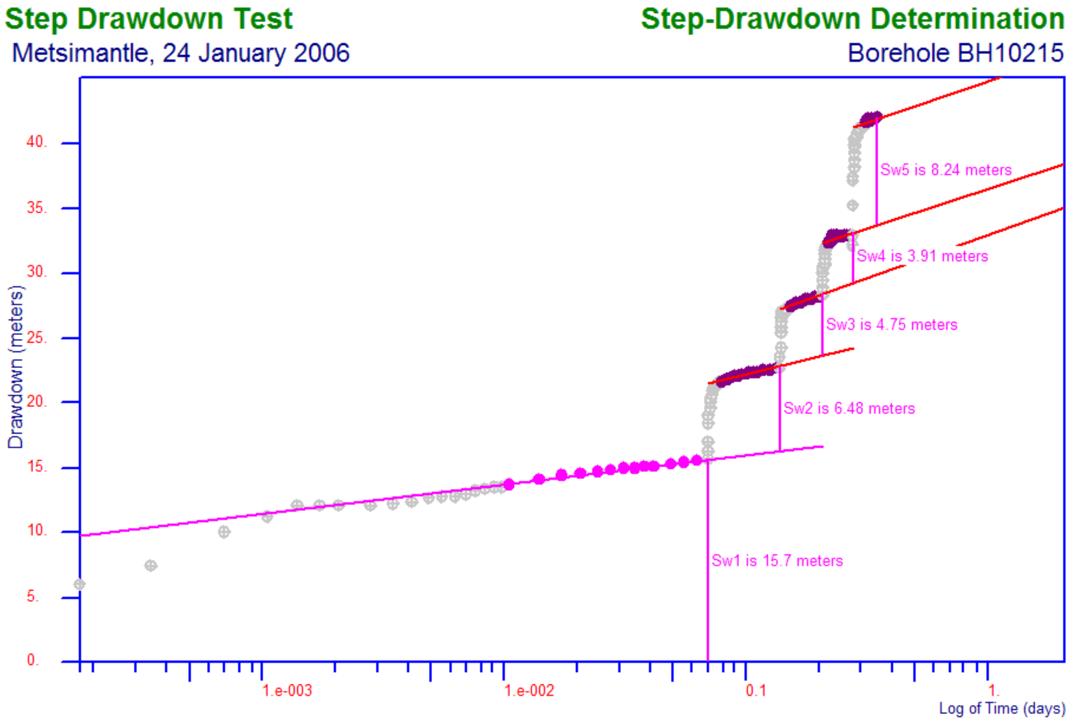

Figure 19-3 Pumping Test Results for BH10215: Step Drawdown Test – Hantush-Bierschenk (semi-log)

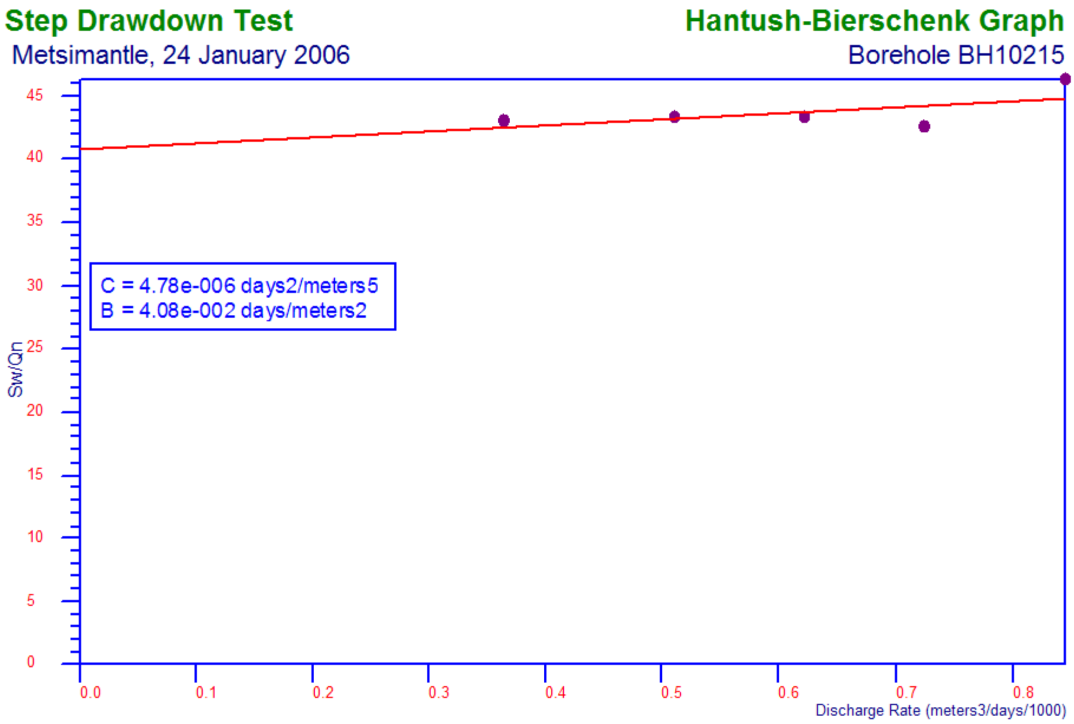

Figure 19-4 Pumping Test Results for BH10215: Step Drawdown Test – Hantush-Bierschenk

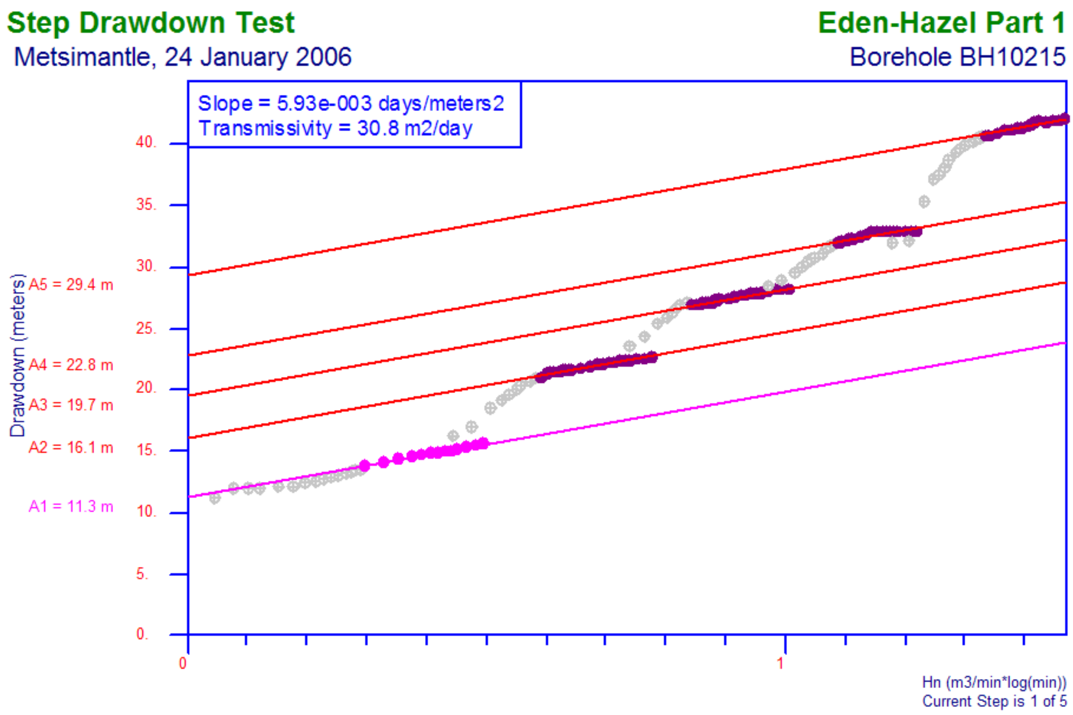

Figure 19-5 Pumping Test Results for BH10215: Step Drawdown Test – Eden-Hazel (Part 1)

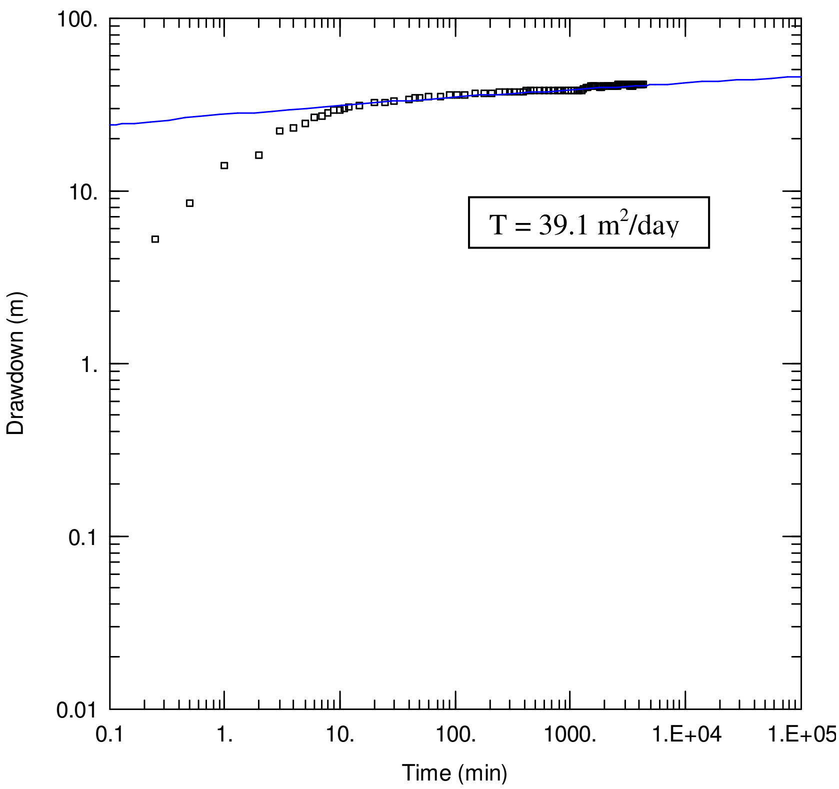

Figure 19-6 Pumping Test Results for BH10215: CRT Theis Solution

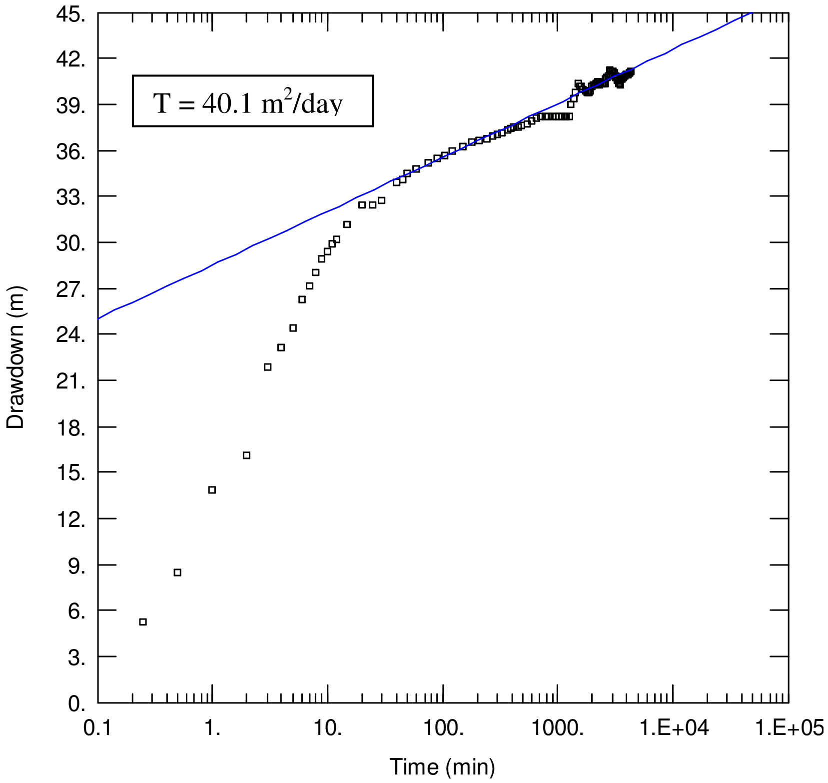

Figure 19-7 Pumping Test Results for BH10215: CRT Cooper- Jacob Solution

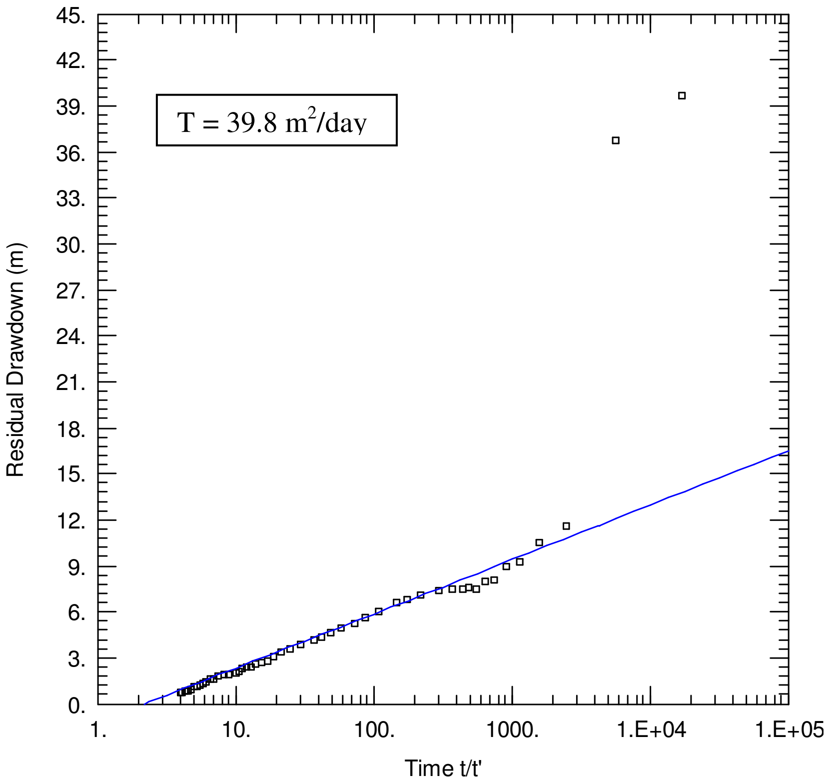

Figure 19-8 Pumping Test Results for BH10215: Theis Recovery Solution

Table 19-6 Calibration Test Data – BH10215

Official BH No.:	10215	District:	Ghanzi
Date of test commencement:	23.01.2006	Location:	Metsimantle
Time of test commencement	1345hrs	BH depth (m):	250
Date of test completion:	23.01.06	Screen Interval (m):	211.86 to 247.76
Time of test completion	1431hrs	Depth of pump intake (m):	150.8m
Method of water level measurement:	dipper	Static water level before test (m):	98.15
Casing diameter (mm)	203	Water strike	173, 203, 215 & 233
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	423554	Northing	7424095

STEP No. 1 / STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	102.25	4.10				0.25	117.33	19.18			
0.5	105.40	7.25				0.5	118.68	20.53			
1	107.20	9.05				1	121.33	23.18	23.12	31.14	
1.5	110.00	11.85				1.5	122.16	24.01			
2	111.00	12.85				2	122.89	24.74	23.28	30.93	
2.5	111.42	13.27				2.5	124.06	25.91			
3	112.00	13.85	34.00	21.18		3	124.75	26.60	23.47	30.68	
4	112.85	14.70	35.19	20.46		4	125.68	27.53	23.91	30.11	
5	113.32	15.17	33.94	21.21		5	126.30	28.15	23.68	30.41	
6	113.67	15.52	34.15	21.08		6	126.80	28.65	23.66	30.43	
7	114.15	16.00	35.69	20.17		7	127.24	29.09	24.47	29.42	
8	114.35	16.20	35.44	20.32		8	127.48	29.33	23.77	30.29	
9	114.88	16.73	35.33	20.38		9	127.77	29.62	23.88	30.15	
10	115.08	16.93	35.39	20.34		10	128.12	29.97	23.91	30.11	
11	115.45	17.30	35.55	20.25		11	128.24	30.09	23.74	30.33	
12	115.80	17.65	35.41	20.33		12	128.42	30.27	23.54	30.59	
15	116.37	18.22	35.31	20.39		15	128.95	30.80	23.81	30.24	

STEPNo. 3 / STEPNo. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	Pumping Rate (m^3/hr)	Comments
0.25	125.62	27.47			adj	0.25	143.74	45.59			
0.5	125.84	27.69				0.5	144.22	46.07	16.82	42.81	
1	126.02	27.87				1					
1.5	128.80	30.65				1.5					
2	133.10	34.95	20.00	36.00	adj	2					
2.5	135.12	36.97				2.5					
3	132.08	33.93	16.35	44.04		3					
4	140.30	42.15	18.10	39.78		4					
5	140.10	41.95	18.13	39.71		5					
6	140.32	42.17	18.44	39.05		6					
7	140.85	42.70	17.93	40.16		7					
8	141.20	43.05	17.95	40.11		8					
9	141.43	43.28	18.13	39.71		9					
10	141.72	43.57	18.15	39.67		10					
11	142.07	43.92	18.06	39.87		11					
12	142.32	44.17	18.14	39.69		12					
15	142.90	44.75	18.16	39.65		15					

Table 19-7 Step Drawdown Test Data

Official BH No.:	10215	District:	Ghanzi
Date of test commencement:	24.01.2006	Location:	Metsimantle
Time of test Commencement:	0700hrs	BH depth (m):	250
Date of test completion:	24.01.2006	Screens(m)	211.86 to 247.76
Time of test Completion:	1522hrs	Depth to pump intake (m)	150.8
Method of water level measurement:	electrical dipper	Description of MP:	top of casing
Observation Bh No.:	n/a	Height of MP above ground:	0.51
Distance to OB. BH (m)	n/a	Static water level before test (m):	98.25
Casing diameter (mm)	203	Water strike	173, 203, 215 & 233
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	423554	Northing	7424095

STEP No. 1 STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments
0.25	104.30	6.05				0.25	114.52	16.27			
0.5	105.70	7.45				0.5	115.22	16.97			
1	108.30	10.05				1	116.74	18.49	33.69	21.37	
1.5	109.50	11.25				1.5	117.32	19.07			
2	110.30	12.05				2	117.88	19.63	33.87	21.26	
2.5	110.30	12.05				2.5	118.28	20.03			
3	110.50	12.25				3	118.54	20.29	34.10	21.11	
4	110.32	12.07	50.41	14.28		4	118.94	20.69	34.26	21.02	
5	110.44	12.19	47.25	15.24		5	119.15	20.90	33.56	21.45	
6	110.66	12.41	47.50	15.16		6	119.28	21.03	33.44	21.53	
7	110.88	12.63	47.45	15.17		7	119.47	21.22	33.68	21.38	
8	111.02	12.77	47.35	15.21		8	119.62	21.37	33.87	21.26	
9	111.09	12.84	46.91	15.35		9	119.64	21.39	34.00	21.18	
10	111.26	13.01	47.15	15.27		10	119.67	21.42	33.91	21.23	
11	111.52	13.27	46.81	15.38		11	119.73	21.48	33.97	21.20	
12	111.67	13.42	47.00	15.32		12	119.83	21.58	33.89	21.25	
13	111.76	13.51	47.25	15.24		13	119.83	21.58	33.77	21.32	
14	111.80	13.55	47.15	15.27		14	119.88	21.63	33.91	21.23	
15	111.98	13.73	47.47	15.17		15	119.90	21.65	33.87	21.26	
20	112.34	14.09	47.13	15.28		20	120.04	21.79	33.93	21.22	
25	112.62	14.37	47.28	15.23		25	120.18	21.93	33.41	21.55	
30	112.79	14.54	47.33	15.21		30	120.30	22.05	33.56	21.45	
35	112.95	14.70	47.32	15.22		35	120.33	22.08	33.65	21.40	
40	113.08	14.83	47.28	15.23		40	120.41	22.16	33.71	21.36	
45	113.19	14.94	47.03	15.31		45	120.48	22.23	33.62	21.42	
50	113.28	15.03	47.41	15.19		50	120.55	22.30	33.56	21.45	
55	113.32	15.07	47.50	15.16		55	120.61	22.36	33.68	21.38	
60	113.36	15.11	47.15	15.27		60	120.61	22.36	33.64	21.40	
70	113.58	15.33	47.42	15.18		70	120.80	22.55	33.77	21.32	
80	113.68	15.43	47.28	15.23		80	120.80	22.55	33.93	21.22	
90	113.84	15.59	47.33	15.21		90	120.83	22.58	33.56	21.45	
100	113.90	15.65	47.11	15.28		100	120.90	22.65	33.71	21.36	

Official BH No.:	10215	District:	Ghanzi
Date of test commencement:	24.01.2006	Location:	Metsimantle
Time of test Commencement:	0700hrs	BH depth (m):	250
Date of test completion:	24.01.2006	Screens(m)	211.86 to 247.76
Time of test Completion:	1522hrs	Depth to pump intake (m)	150.8
Method of water level measurement:	electrical dipper	Description of MP:	top of casing
Observation Bh No.:	n/a	Height of MP above ground:	0.51
Distance to OB. BH (m)	n/a	Static water level before test (m):	98.25
Casing diameter (mm)	203	Water strike	173, 203, 215 & 233
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	423554	Northing	7424095

STEP No. 3 | STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments
0.25	121.75	23.50				0.25	126.70	28.45			
0.5	122.53	24.28				0.5	127.15	28.90			
1	123.65	25.40	26.97	26.70		1	127.75	29.50	25.62	28.10	
1.5	124.05	25.80				1.5	128.26	30.01			
2	124.52	26.27	26.00	27.69		2	128.69	30.44	24.90	28.92	
2.5	124.86	26.61	25.85	27.85		2.5	128.85	30.60			
3	125.20	26.95	27.69	26.00	adj	3	129.00	30.75	23.88	30.15	adj
4	125.40	27.15	27.44	26.24	adj	4	129.25	31.00	23.60	30.51	
5	125.22	26.97	27.70	25.99	adj	5	129.76	31.51	23.56	30.56	
6	125.14	26.89	28.00	25.71		6	129.95	31.70	23.49	30.65	
7	125.18	26.93	27.69	26.00		7	130.10	31.85	24.56	29.32	
8	125.25	27.00	27.81	25.89		8	130.15	31.90	24.00	30.00	
9	125.29	27.04	27.44	26.24		9	130.27	32.02	24.19	29.76	
10	125.35	27.10	27.60	26.09		10	130.30	32.05	23.58	30.53	
11	125.39	27.14	27.91	25.80		11	130.35	32.10	23.70	30.38	
12	125.41	27.16	27.88	25.82		12	130.40	32.15	23.97	30.04	
13	125.45	27.20	27.70	25.99		13	130.45	32.20	23.81	30.24	
14	125.51	27.26	27.85	25.85		14	130.49	32.24	23.94	30.08	
15	125.56	27.31	27.91	25.80		15	130.53	32.28	23.90	30.13	
20	125.70	27.45	27.90	25.81		20	130.62	32.37	23.81	30.24	
25	125.78	27.53	27.72	25.97		25	130.80	32.55	24.00	30.00	
30	125.88	27.63	27.87	25.83		30	131.15	32.90	23.92	30.10	
35	125.95	27.70	27.91	25.80		35	131.15	32.90	23.97	30.04	
40	126.03	27.78	27.81	25.89		40	131.15	32.90	23.90	30.13	
45	126.10	27.85	27.88	25.82		45	131.15	32.90	23.88	30.15	
50	126.15	27.90	27.84	25.86		50	131.07	32.82	23.78	30.28	
55	126.21	27.96	27.91	25.80		55	131.08	32.83	23.98	30.03	
60	126.24	27.99	27.85	25.85		60	131.08	32.83	23.81	30.24	
70	126.32	28.07	27.75	25.95		70	131.12	32.87	23.90	30.13	
80	126.40	28.15	27.80	25.90		80	131.12	32.87	23.87	30.16	
90	126.40	28.15	27.90	25.81		90	131.13	32.88	23.92	30.10	
100	126.48	28.23	27.75	25.95		100	131.23	32.98	23.90	30.13	

Official BH No.:	10215	District:	Ghanzi
Date of test commencement:	24.01.2006	Location:	Metsimantle
Time of test Commencement:	0700hrs	BH depth (m):	250
Date of test completion:	24.01.2006	Screens(m)	211.86 to 247.76
Time of test Completion:	1522hrs	Depth to pump intake (m)	150.8
Method of water level measurement:	electrical dipper	Description of MP:	top of casing
Observation Bh No.:	n/a	Height of MP above ground:	0.51
Distance to OB. BH (m)	n/a	Static water level before test (m):	98.25
Casing diameter (mm)	203	Water strike	173, 203, 215 & 233
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	423554	Northing	7424095

STEP No. 5 STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments
0.25	130.24	31.99				0.25	140.29	42.04			
0.5	130.40	32.15			adj	0.5	141.10	42.85			
1	133.50	35.25	20.37	35.35		1	142.30	44.05	17.69	40.70	
1.5	135.40	37.15				1.5	143.12	44.87			
2	135.67	37.42	20.44	35.23		2	144.42	46.17	17.95	40.11	
2.5	136.35	38.10				2.5					
3	136.93	38.68	20.31	35.45		3					
4	137.57	39.32	20.48	35.16		4					
5	137.90	39.65	20.51	35.10		5					
6	138.17	39.92	20.33	35.42		6					
7	138.37	40.12	20.35	35.38		7					
8	138.50	40.25	20.50	35.12		8					
9	138.58	40.33	20.47	35.17		9					
10	138.71	40.46	20.54	35.05		10					
11	138.78	40.53	20.47	35.17		11					
12	138.83	40.58	20.49	35.14		12					
13	138.83	40.58	20.39	35.31		13					
14	138.90	40.65	20.44	35.23		14					
15	138.95	40.70	20.53	35.07		15					
20	139.13	40.88	20.55	35.04		20					
25	139.30	41.05	20.35	35.38		25					
30	139.42	41.17	20.56	35.02		30					
35	139.50	41.25	20.50	35.12		35					
40	139.58	41.33	20.53	35.07		40					
45	139.73	41.48	20.54	35.05		45					
50	139.85	41.60	20.39	35.31		50					
55	140.00	41.75	20.51	35.10		55					
60	140.10	41.85	20.55	35.04		60					
70	140.00	41.75	20.50	35.12		70					
80	140.10	41.85	20.41	35.28		80					
90	140.18	41.93	20.49	35.14		90					
100	140.23	41.98	20.53	35.07		100					

Table 19-8 Constant Rate Test Data – BH10215

Official BH NO :	10215	District :	Ghanzi
Date of test commencement :	25.01.06	Location :	Metsimantle
Time of test commencement :	0800hrs	BH depth(m) :	250
Date of test completion	28.01.06	Screen Interval (m)	211.86 to 247.76
Time of test completion :	0800hrs	Depth of pump intake (m) :	150.8m
Method of water level measurement	electrical dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.51
Distance ob BH r (m)	n/a	Static Water level before test(m) :	98.30
Casing diameter (mm)	203	Water strike	173, 203, 215 & 233
Orifice plate diameter	4"	Delivery pipe diameter	5"
Easting	423554	Northing	7424095

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 200l	Q(m^3/h)	Temp (^{0}C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO
	0.25	103.56	5.26						Flowmeter 005073.721
	0.5	106.80	8.50						
	1	112.15	13.85						
	2	114.42	16.12						
	3	120.17	21.87	26.12	27.57	27.8			
	4	121.40	23.10	25.75	27.96	27.6			
	5	122.70	24.40	23.72	30.35	28.1			
	6	124.56	26.26	23.25	30.97	28.8			
	7	125.40	27.10	22.68	31.75	28.7			
	8	126.32	28.02	22.60	31.86	28.1			
	9	127.20	28.90	22.63	31.82	28.6			
	10	127.67	29.37	22.57	31.90	28.4			
	11	128.20	29.90	22.69	31.73	28.5			
	12	128.50	30.20	22.12	32.55	28.7			
	15	129.45	31.15	22.45	32.07	28.2	2910	7.69	10
	20	130.75	32.45	22.48	32.03	28.4	2910	7.70	10
	25	130.76	32.46	22.57	31.90	28.4	2900	7.69	10
	30	131.00	32.70	22.56	31.91	28.5	2910	7.69	10
	40	132.15	33.85	22.44	32.09	28.7	2900	7.72	10
	45	132.40	34.10	22.40	32.14	28.6	1980	7.80	10
	50	132.78	34.48	22.28	32.32	28.6	1980	7.70	10
	60	133.06	34.76	22.43	32.10	28.8	1860	7.82	10
	75	133.45	35.15	22.45	32.07	28.7	1740	7.69	10
	90	133.72	35.42	22.41	32.13	28.8	1830	7.68	10
	105	133.98	35.68	23.32	30.87	28.9	1770	7.80	10
	120	134.25	35.95	22.85	31.51	29.0	1690	7.74	10
	150	134.55	36.25	22.91	31.43	29.1	1690	7.72	10
	180	134.80	36.50	22.60	31.86	29.1	1660	7.70	10
	210	134.90	36.60	22.63	31.82	29.3	1660	7.82	10
	240	135.05	36.75	22.57	31.90	29.4	1660	7.80	10
	270	135.22	36.92	22.38	32.17	29.5	1550	7.82	10
	300	135.36	37.06	22.86	31.50	29.4	1550	7.80	10
	330	135.46	37.16	22.80	31.58	29.0	1550	7.84	10
	360	135.65	37.35	22.85	31.51	29.2	1560	7.82	10
	390	135.75	37.45	22.56	31.91	29.0	1550	7.70	10
	420	135.82	37.52	23.00	31.30	29.9	1200	7.78	10
	450	135.86	37.56	22.63	31.82	30.0	1210	7.77	10
	480	135.90	37.60	22.57	31.90	29.8	1200	7.69	10
	540	136.02	37.72	22.60	31.86	29.9	1210	7.77	10
	600	136.22	37.92	23.59	30.52	29.2	1110	7.82	10
	660	136.45	38.15	22.37	32.19	28.6	1080	7.89	10
	720	136.46	38.16	22.28	32.32	28.4	1090	7.82	10
	780	136.46	38.16	22.47	32.04	28.1	1110	7.80	10
	840	136.47	38.17	22.39	32.16	27.9	1030	7.81	10
	900	136.47	38.17	22.44	32.09	27.3	1000	7.76	10
	960	136.48	38.18	22.21	32.42	27.1	1021	7.76	10
	1020	136.48	38.18	22.39	32.16	27.3	1110	7.75	10
	1080	136.49	38.19	22.44	32.09	27.1	1113	7.71	10
	1140	136.49	38.19	22.47	32.04	27.1	1030	7.71	10
	1200	136.50	38.20	22.38	32.17	27.1	1026	7.71	10
	1260	136.80	38.50	22.40	32.14	27.3	1024	7.71	10
	1320	137.31	39.01	22.36	32.20	27.1	1020	7.69	10
	1380	137.70	39.40	22.47	32.04	28.6	960	7.92	10

	1440	138.02	39.72	22.28	32.32	28.7	930	7.89	DO = 1.65mg/l
	1500	138.65	40.35	22.40	32.14	27.7	941	7.90	10
	1560	138.42	40.12	22.78	31.61	28.9	940	7.82	10
	1620	138.42	40.12	22.40	32.14	30.0	870	7.57	10
	1680	138.30	40.00	22.60	31.86	30.7	890	7.70	10
	1740	138.20	39.90	22.51	31.99	30.0	860	7.73	10
	1800	138.04	39.74	22.48	32.03	29.9	880	7.90	10
	1860	138.07	39.77	22.40	32.14	29.6	860	7.75	10
	1920	138.20	39.90	22.16	32.49	29.4	860	7.84	10
	1980	138.46	40.16	22.47	32.04	29.8	850	7.77	10
	2040	138.55	40.25	22.57	31.90	29.6	860	7.87	10
	2100	138.60	40.30	22.41	32.13	29.5	860	7.72	10
	2160	138.65	40.35	22.53	31.96	29.5	870	7.72	10
	2220	138.72	40.42	22.69	31.73	29.5	850	7.73	10
	2280	138.74	40.44	22.34	32.23	29.5	860	7.71	10
	2340	138.60	40.30	22.38	32.17	29.6	860	7.74	10
	2400	138.62	40.32	22.40	32.14	29.5	840	7.71	10
	2460	138.64	40.34	22.50	32.00	29.6	850	7.71	10
	2520	138.65	40.35	22.57	31.90	29.5	860	7.74	10
	2580	138.85	40.55	22.33	32.24	29.7	868	7.60	10
	2640	138.93	40.63	22.48	32.03	29.9	877	7.83	10
	2700	139.09	40.79	22.45	32.07	29.8	850	7.79	10
	2760	139.17	40.87	22.50	32.00	29.7	881	7.60	10
	2820	139.28	40.98	22.38	32.17	28.9	880	7.76	10
	2880	139.53	41.23	22.41	32.13	28.5	887	7.80	DO = 2.45mg/l
	2940	139.45	41.15	22.56	31.91	29.2	870	7.70	10
	3000	139.48	41.18	22.45	32.07	29.9	881	7.69	10
	3060	139.48	41.18	22.30	32.29	28.7	885	7.86	10
	3120	139.32	41.02	22.50	32.00	28.2	820	7.82	10
	3180	139.19	40.89	22.28	32.32	30.2	800	7.81	10
	3240	139.01	40.71	22.34	32.23	30.3	870	7.77	10
	3300	138.88	40.58	22.38	32.17	29.9	840	7.73	10
	3360	138.72	40.42	22.41	32.13	29.9	820	7.70	10
	3420	138.68	40.38	22.51	31.99	29.7	840	7.76	10
	3480	138.55	40.25	22.34	32.23	29.3	840	7.89	10
	3540	138.90	40.60	22.57	31.90	29.0	830	7.94	10
	3600	138.96	40.66	22.41	32.13	29.6	830	7.74	10
	3660	139.00	40.70	22.34	32.23	28.3	830	7.91	10
	3720	139.00	40.70	22.45	32.07	29.3	840	7.73	10
	3780	139.03	40.73	22.40	32.14	29.2	830	7.74	10
	3840	139.12	40.82	22.36	32.20	29.0	830	7.73	10
	3900	139.17	40.87	22.47	32.04	28.8	840	7.74	10
	3960	139.20	40.90	22.42	32.11	28.7	830	7.73	10
	4020	139.24	40.94	22.33	32.24	28.8	840	7.74	10
	4080	139.26	40.96	22.28	32.32	28.5	830	7.73	10
	4140	139.28	40.98	22.43	32.10	28.3	840	7.72	10
	4200	139.30	41.00	22.32	32.26	28.5	830	7.74	10
	4260	139.33	41.03	22.42	32.11	27.3	830	7.85	10
	4320	139.41	41.11	22.43	32.10	29.5	830	7.73	DO = 4.25 mg/l

End of the test Flow meter
005799.626

Table 19-9 Recovery Test Data – BH10215

Official BH NO :	10215	District :	Ghanzi
Date of test commencement :	28.01.2006	Location :	Metsimantle
Time of test commencement :	0800hrs	BH depth(m) :	250
Date of test completion	29.01.2006	Screen Int (m)	211.86 to 247.76
Time of test completion :	0800hrs	Depth of pump intake (m) :	150.8
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	n/a	Height of MP above ground(m) :	0.51
Dist.to Pumping Bh:	n/a	Static Water level before test(m) :	98.3
Casing diameter (mm)	203	Water strike	173, 203, 215 & 233
Orifice plate diameter		Delivery pipe diameter	
Easting	423554	Northing	7424095

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	139.41	41.11
	0.25	138.54	40.24
	0.5	137.98	39.68
	1	135.00	36.70
	2	109.92	11.62
	3	108.80	10.50
	4	107.50	9.20
	5	107.22	8.92
	6	106.46	8.16
	7	106.26	7.96
	8	105.97	7.67
	9	105.90	7.60
	10	105.80	7.50
	12	105.75	7.45
	15	105.68	7.38
	20	105.40	7.10
	25	105.12	6.82
	30	104.90	6.60
	40	104.28	5.98
	50	103.93	5.63
	60	103.58	5.28
	75	103.74	5.44
	90	102.96	4.66
	105	102.69	4.39
	120	102.48	4.18

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	102.18	3.88
	180	101.90	3.60
	210	101.68	3.38
	240	101.40	3.10
	270	101.13	2.83
	300	100.95	2.65
	330	100.85	2.55
	360	100.74	2.44
	390	100.68	2.38
	420	100.62	2.32
	450	100.44	2.14
	480	100.32	2.02
	540	100.25	1.95
	600	100.20	1.90
	660	100.15	1.85
	720	99.95	1.65
	780	99.89	1.59
	840	99.73	1.43
	900	99.64	1.34
	960	99.54	1.24
	1020	99.44	1.14
	1080	99.38	1.08
	1140	99.21	0.91
	1200	99.17	0.87
	1260	99.15	0.85
	1320	99.11	0.81
	1380	99.08	0.78
	1440	99.01	0.71

20 BH10216

BH10216 with siting reference **S6,** line R4 peg 5500m is an exploration borehole drilled to explore the Ecca aquifer in the southwestern part of the Ncojane Block near fault **F6**. This exploration borehole is located about 5km north of Ukwi along the road leading to Ncojane. Drilling at this site commenced on 29 October 2005 and was completed on 19 November 2005. The total drilled depth of this borehole is 251m.

20.1 SITING CRITERIA AND DRILLING OBJECTIVES

The main objective of drilling this borehole was to evaluate the potential of the Ecca aquifer in southwestern part of Ncojane Block near Fault F6. A secondary objective was to assess the role of dolerite sill intrusions in controlling groundwater quality. This borehole will also allow for an evaluation of yield potential, estimation of aquifer Transmissivity and provide water quality data for the Ecca aquifer at this locality.

20.2 DRILLING RESULTS

This exploration borehole intercepted various lithologies including fine grained sand, mudstones, shale, dolerite, coal and fine to medium grained sandstones (**Figure 20-1**). Drilling of BH10216 was carried out with a 15 inch bit using the DTH drilling technique from 0 to 64 m bgl after which 12 inch plain casings were installed and cement grouted. From 64 m to 143m, drilling was carried out using a 12 inch drilling bit after which drilling was carried using a 10 inch bit to the terminal depth of 251 m.

During drilling of this borehole, four water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the four water strikes are as follows;

1. (134m, 3260 µS/cm, 4.4m^3/hr)
2. (168m, 3280 µS/cm, 4.4 m^3/hr)
3. (173m, 2690 µS/cm, 5.4 m^3/hr)
4. (191m, 2950 µS/cm, 22.4 m^3/hr)

After completion of drilling, the borehole was geophysical logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 248m **(Figure 20-2).** After logging, an 8 inch steel casing and factory slotted screen (interval 173.15 to 185.4 and 191.52 to 216 m bgl) assembly was installed in the borehole.

The borehole was developed by air lifting for 4 hours and the final yield was 51 m^3/hr with the electrical conductivity measured as 2000 µS/cm. The water level was measured as 86.85 m bgl on 19 November 2005. Water samples were collected at the four water strikes and also after completion of borehole development and these samples will be submitted to the DWA laboratory for chemical analysis.

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

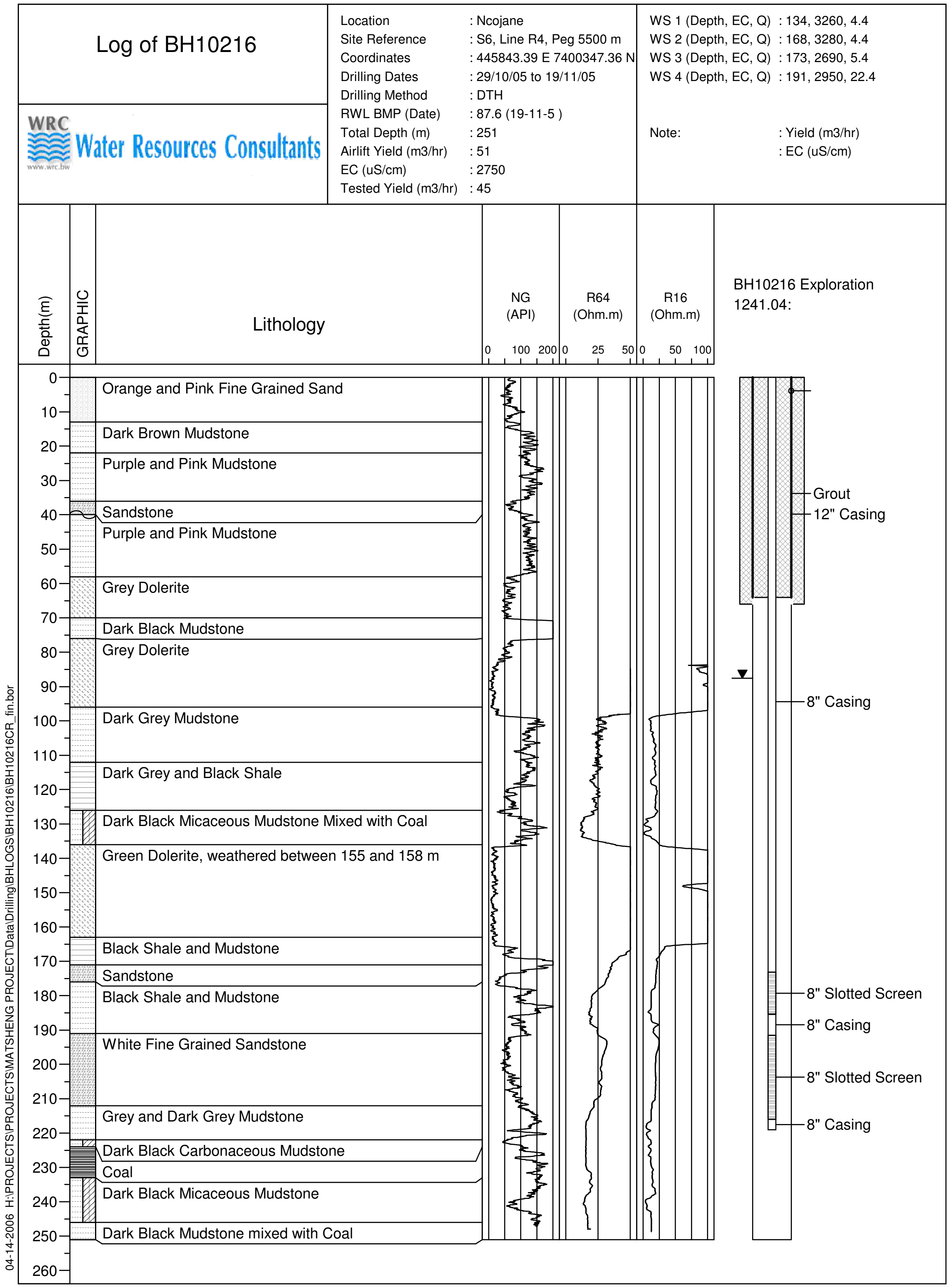

Figure 20-1 Log of BH10216

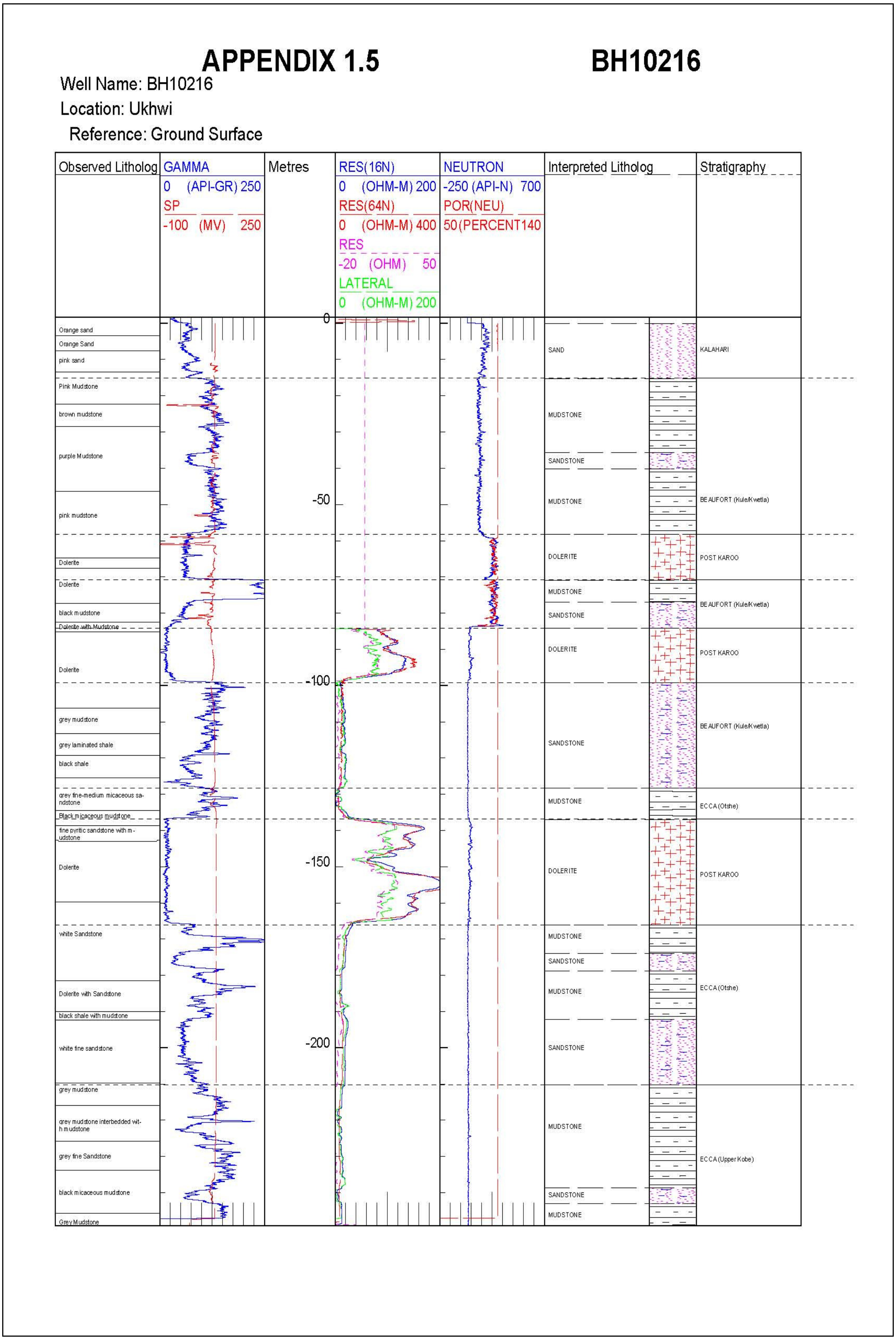

Figure 20-2 Geophysical log of BH10216

20.3 PUMP TESTING RESULTS

Borehole BH10216 was pump tested between 14 and 20 February 2006. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.56 m above ground level (agl) and the pump intake was set at 168.5 m below ground level. A summary of the test pumping activities at this borehole is given **Table 20-1**. The collected pump testing data is presented in **Tables 20-5 to 20-8**.

Table 20-1 Summary of Pumping Test Data BH10216

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	3.94	10
	2	15	8.52	20.2
	3	15	14.7	30.3
	4	15	20.3	40
	5	15	26.39	50
	6	15	32.89	61
Step Test	1	100	11.46	20
	2	100	17.49	30
	3	100	26.37	40
	4	100	34.19	50
	5	100	48.06	61
Constant Rate	1	4500	41.3	45
Recovery*	1	1440	3.82	0

Note. 3.82 Residual Drawdown*

20.3.1 Step Drawdown Test

The step drawdown test at this borehole was carried out on 15 February 2006. The static water level before the start of the test was 86.93 m bmp. The step drawdown test consisted of 5 steps of 100 minutes duration at discharge rates of 10, 20, 30, 40, 50 and 61m^3/hr respectively, for steps 1 to 5.

The step drawdown test data was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted data for this borehole using this method is given in **Figure 20-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, (**Figure 20-4**). The Transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 15 m^2/d, (**Figure 20-5**). The interpreted data for the step drawdown test data is given in **Table 20-2**.

Table 20-2 Results of Step Test Analysis BH10216

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10216	2.10E-02	4.36E-06	15.1	20.0	11.50	11.50	1.74
				30.0	5.27	16.77	1.79
				40.0	7.40	24.17	1.65
				50.0	5.59	29.76	1.68
				61.0	12.00	41.76	1.46

The planned duration for the constant rate test of this borehole was 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 20-2**) to estimate the expected total drawdown after 3 days of pumping. A discharge rate of 45 m^3/hr was selected as an optimal rate for the CRT because at higher rates the slopes were very steep due to the close proximity of fault **F6**.

20.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 16 and 19 February 2006 at a discharge rate of 45 m^3/hr and the total drawdown after 75 hrs of pumping was 41.3 m. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 3.82 m.

Data from the pumping borehole was interpreted using the Theis and Cooper-Jacob (1946) analytical solutions using the computer programme “Aqtesolv”. Transmissivity (T) values obtained by these two analytical solutions were 31 and 29 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 27 m^2/d was obtained. The interpretation of the results are summarised in **Table 20-3** and the interpreted data is presented in **Figures 20-6** to **20-8**.

There is an apparent impermeable barrier interpreted in the CRT data after 4200 minutes of pumping, **Figure 20-7**, which resulted with increasing the duration of the test by 3hrs. This barrier is probably caused by fault **F6** which is close to BH10216.

Table 20-3 Summary of Constant Rate and Recovery Tests BH10216

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10216	75	1080	a) 30.8 b) 28.8	c) 27	Confined

Notes:
<u>Interpretation Techniques</u>
a) Theis
b) Cooper-Jacob
c) Theis Modified Recovery

20.3.2.1 <u>Aquifer Type interpreted</u>

The interpretation of the pump testing data indicates that the aquifer type is confined.

20.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis most of the BOS 32:2000 listed determinants **(Table 20-4).** In addition to these, some samples collected at 72 hrs were submitted for stable and radioactive (^{14}C) isotope analysis at the CSIR laboratory in Pretoria, South Africa **.**

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), and pH are 28.1 ^oC, 2740 µS/cm and 8.34, respectively.

Table 20-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10216	4.4	648	4.9	3.6	195	464	527	4.7	0.69	0.11	<0.05	740	8	474
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10216	<0.1	27	<0.14	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 *is calculated from alkalinity*

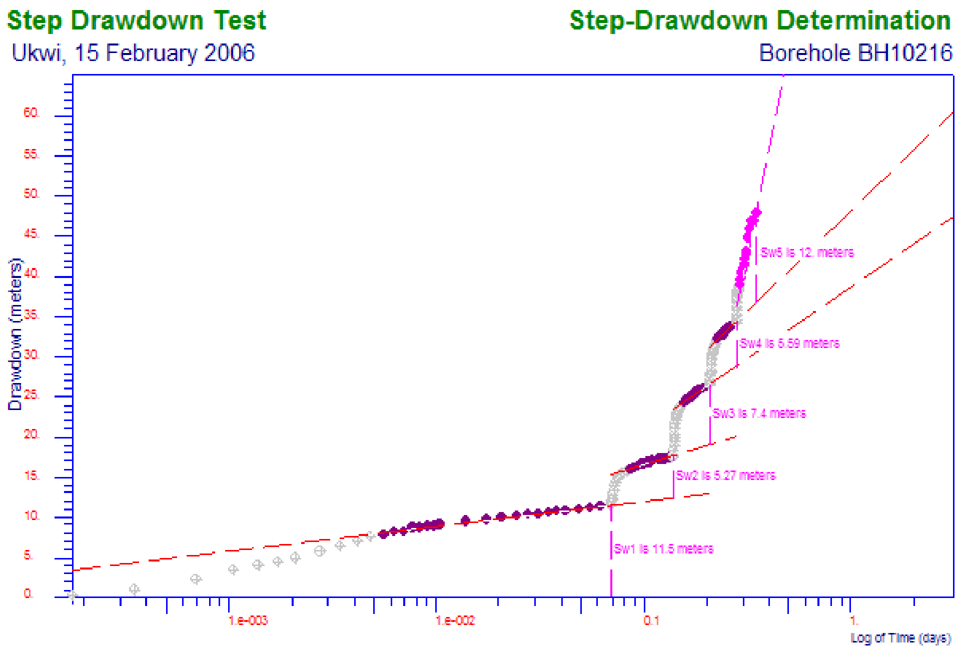

Figure 20-3 Pumping Test Results for BH10216: Step Drawdown Test - Hantush-Bierschenk (semi-log)

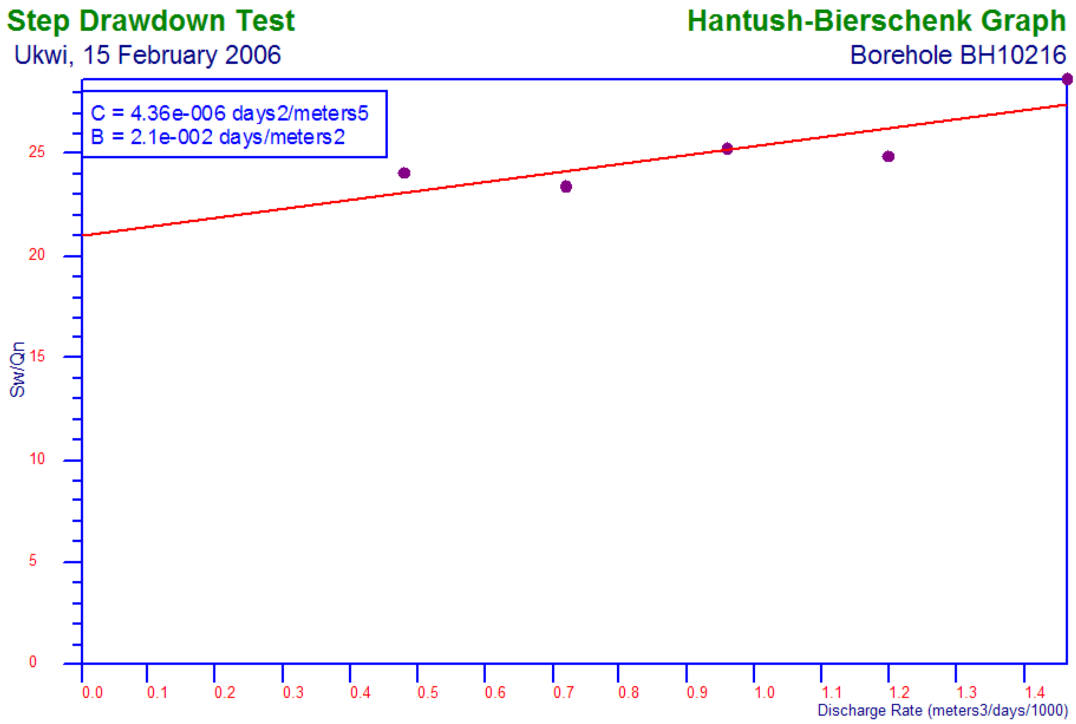

Figure 20-4 Pumping Test Results for BH10216: Step Drawdown Test – Hantush-Bierschenk

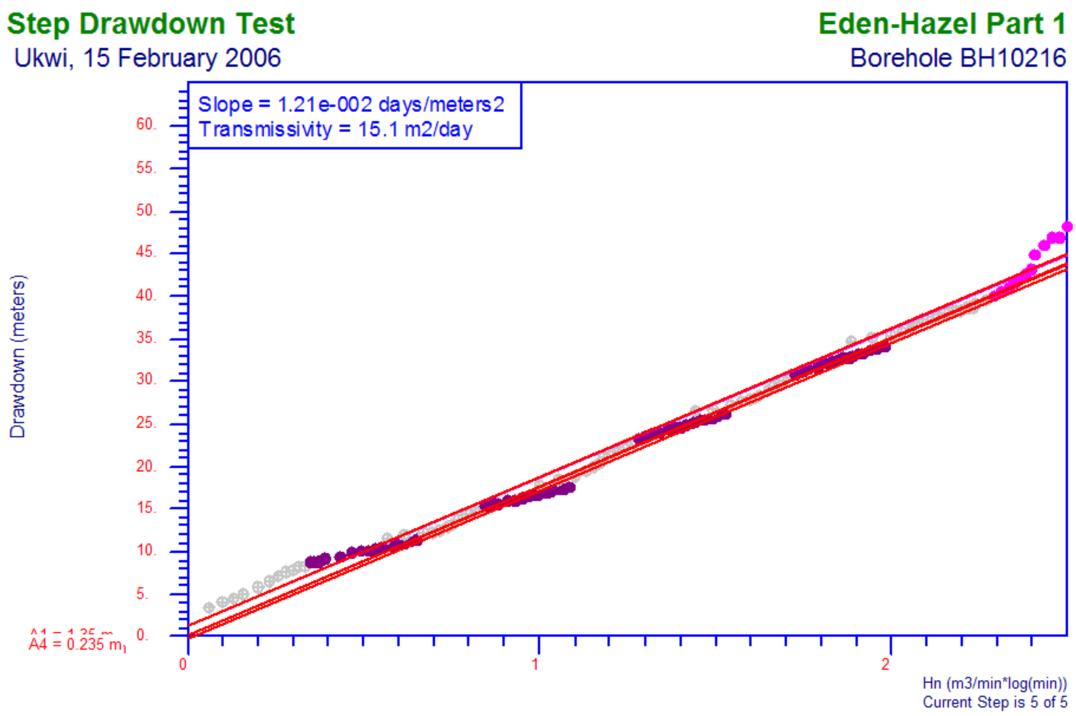

Figure 20-5 Pumping Test Results for BH10216: Step Drawdown Test – Eden-Hazel (Part 1)

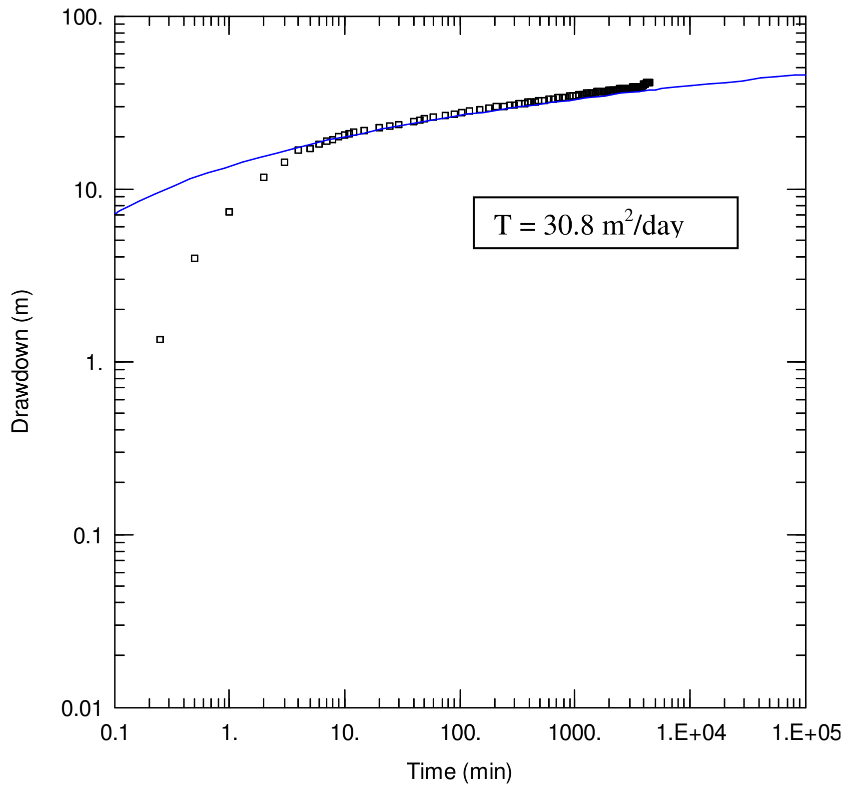

Figure 20-6 Pumping Test Results for BH10216: Theis Solution

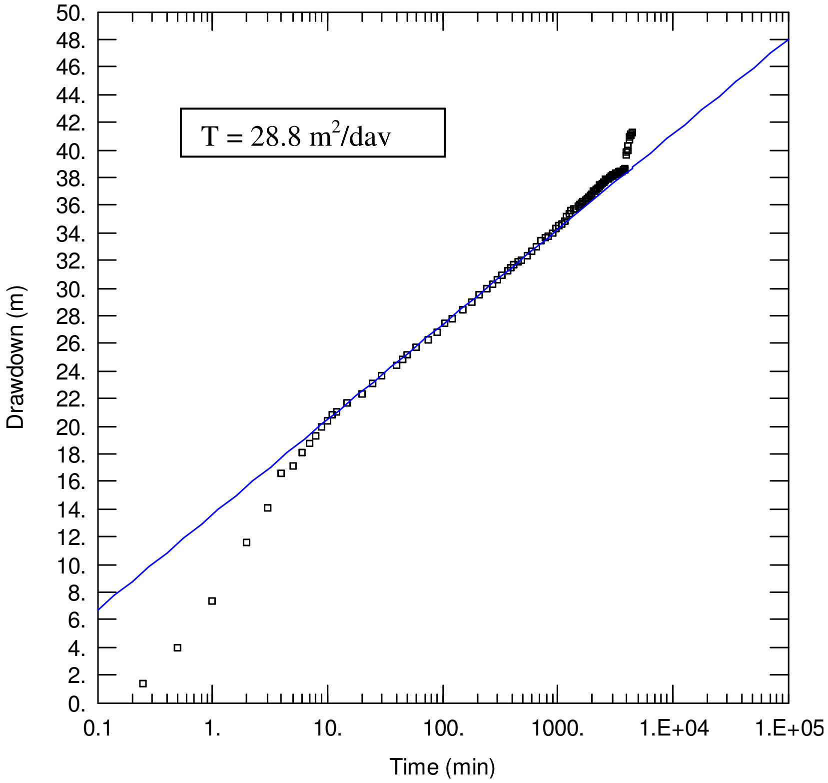

Figure 20-7 Pumping Test Results for BH10216: CRT Cooper Jacob Solution

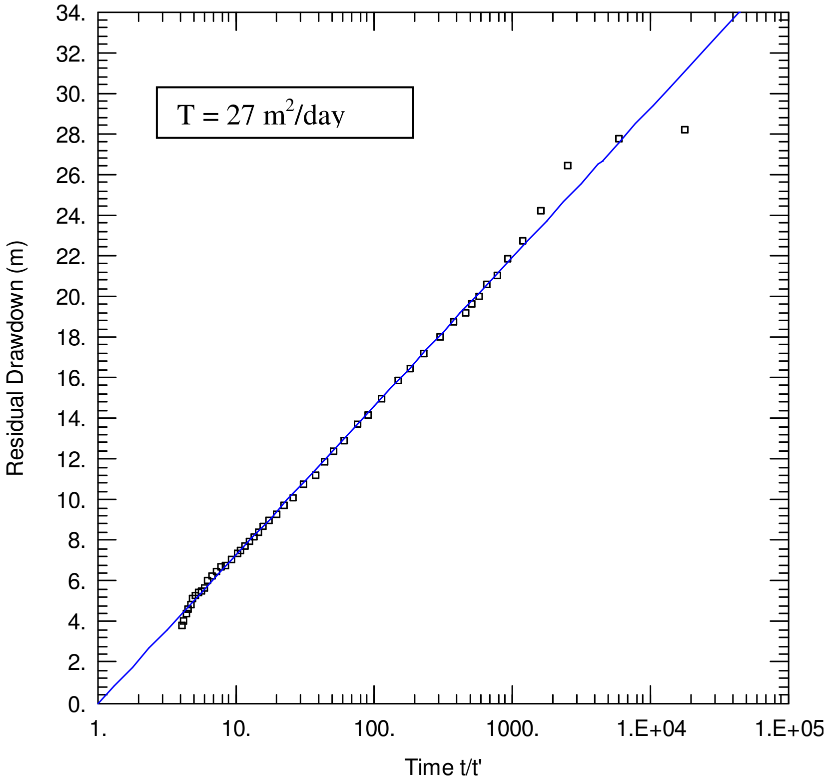

Figure 20-8 Pumping Test Results for BH10216: Theis Recovery Solution

Table 20-5 Calibration Test Data – BH10216

Official BH No.:	10216	District:	Kgalagadi
Date of test commencement:	14.02.06	Location:	Ukhwi
Time of test commencement	1800hrs	BH depth (m):	251
Date of test completion:	14.02.06	Screen Interval (m):	173.15 to 185.40 & 191.52 to 216
Time of test completion	1930hrs	Depth of pump intake (m):	168.5
Method of water level measurement:	dipper	Static water level before test (m):	86.63
Casing diameter (mm)	203	Water strike	134, 168, 173 & 191
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	445850	Northing	7400322

STEP No. 1

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	87.30	0.67			
0.5	87.95	1.32			
1	88.68	2.05			
2	89.61	2.98			
3	89.83	3.20			
4	89.92	3.29	16.19	11.12	
5	90.02	3.39	18.03	9.98	
6	90.13	3.50	17.85	10.08	
7	90.21	3.58	17.90	10.06	
8	90.27	3.64	17.89	10.06	
9	90.34	3.71	17.97	10.02	
10	90.38	3.75	17.90	10.06	
11	90.43	3.80	17.96	10.02	
12	90.47	3.84	17.99	10.01	
15	90.57	3.94	17.89	10.06	

STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	90.63	4.00			
0.5	91.02	4.39			
1	91.80	5.17	8.70	20.69	
2	93.74	7.11	8.94	20.13	
3	94.53	7.90	8.96	20.09	adjust
4	94.84	8.21	8.90	20.22	
5	94.85	8.22	8.86	20.32	
6	94.85	8.22	8.89	20.25	
7	94.85	8.22	8.85	20.34	
8	94.85	8.22	8.94	20.13	
9	94.85	8.22	8.97	20.07	
10	94.86	8.23	8.84	20.36	
11	94.88	8.25	8.80	20.45	
12	94.95	8.32	8.96	20.09	
15	95.15	8.52	8.98	20.04	

STEP No. 3

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments
0.25	95.68	9.05			
0.5	96.44	9.81			
1	97.25	10.62	10.91	33.00	
2	98.38	11.75	11.69	30.80	
3	99.12	12.49	11.70	30.77	
4	99.54	12.91	11.97	30.08	
5	99.90	13.27	11.82	30.46	
6	100.15	13.52	11.93	30.18	
7	100.38	13.75	11.87	30.33	
8	100.54	13.91	11.88	30.30	
9	100.69	14.06	11.94	30.15	
10	100.85	14.22	11.97	30.08	
11	100.98	14.35	11.89	30.28	
12	101.09	14.46	11.86	30.35	
15	101.33	14.70	11.90	30.25	

STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	Pumping Rate (m^3/hr)	Comments
0.25	101.91	15.28			
0.5	102.63	16.00			
1	103.21	16.58	12.56	42.99	
2	104.37	17.74	12.25	44.08	
3	105.00	18.37	13.16	41.03	adj
4	105.36	18.73	13.22	40.85	
5	105.59	18.96	13.40	40.30	
6	105.80	19.17	13.44	40.18	
7	105.99	19.36	13.29	40.63	
8	106.15	19.52	13.36	40.42	
9	106.29	19.66	13.30	40.60	
10	106.43	19.80	13.47	40.09	
11	106.54	19.91	13.42	40.24	
12	106.66	20.03	13.40	40.30	
15	106.95	20.32	13.37	40.39	

Official BH No.:	10216	District:	Kgalagadi
Date of test commencement:	14.02.06	Location:	Ukhwi
Time of test commencement	1800hrs	BH depth (m):	218
Date of test completion:	14.02.06	Screen Interval (m):	173.15 to 185.40 & 191.52 to 216
Time of test completion	1930hrs	Depth of pump intake (m):	168.5
Method of water level measurement:	dipper	Static water level before test (m):	86.63
Casing diameter (mm)	203	Water strike	134, 168, 173 & 191
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	445850	Northing	7400322

STEP No. 5 | STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	107.11	20.48				0.25	113.25	26.62			
0.5	107.53	20.90				0.5	113.73	27.10			
1	108.20	21.57	11.56	46.71		1	114.64	28.01	12.03	59.85	
2	108.92	22.29	10.90	49.54		2	115.90	29.27	11.84	60.81	
3	109.84	23.21	10.66	50.66	adj	3	116.59	29.96	12.00	60.00	
4	110.45	23.82	10.78	50.09		4	116.99	30.36	11.20	64.29	
5	110.99	24.36	10.72	50.37		5	117.44	30.81	11.82	60.91	
6	111.37	24.74	10.81	49.95		6	117.74	31.11	11.90	60.50	
7	111.69	25.06	10.78	50.09		7	118.03	31.40	11.92	60.40	
8	111.87	25.24	10.75	50.23		8	118.24	31.61	11.93	60.35	
9	112.15	25.52	10.80	50.00		9	118.47	31.84	11.69	61.59	
10	112.32	25.69	10.79	50.05		10	118.63	32.00	11.74	61.33	
11	112.44	25.81	10.74	50.28		11	118.78	32.15	11.70	61.54	
12	112.65	26.02	10.70	50.47		12	118.97	32.34	11.75	61.28	
15	113.02	26.39	10.73	50.33		15	119.52	32.89	11.72	61.43	

Table 20-6 Step Drawdown Test – BH10216

Official BH No.:	10216	District:	Kgalagadi
Date of test commencement:	15.02.2006	Location:	Ukhwi
Time of test Commencement:	0800hrs	BH depth (m):	251
Date of test completion:	15.02.2006	Screens(m)	173.15 to 185.40 & 191.52 to 216
Time of test Completion:	1620hrs	Depth to pump intake (m)	168.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.54
Distance to OB. BH (m)	n/a	Static water level before test (m):	86.93
Casing diameter (mm)	203	Water strike	134, 168, 173 & 191
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	445850	Northing	7400322

STEP No. 1 — STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	87.32	0.39				0.25	98.59	11.66			
0.5	87.89	0.96				0.5	99.00	12.07			
1	89.11	2.18				1	99.11	12.18	12.47	28.87	
1.5	90.37	3.44				1.5	99.20	12.27			
2	90.97	4.04	10.50	17.14		2	99.36	12.43	11.72	30.72	adj
2.5	91.44	4.51				2.5	99.81	12.88			
3	91.79	4.86	8.25	21.82		3	100.14	13.21	11.61	31.01	
4	92.76	5.83	8.87	20.29		4	100.78	13.85	11.84	30.41	
5	93.38	6.45	8.94	20.13		5	101.29	14.36	11.96	30.10	
6	93.99	7.06	8.90	20.22		6	101.55	14.62	11.99	30.03	
7	94.50	7.57	8.96	20.09		7	101.76	14.83	11.87	30.33	
8	94.85	7.92	8.93	20.16		8	101.92	14.99	11.90	30.25	
9	95.15	8.22	8.84	20.36		9	102.04	15.11	11.85	30.38	
10	95.29	8.36	8.97	20.07		10	102.15	15.22	11.79	30.53	
11	95.56	8.63	8.91	20.20		11	102.25	15.32	11.97	30.08	
12	95.59	8.66	8.79	20.48		12	102.34	15.41	11.95	30.13	
13	95.72	8.79	8.94	20.13		13	102.42	15.49	11.89	30.28	
14	95.87	8.94	8.88	20.27		14	102.50	15.57	11.83	30.43	
15	95.99	9.06	8.96	20.09		15	102.52	15.59	11.97	30.08	
20	96.38	9.45	8.87	20.29		20	102.81	15.88	11.98	30.05	
25	96.68	9.75	8.93	20.16		25	102.97	16.04	11.96	30.10	
30	96.89	9.96	8.84	20.36		30	103.17	16.24	11.89	30.28	
35	97.05	10.12	8.91	20.20		35	103.36	16.43	11.99	30.03	
40	97.23	10.30	8.90	20.22		40	103.47	16.54	11.98	30.05	
45	97.38	10.45	8.94	20.13		45	103.59	16.66	11.99	30.03	
50	97.51	10.58	8.85	20.34		50	103.70	16.77	12.00	30.00	
55	97.64	10.71	8.87	20.29		55	103.80	16.87	11.96	30.10	
60	97.76	10.83	8.91	20.20		60	103.91	16.98	12.00	30.00	
70	97.94	11.01	8.79	20.48		70	104.13	17.20	11.97	30.08	
80	98.12	11.19	8.96	20.09		80	104.27	17.34	11.99	30.03	
90	98.26	11.33	8.93	20.16		90	104.34	17.41	12.00	30.00	
100	98.39	11.46	8.94	20.13		100	104.42	17.49	11.96	30.10	

Official BH No.:	10216	District:	Kgalagadi
Date of test commencement:	15.02.2006	Location:	Ukhwi
Time of test Commencement:	0800hrs	BH depth (m):	251
Date of test completion:	15.02.2006	Screens(m)	173.15 to 185.40 & 191.52 to 216
Time of test Completion:	1620hrs	Depth to pump intake (m)	168.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.54
Distance to OB. BH (m)	n/a	Static water level before test (m):	86.93
Casing diameter (mm)	203	Water strike	134, 168, 173 & 191
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	445850	Northing	7400322

STEP No. 3 | STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P. Rate (m^3/hr)	Comments
0.25	104.62	17.69				0.25	113.50	26.57			
0.5	105.25	18.32				0.5	113.73	26.80			
1	105.79	18.86	13.22	40.85		1	114.05	27.12	10.61	50.90	
1.5	106.42	19.49				1.5	114.55	27.62			
2	106.95	20.02	13.39	40.33		2	114.91	27.98	10.84	49.82	
2.5	107.35	20.42				2.5	115.05	28.12			
3	107.87	20.94	13.48	40.06		3	115.33	28.40	10.58	51.04	
4	108.57	21.64	13.39	40.33		4	115.87	28.94	10.76	50.19	
5	108.98	22.05	13.44	40.18		5	116.40	29.47	10.76	50.19	
6	109.39	22.46	13.28	40.66		6	116.81	29.88	10.63	50.80	
7	109.56	22.63	13.40	40.30		7	117.09	30.16	10.74	50.28	
8	109.75	22.82	13.45	40.15		8	117.40	30.47	10.76	50.19	
9	109.94	23.01	13.43	40.21		9	117.56	30.63	10.69	50.51	
10	110.08	23.15	13.37	40.39		10	117.66	30.73	10.78	50.09	
11	110.22	23.29	13.40	40.30		11	117.85	30.92	10.74	50.28	
12	110.30	23.37	13.45	40.15		12	117.98	31.05	10.73	50.33	
13	110.42	23.49	13.39	40.33		13	118.07	31.14	10.72	50.37	
14	110.50	23.57	13.40	40.30		14	118.21	31.28	10.63	50.80	
15	110.61	23.68	13.45	40.15		15	118.33	31.40	10.80	50.00	
20	110.93	24.00	13.38	40.36		20	118.65	31.72	10.74	50.28	
25	111.21	24.28	13.40	40.30		25	118.99	32.06	10.77	50.14	
30	111.43	24.50	13.39	40.33		30	119.19	32.26	10.79	50.05	
35	111.57	24.64	13.47	40.09		35	119.41	32.48	10.74	50.28	
40	111.78	24.85	13.44	40.18		40	119.59	32.66	10.78	50.09	
45	111.96	25.03	13.37	40.39		45	119.74	32.81	10.69	50.51	
50	112.15	25.22	13.46	40.12		50	119.90	32.97	10.65	50.70	
55	112.31	25.38	13.44	40.18		55	120.07	33.14	10.76	50.19	
60	112.45	25.52	13.28	40.66		60	120.19	33.26	10.72	50.37	
70	112.67	25.74	13.48	40.06		70	120.50	33.57	10.69	50.51	
80	112.88	25.95	13.40	40.30		80	120.75	33.82	10.75	50.23	
90	113.07	26.14	13.39	40.33		90	120.89	33.96	10.79	50.05	
100	113.30	26.37	13.49	40.03		100	121.12	34.19	10.77	50.14	

Table 20-7 Constant Rate Test Data – BH10216

Official BH NO :	10216	District :	Kgalagadi
Date of test commencement :	16.02.06	Location :	Ukhwi
Time of test commencement :	0900hrs	BH depth(m) :	251
Date of test completion	19.02.06	Screen Interval (m)	173.15 to 185.40 & 191.52 to 216
Time of test completion :	0900hrs	Depth of pump intake (m) :	165.5
Method of water level measurement	dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.54
Distance ob BH r (m)	n/a	Static Water level before test(m) :	88.15
Casing diameter (mm)	8"	Water strike	134, 168, 173 & 191
Orifice plate diameter	3"	Delivery pipe diameter	5"
Easting	445850	Northing	7400322

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 150l	$Q(m^3/h)$	Temp (^0C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO
	0.25	89.50	1.35						
	0.5	92.10	3.95						
	1	95.45	7.30	12.03	44.89				
	2	99.70	11.55	12.00	45.00				
	3	102.22	14.07	11.94	45.23				
	4	104.68	16.53	11.78	45.84				
	5	105.25	17.10	11.79	45.80				
	6	106.21	18.06	11.82	45.69				
	7	106.88	18.73	11.84	45.61				
	8	107.45	19.30	11.80	45.76				
	9	108.10	19.95	11.91	45.34				
	10	108.56	20.41	11.87	45.49				
	11	108.99	20.84	11.79	45.80				
	12	109.15	21.00	11.89	45.42				
	15	109.85	21.70	11.97	45.11	28.8	2520	8.27	22
	20	110.51	22.36	11.84	45.61	28.7	2520	8.29	22
	25	111.25	23.10	11.91	45.34	28.8	2500	8.30	22
	30	111.78	23.63	11.75	45.96	28.8	2510	8.28	22
	40	112.56	24.41	11.81	45.72	28.9	2530	8.31	22
	45	112.94	24.79	11.79	45.80	28.6	2520	8.29	22
	50	113.35	25.20	11.95	45.19	28.8	2560	8.36	22
	60	113.86	25.71	11.99	45.04	28.8	2550	8.37	22
	75	114.41	26.26	11.78	45.84	28.9	2560	8.35	22
	90	114.99	26.84	11.89	45.42	29.0	2560	8.38	22
	105	115.61	27.46	11.96	45.15	29.0	2550	8.37	22
	120	115.96	27.81	12.00	45.00	28.5	2600	8.46	22
	150	116.56	28.41	11.91	45.34	28.4	2550	8.45	22
	180	117.16	29.01	11.84	45.61	27.9	2600	8.38	22
	210	117.67	29.52	11.80	45.76	27.5	2610	8.35	22
	240	118.09	29.94	11.95	45.19	27.7	2610	8.36	22
	270	118.41	30.26	11.78	45.84	27.7	2600	8.31	22
	300	118.75	30.60	11.97	45.11	27.5	2610	8.34	22
	330	119.05	30.90	11.82	45.69	28.7	2600	8.39	22
	360	119.37	31.22	11.95	45.19	28.3	2600	8.35	22
	390	119.59	31.44	11.78	45.84	28.1	2620	8.33	22
	420	119.85	31.70	11.94	45.23	28.0	2620	8.39	22
	450	120.05	31.90	11.91	45.34	27.9	2660	8.36	22
	480	120.17	32.02	11.84	45.61	27.6	2650	8.35	22
	540	120.45	32.30	11.98	45.08	27.3	2690	8.23	22
	600	120.86	32.71	11.97	45.11	26.8	2720	8.37	22
	660	121.19	33.04	11.84	45.61	26	2690	8.39	22
	720	121.58	33.43	11.99	45.04	25.7	2760	8.45	22
	780	121.80	33.65	11.97	45.11	25.8	2750	8.43	22
	840	121.95	33.80	11.84	45.61	25.8	2760	8.44	22
	900	122.14	33.99	11.97	45.11	26.3	2780	8.39	22
	960	122.41	34.26	11.88	45.45	25.4	2770	8.41	22
	1020	122.68	34.53	11.80	45.76	26.0	2780	8.42	22
	1080	122.80	34.65	11.99	45.04	25.9	2780	8.50	22
	1140	122.96	34.81	11.89	45.42	25.8	2670	8.46	22
	1200	123.30	35.15	11.96	45.15	25.9	2560	8.51	22
	1260	123.50	35.35	11.97	45.11	26.4	2650	8.49	22
	1320	123.70	35.55	12.00	45.00	26.9	2740	8.45	22
	1380	123.81	35.66	11.99	45.04	26.8	2740	8.49	22
	1440	123.90	35.75	11.96	45.15	27.5	2770	8.25	DO = 2.30mg/l

	1500	124.04	35.89	11.98	45.08	28.3	2780	8.29	22
	1560	124.19	36.04	11.96	45.15	28.4	2760	8.30	22
	1620	124.27	36.12	11.99	45.04	28.6	2690	8.41	22
	1680	124.38	36.23	11.97	45.11	28.7	2790	8.47	22
	1740	124.52	36.37	11.95	45.19	29.8	2760	8.46	22
	1800	124.64	36.49	11.99	45.04	30.2	2770	8.13	22
	1860	124.71	36.56	12.00	45.00	30.4	2780	8.29	22
	1920	124.84	36.69	11.96	45.15	29.6	2690	8.41	22
	1980	124.93	36.78	11.99	45.04	28.6	2780	8.45	22
	2040	125.12	36.97	11.96	45.15	27.9	2740	8.51	22
	2100	125.19	37.04	12.00	45.00	27.8	2750	8.46	22
	2160	125.25	37.10	11.97	45.11	27.6	2650	8.42	22
	2220	125.36	37.21	11.99	45.04	27.4	2730	8.36	22
	2280	125.44	37.29	11.96	45.15	27.5	2729	8.35	22
	2340	125.57	37.42	11.89	45.42	27.3	2735	8.40	22
	2400	125.63	37.48	11.84	45.61	27.5	2740	8.37	22
	2460	125.71	37.56	11.97	45.11	27.3	2730	8.39	22
	2520	125.80	37.65	11.99	45.04	27.4	2740	8.41	22
	2580	125.89	37.74	11.89	45.42	26.4	2760	8.43	22
	2640	125.98	37.83	11.92	45.30	25.9	2770	8.44	22
	2700	126.02	37.87	11.94	45.23	27.3	2760	8.45	22
	2760	126.05	37.90	11.93	45.26	27.4	2740	8.46	22
	2820	126.10	37.95	11.89	45.42	27.7	2760	8.26	22
	2880	126.17	38.02	11.88	45.45	27.6	2750	8.34	DO = 2.35mg/l 22
	2940	126.24	38.09	11.96	45.15	28.6	2760	8.40	22
	3000	126.30	38.15	11.89	45.42	28.5	2740	8.45	22
	3060	126.25	38.10	11.84	45.61	28.9	2700	8.31	22
	3120	126.38	38.23	11.97	45.11	29.3	2710	8.30	22
	3180	126.41	38.26	11.80	45.76	29.6	2720	8.40	22
	3240	126.44	38.29	11.94	45.23	29.8	2740	8.34	22
	3300	126.47	38.32	11.98	45.08	28.6	2730	8.33	22
	3360	126.50	38.35	11.89	45.42	28.7	2740	8.35	22
	3420	126.53	38.38	11.97	45.11	27.9	2780	8.50	22
	3480	126.55	38.40	11.84	45.61	27.6	2740	8.32	22
	3540	126.58	38.43	11.90	45.38	27.2	2730	8.30	22
	3600	126.60	38.45	11.88	45.45	27.3	2740	8.34	22
	3660	126.62	38.47	11.89	45.42	26.4	2750	8.32	22
	3720	126.65	38.50	11.96	45.15	26.7	2740	8.39	22
	3780	126.65	38.50	11.99	45.04	26.4	2750	8.46	22
	3840	126.69	38.54	12.00	45.00	26.6	2750	8.40	22
	3900	126.74	38.59	11.94	45.23	26.5	2770	8.42	22
	3960	127.76	39.61	11.95	45.19	26.8	2740	8.41	22
	4020	127.98	39.83	11.89	45.42	26.7	2750	8.35	22
	4080	128.15	40.00	11.94	45.23	26.5	2745	8.37	22
	4140	128.43	40.28	11.99	45.04	26.4	2760	8.41	22
	4200	128.89	40.74	11.95	45.19	25.9	2776	8.43	22
	4260	129.08	40.93	11.88	45.45	26.0	2730	8.43	22
	4320	129.21	41.06	11.94	45.23	26.4	2780	8.39	DO = 2.55 mg/l
	4380	129.30	41.15	11.99	45.04	28.2	2750	8.28	22
	4440	129.39	41.24	11.95	45.19	28.6	2720	8.30	22
	4500	129.45	41.30	11.98	45.08	28.1	2740	8.34	22

Table 20-8 Recovery Test Data – BH10216

Official BH NO :	10216	District :	Kgalagadi
Date of test commencement :	19.02.2006	Location :	Ukhwi
Time of test commencement :	1200hrs	BH depth(m) :	218
Date of test completion	20.02.2006	Screen Int (m)	173.15 to 185.40 & 191.52 to 216
Time of test completion :	1200hrs	Depth of pump intake (m) :	168.5
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	n/a	Height of MP above ground(m) :	0.54
Dist.to Pumping Bh:	n/a	Static Water level before test(m) :	88.15
Casing diameter (mm)		Water strike	134, 168, 173 & 191
Orifice plate diameter		Delivery pipe diameter	
Easting	445850	Northing	7400322

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	129.45	41.30
	0.25	119.72	31.57
	0.5	116.33	28.18
	1	115.90	27.75
	2	114.56	26.41
	3	112.33	24.18
	4	110.89	22.74
	5	109.98	21.83
	6	109.15	21.00
	7	108.70	20.55
	8	108.15	20.00
	9	107.75	19.60
	10	107.34	19.19
	12	106.86	18.71
	15	106.14	17.99
	20	105.30	17.15
	25	104.56	16.41
	30	104.03	15.88
	40	103.15	15.00
	50	102.31	14.16
	60	101.85	13.70
	75	101.05	12.90
	90	100.54	12.39
	105	100.04	11.89
	120	99.35	11.20

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	98.88	10.73
	180	98.22	10.07
	210	97.87	9.72
	240	97.43	9.28
	270	97.11	8.96
	300	96.81	8.66
	330	96.53	8.38
	360	96.29	8.14
	390	96.06	7.91
	420	95.86	7.71
	450	95.68	7.53
	480	95.49	7.34
	540	95.22	7.07
	600	94.95	6.80
	660	94.82	6.67
	720	94.64	6.49
	780	94.41	6.26
	840	94.15	6.00
	900	93.83	5.68
	960	93.65	5.50
	1020	93.55	5.40
	1080	93.42	5.27
	1140	93.32	5.17
	1200	92.99	4.84
	1260	92.78	4.63
	1320	92.53	4.38
	1380	92.21	4.06
	1440	91.97	3.82

21 BH10219

BH10219 is an exploration borehole with a siting reference **S8**, Line R5 and Peg 7000m. This borehole was drilled at the same location as that of observation BH10217 and BH10218. It is located 14km south of Ukwi along the road to Hukuntsi. Drilling operations at this site commenced on 27 January and were completed on 17 February 2006 at a depth of 297m.

21.1 SITING CRITERIA AND DRILLING OBJECTIVES

This exploration borehole was drilled to explore the Ecca aquifer between faults **F6** and **F7** and to assess the influence of dolerite sill intrusions on groundwater quality. It will also ascertain the yield potential of the Ecca aquifer at this locality.

21.2 DRILLING RESULTS

The borehole was drilled through various lithologies including fine grained sand, silcrete, calcrete, mudstones, dolerite, coal and fine to medium grained micaceous sandstone (**Figure 21-1**). Drilling of BH10219 was carried out with a 15 inch drilling bit using the DTH drilling technique down to a depth of 26m after which the bit size was changed to 12" due to the high penetration rates. Drilling to a depth of 89m was by various diameters which were later rimmed to 15 inch. After rimming the hole with a 15 inch bit to 89m, 12 inch plain casings were installed and cement grouted. Drilling between 89 to 170m was accomplished using a 12 inch drilling bit. Drilling from 170 to 256m was achieved using a 10" DTH bit and drilling to the terminal depth of 297m was accomplished using a $9^{7/8}$ inch tri-cone bit.

Three different water strikes were encountered at various depths during drilling of this borehole. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the three water strikes are as follows:

1. 180 m, 1397 µS/cm , 30 m^3/hr
2. 188 m, 1320 µS/cm, 13 m^3/hr
3. 212 m, 1340 µS/cm, 14 m^3/hr

Water samples were collected at different water strikes during drilling of BH10219. The samples collected at the water strikes were submitted to the DWA laboratory for chemical analysis and results are shown on **Table 21-1**.

Table 21-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10219	180	6.97	878	9.40	1.665	307.2	1.59	109.49	63.59	0	0	0	532.71	0.15	11.61	MUD 1
10219	188	7.25	764	7.03	4.315	313.1	1.393	109.57	59.49	0	4.7	0	556.06	0.00	0.14	SST 1
10219	212	7.21	784	6.90	1	316.1	1.601	104.57	67.82	0	3.39	0	566.41	0.00	5.61	SST 1
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

After completion of drilling, the borehole was geophysically logged prior to installation of the final casing and screens to a depth of 296 m **(Figure 21-2).** After completion of logging, the borehole was constructed using 8 inch plain and factory slotted casings. The 8 inch plain casings were installed between 0 to 172.94m and 246.43 to 249.56m while the slotted casings were installed between 172.94 and 246.43m

Borehole development was through air jetting with the final yield at the end of development measured as 64 m^3/hr while the electrical conductivity was 1472µS/cm. The rest water level was measured as 86.72 m bgl on 17 February 2006.

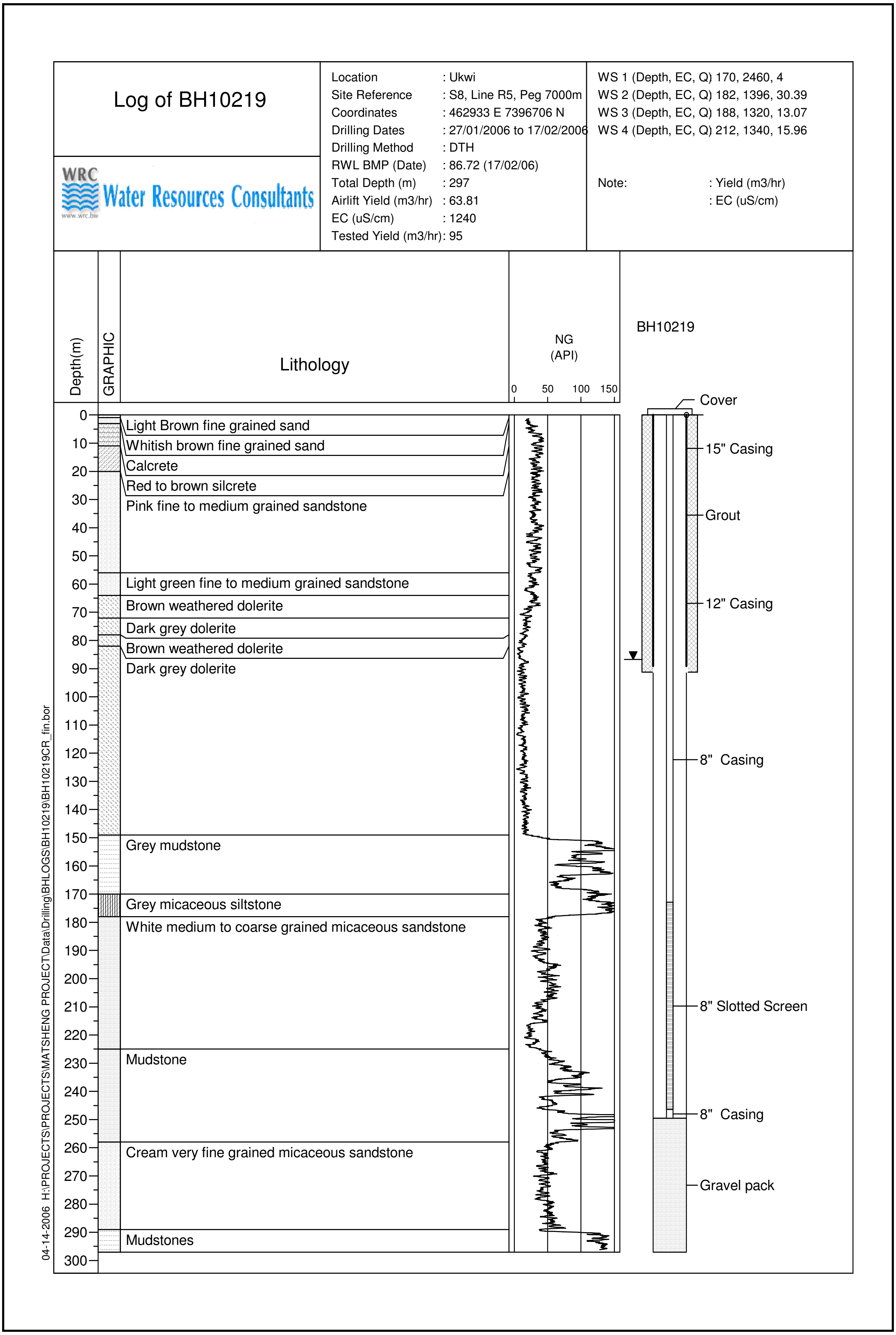

Figure 21-1 Log of BH10219

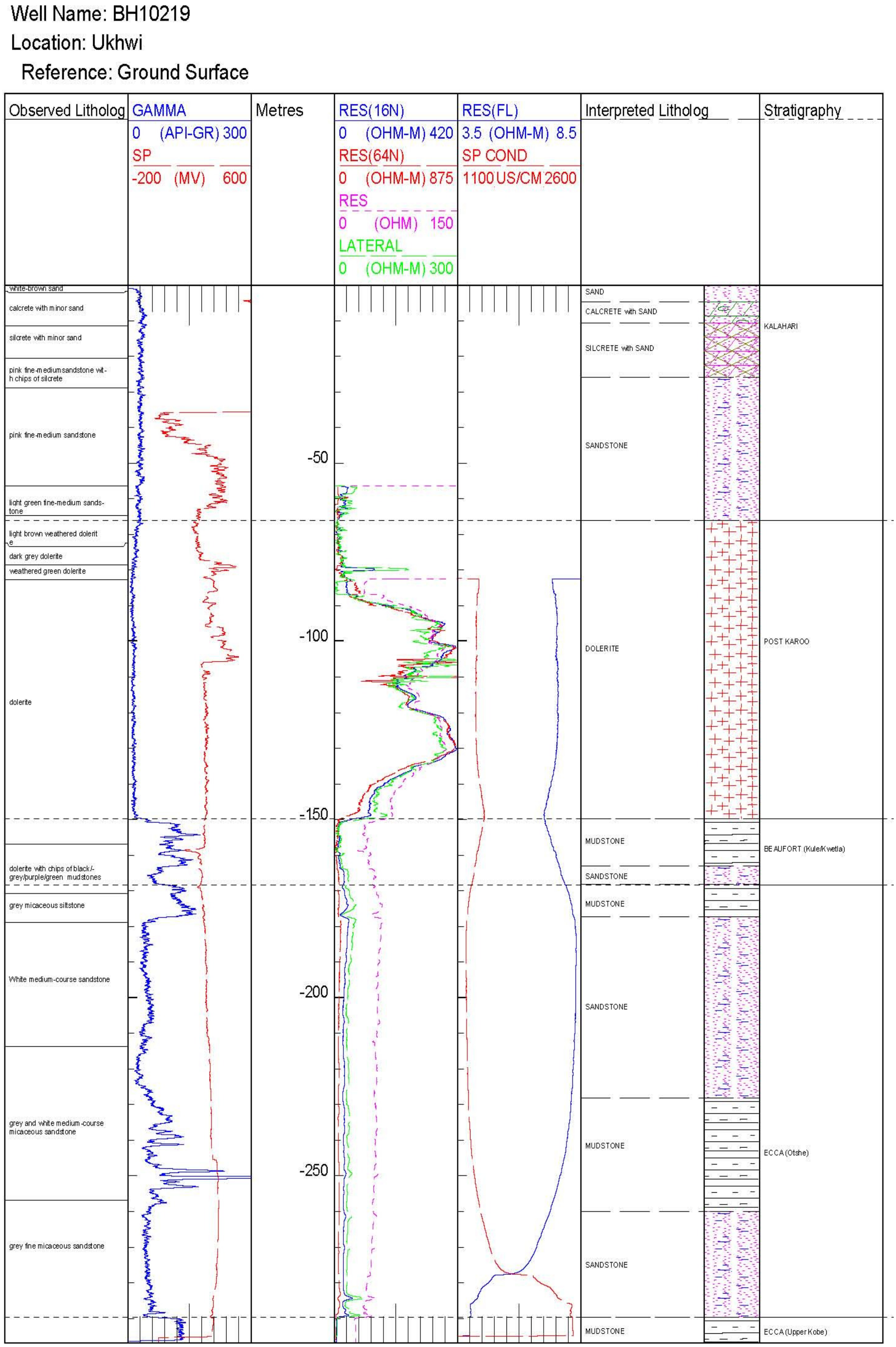

Figure 21-2 Geophysical log of BH10219

21.3 PUMP TESTING RESULTS

Borehole BH10219 was pump tested between 27 February and 4 March 2006. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.44 m above ground level (agl) and the pump intake was set at 150m below ground level. The summary details for the pumping test are given in **Table 21-2**. The collected pump testing data is presented in **Tables 21-6 to 21-13.**

Table 21-2 Summary of Pumping Test Data BH10219

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	13.01	32.3
	2	15	18.38	41.6
	3	15	22.82	50.6
	4	15	31.48	71.8
	5	15	43.35	100
Step Test	1	100	14.53	31.3
	2	100	25.18	50.6
	3	100	34.55	71.9
	4	100	47.87	92.8
Constant Rate	1	3060	52.81	95
Recovery	1	1440	1.58*	0

Note. 1.58 Residual Drawdown*

21.2.1 Step Drawdown Test

The step drawdown test was carried out on 28 February 2006. The static water level before the start of the test was 84.7 m bmp. The step drawdown test consisted of 4 steps of 100 minutes duration at discharge rates of 31.3, 50.6, 71.9 and 93 m^3/hr, respectively for steps 1 to 4.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test using this method is plotted in **Figure 21-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 21-4**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 47.7 m^2/d, **Figure 21-5**. The results for the step test interpretation are tabulated in **Table 21-3**.

Table 21-3 Results of Step Test Analysis BH10219

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10219	1.98E-03	5.98E-08	47.7	31.3	14.800	14.800	2.11
				50.6	9.75	24.550	2.06
				72.0	8.760	33.310	2.16
				93.0	11.70	45.010	2.07

The planned duration for the constant rate test of this borehole is 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 21-3**) to estimate the expected total drawdown after 3 days of pumping. A discharge rate of 93 m^3/hr is ideal for this borehole.

21.2.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 1 and 3 January 2006 at a discharge rate of 95 m^3/hr and the total drawdown after 51 hrs of pumping was 52.81 m. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 1.58 m.

Data from the pumping borehole was interpreted using the Theis, Cooper-Jacob (1946) and the Hantush Leaky with storage analytical solutions using the computer programme "Aqtesolv". Transmissivity (T) values obtained by these three analytical solutions were 57, 52 and 44 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 44 m^2/d was obtained. The interpretation of the results are summarised in **Table 21-4** and the interpreted data is presented in **Figures 21-6** to **21-9**.

Table 21-4 Summary of Constant Rate and Recovery Tests BH10219

BH No.	CRT Duration (hours)	Q (m^3/d)	Pumping borehole T (m^2/d)		Obs. BH No.	Observation borehole Pumping phase		Observation borehole Recovery phase	Aquifer type
			Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
10219	51	2280	a) 44 b) 52 c) 57	d) 44	10218	a) 67 b) 42 c) 45	a) 6.1E-4 b) 8.0E-4 c) 6.1E-4	d) 40	Leaky with storage

Notes:
Interpretation Techniques
a) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

21.2.2.1 Observation Borehole

The water level response was monitored in an observation borehole (BH10218) located 9.12 m away from BH10219 (pumping borehole). This observation borehole is screened between 175.8 to 246.67 m bgl and the total drawdown after 51 hours pumping was 25.15 m.

Various analytical solutions (Theis, Cooper-Jacob and Hantush Leaky with storage) were applied to the pumping test data from this observation borehole using the computer programme "Aqtesolv" and the best fit was obtained based on the Hantush Leaky with storage solution in addition to the standard Theis and Cooper-Jacob interpretations. The transmissivity (T) values obtained by these three analytical solutions are 67, 42 and 45m^2/d respectively while the storativity values were $6.1x10^{-4}$, $8.0x10^{-4}$ and $6.1x10^{-4}$ respectively. The recovery data was analysed using the Theis recovery method and the T value obtained was 40m^2/d. The results are summarised in **Table 21-3** and the interpreted data is presented in **Figures 21-9 to 21-12.**

The water level response was monitored in an observation borehole (BH10217) located 9 m away from BH10219 (pumping borehole). This observation borehole is screened between 371.64 to 374.69 m bgl in the deep and saline Ecca aquifer. The total drawdown after 51 hours pumping was 1.33 m.

The data for this borehole was not interpreted and the data for the constant rate test is shown in **Figure 21.13.** The data for this borehole indicates that the two Ecca aquifers at this locality are connected and that there is possible intrusion of saline waters from the deeper Ecca aquifer.

21.2.2.2 Aquifer Type interpreted

The interpretation of the pump testing data indicates that the aquifer type is leaky with aquitard storage.

21.3 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants **(Table 21-5).** In addition, some samples collected at

72 hrs will be submitted for stable and unstable isotope analysis at the CSIR laboratory in Pretoria, South Africa.

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), pH and dissolved oxygen are 28.8 ^{o}C, 1230 µS/cm and 8.63.

Table 21-5 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10219	1.7	326	1.6	1.1	86	102	455	<0.1	<0.1	2	<0.05	1240	7.7	794
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10219	<0.1	8.6	<0.12	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in µS/cm
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

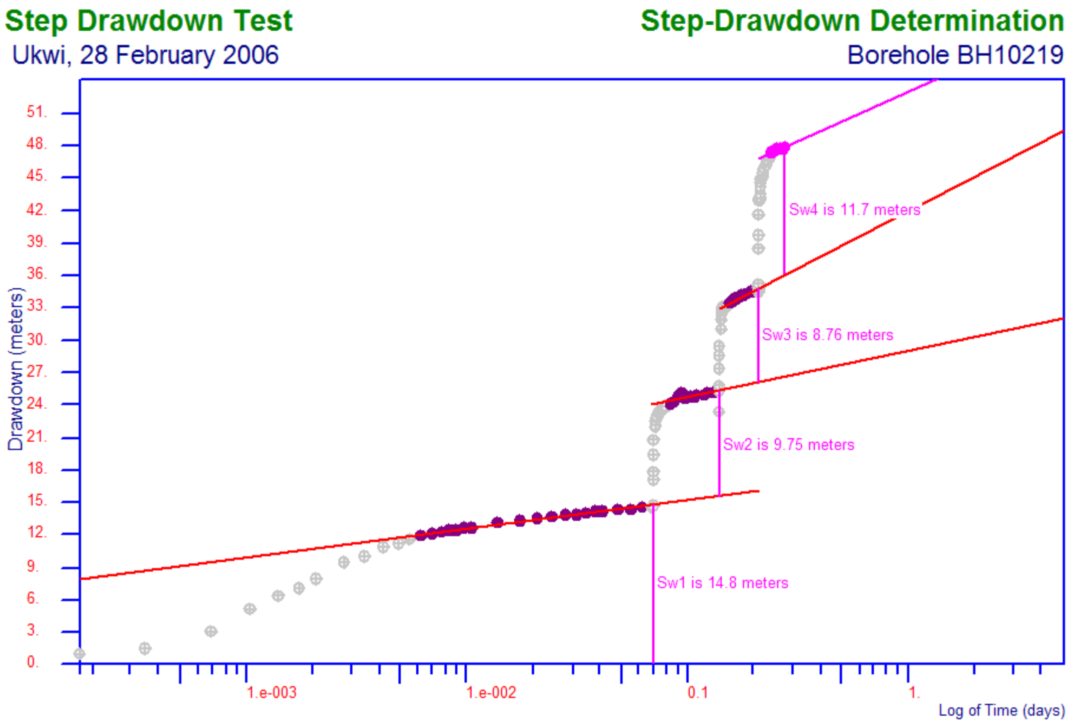

Figure 21-3 Pumping Test Results for BH10219: Step Drawdown Test - Hantush-Bierschenk (semi-log)

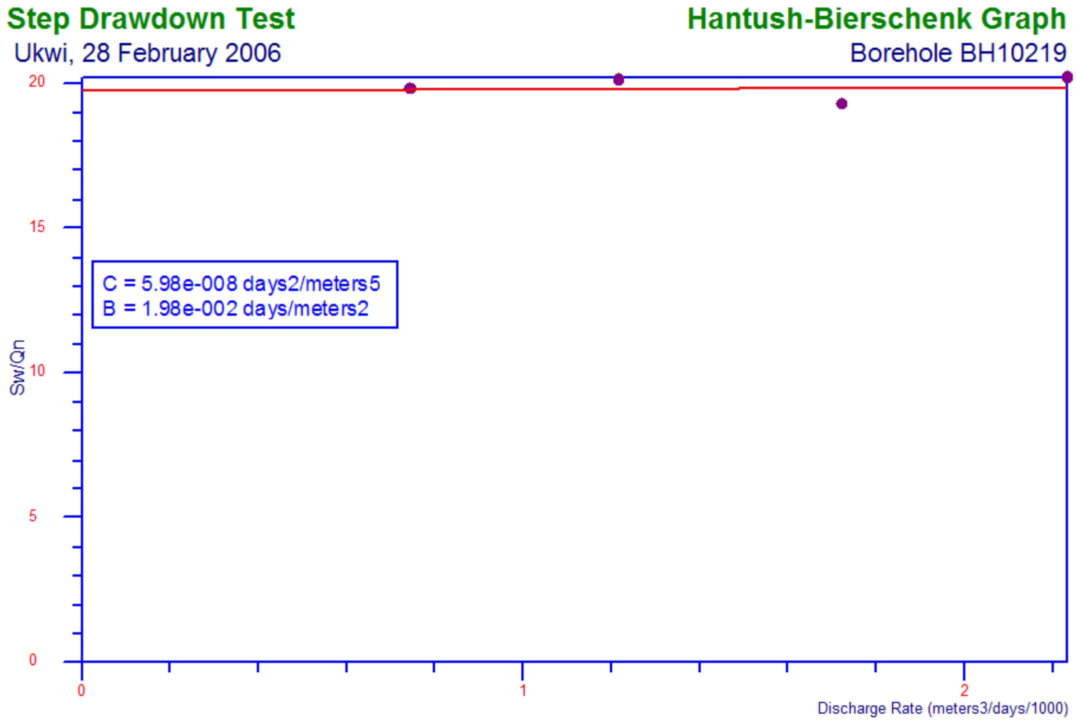

Figure 21-4 Pumping Test Results for BH10219: Step Drawdown Test – Hantush-Bierschenk

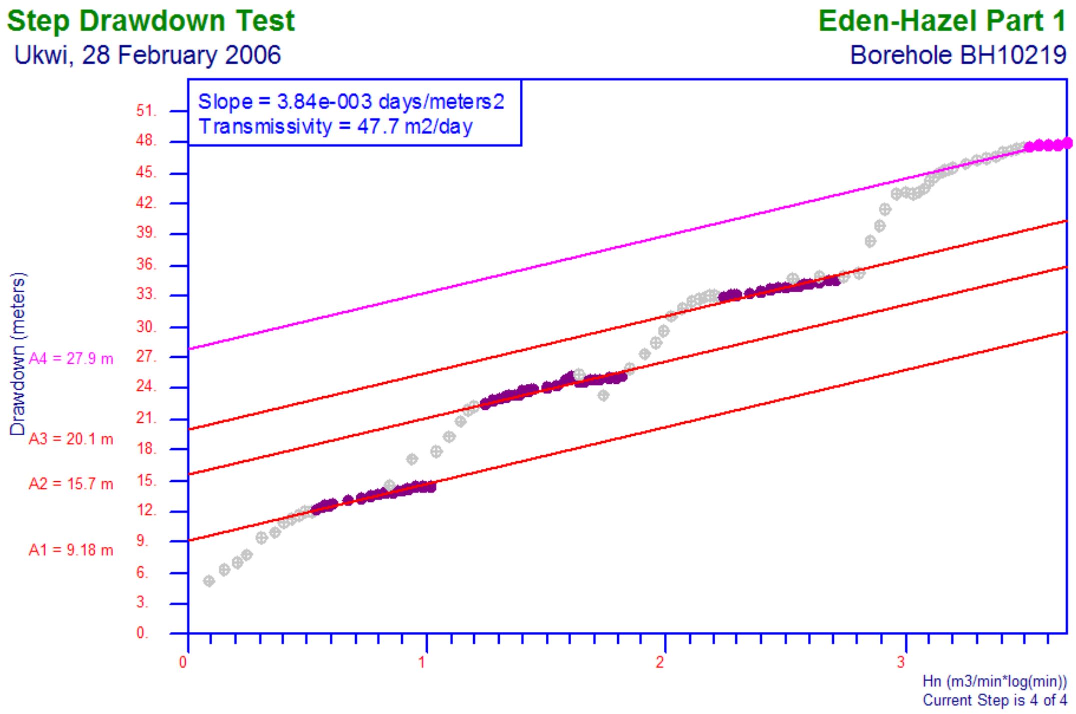

Figure 21-5 Pumping Test Results for BH10219: Step Drawdown Test – Eden-Hazel (Part 1)

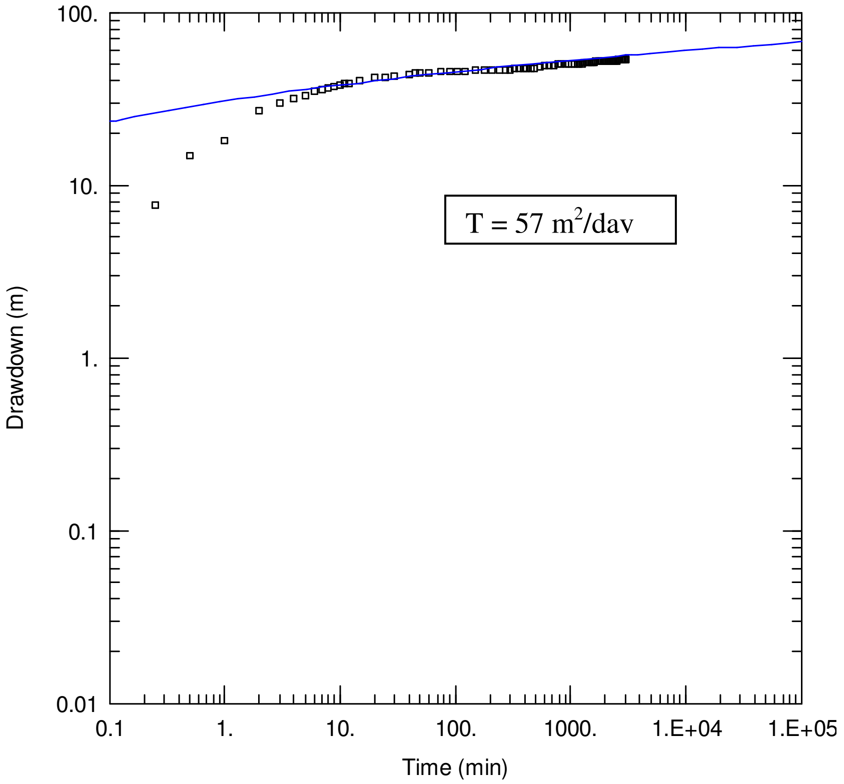

Figure 21-6 Pumping Test Results for BH10219: Theis Solution

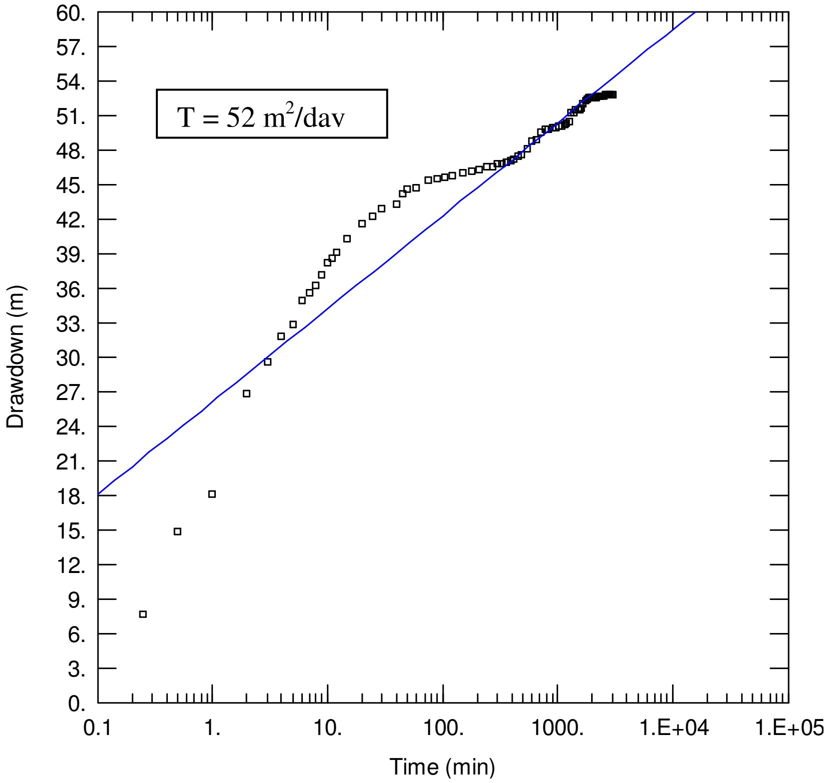

Figure 21-7 Pumping Test Results for BH10219: Cooper-Jacob Solution

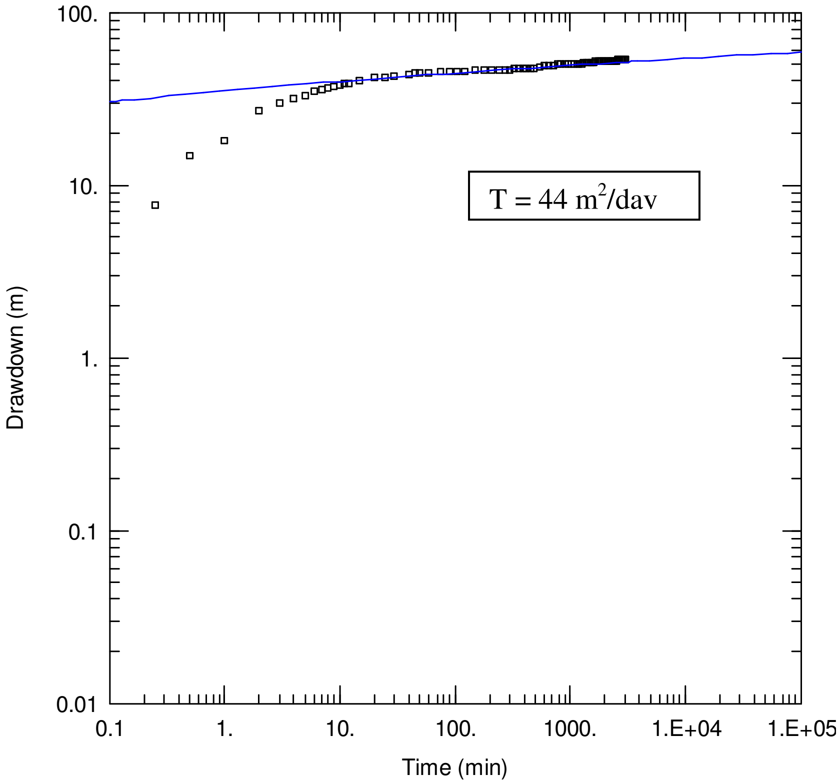

Figure 21-8 Pumping Test Results for BH10219: Hantush Leaky with storage Solution

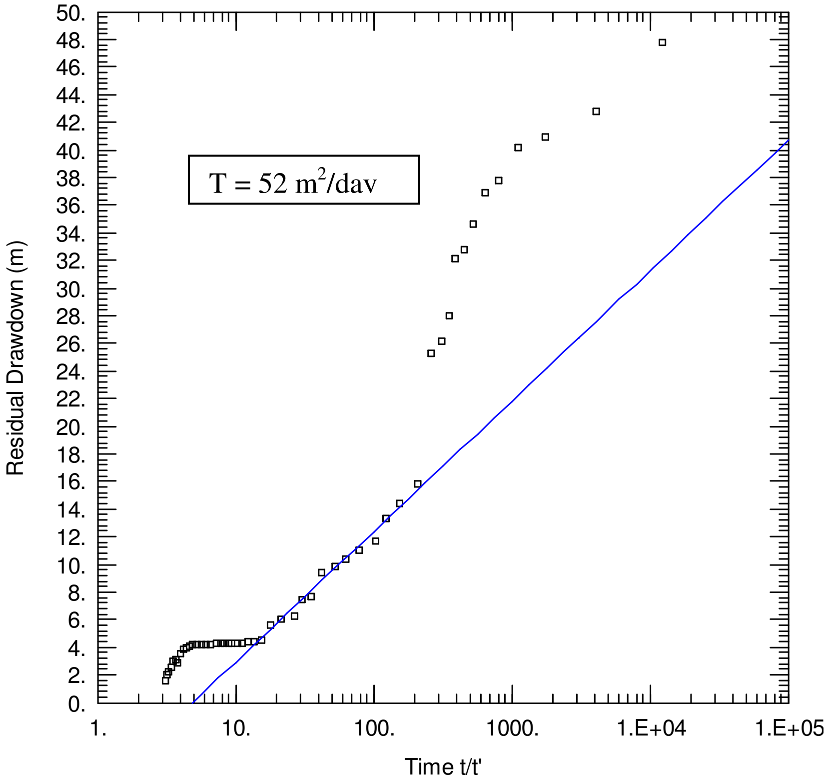

Figure 21-9 Pumping Test Results for BH10219: Theis Recovery Solution

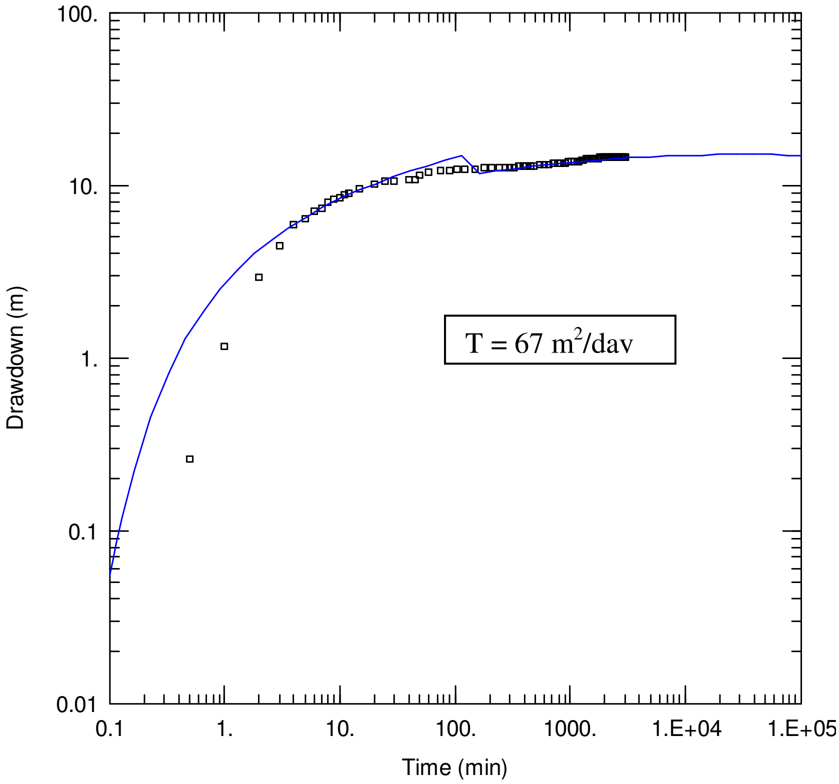

Figure 21-10 Pumping Test Results for BH10218: Theis Solution

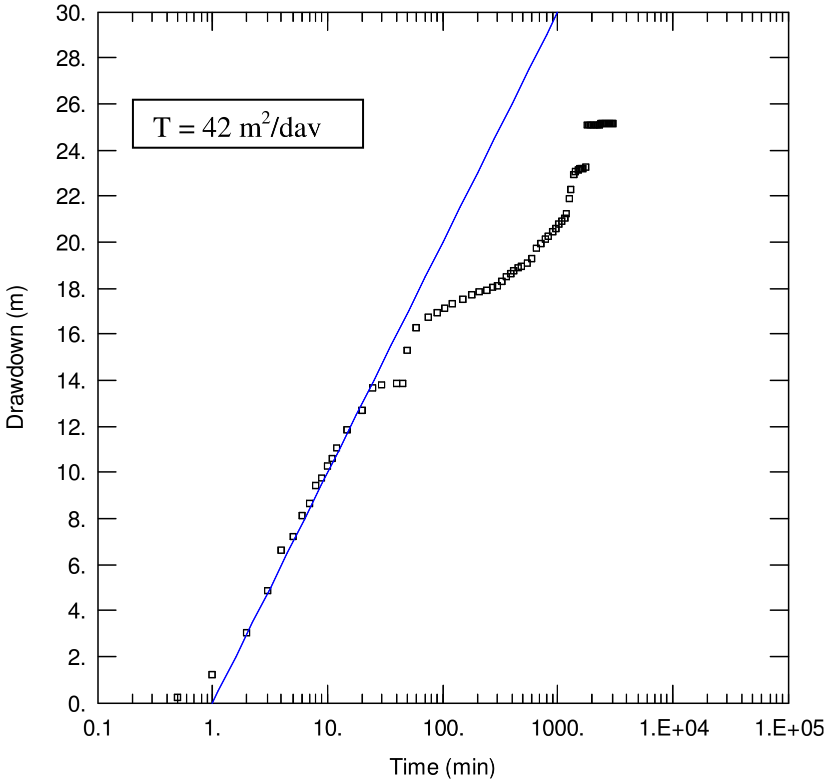

Figure 21-11 Pumping Test Results for BH10218: Cooper - Jacob Solution

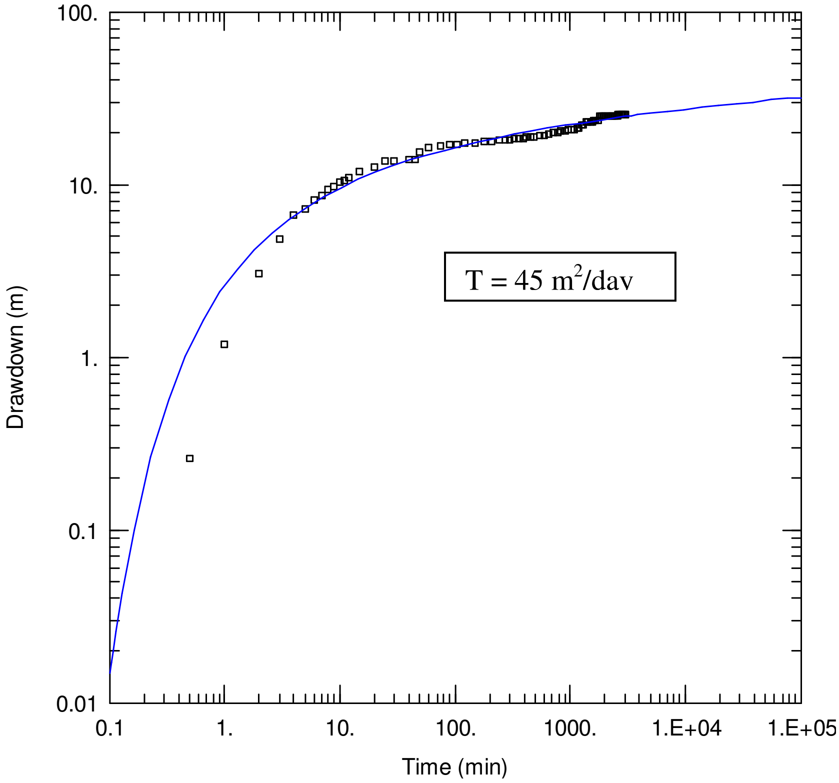

Figure 21-12Pumping Test Results for BH10218: Hantush Leaky with storage Solution

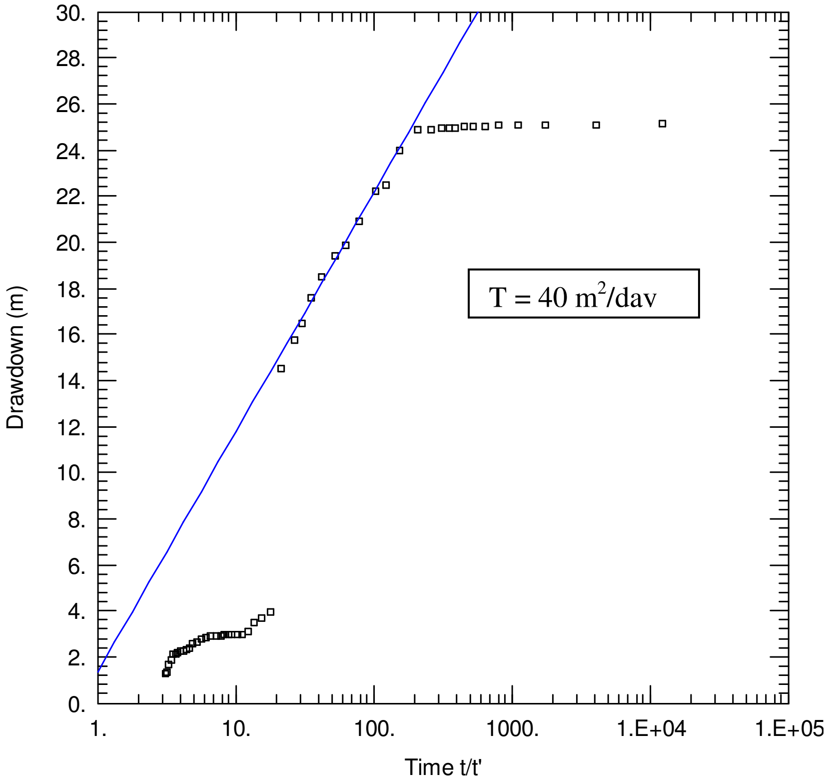

Figure 21-13Pumping Test Results for BH10218: Theis Solution

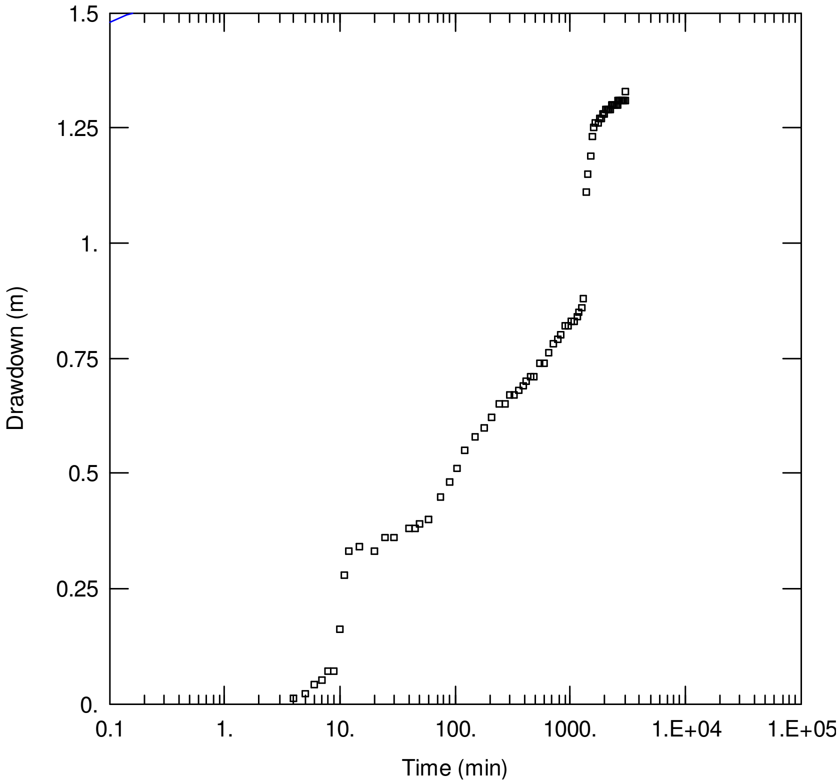

Figure 21-14Pumping Test Results for BH10217

Table 21-6 Calibration Test Data – BH10219

Official BH No.:	10219	District:		Kgalagadi
Date of test commencement:	28.2.2006	Location:		Ukhwi
Time of test commencement		BH depth (m):		296
Date of test completion:	28.2.06	Screen Interval (m):		172.94 to 246.43
Time of test completion		Depth of pump intake (m):		150
Method of water level measurement:	dipper	Static water level before test (m):		84.55
Casing diameter (mm)	8"	Water strike		S
Orifice plate diameter	n/a	Delivery pipe diameter		102mm
Easting	462945	Northing		7396707

STEPNo. 1 — STEPNo. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	84.68	0.13				0.25	98.03	13.48			
0.5	89.05	4.50				0.5	99.14	14.59			
1	90.75	6.20	22.13	32.54		1	99.68	15.13	16.94	42.50	
1.5	91.70	7.15				1.5	100.43	15.88			
2	92.80	8.25	22.29	32.30		2	100.97	16.42	16.72	43.06	
2.5	93.66	9.11	22.20	32.43		2.5	101.24	16.69			
3	94.18	9.63	22.44	32.09		3	101.63	17.08	15.32	47.00	adj
4	95.10	10.55	22.46	32.06		4	101.87	17.32	15.74	45.74	
5	95.64	11.09	22.30	32.29		5	101.87	17.32	17.12	42.06	
6	96.10	11.55	22.20	32.43		6	101.97	17.42	17.03	42.28	
7	96.40	11.85	22.78	31.61		7	102.05	17.50	17.25	41.74	
8	96.61	12.06	22.03	32.68		8	102.20	17.65	17.12	42.06	
9	96.77	12.22	22.40	32.14		9	102.30	17.75	17.59	40.93	
10	96.92	12.37	22.38	32.17		10	102.42	17.87	17.81	40.43	
11	97.12	12.57	22.35	32.21		11	102.53	17.98	17.29	41.64	
12	97.25	12.70	22.37	32.19		12	102.61	18.06	17.35	41.50	
15	97.56	13.01	22.01	32.71		15	102.93	18.38	17.44	41.28	

STEPNo. 3 — STEPNo. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	Pumping Rate (m^3/hr)	Comments
0.25	103.00	18.45				0.25	107.48	22.93			
0.5	103.06	18.51				0.5	108.42	23.87			
1	103.24	18.69	21.44	50.37		1	109.75	25.20	24.44	73.65	
1.5	104.34	19.79				1.5	111.95	27.40			
2	105.02	20.47	20.81	51.90		2	113.10	28.55	24.50	73.47	
2.5	105.74	21.19				2.5	114.04	29.49			
3	105.98	21.43	21.25	50.82		3	114.45	29.90	23.66	76.08	adj
4	106.20	21.65	20.75	52.05		4	115.07	30.52	25.50	70.59	
5	106.32	21.77	20.95	51.55		5	115.10	30.55	25.43	70.78	
6	106.52	21.97	21.47	50.30		6	115.10	30.55	25.00	72.00	
7	106.66	22.11	21.69	49.79		7	115.27	30.72	24.60	73.17	
8	106.87	22.32	21.28	50.75		8	115.34	30.79	24.94	72.17	
9	106.96	22.41	21.44	50.37		9	115.47	30.92	25.17	71.51	
10	107.02	22.47	21.36	50.56		10	115.58	31.03	24.75	72.73	
11	107.12	22.57	21.53	50.16		11	115.68	31.13	25.16	71.54	
12	107.15	22.60	21.34	50.61		12	115.83	31.28	25.18	71.49	
15	107.37	22.82	21.57	50.07		15	116.03	31.48	25.15	71.57	

Official BH No.:	10219	District:	Kgalagadi
Date of test commencement:	28.2.2006	Location:	Ukhwi
Time of test commencement		BH depth (m):	296
Date of test completion:	28.2.06	Screen Interval (m):	172.94 to 246.43
Time of test completion		Depth of pump intake (m):	150
Method of water level measurement:	dipper	Static water level before test (m):	84.55
Casing diameter (mm)	8"	Water strike	S
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	462945	Norhting	7396707

STEP No. 5 STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	116.38	31.83				0.25					
0.5	116.74	32.19				0.5					
1	117.10	32.55	19.75	91.14		1					
1.5	118.60	34.05				1.5					
2	119.55	35.00	19.94	90.27		2					
2.5	120.35	35.80				2.5					
3	121.64	37.09	19.90	90.45		3					
4	122.80	38.25	18.25	98.63	adj	4					
5	123.64	39.09	17.94	100.33		5					
6	125.47	40.92	17.91	100.50		6					
7	126.22	41.67	17.41	103.39		7					
8	126.52	41.97	17.95	100.28		8					
9	126.77	42.22	18.06	99.67		9					
10	126.98	42.43	17.91	100.50		10					
11	127.26	42.71	17.96	100.22		11					
12	127.46	42.91	18.00	100.00		12					
15	127.90	43.35	17.81	101.07		15					

Table 21-7 Step Drawdown Test Data

Official BH No.:	10219	District:	Ghanzi
Date of test commencement:	28.2.2006	Location:	Ukhwi
Time of test Commencement:	0800hrs	BH depth (m):	296
Date of test completion:	28.2.2006	Screens(m)	172.94 to 246.43
Time of test Completion:	1440hrs	Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tube
Observation Bh No.:	n/a	Height of MP above ground:	0.44
Distance to OB. BH (m)	n/a	Static water level before test (m):	84.7
Casing diameter (mm)	203	Water strike	180, 188 and 212
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	462945	Northing	7396707

STEP No. 1 — STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	P. Rate (m^3/hr)	Comments
0.25	85.64	0.94				0.25	99.30	14.60			
0.5	86.17	1.47				0.5	101.88	17.18			
1	87.80	3.10				1	102.54	17.84	20.69	52.20	
1.5	89.88	5.18				1.5	103.98	19.28			
2	91.06	6.36	24.50	29.39		2	105.48	20.78	21.18	50.99	
2.5	91.68	6.98				2.5	106.62	21.92			
3	92.57	7.87	24.40	29.51		3	106.90	22.20	21.25	50.82	
4	94.08	9.38	24.35	29.57		4	107.20	22.50	21.20	50.94	
5	94.74	10.04	22.32	32.26		5	107.46	22.76	21.22	50.90	
6	95.55	10.85	23.03	31.26		6	107.72	23.02	21.29	50.73	
7	95.95	11.25	23.00	31.30		7	107.85	23.15	21.33	50.63	
8	96.26	11.56	23.31	30.89		8	107.98	23.28	21.21	50.92	
9	96.68	11.98	23.06	31.22		9	108.04	23.34	21.18	50.99	
10	96.70	12.00	23.03	31.26		10	108.13	23.43	21.20	50.94	
11	96.92	12.22	22.99	31.32		11	108.41	23.71	21.47	50.30	
12	97.04	12.34	23.10	31.17		12	108.46	23.76	21.30	50.70	
13	97.15	12.45	22.84	31.52		13	108.46	23.76	21.48	50.28	
14	97.23	12.53	23.10	31.17		14	108.51	23.81	21.35	50.59	
15	97.34	12.64	23.00	31.30		15	108.57	23.87	21.22	50.90	
20	97.75	13.05	22.97	31.35		20	108.72	24.02	21.48	50.28	
25	98.00	13.30	22.89	31.45		25	108.92	24.22	21.46	50.33	
30	98.14	13.44	23.06	31.22		30	109.46	24.76	21.34	50.61	
35	98.36	13.66	22.99	31.32		35	109.78	25.08	21.30	50.70	
40	98.48	13.78	22.89	31.45		40	109.34	24.64	21.33	50.63	
45	98.54	13.84	22.90	31.44		45	109.40	24.70	21.36	50.56	
50	98.73	14.03	22.96	31.36		50	109.48	24.78	21.30	50.70	
55	98.79	14.09	22.89	31.45		55	109.51	24.81	21.38	50.51	
60	98.86	14.16	22.94	31.39		60	109.55	24.85	21.33	50.63	
70	98.98	14.28	23.04	31.25		70	109.64	24.94	21.47	50.30	
80	99.06	14.36	22.98	31.33		80	109.73	25.03	21.35	50.59	
90	99.15	14.45	22.99	31.32		90	109.85	25.15	21.40	50.47	
100	99.23	14.53	22.91	31.43		100	109.88	25.18	21.36	50.56	

Official BH No.:	10219	District:	Ghanzi
Date of test commencement:	28.2.2006	Location:	Ukhwi
Time of test Commencement:	0800hrs	BH depth (m):	296
Date of test completion:	28.2.2006	Screens(m)	172.94 to 246.43
Time of test Completion:	1440hrs	Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tube
Observation Bh No.:	n/a	Height of MP above ground:	0.44
Distance to OB. BH (m)	n/a	Static water level before test (m):	84.7
Casing diameter (mm)	203	Water strike	180, 188 and 212
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	462945	Northing	7396707

STEP No. 3 | STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments
0.25	110.02	25.32				0.25	119.38	34.68			
0.5	108.13	23.43				0.5	119.54	34.84			
1	110.57	25.87	24.56	73.29		1	119.63	34.93	18.60	96.77	
1.5	112.00	27.30				1.5	119.86	35.16			
2	113.25	28.55	24.97	72.09		2	123.09	38.39	17.18	104.77	
2.5	114.18	29.48				2.5	124.45	39.75			
3	115.70	31.00	24.94	72.17		3	126.22	41.52	17.80	101.12	
4	116.53	31.83	24.90	72.29		4	127.70	43.00	19.61	91.79	adj
5	117.15	32.45	24.99	72.03		5	127.72	43.02	19.22	93.65	
6	117.46	32.76	24.93	72.20		6	127.65	42.95	19.28	93.36	
7	117.52	32.82	24.91	72.26		7	127.86	43.16	19.25	93.51	
8	117.65	32.95	24.99	72.03		8	128.17	43.47	19.59	91.88	
9	117.70	33.00	25.19	71.46		9	128.94	44.24	19.22	93.65	
10	117.56	32.86	24.98	72.06		10	129.26	44.56	19.31	93.22	
11	117.58	32.88	25.22	71.37		11	129.57	44.87	19.35	93.02	
12	117.58	32.88	25.00	72.00		12	129.75	45.05	19.48	92.40	
13	117.67	32.97	25.10	71.71		13	129.92	45.22	19.38	92.88	
14	117.67	32.97	25.21	71.40		14	130.08	45.38	19.46	92.50	
15	117.76	33.06	25.19	71.46		15	130.20	45.50	19.33	93.12	
20	117.98	33.28	25.00	72.00		20	130.62	45.92	19.48	92.40	
25	118.14	33.44	24.95	72.14		25	130.84	46.14	19.46	92.50	
30	118.30	33.60	24.96	72.12		30	131.08	46.38	19.25	93.51	
35	118.43	33.73	25.10	71.71		35	131.29	46.59	19.40	92.78	
40	118.52	33.82	25.19	71.46		40	131.63	46.93	19.38	92.88	
45	118.62	33.92	25.02	71.94		45	131.76	47.06	19.41	92.74	
50	118.73	34.03	25.06	71.83		50	131.94	47.24	19.48	92.40	
55	118.80	34.10	25.16	71.54		55	132.12	47.42	19.50	92.31	
60	118.88	34.18	25.19	71.46		60	132.24	47.54	19.44	92.59	
70	119.02	34.32	25.05	71.86		70	132.30	47.60	19.48	92.40	
80	119.16	34.46	25.00	72.00		80	132.30	47.60	19.47	92.45	
90	119.22	34.52	25.10	71.71		90	132.38	47.68	19.36	92.98	
100	119.25	34.55	25.06	71.83		100	132.57	47.87	19.48	92.40	

Table 21-8 Constant Rate Test Data – BH10219

Official BH NO :	10219	District :	Ghanzi
Date of test commencement :	1.3.06	Location :	Ukhwi
Time of test commencement :	1300hrs	BH depth(m) :	296
Date of test completion	3.3.06	Screen Interval (m)	172.94 to 246.43
Time of test completion :	1600hrs	Depth of pump intake (m) :	150m
Method of water level measurement	electrical dipper	Description of MP	top of dipper tubing
OB BH NO:	10217 , 10218	Height of MP above ground(m) :	0.44
Distance ob BH r (m)	9m, 9.12m	Static Water level before test(m) :	85.40
Casing diameter (mm)	8"	Water strike	180, 188 and 212
Orifice plate diameter	4"	Delivery pipe diameter	5"
Easting	462945	Northing	7396707

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500l	Q(m^3/h)	Temp (^{0}C)	EC (ms/Cm)	pH	Manometer (cm) /DO
	0.25	93.09	7.69						Flowmeter 007096.670
	0.5	100.16	14.76						
	1	103.42	18.02						
	2	112.14	26.74						
	3	114.93	29.53						
	4	117.10	31.70	19.60	91.84				
	5	118.25	32.85	19.00	94.74				
	6	120.34	34.94	19.22	93.65				
	7	120.90	35.50	18.81	95.69				
	8	121.66	36.26	18.90	95.24				
	9	122.53	37.13	18.83	95.59				
	10	123.50	38.10	18.93	95.09				
	11	124.00	38.60	18.91	95.19				
	12	124.41	39.01	18.84	95.54				
	15	125.60	40.20	18.86	95.44				
	20	126.98	41.58	18.87	95.39	27.3	1300	8.51	49
	25	127.58	42.18	18.81	95.69	27.2	1310	8.54	49
	30	128.20	42.80	18.84	95.54	27.4	1300	8.54	49
	40	128.61	43.21	18.90	95.24	27.4	1300	8.52	49
	45	129.58	44.18	18.86	95.44	28.5	1270	8.44	49
	50	129.88	44.48	18.84	95.54	28.6	1270	8.42	49
	60	130.12	44.72	18.86	95.44	28.6	1270	8.44	49
	75	130.72	45.32	18.80	95.74	28.7	1270	8.46	49
	90	130.90	45.50	18.84	95.54	28.9	1240	8.33	49
	105	130.95	45.55	18.80	95.74	29.0	1240	8.34	49
	120	131.10	45.70	18.85	95.49	29.0	1240	8.33	49
	150	131.32	45.92	18.80	95.74	29.2	1240	8.32	49
	180	131.50	46.10	18.84	95.54	29.2	1240	8.33	49
	210	131.68	46.28	18.87	95.39	28.6	1280	8.36	49
	240	131.84	46.44	18.90	95.24	28.6	1290	8.38	49
	270	131.92	46.52	18.89	95.29	28.5	1290	8.38	49
	300	132.10	46.70	18.80	95.74	28.6	1290	8.33	49
	330	132.18	46.78	18.84	95.54	27.6	1290	8.42	49
	360	132.24	46.84	18.86	95.44	27.3	1340	8.58	49
	390	132.43	47.03	18.80	95.74	28.4	1340	8.42	49
	420	132.60	47.20	18.83	95.59	28.0	1330	8.37	49
	450	132.78	47.38	18.94	95.04	27.9	1330	8.38	49
	480	132.95	47.55	18.90	95.24	27.7	1330	8.42	49
	540	133.43	48.03	18.92	95.14	27.6	1330	8.44	49

	600	134.15	48.75	18.92	95.14	27.4	1330	8.44	49
	660	134.30	48.90	18.90	95.24	27.2	1330	8.48	49
	720	134.86	49.46	18.94	95.04	27.0	1330	8.46	49
	780	135.14	49.74	18.82	95.64	27.0	1330	8.42	49
	840	135.14	49.74	18.91	95.19	27.4	1330	8.40	49
	900	135.23	49.83	18.89	95.29	27.3	1340	8.42	49
	960	135.31	49.91	18.91	95.19	27.0	1340	8.58	49
	1020	135.40	50.00	18.94	95.04	26.8	1330	8.64	49
	1080	135.48	50.08	18.93	95.09	26.7	1330	8.66	49
	1140	135.57	50.17	18.89	95.29	26.4	1340	8.56	49
	1200	135.66	50.26	18.90	95.24	26.0	1330	8.66	49
	1260	135.75	50.35	18.94	95.04	25.7	1340	8.66	49
	1320	136.63	51.23	18.91	95.19	26.3	1340	8.67	49
	1380	136.63	51.23	18.90	95.24	26.8	1330	8.66	49
	1440	136.82	51.42	18.94	95.04	26.9	1340	8.64	49
	1500	136.88	51.48	18.88	95.34	27.8	1330	8.66	49
	1560	136.90	51.50	18.94	95.04	27.5	1310	8.53	49
	1620	137.02	51.62	18.88	95.34	27.8	1310	8.66	49
	1680	137.35	51.95	18.91	95.19	27.5	1310	8.51	49
	1740	137.64	52.24	18.93	95.09	27.6	1320	8.53	49
	1800	137.80	52.40	18.90	95.24	28.4	1310	8.58	49
	1860	137.90	52.50	18.94	95.04	28.3	1320	8.51	49
	1920	137.90	52.50	18.91	95.19	28.0	1220	8.52	49
	1980	137.93	52.53	18.89	95.29	27.9	1210	8.52	49
	2040	137.94	52.54	18.94	95.04	28.0	1220	8.56	49
	2100	137.96	52.56	18.91	95.19	27.9	1230	8.51	49
	2160	137.96	52.56	18.88	95.34	27.9	1230	8.55	49
	2220	137.97	52.57	18.93	95.09	28.0	1220	8.53	49
	2280	137.97	52.57	18.93	95.09	28.0	1220	8.51	49
	2340	137.99	52.59	18.91	95.19	27.7	1220	8.52	49
	2400	138.03	52.63	18.90	95.24	27.9	1210	8.52	49
	2460	138.06	52.66	18.88	95.34	27.9	1210	8.54	49
	2520	138.08	52.68	18.90	95.24	27.9	1210	8.56	49
	2580	138.12	52.72	18.94	95.04	27.9	1220	8.51	49
	2640	138.13	52.73	18.88	95.34	28.0	1220	8.52	49
	2700	138.15	52.75	18.93	95.09	27.9	1220	8.51	49
	2760	138.17	52.77	18.90	95.24	27.9	1220	8.52	49
	2820	138.17	52.77	18.89	95.29	27.9	1220	8.58	49
	2880	138.18	52.78	18.92	95.14	28.0	1230	8.54	49
	2940	138.19	52.79	18.93	95.09	28.2	1220	8.50	49
	3000	138.20	52.80	18.90	95.24	28.4	1210	8.58	49
	3060	138.21	52.81	18.94	95.04	28.8	1230	8.63	49

Table 21-9 Recovery Test Data – BH10219

Official BH NO :	10219	District :	Kgalagadi
Date of test commencement :	3.3.2006	Location :	Ukhwi
Time of test commencement :	1600hrs	BH depth(m) :	296
Date of test completion	4.3.2006	Screen Int (m)	172.94 to 246.43
Time of test completion :	1600hrs	Depth of pump intake (m) :	150
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	10217, 10218	Height of MP above ground(m) :	0.44
Dist.to Pumping Bh:	9m 9.12.	Static Water level before test(m) :	85.4
Casing diameter (mm)	8"	Waterstrike	180,188 and 212
Orifice plate diameter	4"	Delivery pipe diameter	102mm
Easting	462945	Northing	7396707

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	138.21	52.81
	0.25	135.98	50.58
	0.5	133.22	47.82
	1	128.16	42.76
	2	126.37	40.97
	3	125.58	40.18
	4	123.16	37.76
	5	122.30	36.90
	6	119.98	34.58
	7	118.17	32.77
	8	117.56	32.16
	9	113.43	28.03
	10	111.49	26.09
	12	110.72	25.32
	15	101.24	15.84
	20	99.82	14.42
	25	98.70	13.30
	30	97.06	11.66
	40	96.38	10.98
	50	95.74	10.34
	60	95.24	9.84
	75	94.78	9.38
	90	93.06	7.66
	105	92.84	7.44
	120	91.63	6.23

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	91.42	6.02
	180	91.05	5.65
	210	89.86	4.46
	240	89.80	4.40
	270	89.76	4.36
	300	89.72	4.32
	330	89.70	4.30
	360	89.68	4.28
	390	89.66	4.26
	420	89.66	4.26
	450	89.64	4.24
	480	89.64	4.24
	540	89.62	4.22
	600	89.60	4.20
	660	89.58	4.18
	720	89.56	4.16
	780	89.54	4.14
	840	89.49	4.09
	900	89.33	3.93
	960	89.26	3.86
	1020	88.90	3.50
	1080	88.24	2.84
	1140	88.51	3.11
	1200	88.40	3.00
	1260	87.93	2.53
	1320	87.60	2.20
	1380	87.44	2.04
	1440	86.98	1.58

Table 21-10 Observation Borehole data – BH10217 (CRT)

Official BH NO : 10217		District :	Ghanzi
Date of test commencement :	1.3.06	Location :	Ukhwi
Time of test commencement :	1300hrs	BH depth(m) :	400
Date of test completion	3.3.06	Screen Interval (m)	371.64 to 374.49
Time of test completion :	1600hrs	Depth of pump intake (m) :	n/a
Method of water level measurement	electrical dipper	Description of MP	top of pvc
Pumping BH NO:	10219	Height of MP above ground(m) :	0.73
Distance ob BH r (m)	9m	Static Water level before test(m) :	94.55
Casing diameter (mm)	50mm	Water strike	169, 182, 188, 229, 275, 338 and 371 m
Orifice plate diameter	4"	Delivery pipe diameter	5"
Easting	462933	Northing	7396706

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500l	Q(m^3/h)	Temp (^{0}C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO
	0.25								
	0.5	94.55	0.00						
	1	94.55	0.00						
	2	94.55	0.00						
	3	94.55	0.00						
	4	94.56	0.01						
	5	94.57	0.02						
	6	94.59	0.04						
	7	94.60	0.05						
	8	94.62	0.07						
	9	94.62	0.07						
	10	94.71	0.16						
	11	94.83	0.28						
	12	94.88	0.33						
	15	94.89	0.34						
	20	94.88	0.33						
	25	94.91	0.36						
	30	94.91	0.36						
	40	94.93	0.38						
	45	94.93	0.38						
	50	94.94	0.39						
	60	94.95	0.40						
	75	95.00	0.45						
	90	95.03	0.48						
	105	95.06	0.51						
	120	95.10	0.55						
	150	95.13	0.58						
	180	95.15	0.60						
	210	95.17	0.62						
	240	95.20	0.65						
	270	95.20	0.65						
	300	95.22	0.67						
	330	95.22	0.67						
	360	95.23	0.68						
	390	95.24	0.69						
	420	95.25	0.70						
	450	95.26	0.71						
	480	95.26	0.71						
	540	95.29	0.74						

	600	95.29	0.74						
	660	95.31	0.76						
	720	95.33	0.78						
	780	95.34	0.79						
	840	95.35	0.80						
	900	95.37	0.82						
	960	95.37	0.82						
	1020	95.38	0.83						
	1080	95.38	0.83						
	1140	95.39	0.84						
	1200	95.40	0.85						
	1260	95.41	0.86						
	1320	95.43	0.88						
	1380	95.66	1.11						
	1440	95.70	1.15						
	1500	95.74	1.19						
	1560	95.78	1.23						
	1620	95.80	1.25						
	1680	95.81	1.26						
	1740	95.81	1.26						
	1800	95.82	1.27						
	1860	95.82	1.27						
	1920	95.83	1.28						
	1980	95.83	1.28						
	2040	95.84	1.29						
	2100	95.84	1.29						
	2160	95.84	1.29						
	2220	95.84	1.29						
	2280	95.85	1.30						
	2340	95.85	1.30						
	2400	95.85	1.30						
	2460	95.85	1.30						
	2520	95.85	1.30						
	2580	95.85	1.30						
	2640	95.86	1.31						
	2700	95.86	1.31						
	2760	95.86	1.31						
	2820	95.86	1.31						
	2880	95.86	1.31						
	2940	95.86	1.31						
	3000	95.86	1.31						
	3060	95.88	1.33						

Table 21-11 Observation Borehole Data – BH10217 (Recovery Test)

Official BH NO :	10217	District :	Kgalagadi
Date of test commencement :	3.3.06	Location :	Ukhwi
Time of test commencement :	1300hrs	BH depth(m) :	400
Date of test completion	4.3.06	Screen Int (m)	371.64 to 374.49
Time of test completion :	1300hrs	Depth of pump intake (m) :	n/a
Method of water level measurement:	dipper	Description of MP	top of pvc
Pumping BH. No.:	10219	Height of MP above ground(m) :	0..73
Dist.to Pumping Bh:	9m	Static Water level before test(m) :	94.55
Casing diameter (mm)	50mm	Water strike	169, 182, 188, 229, 275, 338 and 371 m
Orifice plate diameter	n/a	Delivery pipe diameter	n/a
Easting	462933	Norhting	7396706

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0		
	0.25	95.86	1.31
	0.5	95.85	1.30
	1	95.85	1.30
	2	95.84	1.29
	3	95.83	1.28
	4	95.82	1.27
	5	95.82	1.27
	6	95.82	1.27
	7	95.82	1.27
	8	95.81	1.26
	9	95.81	1.26
	10	95.81	1.26
	12	95.80	1.25
	15	95.80	1.25
	20	95.80	1.25
	25	95.79	1.24
	30	95.79	1.24
	40	95.79	1.24
	50	95.79	1.24
	60	95.79	1.24
	75	95.77	1.22
	90	95.75	1.20
	105	95.73	1.18
	120	95.70	1.15

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	96.64	2.09
	180	95.60	1.05
	210	95.58	1.03
	240	95.56	1.01
	270	95.55	1.00
	300	95.54	0.99
	330	95.53	0.98
	360	95.52	0.97
	390	95.50	0.95
	420	95.50	0.95
	450	95.45	0.90
	480	95.40	0.85
	540	95.25	0.70
	600	95.24	0.69
	660	95.18	0.63
	720	95.00	0.45
	780	94.90	0.35
	840	94.80	0.25
	900	94.78	0.23
	960	94.76	0.21
	1020	94.74	0.19
	1080	94.72	0.17
	1140	94.70	0.15
	1200	94.70	0.15
	1260	94.68	0.13
	1320	94.68	0.13
	1380	94.62	0.07
	1440	94.60	0.05

Table 21-12 Observation Borehole Data – BH10218 (CRT)

Official BH NO :	10218	District :	Ghanzi
Date of test commencement :	1.3.06	Location :	Ukhwi
Time of test commencement :	1300hrs	BH depth(m) :	290
Date of test completion	3.3.06	Screen Interval (m)	175.8 to 246.67
Time of test completion :	1600hrs	Depth of pump intake (m) :	n/a
Method of water level measurement	electrical dipper	Description of MP	top of pvc
Pumping BH NO:	10219	Height of MP above ground(m) :	0.59
Distance ob BH r (m)	9.12m	Static Water level before test(m) :	85.65
Casing diameter (mm)	50mm	Water strike	172, 183, 189 and 213 m
Orifice plate diameter	4"	Delivery pipe diameter	5"
Easting	462945	Northing	7396707

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500l	Q(m^3/h)	Temp (^{0}C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO
	0.25								
	0.5	85.91	0.26						
	1	86.84	1.19						
	2	88.71	3.06						
	3	90.50	4.85						
	4	92.30	6.65						
	5	92.86	7.21						
	6	93.77	8.12						
	7	94.26	8.61						
	8	95.05	9.40						
	9	95.43	9.78						
	10	95.89	10.24						
	11	96.26	10.61						
	12	96.69	11.04						
	15	97.50	11.85						
	20	98.34	12.69						
	25	99.30	13.65						
	30	99.42	13.77						
	40	99.50	13.85						
	45	99.50	13.85						
	50	100.93	15.28						
	60	101.94	16.29						
	75	102.35	16.70						
	90	102.60	16.95						
	105	102.75	17.10						
	120	102.99	17.34						
	150	103.15	17.50						
	180	103.35	17.70						
	210	103.46	17.81						
	240	103.54	17.89						
	270	103.68	18.03						
	300	103.74	18.09						
	330	103.94	18.29						
	360	104.15	18.50						
	390	104.25	18.60						
	420	104.41	18.76						
	450	104.54	18.89						
	480	104.61	18.96						
	540	104.73	19.08						

	600	104.90	19.25						
	660	105.35	19.70						
	720	105.59	19.94						
	780	105.78	20.13						
	840	105.93	20.28						
	900	106.12	20.47						
	960	106.25	20.60						
	1020	106.44	20.79						
	1080	106.54	20.89						
	1140	106.71	21.06						
	1200	106.90	21.25						
	1260	107.54	21.89						
	1320	107.90	22.25						
	1380	108.60	22.95						
	1440	108.68	23.03						
	1500	108.74	23.09						
	1560	108.83	23.18						
	1620	108.85	23.20						
	1680	108.86	23.21						
	1740	108.87	23.22						
	1800	110.70	25.05						
	1860	110.70	25.05						
	1920	110.70	25.05						
	1980	110.72	25.07						
	2040	110.73	25.08						
	2100	110.73	25.08						
	2160	110.73	25.08						
	2220	110.75	25.10						
	2280	110.75	25.10						
	2340	110.75	25.10						
	2400	110.76	25.11						
	2460	110.76	25.11						
	2520	110.76	25.11						
	2580	110.76	25.11						
	2640	110.77	25.12						
	2700	110.77	25.12						
	2760	110.78	25.13						
	2820	110.78	25.13						
	2880	110.78	25.13						
	2940	110.78	25.13						
	3000	110.78	25.13						
	3060	110.80	25.15						

Table 21-13 Observation Borehole Data – BH10218 (Recovery Test)

Official BH NO :	10218	District :	Kgalagadi
Date of test commencement :	3.3.06	Location :	Ukhwi
Time of test commencement :	1300hrs	BH depth(m) :	290
Date of test completion	4.3.06	Screen Int (m)	175.8 to 246.67
Time of test completion :	1300hrs	Depth of pump intake (m) :	n/a
Method of water level measurement:	dipper	Description of MP	top of pvc
Pumping BH. No.:	10219	Height of MP above ground(m) :	0.59
Dist.to Pumping Bh:	16.4m	Static Water level before test(m) :	85.65
Casing diameter (mm)	50mm	Water strike	172, 183, 189 and 213 m
Orifice plate diameter	n/a	Delivery pipe diameter	n/a
Easting	462945	Northing	7396707

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0		
	0.25	110.80	25.15
	0.5	110.78	25.13
	1	110.74	25.09
	2	110.72	25.07
	3	110.72	25.07
	4	110.70	25.05
	5	110.68	25.03
	6	110.66	25.01
	7	110.64	24.99
	8	110.62	24.97
	9	110.60	24.95
	10	110.58	24.93
	12	110.55	24.90
	15	110.04	24.39
	20	109.63	23.98
	25	108.13	22.48
	30	107.88	22.23
	40	106.52	20.87
	50	105.48	19.83
	60	105.04	19.39
	75	104.16	18.51
	90	103.22	17.57
	105	102.13	16.48
	120	101.38	15.73

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	110.14	24.49
	180	89.62	3.97
	210	89.34	3.69
	240	89.15	3.50
	270	88.72	3.07
	300	88.64	2.99
	330	88.62	2.97
	360	88.61	2.96
	390	88.60	2.95
	420	88.60	2.95
	450	88.58	2.93
	480	88.56	2.91
	540	88.54	2.89
	600	88.50	2.85
	660	88.44	2.79
	720	88.31	2.66
	780	88.22	2.57
	840	88.01	2.36
	900	87.94	2.29
	960	87.90	2.25
	1020	87.88	2.23
	1080	87.85	2.20
	1140	87.80	2.15
	1200	87.78	2.13
	1260	87.50	1.85
	1320	87.30	1.65
	1380	86.98	1.33
	1440	86.91	1.26

22 BH10218

BH10218 with siting reference of **S8,** Line **R5** and Peg 7000m is an observation borehole (piezometer) drilled to allow for the measurement of the head of the Ecca aquifer at this location. It is located about 14km south of Ukwi along the road to Hukuntsi. This borehole was drilled between 14 and 26 January 2006 with a total drilled of depth of 290m.

22.1 SITING CRITERIA AND DRILLING OBJECTIVES

This observation borehole (piezometer) was drilled for comparative measurement of groundwater head between the fresh and saline Ecca aquifers at this site as well as allowing for the calculation of the storativity of the Ecca Aquifer during pump testing of the nearby exploration borehole (BH10219).

22.2 DRILLING RESULTS

This observation borehole was drilled through various lithologies including fine grained sands, calcrete, silcrete, fine grained, mudstones, dolerite and fine and medium grained sandstones (**Figure 22-1**). Drilling of BH10218 was carried out with a 10 inch bit to a depth of 89 m bgl after which 8 inch plain casings were installed and cement grouted. Drilling from 89 m to 213m was achieved using an 8 inch bit and a 6.25 inch tri-cone bit was used to drill from 213m to the terminal depth of 290m.

During drilling of this borehole, four water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows;

1. (172m, 2480 µS/cm, 4.4 m^3/hr)
2. (183m, 1360 µS/cm, 32.17 m^3/hr)
3. (189m, 1295 µS/cm, 14.5 m^3/hr)
4. (213m, 1325 µS/cm, 8.35 m^3/hr)

Water samples were collected at different water strikes during drilling of BH10218. The samples collected at the water strikes were submitted to the DWA laboratory for chemical analysis and results are shown on **Table 22-1**.

Table 22-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10218	183	7.78	792	7.04	1.24	313.4	1.495	114.69	65.44	0	1.65	0	585.11	0.00	4.81	SST 1
10218	189	7.8	786	7.42	1.07	306.5	1.535	102.8	56.18	2.63	1.58	0	588.71	0.00	2.91	SST 1
10218	213	7.62	720	11.06	3.44	323.6	1.32	106.46	62.85	0	1.3	0	567.25	0.00	1.09	SST 1
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

This borehole was constructed with 2.4 inch (60mm) reinforced PVC casing and screen (screened interval 175.8 to 246.67 m bgl) assembly. Gravel pack, comprising of sub-rounded gravel, was tremied down from 147.5 to 290 m bgl. A bentonite seal was placed from 143.67 to 147.5 m and the remaining annulus was cement grouted (143.67 to 0 m). The static water level measured on 26 January 2006 was 84.02 below ground level.

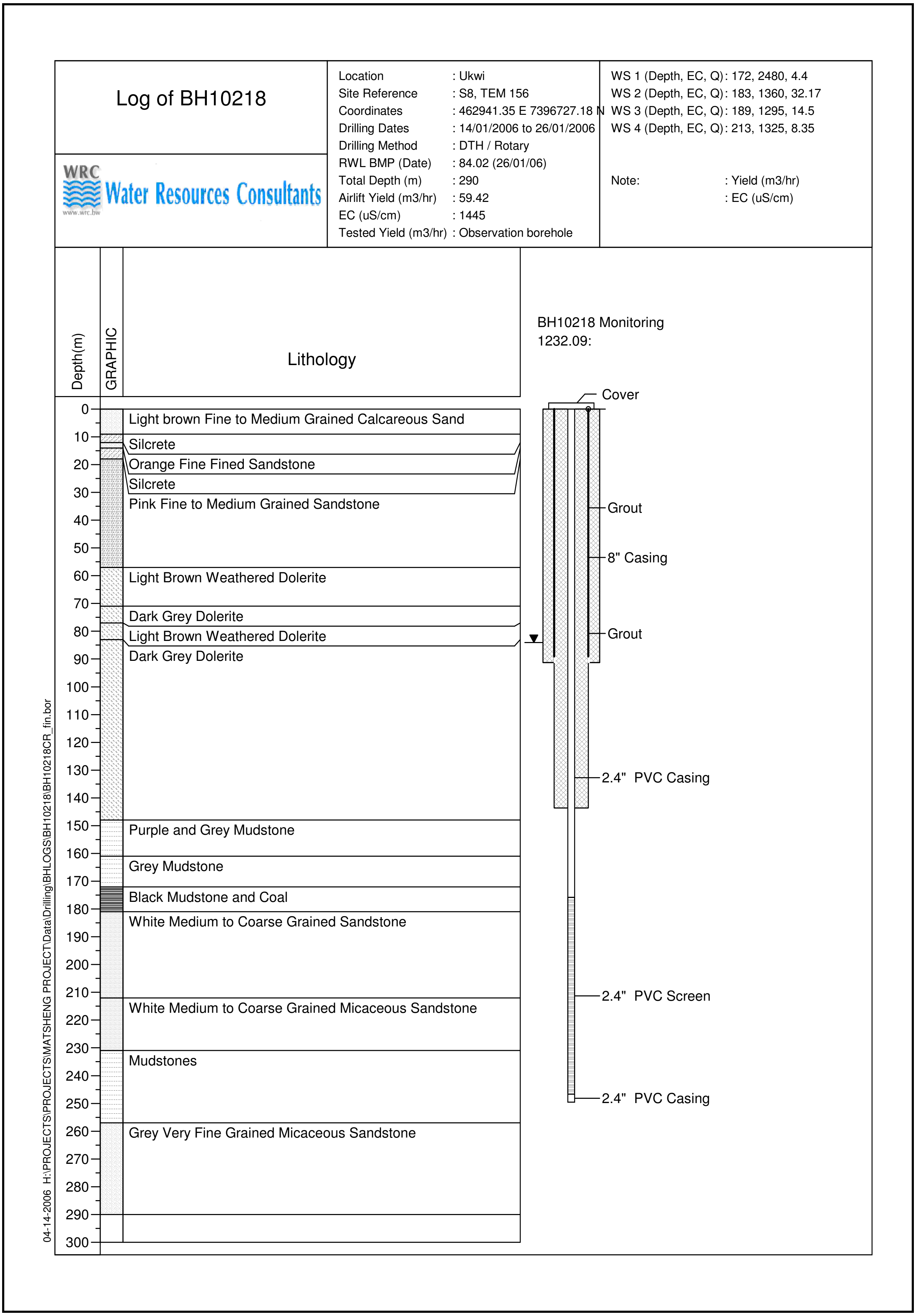

Figure 22-1 Log of BH10218

23 BH10217

BH10217 with siting reference **S8,** Line **R5** and Peg 7000m is an observation borehole (piezometer) drilled to allow for the measurement of the head of the saline Ecca aquifer at this site. It is located about 14km south of Ukwi along the road to Hukuntsi. Drilling at this site commenced on 21 November and was completed on 14 December 2005 at a depth of 400m.

23.1 SITING CRITERIA AND DRILLING OBJECTIVES

This observation borehole (piezometer) was drilled to explore the Ecca aquifer between faults **F6** and **F7** and to assess the influence of dolerite sill intrusions in groundwater quality. This observation borehole (piezometer) was completed in the saline Ecca aquifer. It will allow for measuring the head difference of the saline and fresh Ecca aquifers after completion of the shallower observation borehole at this site. In addition to the head data, this borehole will also generate the data for the deeper stratigraphy of the Ecca aquifer and variation of salinity with depth.

23.2 DRILLING RESULTS

This observation borehole was drilled through various lithologies including fine grained calcareous sand, mudstones, dolerite and fine and medium grained sandstones (**Figure 23-1**). Drilling of BH10217 was carried out with a 10 inch bit to a depth of 164 m bgl after which 8 inch plain casings were installed and cement grouted. Drilling to a depth of 240m was achieved using an 8 inch bit and a 6.25 inch tri-cone bit was used to drill from 240 m to 305 m. This borehole was then rimmed with an 8 inch bit from 240 m to 285 m and plain 6.5 inch casings were cement grouted to 285 m. From the depth of 285 m to 305 m, the borehole was further rimmed with a 6.5 inch bit. A 6.5 inch bit was then used to drill between 305 m and 349 m and a 6.25 inch tri-cone bit was used to overcome the back pressure problems between 349m and the terminal depth of 400m.

During drilling of this borehole, seven water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the seven water strikes are as follows;

1. (169m, 2580 µS/cm, 4.4 m^3/hr)
2. (182m, 1304 µS/cm, 15.61 m^3/hr)
3. (188m, 1237 µS/cm, 16.56 m^3/hr)
4. (229m, 1318 µS/cm, 22.85 m^3/hr)
5. (275m, 1377 µS/cm, 9.13 m^3/hr)
6. (338m, 13500 µS/cm, 4.4 m^3/hr)
7. (371m, 12760 µS/cm, 6.1 m^3/hr)

The borehole was not developed and the conductivity and yield before placement of the PVC casing and screen assembly were 12570 µS/cm and 10.4 m^3/hr, respectively. Water samples were collected at all the water strikes and will be analysed for stable isotopes at the CSIR laboratory in Pretoria.

During drilling, the borehole was geophysicaly logged before placement of casings except for the top 164m where logging was carried out after casing. The total logged depth of this borehole is 399.5m. After final logging, a 2.4 inch (60mm) reinforced PVC casing and screen (screened interval 371.64 to 374.49 m bgl) assembly was installed in the borehole. Gravel pack, comprising of sub-rounded gravel, was tremied down from 260.34 to 400 m bgl. A bentonite seal was placed from 258.66 to 260.34 m and the remaining annulus was cement grouted (258.66 to 0 m). The static water level was 94.02 below ground level, measured on 14 December 2005.

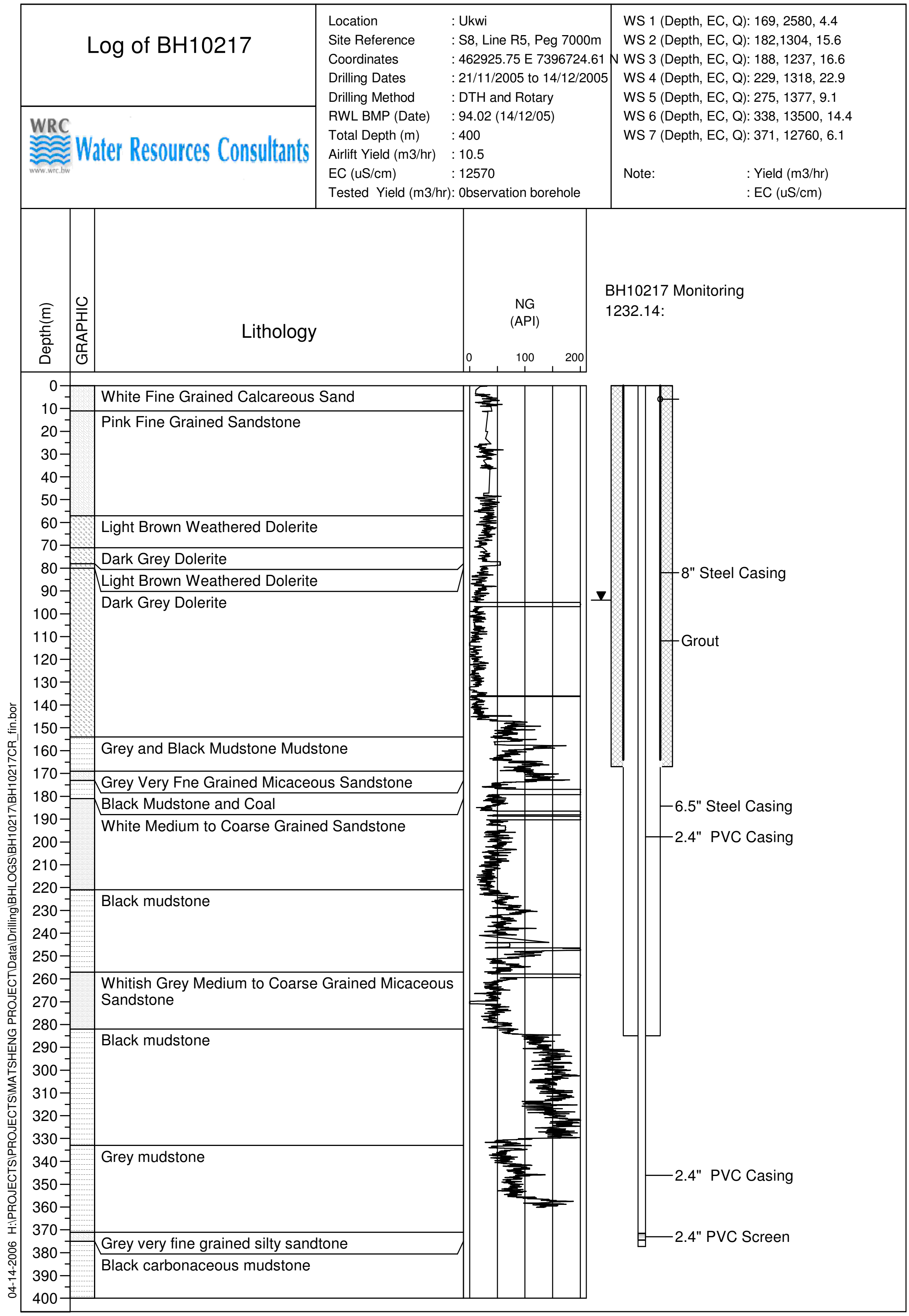

Figure 23-1 Log of BH10217

24 BH10221

Borehole BH10221 is a test production borehole with siting reference of **S13,** Line R10, TEM125 and Peg 4000m. This borehole was initially planned to be an open exploration borehole but the design was changed due to collapsing problems. It is located about 20 km along the gravel road linking Ncojane and Metsimantsho. Drilling at this site commenced on 27 June 2005 and was completed on 11 September 2005. The actual drilling dates were between 27 June to 12 July 2005, 28 to 31 July 2005 and 31 August to 11 September 2005. The days in between were mainly spent sourcing a tri-cone bit, repairing the geophysical logging probe and the President's holidays break. The drilled depth of this borehole is 327m.

24.1 SITING CRITERIA AND DRILLING OBJECTIVES

This borehole was drilled to explore the Ecca aquifer between faults F4 and F6. It will also provide water level data for Ecca aquifer at this locality. It is close to project Rain Gauge RG4 (Ncojane Ranches) and will assess whether there is recharge related to the rainfall.

24.2 DRILLING RESULTS

The borehole was drilled through various lithologies including fine grained sand, calcrete, conglomerate, mudstones, dolerite and fine to medium grained micaceous sandstone and medium to coarse grained sandstones (**Figure 24-1**). Drilling of BH10221 was carried out with a 15 inch drilling bit using the DTH drilling technique down to a depth of 80m bgl and 12 inch plain casings were installed and cement grouted to 80m. Drilling from 80 to 224m was accomplished using a 12 inch drilling bit after which 10 inch casing were installed. A 10 inch drilling bit was used to drill from 224 to 278m. After a water strike at 277m, back pressure problems prevented further drilling using the DTH method and a $9^{7/8}$ inch tri-cone bit was then used to drill from 278m to the terminal depth of 327m.

One water strike was encountered at 277 m with an estimated yield determined using a 90^{o} V-notch weir of 46 m^3/hr and an electrical conductivity of 1160 µS/cm.

The borehole was constructed using 6.5 inch plain casings and 6 inch wire wrap screens (Johnson) Plain casing were placed between 0 to 276 m bgl and 299.2 to 302.2 m bgl while the screens were placed between 276 to 299.2 m bgl. Gravel pack, comprising of sub-rounded gravel, was tremied down from 327 to 256 m bgl. The annulus from 256 to 20m was back filled using drill cuttings and the remaining annulus was cement grouted (20 to 0 m). After development, the final borehole airlift yield was 12 m^3/hr. and this was caused by the fact that the mud sealed most of the aquifer. The borehole was finally capped and a cement slab was constructed.

Water samples were collected at the water strike and after development and submitted to the DWA laboratory for chemical analysis. The results are presented in **Table 24-1.**

Table 24-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10221	277	7.84	616	2.28	3.16	248.2	19.55	99.2	40.5	2.7	1.01	0	531.12	0.00	0.09	SST 1
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

The collapsing resulted in having to geophysically log the borehole after the borehole was completed, (after placement of casings and screens) and only natural gamma was used. The logging results show (**Figure 24-2**) that the screens were placed in inter-layered sandstone and shale/mudstones as opposed to the clean white sandstones which might have resulted in lower air lift yield

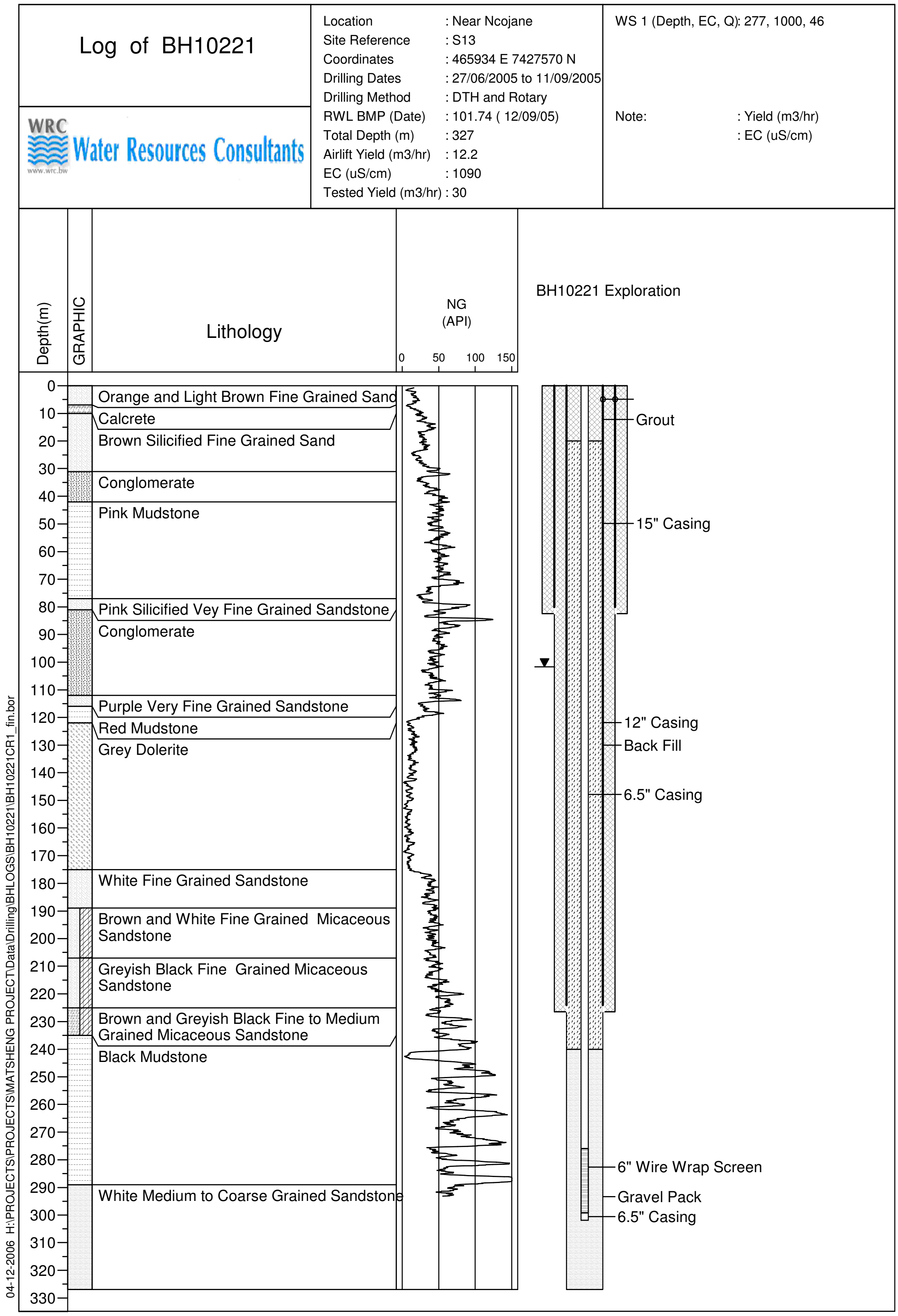

Figure 24-1 Log of BH10221

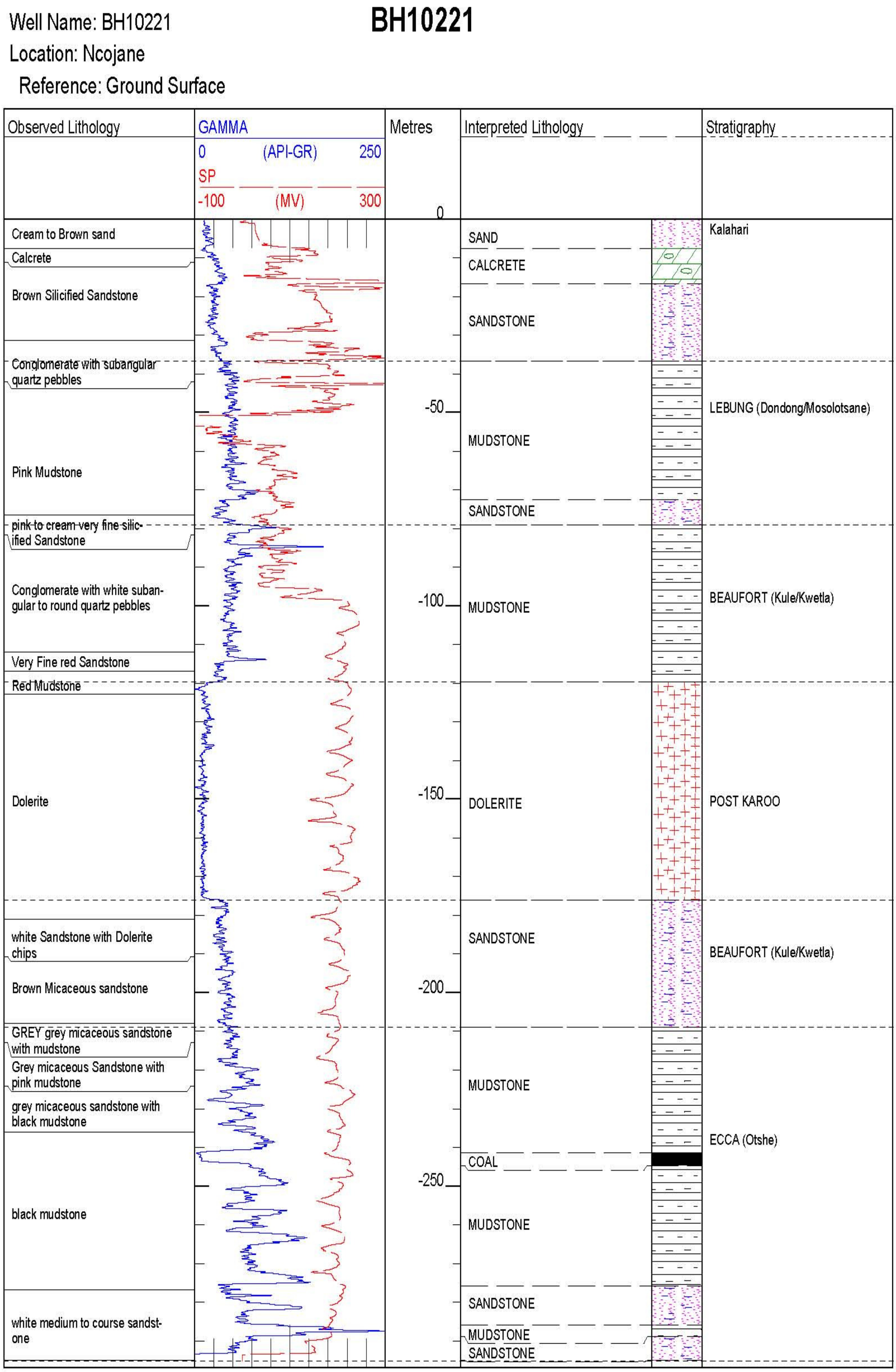

Figure 24-2 Geophysical log of BH10221

24.3 PUMP TESTING RESULTS

BH10221 was initially tested between 16 and 21 November 2005 and the tests carried out were calibration, step drawdown and constant rate. The measuring point was 0.4 m above ground level (agl) and the pump intake was set at 168.5 m below ground level. During the calibration test and step test, the water was found to be muddy and dark in colour implying that the borehole was not sufficiently developed. The first calibration test lasted for 25 minutes and the maximum yield was 9.3 m^3/hr. After the first calibration test, the borehole was over-pumped (developed) for a period of 9 hours and the yield improved and the water cleared.

After completing the third calibration test, the pump intake was increased from 168.5 to 183.5 m to increase the available drawdown, and a step drawdown test was completed and was followed by a constant rate test at 30m^3/hr. The water level reached the pump intake 14 hours into the CRT and it was decided to re-develop the borehole before attempting another test. Summary details for the first pump testing activities at BH10221 are given in **Table 24-2** and the results of the step test analysis are also provided in **Table 24-2**.

Table 24-2 Summary of Pumping Test Data BH10221 (1st test)

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	48.3	7.1
	2	10	66.46	9.3
	1	15	20.46	3.9
	2	15	28.7	5.8
	3	15	33.41	9.9
	4	15	41.17	10.7
	5	15	47.66	13.5
	6	8	65.93	18
	1	15	13.32	5
	2	15	17.83	10
	3	15	30.12	15
	4	15	42.16	20
	5	15	50.56	25
	6	15	63.05	30
Step Test	1	100	19.38	10.2
	2	100	34.89	15.1
	3	100	46.1	20.3
	4	100	64.57	30.3
	5	11	79.63	37.3
Constant Rate	1	840	78.57	30

After the borehole was re-developed using a drilling rig, a second pumping test was carried out between 29 January and 4 February 2006 and the tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.3 m above ground level (agl) and the pump intake was set at 168.5 m below ground level. Summary details for the second pumping test activities at BH10221 are given in **Table 24-3**.The collected pump testing data is presented in **Tables 24-7 to 24-14.**

Table 24-3 Summary of Pumping Test Data BH10221 (2nd test)

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	11.68	9.7
	2	15	21.66	15.2
	3	15	29.67	20.2
	4	15	41.71	30
	5	15	59.46	40
	6	1	63.91	50
Step Test	1	100	13.61	10
	2	100	22.9	15
	3	100	32.58	20
	4	100	39.86	25
	5	100	47.97	30
	6	50	65.52	40
Constant Rate	1	4320	58.49	30
Recovery*	1	1440	11.62*	0

Note. 11.62* Residual Drawdown

24.3.1 Step Drawdown Test

The second step drawdown test (SDT) was carried out on 30 January 2006. The static water level before the start of the test was 99.45 m bmp. The step drawdown test consisted of 5 steps of 100 minutes duration. The discharge rates were 10, 15, 20, 25 and 30m^3/hr for steps 1 to 5 respectively. A sixth step at 40 m^3/hr lasted for 50 minutes only (**Table 24-3**).

The step drawdown pumping test data for the two tests were analysed using the computer programme StepMaster by preparing semi-logarithmic plots of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test data using this method are plotted in **Figures 24-3** and **24-6**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figures 24-4** and **24-7**. The transmissivity value calculated from the step drawdown test data sets using the Eden-Hazel (1973) method were 35.1 and 28.6 m^2/d, **Figures 24-5** and **24-8**. The results for the interpretation of the step tests are tabulated in **Table 24-4**.

Table 24-4 Results of Step Test Analysis BH10221

BH	Test	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10221	1st Test	8.67E-02	6.63E-06	35.1	10.0	19.50	19.50	0.51
					15.0	15.00	34.50	0.43
					20.0	10.90	45.40	0.44
					30.0	17.70	63.10	0.48
	2nd Test	5.82E-02	6.57E-06	28.6	10.0	13.80	13.80	0.72
					15.0	8.55	22.35	0.67
					20.0	8.67	31.02	0.64
					25.0	6.01	37.03	0.68
					30.0	7.25	44.28	0.68

The planned duration of the constant rate test for this borehole was 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figures 24-3 and 24-6**) to estimate the expected total drawdown after 3 days of pumping and the ideal pumping rate was obtained as 30m^3/hr.

24.3.2 Constant Rate and Recovery Tests

The second constant rate test (CRT) was carried out between 31 January and 3 February 2006 at a discharge rate of 30 m^3/hr and the total drawdown was 58.49 m. The CRT test was followed by a 24 hr recovery monitoring period at the end of which the residual drawdown was 11.62 m. Data from the pumping period was interpreted using the Theis and the Cooper-Jacob (1946) analytical solutions using the computer programme "Aqtesolv" and the transmissivity (T) values obtained were 19 and 26 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 22.7 m^2/d was obtained. The interpretation results are summarised in **Table 24-5** and the interpreted data is presented in **Figures 24-9** to **24-11**. The data indicates a possible negative boundary after approximately 500 minutes of pumping (**Figure 24-10**).

Table 24-5 Summary of Constant Rate and Recovery Tests BH10221, 2nd Test

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10221	72	720	a) 19.4 b) 25.8	22.7	Confined

Notes:
Interpretation Techniques
a) Theis *c) Neuman (Unconfined)*
b) Cooper-Jacob *d) Theis Modified Recovery*

24.3.2.1 Aquifer Type interpreted

The aquifer type determined from the pump testing interpretation is confined.

24.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none acidified) were collected and submitted to the CSIR laboratory in Stellenbosch, South Africa for most of the BOS 32:2000 listed determinants. Other samples collected were submitted for both stable and radioactive (^{14}C) isotope analysis at the CSIR laboratory in Pretoria, South Africa . The chemical analysis results from the CISR laboratory indicates that all parameters that were analysed for are within the BOS 32:2000 Class II limits for drinking water with the exception of total dissolved organic carbon which exceeds the limits (**Table 24-6).**

Table 24-6 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10221	3.3	250	2.5	2.1	36	85	388	<0.1	1.1	0.2	<0.05	1090	7.3	698
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10221	0.1	15	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 *is calculated from alkalinity*

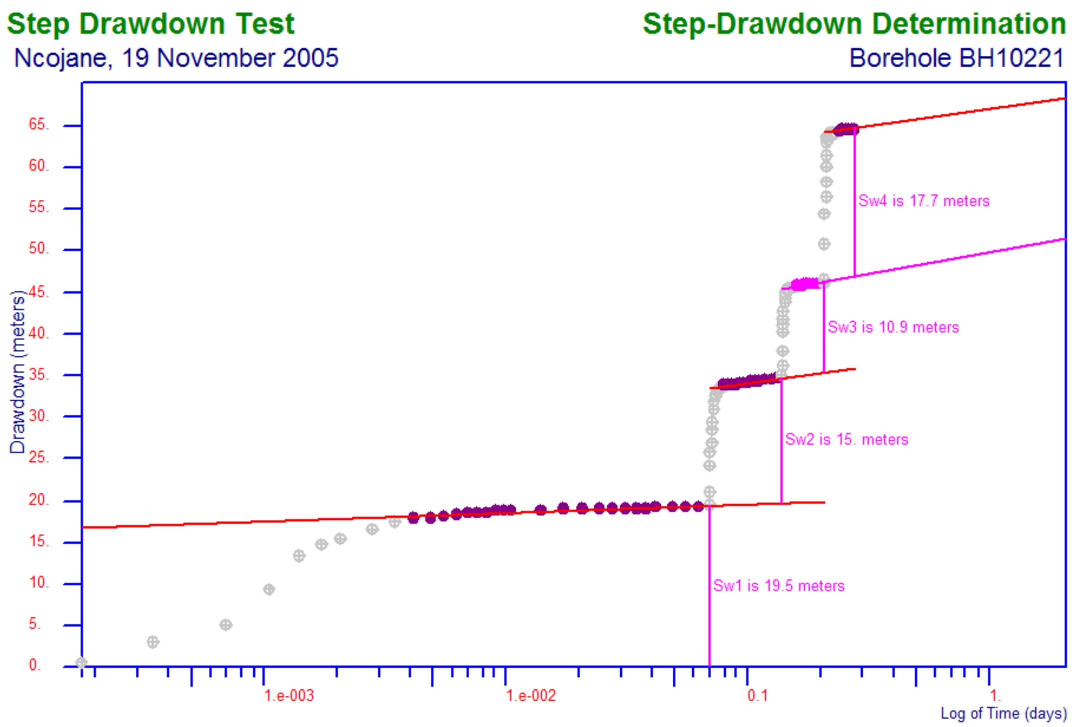

Figure 24-3 Pumping Test Results for BH10221: Step Drawdown Test – Hantush-Bierschenk (semi-log), 1st Test

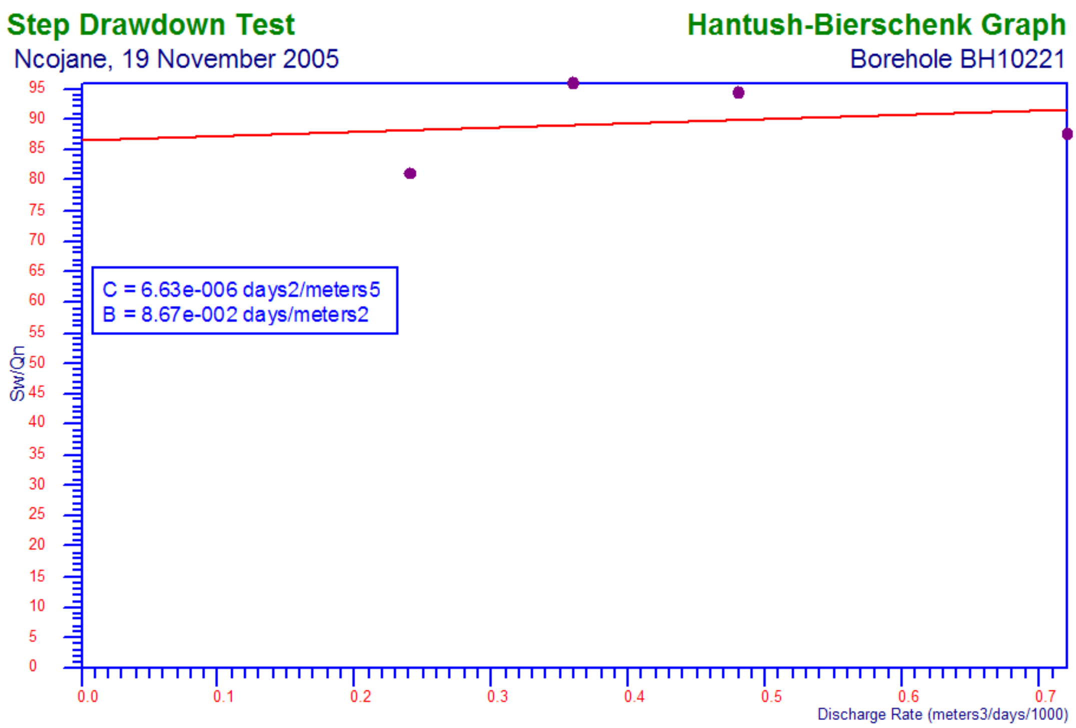

Figure 24-4 Pumping Test Results for BH10221: Step Drawdown Test – Hantush-Bierschenk, 1st Test

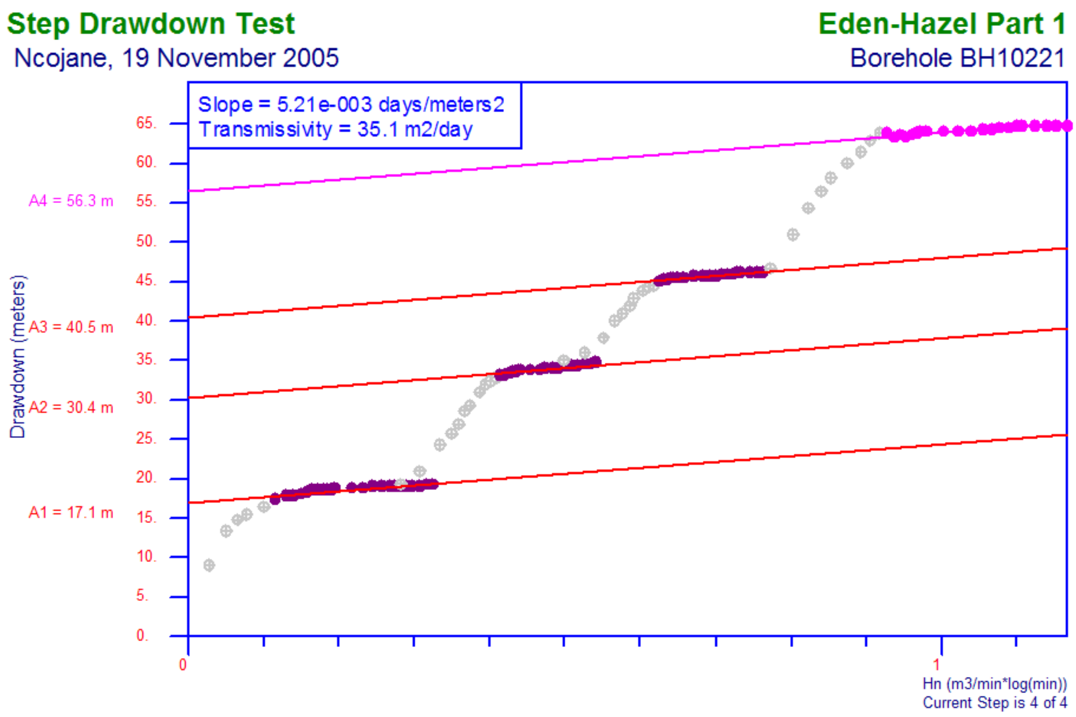

Figure 24-5 Pumping Test Results for BH10221: Step Drawdown Test – Eden-Hazel (Part 1), 1st Test

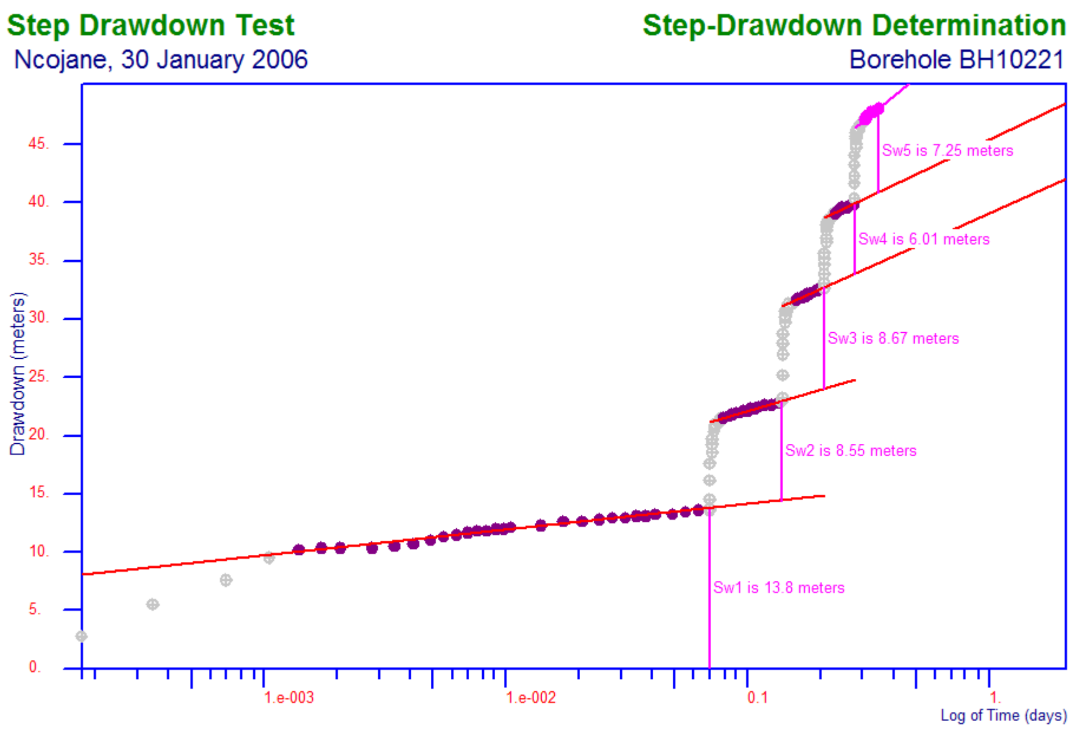

Figure 24-6 Pumping Test Results for BH10221, Step Drawdown Test – Hantush-Bierschenk (semi-log), 2nd Test

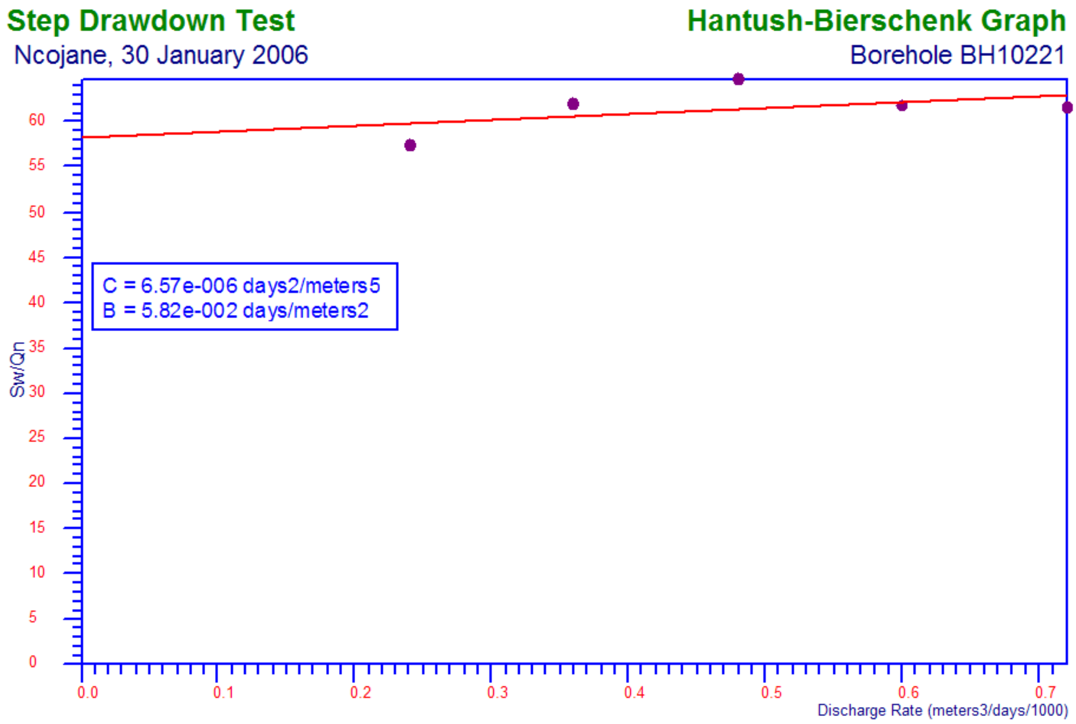

Figure 24-7 Pumping Test Results for BH10221: Step Drawdown Test – Hantush-Bierschenk, 2nd Test

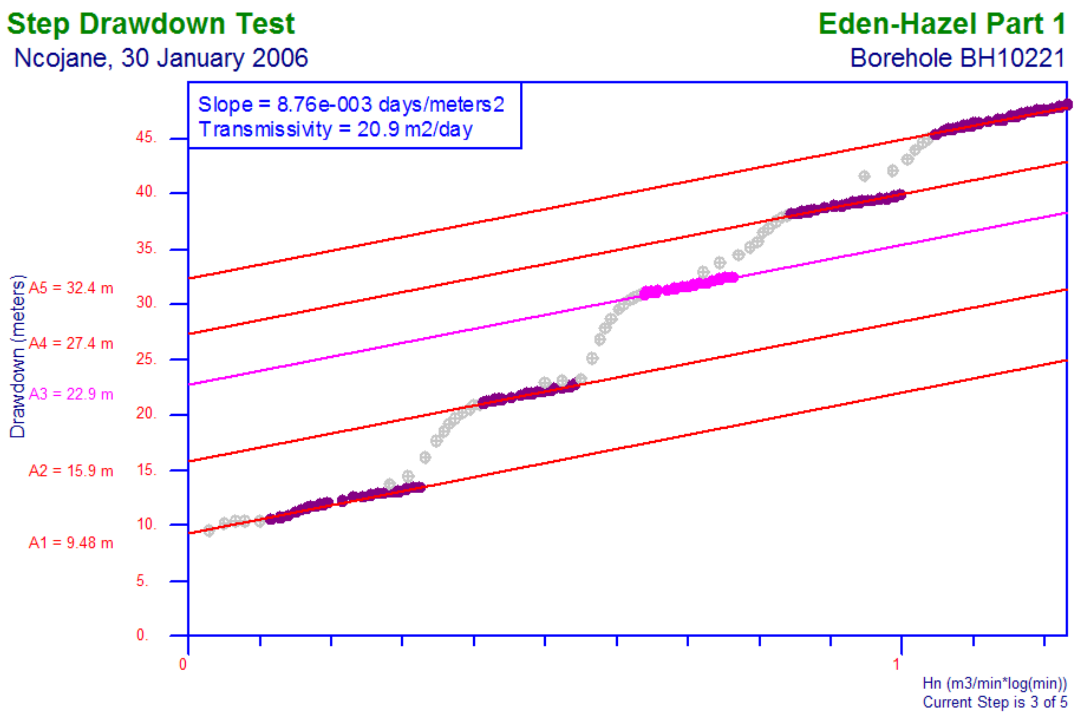

Figure 24-8 Pumping Test Results for BH10221: Step Drawdown Test – Eden-Hazel (Part 1), 2nd Test

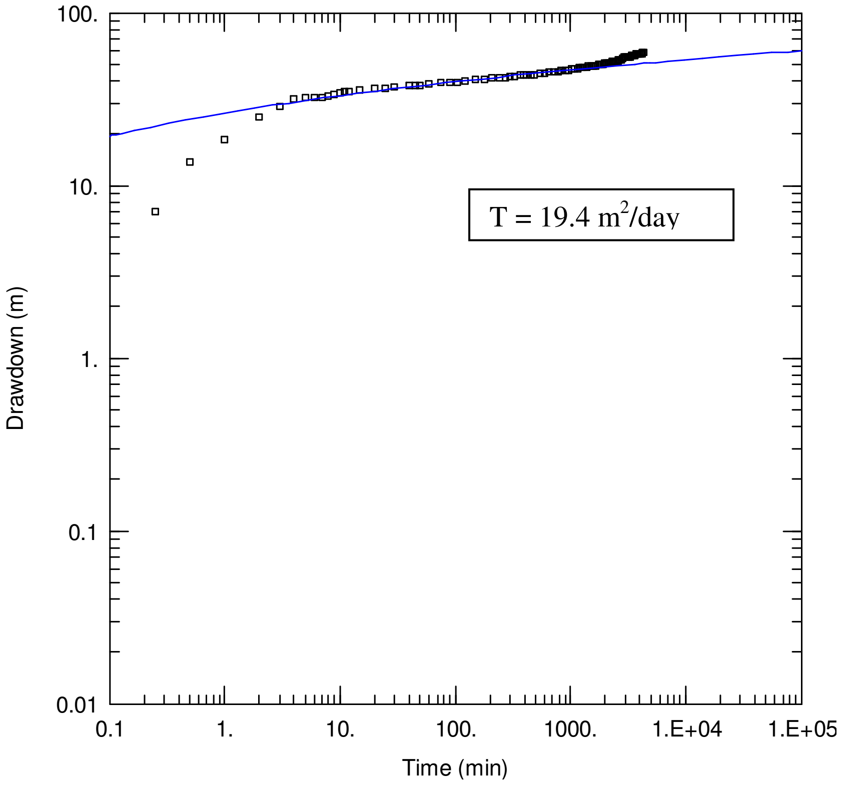

Figure 24-9 Pumping Test Results for BH10221: Theis Solution (2nd Test)

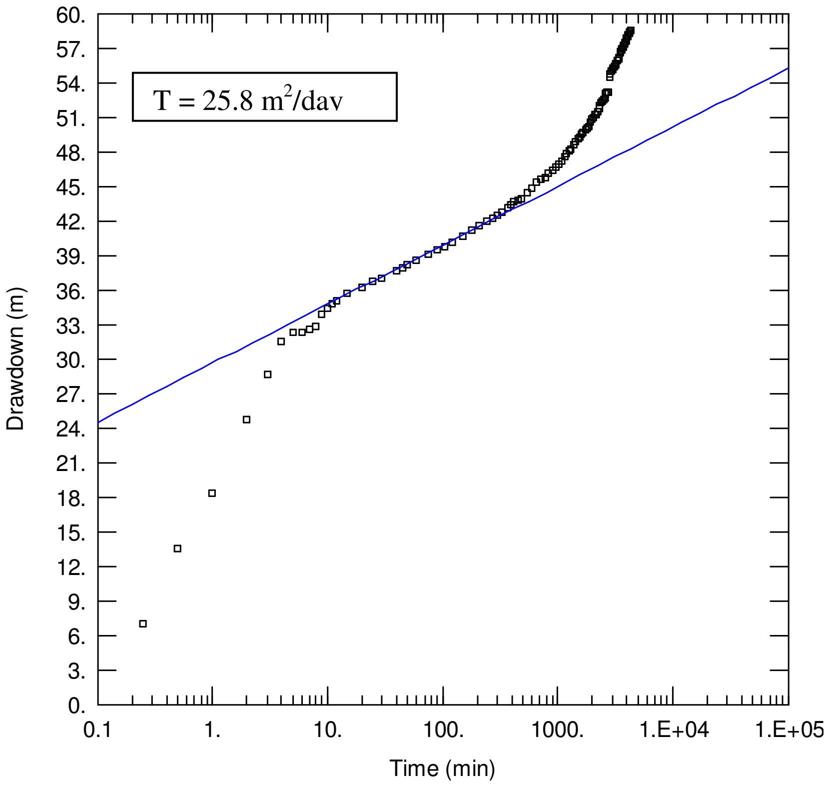

Figure 24-10 Pumping Test Results for BH10221: CRT Cooper Jacob Solution (2nd Test)

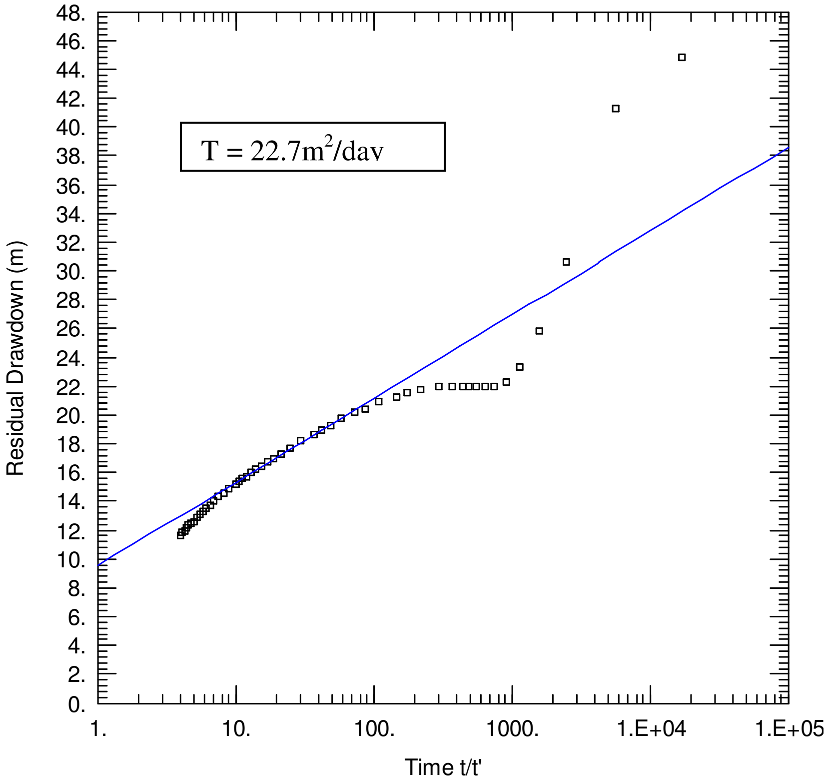

Figure 24-11 Pumping Test Results for BH10221: Theis Recovery Solution (2nd Test)

Table 24-7 Calibration Test Data – BH10221 (Test 1)

Official BH No.:	10221	District:	Ghanzi
Date of test commencement:	16.11.2005	Location:	Metsimantsho
Time of test commencement	1445hrs	BH depth (m):	327
Date of test completion:	16.11.2005	Screen Interval (m):	276 to 299.2
Time of test completion	1510hrs	Depth of pump intake (m):	168.5m
Method of water level measurement:	dipper	Static water level before test (m):	98.72
Casing diameter (mm)	165	Water strike	277
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

STEP No. 1 / STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 20L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 20L	P Rate (m^3/hr)	Comments
0.25						0.25	147.32	48.60			
0.5	102.09	3.37				0.5	148.33	49.61			
1	dipper					1	149.01	50.29	8.33	8.64	
1.5	pull					1.5	149.93	51.21			
2	out					2	151.18	52.46	8.50	8.47	
2.5						2.5	152.09	53.37			
3						3	153.75	55.03	7.28	9.89	
4	130.93	32.21				4	156.30	57.58	8.00	9.00	
5	131.64	32.92				5	158.34	59.62	7.50	9.60	
6	132.33	33.61	9.59	7.51		6	160.09	61.37	7.80	9.23	
7	135.83	37.11	10.01	7.19		7	161.82	63.10	7.64	9.42	
8	138.02	39.30	10.11	7.12		8	163.19	64.47	7.84	9.18	
9	139.81	41.09	10.00	7.20		9	164.24	65.52	7.63	9.44	
10	141.77	43.05	10.24	7.03		10	165.18	66.46	7.50	9.60	
11	143.00	44.28	10.04	7.17		11	suction				
12	144.34	45.62	10.34	6.96		12					
15	147.02	48.30	10.56	6.82		15					

Table 24-8 Calibration Test Data – BH10221 (Repeat)

Official BH No.:	10221	District:	Ghanzi
Date of test commencement:	17.11.2005	Location:	Metsimantsho
Time of test commencement	0700hrs	BH depth (m):	327
Date of test completion:	17.11.2005	Screen Interval (m):	276 to 299.20
Time of test completion	0823hrs	Depth of pump intake (m):	168.5m
Method of water level measurement:	dipper	Static water level before test (m):	99.20
Casing diameter (mm)	165.1	Water strike	277
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

STEP No. 1 / STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 10L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 10L	P Rate (m^3/hr)	Comments
0.25	100.20	1.00				0.25	119.76	20.56			
0.5	103.12	3.92				0.5	120.04	20.84			
1	106.36	7.16				1	120.10	20.90	7.77	4.63	
1.5	109.42	10.22				1.5	120.46	21.26			
2	111.84	12.64				2	120.74	21.54	7.79	4.62	
2.5	113.86	14.66				2.5	121.06	21.86			adj
3	114.76	15.56				3	121.41	22.21	8.00	4.50	
4	116.74	17.54				4	121.90	22.70	8.19	4.40	adj
5	117.24	18.04				5	122.62	23.42	7.80	4.62	
6	117.38	18.18				6	123.69	24.49	5.90	6.10	
7	117.72	18.52				7	124.68	25.48	6.37	5.65	
8	118.12	18.92	9.48	3.80		8	125.56	26.36	6.77	5.32	
9	118.52	19.32	9.30	3.87		9	126.10	26.90	6.60	5.45	
10	118.82	19.62	8.88	4.05		10	126.68	27.48	5.99	6.01	
11	119.08	19.88	9.33	3.86		11	127.07	27.87	6.10	5.90	
12	119.24	20.04	9.22	3.90		12	127.35	28.15	6.15	5.85	
15	119.66	20.46	9.29	3.88		15	127.90	28.70	6.20	5.81	

STEPNo. 3 / STEPNo. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 20L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 20L	P Rate (m^3/hr)	Comments
0.25	127.95	28.75				0.25	132.64	33.44			
0.5	128.41	29.21				0.5	133.06	33.86			
1	128.50	29.30	6.75	10.67		1	134.47	35.27	6.72	10.71	
1.5	128.78	29.58				1.5	135.64	36.44			
2	129.03	29.83	6.66	10.81		2	136.50	37.30	6.25	11.52	
2.5	129.24	30.04			adj	2.5	137.02	37.82			
3	129.40	30.20	7.45	9.66		3	137.54	38.34	7.00	10.29	
4	130.47	31.27	7.54	9.55		4	138.41	39.21	7.28	9.89	
5	131.20	32.00	7.67	9.39		5	139.10	39.90	6.84	10.53	
6	131.84	32.64	7.32	9.84		6	139.56	40.36	6.92	10.40	
7	132.13	32.93	7.43	9.69		7	139.93	40.73	6.43	11.20	
8	132.38	33.18	7.35	9.80		8	140.13	40.93	6.69	10.76	
9	132.50	33.30	7.32	9.84		9	140.37	41.17	6.72	10.71	
10	132.60	33.40	7.29	9.88		10	140.37	41.17	6.63	10.86	
11	132.61	33.41	7.27	9.90		11	140.37	41.17	6.64	10.84	
12	132.61	33.41	7.30	9.86		12	140.37	41.17	6.50	11.08	
15	132.61	33.41	7.27	9.90		15	140.37	41.17	6.74	10.68	

Official BH No.:	10221	District:	Ghanzi
Date of test commencement:	17.11.2005	Location:	Metsimantsho
Time of test commencement	0700hrs	BH depth (m):	327
Date of test completion:	17.11.2005	Screen Interval (m):	276 to 299.20
Time of test completion	0823hrs	Depth of pump intake (m):	168.5m
Method of water level measurement:	dipper	Static water level before test (m):	99.20
Casing diameter (mm)	165.1	Water strike	277
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

STEP No. 5 STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 20L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	140.37	41.17				0.25	146.86	47.66			
0.5	140.56	41.36				0.5	147.91	48.71			
1	141.29	42.09	6.12	11.76		1	149.72	50.52	19.09	9.43	
1.5	142.03	42.83				1.5	150.60	51.40			
2	142.65	43.45	5.81	12.39		2	152.06	52.86	11.00	16.36	
2.5	143.41	44.21			adj	2.5	152.90	53.70			adj
3	143.90	44.70	5.56	12.95	adj	3	154.18	54.98	10.57	17.03	
4	144.83	45.63	5.62	12.81		4	157.15	57.95	9.99	18.02	
5	145.67	46.47	5.11	14.09		5	160.47	61.27	9.82	18.33	
6	146.18	46.98	5.00	14.40		6	163.03	63.83	9.87	18.24	
7	146.50	47.30	5.34	13.48		7	164.34	65.14	9.62	18.71	
8	146.72	47.52	5.25	13.71		8	165.13	65.93	9.84	18.29	
9	146.86	47.66	5.32	13.53		9					
10	146.86	47.66	5.50	13.09		10					
11	146.86	47.66	5.60	12.86		11					
12	146.86	47.66	5.30	13.58		12					
15	146.86	47.66	5.26	13.69		15					

Table 24-9 Step Drawdown Test Data – BH10221

Official BH No.:	10221	District:	Ghanzi
Date of test commencement:	19.11.05	Location:	Metsimantsho
Time of test Commencement:	0700hrs	BH depth (m):	327
Date of test completion:	19.11.2005	Screens(m)	276 to 299.20
Time of test Completion:	1350hrs	Depth to pump intake (m)	183.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:		Height of MP above ground:	0.4
Distance to OB. BH (m)		Static water level before test (m):	100.47
Casing diameter (mm)		Water strike	277
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

STEP No. 1 STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 20L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments
0.25	100.93	0.46				0.25	119.86	19.39			
0.5	103.40	2.93				0.5	121.49	21.02			
1	105.55	5.08				1	124.77	24.30	11.25	16.00	
1.5	109.72	9.25				1.5	126.14	25.67			
2	113.93	13.46				2	127.40	26.93	11.20	16.07	adj
2.5	115.28	14.81				2.5	128.98	28.51			
3	115.98	15.51				3	129.75	29.28	11.94	15.08	
4	117.08	16.61	7.25	9.93		4	131.52	31.05	11.86	15.18	
5	117.83	17.36	7.18	10.03		5	132.30	31.83	11.99	15.01	
6	118.27	17.80	6.99	10.30		6	132.96	32.49	11.87	15.16	
7	118.44	17.97	6.96	10.34		7	133.26	32.79	11.76	15.31	
8	118.64	18.17	7.15	10.07		8	133.48	33.01	11.74	15.33	
9	118.87	18.40	7.09	10.16		9	133.64	33.17	11.78	15.28	
10	118.98	18.51	7.18	10.03		10	133.84	33.37	11.75	15.32	
11	119.05	18.58	7.10	10.14		11	133.90	33.43	11.94	15.08	
12	119.12	18.65	6.94	10.37		12	134.04	33.57	11.96	15.05	
13	119.19	18.72	6.92	10.40		13	134.12	33.65	11.98	15.03	
14	119.21	18.74	7.12	10.11		14	134.20	33.73	11.97	15.04	
15	119.25	18.78	7.06	10.20		15	134.29	33.82	11.88	15.15	
20	119.31	18.84	7.15	10.07		20	134.35	33.88	11.79	15.27	
25	119.45	18.98	6.99	10.30		25	134.38	33.91	11.96	15.05	
30	119.50	19.03	7.08	10.17		30	134.44	33.97	11.89	15.14	
35	119.53	19.06	7.20	10.00		35	134.50	34.03	11.76	15.31	
40	119.53	19.06	7.12	10.11		40	134.58	34.11	11.90	15.13	
45	119.53	19.06	7.16	10.06		45	134.67	34.20	11.86	15.18	
50	119.55	19.08	7.15	10.07		50	134.71	34.24	11.74	15.33	
55	119.60	19.13	7.02	10.26		55	134.74	34.27	11.80	15.25	
60	119.61	19.14	7.06	10.20		60	134.80	34.33	11.97	15.04	
70	119.65	19.18	7.08	10.17		70	134.97	34.50	11.97	15.04	
80	119.70	19.23	7.10	10.14		80	135.07	34.60	11.98	15.03	
90	119.77	19.30	7.18	10.03		90	135.24	34.77	11.94	15.08	
100	119.85	19.38	7.20	10.00		100	135.36	34.89	11.97	15.04	

Table 24-10 Constant Rate Test Data – BH10221

Official BH NO :	10221	District :	Ghanzi
Date of test commencement :	20.11.05	Location :	Metsimantsho
Time of test commencement :	1400hrs	BH depth(m) :	327
Date of test completion	21.11.05	Screen Interval (m)	276 to 299.20
Time of test completion :	0400hrs	Depth of pump intake (m) :	183.5
Method of water level measurement	dipper	Description of MP	top of dipper tubing
OB BH NO:		Height of MP above ground(m) :	0.4
Distance ob BH r (m)		Static Water level before test(m) :	101.38
Casing diameter (mm)	165.1	Water strike	277
Orifice plate diameter		Delivery pipe diameter	
Easting	465934	Northing	7427570

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 100l	Q(m^3/h)	Temp (^{0}C)	TDS (mg/L)	pH	Comments
	0.25	105.60	4.22						Flowmeter reading 003433.466
	0.5	117.48	16.10						
	1	124.30	22.92						
	2	141.49	40.11						
	3	150.41	49.03						
	4	156.72	55.34						
	5	160.90	59.52						
	6	164.22	62.84						
	7	166.12	64.74	11.16	32.26				adj
	8	167.45	66.07	11.14	32.32				
	9	169.30	67.92	11.84	30.41				
	10	170.31	68.93	11.10	32.43				
	11	171.06	69.68	10.97	32.82				
	12	171.43	70.05	10.84	33.21				Manometer reading
	15	171.86	70.48	10.54	34.16	32.7	520	8.33	18cm
	20	171.86	70.48	10.76	33.46	31.1	550	8.39	18cm
	25	171.86	70.48	10.81	33.30	30.9	540	8.38	18cm
	30	171.86	70.48	10.89	33.06	31.0	540	8.39	18cm
	40	171.86	70.48	10.74	33.52	30.8	550	8.40	18cm
	45	171.86	70.48	10.67	33.74	30.7	540	8.49	18cm
	50	171.86	70.48	10.59	33.99	30.9	540	8.39	18cm
	60	171.86	70.48	10.62	33.90	31.2	540	8.41	18cm
	75	171.90	70.52	10.90	33.03	30.2	530	8.42	18cm
	90	172.22	70.84	10.75	33.49	31.3	550	8.41	18cm
	105	172.60	71.22	10.88	33.09	31.1	540	8.30	18cm
	120	172.78	71.40	10.65	33.80	31.2	540	8.31	18cm
	150	173.40	72.02	10.76	33.46	30.9	530	8.30	18cm
	180	173.97	72.59	10.80	33.33	31.4	540	8.42	18cm
	210	174.84	73.46	10.86	33.15	31.5	550	8.41	18cm
	240	174.90	73.52	10.81	33.30	30.4	550	8.44	18cm
	270	175.34	73.96	10.74	33.52	32.0	560	8.43	18cm
	300	175.65	74.27	10.88	33.09	31.1	540	8.41	18cm
	330	175.78	74.40	10.90	33.03	30.5	540	8.40	18cm
	360	176.07	74.69	10.84	33.21	27.4	550	8.55	18cm
	390	176.36	74.98	10.87	33.12	27.6	530	8.51	18cm
	420	176.68	75.30	10.65	33.80	27.8	530	8.54	18cm
	450	176.90	75.52	10.75	33.49	27.0	550	8.57	18cm
	480	177.28	75.90	10.89	33.06	27.4	540	8.56	18cm
	540	177.84	76.46	10.74	33.52	27.2	550	8.54	18cm

	600	178.40	77.02	10.67	33.74	27.2	520	8.41	18cm
	660	178.83	77.45	10.89	33.06	27.6	540	8.64	18cm
	720	179.28	77.90	10.75	33.49	27.3	550	8.61	18cm
	780	179.48	78.10	10.67	33.74	27.6	540	8.63	18cm
	840	179.95	78.57	10.80	33.33	27.6	530	8.65	18cm

Table 24-11 Calibration Test Data – BH10221 (Second Test)

Official BH No.:	10221	District:	Ghanzi
Date of test commencement:	29.1.06	Location:	Metsimatsho
Time of test commencement		BH depth (m):	327
Date of test completion:	29.1.06	Screen Interval (m):	276.00 to 299.20
Time of test completion		Depth of pump intake (m):	170m
Method of water level measurement:	dipper	Static water level before test (m):	98.96
Casing diameter (mm)	8"	Water strike	277
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

STEP No. 1

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	101.10	2.14			
0.5	103.45	4.49			
1	106.72	7.76			
1.5	108.57	9.61			
2	109.55	10.59			
2.5	109.92	10.96			
3	109.93	10.97			
4	109.93	10.97			
5	109.93	10.97	18.53	9.71	
6	110.02	11.06	18.54	9.71	
7	110.11	11.15	18.44	9.76	
8	110.21	11.25	18.57	9.69	
9	110.28	11.32	18.55	9.70	
10	110.38	11.42	18.44	9.76	
11	110.43	11.47	18.49	9.73	
12	110.50	11.54	18.53	9.71	
15	110.64	11.68	18.60	9.68	

STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	110.81	11.85			
0.5	111.47	12.51			
1	113.93	14.97	11.16	16.13	
1.5	115.47	16.51			
2	116.83	17.87	11.64	15.46	
2.5	117.73	18.77			
3	118.37	19.41	11.77	15.29	
4	119.14	20.18	11.80	15.25	
5	119.64	20.68	11.81	15.24	
6	119.92	20.96	11.86	15.18	
7	120.09	21.13	11.90	15.13	
8	120.24	21.28	12.00	15.00	
9	120.33	21.37	11.88	15.15	
10	120.44	21.48	11.93	15.09	
11	120.48	21.52	11.87	15.16	
12	120.53	21.57	11.90	15.13	
15	120.62	21.66	11.81	15.24	

STEP No. 3

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	Pumping Rate (m^3/hr)	Comments
0.25	120.84	21.88			
0.5	121.29	22.33			
1	123.25	24.29	7.72	23.32	
1.5	125.02	26.06			
2	126.04	27.08	8.29	21.71	
2.5	126.91	27.95			
3	127.27	28.31	8.94	20.13	
4	127.77	28.81	8.97	20.07	
5	128.04	29.08	8.89	20.25	
6	128.15	29.19	8.90	20.22	
7	128.16	29.20	8.88	20.27	
8	128.24	29.28	8.98	20.04	
9	128.35	29.39	8.96	20.09	
10	128.47	29.51	8.93	20.16	
11	128.53	29.57	8.95	20.11	

STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments
0.25	129.22	30.26			
0.5	130.59	31.63			
1	132.94	33.98	12.47	28.87	
1.5	134.64	35.68			
2	135.63	36.67	12.85	28.02	
2.5	136.65	37.69			
3	137.76	38.80	12.00	30.00	
4	139.09	40.13	11.94	30.15	
5	139.74	40.78	11.78	30.56	
6	140.11	41.15	11.97	30.08	
7	140.33	41.37	11.92	30.20	
8	140.38	41.42	11.98	30.05	
9	140.40	41.44	11.84	30.41	
10	140.45	41.49	11.89	30.28	
11	140.48	41.52	11.94	30.15	

12	128.55	29.59	8.90	20.22		12	140.52	41.56	11.98	30.05	
15	128.63	29.67	8.97	20.07		15	140.67	41.71	11.96	30.10	

Table 24-12 Step Drawdown Test – BH10221 (Test 2)

Official BH No.:	10221	District:	Ghanzi
Date of test commencement:	30.01.06	Location:	Metsimantsho
Time of test Commencement:		BH depth (m):	327
Date of test completion:	30.01.06	Screens(m)	276.00 to 299.20
Time of test Completion:		Depth to pump intake (m)	170m
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.4
Distance to OB. BH (m)	n/a	Static water level before test (m):	99.45
Casing diameter (mm)	203.2	Water strike	277
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

STEP No. 1 | STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments
0.25	102.33	2.88				0.25	113.24	13.79			
0.5	105.05	5.60				0.5	113.95	14.50			
1	107.15	7.70				1	115.67	16.22	11.28	15.96	
1.5	109.01	9.56				1.5	117.09	17.64			
2	109.72	10.27				2	118.07	18.62	12.00	15.00	
2.5	109.88	10.43				2.5	118.72	19.27			
3	109.88	10.43				3	119.18	19.73	11.81	15.24	
4	109.90	10.45	19.34	9.31		4	119.77	20.32	11.90	15.13	
5	110.02	10.57	19.21	9.37		5	120.09	20.64	11.94	15.08	
6	110.13	10.68	18.24	9.87		6	120.32	20.87	11.87	15.16	
7	110.42	10.97	17.78	10.12		7	120.45	21.00	11.89	15.14	
8	110.76	11.31	17.82	10.10		8	120.54	21.09	11.96	15.05	
9	110.96	11.51	17.90	10.06		9	120.66	21.21	11.95	15.06	
10	111.12	11.67	17.86	10.08		10	120.73	21.28	11.87	15.16	
11	111.20	11.75	17.89	10.06		11	120.76	21.31	11.84	15.20	
12	111.31	11.86	17.91	10.05		12	120.83	21.38	11.94	15.08	
13	111.37	11.92	17.87	10.07		13	120.88	21.43	11.90	15.13	
14	111.45	12.00	17.95	10.03		14	120.89	21.44	11.93	15.09	
15	111.52	12.07	17.90	10.06		15	120.91	21.46	11.88	15.15	
20	111.78	12.33	17.85	10.08		20	121.09	21.64	11.81	15.24	
25	112.02	12.57	17.88	10.07		25	121.21	21.76	11.83	15.22	
30	112.12	12.67	17.98	10.01		30	121.32	21.87	11.96	15.05	
35	112.27	12.82	17.94	10.03		35	121.44	21.99	11.91	15.11	
40	112.37	12.92	17.89	10.06		40	121.52	22.07	11.85	15.19	
45	112.45	13.00	17.95	10.03		45	121.62	22.17	11.99	15.01	
50	112.51	13.06	17.87	10.07		50	121.68	22.23	11.87	15.16	
55	112.58	13.13	17.90	10.06		55	121.78	22.33	11.84	15.20	
60	112.66	13.21	17.92	10.04		60	121.85	22.40	11.88	15.15	
70	112.77	13.32	17.84	10.09		70	121.99	22.54	11.98	15.03	
80	112.91	13.46	17.87	10.07		80	122.09	22.64	11.81	15.24	
90	112.98	13.53	17.89	10.06		90	122.21	22.76	11.96	15.05	
100	113.06	13.61	17.95	10.03		100	122.35	22.90	11.87	15.16	

Official BH No.:	10221	District:	Ghanzi
Date of test commencement:	30.01.06	Location:	Metsimantsho
Time of test Commencement:		BH depth (m):	327
Date of test completion:	30.01.06	Screens(m)	276.00 to 299.20
Time of test Completion:		Depth to pump intake (m)	170m
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.4
Distance to OB. BH (m)	n/a	Static water level before test (m):	99.45
Casing diameter (mm)	203.2	Water strike	277
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

STEP No. 3						STEP No. 4					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	122.42	22.97				0.25	132.48	33.03			
0.5	122.51	23.06				0.5	133.27	33.82			
1	122.69	23.24	9.00	20.00		1	134.02	34.57	14.78	24.36	
1.5	124.65	25.20				1.5	134.61	35.16			
2	126.32	26.87	8.75	20.57		2	135.08	35.63	14.29	25.19	
2.5	127.36	27.91				2.5	135.95	36.50			
3	128.19	28.74	8.60	20.93		3	136.33	36.88	14.39	25.02	
4	129.04	29.59	8.78	20.50		4	136.92	37.47	14.40	25.00	
5	129.55	30.10	8.94	20.13		5	137.27	37.82	14.37	25.05	
6	129.81	30.36	8.88	20.27		6	137.45	38.00	14.26	25.25	
7	130.01	30.56	8.99	20.02		7	137.60	38.15	14.35	25.09	
8	130.15	30.70	8.96	20.09		8	137.68	38.23	14.38	25.03	
9	130.30	30.85	8.93	20.16		9	137.74	38.29	14.35	25.09	
10	130.44	30.99	8.94	20.13		10	137.79	38.34	14.34	25.10	
11	130.50	31.05	8.97	20.07		11	137.83	38.38	14.30	25.17	
12	130.56	31.11	8.92	20.18		12	137.83	38.38	14.36	25.07	
13	130.60	31.15	8.97	20.07		13	137.93	38.48	14.37	25.05	
14	130.62	31.17	8.99	20.02		14	137.96	38.51	14.29	25.19	
15	130.64	31.19	8.98	20.04		15	138.00	38.55	14.34	25.10	
20	130.74	31.29	8.99	20.02		20	138.15	38.70	14.39	25.02	
25	130.93	31.48	8.88	20.27		25	138.28	38.83	14.31	25.16	
30	131.06	31.61	8.98	20.04		30	138.38	38.93	14.35	25.09	
35	131.13	31.68	8.92	20.18		35	138.51	39.06	14.29	25.19	
40	131.20	31.75	8.99	20.02		40	138.61	39.16	14.37	25.05	
45	131.40	31.95	8.94	20.13		45	138.68	39.23	14.40	25.00	
50	131.44	31.99	8.97	20.07		50	138.78	39.33	14.38	25.03	
55	131.46	32.01	8.99	20.02		55	138.84	39.39	14.35	25.09	
60	131.55	32.10	8.96	20.09		60	138.86	39.41	14.36	25.07	
70	131.69	32.24	8.99	20.02		70	138.99	39.54	14.37	25.05	
80	131.87	32.42	8.94	20.13		80	139.07	39.62	14.30	25.17	
90	131.97	32.52	8.88	20.27		90	139.19	39.74	14.38	25.03	
100	132.03	32.58	9.00	20.00		100	139.31	39.86	14.29	25.19	

Official BH No.:	10221	District:	Ghanzi
Date of test commencement:	30.01.06	Location:	Metsimantsho
Time of test Commencement:		BH depth (m):	327
Date of test completion:	30.01.06	Screens(m)	276.00 to 299.20
Time of test Completion:		Depth to pump intake (m)	170m
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.4
Distance to OB. BH (m)	n/a	Static water level before test (m):	99.45
Casing diameter (mm)	203.2	Water strike	277
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

STEP No. 5 | STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P. Rate (m^3/hr)	Comments
0.25	139.77	40.32				0.25	147.85	48.40			
0.5	141.05	41.60				0.5	149.87	50.42			
1	141.63	42.18	11.88	30.30		1	153.50	54.05	13.45	40.15	
1.5	142.62	43.17				1.5	156.21	56.76			
2	143.50	44.05	11.94	30.15		2	158.01	58.56	13.49	40.03	
2.5	144.03	44.58				2.5	159.80	60.35			
3	144.42	44.97	12.00	30.00		3	160.22	60.77	13.50	40.00	
4	144.84	45.39	11.95	30.13		4	161.28	61.83	13.46	40.12	
5	145.05	45.60	11.85	30.38		5	161.83	62.38	13.50	40.00	
6	145.22	45.77	11.97	30.08		6	162.15	62.70	13.34	40.48	
7	145.33	45.88	11.89	30.28		7	162.52	63.07	13.48	40.06	
8	145.47	46.02	11.92	30.20		8	162.60	63.15	13.47	40.09	
9	145.52	46.07	11.99	30.03		9	162.75	63.30	13.34	40.48	
10	145.56	46.11	11.95	30.13		10	162.94	63.49	13.45	40.15	
11	145.62	46.17	11.94	30.15		11	163.04	63.59	13.48	40.06	
12	145.70	46.25	11.89	30.28		12	163.17	63.72	13.49	40.03	
13	145.75	46.30	11.87	30.33		13	163.21	63.76	13.50	40.00	
14	145.78	46.33	11.90	30.25		14	163.23	63.78	13.48	40.06	
15	145.81	46.36	11.98	30.05		15	163.36	63.91	13.50	40.00	
20	145.92	46.47	11.99	30.03		20	163.56	64.11	13.48	40.06	
25	146.10	46.65	11.95	30.13		25	163.82	64.37	13.49	40.03	
30	146.18	46.73	11.89	30.28		30	164.00	64.55	13.46	40.12	
35	146.40	46.95	11.92	30.20		35	164.29	64.84	13.50	40.00	
40	146.55	47.10	11.85	30.38		40	164.51	65.06	13.48	40.06	
45	146.63	47.18	11.87	30.33		45	164.79	65.34	13.44	40.18	
50	146.74	47.29	11.97	30.08		50	suction				
55	146.86	47.41	11.94	30.15		55					
60	146.92	47.47	11.83	30.43		60					
70	147.05	47.60	11.87	30.33		70					
80	147.19	47.74	11.95	30.13		80					
90	147.31	47.86	11.99	30.03		90					
100	147.42	47.97	11.88	30.30		100					

Table 24-13 Constant Rate Test Data – BH10221

Official BH NO :	10221	District :	Ghanzi
Date of test commencement :	31.01.06	Location :	Metsimantsho
Time of test commencement :		BH depth(m) :	327
Date of test completion	3.2.06	Screen Interval (m)	276.00 to 299.20
Time of test completion :		Depth of pump intake (m) :	170m
Method of water level measurement	electrical dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.4
Distance ob BH r (m)	n/a	Static Water level before test(m) :	101.72
Casing diameter (mm)	203.2	Water strike	277
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 200l	$Q(m^3/h)$	Temp (^0C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO
	0.25	108.73	7.01						
	0.5	115.25	13.53						
	1	120.08	18.36						
	2	126.48	24.76		30.00				
	3	130.31	28.59		30.00				
	4	133.18	31.46		30.00				
	5	134.02	32.30		30.00				
	6	134.02	32.30		30.00				
	7	134.20	32.48		30.00				
	8	134.52	32.80		30.00				
	9	135.62	33.90		30.00				
	10	136.09	34.37		30.00				
	11	136.51	34.79		30.00				
	12	136.76	35.04		30.00				
	15	137.36	35.64		30.00				
	20	137.94	36.22		30.00				
	25	138.40	36.68		30.00				
	30	138.74	37.02		30.00				
	40	139.35	37.63		30.00				
	45	139.61	37.89		30.00				
	50	139.88	38.16		30.00				
	60	140.32	38.60		30.00				
	75	140.76	39.04		30.00				
	90	141.12	39.40		30.00				
	105	141.47	39.75		30.00				
	120	141.84	40.12		30.00				
	150	142.38	40.66		30.00				
	180	142.93	41.21		30.00				
	210	143.26	41.54		30.00				
	240	143.62	41.90		30.00				
	270	143.93	42.21		30.00				
	300	144.18	42.46		30.00				
	330	144.44	42.72		30.00				
	360	144.87	43.15		30.00				
	390	145.12	43.40		30.00				
	420	145.29	43.57		30.00				
	450	145.45	43.73		30.00				
	480	145.63	43.91		30.00				
	540	146.08	44.36		30.00				
	600	146.57	44.85		30.00				
	660	147.03	45.31		30.00				
	720	147.33	45.61		30.00				
	780	147.41	45.69		30.00				
	840	147.78	46.06		30.00				
	900	148.03	46.31		30.00				
	960	148.35	46.63		30.00				
	1020	148.64	46.92		30.00				
	1080	148.92	47.20		30.00				
	1140	149.24	47.52		30.00				
	1200	149.55	47.83		30.00				
	1260	149.79	48.07		30.00				
	1320	149.92	48.20		30.00				
	1380	150.27	48.55		30.00				

	1440	150.55	48.83		30.00				
	1500	150.81	49.09		30.00				
	1560	151.01	49.29		30.00				
	1620	151.17	49.45		30.00				
	1680	151.32	49.60		30.00				
	1740	151.64	49.92		30.00				
	1800	151.73	50.01		30.00				
	1860	151.93	50.21		30.00				
	1920	152.25	50.53		30.00				
	1980	152.47	50.75		30.00				
	2040	152.62	50.90		30.00				
	2100	152.86	51.14		30.00				
	2160	152.96	51.24		30.00				
	2220	153.20	51.48		30.00				
	2280	153.47	51.75		30.00				
	2340	153.68	51.96		30.00				
	2400	153.99	52.27		30.00				
	2460	154.09	52.37		30.00				
	2520	154.21	52.49		30.00				
	2580	154.34	52.62		30.00				
	2640	154.73	53.01		30.00				
	2700	154.82	53.10		30.00				
	2760	154.90	53.18		30.00				
	2820	156.21	54.49		30.00				
	2880	156.49	54.77		30.00				
	2940	156.67	54.95		30.00				
	3000	156.85	55.13		30.00				
	3060	156.97	55.25		30.00				
	3120	157.13	55.41		30.00				
	3180	157.24	55.52		30.00				
	3240	157.39	55.67		30.00				
	3300	157.65	55.93		30.00				
	3360	157.77	56.05		30.00				
	3420	157.90	56.18		30.00				
	3480	158.31	56.59		30.00				
	3540	158.39	56.67		30.00				
	3600	158.54	56.82		30.00				
	3660	158.71	56.99		30.00				
	3720	158.81	57.09		30.00				
	3780	158.90	57.18		30.00				
	3840	159.04	57.32		30.00				
	3900	159.15	57.43		30.00				
	3960	159.35	57.63		30.00				
	4020	159.56	57.84		30.00				
	4080	159.71	57.99		30.00				
	4140	159.89	58.17		30.00				
	4200	159.91	58.19		30.00				
	4260	160.08	58.36		30.00				
	4320	160.21	58.49		30.00				

Table 24-14 Recovery Test Data – BH10221

Official BH NO :	10221	District :	Ghanzi
Date of test commencement :	3.2.06	Location :	Metsimantsho
Time of test commencement :		BH depth(m) :	327
Date of test completion	3.2.06	Screen Int (m)	276.00 to 299.20
Time of test completion :		Depth of pump intake (m) :	170m
Method of water level measurement:	electrical dipper	Description of MP	top of dipper tubing
OB. BH. No.:	n/a	Height of MP above ground(m) :	0.4
Dist.to Pumping Bh:	n/a	Static Water level before test(m) :	101.72
Casing diameter (mm)	203	Water strike	277
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	465934	Northing	7427570

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	160.21	58.49
	0.25	149.19	47.47
	0.5	146.54	44.82
	1	143.54	41.82
	2	132.36	30.64
	3	127.51	25.79
	4	125.08	23.36
	5	123.97	22.25
	6	123.73	22.01
	7	123.73	22.01
	8	123.73	22.01
	9	123.73	22.01
	10	123.73	22.01
	12	123.73	22.01
	15	123.73	22.01
	20	123.49	21.77
	25	123.29	21.57
	30	122.94	21.22
	40	122.59	20.87
	50	122.13	20.41
	60	121.92	20.20
	75	121.45	19.73
	90	120.96	19.24
	105	120.65	18.93
	120	120.37	18.65

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	119.89	18.17
	180	119.43	17.71
	210	119.02	17.30
	240	118.68	16.96
	270	118.43	16.71
	300	118.17	16.45
	330	117.92	16.20
	360	117.71	15.99
	390	117.47	15.75
	420	117.29	15.57
	450	117.10	15.38
	480	116.93	15.21
	540	116.60	14.88
	600	116.31	14.59
	660	116.02	14.30
	720	115.75	14.03
	780	115.46	13.74
	840	115.27	13.55
	900	115.01	13.29
	960	114.85	13.13
	1020	114.56	12.84
	1080	114.31	12.59
	1140	114.20	12.48
	1200	114.04	12.32
	1260	113.86	12.14
	1320	113.70	11.98
	1380	113.52	11.80
	1440	113.34	11.62

25 BH10222

BH10222 has a siting reference of **S10,** TEM111, Line **R7** and Peg 7000m and is an exploration borehole drilled to explore relatively undisturbed Ecca aquifer possibly underlain by saline water saturated aquifers. It is located about 60 km east of Ncojane near Metsimantsho. Drilling at this site commenced on 2 August 2005 and was completed on 29 August 2005. The drilled depth of this borehole is 290m.

25.1 SITING CRITERIA AND DRILLING OBJECTIVES

This borehole was drilled to explore the undisturbed Ecca aquifer possibly underlain by saline waters. In addition to giving the aquifer transmissivity, it will also allow for monitoring the head of the Ecca aquifer at this location.

25.2 DRILLING RESULTS

This borehole was drilled through various lithologies including fine grained sand, shales and fine, grained sandstones (**Figure 25-1**). Drilling was started using a 17 inch drilling bit to a depth of 9 m after which a 15 inch surface casing was installed. Drilling was then continued from 9 to 140 m using a 15 inch drilling bit. Blank 12 inch casings were then installed and cement grouted to 140 m. From 140 m to the terminal depth of 290 m drilling was carried out with a 12 inch drilling bit. All the drilling was carried out using the DTH drilling technique.

During drilling of this borehole, three water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows;

1. (150m, 2900 µS/cm, 7 m^3/hr)
2. (188m, 4100 µS/cm, 20 m^3/hr)
3. (289m, 1330 µS/cm, 19 m^3/hr)

After the water strike at 290m, drilling could not be continued beyond 290 m because of back pressure problems.

After completion of drilling, the borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, calliper, neutron and temperature probes (**Figure 25-2).**

The borehole was constructed using a 6.5 inch plain casings and 6 inch louvered screens. Plain casings were installed between 0 to 274.6 m and 286 m to 289 m and the screens were between 274.6 m and 286 m. After construction and development, the final airlift yield was 12 m^3/hr whilst the electrical conductivity was 1670 µS/cm and the water level was 102.72 m. Water samples were collected at the three water strikes and were submitted to the DWA laboratory for chemical analysis. The results are shown in **Table 25-1.**

Table 25-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10222	150	7.87	2124	19.73	25.01	832.4	50.6	769.16	246.68	41.75	0	0	566.14	0.00	0.07	Kule SST
10222	188	8.23	3376	19.52	42.33	1221.5	145.8	1301.75	433.17	25.59	0	0	731.14	0.00	0.07	SST1
10222	289	8.21	854	3.32	3.59	319.7	49.3	101.71	38.67	0	2.65	0	655.22	0.00	0.06	SST 2
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

Verticality and alignment tests were carried out and the borehole was finally capped and a cement slab was constructed.

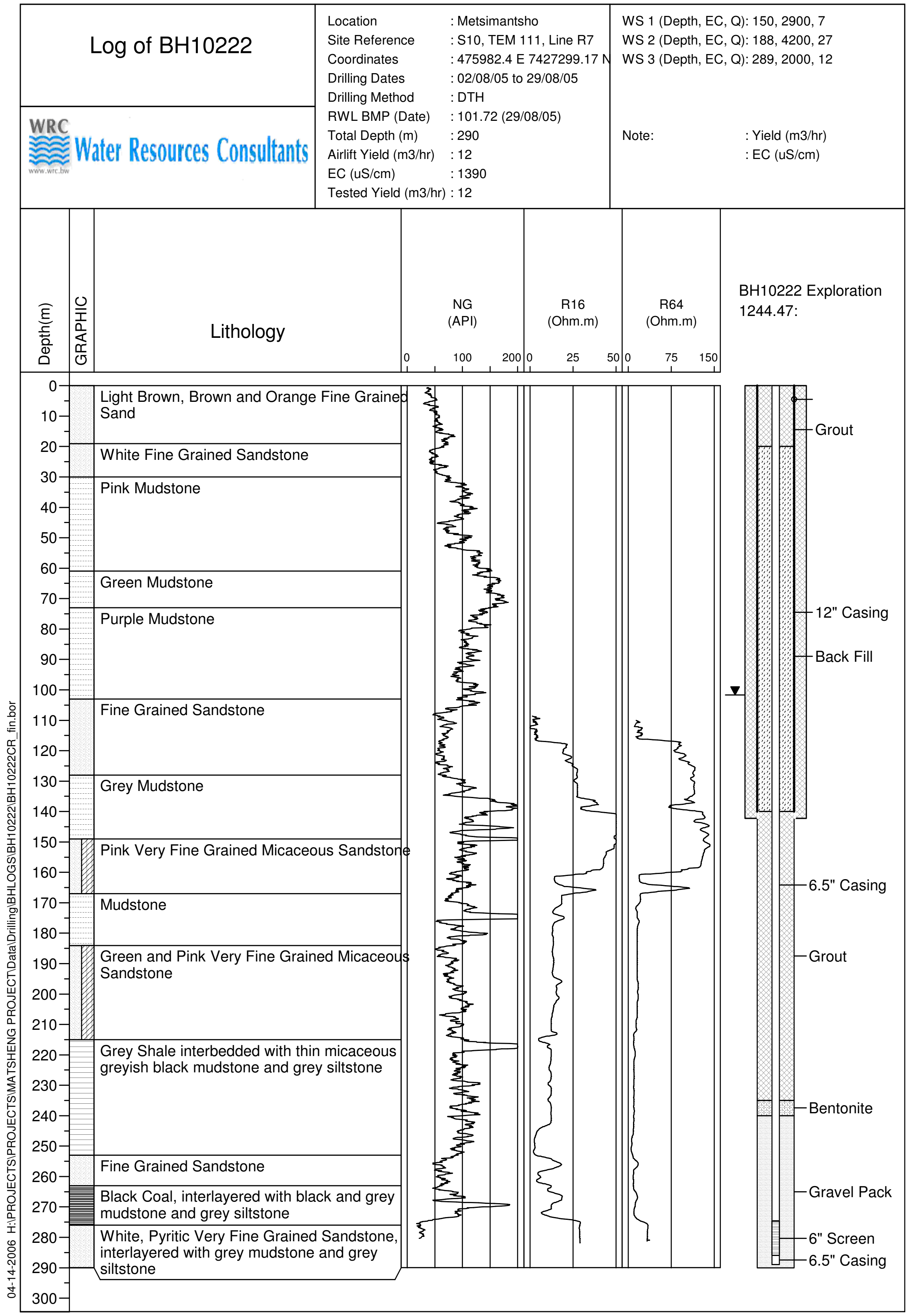

Figure 25-1 Log of BH10222

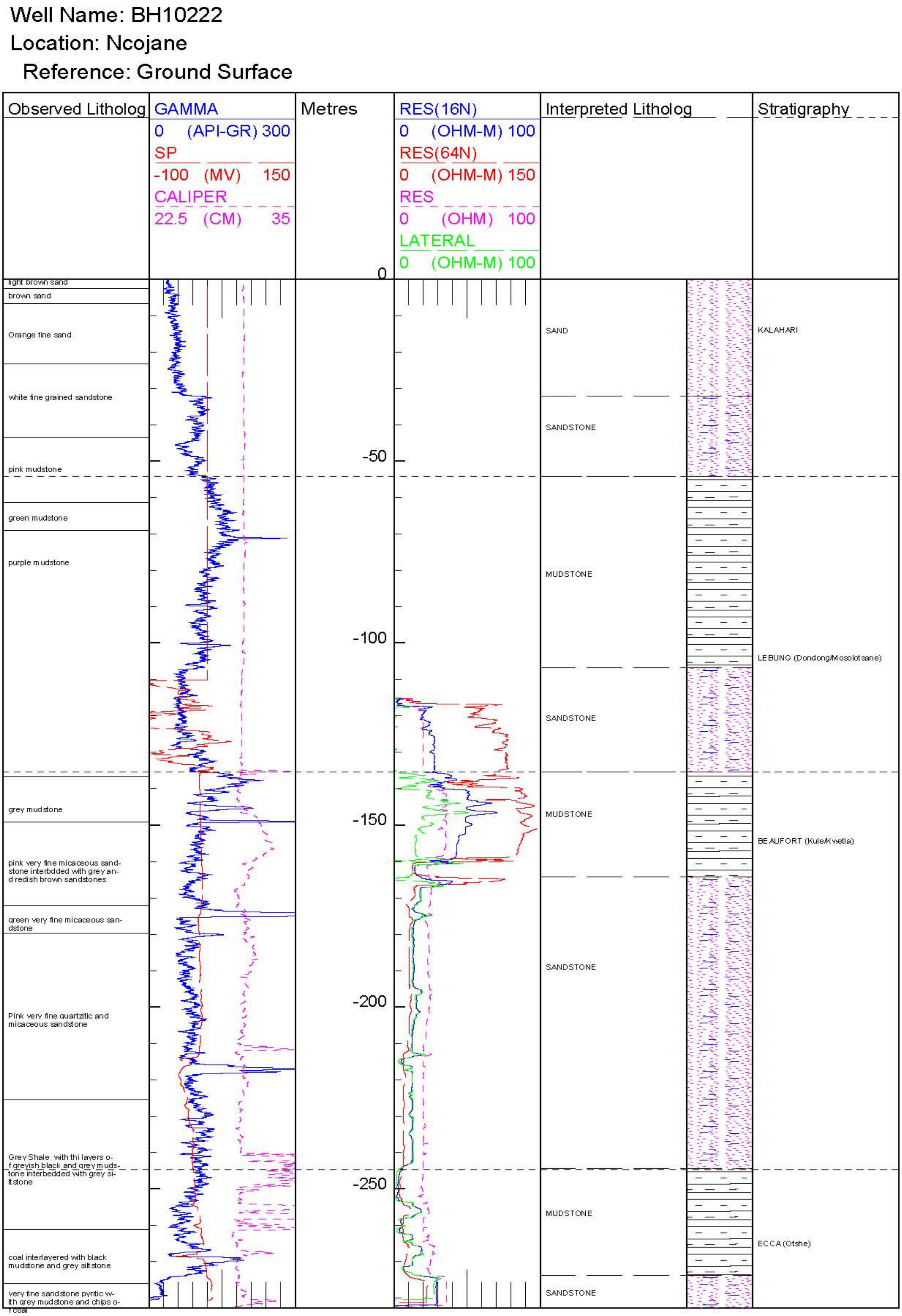

Figure 25-2 Geophysical log of BH10222

25.3 PUMP TESTING RESULTS

BH10222 was tested between 23 and 29 November 2005 and the tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.44 m above ground level (agl) and the pump intake was set at 168.5 m below ground level. Summary details for the pumping test activities at BH10222 are given in **Table 25-2**. The collected pump testing data is presented in **Tables 25-6 to 25-9.**

Table 25-2 Summary of Pumping Test Data BH10222

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	6.85	3.7
	2	15	11.16	6.3
	3	15	30.75	12.9
	4	15	62.77	20.3
	5	3	66.73	25
Step Test	1	100	11.55	4
	2	100	15.63	7
	3	100	25.5	10
	4	100	47.29	13
	5	100	62	16
	6	1.5	65.8	18.3
Constant Rate	1	4320	57.28	12.3
Recovery*	1	1440	2.42*	0

Note.2.42* Residual Drawdown

25.3.1 Step Drawdown Test

The step drawdown test (SDT) was carried out on 24 November 2005. The static water level before the start of the test was 99.3 m bmp. The step drawdown test consisted of 5 steps of 100 minutes duration. The discharge rates were 4, 7, 10, 13 and 16m^3/hr for steps 1 to 5 respectively. A sixth step at 18.3m^3/hr lasted for 1.5 minutes only and the total drawdown was 65.8 m.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method **(Figure 25-3).** This method is suitable for confined, leaky, and unconfined aquifers pumped step-wise at increasing rates. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q. The coefficient B was determined from the intercept and the coefficient C was obtained from the slope of the arithmetic plot of s_w/Q versus Q **(Figure 25-4).**

The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 3.8m^2/d **(Figure 25-5).** The results are tabulated in **Table 25-3**.

Table 25-3 Results of Step Test Analysis BH10222

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10222	8.73E-02	1.10E-04	3.8	4.0	11.30	11.30	0.4
				7.0	2.96	14.26	0.5
				10.0	9.24	23.50	0.4
				13.0	17.90	41.40	0.3
				16.0	9.94	51.34	0.3

25.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 25 and 28 November 2005 at a discharge rate of 12.3 m^3/hr and the total drawdown after 72 hrs of pumping was 57.28 m. The CRT test was followed by a 24 hr recovery monitoring period at the end of which the residual drawdown was 2.42 m. Data from the pumping period was interpreted through the Cooper-Jacob (1946) analytical solution using the computer programme "Aqtesolv" and the transmissivity (T) value obtained was 6.5 m^2/d. The recovery data was analysed using the Theis recovery solution and the T value computed was 6.8 m^2/d. The interpretation results are summarised in **Table 25-4** and the interpreted data is presented in **Figures 25-6** and **25-7**.

Table 25-4 Summary of Constant Rate and Recovery Tests BH10222

BH No.	CRT Duration (hours)	Q (m^3/d)	Pumping borehole T (m^2/d)		Obs. BH No.	Observation borehole Pumping phase		Observation borehole Recovery phase	Aquifer type
			Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
10222	72	295.2	a) 6.5	b) 6.8	NA				Confined

Notes:
Interpretation Techniques
a) Cooper-Jacob *b) Theis Modified Recovery*

25.3.2.1 Aquifer Type interpreted

The aquifer type determined from the pump testing interpretation is confined.

25.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis most of the BOS 32:2000 listed determinants. The results are presented in **Table 25-5**

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC) and pH are 27.9 °C, 1430 µS/cm and 8.51 respectively.

Table 25-5 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10222	5	317	2.8	2.6	44	103	550	<0.1	2.3	0.47	<0.05	1390	8.4	890
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10222	<0.1	18	0.61	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

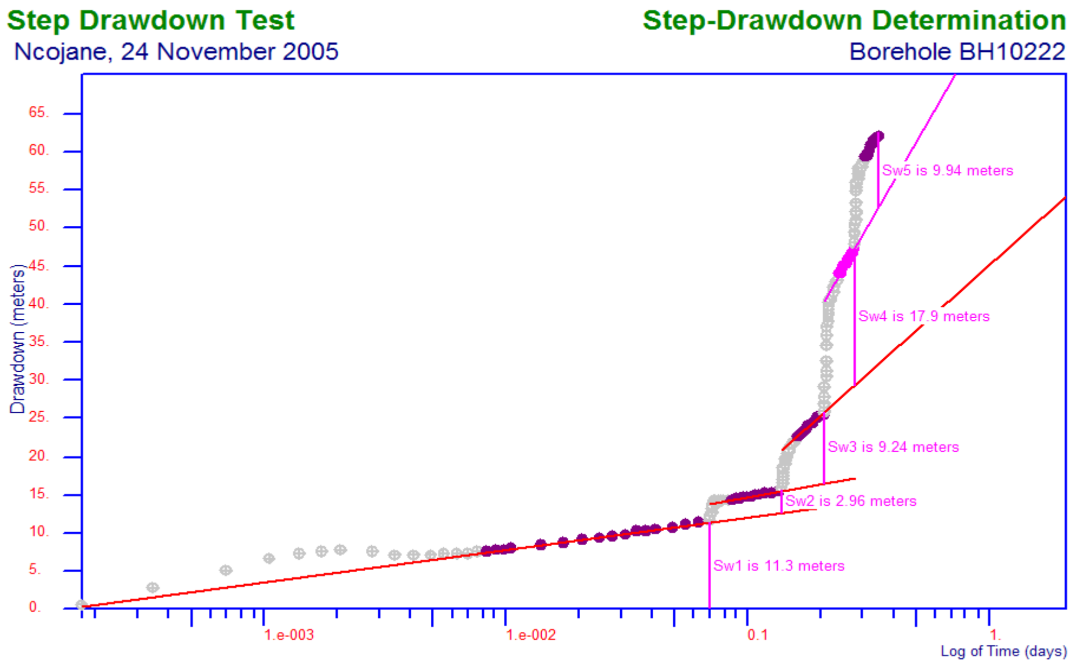

Figure 25-3 Pumping Test Results for BH10222: Step Drawdown Test – Hantush-Bierschenk (semi-log)

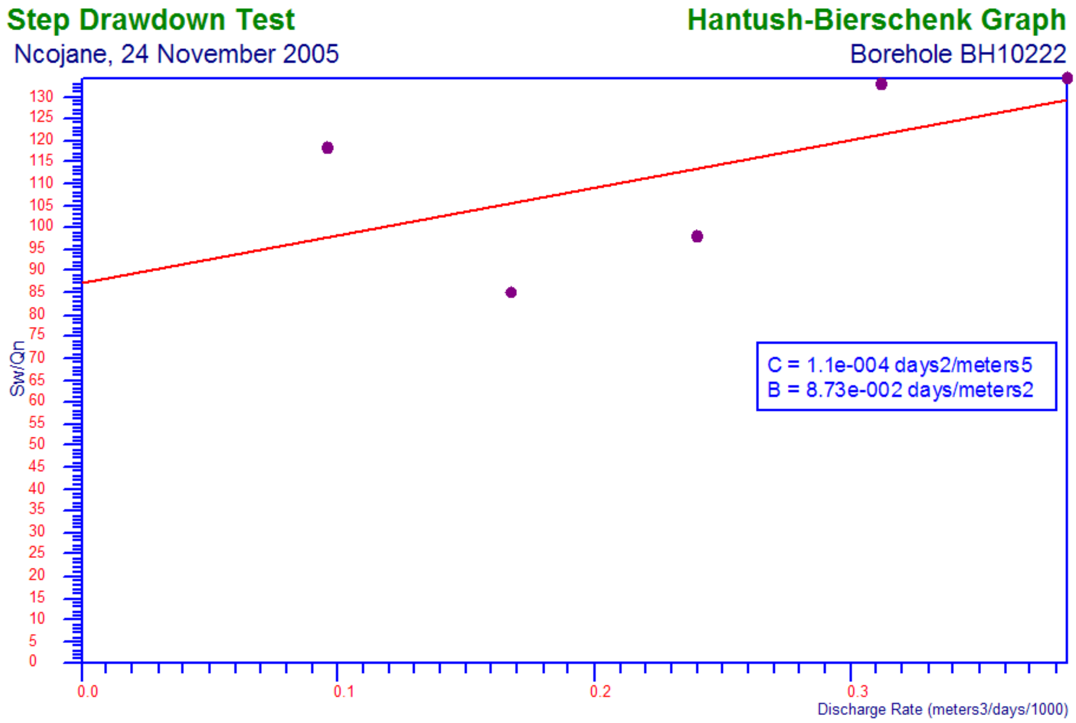

Figure 25-4 Pumping Test Results for BH10222: Step Drawdown Test – Hantush-Bierschenk

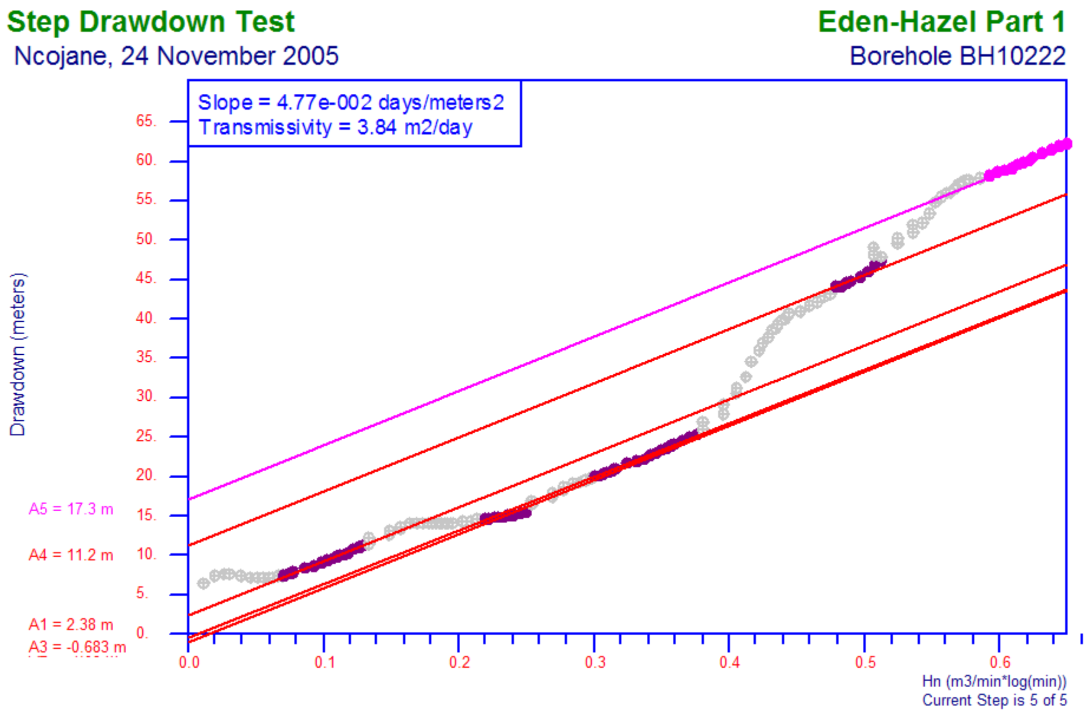

Figure 25-5 Pumping Test Results for BH10222: Step Drawdown Test – Eden-Hazel (Part 1)

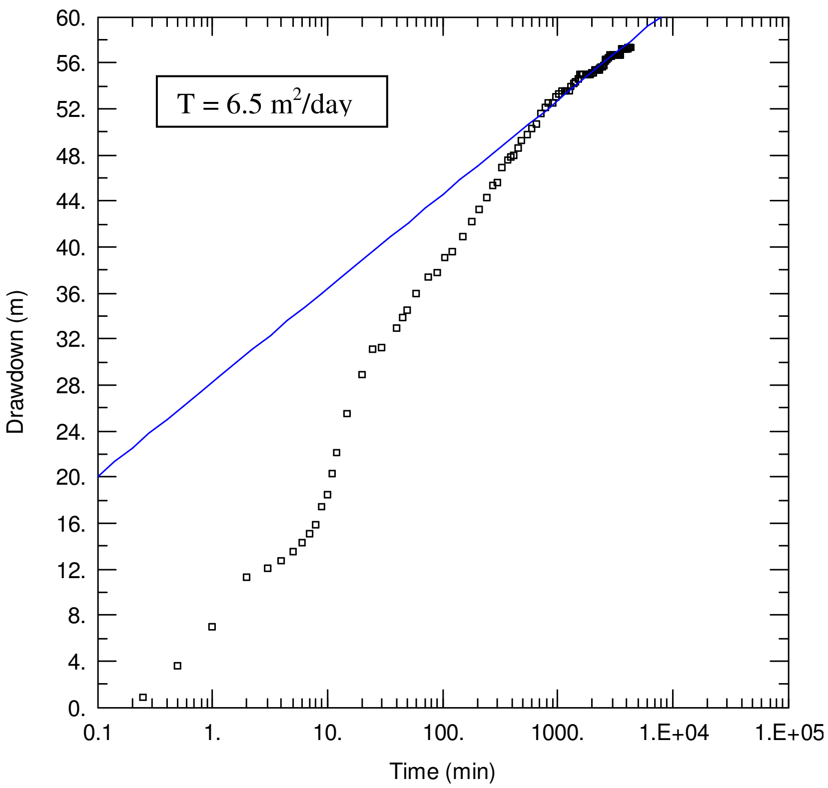

Figure 25-6 Pumping Test Results for BH10222: CRT Cooper- Jacob Solution

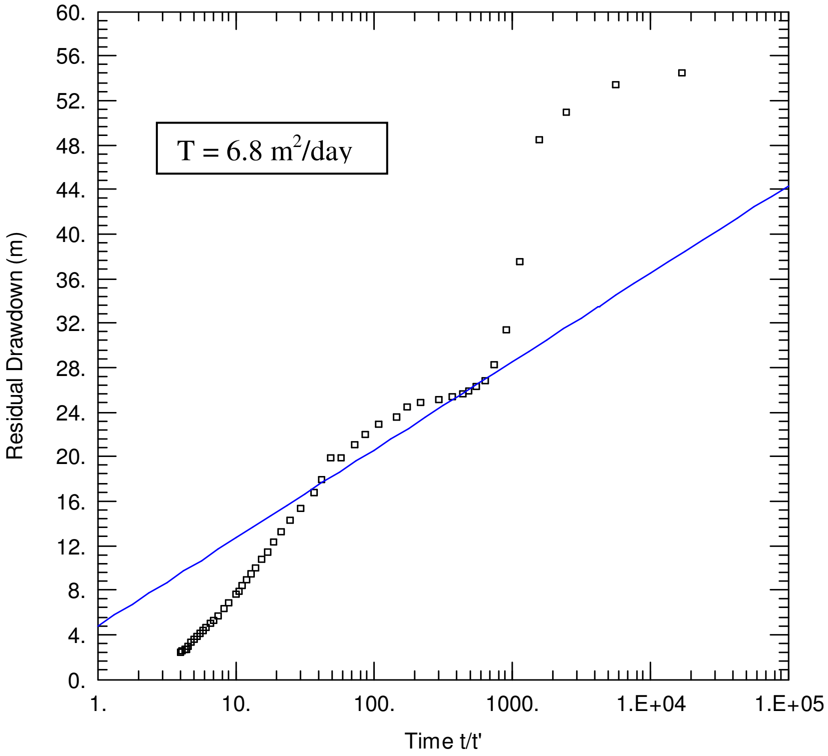

Figure 25-7 Pumping Test Results for BH10222: Theis Recovery Solution

Table 25-6 Calibration Test Dta – BH10222

Official BH No.:	10222	District:	Ghanzi
Date of test commencement:	23.11.2005	Location:	Metsimantsho
Time of test commencement	1345hrs	BH depth (m):	290
Date of test completion:	23.11.2005	Screen Interval (m):	274.6-286
Time of test completion	1448hrs	Depth of pump intake (m):	168.5
Method of water level measurement:	dipper	Static water level before test (m):	97.65
Casing diameter (mm)	165.1	Water strike	150, 188 and 289
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	475985	Northing	7427277

STEP No. 1						STEP No. 2					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 10L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 10L	P Rate (m^3/hr)	Comments
0.25	98.12	0.47				0.25	104.75	7.10			
0.5	99.52	1.87				0.5	105.17	7.52			
1	101.85	4.20				1	105.77	8.12	5.50	6.55	
1.5	103.46	5.81				1.5	106.20	8.55			
2	104.39	6.74				2	106.52	8.87	5.81	6.20	
2.5	104.84	7.19				2.5	106.76	9.11			
3	104.99	7.34				3	106.98	9.33	5.72	6.29	
4	104.99	7.34				4	107.31	9.66	5.81	6.20	
5	104.33	6.68				5	107.53	9.88	5.76	6.25	
6	104.06	6.41				6	107.82	10.17	5.79	6.22	
7	103.99	6.34	9.50	3.79		7	107.88	10.23	5.80	6.21	
8	104.00	6.35	9.90	3.64		8	108.01	10.36	5.56	6.47	
9	104.04	6.39	9.75	3.69		9	108.16	10.51	5.68	6.34	
10	104.11	6.46	9.80	3.67		10	108.28	10.63	5.84	6.16	
11	104.17	6.52	9.70	3.71		11	108.40	10.75	5.71	6.30	
12	104.24	6.59	9.82	3.67		12	108.51	10.86	5.65	6.37	
15	104.50	6.85	9.50	3.79		15	108.81	11.16	5.65	6.37	

STEP No. 3						STEP No. 4					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 20L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	Pumping Rate (m^3/hr)	Comments
0.25	109.12	11.47				0.25	129.09	31.44			
0.5	109.60	11.95				0.5	132.52	34.87			
1	110.10	12.45	7.16	10.06		1	135.25	37.60	9.35	19.25	
1.5	110.56	12.91				1.5	138.04	40.39			
2	110.93	13.28	7.47	9.64	adj	2	140.62	42.97	9.75	18.46	
2.5	111.93	14.28				2.5	142.38	44.73			
3	112.50	14.85	5.50	13.09	adj	3	144.12	46.47	8.78	20.50	
4	114.78	17.13	5.75	12.52		4	148.57	50.92	8.80	20.45	
5	117.16	19.51	5.56	12.95		5	152.03	54.38	8.64	20.83	
6	119.49	21.84	5.60	12.86		6	154.56	56.91	8.79	20.48	
7	121.26	23.61	5.54	13.00		7	156.12	58.47	8.90	20.22	
8	122.78	25.13	5.59	12.88		8	157.19	59.54	8.89	20.25	
9	124.00	26.35	5.63	12.79		9	157.81	60.16	8.86	20.32	
10	124.80	27.15	5.58	12.90		10	158.02	60.37	8.69	20.71	
11	125.01	27.36	5.71	12.61		11	158.12	60.47	8.74	20.59	
12	126.89	29.24	5.63	12.79		12	158.50	60.85	8.80	20.45	
15	128.40	30.75	5.70	12.63		15	160.42	62.77	8.80	20.45	

Official BH No.:	10222	District:	Ghanzi
Date of test commencement:	23.11.2005	Location:	Metsimantsho
Time of test commencement	1345hrs	BH depth (m):	290
Date of test completion:	23.11.2005	Screen Interval (m):	274.6-286
Time of test completion	1448hrs	Depth of pump intake (m):	168.5
Method of water level measurement:	dipper	Static water level before test (m):	97.65
Casing diameter (mm)	165.1	Water strike	150, 188 and 289
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	475985	Northing	7427277

STEP No. 5	STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 10L	P Rate (m^3/hr)	Comments
0.25	160.50	62.85				0.25					
0.5	160.57	62.92				0.5					
1	161.60	63.95	7.86	22.90		1					
1.5	162.24	64.59				1.5					
2	162.85	65.20	7.16	25.14		2					
2.5	163.21	65.56			adj	2.5					
3	164.38	66.73	7.18	25.07		3					
4						4					
5						5					
6						6					
7						7					
8						8					
9						9					
10						10					
11						11					
12						12					
15						15					

Table 25-7 Step Drawdown Test Data – BH10222

Official BH No.:	10222	District:	Ghanzi
Date of test commencement:	24.11.05	Location:	Metsimantsho
Time of test Commencement:	0600hrs	BH depth (m):	290
Date of test completion:	24.11..2005	Screens(m)	274.6 - 286
Time of test Completion:	1422hrs	Depth to pump intake (m)	168.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.55
Distance to OB. BH (m)	n/a	Static water level before test (m):	99.3
Casing diameter (mm)	165	Water strike	150, 188 and 289
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	475985	Northing	7427277

STEP No. 1 / STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 10L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 10L	P. Rate (m^3/hr)	Comments
0.25	99.87	0.57				0.25					
0.5	102.10	2.80				0.5	110.90	11.60			
1	104.35	5.05				1	111.52	12.22	5.13	7.02	
1.5	105.90	6.60				1.5	112.05	12.75			
2	106.67	7.37				2	112.42	13.12	5.25	6.86	
2.5	106.92	7.62				2.5	112.75	13.45			
3	107.05	7.75				3	112.91	13.61	5.15	6.99	
4	106.80	7.50				4	113.30	14.00	5.12	7.03	
5	106.45	7.15				5	113.45	14.15	5.20	6.92	
6	106.42	7.12	8.25	4.36		6	113.45	14.15	5.09	7.07	
7	106.44	7.14	8.13	4.43		7	113.40	14.10	5.14	7.00	
8	106.52	7.22	8.13	4.43		8	113.38	14.08	5.10	7.06	
9	106.61	7.31	8.30	4.34		9	113.38	14.08	5.13	7.02	
10	106.72	7.42	8.50	4.24		10	113.42	14.12	5.09	7.07	
11	106.84	7.54	8.61	4.18		11	113.46	14.16	5.22	6.90	
12	106.88	7.58	8.40	4.29		12	113.48	14.18	5.18	6.95	
13	106.99	7.69	8.64	4.17		13	113.51	14.21	5.15	6.99	
14	107.10	7.80	8.69	4.14		14	113.52	14.22	5.11	7.05	
15	107.23	7.93	8.71	4.13		15	113.52	14.22	5.12	7.03	
20	107.65	8.35	8.73	4.12		20	113.64	14.34	5.15	6.99	
25	108.05	8.75	8.65	4.16		25	113.70	14.40	5.16	6.98	
30	108.35	9.05	8.31	4.33		30	113.78	14.48	5.08	7.09	
35	108.63	9.33	8.47	4.25		35	113.89	14.59	5.10	7.06	

40	108.84	9.54	8.53	4.22		40	113.99	14.69	5.12	7.03	
45	109.09	9.79	8.64	4.17		45	114.07	14.77	5.20	6.92	
50	109.50	10.20	8.49	4.24		50	114.13	14.83	5.10	7.06	
55	109.54	10.24	8.35	4.31		55	114.25	14.95	5.13	7.02	
60	109.70	10.40	8.46	4.26		60	114.28	14.98	5.15	6.99	
70	110.10	10.80	8.39	4.29		70	114.42	15.12	5.14	7.00	
80	110.36	11.06	8.41	4.28		80	114.60	15.30	5.11	7.05	
90	110.60	11.30	8.33	4.32		90	114.77	15.47	5.09	7.07	
100	110.85	11.55	8.46	4.26		100	114.93	15.63	5.15	6.99	

Official BH No.:	10222	District:	Ghanzi
Date of test commencement:	24.11.05	Location:	Metsimantsho
Time of test Commencement:	0600hrs	BH depth (m):	290
Date of test completion:	24.11..2005	Screens(m)	274.6 - 286
Time of test Completion:	1422hrs	Depth to pump intake (m)	168.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.55
Distance to OB. BH (m)	n/a	Static water level before test (m):	99.3
Casing diameter (mm)	165	Water strike	150, 188 and 289
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	475985	Northing	7427277

STEP No. 3 | STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 20L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments
0.25	115.09	15.79				0.25	125.10	25.80			
0.5	115.52	16.22				0.5	125.45	26.15			
1	116.20	16.90	7.22	9.97		1	126.30	27.00	14.87	12.10	
1.5	116.77	17.47				1.5	127.10	27.80			
2	117.33	18.03	7.25	9.93		2	128.39	29.09	13.94	12.91	
2.5	117.72	18.42				2.5	129.70	30.40			adj
3	117.90	18.60	7.16	10.06		3	130.43	31.13	13.71	13.13	
4	118.30	19.00	7.13	10.10		4	131.90	32.60	13.84	13.01	
5	118.70	19.40	7.16	10.06		5	133.79	34.49	13.79	13.05	
6	118.87	19.57	7.19	10.01		6	135.20	35.90	13.67	13.17	
7	119.06	19.76	7.12	10.11		7	136.25	36.95	13.79	13.05	
8	119.30	20.00	7.09	10.16		8	136.99	37.69	13.82	13.02	
9	119.44	20.14	7.18	10.03		9	137.81	38.51	13.83	13.02	
10	119.63	20.33	7.20	10.00		10	138.23	38.93	13.78	13.06	
11	119.78	20.48	7.15	10.07		11	138.64	39.34	13.72	13.12	
12	119.95	20.65	7.11	10.13		12	139.05	39.75	13.80	13.04	
13	120.08	20.78	7.21	9.99		13	139.37	40.07	13.86	12.99	
14	120.28	20.98	7.20	10.00		14	139.62	40.32	13.76	13.08	
15	120.39	21.09	7.20	10.00		15	140.01	40.71	13.74	13.10	
20	120.99	21.69	7.19	10.01		20	140.31	41.01	13.71	13.13	
25	121.31	22.01	7.14	10.08		25	140.87	41.57	13.73	13.11	
30	121.64	22.34	7.15	10.07		30	141.43	42.13	13.76	13.08	
35	121.99	22.69	7.19	10.01		35	142.21	42.91	13.68	13.16	
40	122.30	23.00	7.16	10.06		40	142.37	43.07	13.84	13.01	
45	122.66	23.36	7.11	10.13		45	143.15	43.85	13.66	13.18	
50	122.85	23.55	7.09	10.16		50	143.31	44.01	13.73	13.11	
55	123.17	23.87	7.12	10.11		55	143.74	44.44	13.81	13.03	
60	123.44	24.14	7.19	10.01		60	144.12	44.82	13.65	13.19	
70	123.83	24.53	7.20	10.00		70	144.63	45.33	13.72	13.12	
80	124.29	24.99	7.18	10.03		80	145.30	46.00	13.64	13.20	
90	124.62	25.32	7.12	10.11		90	146.07	46.77	13.73	13.11	
100	124.80	25.50	7.09	10.16		100	146.59	47.29	13.66	13.18	

Official BH No.:	10222	District:	Ghanzi
Date of test commencement:	24.11.05	Location:	Metsimantsho
Time of test Commencement:	0600hrs	BH depth (m):	290
Date of test completion:	24.11..2005	Screens(m)	274.6 - 286
Time of test Completion:	1422hrs	Depth to pump intake (m)	168.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.55
Distance to OB. BH (m)	n/a	Static water level before test (m):	99.3
Casing diameter (mm)	165	Water strike	150, 188 and 289
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	475985	Northing	7427277

STEP No. 5 STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	146.82	47.52				0.25	161.99	62.69			
0.5	147.34	48.04				0.5	162.52	63.22			
1	148.44	49.14	11.63	15.48		1	164.07	64.77	19.67	18.30	
1.5	148.80	49.50				1.5	165.10	65.80			
2	149.50	50.20	11.50	15.65	adj	2					
2.5	150.34	51.04				2.5					
3	151.07	51.77	11.16	16.13		3					
4	152.34	53.04	10.99	16.38		4					
5	153.47	54.17	11.22	16.04		5					
6	154.00	54.70	11.18	16.10		6					
7	154.61	55.31	11.11	16.20		7					
8	155.07	55.77	11.14	16.16		8					
9	155.24	55.94	11.24	16.01		9					
10	155.77	56.47	11.20	16.07		10					
11	156.10	56.80	11.26	15.99		11					
12	156.46	57.16	11.25	16.00		12					
13	156.69	57.39	11.16	16.13		13					
14	156.79	57.49	11.17	16.11		14					
15	156.95	57.65	11.19	16.09		15					
20	157.06	57.76	11.16	16.13		20					
25	157.23	57.93	11.18	16.10		25					
30	157.70	58.40	11.13	16.17		30					
35	158.00	58.70	11.15	16.14		35					
40	158.29	58.99	11.17	16.11		40					
45	158.68	59.38	11.20	16.07		45					
50	158.93	59.63	11.18	16.10		50					
55	159.10	59.80	11.19	16.09		55					
60	159.59	60.29	11.24	16.01		60					
70	160.28	60.98	11.17	16.11		70					
80	160.65	61.35	11.21	16.06		80					
90	161.05	61.75	11.15	16.14		90					
100	161.30	62.00	11.15	16.14		100					

Table 25-8 Constant Rate Test Data – BH10222

Official BH NO :	10222	District :	Ghanzi
Date of test commencement :	25.11.05	Location :	Metsimantsho
Time of test commencement :	0900hrs	BH depth(m) :	290
Date of test completion	28.11.05	Screen Interval (m)	274.6 -286
Time of test completion :	0900hrs	Depth of pump intake (m) :	168.5
Method of water level measurement	dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.55
Distance ob BH r (m)	n/a	Static Water level before test(m) :	99.70
Casing diameter (mm)	165	Water strike	150, 188 and 289
Orifice plate diameter	4"	Delivery pipe diameter	102 mm
Easting	475985	Northing	7427277

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 50l	Q(m^3/h)	Temp (^{0}C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO
	0.25	100.52	0.82						
	0.5	103.25	3.55						
	1	106.72	7.02						
	2	110.92	11.22						
	3	111.81	12.11						
	4	112.46	12.76	15.50	11.61				
	5	113.15	13.45	15.87	11.34				adj
	6	113.94	14.24	15.91	11.31				
	7	114.75	15.05	15.60	11.54				
	8	115.49	15.79	14.50	12.41				
	9	117.11	17.41	14.87	12.10				
	10	118.19	18.49	14.72	12.23				
	11	119.97	20.27	14.80	12.16				
	12	121.86	22.16	14.90	12.08				
	15	125.19	25.49	14.85	12.12	28.8	1420	8.54	11
	20	128.61	28.91	14.76	12.20	28.9	1410	8.53	11
	25	130.85	31.15	14.88	12.10	28.9	1400	8.53	11
	30	130.89	31.19	14.73	12.22	28.7	1400	8.51	11
	40	132.67	32.97	14.81	12.15	29.1	1410	8.53	11
	45	133.54	33.84	14.92	12.06	29.2	1410	8.54	11
	50	134.25	34.55	14.56	12.36	29.4	1420	8.52	11
	60	135.59	35.89	14.66	12.28	29.3	1440	8.52	11
	75	137.04	37.34	14.74	12.21	29.9	1400	8.50	11
	90	137.51	37.81	14.59	12.34	30.1	1420	8.51	11
	105	138.77	39.07	14.64	12.30	29.9	1420	8.51	11
	120	139.25	39.55	14.93	12.06	30.0	1420	8.52	11
	150	140.68	40.98	14.87	12.10	29.8	1410	8.51	11
	180	141.93	42.23	14.54	12.38	30.5	1430	8.51	11
	210	142.95	43.25	14.72	12.23	30.9	1400	8.52	11
	240	143.99	44.29	14.67	12.27	31.0	1380	8.52	11
	270	145.03	45.33	14.88	12.10	31.1	1420	8.52	11
	300	145.83	46.13	14.57	12.35	29.5	1420	8.58	11
	330	146.56	46.86	14.69	12.25	28.9	1410	8.54	11
	360	147.22	47.52	14.94	12.05	28.8	1440	8.52	11
	390	147.56	47.86	14.85	12.12	29.2	1430	8.51	11
	420	147.62	47.92	14.63	12.30	29.5	1420	8.51	11
	450	148.24	48.54	14.76	12.20	29.3	1420	8.51	11
	480	148.95	49.25	14.55	12.37	29.4	1430	8.50	11
	540	149.52	49.82	14.50	12.41	28.8	1420	8.52	11
	600	149.94	50.24	14.92	12.06	28.5	1420	8.50	11
	660	150.42	50.72	14.56	12.36	27.3	1430	8.54	11
	720	151.31	51.61	14.84	12.13	27.5	1430	8.53	11
	780	151.75	52.05	14.79	12.17	27.4	1440	8.54	11
	840	152.14	52.44	14.56	12.36	27.5	1440	8.52	11
	900	152.20	52.50	14.80	12.16	27.8	1420	8.50	11
	960	152.75	53.05	14.79	12.17	28.0	1430	8.40	11
	1020	153.04	53.34	14.91	12.07	27.9	1410	8.45	11
	1080	153.20	53.50	14.67	12.27	26.9	1430	8.51	11
	1140	153.23	53.53	14.84	12.13	27.7	1430	8.52	11
	1200	153.26	53.56	14.92	12.06	27.8	1420	8.54	11
	1260	153.29	53.59	14.84	12.13	27.6	1410	8.69	11

	1320	153.67	53.97	14.56	12.36	27.4	1450	8.72	11
	1380	153.96	54.26	14.91	12.07	28.2	1440	8.81	11
	1440	154.09	54.39	14.79	12.17	29.5	1420	8.49	DO2 = 1.45 mg/l
	1500	154.24	54.54	14.67	12.27	30.0	1450	8.21	11
	1560	154.69	54.99	14.56	12.36	30.1	1440	8.10	11
	1620	154.71	55.01	14.84	12.13	30.2	1430	7.86	11
	1680	154.71	55.01	14.84	12.13	30.0	1420	7.94	11
	1740	154.71	55.01	14.90	12.08	30.1	1430	7.84	11
	1800	154.72	55.02	14.79	12.17	29.9	1420	7.79	11
	1860	154.72	55.02	14.80	12.16	30.2	1420	7.83	11
	1920	154.73	55.03	14.92	12.06	30.4	1440	7.84	11
	1980	154.80	55.10	14.67	12.27	30.1	1440	7.80	11
	2040	154.86	55.16	14.56	12.36	28.8	1430	7.81	11
	2100	155.05	55.35	14.91	12.07	27.8	1450	7.83	11
	2160	155.05	55.35	14.83	12.14	27.9	1440	7.84	11
	2220	155.05	55.35	14.74	12.21	27.7	1420	7.83	11
	2280	155.13	55.43	14.90	12.08	27.8	1430	7.84	11
	2340	155.24	55.54	14.86	12.11	27.4	1440	7.86	11
	2400	155.31	55.61	14.74	12.21	27.6	1440	7.83	11
	2460	155.39	55.69	14.63	12.30	27.7	1420	7.89	11
	2520	155.46	55.76	14.59	12.34	27.8	1420	7.84	11
	2580	155.83	56.13	14.93	12.06	27.5	1440	8.30	11
	2640	155.96	56.26	14.89	12.09	27.1	1450	8.35	11
	2700	156.01	56.31	14.91	12.07	27.2	1420	8.40	11
	2760	156.05	56.35	14.80	12.16	27.4	1440	8.68	11
	2820	156.25	56.55	14.67	12.27	27.8	1450	8.25	11
	2880	156.32	56.62	14.73	12.22	28.5	1450	8.32	DO2=2.20mg/l 11
	2940	156.32	56.62	14.95	12.04	28.6	1450	8.34	11
	3000	156.32	56.62	14.57	12.35	29.4	1440	8.39	11
	3060	156.32	56.62	14.92	12.06	29.5	1450	8.29	11
	3120	156.32	56.62	14.69	12.25	30.3	1450	8.25	11
	3180	156.32	56.62	14.82	12.15	30.5	1450	8.25	11
	3240	156.32	56.62	14.77	12.19	30.4	1440	8.21	11
	3300	156.32	56.62	14.61	12.32	28.4	1460	8.26	11
	3360	156.32	56.62	14.55	12.37	28.5	1460	8.27	11
	3420	156.33	56.63	14.84	12.13	27.7	1470	8.27	11
	3480	156.40	56.70	14.67	12.27	27.3	1490	8.29	11
	3540	156.40	56.70	14.91	12.07	27.2	1460	8.30	11
	3600	156.84	57.14	14.61	12.32	27.4	1440	8.41	11
	3660	156.95	57.25	14.59	12.34	27.3	1450	8.41	11
	3720	156.95	57.25	14.73	12.22	27.4	1420	8.25	11
	3780	156.95	57.25	14.86	12.11	27.8	1430	8.40	11
	3840	156.96	57.26	14.92	12.06	27.6	1440	8.30	11
	3900	156.96	57.26	14.69	12.25	27.9	1420	8.41	11
	3960	156.96	57.26	14.84	12.13	27.7	1420	8.40	11
	4020	156.96	57.26	14.69	12.25	27.8	1430	8.66	11
	4080	156.96	57.26	14.79	12.17	27.9	1440	8.51	11
	4140	156.97	57.27	14.84	12.13	28.1	1420	8.57	11
	4200	156.97	57.27	14.90	12.08	27.9	1420	8.69	11
	4260	156.97	57.27	14.96	12.03	27.8	1430	8.84	11
	4320	156.98	57.28	14.91	12.07	29.8	1440	8.27	DO2=1.55mg/l

Table 25-9 Recovery Test Data – BH10222

Official BH NO :	10222	District :	Ghanzi
Date of test commencement :	28.11.2005	Location :	Metsimantsho
Time of test commencement :	0900hrs	BH depth(m) :	290
Date of test completion	29.11.05	Screen Int (m)	274.6 - 286
Time of test completion :	0900hrs	Depth of pump intake (m) :	168.5
Method of water level measurement:	dipper	Description of MP	top of casing
OB. BH. No.:	n/a	Height of MP above ground(m) :	0.55
Dist.to Pumping Bh:	n/a	Static Water level before test(m) :	99.7
Casing diameter (mm)		Water strike	150, 188 and 289
Orifice plate diameter		Delivery pipe diameter	NA
Easting	475985	Northing	7427277

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	156.98	57.28
	0.25	156.96	57.26
	0.5	154.20	54.50
	1	153.10	53.40
	2	150.70	51.00
	3	143.22	43.52
	4	137.22	37.52
	5	131.03	31.33
	6	127.94	28.24
	7	126.53	26.83
	8	125.95	26.25
	9	125.63	25.93
	10	125.34	25.64
	12	125.08	25.38
	15	124.84	25.14
	20	124.58	24.88
	25	124.17	24.47
	30	123.27	23.57
	40	122.53	22.83
	50	121.69	21.99
	60	120.76	21.06
	75	119.54	19.84
	90	118.53	18.83
	105	117.62	17.92
	120	116.45	16.75

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	115.05	15.35
	180	114.00	14.30
	210	112.95	13.25
	240	112.01	12.31
	270	111.13	11.43
	300	110.41	10.71
	330	109.69	9.99
	360	109.12	9.42
	390	108.57	8.87
	420	108.06	8.36
	450	107.64	7.94
	480	107.35	7.65
	540	106.61	6.91
	600	106.04	6.34
	660	105.42	5.72
	720	104.94	5.24
	780	104.66	4.96
	840	104.38	4.68
	900	104.10	4.40
	960	103.83	4.13
	1020	103.54	3.84
	1080	103.26	3.56
	1140	102.98	3.28
	1200	102.70	3.00
	1260	102.39	2.69
	1320	102.32	2.62
	1380	102.21	2.51
	1440	102.12	2.42

26 BH10228

BH10228 is an exploration borehole with a siting reference **S3**, TEM 69, Peg 15000m and line R3. This borehole was drilled to explore the Ecca aquifer south west of fault F4 at the same site as that of piezometer BH10227 to allow for collection of pump testing data that can be utilised for calculation of the aquifer hydraulic parameters of the Ecca aquifer to the south west of fault F4. This exploration borehole is located about 22km south east of Ncojane Village. Drilling operations at this site commenced on 15 October and were completed on 31 October 2005.

26.1 SITING CRITERIA AND DRILLING OBJECTIVES

This exploration borehole was drilled to explore the potential of the Ecca aquifer near or south west of fault F4 and will also provide aquifer hydraulic data (Transmissivity and Storativity) for the Ecca as well as providing water level data.

26.2 DRILLING RESULTS

The borehole was drilled through various lithologies including fine grained sand, silcrete, calcrete, mudstones, dolerite, coal and fine to medium grained micaceous sandstone and fine to medium grained sandstones (**Figure 26-1**). Drilling of BH10228 was carried out with a 15 inch bit using the DTH drilling technique down to a depth of 71m bgl after which 12 inch plain casings were installed and grouted. Drilling between 71 to 191m was accomplished using 12 inch drilling bit after which 10 inch casings were installed to allow for further drilling. Drilling was by a 10" DTH bit to depth of 216 m after which a $9^{7/8}$ inch tri-cone bit was utilised to complete the borehole to the terminal depth of 256 m due to back pressure problems.

During drilling of this borehole, three water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the three water strikes are as follows;

1. (126m, Unmeasurable)
2. (165m, 1100 µS/cm, 8 m^3/hr)
3. (199m, 650 µS/cm, 101 m^3/hr)

Water samples were collected at water strike 2 and 3 for basic chemical analysis at DWA lab. The results of analysis are presented in **Table 26-1**.

Table 26-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10228	165	7.92	318	16.36	15.06	82	33.15	45.17	15.48	18.72	0.48	0	283.15	0.00	0.08	MUD 1
10228	199	7.89	322	26.28	17.12	86	8.04	44.7	16.19	25.25	0.5	0	286.26	0.01	0.35	SST 1
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

After completion of drilling, the borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, calliper, neutron and temperature probes (**Figure 26-2).**

The borehole was constructed using 8 inch plain and factory slotted casings. The 8 inch plain casings were installed between 0 to 191m and 250.9 to 253.9m while the slotted casings were installed between 191 and 250.9m, representing a zone of 59.9m. The borehole was not gravel packed. Development was through air jetting with the final yield at the end of development measured was 74 m^3/hr while the electrical conductivity was 630 µS/cm. The static water level after completion was 107 m bgl on 31 October 2005.

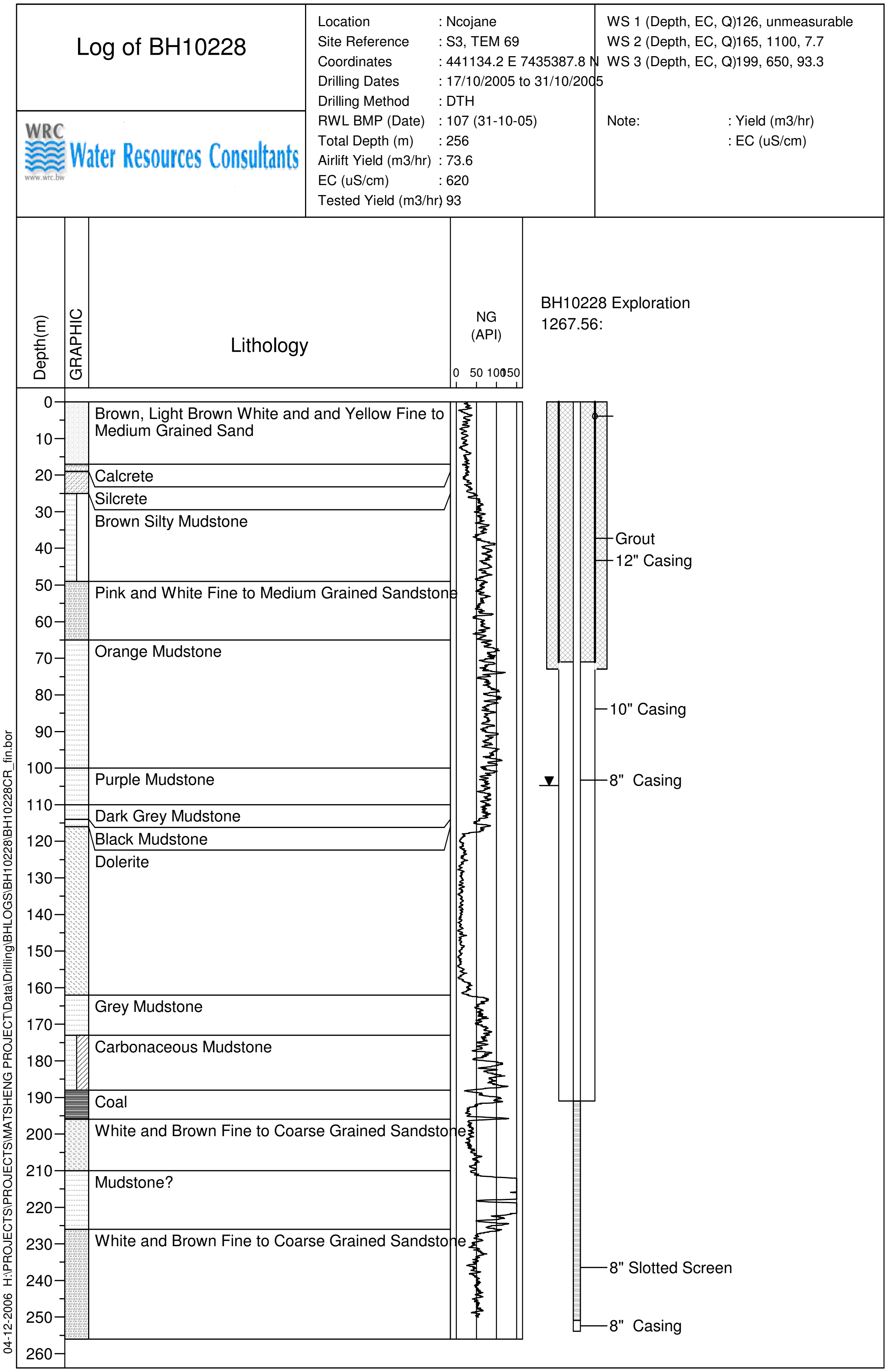

Figure 26-1 Log of BH10228

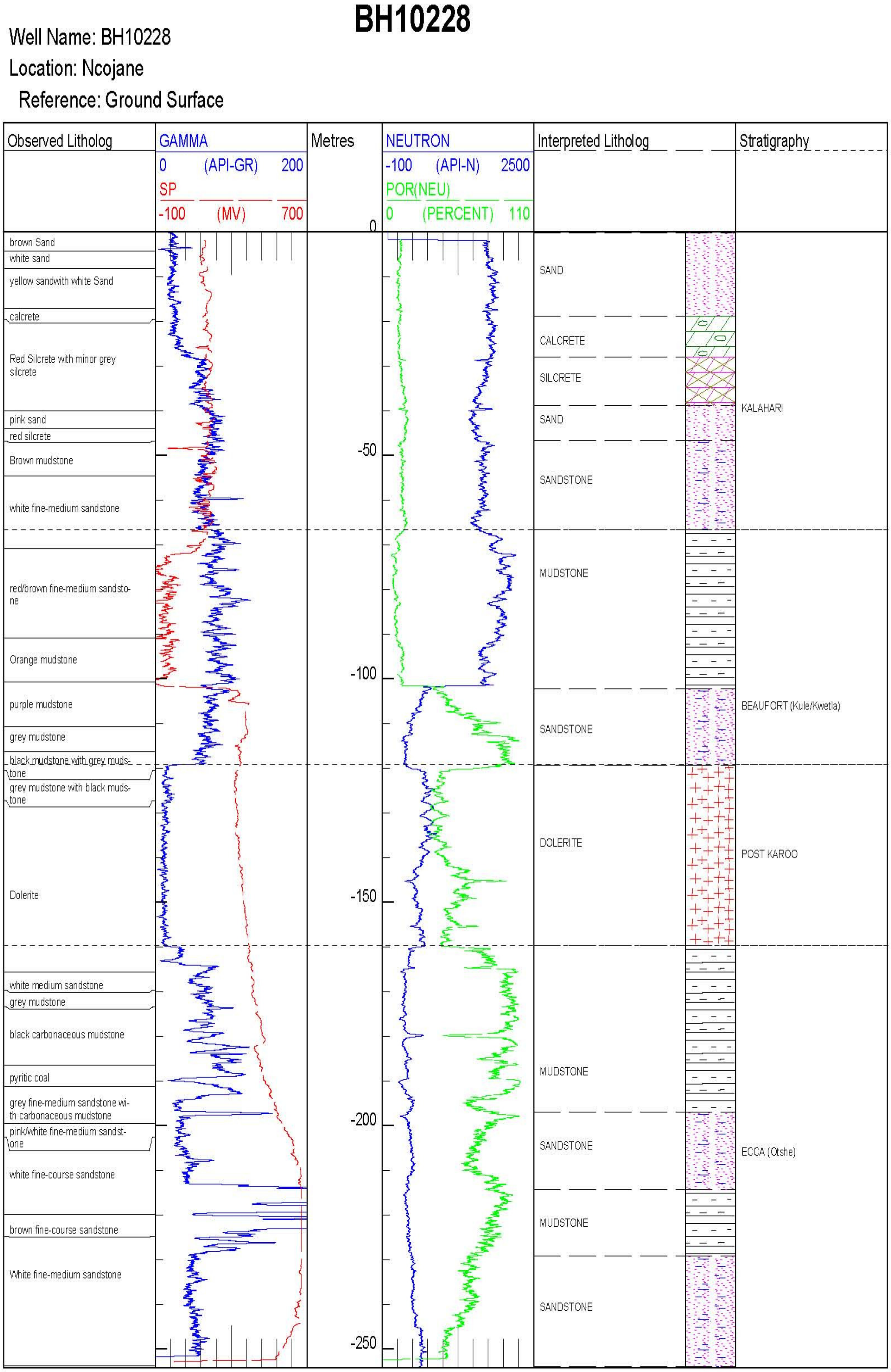

Figure 26-2 Geophysical log of BH10228

26.3 PUMP TESTING RESULTS

BH10228 was tested between 28 November and 6 December 2005 and the tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.75 m above ground level (agl) and the pump intake was set at 150 m below ground level. Summary details for the pumping test activities at BH10228 are given in **Table 26-2**. The collected pump testing data is represented in **Tables 26-6 to 26-11**.

Table 26-2 Summary of Pumping Test Data BH10228

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	11.23	41
	2	15	14.37	53
	3	15	17.2	64
	4	15	21.47	81
	5	3	24.7	92
Step Test	1	100	8.89	30.2
	2	100	15.8	45.5
	3	100	17.8	60.2
	4	100	24.32	75.3
	5	1.5	27.5	92.5
Constant Rate	1	6900	27.78	93
Recovery*	1	1440	0.18*	0

Note.0.18 Residual Drawdown*

26.3.1 Step Drawdown Test

The step drawdown test (SDT) was carried out on 29 November 2005. The static water level before the start of the test was 105.5 m bmp. The step drawdown test consisted of 5 steps of 100 minutes duration. The discharge rates were 30.2, 45.5, 60.2, 75.3 and 92.5 m^3/hr, respectively for steps 1 to 5.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test using this method is plotted in **Figure 26-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 26-4**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 111 m^2/d, **Figure 26-5**. The results for the step test interpretation are tabulated in **Table 26-3**.

Table 26-3 Results of Step Test Analysis BH10228

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10228	1.37E-02	-7.79E-07	111	30.2	8.76	8.76	3.4
				45.5	7.09	15.85	2.9
				60.2	1.13	16.98	3.5
				75.3	6.11	23.09	3.3
				92.5	2.49	25.58	3.6

The planned duration of the constant rate test for this borehole is 5 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slope of the semi-logarithmic plot of drawdown versus time (**Figure 26-3**) to estimate expected total drawdown after 5 days of pumping. There was also a total of 15.5m of available drawdown at the end of the step test.

26.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 30 November and 5 December 2005 at a discharge rate of $93m^3/hr$ and the total drawdown after 115hrs of pumping was 27.78m. The CRT test was followed by a 24 hr recovery monitoring period at the end of which the residual drawdown was 0.18m. Data from the pumping period was interpreted using the Theis and the Cooper-Jacob (1946) analytical solution using the computer programme "Aqtesolv" and the transmissivity (T) values obtained were 422 and $414m^2/d$. The recovery data was analysed using the Theis recovery solution and the T value computed was $474m^2/d$. The interpretation of the results are summarised in **Table 26-4** and the interpreted data is presented in **Figures 26-6** and **26-8**.

Table 26-4 Summary of Constant Rate and Recovery Tests BH10228

BH No.	CRT Duration (hours)	Q (m^3/d)	Pumping borehole T (m^2/d)		Obs. BH No.	Observation borehole			Aquifer type
						Pumping phase		Recovery phase	
			Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
10228	115	2232	a) 422 b) 414	d) 474	10227	a) 537 b) 537	a) 4.4E-6 b) 3.7E-6	d) 431	Confined

Notes:
Interpretation Techniques
a) Theis *c) Neuman (Unconfined)*
b) Cooper-Jacob *d) Theis Modified Recovery*

26.3.2.1 Observation Borehole

The water level response was monitored in an observation borehole (BH10227) located 10 m away from BH10228 (pumping borehole). This observation borehole is screened between 190 to 250.9 m bgl and the total drawdown in this borehole at the end of pumping (115 hrs) was 13.81 m.

Various analytical solutions (Theis, Cooper-Jacob, Hantush Leaky,) were applied to the pumping test data from this observation borehole using the computer programme "Aqtesolv" and the best fit was obtained based on the Theis and Hantush Leaky solutions in addition to the Cooper-Jacob interpretation. The Transmissivity (T) values obtained by these three analytical solutions are 537, 537 and $271m^2/d$ respectively while the storativity values calculated from the Theis, Cooper-Jacob and Hantush Leaky solutions $4.4x10^{-6}$, $3.7x10^{-6}$ and $1.3x10^{-4}$ respectively. Though a good fit was obtained using the Hantush Leaky method, the aquifer parameters obtained are low and do not compare to those obtained by the other methods. The recovery data was analysed using the Theis recovery method and the T value obtained was $431m^2/d$. The results are summarised in **Table 26-4** and the interpreted data is presented in **Figures 26-9 to 26-11.**

26.3.2.2 Aquifer Type interpreted

The aquifer type determined from the pump testing interpretation is confined.

26.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for most of the BOS 32:2000 listed determinants. The results are presented in **Table 26-5.** The other samples collected submitted for both stable and unstable isotope analysis at the CSIR laboratory in Pretoria, South Africa **.**

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), pH and dissolved oxygen are 28.7 ^oC, 630µS/cm, 7.6 and 4.25 mg/L respectively.

Table 26-5 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10228	6	81	25	15	13	41	211	4.4	0.59	0.41	<0.05	620	7.4	397
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10228	<0.1	126	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

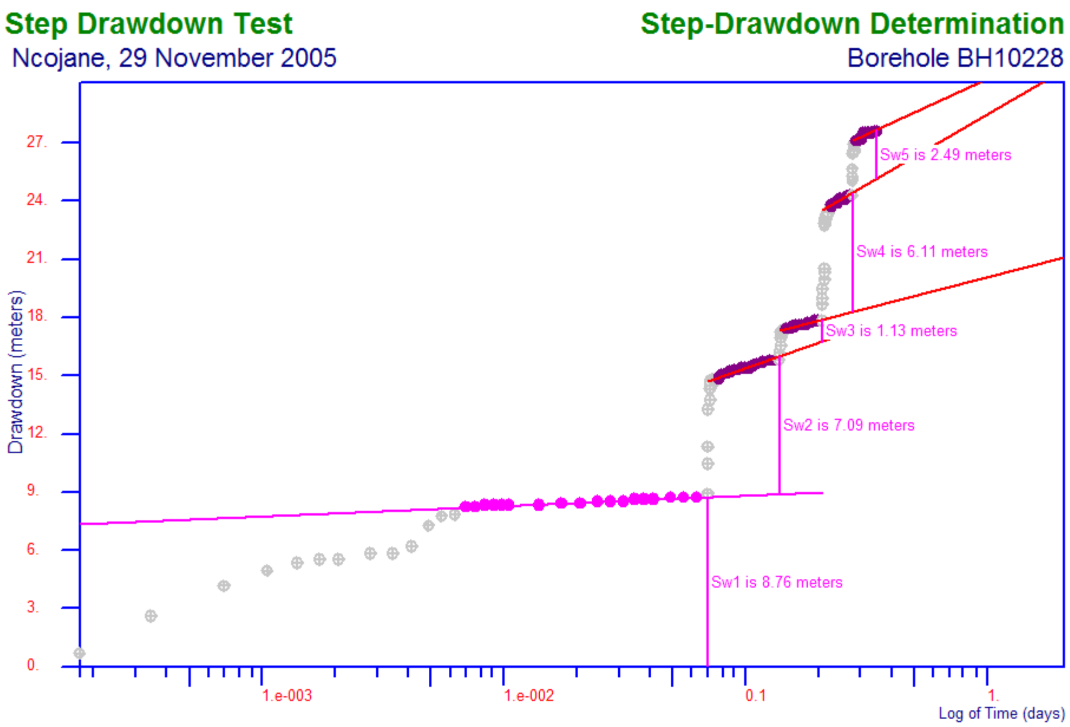

Figure 26-3 Pumping Test Results for BH10228: Step Drawdown Test – Hantush-Bierschenk (semi-log)

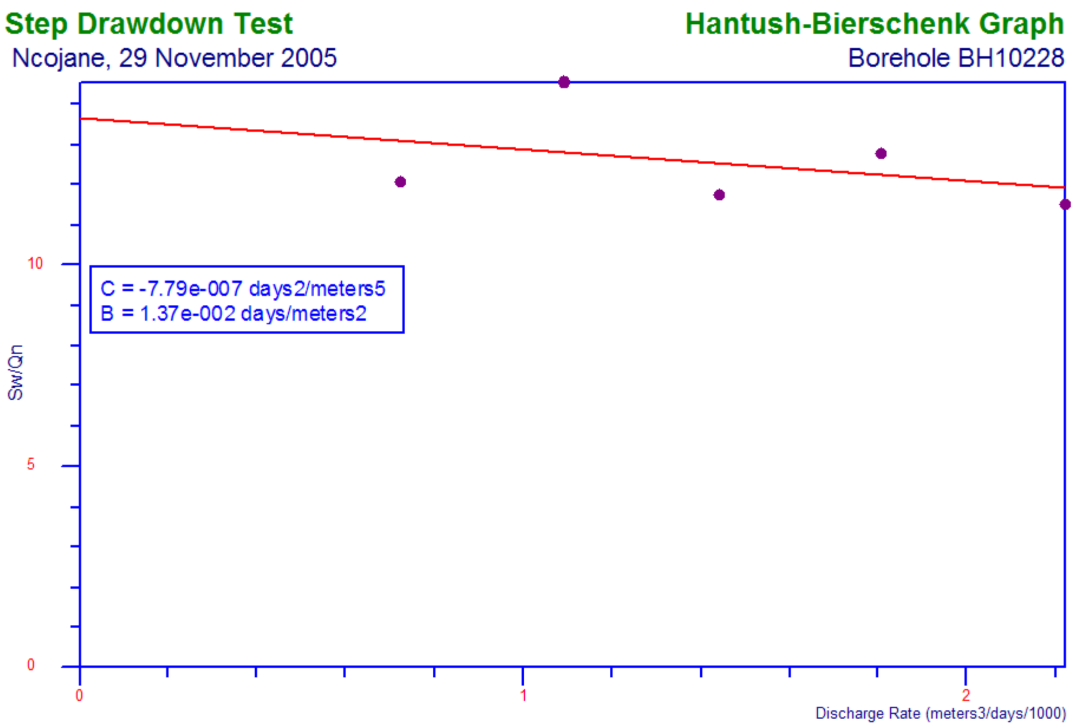

Figure 26-4 Pumping Test Results for BH10228: Step Drawdown Test – Hantush-Bierschenk

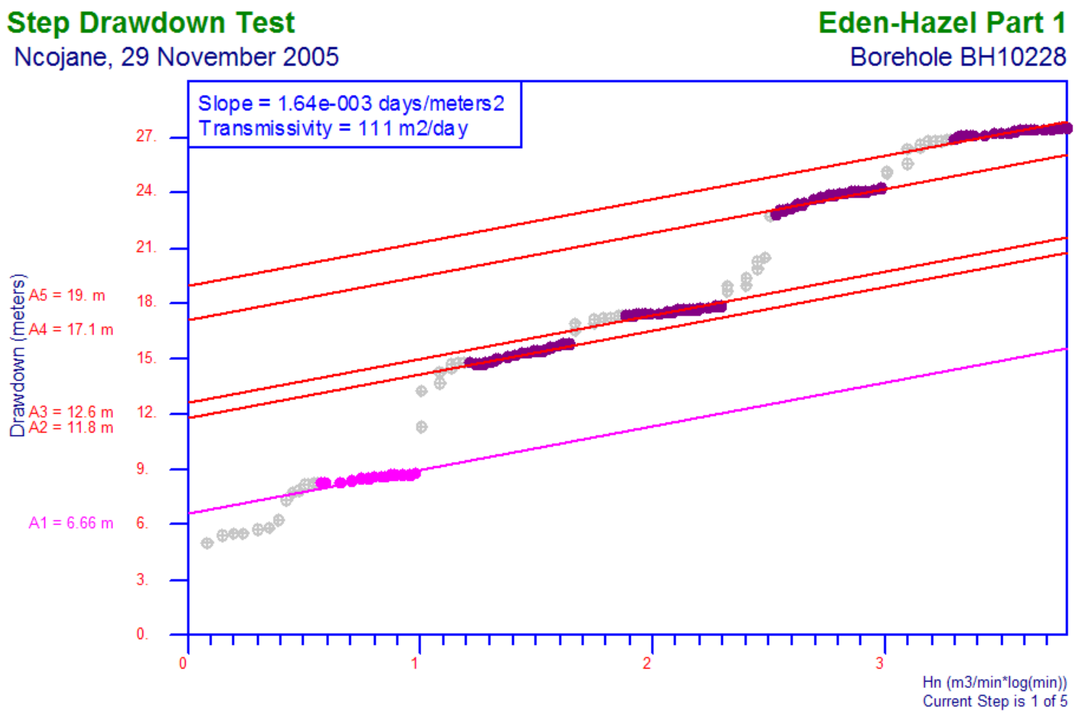

Figure 26-5 Pumping Test Results for BH10228: Step Drawdown Test – Eden-Hazel (Part 1)

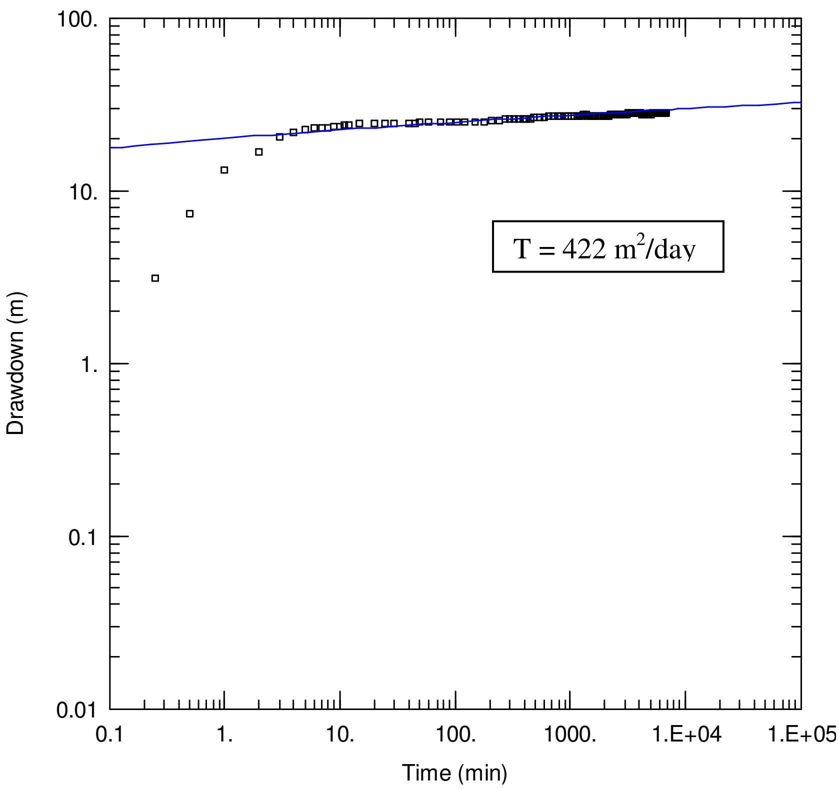

Figure 26-6 Pumping Test Results for BH10228: CRT Theis Solution

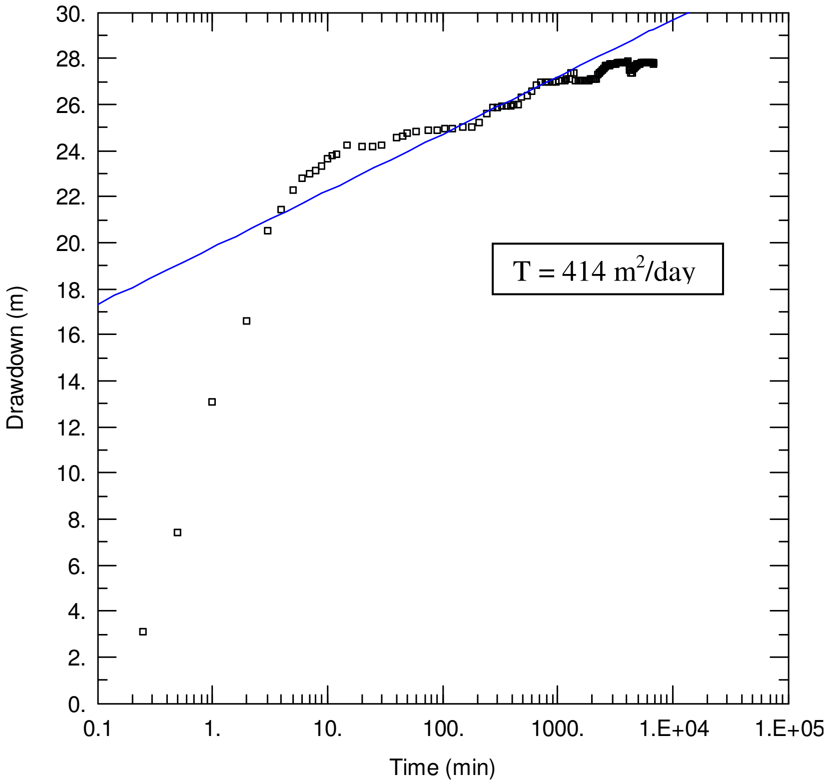

Figure 26-7 Pumping Test Results for BH10228: CRT Cooper- Jacob Solution

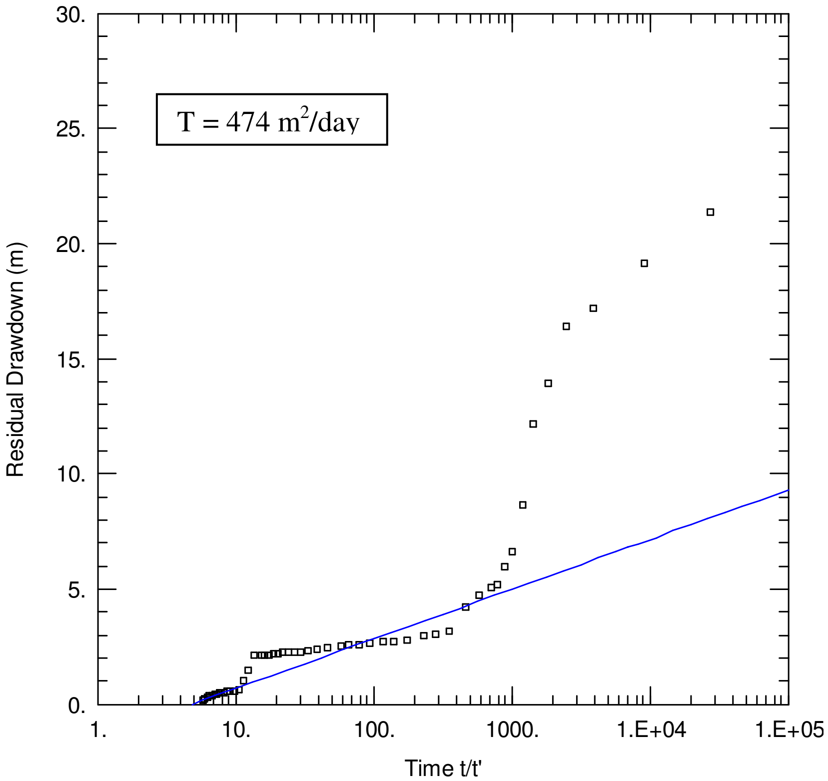

Figure 26-8 Pumping Test Results for BH10228: Theis Recovery Solution

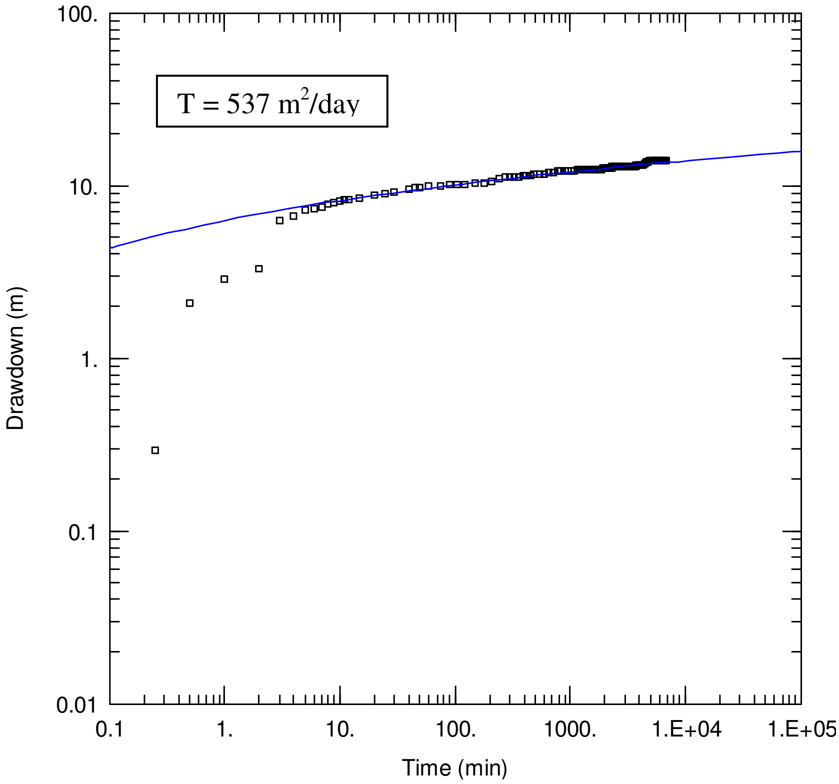

Figure 26-9 Pumping Test Results for BH10227: CRT Theis Solution

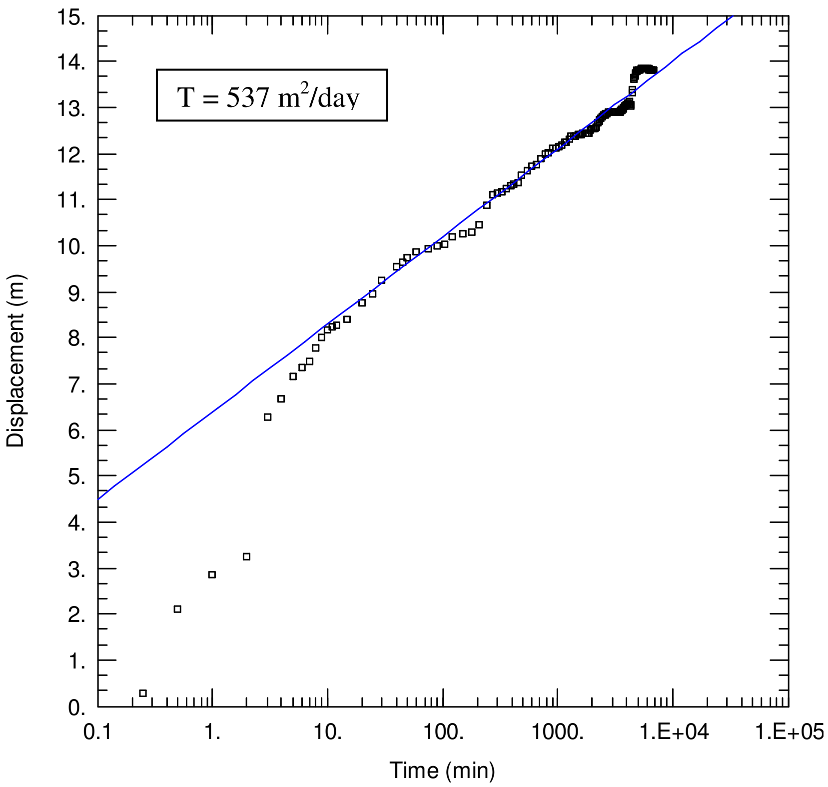

Figure 26-10 Pumping Test Results for BH10227: CRT Cooper- Jacob Solution

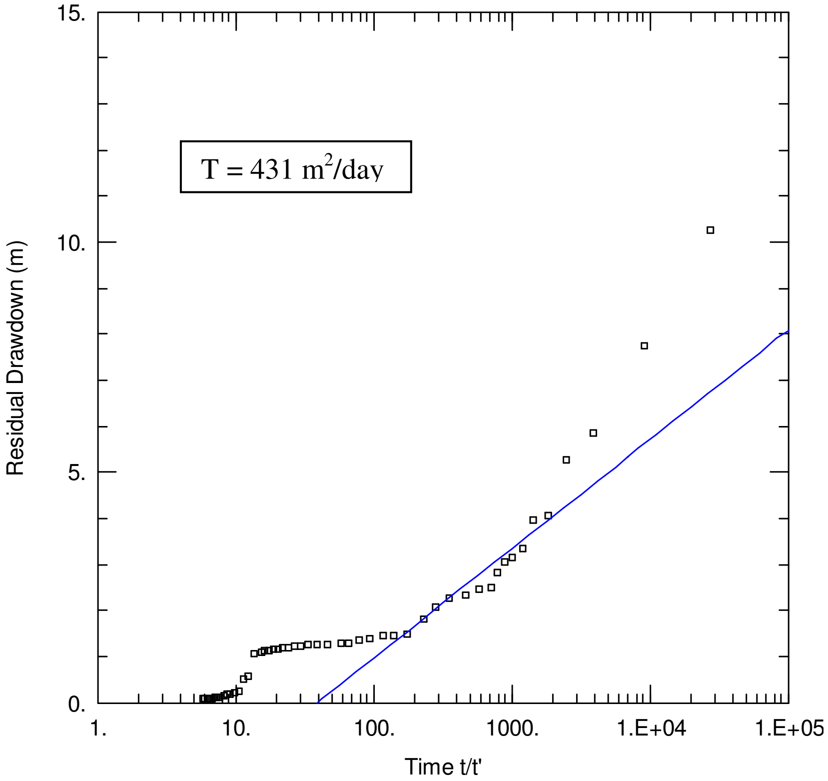

Figure 26-11 Pumping Test Results for BH10227: Theis Recovery Solution

Table 26-6 Calibration Test Data – BH10228

Official BH No.:	10228	District:	Ghanzi
Date of test commencement:	28.11.2005	Location:	Ncojane
Time of test commencement		BH depth (m):	256
Date of test completion:	28.11.2005	Screen Interval (m):	191-250.90
Time of test completion		Depth of pump intake (m):	150
Method of water level measurement:	dipper	Static water level before test (m):	106.35
Casing diameter (mm)	203	Water strike	165 and 199
Orifice plate diameter	4"	Delivery pipe diameter	102mm
Easting	441178	Northing	7435363

STEP No.1						STEPNo.2					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 400L	P Rate (m^3/hr)	Comments
0.25	106.89	0.54				0.25	117.64	11.29			
0.5	114.40	8.05				0.5	118.00	11.65			
1	115.25	8.90				1	118.66	12.31	27.50	52.36	
1.5	115.46	9.11				1.5	119.49	13.14	26.96	53.41	
2	115.67	9.32				2	119.65	13.30	26.99	53.35	
2.5	115.97	9.62				2.5	119.73	13.38	27.54	52.29	
3	116.10	9.75				3	119.81	13.46	27.54	52.29	
4	116.46	10.11	26.06	41.44		4	120.02	13.67	27.41	52.54	
5	116.65	10.30	25.69	42.04		5	120.10	13.75	25.75	55.92	
6	116.81	10.46	25.69	42.04		6	120.17	13.82	26.89	53.55	
7	116.93	10.58	25.74	41.96		7	120.25	13.90	26.78	53.77	
8	117.03	10.68	26.03	41.49		8	120.28	13.93	26.96	53.41	
9	117.10	10.75	26.58	40.63		9	120.41	14.06	27.41	52.54	
10	117.23	10.88	26.59	40.62		10	120.43	14.08	26.89	53.55	
11	117.30	10.95	26.63	40.56		11	120.44	14.09	26.96	53.41	
12	117.41	11.06	26.65	40.53		12	120.54	14.19	26.10	55.17	
15	117.58	11.23	26.65	40.53		15	120.72	14.37	26.96	53.41	

STEP No.3						STEP No.4					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	Pumping Rate (m^3/hr)	Comments
0.25	120.86	14.51				0.25	123.67	17.32			
0.5	121.39	15.04				0.5	125.09	18.74			
1	122.27	15.92	28.34	63.51		1	126.07	19.72	22.63	79.54	
1.5	122.56	16.21				1.5	126.47	20.12			
2	122.66	16.31	27.91	64.49		2	126.76	20.41	22.31	80.68	
2.5	122.79	16.44				2.5	126.93	20.58			
3	122.94	16.59	28.29	63.63		3	126.99	20.64	21.88	82.27	
4	123.00	16.65	27.99	64.31		4	127.15	20.80	22.46	80.14	
5	123.05	16.70	28.50	63.16		5	127.23	20.88	22.01	81.78	
6	123.13	16.78	28.41	63.36		6	127.32	20.97	21.39	84.15	
7	123.22	16.87	28.49	63.18		7	127.42	21.07	21.83	82.46	
8	123.26	16.91	28.50	63.16		8	127.45	21.10	22.14	81.30	
9	123.32	16.97	27.06	66.52		9	127.54	21.19	22.50	80.00	
10	123.35	17.00	27.99	64.31		10	127.58	21.23	22.48	80.07	
11	123.37	17.02	27.91	64.49		11	127.63	21.28	22.37	80.46	
12	123.42	17.07	27.40	65.69		12	127.67	21.32	22.38	80.43	
15	123.55	17.20	28.03	64.22		15	127.82	21.47	22.46	80.14	

Official BH No.:	10228	District:	Ghanzi
Date of test commencement:	28.11.2005	Location:	Ncojane
Time of test commencement		BH depth (m):	256
Date of test completion:	28.11.2005	Screen Interval (m):	191-250.90
Time of test completion		Depth of pump intake (m):	150
Method of water level measurement:	dipper	Static water level before test (m):	106.35
Casing diameter (mm)	203	Water strike	165 and 199
Orifice plate diameter	4"	Delivery pipe diameter	102mm
Easting	441178	Northing	7435363
STEP No.5		STEP No.6	

TIME (min)	Depth to WL (m)	Dd (m)	Time to fill 500L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 400L	P Rate (m^3/hr)	Comments
0.25	128.25	21.90				0.25					
0.5	128.77	22.42				0.5					
1	129.77	23.42	19.53	92.17		1					
1.5	130.07	23.72				1.5					
2	130.22	23.87	19.34	93.07		2					
2.5	130.36	24.01				2.5					
3	130.40	24.05	19.55	92.07		3					
4	130.50	24.15	19.75	91.14		4					
5	130.63	24.28	19.31	93.22		5					
6	130.63	24.28	19.14	94.04		6					
7	130.68	24.33	19.44	92.59		7					
8	130.73	24.38	19.46	92.50		8					
9	130.81	24.46	19.51	92.26		9					
10	130.90	24.55	19.61	91.79		10					
11	130.91	24.56	19.34	93.07		11					
12	130.98	24.63	19.71	91.32		12					
15	131.05	24.70	19.51	92.26		15					

STEP No. 7 STEP No. 8

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	Pumping Rate (m^3/hr)	Comments
0.25						0.25					
0.5						0.5					
1						1					
1.5						1.5					
2						2					
2.5						2.5					
3						3					
4						4					
5						5					
6						6					
7						7					
8						8					
9						9					
10						10					
11						11					
12						12					
15						15					

Table 26-7 Step Drawdown Test Data – BH10228

Official BH No.:	10228	District:	Ghanzi
Date of test commencement:	29.11.05	Location:	Ncojane
Time of test Commencement:		BH depth (m):	256
Date of test completion:	29.11.2005	Screens(m)	191-250.90
Time of test Completion:		Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	10227	Height of MP above ground:	0.74
Distance to OB. BH (m)	10	Static water level before test (m):	105.5
Casing diameter (mm)		Water strike	165 and 199
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	441178	Northing	7435363

STEP No. 1 STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	P. Rate (m^3/hr)	Comments
0.25	106.27	0.77				0.25	115.98	10.48			
0.5	108.20	2.70				0.5	116.77	11.27			
1	109.73	4.23				1	118.80	13.30	24.08	44.85	
1.5	110.49	4.99				1.5	119.23	13.73			adj
2	110.90	5.40				2	119.82	14.32	19.54	55.27	
2.5	111.04	5.54				2.5	119.97	14.47	22.80	47.37	
3	111.04	5.54	37.50	19.20		3	120.15	14.65	22.88	47.20	
4	111.29	5.79	35.20	20.45	adj	4	120.26	14.76	22.54	47.91	
5	111.30	5.80	23.47	30.68		5	120.26	14.76	23.91	45.17	
6	111.71	6.21	25.32	28.44		6	120.26	14.76	23.90	45.19	
7	112.83	7.33	23.85	30.19		7	120.15	14.65	23.99	45.02	
8	113.28	7.78	23.65	30.44		8	120.20	14.70	23.88	45.23	
9	113.34	7.84	23.70	30.38		9	120.22	14.72	23.94	45.11	
10	113.73	8.23	23.74	30.33		10	120.31	14.81	23.88	45.23	
11	113.73	8.23	23.85	30.19		11	120.33	14.83	23.78	45.42	
12	113.83	8.33	23.64	30.46		12	120.34	14.84	23.78	45.42	
13	113.83	8.33	23.88	30.15		13	120.35	14.85	23.89	45.21	
14	113.83	8.33	23.94	30.08		14	120.46	14.96	23.78	45.42	
15	113.83	8.33	23.98	30.03		15	120.50	15.00	23.89	45.21	
20	113.83	8.33	23.82	30.23		20	120.62	15.12	23.75	45.47	
25	113.90	8.40	23.64	30.46		25	120.68	15.18	23.90	45.19	
30	113.96	8.46	23.94	30.08		30	120.75	15.25	23.98	45.04	
35	113.99	8.49	23.82	30.23		35	120.82	15.32	23.90	45.19	
40	114.05	8.55	23.98	30.03		40	120.91	15.41	23.86	45.26	
45	114.05	8.55	23.78	30.28		45	120.92	15.42	23.89	45.21	
50	114.10	8.60	23.94	30.08		50	120.93	15.43	23.94	45.11	
55	114.15	8.65	23.82	30.23		55	121.00	15.50	23.85	45.28	
60	114.15	8.65	23.70	30.38		60	121.09	15.59	23.88	45.23	
70	114.20	8.70	23.99	30.01		70	121.16	15.66	23.99	45.02	
80	114.23	8.73	23.65	30.44		80	121.25	15.75	23.80	45.38	
90	114.25	8.75	23.85	30.19		90	121.30	15.80	23.99	45.02	
100	114.39	8.89	23.99	30.01		100	121.30	15.80	23.86	45.26	

Official BH No.:	10228	District:	Ghanzi
Date of test commencement:	29.11.05	Location:	Ncojane
Time of test Commencement:		BH depth (m):	256
Date of test completion:	29.11.2005	Screens(m)	191-250.90
Time of test Completion:		Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	10227	Height of MP above ground:	0.74
Distance to OB. BH (m)	10	Static water level before test (m):	105.5
Casing diameter (mm)		Water strike	165 and 199
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	441178	Northing	7435363

STEP No. 3 — STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 400L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments
0.25	121.68	16.18				0.25	123.34	17.84			
0.5	122.02	16.52				0.5	124.20	18.70			
1	122.38	16.88	23.53	61.20		1	124.48	18.98			
1.5	122.45	16.95				1.5	124.54	19.04			adj
2	122.60	17.10	24.19	59.53		2	124.92	19.42	25.02	71.94	
2.5	122.69	17.19				2.5	125.36	19.86			
3	122.70	17.20	23.80	60.50		3	125.76	20.26	23.87	75.41	
4	122.73	17.23	23.88	60.30		4	125.97	20.47	23.90	75.31	
5	122.78	17.28	23.96	60.10		5	128.20	22.70	23.99	75.03	
6	122.79	17.29	23.86	60.35		6	128.26	22.76	23.86	75.44	
7	122.79	17.29	23.87	60.33		7	128.48	22.98	23.94	75.19	
8	122.83	17.33	23.94	60.15		8	128.53	23.03	23.77	75.73	
9	122.83	17.33	23.92	60.20		9	128.60	23.10	23.89	75.35	
10	122.86	17.36	23.86	60.35		10	128.64	23.14	23.87	75.41	
11	122.86	17.36	23.89	60.28		11	128.71	23.21	23.91	75.28	
12	122.89	17.39	23.94	60.15		12	128.77	23.27	23.98	75.06	
13	122.89	17.39	23.98	60.05		13	128.80	23.30	23.93	75.22	
14	122.92	17.42	23.90	60.25		14	128.81	23.31	23.86	75.44	
15	122.92	17.42	23.87	60.33		15	128.93	23.43	23.89	75.35	
20	122.95	17.45	23.90	60.25		20	129.05	23.55	23.99	75.03	
25	123.04	17.54	23.99	60.03		25	129.17	23.67	23.91	75.28	
30	123.04	17.54	23.97	60.08		30	129.25	23.75	23.87	75.41	
35	123.08	17.58	23.92	60.20		35	129.31	23.81	23.85	75.47	
40	123.09	17.59	23.85	60.38		40	129.37	23.87	23.92	75.25	
45	123.15	17.65	23.88	60.30		45	129.42	23.92	23.86	75.44	
50	123.15	17.65	23.94	60.15		50	129.49	23.99	23.94	75.19	
55	123.15	17.65	23.93	60.18		55	129.56	24.06	23.99	75.03	
60	123.22	17.72	23.84	60.40		60	129.56	24.06	23.87	75.41	
70	123.22	17.72	23.97	60.08		70	129.65	24.15	23.91	75.28	
80	123.29	17.79	23.88	60.30		80	129.70	24.20	23.85	75.47	
90	123.30	17.80	23.89	60.28		90	129.77	24.27	23.91	75.28	
100	123.30	17.80	23.94	60.15		100	129.82	24.32	23.99	75.03	

Official BH No.:	10228	District:	Ghanzi
Date of test commencement:	29.11.05	Location:	Ncojane
Time of test Commencement:		BH depth (m):	256
Date of test completion:	29.11.2005	Screens(m)	191-250.90
Time of test Completion:		Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	10227	Height of MP above ground:	0.74
Distance to OB. BH (m)	10	Static water level before test (m):	105.5
Casing diameter (mm)		Water strike	165 and 199
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	441178	Northing	7435363

STEP No. 5 STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments
0.25	130.50	25.00				0.25					
0.5	130.61	25.11				0.5					
1	130.72	25.22	19.48	92.40		1					
1.5	131.08	25.58				1.5					adj
2	131.90	26.40	19.36	92.98		2					
2.5	132.02	26.52				2.5					
3	132.14	26.64	19.44	92.59		3					
4	132.30	26.80	19.48	92.40		4					
5	132.30	26.80	19.52	92.21		5					
6	132.34	26.84	19.41	92.74		6					
7	132.40	26.90	19.43	92.64		7					
8	132.42	26.92	19.38	92.88		8					
9	132.45	26.95	19.42	92.69		9					
10	132.46	26.96	19.45	92.54		10					
11	132.55	27.05	19.44	92.59		11					
12	132.57	27.07	19.40	92.78		12					
13	132.57	27.07	19.41	92.74		13					
14	132.58	27.08	19.41	92.74		14					
15	132.59	27.09	19.43	92.64		15					
20	132.60	27.10	19.48	92.40		20					
25	132.67	27.17	19.42	92.69		25					
30	132.70	27.20	19.47	92.45		30					
35	132.72	27.22	19.54	92.12		35					
40	132.81	27.31	19.55	92.07		40					
45	132.87	27.37	19.48	92.40		45					
50	132.87	27.37	19.41	92.74		50					
55	132.90	27.40	19.52	92.21		55					
60	132.90	27.40	19.48	92.40		60					
70	132.90	27.40	19.48	92.40		70					
80	132.94	27.44	19.49	92.36		80					
90	132.96	27.46	19.56	92.02		90					
100	133.00	27.50	19.55	92.07		100					

Table 26-8 Constant Rate Test – BH10228

Official BH NO :	10228	District :	Ghanzi
Date of test commencement :	30.11.05	Location :	Ncojane
Time of test commencement :	1000hrs	BH depth(m) :	256
Date of test completion	3.12.05	Screen Interval (m)	191-250.90
Time of test completion :	0500hrs	Depth of pump intake (m) :	150m
Method of water level measurement	dipper	Description of MP	top of dipper tubing
OB BH NO:	10227	Height of MP above ground(m) :	0.75m
Distance ob BH r (m)	10	Static Water level before test(m) :	106.60
Casing diameter (mm)	203	Water strike	165 and 199
Orifice plate diameter	4"	Delivery pipe diameter	102 mm
Easting	441178	Northing	7435363

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500l	Q(m^3/h)	Temp (^{0}C)	EC (ms/Cm)	pH	Manometer (cm)
	0.25	109.73	3.13						
	0.5	113.97	7.37						
	1	119.65	13.05						
	2	123.18	16.58						
	3	127.14	20.54						
	4	128.01	21.41	20.11	89.51				
	5	128.88	22.28						
	6	129.40	22.80	19.04	94.54				
	7	129.58	22.98						
	8	129.69	23.09						
	9	129.90	23.30	18.44	97.61				
	10	130.24	23.64	19.56	92.02				
	11	130.39	23.79	19.51	92.26				
	12	130.44	23.84	19.59	91.88				
	15	130.80	24.20	19.34	93.07	28.7	680	7.64	42
	20	130.75	24.15	19.22	93.65	28.6	640	7.64	42
	25	130.77	24.17	19.04	94.54	28.5	620	7.51	42
	30	130.80	24.20	19.35	93.02	28.5	620	7.51	42
	40	131.15	24.55	19.51	92.26	28.4	660	7.59	42
	45	131.22	24.62	19.34	93.07	28.6	660	7.59	42
	50	131.36	24.76	19.24	93.56	28.4	650	7.56	42
	60	131.41	24.81	19.35	93.02	28.4	650	7.58	42
	75	131.48	24.88	19.33	93.12	28.3	660	7.57	42
	90	131.51	24.91	19.24	93.56	28.6	660	7.58	42
	105	131.54	24.94	19.36	92.98	28.4	650	7.57	42
	120	131.56	24.96	19.35	93.02	28.6	650	7.57	42
	150	131.59	24.99	19.24	93.56	28.7	650	7.58	42
	180	131.63	25.03	19.35	93.02	28.6	650	7.59	42
	210	131.78	25.18	19.35	93.02	28.7	650	7.58	42
	240	132.22	25.62	19.34	93.07	28.7	660	7.51	42
	270	132.44	25.84	19.36	92.98	28.6	660	7.57	42
	300	132.49	25.89	19.34	93.07	28.4	660	7.58	42
	330	132.51	25.91	19.36	92.98	28.3	660	7.58	42
	360	132.53	25.93	19.32	93.17	28.8	660	7.59	42
	390	132.55	25.95	19.28	93.36	28.7	660	7.58	42
	420	132.57	25.97	19.35	93.02	28.8	650	7.51	42
	450	132.59	25.99	19.33	93.12	28.5	640	7.55	42
	480	132.93	26.33	19.24	93.56	28.6	650	7.57	42
	540	132.99	26.39	19.28	93.36	28.1	650	7.56	42
	600	133.17	26.57	19.34	93.07	28.8	650	7.57	42
	660	133.43	26.83	19.35	93.02	28.9	640	7.56	42
	720	133.59	26.99	19.24	93.56	28.8	650	7.56	42
	780	133.60	27.00	19.34	93.07	28.9	650	7.56	42

	840	133.60	27.00	19.36	92.98	27.7	640	7.62	42
	900	133.60	27.00	19.41	92.74	27.6	650	7.57	42
	960	133.60	27.00	19.38	92.88	27.8	660	7.62	42
	1020	133.64	27.04	19.36	92.98	27.6	650	7.57	42
	1080	133.64	27.04	19.38	92.88	27.4	650	7.57	42
	1140	133.65	27.05	19.35	93.02	27.8	650	7.56	42
	1200	133.68	27.08	19.36	92.98	27.7	650	7.58	42
	1260	133.70	27.10	19.38	92.88	27.6	650	7.58	42
	1320	133.97	27.37	19.39	92.83	29.5	630	7.55	42
	1380	133.99	27.39	19.36	92.98	28.2	650	7.54	42
	1440	133.63	27.03	19.50	92.31	28.7	650	7.60	
	1500	133.63	27.03	19.44	92.59	29.0	610	7.63	
	1560	133.63	27.03	19.41	92.74	29.2	630	7.61	42
	1620	133.63	27.03	19.36	92.98	29.3	650	7.60	42
	1680	133.63	27.03	19.35	93.02	29.4	650	7.60	42
	1740	133.64	27.04	19.36	92.98	29.1	650	7.60	42
	1800	133.64	27.04	19.34	93.07	29.4	650	7.60	42
	1860	133.64	27.04	19.35	93.02	29.3	650	7.61	42
	1920	133.68	27.08	19.36	92.98	29.1	650	7.60	42
	1980	133.68	27.08	19.35	93.02	29.0	650	7.60	42
	2040	133.68	27.08	19.34	93.07	29.1	650	7.60	42
	2100	133.68	27.08	19.50	92.31	29.4	650	7.60	42
	2160	133.68	27.08	19.35	93.02	29.1	650	7.61	42
	2220	133.92	27.32	19.34	93.07	29.2	650	7.60	42
	2280	133.93	27.33	19.35	93.02	29.0	650	7.60	42
	2340	133.99	27.39	19.44	92.59	29.2	630	7.60	42
	2400	134.05	27.45	19.38	92.88	29.0	650	7.57	42
	2460	134.10	27.50	19.32	93.17	29.1	630	7.54	42
	2520	134.16	27.56	19.37	92.93	29.0	650	7.57	42
	2580	134.20	27.60	19.34	93.07	29.0	640	7.56	42
	2640	134.26	27.66	19.36	92.98	29.0	650	7.57	42
	2700	134.29	27.69	19.34	93.07	29.1	630	7.58	42
	2760	134.29	27.69	19.33	93.12	29.3	640	7.58	42
	2820	134.29	27.69	19.34	93.07	29.0	658	7.51	42
	2880	134.32	27.72	19.36	92.98	29.1	630	7.57	
	2940	134.34	27.74	19.47	92.45	29.3	630	7.60	42
	3000	134.36	27.76	19.42	92.69	28.7	630	7.57	42
	3060	134.36	27.76	19.34	93.07	29.2	640	7.57	42
	3120	134.36	27.76	19.33	93.12	29.3	640	7.57	42
	3180	134.37	27.77	19.36	92.98	29.6	640	7.51	42
	3240	134.37	27.77	19.38	92.88	29.6	640	7.56	42
	3300	134.40	27.80	19.50	92.31	29.6	640	7.57	42
	3360	134.40	27.80	19.36	92.98	29.5	640	7.62	42
	3420	134.40	27.80	19.34	93.07	28.2	640	7.61	42
	3480	134.40	27.80	19.44	92.59	28.0	650	7.67	42
	3540	134.40	27.80	19.45	92.54	27.9	640	7.56	42
	3600	134.40	27.80	19.40	92.78	27.5	650	7.66	42
	3660	134.40	27.80	19.32	93.17	27.4	640	7.67	42
	3720	134.40	27.80	19.38	92.88	27.4	650	7.57	42
	3780	134.40	27.80	19.47	92.45	27.3	640	7.58	42
	3840	134.40	27.80	19.30	93.26	27.0	650	7.66	42
	3900	134.40	27.80	19.32	93.17	27.1	630	7.62	42
	3960	134.40	27.80	19.40	92.78	27.3	650	7.57	42
	4020	134.40	27.80	19.43	92.64	27.0	640	7.62	42
	4080	134.40	27.80	19.36	92.98	27.5	660	7.62	42
	4140	134.46	27.86	19.47	92.45	27.3	650	7.66	42
	4200	134.25	27.65	19.53	92.17	28.2	640	7.64	42
	4260	134.09	27.49	19.50	92.31	29.0	650	7.64	42
	4320	134.12	27.52	19.54	92.12	29.8	640	7.54	
	4380	133.96	27.36	19.50	92.31	29.7	650	7.63	42
	4440	133.96	27.36	19.28	93.36	29.1	640	7.61	42
	4500	134.12	27.52	19.48	92.40	30.2	630	7.57	42
	4560	134.15	27.55	19.46	92.50	30.0	650	7.62	42

	4620	134.21	27.61	19.49	92.36	29.7	640	7.67	42
	4680	134.22	27.62	19.50	92.31	29.8	630	7.67	42
	4740	134.25	27.65	19.48	92.40	29.7	650	7.57	42
	4800	134.27	27.67	19.46	92.50	27.8	650	7.65	42
	4860	134.30	27.70	19.48	92.40	28.4	630	7.62	42
	4920	134.32	27.72	19.47	92.45	28.0	640	7.65	42
	4980	134.34	27.74	19.50	92.31	28.5	650	7.67	42
	5040	134.34	27.74	19.45	92.54	28.4	640	7.62	42
	5100	134.36	27.76	19.41	92.74	28.3	630	7.65	42
	5160	134.37	27.77	19.51	92.26	28.2	640	7.67	42
	5220	134.38	27.78	19.48	92.40	28.0	650	7.62	42
	5280	134.39	27.79	19.50	92.31	28.1	640	7.65	42
	5340	134.39	27.79	19.45	92.54	28.4	630	7.67	42
	5400	134.40	27.80	19.38	92.88	28.3	640	7.67	42
	5460	134.40	27.80	19.35	93.02	28.2	630	7.63	42
	5520	134.40	27.80	19.35	93.02	28.1	640	7.61	42
	5580	134.40	27.80	19.38	92.88	28.4	650	7.6	42
	5640	134.40	27.80	19.81	90.86	28.5	650	7.63	42
	5700	134.40	27.80	19.47	92.45	28.9	650	7.61	42
	5760	134.40	27.80	19.41	92.74	29.2	670	7.61	
	5820	134.40	27.80	19.43	92.64	29.6	650	7.67	42
	5880	134.40	27.80	19.50	92.31	29.7	640	7.62	42
	5940	134.40	27.80	19.49	92.36	29.8	670	7.57	42
	6000	134.40	27.80	19.45	92.54	29.9	640	7.63	42
	6060	134.40	27.80	19.40	92.78	29.2	630	7.66	42
	6120	134.40	27.80	19.43	92.64	29.1	650	7.65	42
	6180	134.40	27.80	19.53	92.17	29.7	640	7.63	42
	6240	134.39	27.79	19.54	92.12	28.6	650	7.75	42
	6300	134.39	27.79	19.38	92.88	28.8	640	7.68	42
	6360	134.39	27.79	19.38	92.88	28.7	630	7.62	42
	6420	134.39	27.79	19.36	92.98	28.7	630	7.16	42
	6480	134.39	27.79	19.37	92.93	29.0	630	7.61	42
	6540	134.39	27.79	19.32	93.17	29.0	630	7.61	42
	6600	134.39	27.79	19.38	92.88	29.3	630	7.60	42
	6660	134.39	27.79	19.41	92.74	28.1	650	7.60	42
	6720	134.39	27.79	19.40	92.78	29.1	650	7.60	42
	6780	134.39	27.79	19.54	92.12	28.7	640	7.60	42
	6840	134.38	27.78	19.38	92.88	28.7	650	7.80	42
	6900	134.38	27.78	19.35	93.02	28.7	630	7.60	

Table 26-9 Recovery Data – BH10228

Official BH NO :	10228	District :	Ghanzi
Date of test commencement :	3.12.2005	Location :	Ncojane
Time of test commencement :	0500hrs	BH depth(m) :	256
Date of test completion	4.12.05	Screen Int (m)	191-250.90
Time of test completion :	0500hrs	Depth of pump intake (m) :	150
Method of water level measurement:	dipper	Description of MP	top of casing
OB. BH. No.:	10227	Height of MP above ground(m) :	0.74
Dist.to Pumping Bh:	10	Static Water level before test(m) :	106.6
Casing diameter (mm)		Waterstrike	165 and 199
Orifice plate diameter		Delivery pipe diameter	NA
Easting	441178	Northing	7435363

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	134.38	27.78
	0.25	130.77	24.17
	0.5	127.98	21.38
	1	125.77	19.17
	2	123.78	17.18
	3	122.98	16.38
	4	120.55	13.95
	5	118.74	12.14
	6	115.22	8.62
	7	113.25	6.65
	8	112.55	5.95
	9	111.80	5.20
	10	111.66	5.06
	12	111.32	4.72
	15	110.80	4.20
	20	109.74	3.14
	25	109.66	3.06
	30	109.54	2.94
	40	109.35	2.75
	50	109.33	2.73
	60	109.31	2.71
	75	109.25	2.65
	90	109.20	2.60
	105	109.15	2.55
	120	109.10	2.50

clock time	Elapsed time (min)	Depth to Water level (m)	RDD (m) (
-	150	109.05	2.45
	180	109.00	2.40
	210	108.90	2.30
	240	108.88	2.28
	270	108.86	2.26
	300	108.84	2.24
	330	108.82	2.22
	360	108.80	2.20
	390	108.77	2.17
	420	108.75	2.15
	450	108.73	2.13
	480	108.71	2.11
	540	108.69	2.09
	600	108.10	1.50
	660	107.64	1.04
	720	107.21	0.61
	780	107.17	0.57
	840	107.15	0.55
	900	107.13	0.53
	960	107.10	0.50
	1020	107.08	0.48
	1080	107.04	0.44
	1140	107.00	0.40
	1200	106.98	0.38
	1260	106.95	0.35
	1320	106.90	0.30
	1380	106.81	0.21
	1440	106.78	0.18

Table 26-10 Observation Borehole – BH10227 (CRT)

Official BH NO :	10227	District :	Ghanzi
Date of test commencement :	30.11.05	Location :	Ncojane
Time of test commencement :	1000hrs	BH depth(m) :	300
Date of test completion	3.12.05	Screen Interval (m)	190 - 250.90
Time of test completion :	0500hrs	Depth of pump intake (m) :	n/a
Method of water level measurement	dipper	Description of MP	top of dipper tubing
Pumping BH NO:	10228	Height of MP above ground(m) :	0.84m
Distance Pumping BH r (m)	10	Static Water level before test(m) :	106.50
Casing diameter (mm)	50	Water strike	165 and 199
Orifice plate diameter	n/a	Delivery pipe diameter	n/a
Easting	441178	Northing	7435363

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500l	Q(m^3/h)	Temp (^{0}C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO2
	0.25	106.79	0.29						
	0.5	108.59	2.09						
	1	109.36	2.86						
	2	109.76	3.26						
	3	112.77	6.27						
	4	113.17	6.67						
	5	113.67	7.17						
	6	113.85	7.35						
	7	113.98	7.48						
	8	114.29	7.79						
	9	114.49	7.99						
	10	114.66	8.16						
	11	114.75	8.25						
	12	114.76	8.26						
	15	114.90	8.40						
	20	115.26	8.76						
	25	115.44	8.94						
	30	115.73	9.23						
	40	116.03	9.53						
	45	116.14	9.64						
	50	116.24	9.74						
	60	116.36	9.86						
	75	116.44	9.94						
	90	116.51	10.01						
	105	116.54	10.04						
	120	116.68	10.18						
	150	116.74	10.24						
	180	116.79	10.29						
	210	116.94	10.44						
	240	117.39	10.89						
	270	117.59	11.09						
	300	117.64	11.14						
	330	117.68	11.18						
	360	117.72	11.22						
	390	117.79	11.29						
	420	117.83	11.33						
	450	117.86	11.36						
	480	118.02	11.52						
	540	118.14	11.64						
	600	118.23	11.73						
	660	118.26	11.76						
	720	118.39	11.89						
	780	118.50	12.00						
	840	118.51	12.01						
	900	118.60	12.10						
	960	118.62	12.12						
	1020	118.66	12.16						
	1080	118.68	12.18						
	1140	118.73	12.23						
	1200	118.75	12.25						
	1260	118.80	12.30						
	1320	118.87	12.37						
	1380	118.88	12.38						
	1440	118.89	12.39						
	1500	118.90	12.40						
	1560	118.90	12.40						
	1620	118.90	12.40						

	1680	118.93	12.43						
	1740	118.93	12.43						
	1800	118.95	12.45						
	1860	118.95	12.45						
	1920	118.99	12.49						
	1980	119.03	12.53						
	2040	119.05	12.55						
	2100	119.05	12.55						
	2160	119.06	12.56						
	2220	119.18	12.68						
	2280	119.20	12.70						
	2340	119.25	12.75						
	2400	119.27	12.77						
	2460	119.30	12.80						
	2520	119.32	12.82						
	2580	119.32	12.82						
	2640	119.38	12.88						
	2700	119.38	12.88						
	2760	119.40	12.90						
	2820	119.40	12.90						
	2880	119.40	12.90						
	2940	119.40	12.90						
	3000	119.40	12.90						
	3060	119.40	12.90						
	3120	119.40	12.90						
	3180	119.40	12.90						
	3240	119.40	12.90						
	3300	119.40	12.90						
	3360	119.40	12.90						
	3420	119.41	12.91						
	3480	119.41	12.91						
	3540	119.44	12.94						
	3600	119.44	12.94						
	3660	119.45	12.95						
	3720	119.47	12.97						
	3780	119.50	13.00						
	3840	119.52	13.02						
	3900	119.52	13.02						
	3960	119.55	13.05						
	4020	119.57	13.07						
	4080	119.59	13.09						
	4140	119.60	13.10						
	4200	119.61	13.11						
	4260	119.57	13.07						
	4320	119.56	13.06						
	4380	119.52	13.02						
	4440	119.83	13.33						
	4500	119.90	13.40						
	4560	120.10	13.60						
	4620	120.15	13.65						
	4680	120.18	13.68						
	4740	120.21	13.71						
	4800	120.26	13.76						
	4860	120.28	13.78						
	4920	120.30	13.80						
	4980	120.30	13.80						
	5040	120.31	13.81						
	5100	120.31	13.81						
	5160	120.32	13.82						
	5220	120.32	13.82						
	5280	120.33	13.83						
	5340	120.33	13.83						
	5400	120.33	13.83						
	5460	120.33	13.83						
	5520	120.33	13.83						
	5580	120.33	13.83						
	5640	120.33	13.83						
	5700	120.33	13.83						
	5760	120.33	13.83						
	5820	120.33	13.83						
	5880	120.33	13.83						
	5940	120.33	13.83						
	6000	120.33	13.83						
	6060	120.33	13.83						
	6120	120.33	13.83						

	6180	120.33	13.83						
	6240	120.31	13.81						
	6300	120.31	13.81						
	6360	120.31	13.81						
	6420	120.31	13.81						
	6480	120.31	13.81						
	6540	120.31	13.81						
	6600	120.31	13.81						
	6660	120.31	13.81						
	6720	120.31	13.81						
	6780	120.31	13.81						
	6840	120.31	13.81						
	6900	120.31	13.81						

Table 26-11 Observation Borehole Test Data – BH10227 (Recovery Test)

Official BH NO :	10227	District :	Ghanzi
Date of test commencement :	3.12.2005	Location :	Ncojane
Time of test commencement :	0500hrs	BH depth(m) :	300
Date of test completion	4.12.05	Screen Int (m)	190-250.90
Time of test completion :	0500hrs	Depth of pump intake (m) :	n/a
Method of water level measurement:	electrical dipper	Description of MP	top of casing
Pumping BH. No.:	10228	Height of MP above ground(m) :	0.84
Dist.to Pumping Bh:	10	Static Water level before test(m) :	106.5
Casing diameter (mm)	50	Water strike	165 and 199
Orifice plate diameter	NA	Delivery pipe diameter	NA
Easting	441178	Northing	7435363

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	130.31	23.81
	0.25	118.93	12.43
	0.5	116.77	10.27
	1	114.25	7.75
	2	112.36	5.86
	3	111.77	5.27
	4	110.55	4.05
	5	110.45	3.95
	6	109.85	3.35
	7	109.66	3.16
	8	109.54	3.04
	9	109.32	2.82
	10	109.00	2.50
	12	108.95	2.45
	15	108.84	2.34
	20	108.76	2.26
	25	108.58	2.08
	30	108.31	1.81
	40	108.00	1.50
	50	107.96	1.46
	60	107.94	1.44
	75	107.90	1.40
	90	107.85	1.35
	105	107.80	1.30
	120	107.78	1.28

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	107.76	1.26
	180	107.74	1.24
	210	107.74	1.24
	240	107.73	1.23
	270	107.71	1.21
	300	107.69	1.19
	330	107.68	1.18
	360	107.66	1.16
	390	107.65	1.15
	420	107.63	1.13
	450	107.61	1.11
	480	107.59	1.09
	540	107.57	1.07
	600	107.06	0.56
	660	107.02	0.52
	720	106.73	0.23
	780	106.71	0.21
	840	106.69	0.19
	900	106.67	0.17
	960	106.65	0.15
	1020	106.63	0.13
	1080	106.63	0.13
	1140	106.61	0.11
	1200	106.58	0.08
	1260	106.57	0.07
	1320	106.57	0.07
	1380	106.57	0.07
	1440	106.57	0.07

27 BH10227

BH10227 is a piezometer with a siting reference **S3**, TEM 69, Peg 15000m and line R3. This piezometer is drilled to explore the Ecca aquifer south west of fault F4 and will also allow for the estimation of the Ecca storativity during pump testing of a nearby exploration borehole BH10228. The piezometer is located about 22km south east of Ncojane Village. Drilling operations at this site commenced on 17 October and was completed on 31 October 2005.

27.1 SITING CRITERIA AND DRILLING OBJECTIVES

This piezometer was drilled to explore the potential of Ecca aquifer near or to the south west of fault F4, and will also provide aquifer hydraulic data (transmissivity and storativity) for the Ecca as well as providing water level data.

27.2 DRILLING RESULTS

The borehole was drilled through various lithologies including fine grained sand, silcrete, calcrete, mudstones, dolerite, coal and fine to medium grained micaceous sandstone and fine to medium grained sandstones (**Figure 27-1**). Drilling of BH10227 was carried out with a 10 inch bit using the DTH drilling technique down to a depth of 71m bgl after which 8 inch plain casings were installed and grouted. Drilling between 71 to 215m was accomplished using an 8 inch drilling bit after which 6.5 inch casings were installed to allow for further drilling. Drilling was by a 6.5" DTH bit to depth of 252 m after which a 6.25 tricone bit was utilised to complete the borehole to the terminal depth of 300 m due to back pressure problems.

During drilling of this borehole, three water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the three water strikes are as follows;

1. (126m, Unmeasurable)
2. (165m, 1100 µS/cm, 8 m^3/hr)
3. (199m, 650 µS/cm, 101 m^3/hr)

This borehole was constructed as piezometer using 2 inch PVC plain casing and screens. The plain casings were installed between 0 to 190m and 250.9 to 253.9m. The screens were installed between 190 to 250.9m, representing a zone of 60.9m. After installing the screens and casings assembly, the hole was back filled from 260 to 300m and was gravel packed from the 179.08 to 260m. A bentonite seal was installed between 176.08 and 176m and the remaining annulus was cement grouted to the surface. The rest water level was measured as 106 m bgl on 31 October 2005. BH10227 was geophysically logged down to the depth 257m after borehole construction **(Figure 27-2).**

Log of BH10227

Water Resources Consultants (WRC) — www.wrc.bw

Location	: Ncojane
Site Reference	: S3P1, TEM 69
Coordinates	: 441139.63 E 7435376.94 N
Drilling Dates	: 17/10/2005 to
Drilling Method	: DTH
RWL BMP (Date)	: 106 (31-10-5)
Total Depth (m)	: 300
Airlift Yield (m3/hr)	: 101 (before 2" casing)
EC (uS/cm)	: 630
Tested Yield (m3/hr)	: Observation borehole

WS 1 (Depth, EC, Q)	: 126, unmeasurable
WS 2 (Depth, EC, Q)	: 165, 1100, 7.7
WS 3 (Depth, EC, Q)	: 199, 650, 93.3
Note:	: Yield (m3/hr)
	: EC (uS/cm)

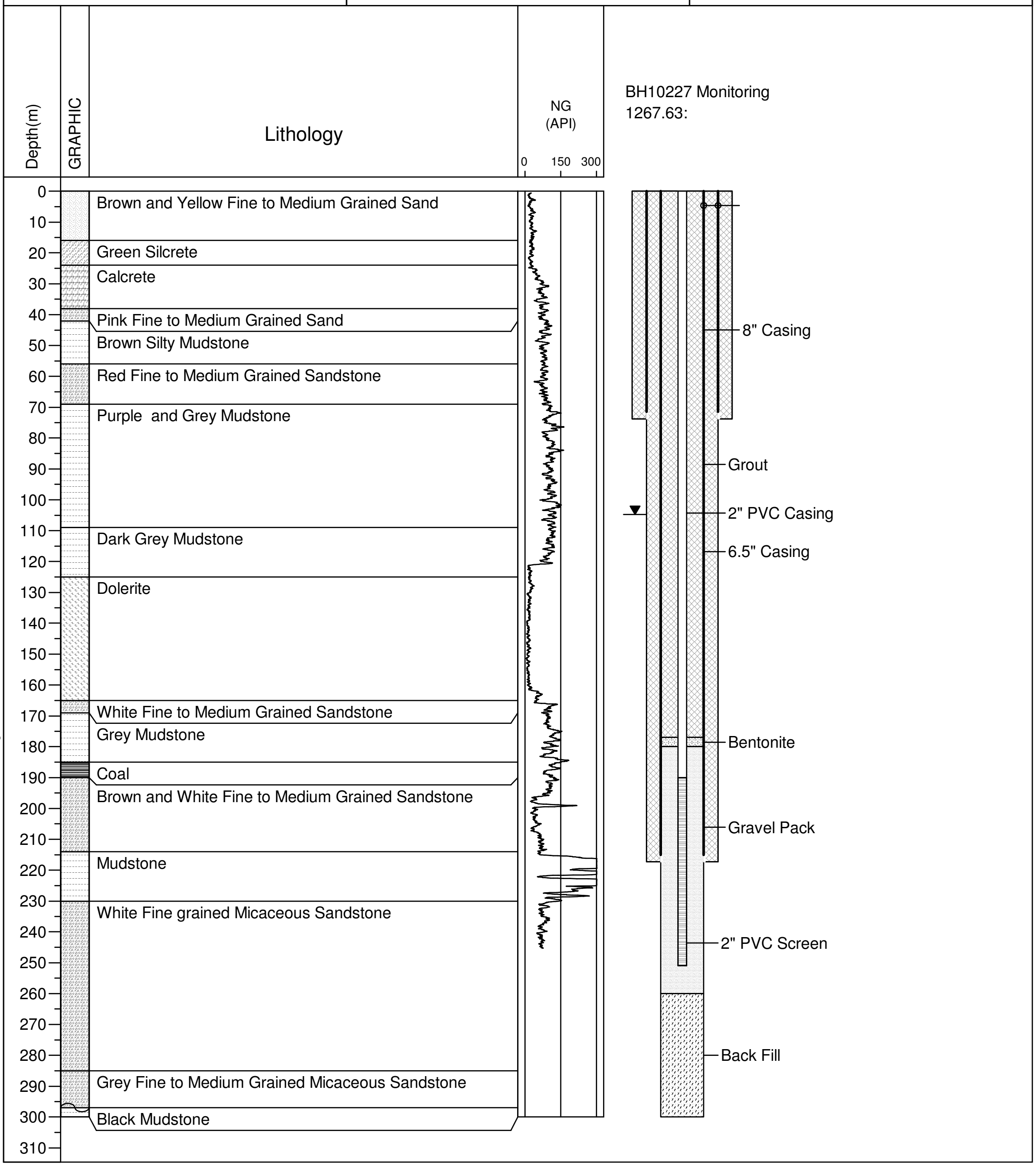

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Figure 27-1 Log of BH10227

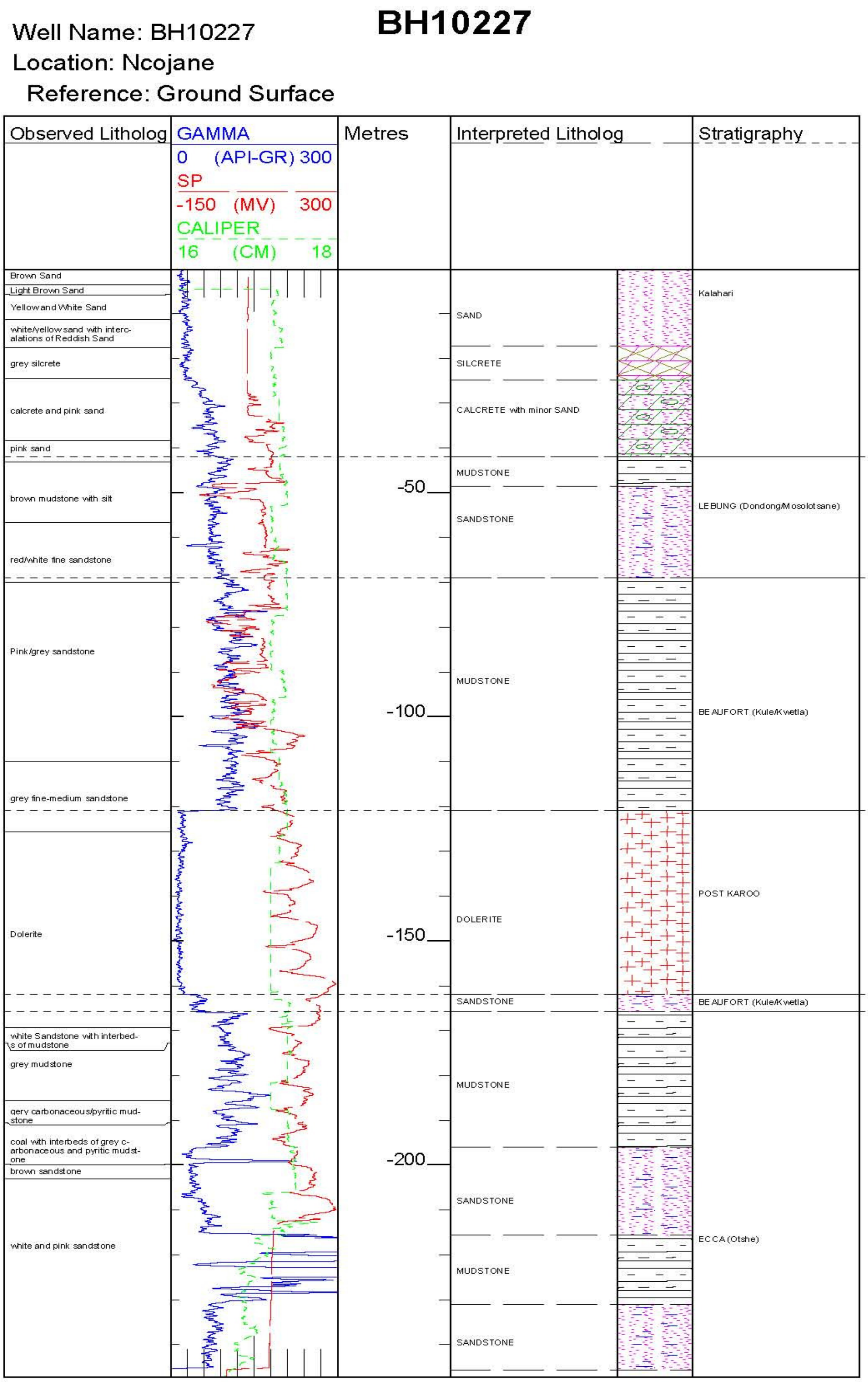

Figure 27-2 Geophysical log of BH10227

28 BH10229

BH10229 with siting reference **S5,** line R7 peg 10000m and TEM114 is an exploration borehole located about 35 km south west of Metsimantsho and 4 km north of the Gantsi – Kgalagadi District boundary cut line. Drilling at this site commenced on 5 November 2005 and was completed on 25 November 2005 at a depth of 320 m.

28.1 SITING CRITERIA AND DRILLING OBJECTIVES

The main objective of drilling this borehole was to evaluate the potential of the relatively undisturbed Ecca aquifer southwest of fault **F4** and southeast of fault **F6**. This borehole will also allow for an evaluation of yield potential, provide water quality data and water level data for Ecca aquifer at this locality.

28.2 DRILLING RESULTS

This exploration borehole intercepted various lithologies including fine to medium grained sands, silcrete, mudstones and fine to medium grained micaceous sandstones (**Figure 28-1**). Drilling of BH10229 was carried out with a 15 inch bit using the DTH drilling technique from 0 to 86 m bgl after which 12 inch plain casings were installed and cement grouted. From 86 m to 230m, drilling was carried out using a 12 inch drilling bit. The penetration rate was high and the mudstone was blocking the hammer and it was decided to change the bit to 10 inch and install 10 inch plain casings to 230m. Drilling from 230m to the terminal depth of 320 m was carried out using a 10 inch bit.

During drilling of this borehole, six water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the six water strikes are as follows;

1. (183m, 5510 µS/cm, 6.5m^3/hr)
2. (198m, 5970 µS/cm, 13.5 m^3/hr)
3. (253m, 2080 µS/cm, 4.44 m^3/hr)
4. (266m, 1775 µS/cm, 4.66 m^3/hr)
5. (282m, 1503 µS/cm, 20.3 m^3/hr)
6. (289m, 1460 µS/cm, 18.6 m^3/hr)

The top two water strikes were grouted off at a depth of 230m. After completion of drilling, the borehole was geophysical logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 317m. After logging, an 8 inch steel casing and factory slotted screen (interval 268.02 to 317 m bgl) assembly was installed in the borehole **(Figure 28-2)**.

The borehole was developed by air lifting for 4.5 hours and the final yield was 43.6 m^3/hr and the electrical conductivity was 1430 µS/cm. The static water level measured was 99.98 m bgl on 24 November 2005.

Water samples were collected at all the water strikes. The samples collected at the different water strikes are were analysed for stable isotopes while the samples collected after development will be submitted to the DWA laboratory for chemical analysis.

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

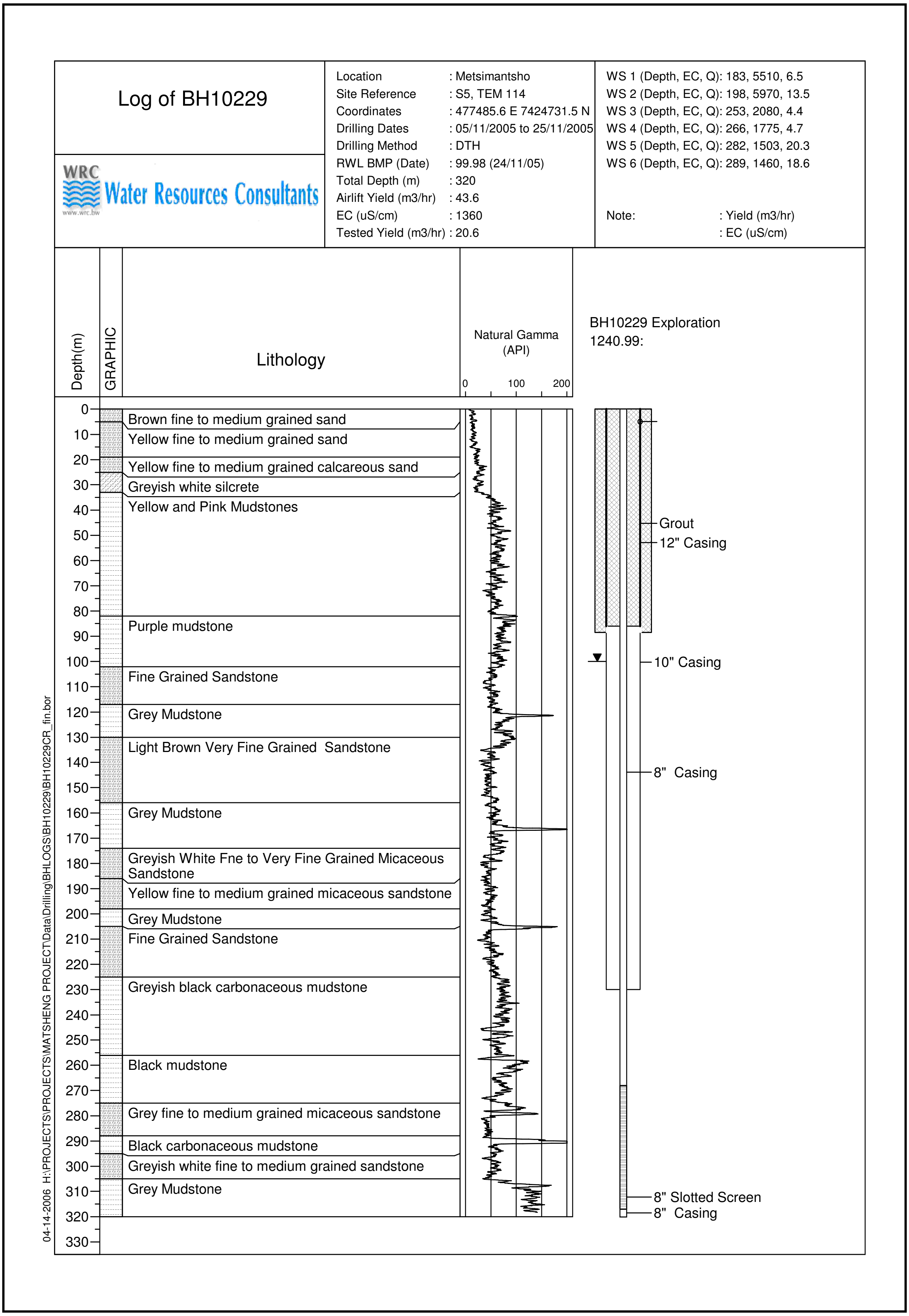

Figure 28-1 Log of BH10229

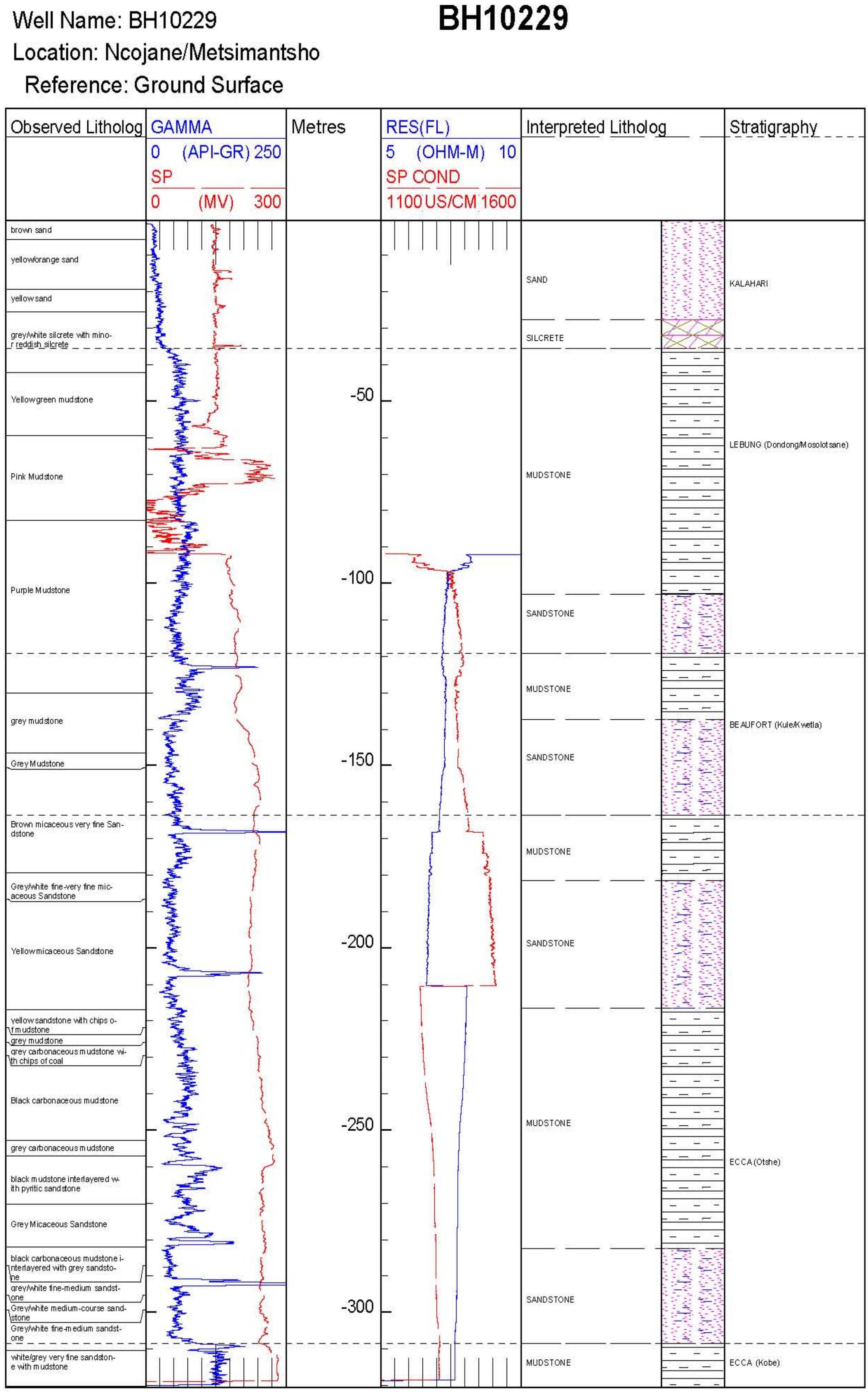

Figure 28-2 Geophysical log of BH10229

28.3 PUMP TESTING RESULTS

Borehole BH10229 was pump tested between 5 and 11 December 2005. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.65 m above ground level (agl) and the pump intake was set at 150.5 m below ground level. Summary details for the pumping test are given in **Table 28-1**. The collected data is presented in **Tables 28-5 to 28-10.**

Table 28-1 Summary of Pumping Test Data BH10229

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	15.68	10
	2	15	25.23	15
	3	15	37.73	21
	4	15	43.21	25.3
	5	6	46.16	29.4
Step Test	1	100	19.35	10.1
	2	100	30.1	14.1
	3	100	35.05	18.2
	4	100	43.7	22.2
	5	8	50.57	26.3
Constant Rate	1	4320	44.23	20.2
Recovery	1	1440	1.83*	0

Note. 1.83 Residual Drawdown*

28.3.1 Step Drawdown Test

The step drawdown test was carried out on 6 December 2005. The static water level before the start of the test was 96.3 m bmp. The step drawdown test consisted of 4 steps of 100 minutes duration at discharge rates of 10.1, 14.1, 18.2 and 22.2 m^3/hr, respectively for steps 1 to 4. A fifth step at 26.3 m^3/hr lasted for 8 minutes only.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test using this method is plotted in **Figure 28-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 28-4**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 19.7 m^2/d, **Figure 28-5**.

The results for the step test interpretation are tabulated in **Table 28.2**.

Table 28-2 Results of Step Test Analysis BH10229

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10229	9.09E-02	-3.19E-5	19.7	10.1	19.70	19.70	0.51
				14.1	8.74	28.44	0.50
				18.2	3.70	32.14	0.57
				22.2	7.60	39.74	0.56

The planned duration for the constant rate test of this borehole is 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slope of the semi-logarithmic plot of drawdown versus time (**Figure 28-3**) to estimate the expected total drawdown after 3 days of pumping.

28.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 7 and 10 December 2005 at a discharge rate of 20.2 m^3/hr and the total drawdown after 72 hrs of pumping was 44.23 m. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 1.83 m. This discharge rate is very low compared to the air lift yield and is probably due the pump testing set up and pump intake.

Data from the pumping borehole was interpreted using the Theis and Cooper-Jacob (1946) analytical solutions using the computer programme "Aqtesolv". Transmissivity (T) values obtained by these two analytical solutions were 21.9 and 20 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 15.4 m^2/d was obtained. The interpretation of the results are summarised in **Table 28.3** and the interpreted data is presented in **Figures 28.6** to **28.8**.

Table 28-3 Summary of Constant Rate and Recovery Tests BH10229

BH No.	CRT Duration (hours)	Q (m^3/d)	Pumping borehole T (m^2/d)		Obs. BH No.	Observation borehole			Aquifer type
						Pumping phase		Recovery phase	
			Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
10229	4320	485	a) 21.9 b) 20	d) 15.4	N/A	N/A	N/A	N/A	Confined

Notes:
Interpretation Techniques
b) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

28.3.2.1 Aquifer Type interpreted

The interpretation of the pump testing data indicates that the aquifer type is confined.

28.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none acidified) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. In addition, some samples collected were submitted for stable and unstable isotope analysis at the CSIR laboratory in Pretoria, South Africa.

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), pH and dissolved oxygen are 29.4 ^oC, 1440 µS/cm, 8.68 and 2.2 mg/L respectively.

Table 28-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10229	3	317	2.3	2.1	43	88	547	<0.1	2.3	0.47	<0.05	1360	8	870
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10229	<0.1	14	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

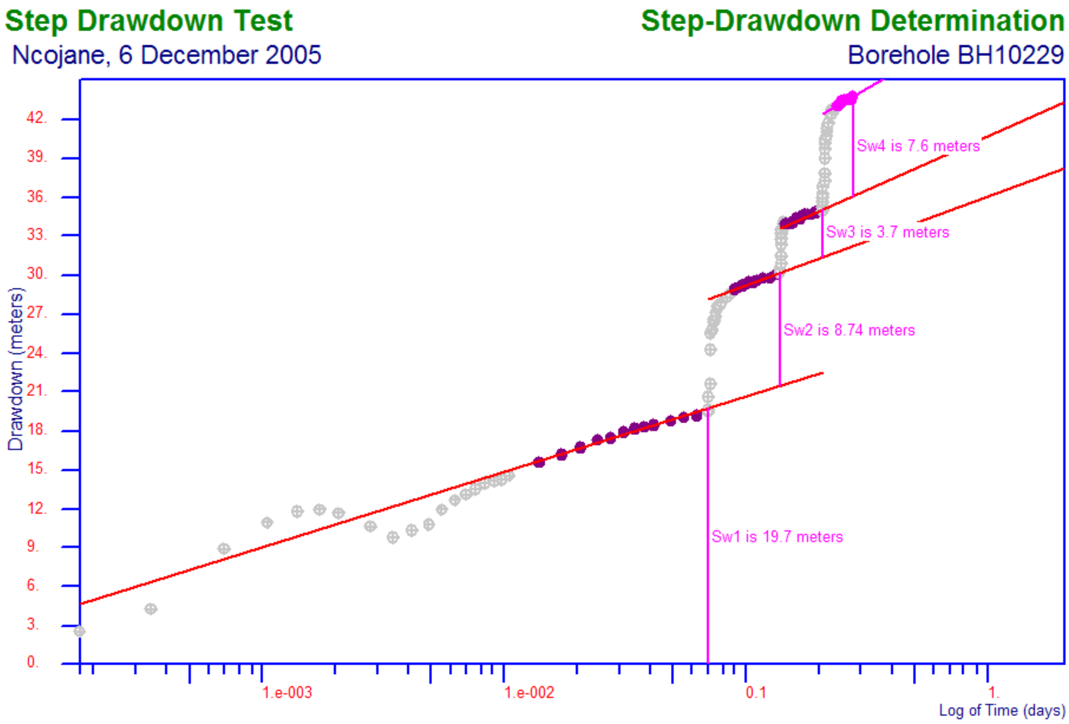

Figure 28-3 Pumping Test Results for BH10229: Step Drawdown Test - Hantush-Bierschenk (semi-log)

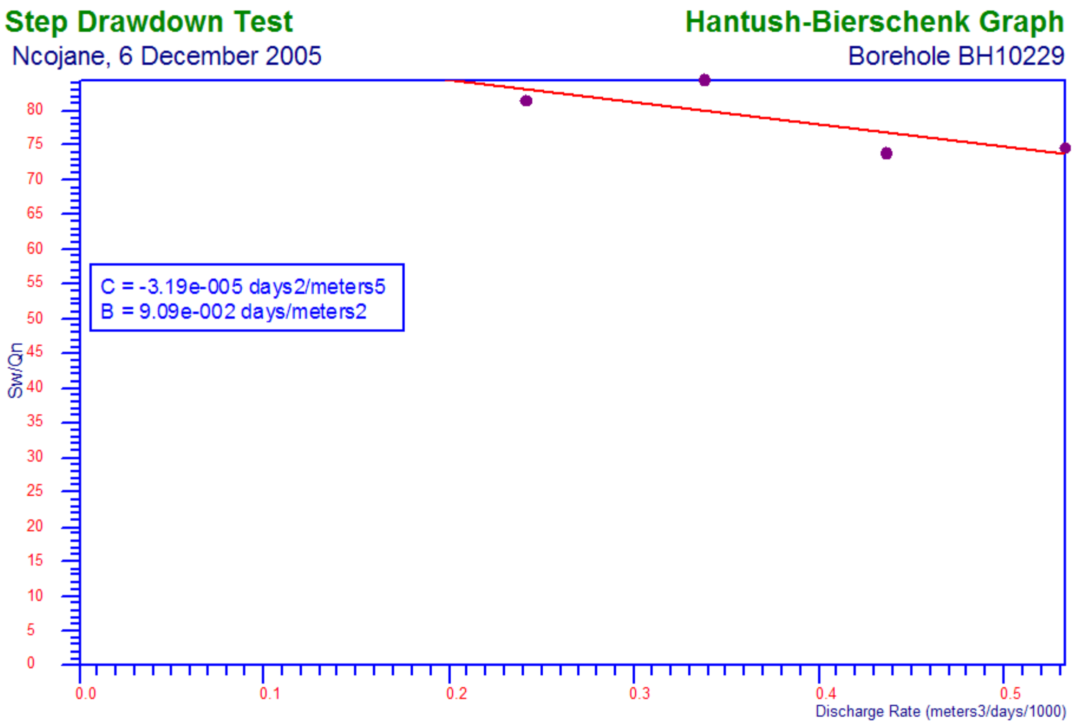

Figure 28-4 Pumping Test Results for BH10229: Step Drawdown Test – Hantush-Bierschenk

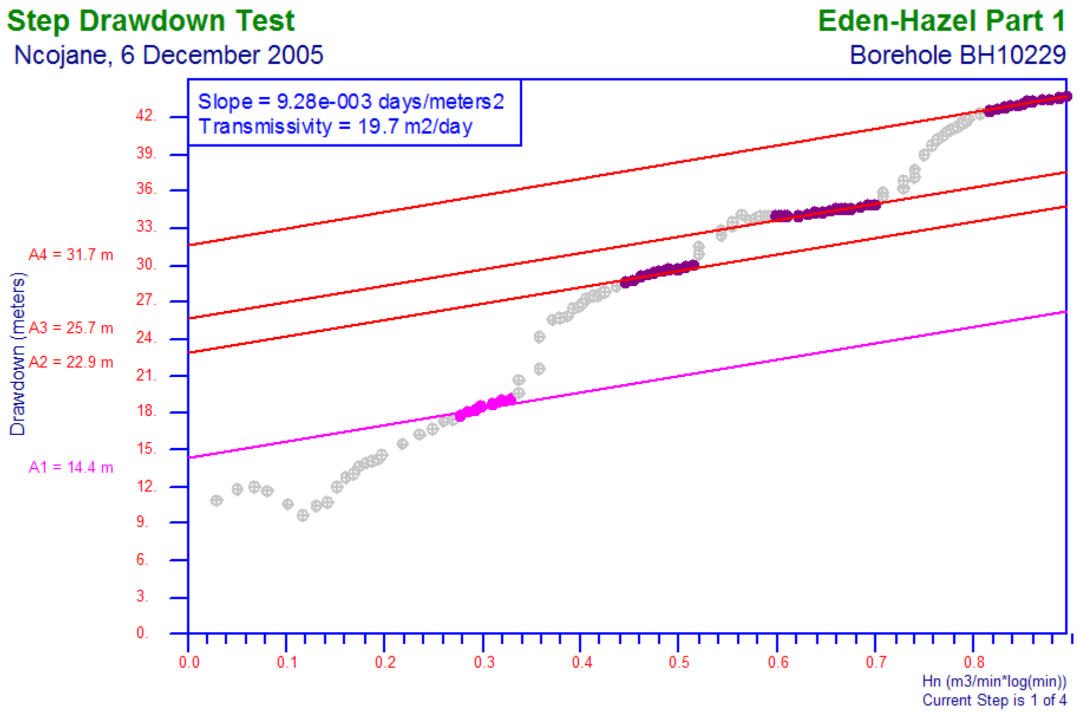

Figure 28-5 Pumping Test Results for BH10229: Step Drawdown Test – Eden-Hazel (Part 1)

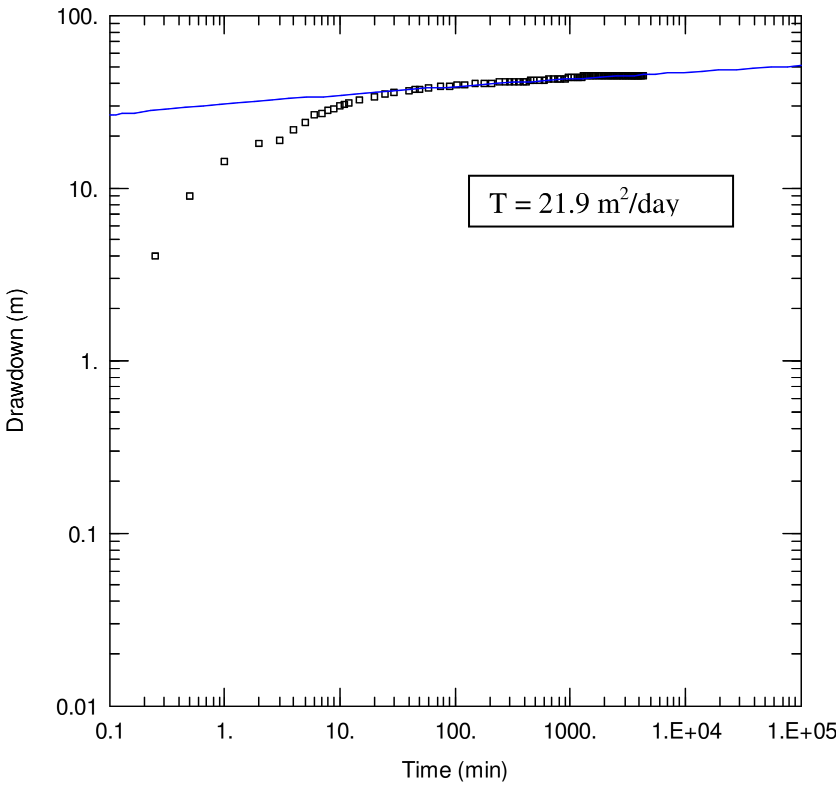

Figure 28-6 Pumping Test Results for BH10229: Theis Solution

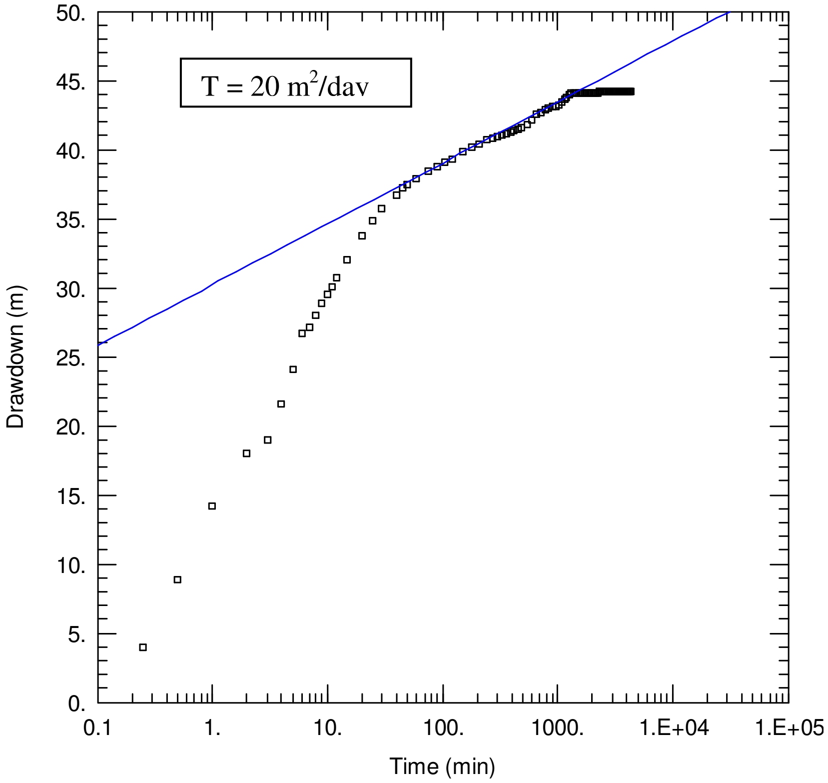

Figure 28-7 Pumping Test Results for BH10229: CRT Cooper Jacob Solution

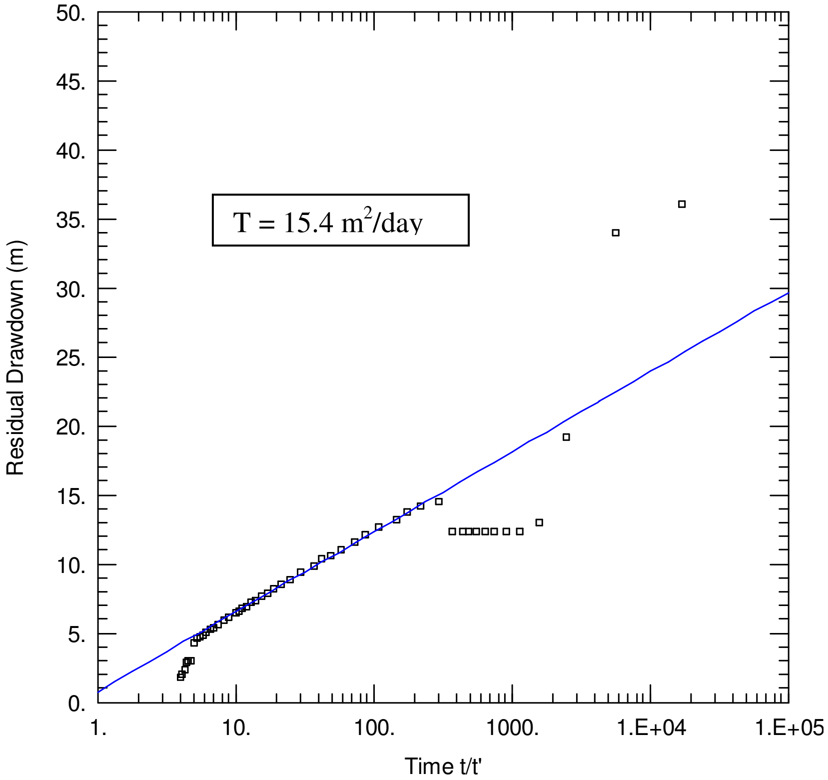

Figure 28-8 Pumping Test Results for BH10229: Theis Recovery Solution

Table 28-5 Calibration Test Data – BH10229

Official BH No.:	10229	District:	Kgalagadi
Date of test commencement:	05.12.2005	Location:	Metsimantsho
Time of test commencement	1330hrs	BH depth (m):	320
Date of test completion:	05.12.2005	Screen Interval (m):	
Time of test completion	1405hrs	Depth of pump intake (m):	150.5
Method of water level measurement:	dipper	Static water level before test (m):	94.18
Casing diameter (mm)	203	Water strike	
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	477490	Northing	74224711

STEP No. 1 / STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments
0.25	96.12	1.94				0.25	110.91	16.73			
0.5	97.39	3.21				0.5	111.57	17.39			
1	98.02	3.84				1	120.56	26.38	14.10	25.53	
1.5	101.35	7.17				1.5	124.04	29.86			adj
2	105.38	11.20				2	123.55	29.37	18.06	19.93	
2.5	106.76	12.58				2.5	123.31	29.13			
3	108.48	14.30				3	123.35	29.17	18.86	19.09	
4	108.61	14.43				4	123.45	29.27	17.82	20.20	adj
5	108.61	14.43	17.31	10.40		5	124.48	30.30	18.00	20.00	
6	108.61	14.43	17.50	10.29		6	125.42	31.24	18.19	19.79	
7	108.61	14.43	17.12	10.51		7	126.20	32.02	18.40	19.57	
8	108.75	14.57	17.21	10.46		8	126.85	32.67	18.24	19.74	
9	109.09	14.91	17.50	10.29		9	127.18	33.00	18.12	19.87	
10	109.39	15.21	17.22	10.45		10	127.69	33.51	18.51	19.45	
11	109.65	15.47	17.30	10.40		11	128.06	33.88	18.35	19.62	
12	109.89	15.71	17.29	10.41		12	128.46	34.28	18.26	19.72	
15	110.45	16.27	17.45	10.32		15	129.05	34.87	18.16	19.82	

STEP No. 3 / STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	129.92	35.74				0.25					
0.5	131.91	37.73				0.5					
1	135.73	41.55	27.01	26.66		1					
1.5	138.61	44.43			adj	1.5					
2	140.18	46.00	25.18	28.59		2					
2.5	141.39	47.21				2.5					
3	142.83	48.65	25.14	28.64		3					
4	145.00	50.82	25.21	28.56		4					
5	146.84	52.66	25.20	28.57		5					
6	suction					6					
7						7					
8						8					
9						9					
10						10					
11						11					
12						12					
15						15					

Table 28-6 Calibration Test Data – BH10229 (Repeat)

Official BH No.:	10229	District:	Kgalagadi
Date of test commencement:	05.12.2005	Location:	Metsimantsho
Time of test commencement	1700hrs	BH depth (m):	320
Date of test completion:	05.12.2005	Screen Interval (m):	
Time of test completion	1715hrs	Depth of pump intake (m):	150.5
Method of water level measurement:	dipper	Static water level before test (m):	96.74
Casing diameter (mm)	203	Water strike	
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	477490	Northing	74224711

STEP No. 1 | STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments
0.25	98.45	1.71				0.25					
0.5	99.96	3.22				0.5					
1	101.34	4.60				1					
1.5	102.10	5.36				1.5					
2	102.13	5.39				2					
2.5	102.05	5.31				2.5					
3	101.79	5.05				3					
4	101.33	4.59				4					
5	100.89	4.15	pumping 5m3/hr			5					
6	100.46	3.72	no water emerging			6					
7	100.09	3.35	borehole developing			7					
8	99.67	2.93				8					
9	99.29	2.55	calibration restarted			9					
10	99.00	2.26	at higher rate			10					
11	98.74	2.00				11					
12	98.55	1.81				12					
15	98.51	1.77				15					

Table 28-7 Calibration Test Data – BH10229 (Second repeat)

Official BH No.:	10229	District:	Kgalagadi
Date of test commencement:	05.12.2005	Location:	Metsimantsho
Time of test commencement	1730hrs	BH depth (m):	320
Date of test completion:	05.12.2005	Screen Interval (m):	
Time of test completion	1836hrs	Depth of pump intake (m):	150.5
Method of water level measurement:	dipper	Static water level before test (m):	96.02
Casing diameter (mm)		Water strike	
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	477490	Northing	74224711

STEPNo. 1 | STEPNo. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments
0.25	97.92	1.90				0.25	113.51	17.49			
0.5	100.21	4.19				0.5	113.97	17.95			
1	104.67	8.65				1	113.91	17.89	17.10	21.05	
1.5	107.09	11.07				1.5	114.06	18.04			
2	108.41	12.39				2	114.34	18.32	17.30	20.81	adj
2.5	108.97	12.95				2.5	114.65	18.63			adj
3	108.85	12.83				3	116.44	20.42	20.60	17.48	
4	108.02	12.00			adj	4	119.25	23.23	20.40	17.65	
5	107.88	11.86	17.78	10.12		5	120.46	24.44	24.94	14.43	adj
6	108.55	12.53	18.02	9.99		6	119.98	23.96	24.47	14.71	
7	109.22	13.20	17.91	10.05		7	120.00	23.98	23.91	15.06	
8	109.83	13.81	17.85	10.08		8	120.14	24.12	23.86	15.09	
9	110.07	14.05	17.90	10.06		9	120.33	24.31	23.89	15.07	
10	110.64	14.62	17.94	10.03		10	120.53	24.51	23.90	15.06	
11	110.69	14.67	17.86	10.08		11	120.69	24.67	23.94	15.04	
12	111.06	15.04	17.92	10.04		12	120.85	24.83	23.86	15.09	
15	111.70	15.68	17.94	10.03		15	121.25	25.23	23.88	15.08	

STEPNo. 3 | STENo. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P Rate (m^3/hr)	Comments
0.25	121.91	25.89				0.25	134.12	38.10			
0.5	124.45	28.43				0.5	134.99	38.97			
1	127.63	31.61	12.47	28.87		1	136.05	40.03	14.41	24.98	
1.5	130.19	34.17				1.5	136.90	40.88			
2	132.05	36.03	13.00	27.69	adj	2	137.06	41.04	14.10	25.53	
2.5	132.33	36.31				2.5	137.13	41.11			
3	132.68	36.66	15.49	23.24	adj	3	137.31	41.29	14.28	25.21	
4	132.14	36.12	16.69	21.57		4	137.69	41.67	14.25	25.26	
5	132.02	36.00	17.00	21.18		5	137.94	41.92	14.14	25.46	
6	131.89	35.87	17.20	20.93		6	138.28	42.26	14.20	25.35	
7	132.05	36.03	17.30	20.81		7	138.41	42.39	14.15	25.44	
8	132.33	36.31	17.60	20.45		8	138.57	42.55	14.18	25.39	
9	132.67	36.65	17.68	20.36		9	138.73	42.71	14.21	25.33	
10	132.98	36.96	17.59	20.47		10	138.95	42.93	14.23	25.30	
11	133.18	37.16	17.64	20.41		11	139.01	42.99	14.16	25.42	
12	133.36	37.34	17.69	20.35		12	139.08	43.06	14.19	25.37	
15	133.75	37.73	17.68	20.36		15	139.23	43.21	14.23	25.30	

Official BH No.:	10229	District:	Kgalagadi
Date of test commencement:	05.12.2005	Location:	Metsimantsho
Time of test commencement	1730hrs	BH depth (m):	320
Date of test completion:	05.12.2005	Screen Interval (m):	
Time of test completion	1836hrs	Depth of pump intake (m):	150.5
Method of water level measurement:	dipper	Static water level before test (m):	96.02
Casing diameter (mm)		Water strike	
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	477490	Northing	74224711

STEP No. 5 | STEP No. 6

TIME (min)	Depth	Drawdow	Time to	P Rate	Comments	TIME	Dept	Drawd	Time	P	Comment

	to WL (m)	n (m)	fill 100L	(m^3/hr)		(min)	h to WL (m)	own (m)	to fill 100L	Rate (m^3/hr)	s
0.25	139.99	43.97				0.25					
0.5	140.42	44.40				0.5					
1	140.57	44.55	13.96	25.79		1					
1.5	140.63	44.61				1.5					
2	140.71	44.69	12.72	28.30	adj	2					
2.5	141.33	45.31				2.5					
3	141.47	45.45	12.77	28.19		3					
4	142.01	45.99	11.00	32.73		4					
5	142.18	46.16	12.10	29.75	adj	5					
6	142.18	46.16	12.78	28.17		6					
7	suction					7					
8						8					
9						9					
10						10					
11						11					
12						12					
15						15					

Table 28-8 Step Drawdown Test Data – BH10229

Official BH No.:	10229	District:	Ghanzi
Date of test commencement:	06.12.2005	Location:	Metsimantsho
Time of test Commencement:	0630hrs	BH depth (m):	320
Date of test completion:	06.12.2005	Screens(m)	
Time of test Completion:	1318hrs	Depth to pump intake (m)	150.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	NA	Height of MP above ground:	0.65
Distance to OB. BH (m)	NA	Static water level before test (m):	96.3
Casing diameter (mm)	NA	Water strike	
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	477490	Northing	74224711

STEP No. 1 / STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments
0.25	98.77	2.47				0.25	115.71	19.41			
0.5	100.63	4.33				0.5	115.89	19.59			
1	105.19	8.89				1	116.91	20.61	12.91	13.94	
1.5	107.25	10.95				1.5	117.94	21.64	13.41	13.42	
2	108.14	11.84				2	120.49	24.19	13.01	13.84	
2.5	108.30	12.00				2.5	121.79	25.49	12.70	14.17	adj
3	107.91	11.61				3	121.95	25.65	12.89	13.96	
4	106.90	10.60				4	122.01	25.71	12.96	13.89	
5	106.00	9.70	17.69	10.18	adj	5	122.25	25.95	12.88	13.98	
6	106.70	10.40	17.24	10.44		6	122.68	26.38	12.79	14.07	
7	107.08	10.78	17.86	10.08		7	122.95	26.65	12.62	14.26	
8	108.23	11.93	17.79	10.12		8	123.20	26.90	12.56	14.33	
9	108.99	12.69	17.91	10.05		9	123.47	27.17	12.49	14.41	
10	109.44	13.14	17.96	10.02		10	123.65	27.35	12.40	14.52	
11	109.85	13.55	17.87	10.07		11	123.76	27.46	12.64	14.24	
12	110.19	13.89	17.90	10.06		12	123.91	27.61	12.77	14.10	
13	110.37	14.07	17.76	10.14		13	124.02	27.72	12.85	14.01	
14	110.51	14.21	17.89	10.06		14	124.09	27.79	12.81	14.05	
15	110.77	14.47	17.74	10.15		15	124.25	27.95	12.67	14.21	
20	111.78	15.48	17.95	10.03		20	124.61	28.31	12.80	14.06	
25	112.49	16.19	17.66	10.19		25	124.87	28.57	12.65	14.23	
30	113.02	16.72	17.77	10.13		30	125.11	28.81	12.64	14.24	
35	113.55	17.25	17.81	10.11		35	125.30	29.00	12.49	14.41	
40	113.81	17.51	17.63	10.21		40	125.50	29.20	12.67	14.21	
45	114.11	17.81	17.56	10.25		45	125.59	29.29	12.80	14.06	
50	114.35	18.05	17.92	10.04		50	125.76	29.46	12.77	14.10	
55	114.59	18.29	17.87	10.07		55	125.82	29.52	12.64	14.24	
60	114.80	18.50	17.51	10.28		60	125.90	29.60	12.49	14.41	
70	115.04	18.74	17.68	10.18		70	126.04	29.74	12.65	14.23	
80	115.31	19.01	17.73	10.15		80	126.13	29.83	12.67	14.21	
90	115.51	19.21	17.94	10.03		90	126.26	29.96	12.64	14.24	
100	115.65	19.35	17.87	10.07		100	126.40	30.10	12.85	14.01	

Official BH No.:	10229	District:	Ghanzi
Date of test commencement:	06.12.2005	Location:	Metsimantsho
Time of test Commencement:	0630hrs	BH depth (m):	320
Date of test completion:	06.12.2005	Screens(m)	
Time of test Completion:	1318hrs	Depth to pump intake (m)	150.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	NA	Height of MP above ground:	0.65
Distance to OB. BH (m)	NA	Static water level before test (m):	96.3
Casing diameter (mm)	NA	Water strike	
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	477490	Northing	74224711

STEP No. 3 — STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	126.71	30.41				0.25	131.58	35.28			
0.5	127.17	30.87				0.5	131.89	35.59			
1	127.83	31.53	19.32	18.63		1	132.19	35.89	17.85	20.17	
1.5	128.67	32.37				1.5	132.55	36.25			
2	129.09	32.79	19.08	18.87	adj	2	133.05	36.75	16.45	21.88	
2.5	129.49	33.19				2.5	133.46	37.16			
3	129.81	33.51	19.72	18.26		3	134.09	37.79	16.47	21.86	Adj
4	130.43	34.13	19.86	18.13		4	135.29	38.99	16.00	22.50	
5	130.02	33.72	19.54	18.42		5	136.01	39.71	16.19	22.24	
6	130.12	33.82	19.70	18.27		6	136.46	40.16	16.29	22.10	
7	130.22	33.92	19.83	18.15		7	136.85	40.55	16.18	22.25	
8	130.22	33.92	19.91	18.08		8	137.05	40.75	16.15	22.29	
9	130.22	33.92	19.76	18.22		9	137.31	41.01	16.25	22.15	
10	130.22	33.92	19.79	18.19		10	137.43	41.13	16.23	22.18	
11	130.22	33.92	19.60	18.37		11	137.61	41.31	16.13	22.32	
12	130.22	33.92	19.86	18.13		12	137.77	41.47	16.20	22.22	
13	130.22	33.92	19.90	18.09		13	137.85	41.55	16.26	22.14	
14	130.22	33.92	19.77	18.21		14	138.00	41.70	16.28	22.11	
15	130.23	33.93	19.86	18.13		15	138.13	41.83	16.19	22.24	
20	130.34	34.04	19.83	18.15		20	138.57	42.27	16.21	22.21	
25	130.44	34.14	19.94	18.05		25	138.85	42.55	16.24	22.17	
30	130.51	34.21	19.60	18.37		30	138.98	42.68	16.19	22.24	
35	130.63	34.33	19.59	18.38		35	139.10	42.80	16.23	22.18	
40	130.72	34.42	19.67	18.30		40	139.24	42.94	16.29	22.10	
45	130.80	34.50	19.69	18.28		45	139.30	43.00	16.34	22.03	
50	130.86	34.56	19.57	18.40		50	139.43	43.13	16.09	22.37	
55	130.91	34.61	19.70	18.27		55	139.52	43.22	16.23	22.18	
60	130.95	34.65	19.68	18.29		60	139.61	43.31	16.26	22.14	
70	131.00	34.70	19.74	18.24		70	139.73	43.43	16.26	22.14	
80	131.11	34.81	19.76	18.22		80	139.75	43.45	16.29	22.10	
90	131.21	34.91	19.77	18.21		90	139.80	43.50	16.25	22.15	
100	131.35	35.05	19.55	18.41		100	140.00	43.70	16.21	22.21	

Official BH No.:	10229	District:	Ghanzi
Date of test commencement:	06.12.2005	Location:	Metsimantsho
Time of test Commencement:	0630hrs	BH depth (m):	320
Date of test completion:	06.12.2005	Screens(m)	
Time of test Completion:	1318hrs	Depth to pump intake (m)	150.5
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	NA	Height of MP above ground:	0.65
Distance to OB. BH (m)	NA	Static water level before test (m):	96.3
Casing diameter (mm)	NA	Water strike	
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	477490	Northing	74224711

STEP No. 5 | STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments
0.25	140.08	43.78				0.25					
0.5	140.75	44.45				0.5					
1	141.05	44.75	13.94	25.82		1					
1.5	141.53	45.23				1.5					
2	141.85	45.55	13.87	25.96	adj	2					
2.5	142.33	46.03	13.56	26.55		2.5					
3	142.83	46.53	13.49	26.69		3					
4	143.50	47.20	13.52	26.63		4					
5	143.92	47.62	13.62	26.43		5					
6	144.21	47.91	13.70	26.28		6					
7	145.69	49.39	13.72	26.24		7					
8	146.87	50.57	13.80	26.09		8					
9	suction					9					
10						10					
11						11					
12						12					
13						13					
14						14					
15						15					
20						20					
25						25					
30						30					
35						35					
40						40					
45						45					
50						50					
55						55					
60						60					
70						70					
80						80					
90						90					
100						100					

Table 28-9 Constant Rate Test Data – BH10229

Official BH NO :	10229	District :	Ghanzi
Date of test commencement :	07.12.2005	Location :	Metsimantsho
Time of test commencement :	0800hrs	BH depth(m) :	320
Date of test completion	10.12.2005	Screen Interval (m)	
Time of test completion :	0800hrs	Depth of pump intake (m) :	150.5m
Method of water level measurement	dipper	Description of MP	top of dipper tuping
OB BH NO:	n/a	Height of MP above ground(m) :	0.65
Distance ob BH r (m)	n/a	Static Water level before test(m) :	97.05
Casing diameter (mm)	203	Water strike	
Orifice plate diameter	4"	Delivery pipe diameter	75 mm
Easting	477490	Northing	74224711

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 100l	$Q(m^3/h)$	Temp (^0C)	EC (µs/Cm)	pH	Manometer
	0.25	101.05	4.00						
	0.5	105.95	8.90						
	1	111.26	14.21						
	2	115.09	18.04						
	3	115.97	18.92	18.20	19.78				Adj
	4	118.59	21.54	17.56	20.50				
	5	121.09	24.04	17.75	20.28				
	6	123.72	26.67	17.86	20.16				
	7	124.15	27.10	17.69	20.35				
	8	125.00	27.95	17.80	20.22				
	9	125.91	28.86	17.64	20.41				
	10	126.57	29.52	17.76	20.27				
	11	127.14	30.09	17.83	20.19				
	12	127.75	30.70	17.90	20.11				
	15	129.09	32.04	17.70	20.34	28.6	1420	8.34	11
	20	130.78	33.73	17.69	20.35	28.2	1410	8.41	11
	25	131.88	34.83	17.85	20.17	28.3	1380	8.38	11
	30	132.75	35.70	17.61	20.44	28.4	1420	8.38	11
	40	133.72	36.67	17.93	20.08	28.5	1410	8.36	11
	45	134.24	37.19	17.57	20.49	28.6	1430	8.35	11
	50	134.48	37.43	17.88	20.13	28.8	1450	8.32	11
	60	134.98	37.93	17.72	20.32	28.8	1420	8.34	11
	75	135.45	38.40	17.54	20.52	28.9	1410	8.35	11
	90	135.76	38.71	17.94	20.07	29.2	1430	8.32	11
	105	136.08	39.03	17.66	20.39	29.4	1420	8.34	11
	120	136.36	39.31	17.82	20.20	29.3	1430	8.34	11
	150	136.87	39.82	17.73	20.30	29.6	1430	8.31	11
	180	137.25	40.20	17.38	20.71	29.7	1430	8.32	11
	210	137.39	40.34	17.96	20.04	29.8	1430	8.32	11
	240	137.79	40.74	17.56	20.50	29.9	1430	8.33	11
	270	137.91	40.86	17.69	20.35	29.9	1430	8.34	11
	300	138.01	40.96	17.76	20.27	30.0	1430	8.34	11
	330	138.10	41.05	17.81	20.21	30.0	1410	8.29	11
	360	138.15	41.10	17.88	20.13	30.1	1410	8.28	11
	390	138.28	41.23	17.67	20.37	30.2	1430	8.30	11
	420	138.40	41.35	17.55	20.51	30.2	1420	8.30	11
	450	138.49	41.44	17.96	20.04	30.2	1420	8.25	11
	480	138.63	41.58	17.68	20.36	30.5	1420	8.26	11
	540	138.81	41.76	17.73	20.30	30.6	1380	8.26	11
	600	139.18	42.13	17.56	20.50	30.7	1410	8.31	11
	660	139.59	42.54	17.79	20.24	29.5	1420	8.32	11
	720	139.72	42.67	17.63	20.42	28.8	1430	8.35	11
	780	139.89	42.84	17.87	20.15	28.7	1430	8.34	11
	840	140.03	42.98	17.90	20.11	28.5	1430	8.34	11
	900	140.14	43.09	17.79	20.24	28.7	1390	8.35	11
	960	140.20	43.15	17.80	20.22	28.6	1420	8.35	11
	1020	140.31	43.26	17.63	20.42	27.9	1410	8.34	11
	1080	140.49	43.44	17.76	20.27	27.6	1410	8.36	11
	1140	140.64	43.59	17.89	20.12	27.8	1420	8.35	11
	1200	140.84	43.79	17.80	20.22	27.6	1430	8.64	11
	1260	141.01	43.96	17.89	20.12	27.8	1440	8.71	11
	1320	141.16	44.11	17.94	20.07	27.4	1450	8.39	11
	1380	141.18	44.13	17.80	20.22	27.6	1440	8.67	11
	1440	141.18	44.13	17.63	20.42	26.9	1430	8.38	DO2 = 2.5mg/l
	1500	141.18	44.13	17.76	20.27	28.8	1440	8.02	11

	1560	141.18	44.13	17.89	20.12	28.7	1430	8.00	11
	1620	141.18	44.13	17.80	20.22	29.4	1450	7.97	11
	1680	141.18	44.13	17.89	20.12	28.6	1440	7.86	11
	1740	141.18	44.13	17.94	20.07	29.2	1450	7.83	11
	1800	141.18	44.13	17.87	20.15	28.8	1430	7.92	11
	1860	141.18	44.13	17.94	20.07	29.6	1410	8.09	11
	1920	141.18	44.13	17.89	20.12	29.4	1410	8.08	11
	1980	141.18	44.13	17.80	20.22	29.6	1430	8.41	11
	2040	141.18	44.13	17.89	20.12	28.6	1440	8.61	11
	2100	141.18	44.13	17.94	20.07	28.9	1450	8.45	11
	2160	141.18	44.13	17.94	20.07	28.6	1440	8.46	11
	2220	141.18	44.13	17.76	20.27	29.2	1430	8.54	11
	2280	141.19	44.14	17.94	20.07	28.6	1440	8.62	11
	2340	141.19	44.14	17.57	20.49	28.3	1440	8.61	11
	2400	141.19	44.14	17.86	20.16	28.2	1430	8.65	11
	2460	141.19	44.14	17.91	20.10	28.2	1420	8.62	11
	2520	141.19	44.14	17.66	20.39	28.1	1420	8.60	11
	2580	141.19	44.14	17.57	20.49	27.9	1430	8.53	11
	2640	141.20	44.15	17.94	20.07	27.7	1420	8.54	11
	2700	141.20	44.15	17.89	20.12	27.6	1430	8.52	11
	2760	141.21	44.16	17.80	20.22	27.9	1440	8.53	11
	2820	141.21	44.16	17.63	20.42	27.6	1410	8.28	11
	2880	141.21	44.16	17.79	20.24	27.7	1410	8.30	DO2 = 1.8mg/l
	2940	141.22	44.17	17.76	20.27	27.8	1420	8.31	11
	3000	141.22	44.17	17.70	20.34	27.5	1410	8.34	11
	3060	141.23	44.18	17.76	20.27	29.0	1420	8.24	11
	3120	141.24	44.19	17.86	20.16	29.7	1400	8.26	11
	3180	141.24	44.19	17.89	20.12	29.8	1410	8.25	11
	3240	141.24	44.19	17.56	20.50	30.2	1410	8.25	11
	3300	141.25	44.20	17.74	20.29	29.8	1400	8.14	11
	3360	141.25	44.20	17.69	20.35	29.7	1410	8.24	11
	3420	141.25	44.20	17.97	20.03	29.8	1350	8.13	11
	3480	141.25	44.20	17.85	20.17	29.9	1410	8.20	11
	3540	141.25	44.20	17.76	20.27	29.7	1440	8.22	11
	3600	141.26	44.21	17.57	20.49	29.5	1400	8.29	11
	3660	141.26	44.21	17.63	20.42	28.7	1410	8.32	11
	3720	141.26	44.21	17.89	20.12	28.5	1410	8.34	11
	3780	141.27	44.22	17.80	20.22	28.6	1440	8.61	11
	3840	141.27	44.22	17.94	20.07	28.5	1430	8.70	11
	3900	141.27	44.22	17.89	20.12	28.8	1410	8.68	11
	3960	141.27	44.22	17.80	20.22	28.4	1450	8.57	11
	4020	141.27	44.22	17.87	20.15	28.6	1440	8.64	11
	4080	141.27	44.22	17.96	20.04	28.4	1410	8.56	11
	4140	141.28	44.23	17.80	20.22	28.2	1420	8.54	11
	4200	141.28	44.23	17.94	20.07	28.7	1440	8.67	11
	4260	141.28	44.23	17.87	20.15	28.6	1460	8.74	11

Table 28-10 Recovery Test Data – BH10229

Official BH NO :	10229	District :	Ghanzi
Date of test commencement :	10.12.2005	Location :	Metsimantsho
Time of test commencement :	0800hrs	BH depth(m) :	320
Date of test completion	11.12.2005	Screen Int (m)	
Time of test completion :	0800hrs	Depth of pump intake (m) :	150.5
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	NA	Height of MP above ground(m) :	0.65
Dist.to Pumping Bh:	NA	Static Water level before test(m) :	97.05
Casing diameter (mm)	203	Water strike	
Orifice plate diameter		Delivery pipe diameter	
Easting	477490	Northing	74224711

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	141.28	44.23
	0.25	138.12	41.07
	0.5	133.10	36.05
	1	131.03	33.98
	2	116.19	19.14
	3	110.01	12.96
	4	109.38	12.33
	5	109.38	12.33
	6	109.38	12.33
	7	109.38	12.33
	8	109.38	12.33
	9	109.38	12.33
	10	109.38	12.33
	12	109.38	12.33
	15	111.56	14.51
	20	111.21	14.16
	25	110.79	13.74
	30	110.25	13.20
	40	109.75	12.70
	50	109.16	12.11
	60	108.68	11.63
	75	108.11	11.06
	90	107.66	10.61
	105	107.38	10.33
	120	106.92	9.87

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	106.48	9.43
	180	105.95	8.90
	210	105.55	8.50
	240	105.21	8.16
	270	104.93	7.88
	300	104.68	7.63
	330	104.44	7.39
	360	104.23	7.18
	390	103.99	6.94
	420	103.82	6.77
	450	103.66	6.61
	480	103.49	6.44
	540	103.19	6.14
	600	102.94	5.89
	660	102.69	5.64
	720	102.48	5.43
	780	102.29	5.24
	840	102.09	5.04
	900	101.91	4.86
	960	101.83	4.78
	1020	101.68	4.63
	1080	101.30	4.25
	1140	100.09	3.04
	1200	100.01	2.96
	1260	99.92	2.87
	1320	99.41	2.36
	1380	99.03	1.98
	1440	98.88	1.83

29 BH10314

BH10314 is an exploration borehole with a siting reference **S11,** TEM 92, line R8 and peg 3000m. It is located in the Ncojane Ranches, about 20 km south-east of Metsimantsho Village. Drilling of this borehole commenced on 13 November 2005 and was completed on 8 December 2005 at a depth of 300 m.

29.1 SITING CRITERIA AND DRILLING OBJECTIVES

This exploration borehole was drilled to explore the relatively undisturbed Ecca aquifer near fault **F6** and to assess Ecca aquifer overlain by thick argillaceous units.

29.2 DRILLING RESULTS

Various lithologies including fine grained sand, calcrete, silcrete, mudstones, coal and fine to medium grained sandstones were intercepted during drilling of this exploration borehole (**Figure 29-1**). Drilling was carried out with a 15 inch bit using the DTH drilling technique from 0 to 87 m bgl after which 12 inch plain casings were installed and cement grouted. From 87 m to 194 m drilling was carried out using a 12 inch drilling bit after which 10 inch casings were installed. The annulus between the 10 inch casing and 12 inch hole was cement grouted to a depth of 15 m from the ground surface to seal off the saline water strikes. A 10 inch DTH bit was used to drill from 194 m to 282 m and a $9^{7/8}$ inch tri-cone bit was used from 282 m to the terminal depth of 300 m.

Seven different water strikes were encountered at various depths during drilling of this borehole. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for these water strikes are as follows:

1. 105m, 14230 µS/cm, Not measurable
2. 116m, 18700 µS/cm, 4.5 m^3/hr
3. 152m, 18600 µS/cm, 7.8 m^3/hr
4. 155m, 19000 µS/cm, 17.28 m^3/hr
5. 232m, 5040 µS/cm, 9.18 m^3/hr
6. 258m, 3700 µS/cm, 6.76 m^3/hr
7. 276m, 2800 µS/cm, 20.78 m^3/hr

The top four water strikes were grouted and the cumulative yield at the end of drilling before installation of the casing and screens assembly was 36.72 m^3/hr.

The borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 252.8m but has to be re-logged due to the poor data quality caused by the malfunctioning probe **(Figure 29-2).** An 8 inch steel casing and factory slotted screen (intervals 275.48 to 281.61 m bgl and 284.74 to 297 m bgl) assembly was installed.

The borehole was developed using the air lifting method for 6 hours and the final airlift yield measured was 42.9m^3/hr and the electrical conductivity was 3010µS/cm. The static water level measured on 8 December 2005 was 99.52m bgl.

Water samples were collected at all the water strikes and after borehole development. The samples collected at the different water strikes were submitted to the CSIR laboratory in Pretoria for isotope analysis (^{18}O and ^{2}H) and the result are presented in **Appendix 3.**

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

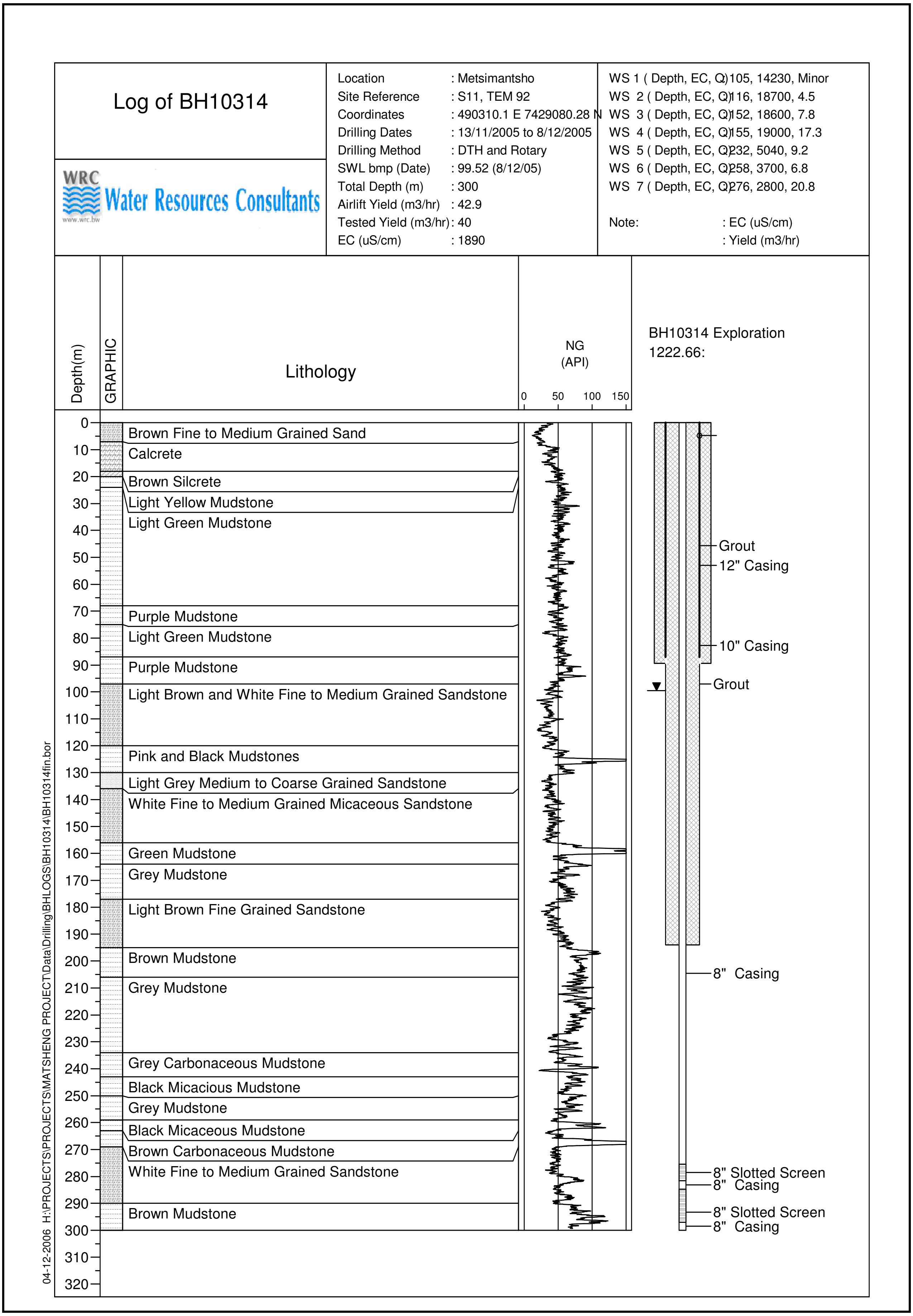

Figure 29-1 Log of BH10314

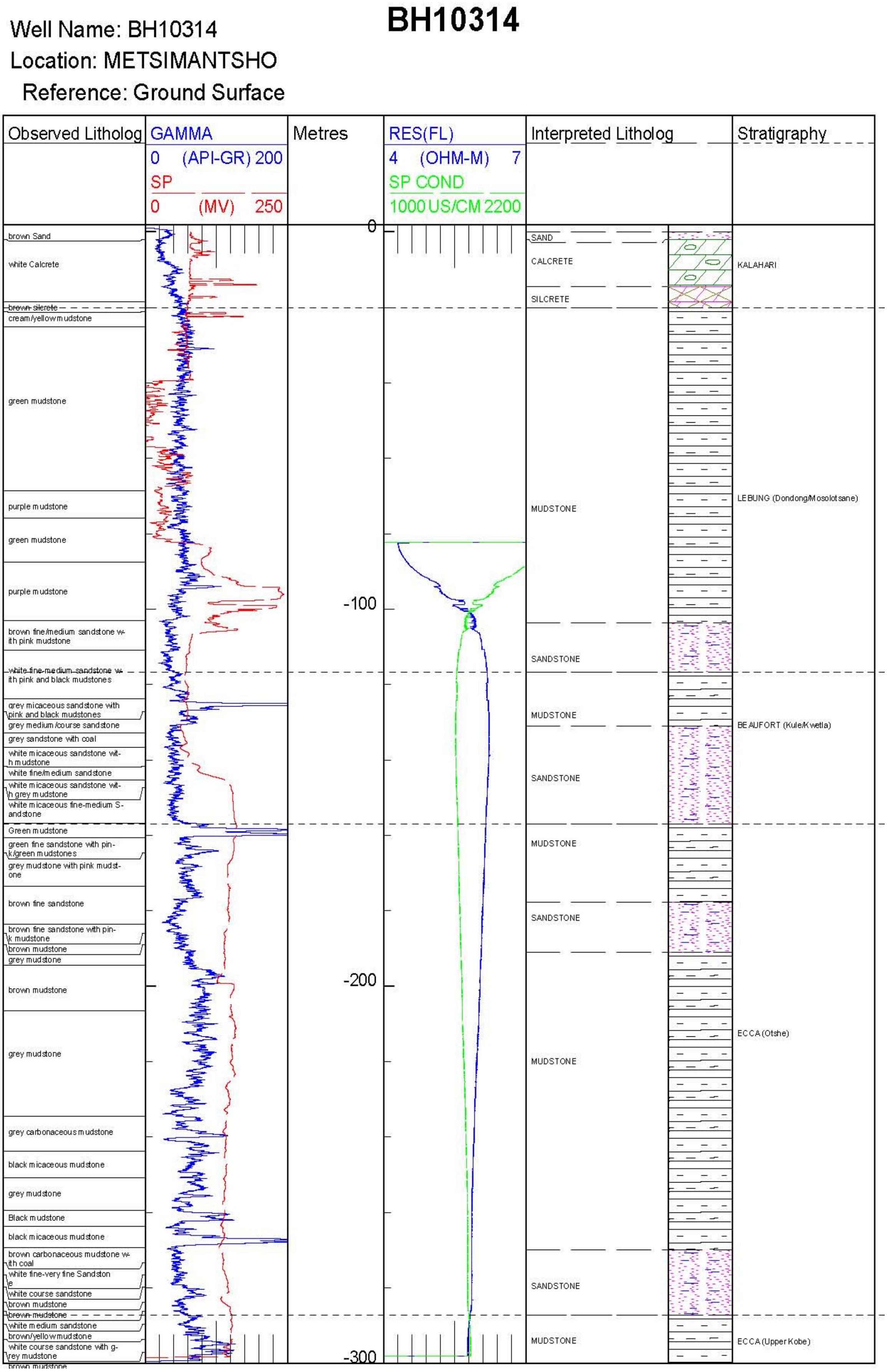

Figure 29-2 Geophysical log of BH10314

29.3 PUMP TESTING RESULTS

Borehole BH10314 was pump tested between 16 and 27 January 2006. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.45 m above ground level (agl) and the pump intake was set at 150.5 m below ground level. There were two mechanical breakdowns during the constant rate tests and this resulted in more days used to complete the test. The summary details for the pumping test are given in **Table 29-1**. The collected data is presented in **Tables 29-5 to 29-8**.

Table 29-1 Summary of Pumping Test Data BH10314

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m³/hr]
Calibration	1	15	7.95	9.9
	2	15	13.56	15
	3	15	19.68	20
	4	15	25.4	25
	5	15	30.32	30
	6	15	38.82	40
	7	15	51.96	50
Step Test	1	100	11.22	10
	2	100	21.05	20
	3	100	34.71	30
	4	100	44.38	40
	5	100	58.46	50
Constant Rate	1	4320	51.52	40
Recovery	1	1440	6.46	0

Note. 6.46 Residual Drawdown*

29.3.1 Step Drawdown Test

The step drawdown test was carried out on 17 January 2006. The static water level before the start of the test was 82.15 m bmp. The step drawdown test consisted of 5 steps of 100 minutes duration at discharge rates of 10, 20, 30, 40 and 50 m^3/hr, respectively for steps 1 to 5. A sixth step at 60 m^3/hr lasted for 15 minutes only.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test using this method is plotted in **Figure 29-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 29-4**. The Transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 24.9 m^2/d, **Figure 29-5**.

The results for the step test interpretation are tabulated in **Table 29-2**.

Table 29-2 Results of Step Test Analysis BH10314

BH	B (d/m²)	C (d²/m⁵)	T (m²/d)	Q (m³/hr)	ΔS (m)	s_w (m)	Q/s_w (m³/hr/m)
10314	4.61E-02	-1.93E-06	24.9	10.0	11.50	11.50	0.87
				20.0	8.69	20.19	0.99
				30.0	12.70	32.89	0.91
				40.0	8.18	41.07	0.97
				50.0	13.20	54.27	0.92

The planned duration for the constant rate test of this borehole is 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 29-3**) to estimate the expected total drawdown after 3 days of pumping. A discharge rate of 45m^3/hr is ideal for this borehole but since the borehole is close to fault **F6**, a conservative rate of 40 m^3/hr was instead selected for the CRT.

29.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 23 and 26 January 2006 at a discharge rate of 40 m^3/hr and the total drawdown after 72 hrs of pumping was 51.52 m. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 6.46 m.

Data from the pumping borehole was interpreted using the Theis and Cooper-Jacob (1946) analytical solutions using the computer programme "Aqtesolv". Transmissivity (T) values obtained by these two analytical solutions were 34 and 36 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 32.8 m^2/d was obtained. The interpretation of the results are summarised in **Table 29-3** and the interpreted data is presented in **Figures 29-6** to **29-8**.

There is an apparent impermeable barrier interpreted in the CRT data after 1000 minutes of pumping, **Figure 29-.2**. This barrier is caused by fault **F6** which is close to BH10314.

Table 29-3 Summary of Constant Rate and Recovery Tests BH10314

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10314	72	960	a) 34 b) 36	d) 32.8	Confined

Notes:
Interpretation Techniques
a) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

29.3.2.1 Aquifer Type interpreted

The interpretation of the pump testing data indicates that the aquifer type is confined.

29.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. The results are presented in **Table 29-4**. In addition, some samples collected at 72 hrs were be submitted for stable and unstable isotope analysis at the CSIR laboratory in Pretoria, South Africa.

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), pH and dissolved oxygen are 29.7 ^{o}C, 1890 µS/cm, 8.56 and 1.82 mg/L respectively.

Table 29-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10314	2.7	317	1.1	0.6	76	115	744	<0.1	2.5	0.16	<0.05	1890	7.5	1210
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10314	<0.1	5	0.15	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

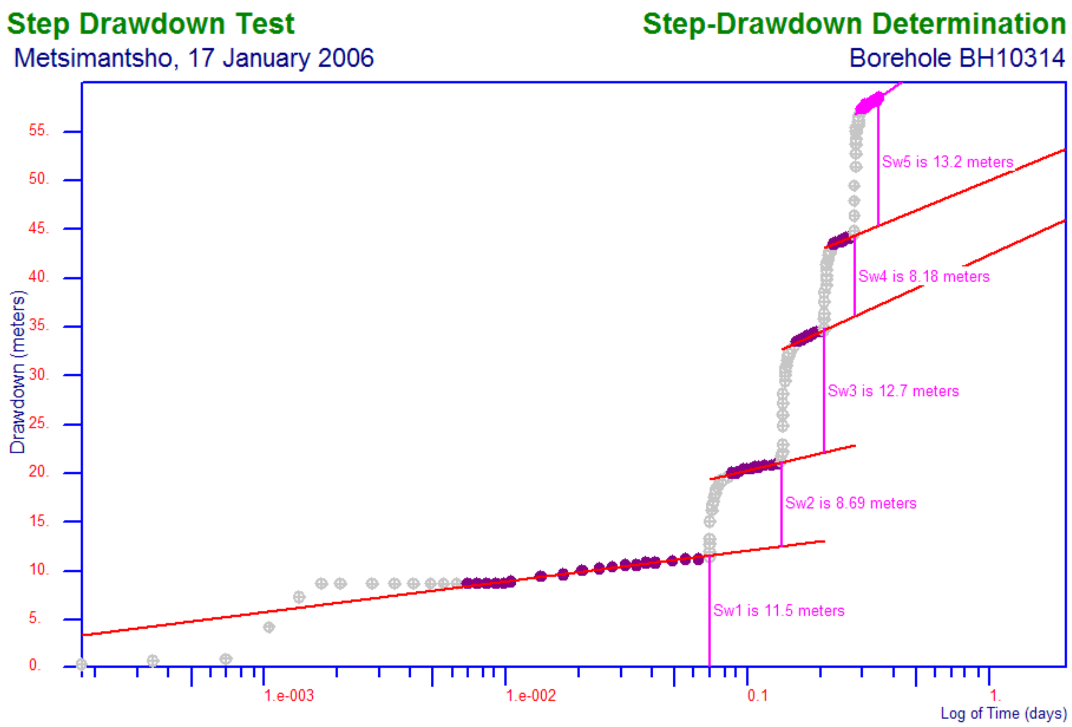

Figure 29-3 Pumping Test Results for BH10314: Step Drawdown Test - Hantush-Bierschenk (semi-log)

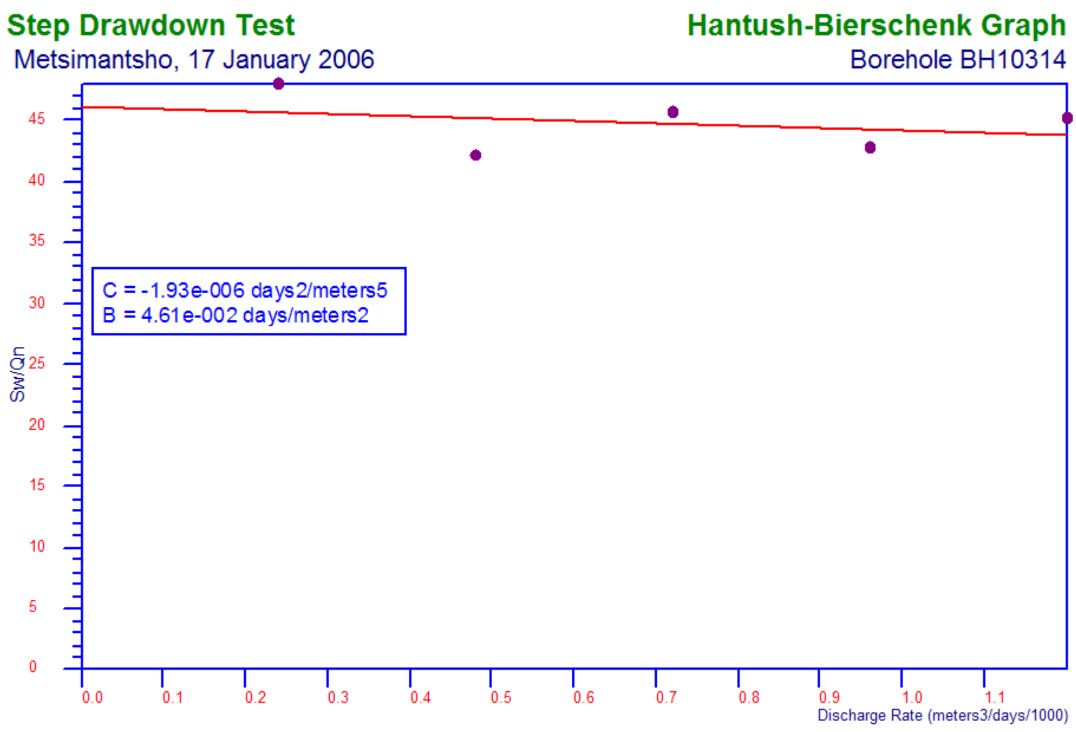

Figure 29-4 Pumping Test Results for BH10314: Step Drawdown Test – Hantush-Bierschenk

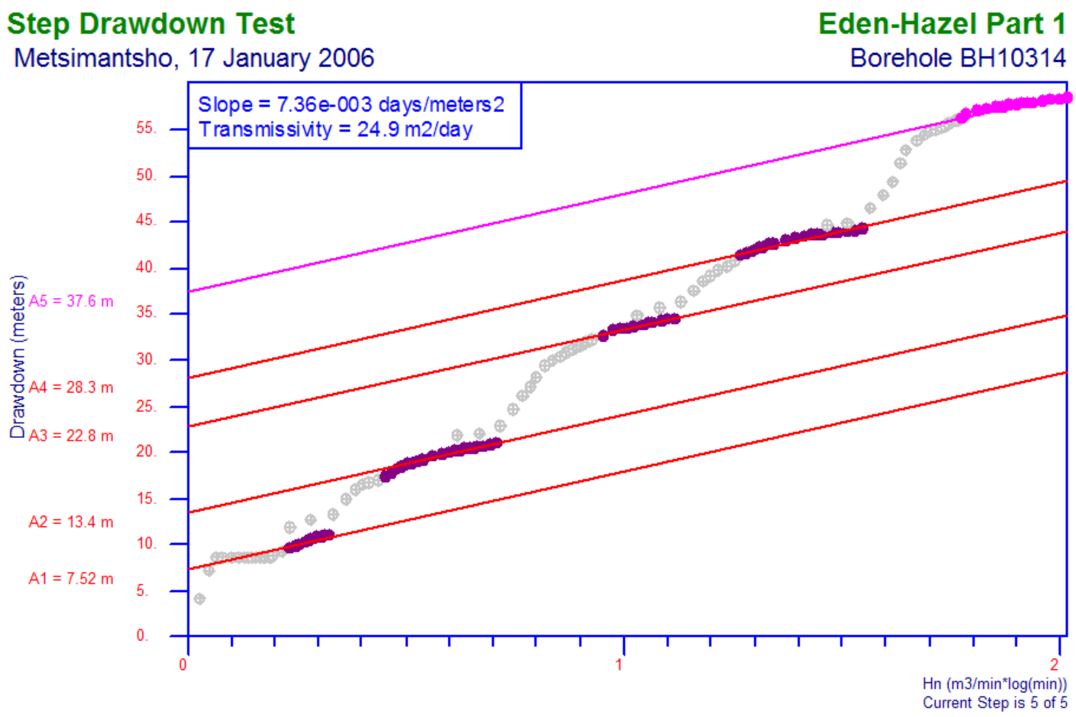

Figure 29-5 Pumping Test Results for BH10314: Step Drawdown Test – Eden-Hazel (Part 1)

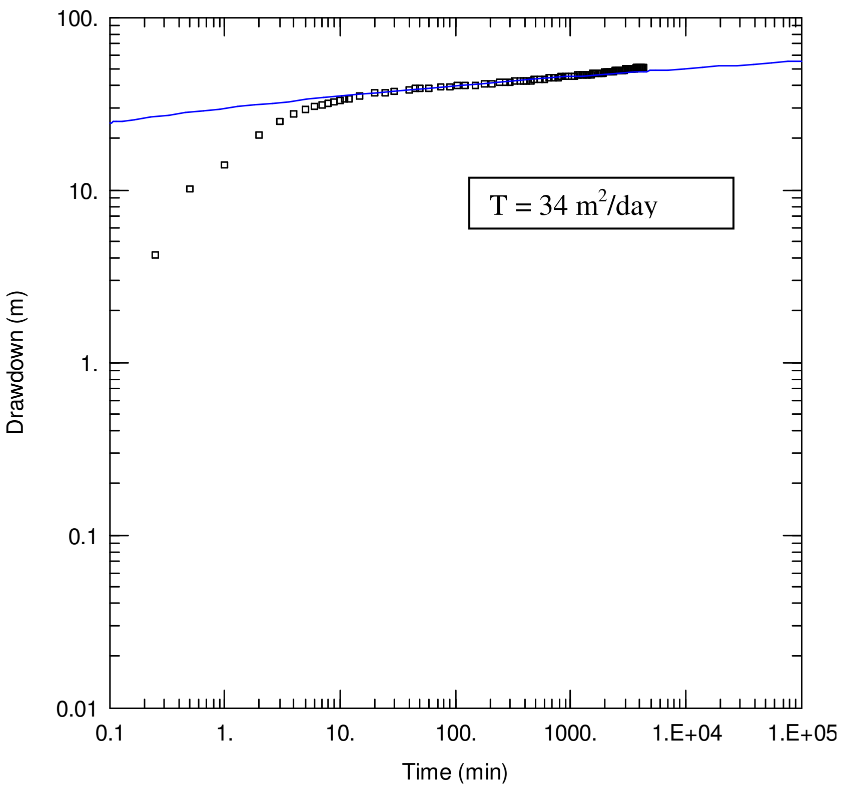

Figure 29-6 Pumping Test Results for BH10229: Theis Solution

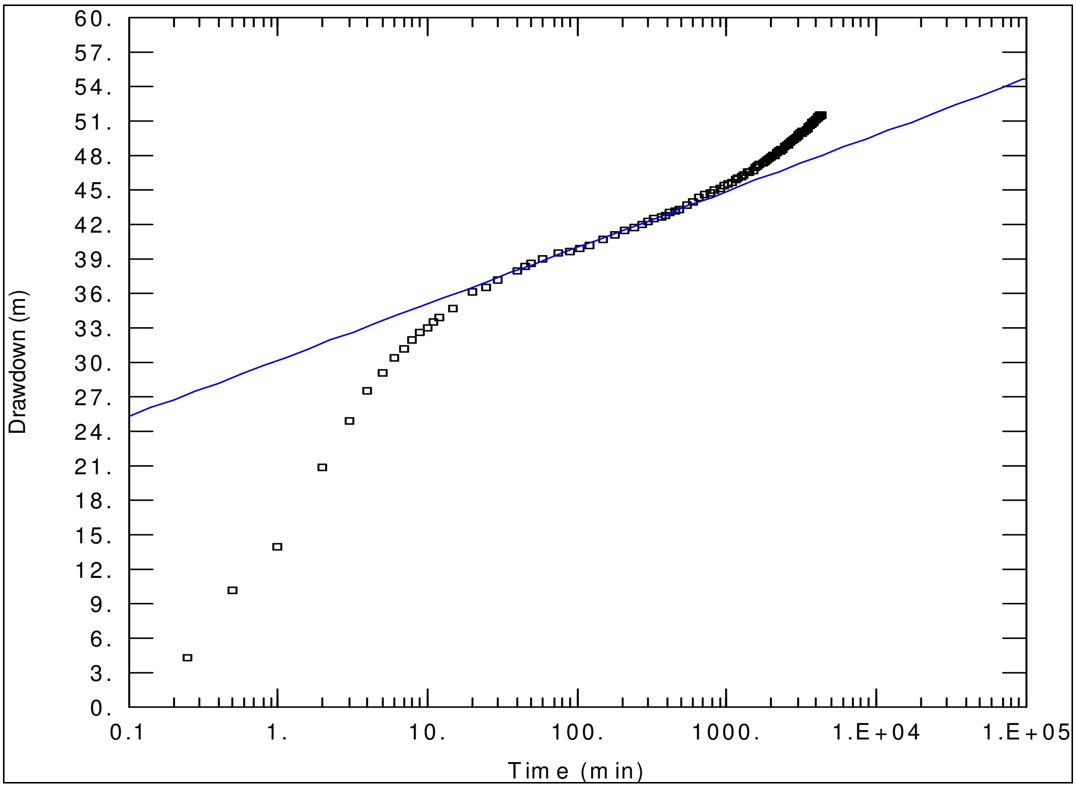

Figure 29-7 Pumping Results for BH10314 CRT Cooper Jacob Solution

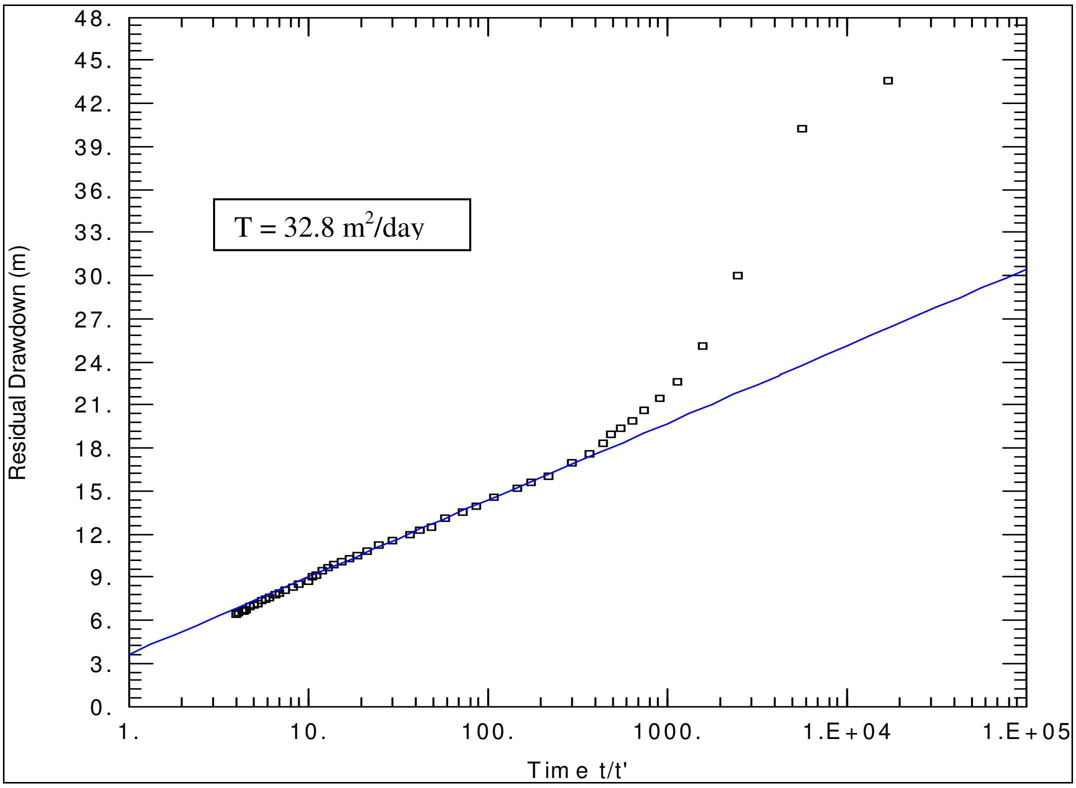

Figure 29-8 Pumping Test Results for BH10314: Theis Recovery Solution

Table 29-5 Calibration Test Data – BH10314 (Test 1)

Official BH No.:	10314	District:	Ghanzi
Date of test commencement:	16.01.2006	Location:	Metsimantsho
Time of test commencement	1500hrs	BH depth (m):	300
Date of test completion:	16.01.06	Screen Interval (m):	
Time of test completion	1645hrs	Depth of pump intake (m):	150.5m
Method of water level measurement:	dipper	Static water level before test (m):	81.69
Casing diameter (mm)		Water strike	
Orifice plate diameter		Delivery pipe diameter	102mm
Latitude		Longitude	

STEP No. 1 / STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P Rate (m^3/hr)	Comments
0.25	82.86	1.17				0.25	89.65	7.96			
0.5	84.34	2.65				0.5	89.69	8.00			
1	86.66	4.97				1	90.98	9.29	11.94	15.08	
1.5	88.32	6.63				1.5	91.67	9.98			
2	88.60	6.91				2	92.04	10.35	11.88	15.15	
2.5	88.44	6.75				2.5	92.34	10.65			
3	87.34	5.65				3	92.65	10.96	11.69	15.40	
4	86.33	4.64				4	93.05	11.36	12.00	15.00	
5	86.14	4.45				5	93.53	11.84	11.96	15.05	
6	86.17	4.48	22.00	8.18		6	93.76	12.07	12.03	14.96	
7	86.17	4.48	22.15	8.13		7	93.99	12.30	11.99	15.01	
8	86.43	4.74	18.19	9.90		8	94.22	12.53	12.01	14.99	
9	87.15	5.46	18.24	9.87		9	94.45	12.76	11.97	15.04	
10	87.93	6.24	19.00	9.47		10	94.64	12.95	11.99	15.01	
11	88.48	6.79	18.34	9.81		11	94.76	13.07	11.96	15.05	
12	88.97	7.28	18.24	9.87		12	94.95	13.26	11.94	15.08	
15	89.64	7.95	18.19	9.90		15	95.25	13.56	12.01	14.99	

STEP No. 3 / STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	Pumping Rate (m^3/hr)	Comments
0.25	95.93	14.24				0.25	105.54	23.85			
0.5	97.25	15.56				0.5	106.06	24.37			
1	98.20	16.51	15.75	22.86		1	106.96	25.27	10.88	33.09	
1.5	98.88	17.19				1.5	106.99	25.30			
2	99.51	17.82	16.69	21.57		2	107.09	25.40	14.30	25.17	adj
2.5	99.63	17.94				2.5	107.09	25.40			
3	99.74	18.05	17.82	20.20		3	107.09	25.40	14.41	24.98	
4	99.75	18.06	17.80	20.22		4	107.09	25.40	14.34	25.10	
5	99.99	18.30	17.77	20.26		5	107.09	25.40	14.64	24.59	
6	100.10	18.41	17.92	20.09		6	107.09	25.40	14.37	25.05	
7	100.31	18.62	17.86	20.16		7	107.09	25.40	14.44	24.93	
8	100.49	18.80	17.84	20.18		8	107.09	25.40	14.38	25.03	
9	100.78	19.09	17.92	20.09		9	107.09	25.40	14.42	24.97	
10	100.94	19.25	17.90	20.11		10	107.09	25.40	14.41	24.98	
11	101.31	19.62	17.88	20.13		11	107.09	25.40	14.45	24.91	
12	101.35	19.66	17.91	20.10		12	107.09	25.40	14.41	24.98	
15	101.37	19.68	17.95	20.06		15	107.09	25.40	14.38	25.03	

Table 29-6 Step Drawdown Test Data – BH10314

Official BH No.:	10314	District:	Ghanzi
Date of test commencement:	17.01.2006	Location:	Metsimantsho
Time of test Commencement:	1000hrs	BH depth (m):	300
Date of test completion:	17.01.2006	Screens(m)	275.48 to 281.61 & 284.74 to 297
Time of test Completion:	18.35hrs	Depth to pump intake (m)	150.5
Method of water level measurement:	electrical dipper	Description of MP:	top of casing
Observation Bh No.:	n/a	Height of MP above ground:	0.47
Distance to OB. BH (m)	n/a	Static water level before test (m):	82.15
Casing diameter (mm)	203	Water strike	105, 116, 152, 155, 232, 258 & 276
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	490313	Northing	7429063

STEP No. 1 | STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 50L	P. Rate (m^3/hr)	Comments
0.25	82.49	0.34				0.25	94.10	11.95			
0.5	82.87	0.72				0.5	94.87	12.72			
1	83.01	0.86				1	95.45	13.30	8.56	21.03	
1.5	86.38	4.23				1.5	97.07	14.92			
2	89.46	7.31				2	98.19	16.04	8.94	20.13	
2.5	90.71	8.56				2.5	98.80	16.65			
3	90.71	8.56				3	98.84	16.69	8.78	20.50	
4	90.71	8.56				4	99.19	17.04	8.92	20.18	
5	90.71	8.56	18.04	9.98		5	99.63	17.48	8.97	20.07	
6	90.71	8.56	18.06	9.97		6	99.99	17.84	8.82	20.41	
7	90.71	8.56	18.06	9.97		7	100.31	18.16	8.94	20.13	
8	90.71	8.56	17.94	10.03		8	100.51	18.36	8.76	20.55	
9	90.71	8.56	17.96	10.02		9	100.67	18.52	8.80	20.45	
10	90.71	8.56	17.99	10.01		10	100.89	18.74	8.78	20.50	
11	90.71	8.56	17.94	10.03		11	101.04	18.89	8.92	20.18	
12	90.71	8.56	17.99	10.01		12	101.15	19.00	8.74	20.59	
13	90.73	8.58	17.97	10.02		13	101.26	19.11	8.87	20.29	
14	90.79	8.64	17.89	10.06		14	101.37	19.22	8.92	20.18	
15	90.95	8.80	17.93	10.04		15	101.43	19.28	8.97	20.07	
20	91.46	9.31	17.85	10.08		20	101.79	19.64	8.84	20.36	
25	91.78	9.63	17.79	10.12		25	102.03	19.88	8.93	20.16	
30	92.08	9.93	17.63	10.21		30	102.15	20.00	8.92	20.18	
35	92.29	10.14	17.74	10.15		35	102.38	20.23	8.79	20.48	
40	92.48	10.33	17.91	10.05		40	102.43	20.28	8.86	20.32	
45	92.64	10.49	17.82	10.10		45	102.52	20.37	8.75	20.57	
50	92.73	10.58	17.74	10.15		50	102.60	20.45	8.85	20.34	
55	92.85	10.70	17.95	10.03		55	102.68	20.53	8.92	20.18	
60	92.94	10.79	17.69	10.18		60	102.75	20.60	8.94	20.13	
70	93.08	10.93	17.83	10.10		70	102.82	20.67	8.87	20.29	
80	93.19	11.04	17.66	10.19		80	102.94	20.79	8.93	20.16	
90	93.29	11.14	17.98	10.01		90	103.10	20.95	8.99	20.02	
100	93.37	11.22	17.99	10.01		100	103.20	21.05	8.92	20.18	

Official BH No.:	10314	District:	Ghanzi
Date of test commencement:	17.01.2006	Location:	Metsimantsho
Time of test Commencement:	1000hrs	BH depth (m):	300
Date of test completion:	17.01.2006	Screens(m)	275.48 to 281.61 & 284.74 to 297
Time of test Completion:	18.35hrs	Depth to pump intake (m)	150.5
Method of water level measurement:	electrical dipper	Description of MP:	top of casing
Observation Bh No.:	n/a	Height of MP above ground:	0.47
Distance to OB. BH (m)	n/a	Static water level before test (m):	82.15
Casing diameter (mm)	203	Water strike	105, 116, 152, 155, 232, 258 & 276
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	490313	Northing	7429063

STEP No. 3 | STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 100L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P. Rate (m^3/hr)	Comments
0.25	103.94	21.79				0.25	116.99	34.84			
0.5	104.31	22.16				0.5	117.87	35.72			
1	105.03	22.88	11.81	30.48		1	118.50	36.35	13.28	40.66	
1.5	106.95	24.80				1.5	119.61	37.46			
2	108.19	26.04	12.75	28.24		2	120.66	38.51	13.72	39.36	
2.5	109.32	27.17				2.5	121.39	39.24			
3	110.28	28.13	11.91	30.23		3	121.90	39.75	13.40	40.30	
4	111.58	29.43	11.96	30.10		4	122.31	40.16	13.31	40.57	
5	112.09	29.94	11.92	30.20		5	122.90	40.75	13.44	40.18	
6	112.54	30.39	11.86	30.35		6	123.44	41.29	13.46	40.12	
7	112.88	30.73	11.89	30.28		7	123.76	41.61	13.48	40.06	
8	113.21	31.06	11.94	30.15		8	123.98	41.83	13.29	40.63	
9	113.44	31.29	11.96	30.10		9	124.18	42.03	13.36	40.42	
10	113.65	31.50	11.78	30.56		10	124.35	42.20	13.39	40.33	
11	113.84	31.69	11.97	30.08		11	124.45	42.30	13.49	40.03	
12	113.99	31.84	11.99	30.03		12	124.62	42.47	13.47	40.09	
13	114.12	31.97	11.96	30.10		13	124.68	42.53	13.46	40.12	
14	114.28	32.13	11.99	30.03		14	124.73	42.58	13.49	40.03	
15	114.40	32.25	12.00	30.00		15	124.84	42.69	13.50	40.00	
20	114.88	32.73	11.96	30.10		20	125.24	43.09	13.35	40.45	
25	115.31	33.16	11.92	30.20		25	125.38	43.23	13.28	40.66	
30	115.55	33.40	11.78	30.56		30	125.60	43.45	13.42	40.24	
35	115.67	33.52	11.97	30.08		35	125.79	43.64	13.33	40.51	
40	115.84	33.69	11.99	30.03		40	125.81	43.66	13.47	40.09	
45	115.95	33.80	11.96	30.10		45	125.81	43.66	13.34	40.48	
50	116.05	33.90	11.97	30.08		50	125.89	43.74	13.49	40.03	
55	116.15	34.00	11.99	30.03		55	125.95	43.80	13.29	40.63	
60	116.22	34.07	12.00	30.00		60	126.06	43.91	13.41	40.27	
70	116.36	34.21	11.96	30.10		70	126.16	44.01	13.37	40.39	
80	116.54	34.39	12.00	30.00		80	126.28	44.13	13.43	40.21	
90	116.64	34.49	11.96	30.10		90	126.34	44.19	13.38	40.36	
100	116.86	34.71	12.00	30.00		100	126.53	44.38	13.47	40.09	

Official BH No.:	10314	District:	Ghanzi
Date of test commencement:	17.01.2006	Location:	Metsimantsho
Time of test Commencement:	1000hrs	BH depth (m):	300
Date of test completion:	17.01.2006	Screens(m)	275.48 to 281.61 & 284.74 to 297
Time of test Completion:	18.35hrs	Depth to pump intake (m)	150.5
Method of water level measurement:	electrical dipper	Description of MP:	top of casing
Observation Bh No.:	n/a	Height of MP above ground:	0.47
Distance to OB. BH (m)	n/a	Static water level before test (m):	82.15
Casing diameter (mm)	203	Water strike	105, 116, 152, 155, 232, 258 & 276
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	490313	Northing	7429063

STEP No. 5 STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 150L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments
0.25	126.78	44.63				0.25	140.89	58.74			
0.5	127.00	44.85				0.5	141.09	58.94			
1	128.55	46.40	10.72	50.37		1	141.25	59.10	12.00	60.00	
1.5	130.07	47.92				1.5	141.60	59.45			
2	131.56	49.41	10.68	50.56		2	142.22	60.07	11.99	60.05	
2.5	132.78	50.63				2.5	142.87	60.72			
3	133.58	51.43	10.80	50.00		3	143.46	61.31	11.86	60.71	
4	134.88	52.73	10.75	50.23		4	144.05	61.90	11.90	60.50	
5	135.89	53.74	10.76	50.19		5	144.87	62.72	11.89	60.56	
6	136.47	54.32	10.69	50.51		6	145.28	63.13	11.75	61.28	
7	136.95	54.80	10.73	50.33		7	145.50	63.35	11.84	60.81	
8	137.26	55.11	10.78	50.09		8	145.62	63.47	11.97	60.15	
9	137.41	55.26	10.74	50.28		9	145.70	63.55	11.93	60.35	
10	137.66	55.51	10.74	50.28		10	145.89	63.74	11.88	60.61	
11	137.82	55.67	10.80	50.00		11	146.00	63.85	11.94	60.30	
12	137.94	55.79	10.72	50.37		12	146.24	64.09	11.96	60.20	
13	138.11	55.96	10.76	50.19		13	146.69	64.54	11.99	60.05	
14	138.26	56.11	10.80	50.00		14	146.89	64.74	11.98	60.10	
15	138.35	56.20	10.72	50.37		15	146.98	64.83	11.96	60.20	
20	138.84	56.69	10.69	50.51		20					
25	139.14	56.99	10.76	50.19		25					
30	139.40	57.25	10.79	50.05		30					
35	139.57	57.42	10.71	50.42		35					
40	139.62	57.47	10.73	50.33		40					
45	139.74	57.59	10.75	50.23		45					
50	139.87	57.72	10.74	50.28		50					
55	139.94	57.79	10.72	50.37		55					
60	140.00	57.85	10.78	50.09		60					
70	140.09	57.94	10.77	50.14		70					
80	140.22	58.07	10.68	50.56		80					
90	140.40	58.25	10.70	50.47		90					
100	140.61	58.46	10.81	49.95		100					

Table 29-7 Constant Rate Test – BH10314 (Test 1)

Official BH NO :	10314	District :	Ghanzi
Date of test commencement :	18.01.06	Location :	Metsimantsho
Time of test commencement :	0800hrs	BH depth(m) :	300
Date of test completion	19.01.06	Screen Interval (m)	275.48 to 281.61 & 284.74 to 297
Time of test completion :	0835hrs	Depth of pump intake (m) :	150.5m
Method of water level measurement	dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.47
Distance ob BH r (m)	n/a	Static Water level before test(m) :	83.46
Casing diameter (mm)		Water strike	105, 116, 152, 155, 232, 258 & 276
Orifice plate diameter	4"	Delivery pipe diameter	5"
Easting	490313	Northing	7429063

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 200l	$Q(m^3/h)$	Temp (^0C)	EC (ms/Cm)	pH	Manometer (cm) /DO2
	0.25	87.34	3.88						Flowmeter 168898
	0.5	94.91	11.45						
	1	100.23	16.77	19.91	36.16				
	2	107.02	23.56	15.65	46.01				
	3	109.82	26.36	15.89	45.31				
	4	114.85	31.39	15.87	45.37				
	5	118.62	35.16	15.97	45.08				
	6	121.34	37.88	15.99	45.03				
	7	123.12	39.66	15.94	45.17				
	8	124.85	41.39	15.99	45.03				
	9	125.91	42.45	16.00	45.00				
	10	126.88	43.42	15.97	45.08				
	11	127.65	44.19	15.92	45.23				
	12	128.44	44.98	15.88	45.34				
	15	130.25	46.79	15.91	45.25	27.6	1800	8.45	24cm
	20	132.51	49.05	15.83	45.48	27.7	1800	8.44	24cm
	25	133.88	50.42	15.98	45.06	27.7	1810	8.45	24cm
	30	134.59	51.13	15.88	45.34	27.5	1830	8.43	24cm
	40	135.71	52.25	15.75	45.71	27.6	1830	8.43	24cm
	45	136.07	52.61	15.93	45.20	27.7	1830	8.45	24cm
	50	136.46	53.00	15.89	45.31	27.7	1820	8.44	24cm
	60	136.91	53.45	15.79	45.60	27.8	1830	8.45	24cm
	75	137.42	53.96	15.91	45.25	27.8	1830	8.42	24cm
	90	137.99	54.53	15.72	45.80	27.9	1820	8.41	24cm
	105	138.39	54.93	15.84	45.45	27.9	1830	8.42	24cm
	120	138.71	55.25	15.99	45.03	28.0	1820	8.42	24cm
	150	139.19	55.73	15.93	45.20	28.2	1840	8.43	24cm
	180	139.53	56.07	15.76	45.69	28.2	1830	8.42	24cm
	210	139.83	56.37	15.84	45.45	28.3	1840	8.43	24cm
	240	140.14	56.68	15.96	45.11	28.5	1820	8.43	24cm
	270	140.43	56.97	15.70	45.86	28.6	1820	8.43	24cm
	300	140.61	57.15	15.89	45.31	28.9	1820	8.38	24cm
	330	140.84	57.38	15.97	45.08	28.9	1830	8.39	24cm
	360	141.00	57.54	15.81	45.54	29.1	1840	8.39	24cm
	390	141.33	57.87	15.95	45.14	29.3	1830	8.38	24cm
	420	141.46	58.00	15.77	45.66	29.5	1840	8.41	24cm
	450	141.54	58.08	15.83	45.48	29.6	1830	8.41	24cm
	480	141.67	58.21	15.97	45.08	29.7	1820	8.40	24cm
	540	142.05	58.59	15.73	45.77	29.8	1830	8.40	24cm
	600	142.30	58.84	15.89	45.31	29.8	1820	8.40	24cm

	660	142.68	59.22	15.97	45.08	28.7	1840	8.44	24cm
	720	142.86	59.40	15.76	45.69	27.5	1820	8.45	24cm
	780	143.19	59.73	15.90	45.28	27.1	1830	8.47	24cm
	840	143.43	59.97	15.84	45.45	27.2	1830	8.46	24cm
	900	143.67	60.21	15.99	45.03	27.4	1820	8.57	24cm
	960	144.00	60.54	15.97	45.08	27.6	1840	8.64	24cm
	1020	144.18	60.72	15.99	45.03	27.2	1840	7.44	24cm
	1080	144.46	61.00	15.96	45.11	27.4	1850	8.62	24cm
	1140	144.46	61.00	15.98	45.06	27.6	1830	8.42	24cm
	1200	144.46	61.00	15.84	45.45	25.9	1840	8.47	24cm
	1260	144.46	61.00	15.86	45.40	25.6	1850	8.45	24cm
	1320	144.46	61.00	15.96	45.11	26.7	1840	8.42	24cm
	1380	144.46	61.00	15.89	45.31	27.8	1830	8.46	24cm
	1440	144.47	61.01	15.94	45.17	27.5	1840	8.45	24cm; Dissolved O2 1.65mg/l

Table 29-8 Constant Rate Test – BH10314 (Repeat)

Official BH NO :	10314	District :	Ghanzi
Date of test commencement :	23.01.06	Location :	Metsimantsho
Time of test commencement :	0700hrs	BH depth(m) :	300
Date of test completion	26.01.06	Screen Interval (m)	275.48 to 281.61 & 284.74 to 297
Time of test completion :	0700hrs	Depth of pump intake (m) :	150.5m
Method of water level measurement	dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.47
Distance ob BH r (m)	n/a	Static Water level before test(m) :	85.69
Casing diameter (mm)	203	Water strike	105, 116, 152, 155, 232, 258 & 276
Orifice plate diameter	4"	Delivery pipe diameter	5"
Easting	490313	Northing	7429063

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 150l	$Q(m^3/h)$	Temp (^0C)	EC (ms/Cm)	pH	Manometer (cm) /DO2
	0.25	89.87	4.18						Flowmeter 167171
	0.5	95.83	10.14						
	1	99.64	13.95	13.78	39.19	24.1	1840	8.46	Flowmeter 170454
	2	106.55	20.86	13.50	40.00				
	3	110.54	24.85	13.42	40.24				
	4	113.11	27.42	13.46	40.12	25.8	1810	8.46	
	5	114.73	29.04	13.45	40.15	25.8	1810	8.46	
	6	115.96	30.27	13.42	40.24				
	7	116.86	31.17	13.47	40.09				
	8	117.61	31.92	13.41	40.27				
	9	118.24	32.55	13.44	40.18				
	10	118.66	32.97	13.46	40.12	27.3	1790	8.47	
	11	119.10	33.41	13.47	40.09				
	12	119.49	33.80	13.48	40.06				
	15	120.34	34.65	13.49	40.03	26.9	1800	8.46	14cm
	20	121.74	36.05	13.50	40.00	28.4	1820	8.47	14cm
	25	122.18	36.49	13.43	40.21	27.3	1800	8.43	14cm
	30	122.77	37.08	13.46	40.12	26.9	1820	8.49	14cm
	40	123.64	37.95	13.42	40.24	27.4	1820	8.51	14cm
	45	123.94	38.25	13.40	40.30	27.6	1800	8.48	14cm
	50	124.19	38.50	13.45	40.15	28.4	1810	8.47	14cm
	60	124.65	38.96	13.47	40.09	27.0	1810	8.52	14cm
	75	125.10	39.41	13.39	40.33	26.9	1800	8.50	14cm
	90	125.26	39.57	13.48	40.06	27.3	1820	8.49	14cm
	105	125.55	39.86	13.43	40.21	28.6	1800	8.50	14cm
	120	125.82	40.13	13.47	40.09	28.4	1810	8.49	14cm
	150	126.29	40.60	13.44	40.18	29.3	1820	8.45	14cm
	180	126.73	41.04	13.40	40.30	29.2	1820	8.46	14cm
	210	127.05	41.36	13.44	40.18	29.5	1820	8.48	14cm
	240	127.39	41.70	13.50	40.00	29.7	1810	8.47	14cm
	270	127.65	41.96	13.43	40.21	29.8	1800	8.48	14cm
	300	127.89	42.20	13.41	40.27	29.7	1810	8.47	14cm
	330	128.17	42.48	13.47	40.09	29.8	1820	8.49	14cm
	360	128.25	42.56	13.45	40.15	29.6	1810	8.47	14cm
	390	128.45	42.76	13.42	40.24	30.3	1820	8.46	14cm
	420	128.66	42.97	13.50	40.00	29.9	1810	8.46	14cm
	450	128.78	43.09	13.49	40.03	29.6	1820	8.47	14cm
	480	128.96	43.27	13.43	40.21	30.4	1800	8.46	14cm
	540	129.27	43.58	13.46	40.12	30.1	1820	8.49	14cm
	600	129.57	43.88	13.40	40.30	29.6	1820	8.49	14cm
	660	129.91	44.22	13.49	40.03	29.4	1830	8.54	14cm
	720	130.21	44.52	13.46	40.12	29.2	1840	8.46	14cm
	780	130.37	44.68	13.45	40.15	29.4	1820	8.45	14cm
	840	130.61	44.92	13.49	40.03	28.8	1820	8.46	14cm
	900	130.78	45.09	13.49	40.03	29.4	1840	8.45	14cm
	960	130.99	45.30	13.44	40.18	27.5	1850	8.52	14cm
	1020	131.15	45.46	13.41	40.27	27.6	1840	8.53	14cm
	1080	131.29	45.60	13.49	40.03	27.5	1840	8.55	14cm
	1140	131.50	45.81	13.46	40.12	27.6	1850	8.54	14cm
	1200	131.69	46.00	13.50	40.00	27.4	1840	8.53	14cm
	1260	131.84	46.15	13.48	40.06	27.7	1830	8.51	14cm
	1320	131.98	46.29	13.42	40.24	27.9	1830	8.49	14cm

	1380	132.14	46.45	13.46	40.12	25.6	1850	8.54	14cm
	1440	132.24	46.55	13.44	40.18	27.6	1830	8.51	14cm DO = 1.65 mg/l
	1500	132.38	46.69	13.49	40.03	27.7	1840	8.53	14cm
	1560	132.53	46.84	13.47	40.09	27.4	1830	8.53	14cm
	1620	132.67	46.98	13.41	40.27	26.5	1840	8.51	14cm
	1680	132.86	47.17	13.50	40.00	26.6	1830	8.49	14cm
	1740	132.97	47.28	13.49	40.03	27.1	1820	8.51	14cm
	1800	133.08	47.39	13.42	40.24	27.8	1840	8.48	14cm
	1860	133.24	47.55	13.46	40.12	28.9	1830	8.47	14cm
	1920	133.35	47.66	13.47	40.09	28.6	1790	8.49	14cm
	1980	133.46	47.77	13.41	40.27	28.8	1800	8.48	14cm
	2040	133.57	47.88	13.45	40.15	29.4	1810	8.49	14cm
	2100	133.66	47.97	13.44	40.18	29.7	1820	8.47	14cm
	2160	133.85	48.16	13.42	40.24	26.5	1840	8.51	14cm
	2220	133.96	48.27	13.40	40.30	28.6	1840	8.52	14cm
	2280	134.05	48.36	13.43	40.21	28.9	1850	8.50	14cm
	2340	134.14	48.45	13.49	40.03	29.5	1840	8.50	14cm
	2400	134.21	48.52	13.48	40.06	29.4	1840	8.46	14cm
	2460	134.43	48.74	13.47	40.09	29.8	1820	8.49	14cm
	2520	134.49	48.80	13.44	40.18	29.2	1830	8.50	14cm
	2580	134.60	48.91	13.40	40.30	29.7	1820	8.43	14cm
	2640	134.71	49.02	13.50	40.00	28.8	1820	8.56	14cm
	2700	134.82	49.13	13.41	40.27	27.1	1850	8.52	14cm
	2760	134.91	49.22	13.45	40.15	27.3	1840	8.51	14cm
	2820	135.02	49.33	13.42	40.24	27.3	1850	8.52	14cm
	2880	135.10	49.41	13.49	40.03	27.5	1840	8.52	14cm DO = 1.75mg/l
	2940	135.19	49.50	13.44	40.18	27.5	1850	8.52	14cm
	3000	135.31	49.62	13.48	40.06	27.6	1840	8.53	14cm
	3060	135.45	49.76	13.50	40.00	27.7	1840	8.54	14cm
	3120	135.53	49.84	13.46	40.12	28.5	1850	8.51	14cm
	3180	135.60	49.91	13.43	40.21	29.0	1850	8.52	14cm
	3240	135.71	50.02	13.47	40.09	29.1	1860	8.50	14cm
	3300	135.76	50.07	13.44	40.18	29.4	1880	8.50	14cm
	3360	135.82	50.13	13.49	40.03	29.5	1860	8.51	14cm
	3420	135.89	50.20	13.40	40.30	29.3	1830	8.46	14cm
	3480	136.02	50.33	13.42	40.24	29.2	1870	8.48	14cm
	3540	136.10	50.41	13.46	40.12	28.1	1850	8.50	14cm
	3600	136.18	50.49	13.41	40.27	27.9	1850	8.52	14cm
	3660	136.29	50.60	13.50	40.00	27.8	1840	8.53	14cm
	3720	136.37	50.68	13.48	40.06	27.7	1830	8.54	14cm
	3780	136.46	50.77	13.45	40.15	27.7	1840	8.52	14cm
	3840	136.51	50.82	13.42	40.24	28.9	1840	8.51	14cm
	3900	136.63	50.94	13.44	40.18	29.9	1850	8.52	14cm
	3960	136.70	51.01	13.48	40.06	30.7	1830	8.53	14cm
	4020	136.76	51.07	13.40	40.30	30.2	1830	8.52	14cm
	4080	136.84	51.15	13.46	40.12	30.3	1840	8.50	14cm
	4140	136.96	51.27	13.46	40.12	30.2	1830	8.46	14cm
	4200	137.07	51.38	13.49	40.03	30.2	1840	8.52	14cm
	4260	137.14	51.45	13.47	40.09	29.9	1810	8.49	14cm
	4320	137.21	51.52	13.46	40.12	29.7	1890	8.56	14cm DO = 1.82mg/l

Table 29-9 Recovery Test Data – BH10314

Official BH NO :	10314	District :	Ghanzi
Date of test commencement :	26.01.2006	Location :	Metsimantsho
Time of test commencement :	0700hrs	BH depth(m) :	300
Date of test completion	27.01.2006	Screen Int (m)	275.48 to 281.61 & 284.74 to 297
Time of test completion :	0700hrs	Depth of pump intake (m) :	150.5
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	n/a	Height of MP above ground(m) :	0.47
Dist.to Pumping Bh:	n/a	Static Water level before test(m) :	85.69
Casing diameter (mm)	203	Water strike	105, 116, 152, 155, 232, 258 & 276
Orifice plate diameter		Delivery pipe diameter	
Easting	490313	Northing	7429063

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	137.21	51.52
	0.25	135.55	49.86
	0.5	129.27	43.58
	1	125.90	40.21
	2	115.69	30.00
	3	110.74	25.05
	4	108.23	22.54
	5	107.09	21.40
	6	106.29	20.60
	7	105.60	19.91
	8	105.06	19.37
	9	104.60	18.91
	10	104.04	18.35
	12	103.32	17.63
	15	102.63	16.94
	20	101.73	16.04
	25	101.25	15.56
	30	100.85	15.16
	40	100.24	14.55
	50	99.63	13.94
	60	99.24	13.55
	75	98.77	13.08
	90	98.18	12.49
	105	98.00	12.31
	120	97.65	11.96

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	97.23	11.54
	180	96.88	11.19
	210	96.44	10.75
	240	96.14	10.45
	270	95.99	10.30
	300	95.73	10.04
	330	95.54	9.85
	360	95.35	9.66
	390	95.12	9.43
	420	94.77	9.08
	450	94.70	9.01
	480	94.44	8.75
	540	94.16	8.47
	600	93.96	8.27
	660	93.81	8.12
	720	93.62	7.93
	780	93.45	7.76
	840	93.29	7.60
	900	93.13	7.44
	960	93.03	7.34
	1020	92.85	7.16
	1080	92.75	7.06
	1140	92.64	6.95
	1200	92.44	6.75
	1260	92.35	6.66
	1320	92.28	6.59
	1380	92.21	6.52
	1440	92.15	6.46

30 BH10315

BH10315 is an exploration borehole with siting reference of **S12,** TEM 84, line R9 and peg 9000m. It is located along the road from Metsimantsho to Ncaang, about 10 km from the turn off from the cattle route track road. Drilling of this borehole commenced on 28 November 2005 and was completed on 24 January 2006 at a depth of 287m.

30.1 SITING CRITERIA AND DRILLING OBJECTIVES

This exploration borehole was drilled to explore the Ecca aquifer between faults **F6** and **F7** and to assess the high resistivity zone interpreted between 240m and 350 m. It will also generate water level data in this locality.

30.2 DRILLING RESULTS

Various lithologies including fine grained sands, calcrete, silcrete, dolerite, mudstones and fine to coarse grained sandstones were intercepted during drilling of this exploration borehole (**Figure 30-1**). Drilling was carried out with a 15 inch bit using the DTH drilling technique from 0 to 50 m bgl and 12 inch plain casings were installed and cement grouted. From 50 to 227m, drilling was carried out using a 12 inch drilling bit after which 10 inch casings were installed. The annulus between the 12 inch hole and the 10 inch casings was cement grouted. A 10 inch DTH bit was used to drill from 227 to 269 m and a $9^{7/8}$ inch tri-cone bit was used from 269 m to the terminal depth of 287m.

During drilling of this borehole, four water strikes were encountered at different depths. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the four water strikes are as follows;

1. (156m, 2780 µS/cm, 7.68 m^3/hr)
2. (177m, 3310 µS/cm, 47.65 m^3/hr)
3. (210m, 4330 µS/cm, 41.85 m^3/hr)
4. (250m, 890 µS/cm, 156.3 m^3/hr)

An 8 inch steel casing and factory slotted screen (interval 248.31 to 279 m bgl) assembly was installed. The borehole was developed using the air lifting method for 3 hours and the final airlift yield measured was 126.96m^3/hr and the electrical conductivity was 890 µS/cm. The static water level measured on 24 January 2006 was 130.89m bgl.

Water samples were collected at all the water strikes for chemical analysis. The samples collected were analysed at the DWA laboratory and the results are presented in **Table 30-1**

Table 30-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10315	156	7.5	1802	18.72	10.15	669.2	16.08	451.32	254.38	0	0	0	815.10	0.00	0.13	Kule SST
10315	177	8.05	2118	28.10	11.29	809.5	19.34	653.56	228.21	0	2.06	0	910.16	0.00	0.09	Kule SST
10315	216	7.95	2476	36.80	10.73	960	17.6	754.69	272.07	0	0	0	1039.32	0.00	0.13	MUD 1
10315	250	7.62	426	2.15	4.028	180.95	8.125	45.80	22.4	5.3	0.79	0	365.98	0.08	10.00	SST 1
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

After successfully carrying out the verticality and alignment tests, the borehole was capped and a cement slab was constructed.

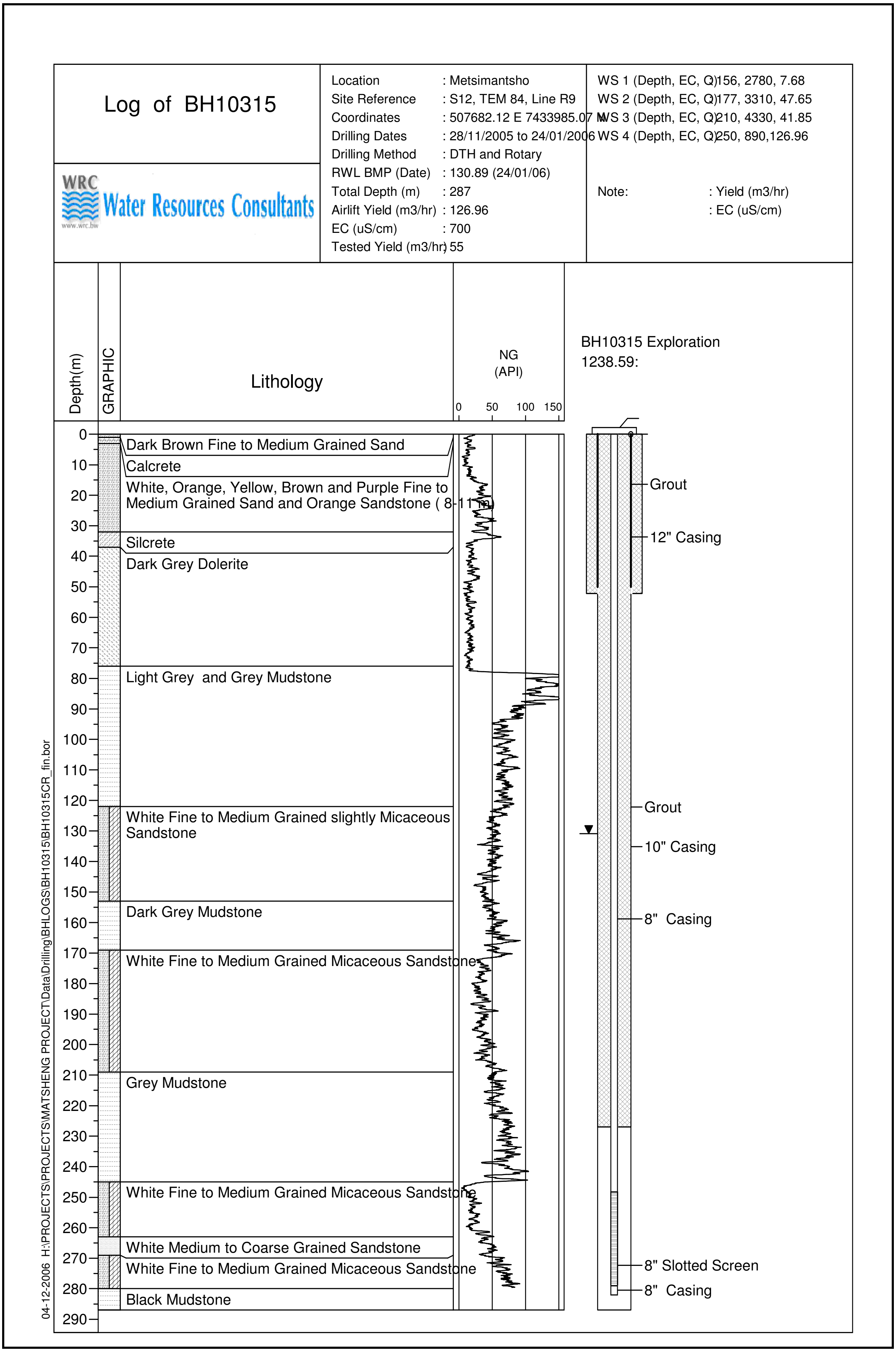

Figure 30-1 Log of BH10315

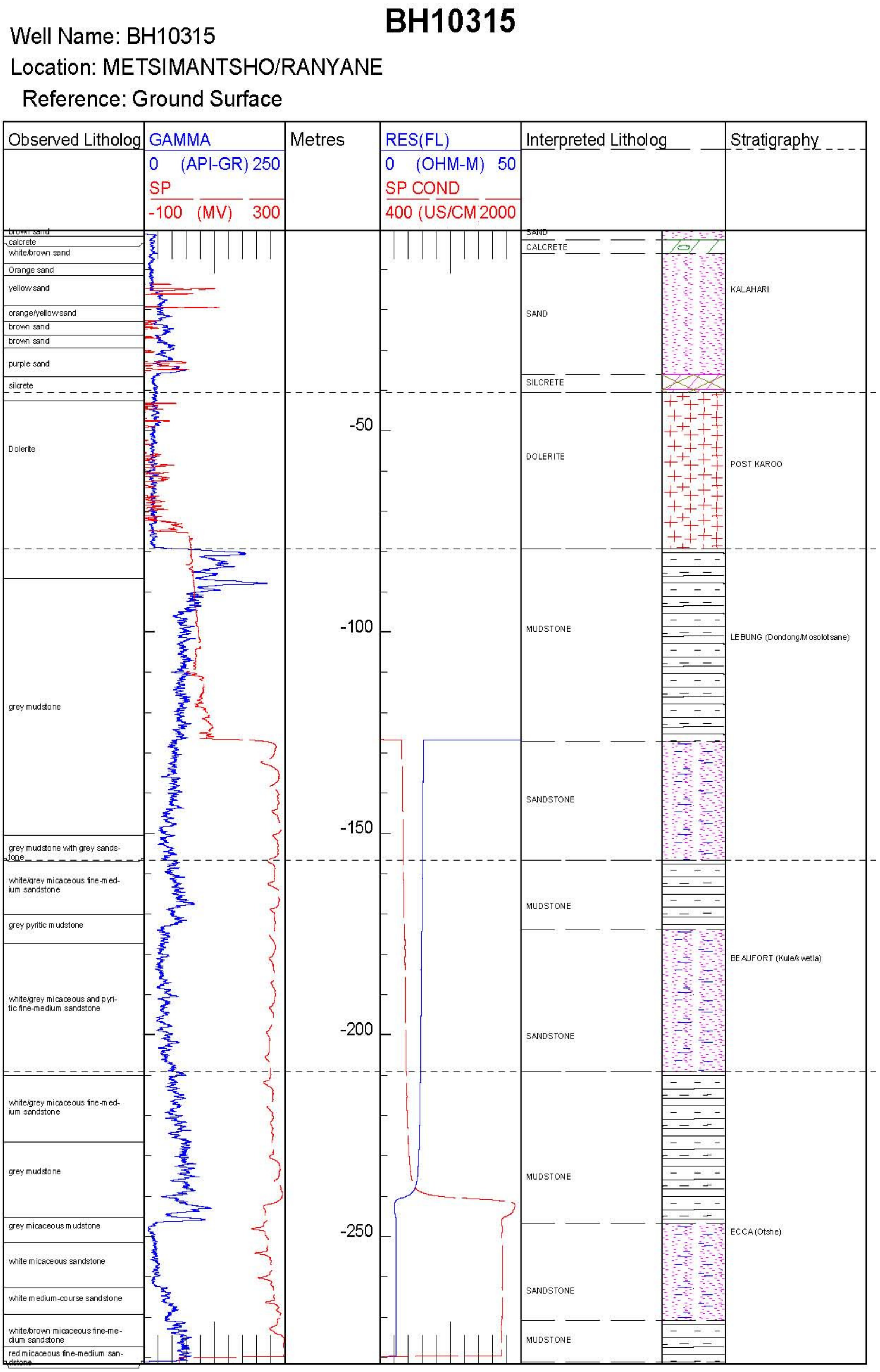

Figure 30-2 Geophysical log of BH10315

30.3 PUMP TESTING RESULTS

Borehole BH10315 was pump tested between 2 and 9 February 2006. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.61 m above ground level (agl) and the pump intake was set at 150.8 m below ground level. The summary details for the pumping test are given in **Table 30-2**. The collected pump testing data is presented in **Tables in 30-6 to 30-10.**

Table 30-2 Summary of Pumping Test Data BH10315

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	5.11	28
	2	15	7.89	44
	3	15	10.76	60
	4	15	13.88	74
	5	7	17.05	92
Step Test	1	100	6.67	32.5
	2	100	9.6	45.3
	3	100	12.81	60.3
	4	100	14.75	70
	5	10	16.8	80
Constant Rate	1	960	15.73	70
	2	4320	12.1	55
Recovery	1	1440	1.14	0

Note. 1.14 Residual Drawdown*

30.3.1 Step Drawdown Test

The step drawdown test was carried out on 3 February 2006. The static water level before the start of the test was 130.25 m bmp. The step drawdown test consisted of 4 steps of 100 minutes duration at discharge rates of 32.5, 45.3, 60.3 and 70m^3/hr for steps 1 to 4 respectively. A fifth step at a discharge rate of 80 m^3/hr lasted for 10 minutes only before the pump intake was reached.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test using this method is plotted in **Figure 30-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 30-4**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method is 64m^2/d, **Figure 30-5**. The results of the step test interpretation are given in **Table 30-3**.

Table 30-3 Results of Step Test Analysis BH10315

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10315	9.10E-03	-6.20E-07	64.3	32.5	6.73	6.73	4.83
				45.3	2.38	9.11	4.97
				60.3	2.87	11.98	5.03
				70.0	1.41	13.39	5.23

The planned duration for the constant rate test of this borehole is 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 30-3**) to estimate the expected total drawdown after 3 days of pumping. A discharge rate of 70 m^3/hr was interpreted as ideal for this borehole.

30.3.2 Constant Rate and Recovery Tests

A constant rate test (CRT) at 70m^3/hr was started on 4 February 2006 but the water level reached the pump intake after 16 hours of pumping. It was repeated at a lower discharge rate of 55m^3/hr, between 5 and 8 February 2006 and the total drawdown after 72 hrs of pumping was 12.1 m. The CRT was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 1.14 m.

Data from this borehole was interpreted using the Theis and Cooper-Jacob (1946) analytical solutions using the computer programme "Aqtesolv". Transmissivity (T) values obtained by these three analytical solutions were 124 and 129 respectively. The recovery data was analysed using the Theis recovery solution and a T value of 151 m^2/d was obtained. The interpreted data is summarised in **Table 30-4** and the plots are presented in **Figures 30-6** to**30-8**.

Table 30-4 Summary of Constant Rate and Recovery Tests BH10315

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10315	72	1320	a) 124 b) 129 c) 80	d) 151	Confined

Notes:
Interpretation Techniques
a) Theis
b) Cooper-Jacob
c) Hantush (Leaky with aquitard storage)
d) Theis Modified Recovery

30.3.2.1 Aquifer Type interpreted

The interpretation of the pump testing data shows that the aquifer type is confined.

30.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. The results of chemical analysis are presented in **Table 30-5.** In addition to these, some samples collected were submitted for stable and radioactive (^{14}C) isotope analysis at the CSIR laboratory in Pretoria, South Africa.

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), pH and dissolved oxygen are 28.71 °C, 660µS/cm, 8.02 and 1.75 mg/L respectively.

Table 30-5 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10315	4.7	168	1.1	1.2	19	41	290	<0.1	1.1	<0.05	<0.05	700	7.7	448
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10315	<0.1	8	<0.15	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

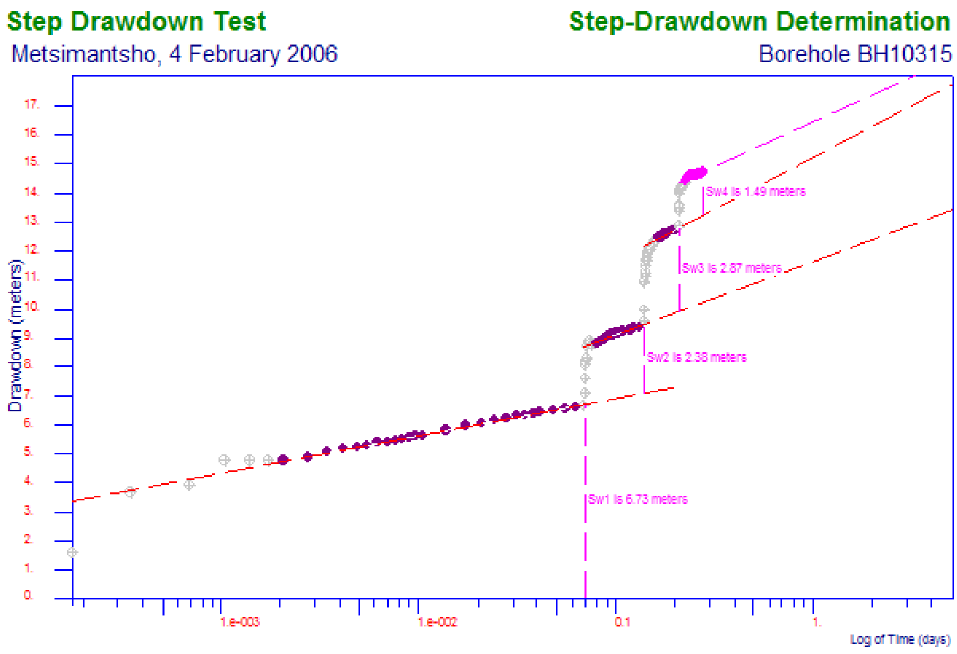

Figure 30-3 Pumping Test Results for BH10315: Step Drawdown Test - Hantush-Bierschenk (semi-log)

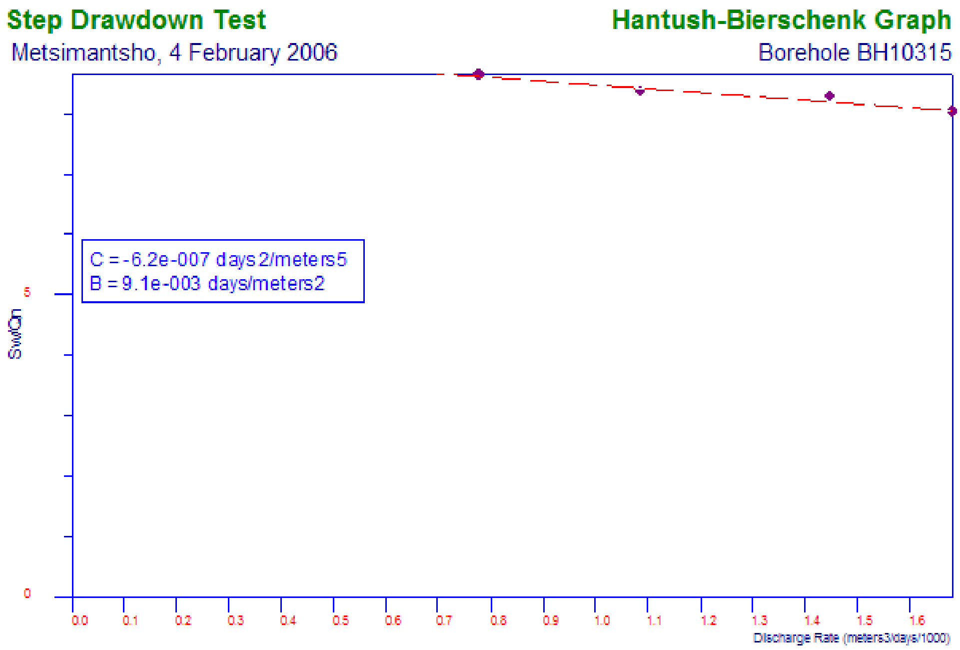

Figure 30-4 Pumping Test Results for BH10315: Step Drawdown Test – Hantush-Bierschenk

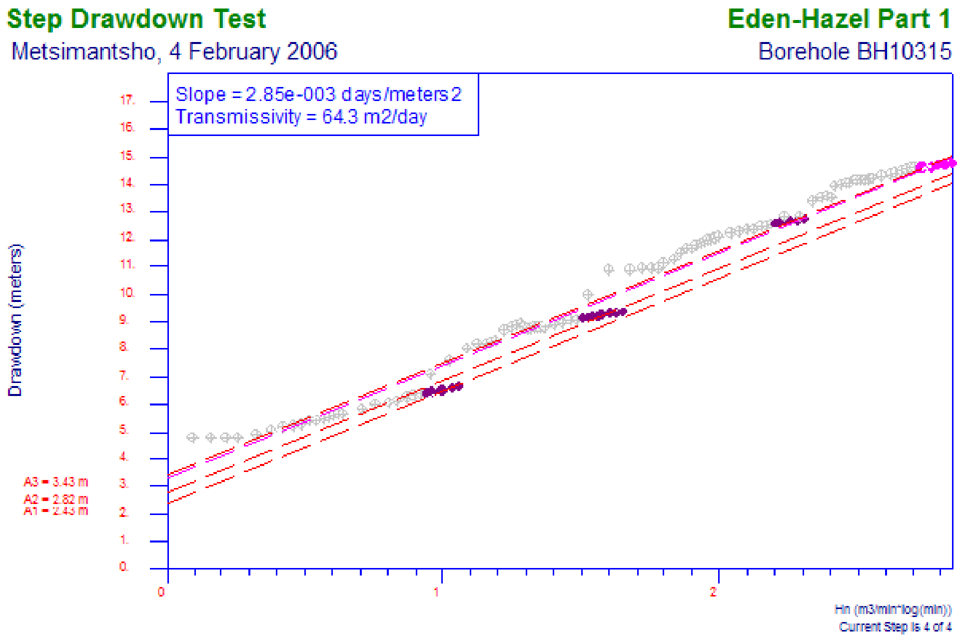

Figure 30-5 Pumping Test Results for BH10315: Step Drawdown Test – Eden-Hazel (Part 1)

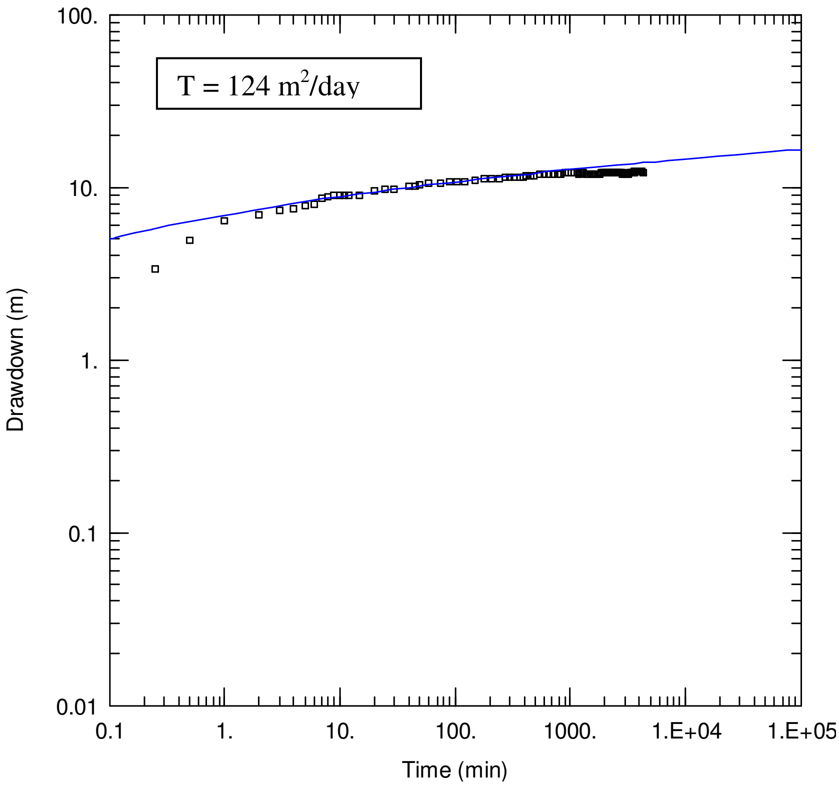

Figure 30-6 Pumping Test Results for BH10315: Theis Solution

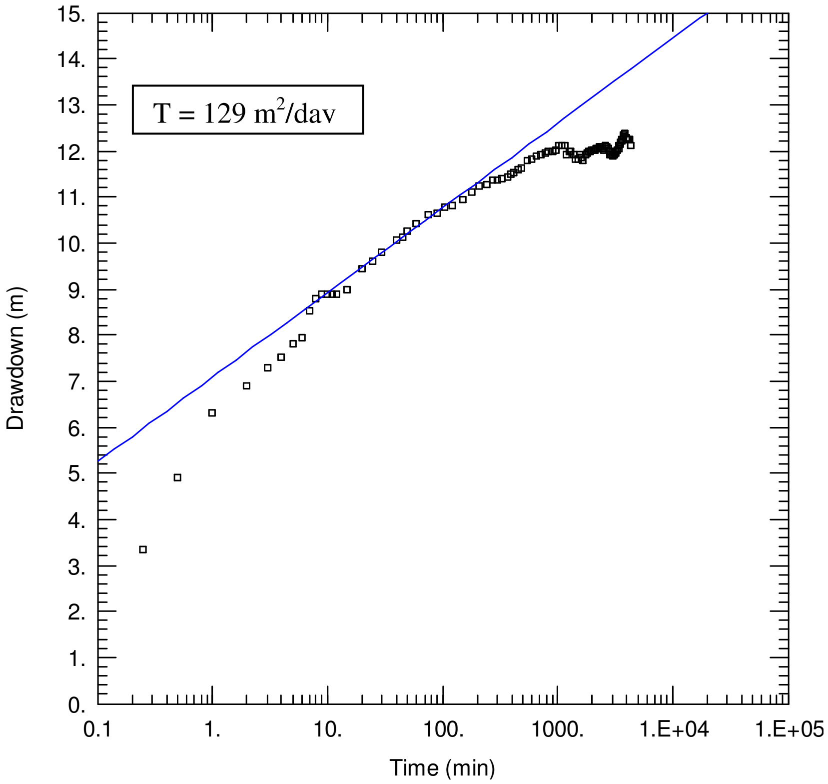

Figure 30-7 Pumping Test Results for BH10315 CRT Cooper Jacob Solution

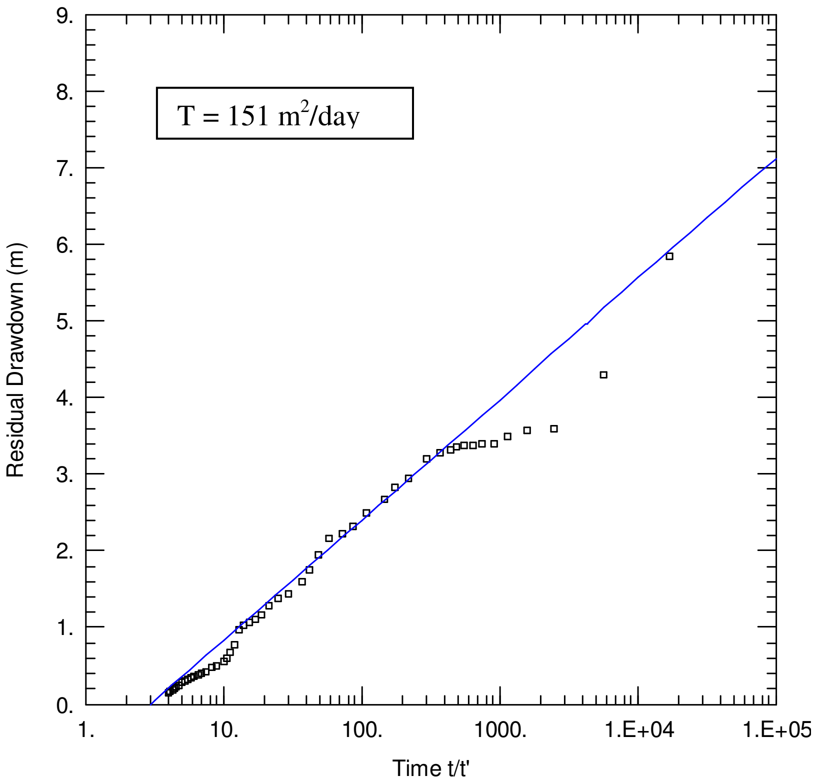

Figure 30-8 Pumping Test Results for BH10315: Theis Recovery Solution

Table 30-6 Calibration Test Data – BH10315

Official BH No.:	10315	District:	Ghanzi
Date of test commencement:	02.02.2006	Location:	Metsimantsho
Time of test commencement		BH depth (m):	287
Date of test completion:	02.02.2006	Screen Interval (m):	248.31 to 279
Time of test completion		Depth of pump intake (m):	150.8
Method of water level measurement:	dipper	Static water level before test (m):	130.18
Casing diameter (mm)	8"	Water strike	156, 177, 210 & 250
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	507688	Northing	7433865

STEPNo. 1 — STEPNo. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	131.25	1.07				0.25	135.35	5.17			
0.5	131.78	1.60				0.5	135.70	5.52			
1	134.03	3.85				1	136.80	6.62	16.08	44.78	
1.5	134.31	4.13				1.5	137.04	6.86	16.04	44.89	
2	134.48	4.30				2	137.17	6.99	16.18	44.50	
2.5	134.00	3.82				2.5	137.24	7.06	16.25	44.31	
3	134.20	4.02				3	137.38	7.20	16.28	44.23	
4	134.20	4.02	30.78	23.39		4	137.44	7.26	16.30	44.17	
5	134.20	4.02	27.22	26.45		5	137.51	7.33	16.31	44.14	
6	134.34	4.16	26.54	27.13		6	137.60	7.42	16.25	44.31	
7	134.52	4.34	25.19	28.58		7	137.67	7.49	16.37	43.98	
8	134.82	4.64	25.47	28.27		8	137.75	7.57	16.25	44.31	
9	134.95	4.77	25.33	28.42		9	137.79	7.61	16.32	44.12	
10	135.00	4.82	25.40	28.35		10	137.82	7.64	16.30	44.17	
11	135.03	4.85	25.29	28.47		11	137.90	7.72	16.25	44.31	
12	135.10	4.92	25.19	28.58		12	137.94	7.76	16.28	44.23	
15	135.29	5.11	25.33	28.42		15	138.07	7.89	16.20	44.44	

STEPNo. 3 — STEPNo. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 400L	Pumping Rate (m^3/hr)	Comments
0.25	136.52	6.34				0.25	141.55	11.37			
0.5	138.15	7.97				0.5	142.40	12.22			
1	139.09	8.91	19.75	54.68		1	142.94	12.76	18.91	76.15	
1.5	139.48	9.30				1.5	143.05	12.87			
2	139.65	9.47	19.38	55.73		2	143.12	12.94	18.81	76.56	
2.5	139.90	9.72				2.5	143.12	12.94			
3	140.03	9.85	17.93	60.23	adj	3	143.14	12.96	19.61	73.43	
4	140.34	10.16	17.97	60.10		4	143.30	13.12	19.50	73.85	
5	140.50	10.32	17.70	61.02		5	143.40	13.22	19.48	73.92	
6	140.54	10.36	17.91	60.30		6	143.52	13.34	19.44	74.07	
7	140.56	10.38	18.00	60.00		7	143.63	13.45	19.50	73.85	
8	140.65	10.47	17.78	60.74		8	143.67	13.49	19.53	73.73	
9	140.67	10.49	17.88	60.40		9	143.75	13.57	19.35	74.42	
10	140.70	10.52	17.95	60.17		10	143.82	13.64	19.22	74.92	
11	140.81	10.63	17.81	60.64		11	143.87	13.69	19.26	74.77	
12	140.83	10.65	17.96	60.13		12	143.92	13.74	19.40	74.23	
15	140.94	10.76	18.00	60.00		15	144.06	13.88	19.37	74.34	

Official BH No.:	10315	District:	Ghanzi
Date of test commencement:	02.02.2006	Location:	Metsimantsho
Time of test commencement		BH depth (m):	287
Date of test completion:	02.02.2006	Screen Interval (m):	248.31 to 279
Time of test completion		Depth of pump intake (m):	150.8
Method of water level measurement:	dipper	Static water level before test (m):	130.18
Casing diameter (mm)	8"	Water strike	156, 177, 210 & 250
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	507688	Northing	7433865

STEP No. 5 STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	144.41	14.23				0.25					
0.5	144.58	14.40				0.5					
1	144.94	14.76	18.91	95.19		1					
1.5	145.96	15.78				1.5					
2	146.45	16.27	19.61	91.79		2					
2.5	146.59	16.41				2.5					
3	146.76	16.58	19.58	91.93		3					
4	146.95	16.77	19.50	92.31		4					
5	147.07	16.89	19.48	92.40		5					
6	147.18	17.00	19.61	91.79		6					
7	147.23	17.05	19.29	93.31		7					
8						8					
9						9					
10						10					
11						11					
12						12					
15						15					

Table 30-7 Step Drawdown Test – BH10315

Official BH No.:	10315	District:	Ghanzi
Date of test commencement:	03.02.06	Location:	Metsimantsho
Time of test Commencement:	0700hrs	BH depth (m):	287
Date of test completion:	03.02.06	Screens(m)	248.31 to 279
Time of test Completion:		Depth to pump intake (m)	150.8
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.61
Distance to OB. BH (m)	n/a	Static water level before test (m):	130.25
Casing diameter (mm)		Water strike	156, 177, 210 & 250
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	507688	Northing	7433865

STEP No. 1 | STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments
0.25	131.85	1.60				0.25	137.33	7.08			
0.5	133.94	3.69				0.5	137.84	7.59			
1	134.18	3.93	24.44	29.46		1	138.30	8.05	16.28	44.23	
1.5	135.05	4.80				1.5	138.44	8.19			
2	135.05	4.80	23.56	30.56		2	138.44	8.19	16.07	44.80	
2.5	135.05	4.80	23.22	31.01		2.5	138.50	8.25			
3	135.05	4.80	23.47	30.68		3	138.55	8.30	15.91	45.25	
4	135.16	4.91	22.60	31.86		4	138.96	8.71	16.00	45.00	
5	135.30	5.05	22.19	32.45		5	139.05	8.80	15.94	45.17	
6	135.42	5.17	22.06	32.64		6	139.13	8.88	15.90	45.28	
7	135.47	5.22	21.87	32.92		7	139.17	8.92	15.87	45.37	
8	135.55	5.30	21.81	33.01		8	139.06	8.81	15.81	45.54	
9	135.64	5.39	22.03	32.68		9	139.00	8.75	15.95	45.14	
10	135.68	5.43	22.90	31.44		10	139.00	8.75	15.99	45.03	
11	135.73	5.48	22.15	32.51		11	139.05	8.80	15.89	45.31	
12	135.80	5.55	22.15	32.51		12	139.05	8.80	15.95	45.14	
13	135.84	5.59	22.03	32.68		13	139.06	8.81	15.89	45.31	
14	135.88	5.63	22.50	32.00		14	139.06	8.81	15.90	45.28	
15	135.91	5.66	22.28	32.32		15	139.08	8.83	15.97	45.08	
20	136.09	5.84	22.20	32.43		20	139.15	8.90	16.00	45.00	
25	136.24	5.99	22.44	32.09		25	139.20	8.95	15.97	45.08	
30	136.81	6.56	22.40	32.14		30	139.30	9.05	15.88	45.34	
35	136.41	6.16	22.37	32.19		35	139.34	9.09	15.83	45.48	
40	136.50	6.25	22.43	32.10		40	139.39	9.14	15.96	45.11	
45	136.56	6.31	22.16	32.49		45	139.40	9.15	15.84	45.45	
50	136.60	6.35	22.17	32.48		50	139.42	9.17	15.90	45.28	
55	136.64	6.39	22.16	32.49		55	139.46	9.21	15.87	45.37	
60	136.68	6.43	22.20	32.43		60	139.50	9.25	15.84	45.45	
70	136.75	6.50	22.21	32.42		70	139.55	9.30	15.86	45.40	
80	136.81	6.56	22.23	32.39		80	139.58	9.33	15.87	45.37	
90	136.86	6.61	22.19	32.45		90	139.62	9.37	15.83	45.48	
100	136.92	6.67	22.21	32.42		100	139.85	9.60	15.88	45.34	

Official BH No.:	10315	District:	Ghanzi
Date of test commencement:	03.02.06	Location:	Metsimantsho
Time of test Commencement:	0700hrs	BH depth (m):	287
Date of test completion:	03.02.06	Screens(m)	248.31 to 279
Time of test Completion:		Depth to pump intake (m)	150.8
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.61
Distance to OB. BH (m)	n/a	Static water level before test (m):	130.25
Casing diameter (mm)		Water strike	156, 177, 210 & 250
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	507688	Northing	7433865

STEP No. 3 | STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	P. Rate (m^3/hr)	Comments
0.25	140.24	9.99				0.25	143.09	12.84			
0.5	141.15	10.90				0.5	143.10	12.85			
1	141.15	10.90	20.28	53.25		1	143.65	13.40	16.75	64.48	
1.5	141.20	10.95	18.87			1.5	143.77	13.52			
2	141.20	10.95	18.50	58.38		2	143.80	13.55	16.59	65.10	
2.5	141.20	10.95	17.78	60.74		2.5	143.86	13.61			
3	141.39	11.14	18.00	60.00		3	144.20	13.95	15.17	71.19	
4	141.52	11.27	17.81	60.64		4	144.25	14.00	15.50	69.68	
5	141.76	11.51	17.98	60.07		5	144.32	14.07	15.67	68.92	
6	141.94	11.69	17.90	60.34		6	144.34	14.09	15.56	69.41	
7	141.94	11.69	17.88	60.40		7	144.43	14.18	15.39	70.18	
8	142.04	11.79	17.87	60.44		8	144.43	14.18	15.25	70.82	
9	142.14	11.89	17.92	60.27		9	144.43	14.18	15.40	70.13	
10	142.20	11.95	17.89	60.37		10	144.44	14.19	15.42	70.04	
11	142.25	12.00	18.00	60.00		11	144.44	14.19	15.39	70.18	
12	142.26	12.01	17.98	60.07		12	144.46	14.21	15.28	70.68	
13	142.29	12.04	17.96	60.13		13	144.48	14.23	15.30	70.59	
14	142.31	12.06	17.87	60.44		14	144.48	14.23	15.40	70.13	
15	142.34	12.09	17.98	60.07		15	144.50	14.25	15.38	70.22	
20	142.50	12.25	18.00	60.00		20	144.58	14.33	15.41	70.08	
25	142.54	12.29	17.91	60.30		25	144.64	14.39	15.39	70.18	
30	142.58	12.33	17.86	60.47		30	144.70	14.45	15.30	70.59	
35	142.63	12.38	17.92	60.27		35	144.74	14.49	15.25	70.82	
40	142.70	12.45	17.89	60.37		40	144.82	14.57	15.36	70.31	
45	142.74	12.49	17.90	60.34		45	144.84	14.59	15.34	70.40	
50	142.79	12.54	17.86	60.47		50	144.84	14.59	15.37	70.27	
55	142.81	12.56	17.91	60.30		55	144.84	14.59	15.40	70.13	
60	142.82	12.57	17.96	60.13		60	144.84	14.59	15.44	69.95	
70	142.91	12.66	17.88	60.40		70	144.89	14.64	15.34	70.40	
80	142.94	12.69	17.90	60.34		80	144.92	14.67	15.37	70.27	
90	142.98	12.73	17.92	60.27		90	144.94	14.69	15.38	70.22	
100	143.06	12.81	17.91	60.30		100	145.00	14.75	15.40	70.13	

Official BH No.:	10315	District:	Ghanzi
Date of test commencement:	03.02.06	Location:	Metsimantsho
Time of test Commencement:	0700hrs	BH depth (m):	287
Date of test completion:	03.02.06	Screens(m)	248.31 to 279
Time of test Completion:		Depth to pump intake (m)	150.8
Method of water level measurement:	electrical dipper	Description of MP:	top of dipper tubing
Observation Bh No.:	n/a	Height of MP above ground:	0.61

Distance to OB. BH (m)	n/a	Static water level before test (m):	130.25
Casing diameter (mm)		Water strike	156, 177, 210 & 250
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	507688	Northing	7433865

STEP No. 5 | STEP No. 6

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	P. Rate (m^3/hr)	Comments
0.25	145.04	14.79				0.25					
0.5	145.35	15.10				0.5					
1	145.72	15.47	23.63	76.17		1					
1.5	145.98	15.73				1.5					
2	146.10	15.85	23.72	75.89		2					
2.5	146.16	15.91				2.5					
3	146.20	15.95	22.47	80.11		3					
4	146.69	16.44	22.00	81.82		4					
5	146.81	16.56	22.51	79.96		5					
6	146.89	16.64	22.55	79.82		6					
7	146.98	16.73	22.62	79.58		7					
8	146.99	16.74	22.65	79.47		8					
9	147.00	16.75	22.45	80.18		9					
10	147.05	16.80	22.40	80.36		10					
11						11					
12						12					
13						13					
14						14					
15						15					
20						20					
25						25					
30						30					
35						35					
40						40					
45						45					
50						50					
55						55					
60						60					
70						70					
80						80					
90						90					
100						100					

Table 30-8 Constant Rate Test Data – BH10315

Official BH NO :	10315	District :	Ghanzi
Date of test commencement :	04.02.2006	Location :	Metsimantsho
Time of test commencement :		BH depth(m) :	287
Date of test completion	04.02.06	Screen Interval (m)	248.31 to 279
Time of test completion :		Depth of pump intake (m) :	150.8
Method of water level measurement	electrical dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.61
Distance ob BH r (m)	n/a	Static Water level before test(m) :	131.30
Casing diameter (mm)	203.2	Water strike	156, 177, 210 & 250
Orifice plate diameter	4"	Delivery pipe diameter	8"
Easting	507688	Northing	7433865

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500l	Q(m^3/h)	Temp (^{0}C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer /DO2
	0.25	133.48	2.18						
	0.5	134.15	2.85						
	1	136.20	4.90						
	2	140.37	9.07						
	3	141.00	9.70	24.97	72.09				
	4	141.55	10.25	24.34	73.95				
	5	141.75	10.45	24.66	72.99				
	6	141.80	10.50	24.50	73.47				
	7	141.80	10.50	26.34	68.34				
	8	141.80	10.50	25.25	71.29				
	9	141.80	10.50	25.41	70.84				
	10	141.80	10.50	25.53	70.51				
	11	141.80	10.50	25.61	70.29				
	12	142.14	10.84	25.66	70.15				
	15	142.55	11.25	25.69	70.07	28.8	670	8.16	23.5
	20	142.92	11.62	25.66	70.15	28.7	650	8.14	23.5
	25	143.19	11.89	25.69	70.07	28.5	648	8.10	23.5
	30	143.38	12.08	25.71	70.01	28.4	643	8.09	23.5
	40	143.72	12.42	25.60	70.31	28.5	643	8.09	23.5
	45	143.85	12.55	25.69	70.07	28.6	643	8.10	23.5
	50	143.91	12.61	25.64	70.20	28.6	642	8.09	23.5
	60	144.20	12.90	25.68	70.09	28.7	642	8.09	23.5
	75	144.45	13.15	25.60	70.31	28.6	670	8.28	23.5
	90	144.63	13.33	25.48	70.64	28.4	680	8.27	23.5
	105	144.78	13.48	25.67	70.12	28.5	680	8.29	23.5
	120	144.93	13.63	25.69	70.07	28.6	680	8.29	23.5
	150	145.13	13.83	25.65	70.18	28.4	680	8.29	23.5
	180	145.30	14.00	25.52	70.53	28.2	680	8.29	23.5
	210	145.47	14.17	25.60	70.31	28.2	685	8.33	23.5
	240	145.64	14.34	25.58	70.37	27.7	680	8.38	23.5
	270	145.80	14.50	25.69	70.07	27.8	680	8.30	23.5
	300	145.89	14.59	25.60	70.31	27.6	680	8.30	23.5
	330	146.03	14.73	25.58	70.37	26.8	680	8.26	23.5
	360	146.10	14.80	25.64	70.20	26.7	680	8.27	23.5
	390	146.16	14.86	25.70	70.04	26.5	680	8.28	23.5
	420	146.23	14.93	25.65	70.18	26.4	680	8.27	23.5
	450	146.33	15.03	25.66	70.15	26.7	670	8.27	23.5
	480	146.46	15.16	25.71	70.01	26.7	673	8.26	23.5
	540	146.52	15.22	25.68	70.09	26.3	675	8.26	23.5
	600	146.59	15.29	25.71	70.01	26.6	670	8.67	23.5
	660	146.65	15.35	25.61	70.29	26.5	673	8.63	23.5

	720	146.70	15.40	25.66	70.15	26.4	680	8.60	23.5
	780	146.74	15.44	25.58	70.37	26.6	679	8.61	23.5
	840	146.79	15.49	25.61	70.29	26.5	674	8.60	23.5
	900	146.84	15.54	25.66	70.15	26.1	677	8.63	23.5
	960	147.03	15.73	25.63	70.23	26.5	678	8.61	23.5

Table 30-9 Constant Rate Test Data – BH10315

Official BH NO :	10315	District :	Ghanzi
Date of test commencement :	05.02.06	Location :	Metsimantsho
Time of test commencement :	1500hrs	BH depth(m) :	287
Date of test completion	08.02.06	Screen Interval (m)	248.31 to 279
Time of test completion :	1500hrs	Depth of pump intake (m) :	150.8
Method of water level measurement	electrical dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.61
Distance ob BH r (m)	n/a	Static Water level before test(m) :	131.30
Casing diameter (mm)	203.2	Water strike	156, 177, 210 & 250
Orifice plate diameter	4"	Delivery pipe diameter	8"
Easting	507688	Northing	7433865

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 200l	Q(m^3/h)	Temp (^{0}C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO2
	0.25	134.64	3.34						
	0.5	136.22	4.92						
	1	137.62	6.32						
	2	138.21	6.91	13.75	52.36				
	3	138.60	7.30	13.06	55.13				
	4	138.83	7.53	13.56	53.10				
	5	139.10	7.80	13.20	54.55				
	6	139.25	7.95	13.16	54.71				
	7	139.82	8.52	13.08	55.05				
	8	140.10	8.80	13.05	55.17				
	9	140.20	8.90	13.00	55.38				
	10	140.20	8.90	13.09	55.00				
	11	140.20	8.90	13.03	55.26				
	12	140.20	8.90	13.06	55.13				
	15	140.30	9.00	13.10	54.96				
	20	140.73	9.43	13.01	55.34	28.1	670	8.22	13.5
	25	140.91	9.61	13.05	55.17	28.3	670	8.22	13.5
	30	141.09	9.79	12.99	55.43	28.5	670	8.22	13.5
	40	141.35	10.05	13.08	55.05	29.1	670	8.17	13.5
	45	141.42	10.12	13.03	55.26	29.8	670	8.18	13.5
	50	141.55	10.25	12.88	55.90	29.8	670	8.22	13.5
	60	141.72	10.42	13.04	55.21	29.2	670	8.18	13.5
	75	141.90	10.60	12.89	55.86	28.2	680	8.14	13.5
	90	141.96	10.66	13.02	55.30	28.1	680	8.14	13.5
	105	142.07	10.77	13.09	55.00	28.0	680	8.14	13.5
	120	142.12	10.82	12.87	55.94	28.3	670	8.16	13.5
	150	142.25	10.95	13.09	55.00	28.2	670	8.16	13.5
	180	142.40	11.10	13.05	55.17	28.2	670	8.16	13.5
	210	142.53	11.23	13.06	55.13	28.1	680	8.16	13.5
	240	142.57	11.27	13.02	55.30	28.1	670	8.16	13.5
	270	142.68	11.38	12.97	55.51	28.0	670	8.15	13.5
	300	142.68	11.38	13.08	55.05	28.0	670	8.16	13.5
	330	142.69	11.39	13.10	54.96	28.0	670	8.15	13.5

	360	142.72	11.42	13.04	55.21	28.1	670	8.16	13.5
	390	142.78	11.48	13.07	55.09	27.9	670	8.15	13.5
	420	142.83	11.53	13.10	54.96	27.8	680	8.15	13.5
	450	142.90	11.60	13.05	55.17	27.8	670	8.16	13.5
	480	142.94	11.64	13.07	55.09	27.7	680	8.16	13.5
	540	143.08	11.78	13.10	54.96	27.6	670	8.16	13.5
	600	143.13	11.83	13.04	55.21	27.5	670	8.15	13.5
	660	143.19	11.89	13.10	54.96	27.6	670	8.16	13.5
	720	143.23	11.93	13.07	55.09	27.4	680	8.16	13.5
	780	143.25	11.95	13.04	55.21	27.3	670	8.14	13.5
	840	143.27	11.97	13.09	55.00	27.4	660	8.13	13.5
	900	143.29	11.99	13.03	55.26	27.3	670	8.16	13.5
	960	143.33	12.03	13.05	55.17	27.1	680	8.16	13.5
	1020	143.41	12.11	13.04	55.21	27.4	670	8.15	13.5
	1080	143.41	12.11	13.08	55.05	27.3	680	8.14	13.5
	1140	143.41	12.11	13.09	55.00	27.1	690	8.16	13.5
	1200	143.23	11.93	13.04	55.21	28.6	687	8.10	13.5
	1260	143.28	11.98	13.08	55.05	28.4	670	8.13	13.5
	1320	143.28	11.98	13.02	55.30	28.4	670	8.15	13.5
	1380	143.22	11.92	13.10	54.96	28.5	670	8.16	13.5
	1440	143.12	11.82	13.06	55.13	28.4	670	8.20	13.5
	1500	143.12	11.82	13.03	55.26	28.4	680	8.16	13.5
	1560	143.22	11.92	13.06	55.13	28.4	670	8.16	13.5
	1620	143.16	11.86	13.09	55.00	28.4	670	8.20	13.5
	1680	143.10	11.80	13.01	55.34	28.4	680	8.16	13.5
	1740	143.22	11.92	13.07	55.09	28.0	690	8.16	13.5
	1800	143.25	11.95	13.09	55.00	27.9	680	8.16	13.5
	1860	143.30	12.00	13.02	55.30	27.8	670	8.16	13.5
	1920	143.30	12.00	13.10	54.96	27.9	680	8.15	13.5
	1980	143.32	12.02	13.06	55.13	27.9	670	8.16	13.5
	2040	143.32	12.02	13.00	55.38	27.9	670	8.17	13.5
	2100	143.33	12.03	13.08	55.05	28.0	680	8.17	13.5
	2160	143.35	12.05	13.10	54.96	28.0	680	8.18	13.5
	2220	143.35	12.05	13.08	55.05	28.1	670	8.16	13.5
	2280	143.37	12.07	13.04	55.21	28.1	680	8.16	13.5
	2340	143.37	12.07	13.04	55.21	28.1	670	8.17	13.5
	2400	143.38	12.08	13.09	55.00	28.1	670	8.17	13.5
	2460	143.35	12.05	13.03	55.26	28.0	670	8.17	13.5
	2520	143.32	12.02	13.08	55.05	28.2	680	8.17	13.5
	2580	143.40	12.10	13.04	55.21	28.4	670	8.16	13.5
	2640	143.40	12.10	13.06	55.13	28.7	680	8.16	13.5
	2700	143.37	12.07	13.09	55.00	28.5	670	8.16	13.5
	2760	143.34	12.04	13.01	55.34	28.6	670	8.09	13.5
	2820	143.30	12.00	13.08	55.05	28.9	670	8.07	13.5
	2880	143.22	11.92	13.06	55.13	29.0	670	8.07	13.5
	2940	143.22	11.92	13.04	55.21	28.9	670	8.09	13.5
	3000	143.22	11.92	13.00	55.38	28.8	670	8.09	13.5
	3060	143.20	11.90	13.09	55.00	28.4	670	8.14	13.5
	3120	143.22	11.92	13.02	55.30	28.3	680	8.05	13.5
	3180	143.25	11.95	13.08	55.05	28.9	680	8.14	13.5
	3240	143.27	11.97	13.01	55.34	28.8	670	8.14	13.5
	3300	143.33	12.03	13.08	55.05	28.9	670	8.15	13.5
	3360	143.36	12.06	13.03	55.26	28.8	680	8.13	13.5
	3420	143.41	12.11	13.02	55.30	28.7	680	8.15	13.5
	3480	143.45	12.15	13.06	55.13	28.6	670	8.16	13.5
	3540	143.48	12.18	13.02	55.30	28.5	680	8.13	13.5
	3600	143.51	12.21	13.09	55.00	28.6	670	8.13	13.5
	3660	143.54	12.24	13.08	55.05	28.3	680	8.05	13.5

	3720	143.60	12.30	13.03	55.26	28.4	680	8.07	13.5
	3780	143.63	12.33	13.02	55.30	28.9	670	8.14	13.5
	3840	143.66	12.36	13.08	55.05	28.7	680	8.15	13.5
	3900	143.66	12.36	13.03	55.26	28.6	680	8.16	13.5
	3960	143.57	12.27	13.04	55.21	28.0	670	8.16	13.5
	4020	143.57	12.27	13.07	55.09	28.1	670	8.12	13.5
	4080	143.55	12.25	13.09	55.00	28.1	670	8.14	13.5
	4140	143.55	12.25	13.03	55.26	28.9	660	8.05	13.5
	4200	143.54	12.24	13.07	55.09	28.75	660	8.04	13.5
	4260	143.54	12.24	13.06	55.13	28.7	660	8.03	13.5
	4320	143.40	12.10	13.07	55.09	28.71	660	8.02	Dissolved O2 = 1.75mg/l

Table 30-10 Recovery Test Data – BH10315

Official BH NO :	10315	District :	Ghanzi
Date of test commencement :	08.02.06	Location :	Metsimantsho
Time of test commencement :		BH depth(m) :	287
Date of test completion	09.02.06	Screen Int (m)	248.31 to 279
Time of test completion :		Depth of pump intake (m) :	150.8
Method of water level measurement:	dipper	Description of MP	top of casing
OB. BH. No.:	n/a	Height of MP above ground(m) :	0.61
Dist.to Pumping Bh:	n/a	Static Water level before test(m) :	130.3
Casing diameter (mm)	203	Water strike	156, 177, 210 & 250
Orifice plate diameter		Delivery pipe diameter	
Easting	507688	Northing	7433865

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	143.40	13.10
	0.25	141.02	10.72
	0.5	137.15	6.85
	1	135.59	5.29
	2	134.90	4.60
	3	134.87	4.57
	4	134.80	4.50
	5	134.70	4.40
	6	134.69	4.39
	7	134.68	4.38
	8	134.68	4.38
	9	134.66	4.36
	10	134.61	4.31
	12	134.57	4.27
	15	134.50	4.20
	20	134.25	3.95
	25	134.12	3.82
	30	133.98	3.68
	40	133.80	3.50
	50	133.61	3.31
	60	133.53	3.23
	75	133.46	3.16
	90	133.24	2.94
	105	133.05	2.75
	120	132.90	2.60

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	132.74	2.44
	180	132.67	2.37
	210	132.58	2.28
	240	132.47	2.17
	270	132.41	2.11
	300	132.36	2.06
	330	132.33	2.03
	360	132.26	1.96
	390	132.08	1.78
	420	131.98	1.68
	450	131.90	1.60
	480	131.85	1.55
	540	131.79	1.49
	600	131.77	1.47
	660	131.73	1.43
	720	131.70	1.40
	780	131.68	1.38
	840	131.66	1.36
	900	131.64	1.34
	960	131.62	1.32
	1020	131.60	1.30
	1080	131.58	1.28
	1140	131.55	1.25
	1200	131.52	1.22
	1260	131.50	1.20
	1320	131.48	1.18
	1380	131.46	1.16
	1440	131.44	1.14

31 BH10316

BH10316 is an exploration borehole with a siting reference of **S14,** TEM 39 (spot sounding). It is located south-east of Metsimantle Village and is 39km east of the Ncojane – Ukwi road, along the Ghanzi and Kgalagadi district boundary. Drilling of this borehole commenced on 22 January and was completed on 10 February 2006 at a depth of 250m.

31.1 SITING CRETERIA AND DRILLING OBJECTIVES

This exploration borehole was drilled to explore the yield and water quality of the Ecca aquifer to the west of the Ncojane Block and also provide water level data of the Ecca aquifer in the western most part of the Ncojane Block.

31.2 DRILLING RESULTS

Various lithologies including fine grained sands, silcrete, mudstones, coal and fine to coarse grained sandstones were intercepted during drilling of this exploration borehole (**Figure 31-1**). Drilling was carried out with a 15 inch bit using the DTH drilling technique from 0 to 93 m bgl after which 12 inch plain casings were installed and cement grouted. From the 93 to 174 m, drilling was carried out using a 12 inch drilling bit after which 10 inch casings were installed. It has to be noted that there was a lot of collapsing between depths of 135 and 174m which was overcome by drilling and casing at the same time. A $9^{7/8}$ inch tri-cone bit was used to drill from 174 m to the terminal depth of 250m.

During drilling of this borehole, two water strikes were encountered. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows:

1. (162m, 280 µS/cm, 6 m^3/hr)
2. (174m, 300 µS/cm, 37 m^3/hr)

The top water strike was cased off and the total yield before installation of casings and screens assembly was 44 m^3/hr.

The borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 250m. An 8 inch steel casing and factory slotted screen (interval 173.09 to 215.99 m bgl) assembly was installed after borehole geophysical logging **(Figure 31-2).**

The borehole was developed using the air lifting method for 6 hours and the final measured airlift yield was 47m^3/hr and the electrical conductivity was 300µS/cm. The static water level measured on 10 February 2006 was 115.23 m bgl.

Water samples were collected at the two water strikes for chemical analysis at DWA lab and the results are shown in **Table 31-1.** The other samples collected at the different water strikes were submitted to the CSIR laboratory in Pretoria for isotope analysis (^{18}O and ^{2}H) and results are in **Appendix 3.**

Table 31-1 Drilling Chemistry results (DWA)

BH No	Depth	pH	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	F mg/L	CO3 mg/L	HCO3 mg/L	Mn mg/L	Fe mg/L	Aquifer
10316	162	6.76	168	13.56	5.64	41.29	5.447	13.51	9.09	0	0.3	0	141.08	0.00	3.28	SST 2
10316	174	7.16	152	23.00	5.84	30.09	4.33	14.02	8.05	3.06	0.28	0	145.19	0.00	0.70	SST 2
BOS 32:2000 Class II		5.5-9.5	1000	150.00	70	200	50	200	250	45	1	200	250	1.00	3.00	
BOS 32:2000 Class III		5.0 - 10.0	2000	200.00	100	400	100	600	400	45	1.5	600	400	5.00	20.00	

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

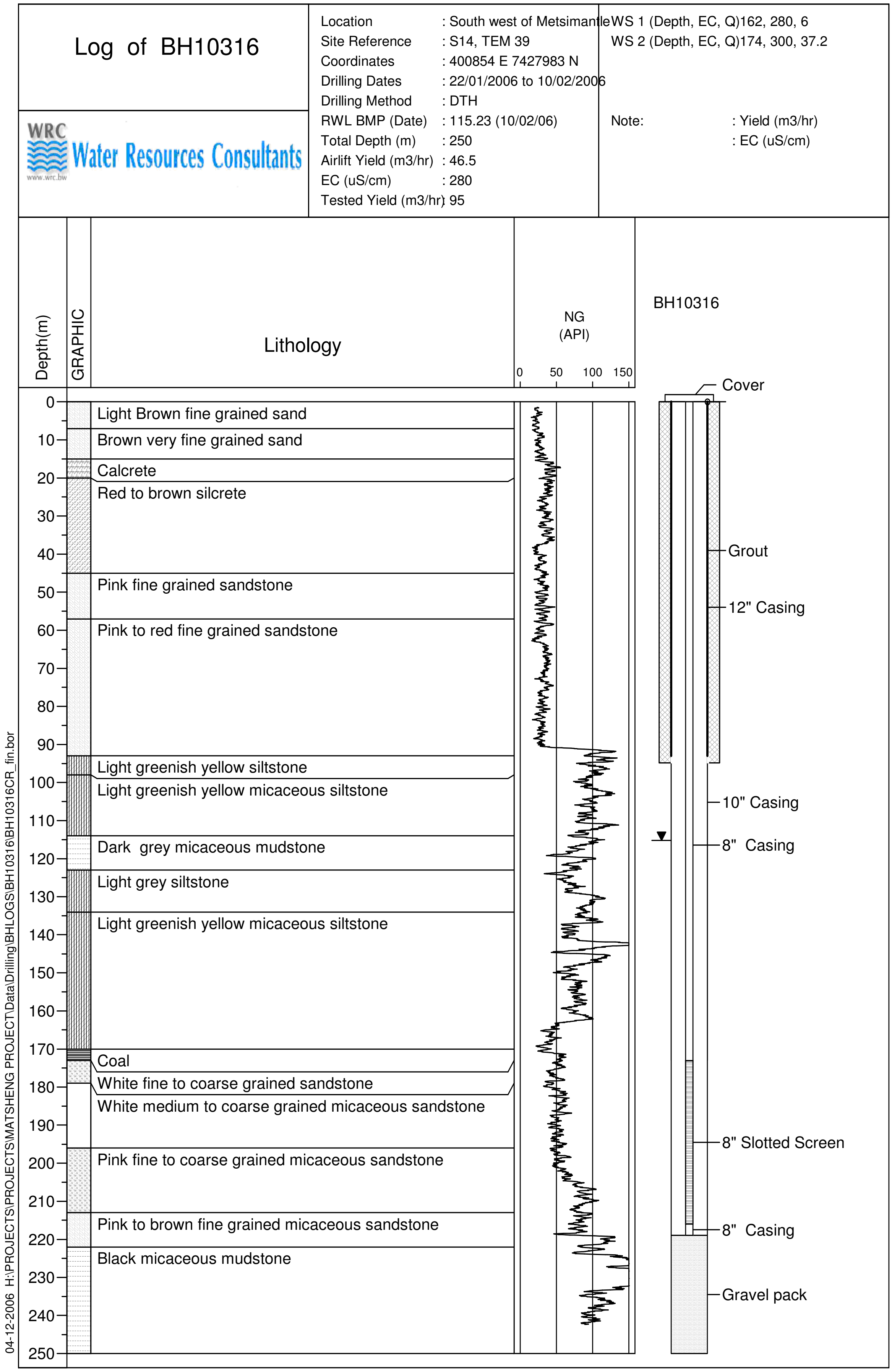

Figure 31-1 Log of BH10316

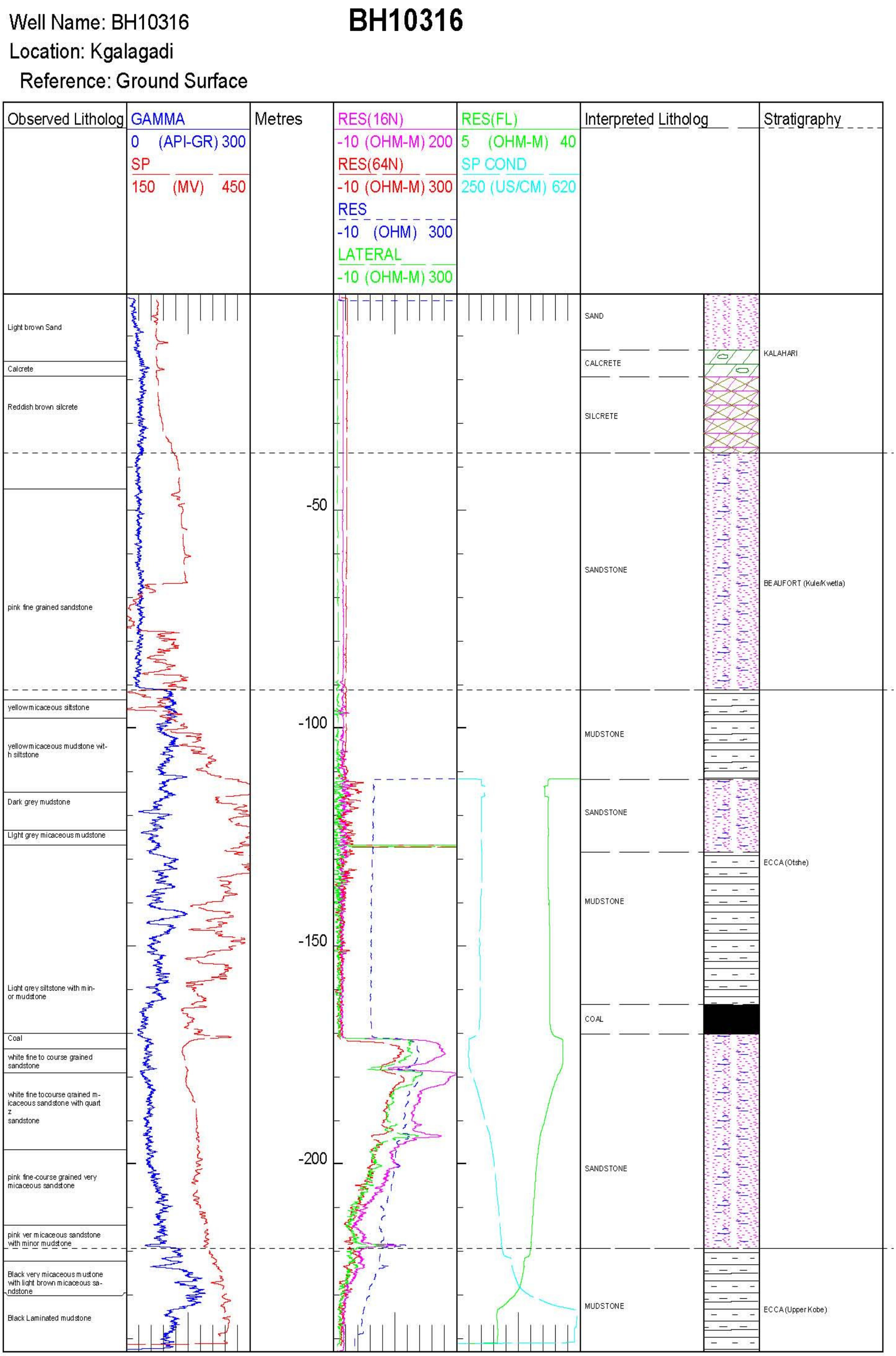

Figure 31-2 Geophysical log of BH10316

31.3 PUMP TESTING RESULTS

Borehole BH10316was pump tested between 16 and 22 February 2006. The tests carried out were calibration, step drawdown, constant rate and recovery. The measuring point was 0.67 m above ground level (agl) and the pump intake was set at 150 m below ground level. Summary details for the pump testing activities are given in **Table 31-2**. The collcted pump testing data is presented in **Tables 31-6 to 31-9.**

Table 31-2 Summary of Pumping Test Data BH10316

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	0.78	32
	2	15	1.21	45
	3	15	2.16	67
	4	15	3.25	95
Step Test	1	100	0.93	25
	2	100	2.25	55
	3	100	3.11	75
	4	100	4.47	95
Constant Rate	1	4320	5.47	95
Recovery	1	1440	0.37	0

Note. 0.37 Residual Drawdown*

31.3.1 Step Drawdown Test

The step drawdown test was carried out on 17 February 2006 and the static water level before the start of the test was 114.5 m bmp. The step drawdown test consisted of 4 steps of 100 minutes duration at discharge rates of 25, 55, 75 and 95m^3/hr for steps 1 to 4 respectively.

The step drawdown pumping test was analysed using the computer programme StepMaster by preparing semi-logarithmic plot of drawdown versus time and determining the incremental drawdown for each pumping step using the Hantush-Bierschenk Method. The interpreted step test data using this method is presented in **Figure 31-3**. This method is suitable for confined, leaky, and unconfined aquifers. The coefficients B (aquifer loss + linear well loss) and C (non-linear well loss) were derived graphically from an arithmetic plot of specific drawdown (s_w/Q) versus Q, **Figure 31-4**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 300m^2/d (**Figure 31-5**). The results of the step test data interpretation are given in **Table 31-3**.

Table 31-3 Results of Step Test Analysis BH10316

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10316	1.49E-03	7.46E-08	300	25.0	0.943	0.943	26.51
				55.0	1.11	2.053	26.79
				75.0	0.732	2.785	26.93
				95.0	1.14	3.925	24.20

The planned duration for the constant rate test of this borehole is 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 31-3**) to estimate the expected total drawdown after 3 days of pumping. It was found out that a discharge rate of 95m^3/hr was ideal for this borehole.

31.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 18 and 21 February 2006 at a discharge rate of 95 m^3/hr and the total drawdown after 72 hrs of pumping was 5.47 m. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 0.37m.

Data from this borehole was interpreted using the Theis and Cooper-Jacob (1946) analytical solutions using the computer programme "Aqtesolv". Transmissivity (T) values obtained by these two analytical solutions were 414 and 394 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 372m^2/d was obtained. The results are summarised in **Table 31-4** and the data plots are is presented in **Figures 31-6** to **31-8**.

Table 31-4 Summary of Constant Rate and Recovery Tests BH10316

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10316	72	2280	a) 414 b) 394	d) 372	Confined

Notes:
Interpretation Techniques
c) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

31.3.2.1 Aquifer Type interpreted

The interpretation of the pump testing data indicates that the aquifer type is confined.

31.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. The results of chemical analyses from CSIR lab are presented in **Table 31-5**. In addition some samples collected were submitted for stable and radioactive (^{14}C) isotope analysis at the CSIR laboratory in Pretoria, South Africa, **.**

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), pH and dissolved oxygen are 28.9 ^oC, 270µS/cm, 7.63 and 3 mg/L respectively.

Table 31-5 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10316	3.5	30	20	5.9	8.3	13	87	0.85	0.4	<0.05	<0.05	280	6.5	179
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10316	<0.1	74	<0.11	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 *is calculated from alkalinity*

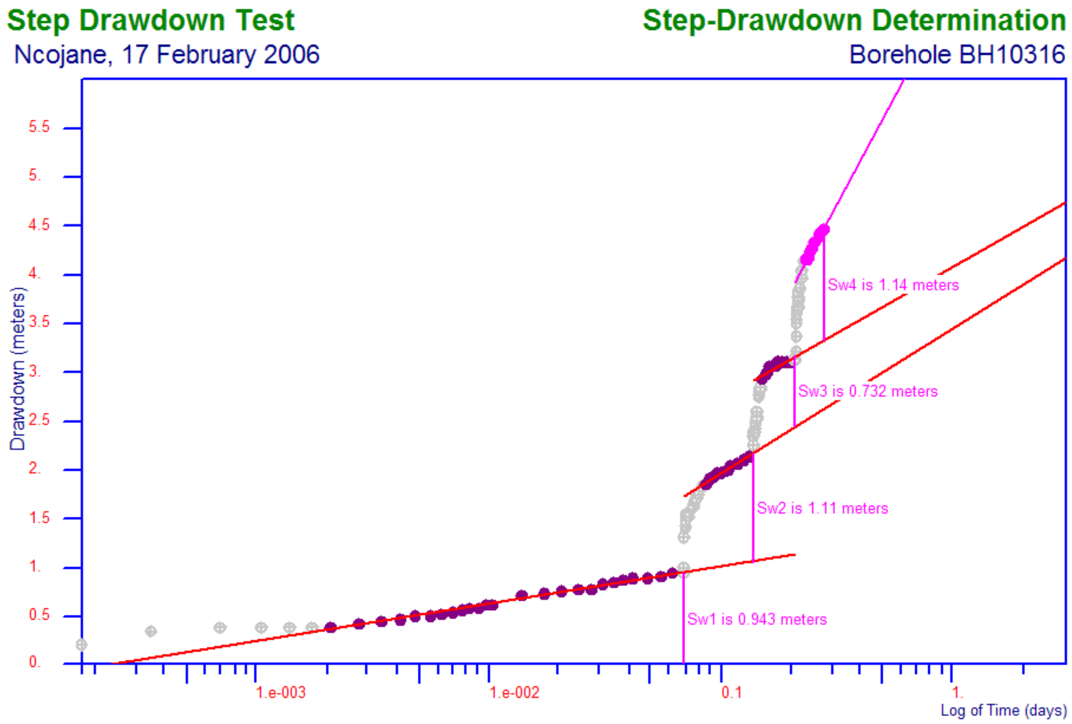

Figure 31-3 Pumping Test Results for BH10316: Step Drawdown Test - Hantush-Bierschenk (semi-log)

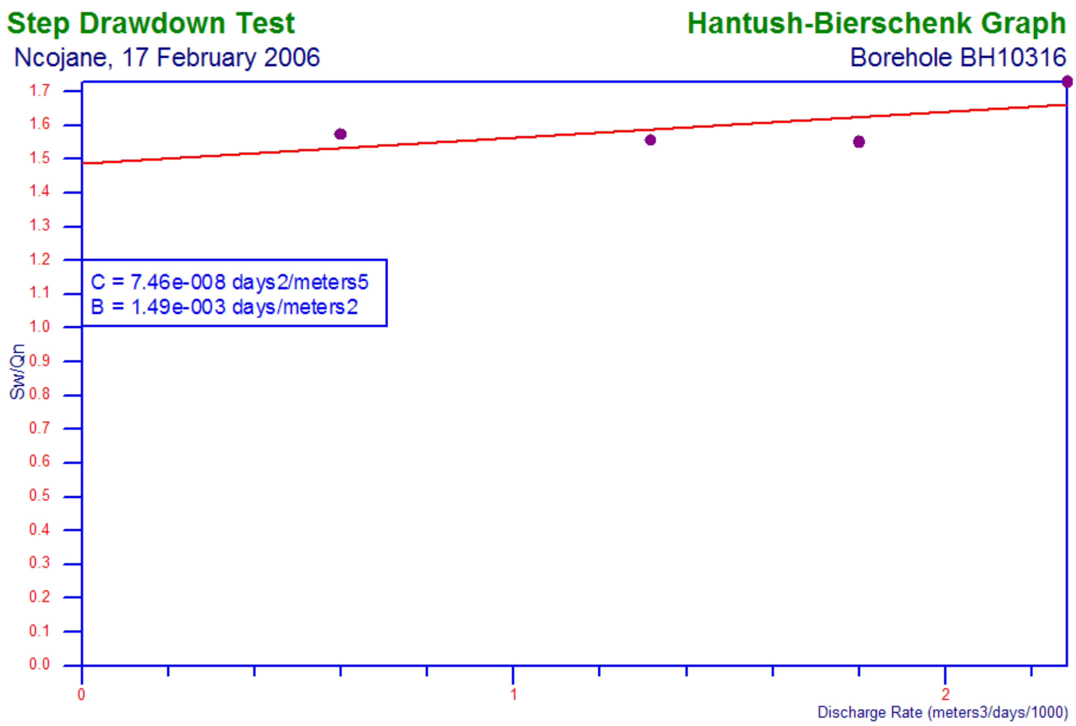

Figure 31-4 Pumping Test Results for BH10316: Step Drawdown Test – Hantush-Bierschenk

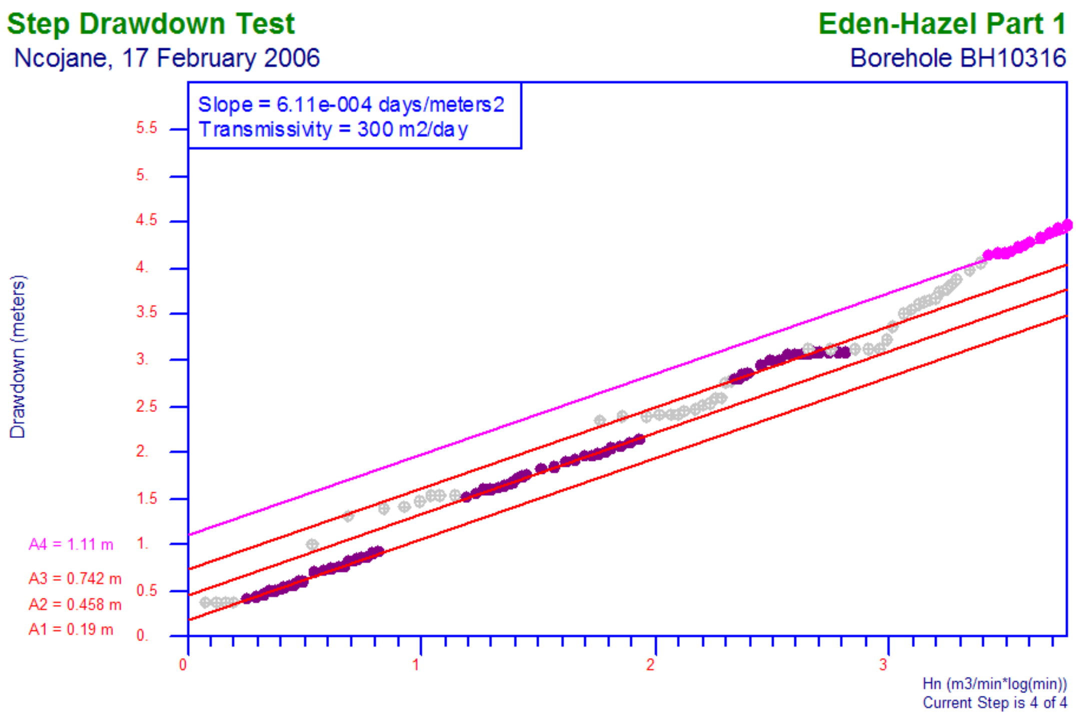

Figure 31-5 Pumping Test Results for BH10316: Step Drawdown Test – Eden-Hazel (Part 1)

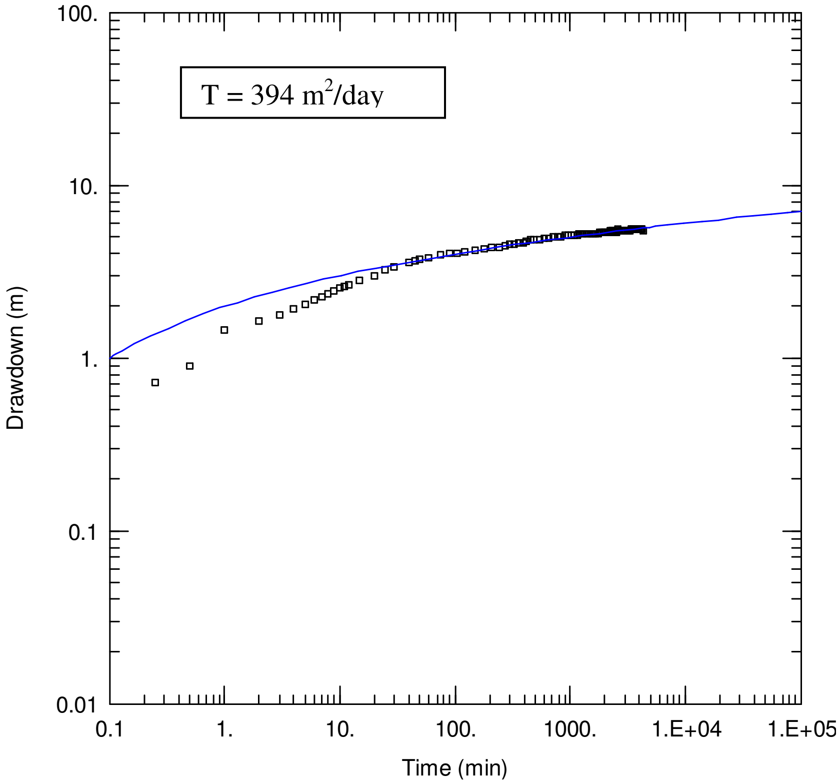

Figure 31-6 Pumping Test Results for BH10316: Theis Solution

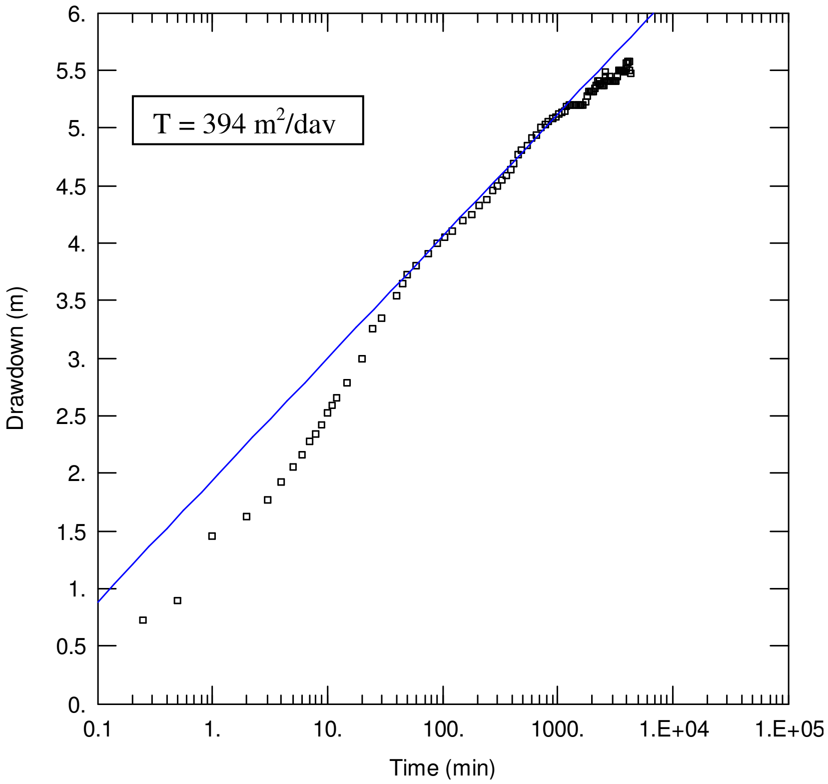

Figure 31-7 Pumping Test Results for BH10316: CRT Cooper Jacob Solution

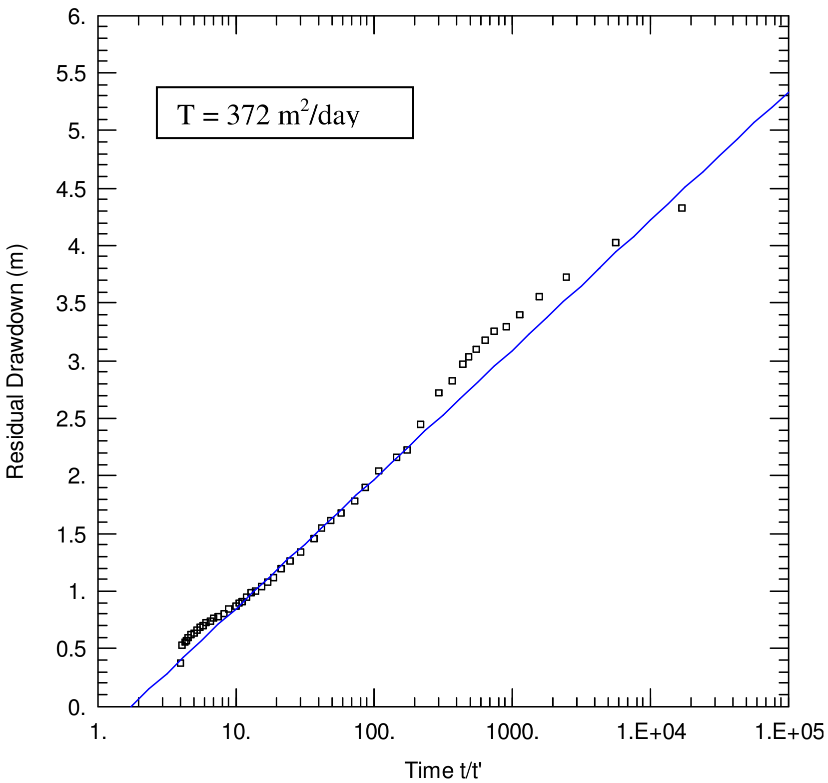

Figure 31-8 Pumping Test Results for BH10316: Theis Recovery Solution

Table 31-6 Calibration Test Data – BH10316

Official BH No.:	10316	District:	Ghanzi
Date of test commencement:	16.2.2006	Location:	Matsimantle
Time of test commencement	1215hrs	BH depth (m):	250
Date of test completion:	16.2.06	Screen Interval (m):	173.09 to 215.99
Time of test completion	1315hrs	Depth of pump intake (m):	150
Method of water level measurement:	dipper	Static water level before test (m):	114.47
Casing diameter (mm)		Water strike	162 and 174
Orifice plate diameter		Delivery pipe diameter	102mm
Easting	400854	Northing	7427983

STEPNo.	1					STEPNo.	2				
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P Rate (m^3/hr)	Comments
0.25	114.77	0.30				0.25	115.03	0.56			
0.5	114.90	0.43				0.5	115.43	0.96			
1	114.96	0.49				1	115.47	1.00	13.75	52.36	
1.5	114.96	0.49				1.5	115.48	1.01			
2	114.96	0.49				2	115.48	1.01	14.45	49.83	
2.5	114.96	0.49				2.5	115.55	1.08			
3	114.96	0.49	24.19	29.76		3	115.44	0.97	15.33	46.97	
4	114.98	0.51	24.10	29.88		4	115.49	1.02	16.70	43.11	
5	115.03	0.56	23.00	31.30		5	115.50	1.03	16.50	43.64	
6	115.05	0.58	22.97	31.35		6	115.55	1.08	16.03	44.92	
7	115.08	0.61	22.55	31.93		7	115.55	1.08	16.09	44.75	
8	115.12	0.65	22.25	32.36		8	115.57	1.10	16.01	44.97	
9	115.13	0.66	22.31	32.27		9	115.60	1.13	15.70	45.86	
10	115.14	0.67	22.39	32.16		10	115.61	1.14	15.44	46.63	
11	115.18	0.71	22.35	32.21		11	115.63	1.16	15.62	46.09	
12	115.18	0.71	22.33	32.24		12	115.65	1.18	15.59	46.18	
15	115.25	0.78	22.24	32.37		15	115.68	1.21	15.44	46.63	

STEPNo.	3					STEPNo.	4				
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	Pumping Rate (m^3/hr)	Comments
0.25	115.70	1.23				0.25	116.82	2.35			
0.5	115.84	1.37				0.5	116.90	2.43			
1	116.09	1.62	16.56	65.22		1	116.90	2.43	18.91	95.19	
1.5	116.11	1.64				1.5	116.92	2.45			
2	116.12	1.65	16.12	67.00		2	116.94	2.47	19.22	93.65	adj
2.5	116.17	1.70				2.5	116.50	2.03			
3	116.23	1.76	16.09	67.12		3	116.00	1.53	18.94	95.04	change
4	116.25	1.78	16.00	67.50		4	117.20	2.73	18.75	96.00	gear
5	116.28	1.81	16.13	66.96		5	117.27	2.80	18.68	96.36	
6	116.32	1.85	16.14	66.91		6	117.34	2.87	18.75	96.00	
7	116.35	1.88	16.06	67.25		7	117.40	2.93	18.97	94.89	
8	116.40	1.93	16.41	65.81		8	117.43	2.96	18.98	94.84	
9	116.43	1.96	16.38	65.93		9	117.53	3.06	18.77	95.90	
10	116.44	1.97	16.35	66.06		10	117.53	3.06	18.66	96.46	
11	116.45	1.98	16.34	66.10		11	117.56	3.09	18.93	95.09	
12	116.49	2.02	16.33	66.14		12	117.63	3.16	18.56	96.98	
15	116.63	2.16	16.50	65.45		15	117.72	3.25	18.75	96.00	

Table 31-7 Step Drawdown Test Data – BH10316

Official BH No.:	10316	District:	Ghanzi
Date of test commencement:	17.2.2006	Location:	Metsimantle
Time of test Commencement:	0730hrs	BH depth (m):	250
Date of test completion:	17.2.2006	Screens(m)	173.09 and 215.99
Time of test Completion:		Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of casing
Observation Bh No.:	n/a	Height of MP above ground:	0.27
Distance to OB. BH (m)	n/a	Static water level before test (m):	114.5
Casing diameter (mm)	203	Water strike	162 and 174
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	400854	Northing	7427983

STEP No. 1 / STEP No. 2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 200L	P. Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 300L	P. Rate (m^3/hr)	Comments
0.25	114.71	0.21				0.25	115.50	1.00			
0.5	114.83	0.33				0.5	115.81	1.31			
1	114.87	0.37	27.60	26.09		1	115.89	1.39	17.72	60.95	
1.5	114.87	0.37				1.5	115.91	1.41			
2	114.87	0.37	25.90	27.80		2	115.98	1.48	18.91	57.11	
2.5	114.88	0.38				2.5	116.04	1.54			
3	114.88	0.38	28.80	25.00		3	116.04	1.54	19.94	54.16	
4	114.92	0.42	28.44	25.32		4	116.03	1.53	19.44	55.56	adj
5	114.94	0.44	28.50	25.26		5	116.02	1.52	19.72	54.77	
6	114.96	0.46	28.25	25.49		6	116.05	1.55	19.44	55.56	
7	114.99	0.49	28.66	25.12		7	116.10	1.60	19.69	54.85	
8	114.99	0.49	28.75	25.04		8	116.10	1.60	19.85	54.41	
9	115.02	0.52	28.80	25.00		9	116.12	1.62	19.16	56.37	
10	115.04	0.54	28.81	24.99		10	116.13	1.63	19.44	55.56	
11	115.05	0.55	28.75	25.04		11	116.16	1.66	19.46	55.50	
12	115.06	0.56	28.68	25.10		12	116.18	1.68	20.19	53.49	
13	115.07	0.57	28.84	24.97		13	116.21	1.71	19.94	54.16	
14	115.10	0.60	28.70	25.09		14	116.24	1.74	19.96	54.11	
15	115.10	0.60	28.77	25.03		15	116.25	1.75	19.45	55.53	
20	115.20	0.70	28.80	25.00		20	116.32	1.82	19.44	55.56	
25	115.23	0.73	28.81	24.99		25	116.35	1.85	19.17	56.34	
30	115.25	0.75	28.76	25.03		30	116.40	1.90	19.46	55.50	
35	115.27	0.77	28.44	25.32		35	116.42	1.92	19.44	55.56	
40	115.27	0.77	28.67	25.11		40	116.46	1.96	19.50	55.38	
45	115.32	0.82	28.75	25.04		45	116.46	1.96	19.47	55.47	
50	115.33	0.83	28.66	25.12		50	116.48	1.98	19.50	55.38	
55	115.35	0.85	28.68	25.10		55	116.50	2.00	19.48	55.44	
60	115.37	0.87	28.80	25.00		60	116.54	2.04	19.51	55.36	
70	115.37	0.87	28.66	25.12		70	116.56	2.06	19.47	55.47	
80	115.40	0.90	28.68	25.10		80	116.60	2.10	19.44	55.56	
90	115.43	0.93	28.77	25.03		90	116.64	2.14	19.16	56.37	
100	115.43	0.93	28.75	25.04		100	116.75	2.25	19.46	55.50	

Official BH No.:	10316	District:	Ghanzi
Date of test commencement:	17.2.2006	Location:	Metsimantle
Time of test Commencement:	0730hrs	BH depth (m):	250
Date of test completion:	17.2.2006	Screens(m)	173.09 and 215.99
Time of test Completion:		Depth to pump intake (m)	150
Method of water level measurement:	electrical dipper	Description of MP:	top of casing
Observation Bh No.:	n/a	Height of MP above ground:	0.27
Distance to OB. BH (m)	n/a	Static water level before test (m):	114.5
Casing diameter (mm)	203	Water strike	162 and 174
Orifice plate diameter	n/a	Delivery pipe diameter	102mm
Easting	400854 400854	Northing	7427983

STEP No. 3 STEP No. 4

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill 500L	P. Rate (m^3/hr)	Comments
0.25	116.85	2.35				0.25	117.62	3.12			
0.5	116.89	2.39				0.5	117.62	3.12			
1	116.89	2.39	26.22	68.65		1	117.62	3.12	18.94	95.04	
1.5	116.92	2.42				1.5	117.63	3.13			
2	116.92	2.42	25.28	71.20		2	117.63	3.13	18.97	94.89	
2.5	116.96	2.46				2.5	117.72	3.22			
3	116.96	2.46	25.75	69.90		3	118.86	4.36	18.94	95.04	
4	116.98	2.48	25.63	70.23		4	118.00	3.50	18.77	95.90	
5	117.02	2.52	25.50	70.59	adj	5	118.04	3.54	18.65	96.51	
6	117.04	2.54	25.53	70.51		6	118.10	3.60	18.87	95.39	
7	117.09	2.59	25.69	70.07		7	118.13	3.63	19.00	94.74	
8	117.10	2.60	23.62	76.21		8	118.15	3.65	18.81	95.69	
9	117.25	2.75	24.03	74.91		9	118.18	3.68	18.88	95.34	
10	117.27	2.77	23.85	75.47		10	118.23	3.73	18.95	94.99	
11	117.30	2.80	23.84	75.50		11	118.26	3.76	18.93	95.09	
12	117.30	2.80	23.84	75.50		12	118.28	3.78	18.88	95.34	
13	117.33	2.83	23.81	75.60		13	118.32	3.82	18.66	96.46	
14	117.34	2.84	23.84	75.50		14	118.34	3.84	18.75	96.00	
15	117.35	2.85	23.69	75.98		15	118.37	3.87	18.90	95.24	
20	117.43	2.93	23.85	75.47		20	118.47	3.97	18.93	95.09	
25	117.49	2.99	23.88	75.38		25	118.55	4.05	18.95	94.99	
30	117.50	3.00	23.74	75.82		30	118.64	4.14	18.97	94.89	
35	117.56	3.06	23.86	75.44		35	118.65	4.15	18.75	96.00	
40	117.56	3.06	23.89	75.35		40	118.66	4.16	18.93	95.09	
45	117.56	3.06	23.91	75.28		45	118.68	4.18	18.95	94.99	
50	117.56	3.06	23.88	75.38		50	118.72	4.22	18.90	95.24	
55	117.59	3.09	23.85	75.47		55	118.75	4.25	18.93	95.09	
60	117.59	3.09	23.97	75.09		60	118.78	4.28	18.94	95.04	
70	117.59	3.09	24.00	75.00		70	118.83	4.33	18.93	95.09	
80	117.59	3.09	23.88	75.38		80	118.88	4.38	18.95	94.99	
90	117.59	3.09	23.86	75.44		90	118.92	4.42	18.90	95.24	
100	117.61	3.11	23.89	75.35		100	118.97	4.47	18.93	95.09	

Table 31-8 Constant Rate Test – BH10316

Official BH NO :	10316	District :	Ghanzi
Date of test commencement :	18.2.06	Location :	Metsimantle
Time of test commencement :	1300hrs	BH depth(m) :	250
Date of test completion	21.2.06	Screen Interval (m)	173.09 to 215.99
Time of test completion :	1300hrs	Depth of pump intake (m) :	150m
Method of water level measurement	dipper	Description of MP	top of dipper tubing
OB BH NO:	n/a	Height of MP above ground(m) :	0.26
Distance ob BH r (m)	n/a	Static Water level before test(m) :	114.60
Casing diameter (mm)	203	Water strike	162 and 174
Orifice plate diameter	4"	Delivery pipe diameter	5"
Easting	400854	Northing	7427983

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500l	Q(m^3/h)	Temp (^{0}C)	TDS / EC (mg/L)/(ms/Cm)	pH	Manometer (cm) /DO2
	0.25	115.32	0.72						Flowmeter 005073.721
	0.5	115.49	0.89						
	1	116.06	1.46	18.85	95.49				
	2	116.22	1.62	18.93	95.09				
	3	116.37	1.77	19.00	94.74				
	4	116.53	1.93	18.74	96.05				
	5	116.65	2.05	19.00	94.74				
	6	116.76	2.16	18.88	95.34				
	7	116.87	2.27	18.80	95.74				
	8	116.94	2.34	18.84	95.54				
	9	117.02	2.42	18.70	96.26				
	10	117.12	2.52	18.91	95.19				
	11	117.19	2.59	18.93	95.09				
	12	117.26	2.66	18.91	95.19	28.1	270	7.78	43
	15	117.38	2.78	18.87	95.39	28.3	280	7.71	43
	20	117.59	2.99	18.93	95.09	28.4	300	7.73	43
	25	117.85	3.25	18.95	94.99	28.3	300	7.71	43
	30	117.94	3.34	18.91	95.19	28.1	300	7.74	43
	40	118.14	3.54	18.66	96.46	28.3	270	7.68	43
	45	118.24	3.64	18.77	95.90	28.4	280	7.79	43
	50	118.33	3.73	18.93	95.09	28.3	280	7.74	43
	60	118.40	3.80	18.96	94.94	28.4	270	7.74	43
	75	118.51	3.91	18.96	94.94	28.5	270	7.71	43
	90	118.60	4.00	18.88	95.34	28.4	280	7.66	43
	105	118.65	4.05	18.90	95.24	28.3	280	7.73	43
	120	118.70	4.10	18.97	94.89	28.6	280	7.71	43
	150	118.79	4.19	18.94	95.04	28.5	280	7.74	43
	180	118.84	4.24	18.92	95.14	28.6	270	7.63	43
	210	118.93	4.33	18.90	95.24	28.7	280	7.67	43
	240	118.98	4.38	18.93	95.09	28.6	280	7.61	43
	270	119.06	4.46	18.90	95.24	28.7	280	7.64	43
	300	119.10	4.50	18.91	95.19	28.0	270	7.58	43
	330	119.14	4.54	18.93	95.09	28.0	270	7.61	43
	360	119.19	4.59	18.87	95.39	28.0	270	7.62	43
	390	119.24	4.64	18.90	95.24	28.0	270	7.64	43
	420	119.29	4.69	18.86	95.44	27.1	270	7.77	43
	450	119.37	4.77	18.84	95.54	27.5	280	7.66	43
	480	119.41	4.81	18.88	95.34	27.5	270	7.67	43
	540	119.44	4.84	18.91	95.19	27.4	280	7.66	43
	600	119.51	4.91	18.92	95.14	27.5	280	7.67	43
	660	119.54	4.94	18.89	95.29	27.6	270	7.66	43
	720	119.60	5.00	18.90	95.24	27.4	280	7.64	43
	780	119.63	5.03	18.88	95.34	27.4	270	7.77	43
	840	119.65	5.05	18.91	95.19	27.3	270	7.61	43
	900	119.68	5.08	18.86	95.44	27.1	270	7.64	43
	960	119.70	5.10	18.94	95.04	27.1	270	7.67	43
	1020	119.72	5.12	18.91	95.19	27.4	270	7.67	43
	1080	119.73	5.13	18.90	95.24	27.3	270	7.64	43
	1140	119.75	5.15	18.84	95.54	27.2	270	7.64	43
	1200	119.78	5.18	18.89	95.29	27.4	270	7.63	43
	1260	119.80	5.20	18.92	95.14	27.6	270	7.62	43
	1320	119.80	5.20	18.81	95.69	28.6	280	7.64	43
	1380	119.80	5.20	18.94	95.04	28.9	270	7.52	43

	1440	119.80	5.20	18.90	95.24	28.8	280	7.63	DO = 2.80mg/l
	1500	119.80	5.20	18.82	95.64	28.6	270	7.61	43
	1560	119.80	5.20	18.94	95.04	28.9	270	7.52	43
	1620	119.80	5.20	18.93	95.09	28.4	280	7.66	43
	1680	119.80	5.20	18.88	95.34	28.2	270	7.66	43
	1740	119.82	5.22	18.95	94.99	28.2	270	7.70	43
	1800	119.88	5.28	18.90	95.24	27.8	270	7.65	43
	1860	119.92	5.32	18.93	95.09	27.6	280	7.63	43
	1920	119.92	5.32	18.89	95.29	27.4	270	7.64	43
	1980	119.92	5.32	18.91	95.19	27.2	270	7.65	43
	2040	119.92	5.32	18.88	95.34	27.0	280	7.64	43
	2100	119.94	5.34	18.94	95.04	27.4	270	7.60	43
	2160	119.97	5.37	18.89	95.29	27.3	270	7.63	43
	2220	120.00	5.40	18.88	95.34	27.2	280	7.65	43
	2280	120.00	5.40	18.93	95.09	26.9	277	7.60	43
	2340	119.98	5.38	18.90	95.24	26.9	281	7.63	43
	2400	119.98	5.38	18.88	95.34	26.9	280	7.66	43
	2460	119.97	5.37	18.94	95.04	27.0	279	7.64	43
	2520	119.97	5.37	18.88	95.34	27.2	270	7.67	43
	2580	120.09	5.49	18.90	95.24	27.4	270	7.65	43
	2640	120.04	5.44	18.88	95.34	28.9	265	7.50	43
	2700	120.00	5.40	18.90	95.24	28.9	230	7.56	43
	2760	120.00	5.40	18.94	95.04	28.9	235	7.50	43
	2820	120.05	5.45	18.88	95.34	29.0	230	7.56	43
	2880	120.00	5.40	18.94	95.04	29.4	280	7.55	DO = 2.90mg/l 43
	2940	120.00	5.40	18.89	95.29	29.2	280	7.68	43
	3000	120.00	5.40	18.91	95.19	29.0	270	7.68	43
	3060	120.00	5.40	18.93	95.09	28.9	270	7.64	43
	3120	120.00	5.40	18.92	95.14	28.8	280	7.64	43
	3180	120.00	5.40	18.90	95.24	28.7	270	7.64	43
	3240	120.00	5.40	18.94	95.04	28.6	270	7.65	43
	3300	120.04	5.44	18.91	95.19	28.4	270	7.64	43
	3360	120.10	5.50	18.89	95.29	28.1	280	7.62	43
	3420	120.10	5.50	18.91	95.19	27.8	270	7.64	43
	3480	120.10	5.50	18.88	95.34	27.5	271	7.60	43
	3540	120.10	5.50	18.90	95.24	26.9	269	7.73	43
	3600	120.10	5.50	18.93	95.09	27.0	270	7.58	43
	3660	120.10	5.50	18.89	95.29	26.9	273	7.61	43
	3720	120.09	5.49	18.94	95.04	27.0	270	7.68	43
	3780	120.09	5.49	18.88	95.34	26.9	268	7.61	43
	3840	120.09	5.49	18.90	95.24	26.9	269	7.60	43
	3900	120.09	5.49	18.94	95.04	27.4	272	7.59	43
	3960	120.11	5.51	18.90	95.24	27.2	275	7.54	43
	4020	120.16	5.56	18.94	95.04	27.4	280	7.50	43
	4080	120.16	5.56	18.88	95.34	27.5	270	7.56	43
	4140	120.18	5.58	18.90	95.24	27.7	280	7.56	43
	4200	120.18	5.58	18.94	95.04	28.5	270	7.61	43
	4260	120.10	5.50	18.90	95.24	28.7	270	7.64	43
	4320	120.07	5.47	18.94	95.04	28.9	270	7.63	DO = 3.00 mg/l

Table 31-9 Recovery Test Data – BH10316

Official BH NO :	10316	District :	Ghanzi
Date of test commencement :	21.2.2006	Location :	Metsimantle
Time of test commencement :	1300hrs	BH depth(m) :	250m
Date of test completion	22.02.2006	Screen Int (m)	173.09 to 215.99
Time of test completion :	0800hrs	Depth of pump intake (m) :	150
Method of water level measurement:	dipper	Description of MP	top of dipper tubing
OB. BH. No.:	n/a	Height of MP above ground(m) :	0.27
Dist.to Pumping Bh:	n/a	Static Water level before test(m) :	114.6
Casing diameter (mm)		Water strike	162 and 174
Orifice plate diameter		Delivery pipe diameter	
Easting	400854	Northing	7427983

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0		-114.60
	0.25	119.20	4.60
	0.5	118.92	4.32
	1	118.62	4.02
	2	118.32	3.72
	3	118.15	3.55
	4	118.00	3.40
	5	117.90	3.30
	6	117.85	3.25
	7	117.78	3.18
	8	117.70	3.10
	9	117.63	3.03
	10	117.57	2.97
	12	117.42	2.82
	15	117.32	2.72
	20	117.05	2.45
	25	116.83	2.23
	30	116.76	2.16
	40	116.64	2.04
	50	116.50	1.90
	60	116.38	1.78
	75	116.28	1.68
	90	116.21	1.61
	105	116.14	1.54
	120	116.06	1.46

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	115.94	1.34
	180	115.86	1.26
	210	115.79	1.19
	240	115.72	1.12
	270	115.68	1.08
	300	115.64	1.04
	330	115.60	1.00
	360	115.58	0.98
	390	115.54	0.94
	420	115.51	0.91
	450	115.49	0.89
	480	115.47	0.87
	540	115.44	0.84
	600	115.40	0.80
	660	115.38	0.78
	720	115.36	0.76
	780	115.34	0.74
	840	115.32	0.72
	900	115.30	0.70
	960	115.28	0.68
	1020	115.26	0.66
	1080	115.23	0.63
	1140	115.22	0.62
	1200	115.20	0.60
	1260	115.17	0.57
	1320	115.15	0.55
	1380	115.13	0.53
	1440	114.97	0.37

32 BH10318

Abandoned borehole BH10318 with a siting reference of **S4,** line R3, peg 9000m, TEM 63, was drilled to explore the Ecca aquifer northeast of fault **F4**. This abandoned borehole is located about 20 km east of Ncojane Village, 2 km off (south) the to gravel road leading to Metsimantsho village. Drilling of this borehole commenced on 27 October 2005 and was abandoned on 11 November 2005. The total drilled depth for this borehole is 250 m.

32.1 SITING CRITERIA AND DRILLING OBJECTIVES

This exploration borehole was drilled 10.6 m from monitoring borehole BH10210 to allow for the calculation of the hydraulic properties (Transmissivity and storativity) of the Ecca aquifer at this site.

33 BH10402

BH10402 is a production borehole drilled at site **P01**, Line **R3, TEM 69** and is replacement of BH10228 drilled during the Exploration Phase. It is located approximately 18 km east of Ncojane south of the gravel road to Metsimantsho. Drilling of this borehole commenced on 27 January and was completed on 23 March 2007.

33.1 SITING CRITERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block with thin dolerite sill/dyke.

33.2 DRILLING RESULTS

Drilling was started using a 17 inch drilling bit to a depth of 4m after which 4m of 17 inch surface casing was installed. Drilling was continued to 86 m with the 17 inch drilling bit and 15 inch plain casing was installed and grouted. From 86 m to 191 m, drilling was carried out using a 15 inch drilling bit after which 12 inch casing was installed to allow for further drilling and sealing off of the top water strike. Drilling was then continued with 12 inch DTH bit to a depth of 207 m after which a 12 inch tricone bit was utilised to complete the borehole to the terminal depth of 257 m to over come back pressure problems. Various lithologies including fine grained sands, silcrete, mudstones, coal and fine to coarse grained sandstones were intercepted during drilling of this borehole (**Figure 33-1**).

During drilling of this borehole, two water strikes were encountered. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows:

1. (167m, 1100 µS/cm, 4.5 m^3/hr
2. (198m, 630 µS/cm, 72 m^3/hr)

On completion of drilling, the borehole was constructed using 8 inch epoxy coated plain casings and screens. The 8 inch epoxy casings were installed between 0 to 189m and 248 to 253 m while the screens were installed between 189 and 248 m, representing a zone of 59 m. Borehole development was through airlift pumping and air jetting with the final air lift yield at the end of development measured as 53 m^3/hr while the electrical conductivity was 630 µS/cm. The rest water level recorded on 19 March 2007 was 106.4 m bgl. The borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 250m **(Figure 33-2).** A verticality and alignment tests were conducted, the borehole was capped and a cement slab was constructed.

Log of BH10402

WRC Water Resources Consultants
www.wrc.bw

Location	: Ncojane
Site Reference	: P01,Line R3, TEM 69
Coordinates	: 441130 E 7435358 N
Drilling Dates	: 27/01/2007 to 31/10/2005
Drilling Method	: DTH
RWL BMP (Date)	: 106.4 (19-03-07)
Total Depth (m)	: 257
Airlift Yield (m3/hr)	: 52.74
EC (uS/cm)	: 550
Tested Yield (m3/hr)	: 70

WS 1 (Depth, EC, Q) 167,1050,4.5
WS 2 (Depth, EC, Q) 198, 630, 72.3

Note: : Yield (m3/hr)
: EC (uS/cm)

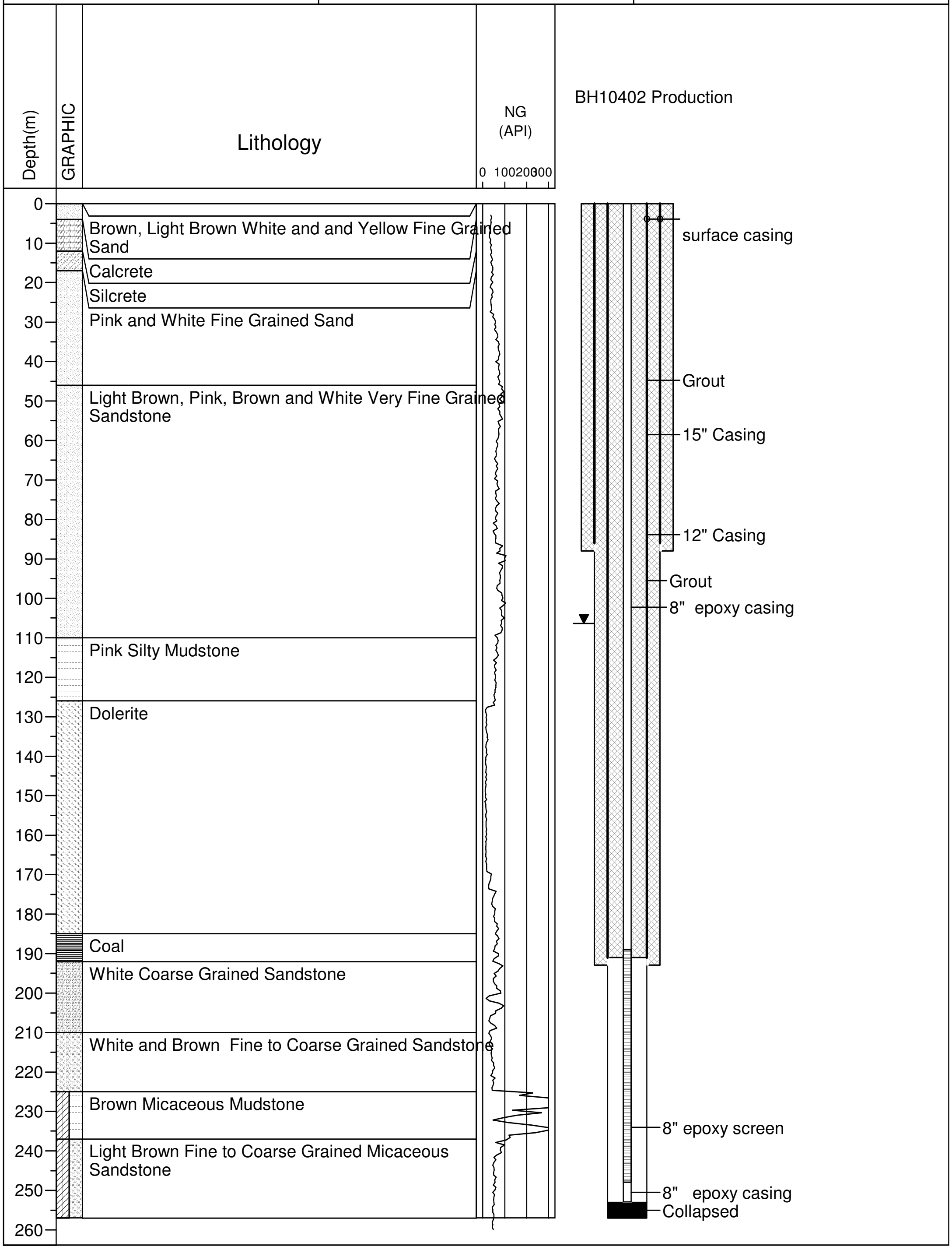

Figure 33-1 Log of BH10402

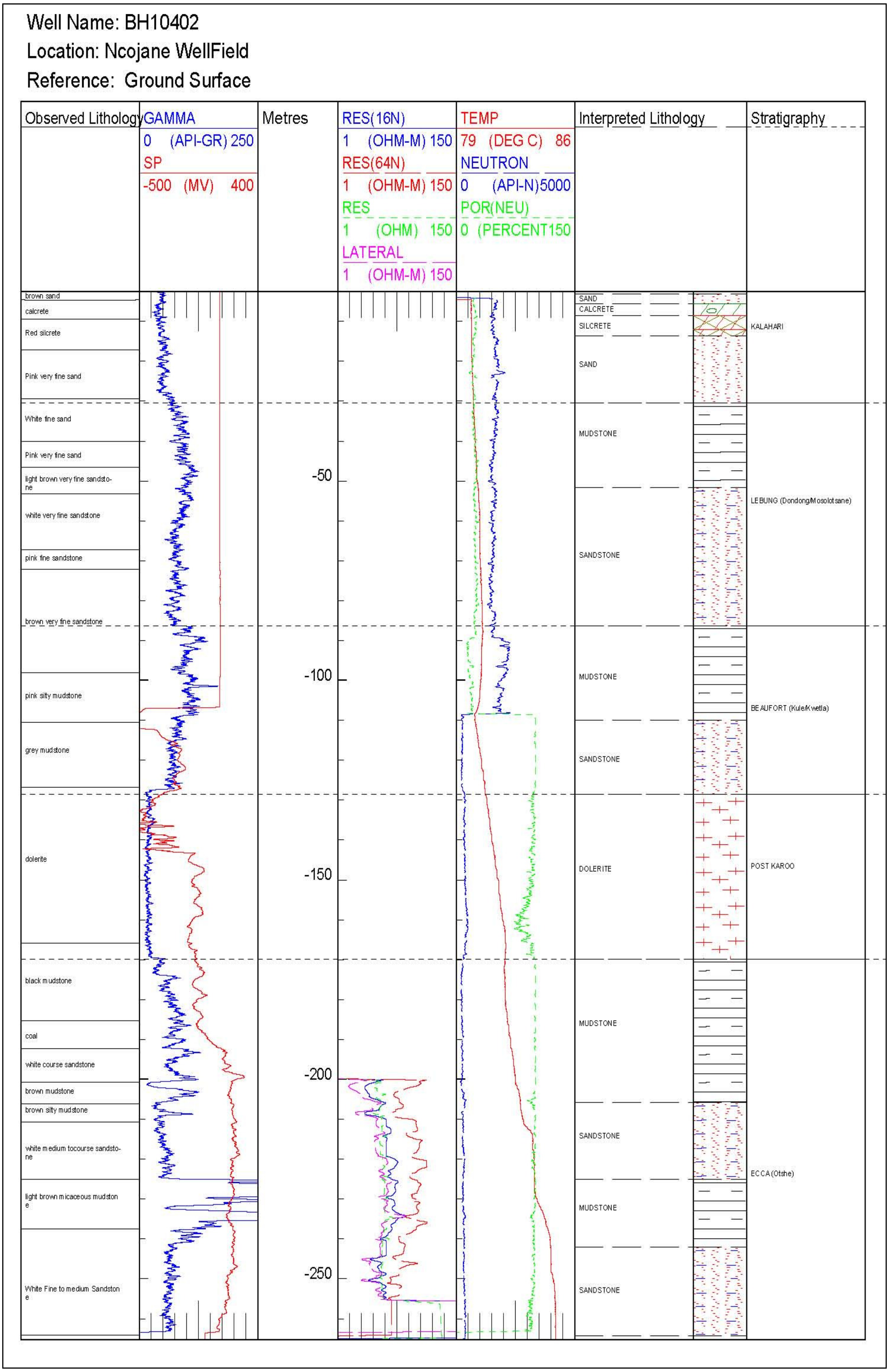

Figure 33-2 Geophysical log of BH10402

33.3 PUMP TESTING RESULTS

Test pumping operations at this borehole were started on 16th September 2007 and completed on 25th September 2007. The tests carried out were calibration, step drawdown, constant rate and recovery tests. A summary of the pumping test data for BH10402 is presented in **Table 33-2.**). The static water level at the beginning of the test was 106.60m bmp. The collected pump testing data is presented in **Tables 33-6 to 33-10**.

Table 33-1 Summary of Pumping Test Data BH10402

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	5.91	20
	2	15	9.35	40
	3	15	14.23	60
	4	15	19.97	78
Step Test	1	100	8.06	25
	2	100	11.10	40
	3	100	15.52	55
	4	100	21.24	70
	5	100	31.24	77
Constant Rate	1	4320	25.75	70
Recovery	1	1440	1.56*	0

Note. 0.37 Residual Drawdown*

33.3.1 Step Drawdown Test

The step drawdown test was carried out on 17th September 2007 and consisted of 5 steps of 100 minutes duration at discharge rates of 25, 40, 55, 70 and 77 m^3/hr respectively. The static water level before the start of the test was 106.67 m bmp.

The interpreted step test data is presented in, **Figures 33-3 to 33-5**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 75m^2/d **(Figure 33-5).** The results of the interpreted step test data are given in **Table 33-2**.

Table 33-2 Results of Step Test Analysis BH10402

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10402	1.30E-002	1.07E-006	75	25	7.68	7.68	3.26
				40	3.79	11.47	3.49
				55	2.66	14.13	3.89
				70	3.12	17.25	4.06
				77	5.39	22.64	3.40

The planned duration for the constant rate test at this borehole was 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time **(Figure 33-3)** to estimate the expected total drawdown after 3 days of pumping.

33.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 21st to 24th September 2007 at a discharge rate of 70m^3/hr. The total drawdown after 72 hrs of pumping was 20.64 m. The static water level before the start of the test was 106.67 m bmp. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 0.41 m.

Transmissivity (T) values obtained from Cooper-Jacob (1946) and Hantush leaky analytical solutions were 181 and 119 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 111m^2/d was obtained. The results are summarised in **Table 33-3** and the interpreted data is presented in **Figures 33-6** to **33-8**. There is an apparent impermeable barrier interpreted in the CRT data after approximately 1500 minutes of pumping.

33.3.3 Observation borehole BH10227

The water level response was monitored in an observation borehole (BH10227) located 12.4 m away from the pumped borehole (BH10402). The static water level before the start of the test was 106.75 m bmp. The total drawdown at the end of pumping (72) was 8.56 m. A 24 hour Recovery test followed CRT and the residual drawdown after 24 hrs monitoring was 0.27 m.

Various analytical solutions (Cooper-Jacob, Theis and Hantush Leaky,) were applied to the data obtained from this observation borehole using the computer programme "Aqtesolv" and the best fit was obtained based on the Cooper Jacob and Hantush Leaky (with aquitard storage) solutions. The transmissivity (T) values obtained by these two analytical solutions were 267 and 264 m^2/d respectively while the storativity values calculated from the Hantush Leaky solution 1.31×10^{-4} respectively. The Transmissivity obtained from recovery data using the Theis recovery method was 259m^2/d. The results are summarised in **Table 33-3** and the interpreted data is presented in **Figures 33-9 to 33-11.** There is an apparent impermeable barrier interpreted in the CRT data after approximately 1680 minutes of pumping, **(Figure 33-6)**.

33.3.4 Observation borehole BH10228

The water level response was also monitored in another observation borehole (BH10228) located 13.2 m away from BH10402. The static water level before the start of the test was 106.78 m bmp. The total drawdown at the end of pumping (72 hrs) was 8.88 m. A 24 hour Recovery test was carried out immediately after completion of the CRT and the residual drawdown after 24 hrs was 0.36 m.

Similar to data from BH10227, the best fit was obtained based on the Cooper Jacob and Hantush Leaky (with aquitard storage) solutions. The transmissivity (T) values obtained by these two analytical solutions were 252 and 250 m^2/d respectively while the storativity value calculated from the Hantush Leaky solution was 1.31×10^{-4}. The Transmissivity obtained from recovery data using the Theis recovery method was 243m^2/d. The results are summarised in **Table 33-3** and the interpreted data is presented in **Figures 33.12 to 33.14.** There is an apparent impermeable barrier interpreted in the CRT data after approximately 1680 minutes of pumping, (**Figure 33.12).**

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Table 33-3 Summary of Constant Rate and Recovery Tests BH10402

BH No.	Pump Intake (m)	Test Dates	CRT Duration (hours)	Q (m^3/d)	Pumping borehole		Obs. BH No	Observation boreholes		Aquifer type/ Response	
					T (m^2/d)			Pumping phase		Recovery phase	
					Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
10402	155	21/09/07 25/09/07	72	1680	a) 181 b) 119	c) 111	10227	a) 267 b) 264	b) 1.31E-4	c) 259	Confined leaky with storage and negative boundary
							10228	a) 252 b) 250	b) 1.31E-4	c) 243	

Notes:
<u>Interpretation Techniques</u>
a) Cooper-Jacob)
b) Hantush (Leaky with aquitard storage)
c) Theis Modified Recovery

33.3.4.1 <u>Aquifer Type interpreted</u>

The interpretation of the pump testing data indicates that the aquifer type is confined-leaky with negative (barrier) boundary.

33.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. The results of chemical analyses from CSIR lab are presented in **Table 34-4.**

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The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC) and pH are 30.9°C, 567 µS/cm and 7.63 respectively.

Table 33-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10402	7.3	88.2	25.9	19.3	18.8	67.9	204	17.1	0.72	<0.05	<0.05	690	6.80	442
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10402	<0.05	114	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in µS/cm
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

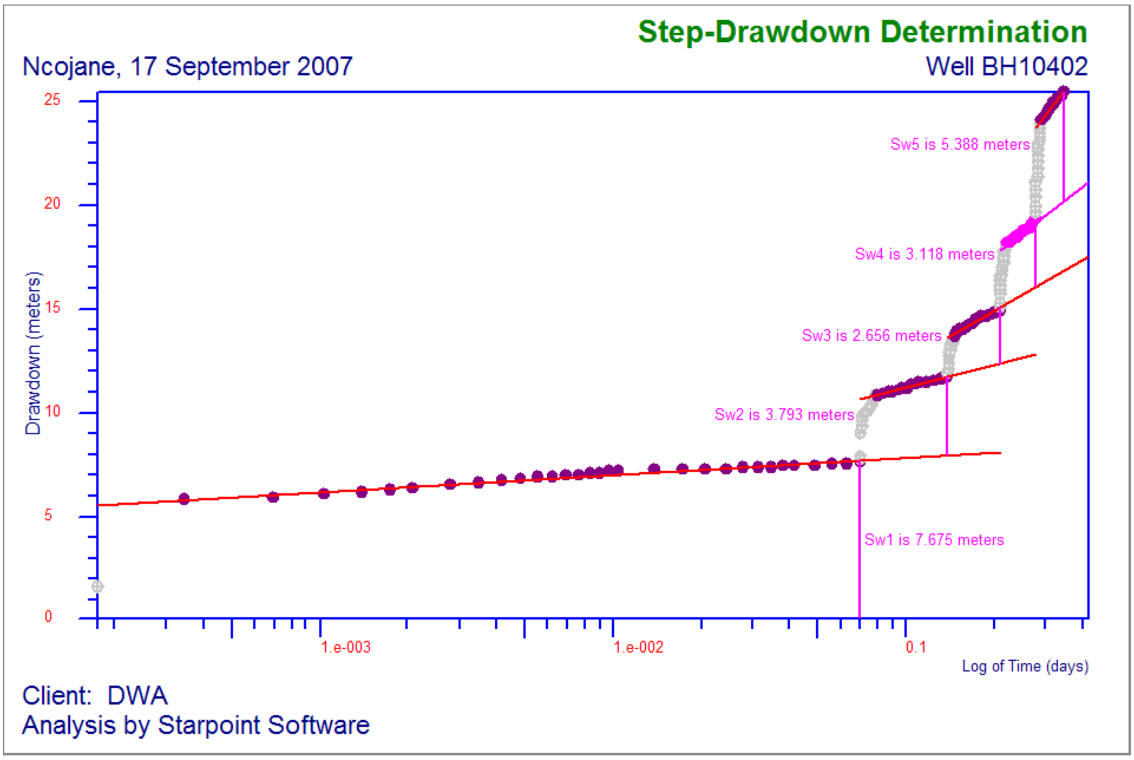

Figure 33-3 Pumping Test Results for BH10316: Step Drawdown Test - Hantush-Bierschenk (semi-log)

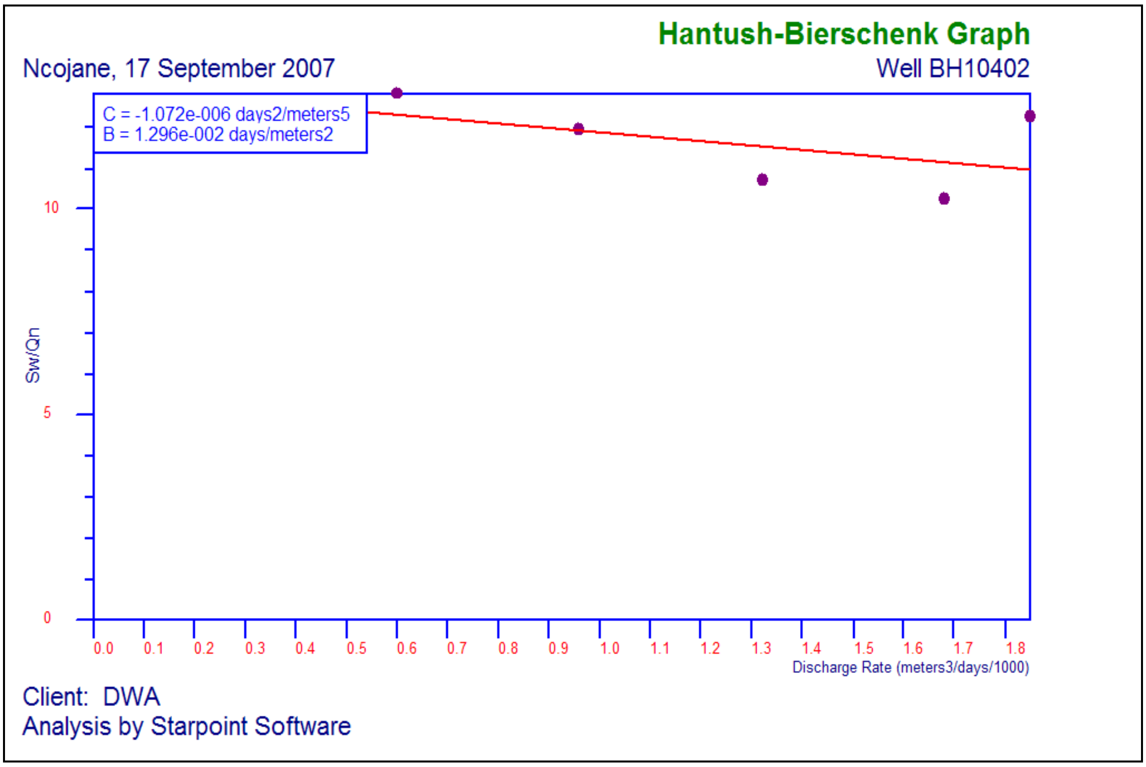

Figure 33-4 Pumping Test Results for BH10402: Step Drawdown Test – Hantush-Bierschenk

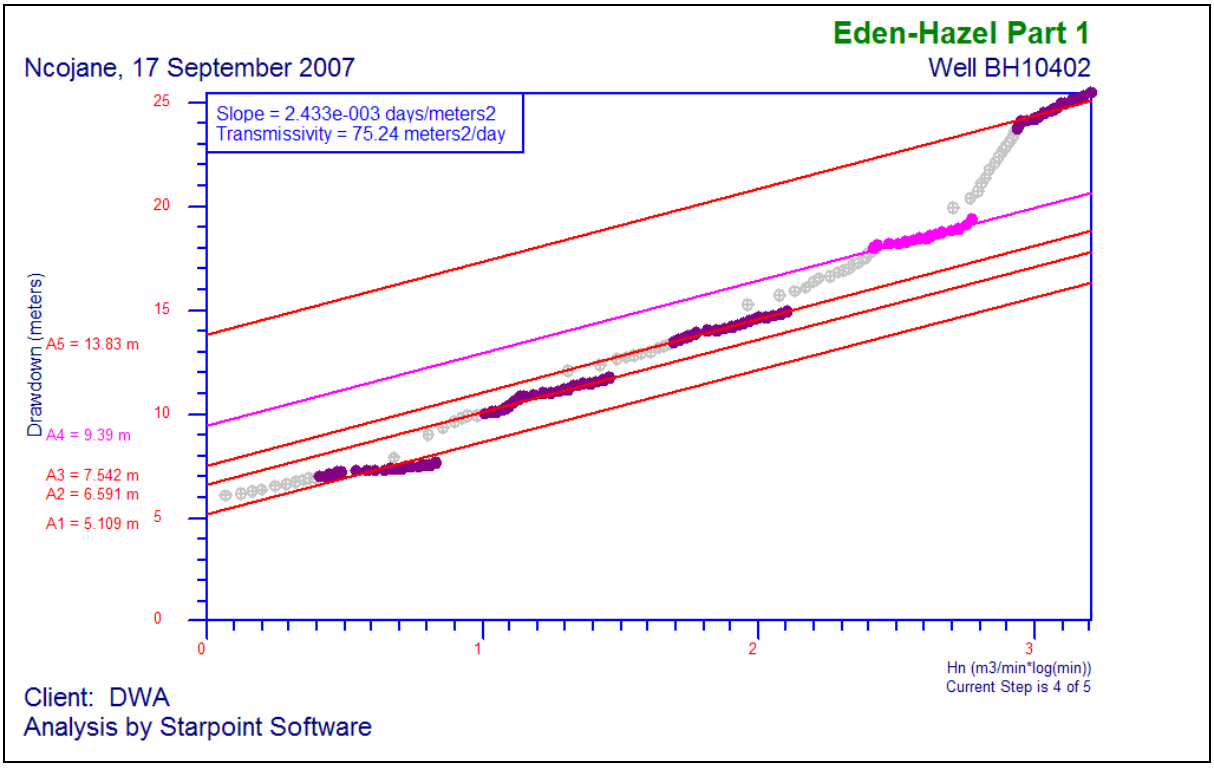

Figure 33-5 Pumping Test Results for BH10402: Step Drawdown Test – Eden-Hazel (Part 1)

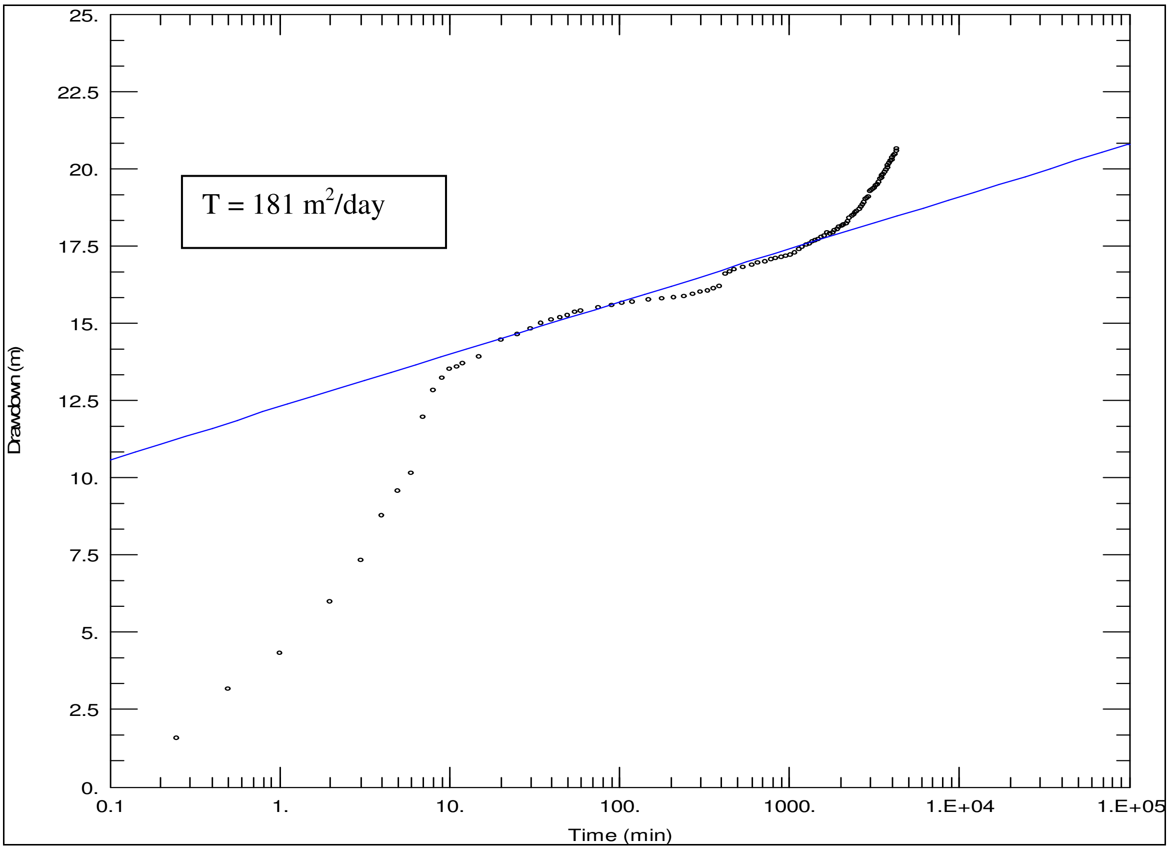

Figure 33-6 Pumping Test Results for BH10402: Cooper Jacob Solution

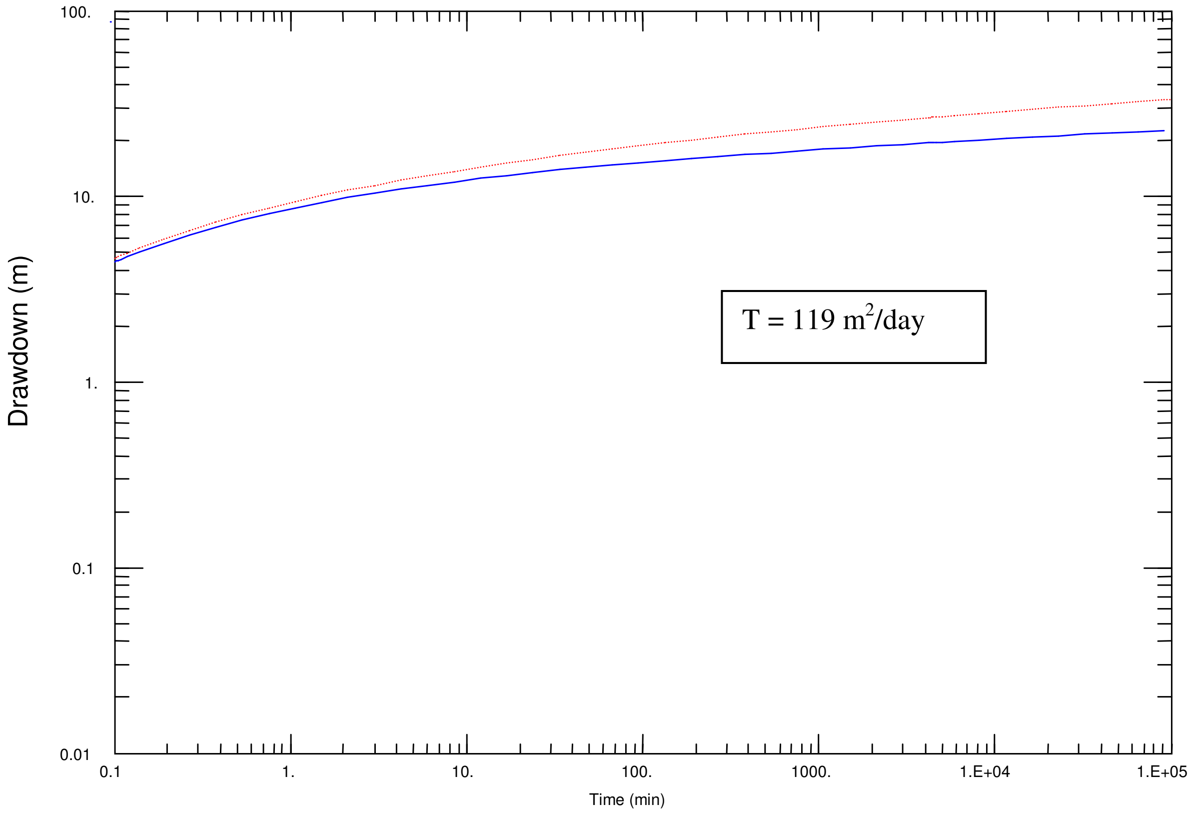

Figure 33-7 Pumping Test Results for BH10402: CRT Hantush leaky withstorage in the aquitard

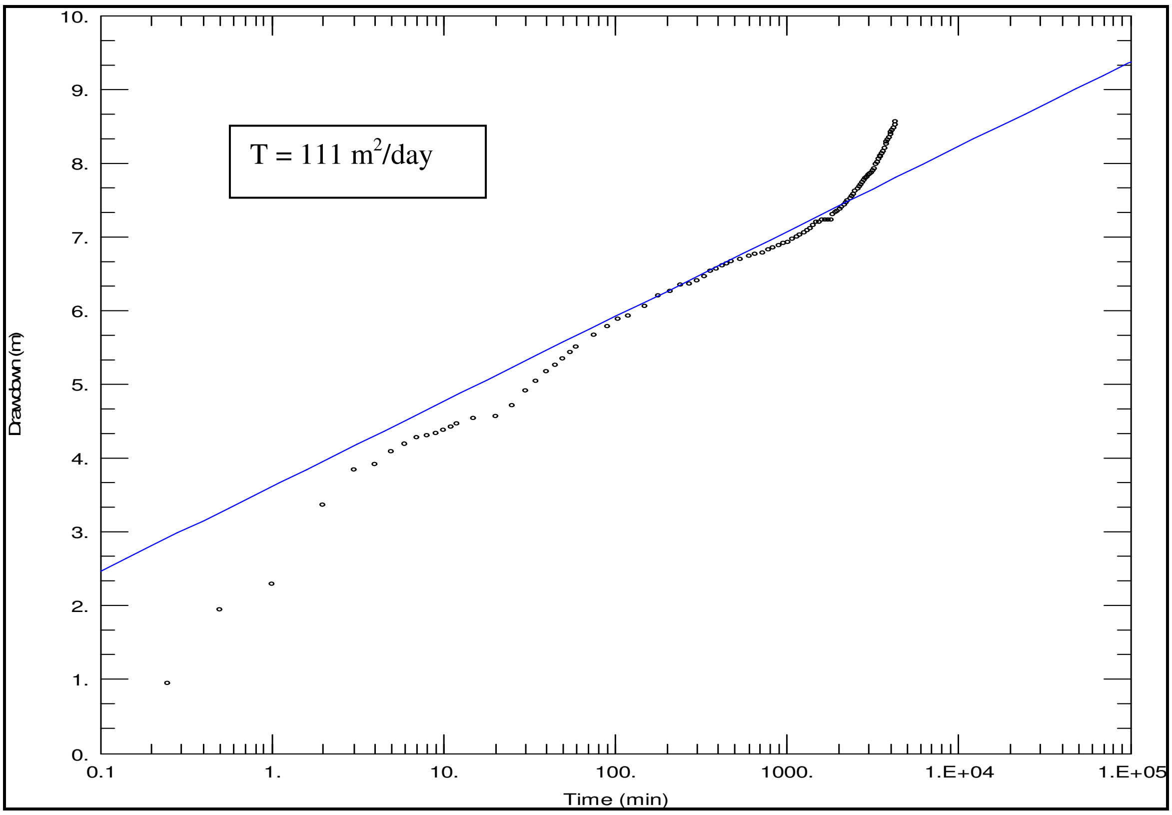

Figure 33-8 Pumping Test Results for BH10402: Theis Recovery Solution

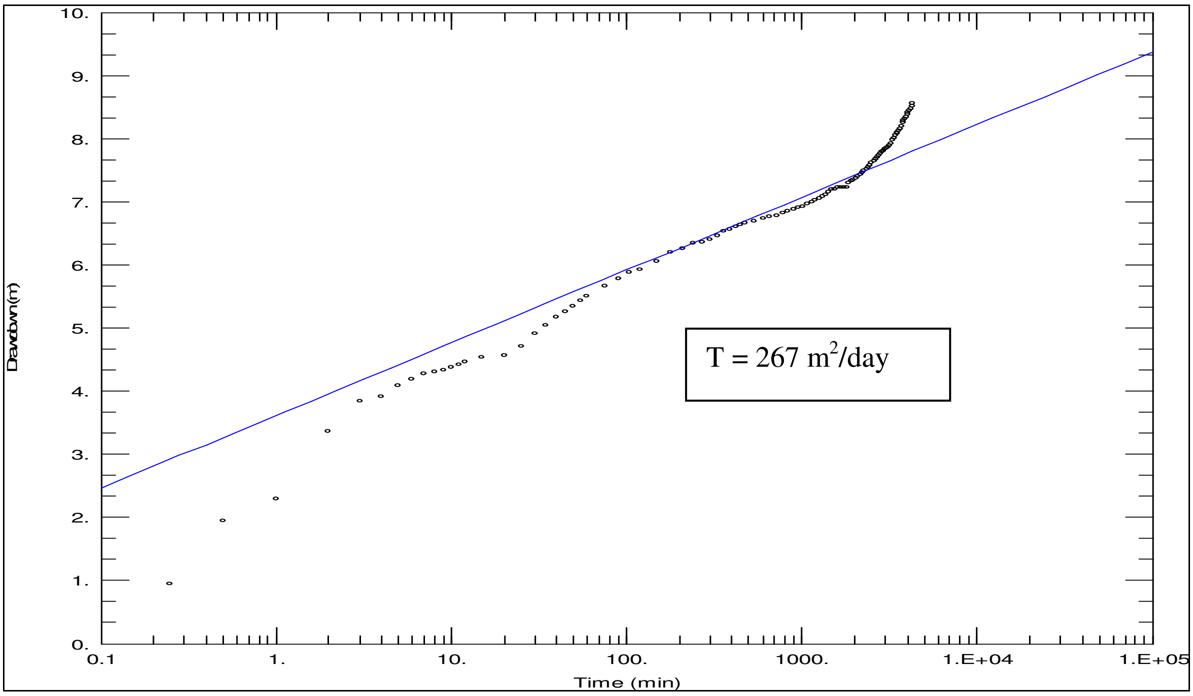

Figure 33-9 Pumping Test Results forBH10227 : Cooper Jacob Solution

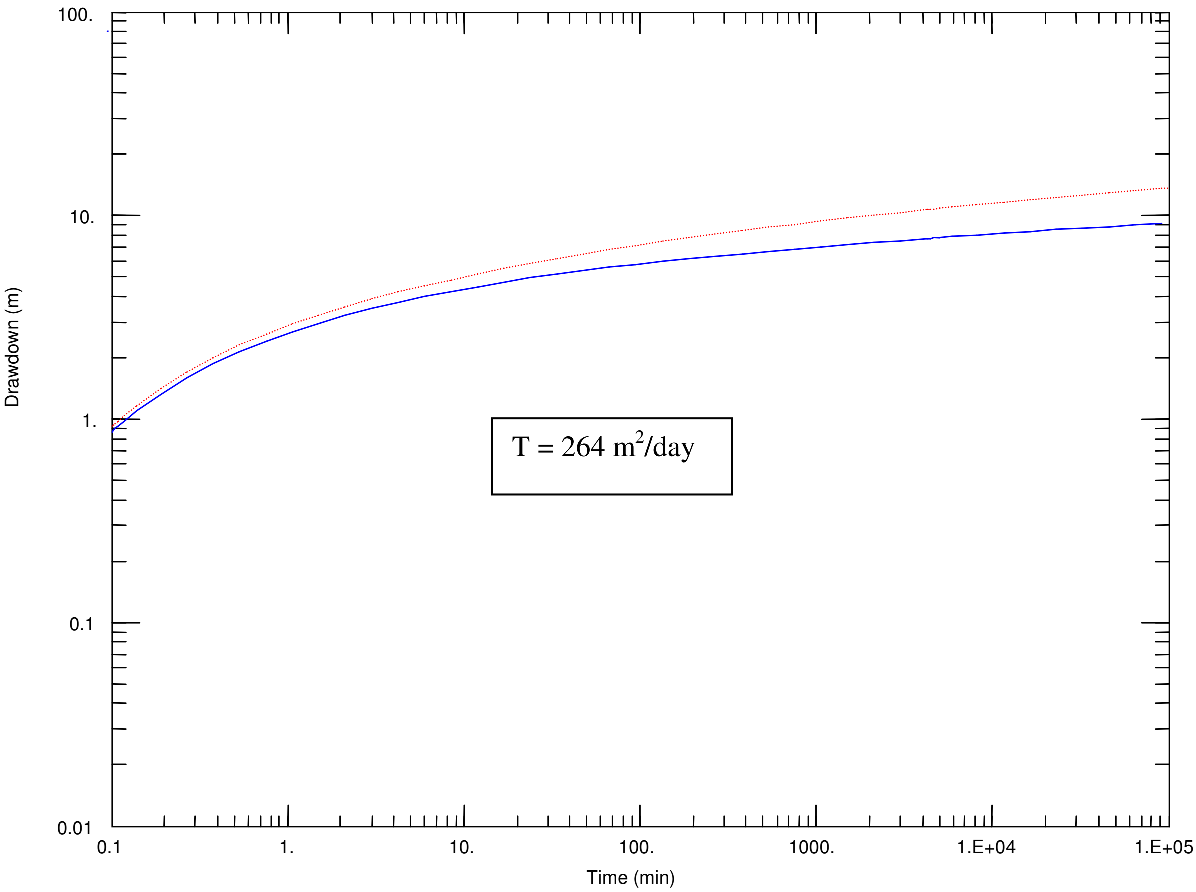

Figure 33-10 Pumping Test Results for BH10227 : Hantush leaky with storage in the aquitard.

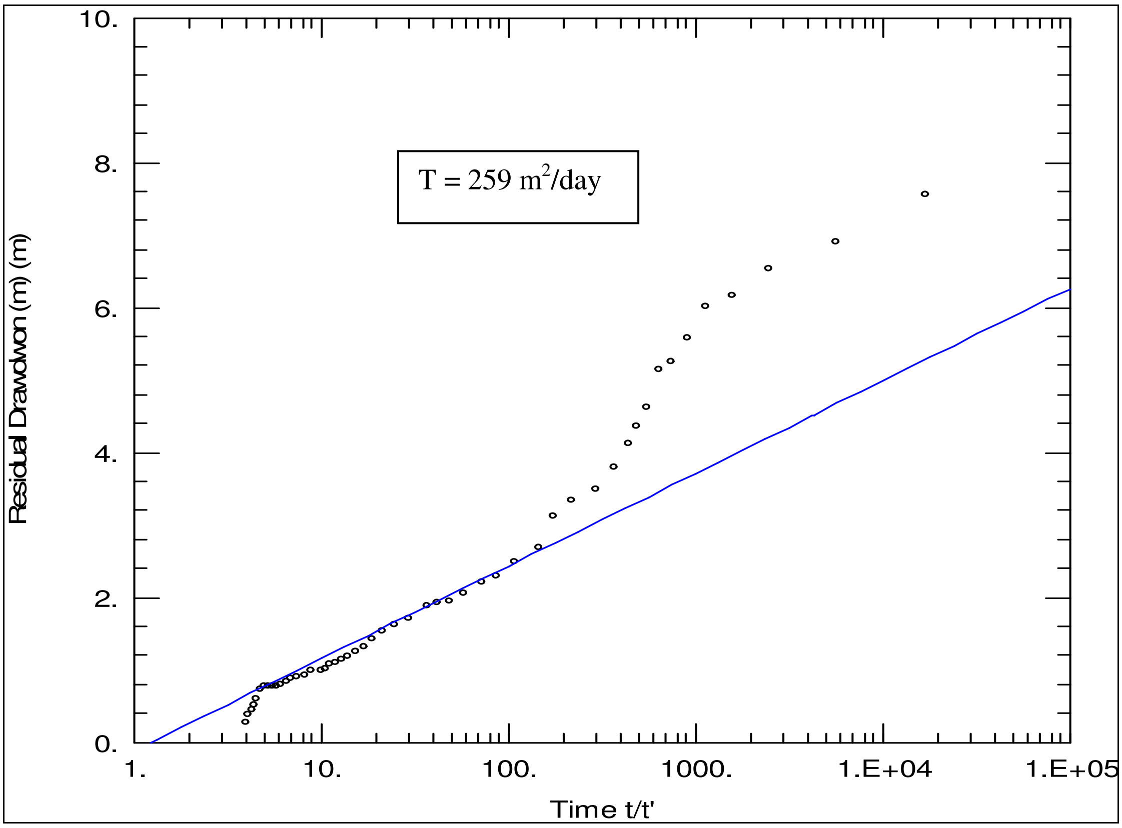

Figure 33-11 Pumping Test Results for BH10227 : Theis Recovery Solution

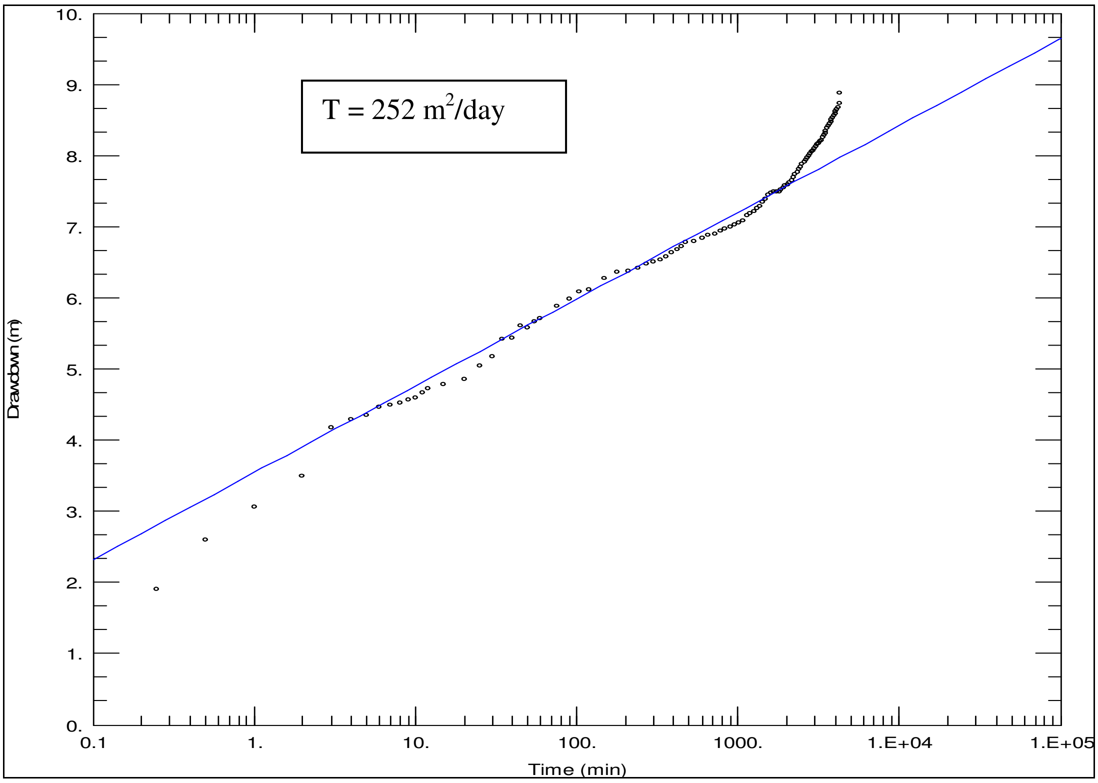

Figure 33-12 Pumping Test Results for BH10228 : Cooper Jacob Solution

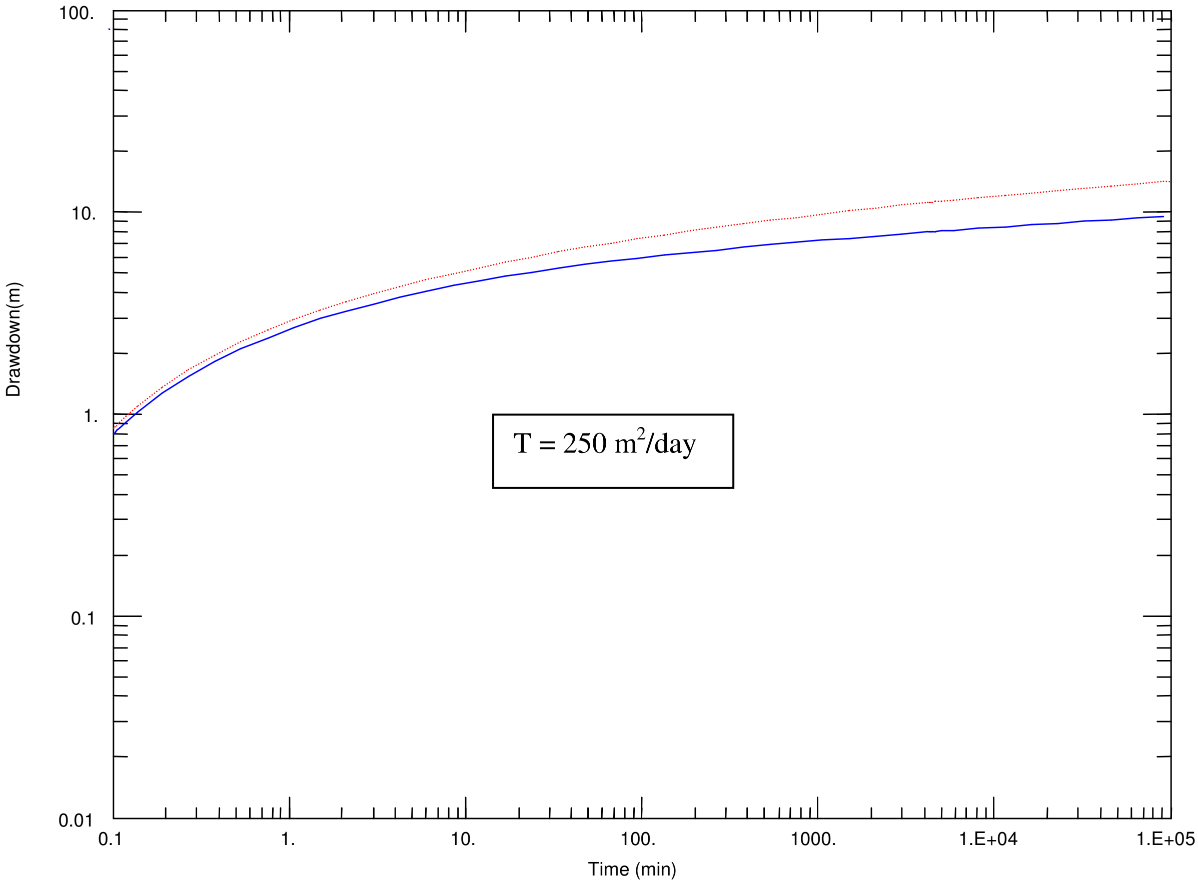

Figure 33-13 Pumping Test Results for BH10228 : Hantush leaky with storage in the aquitard.

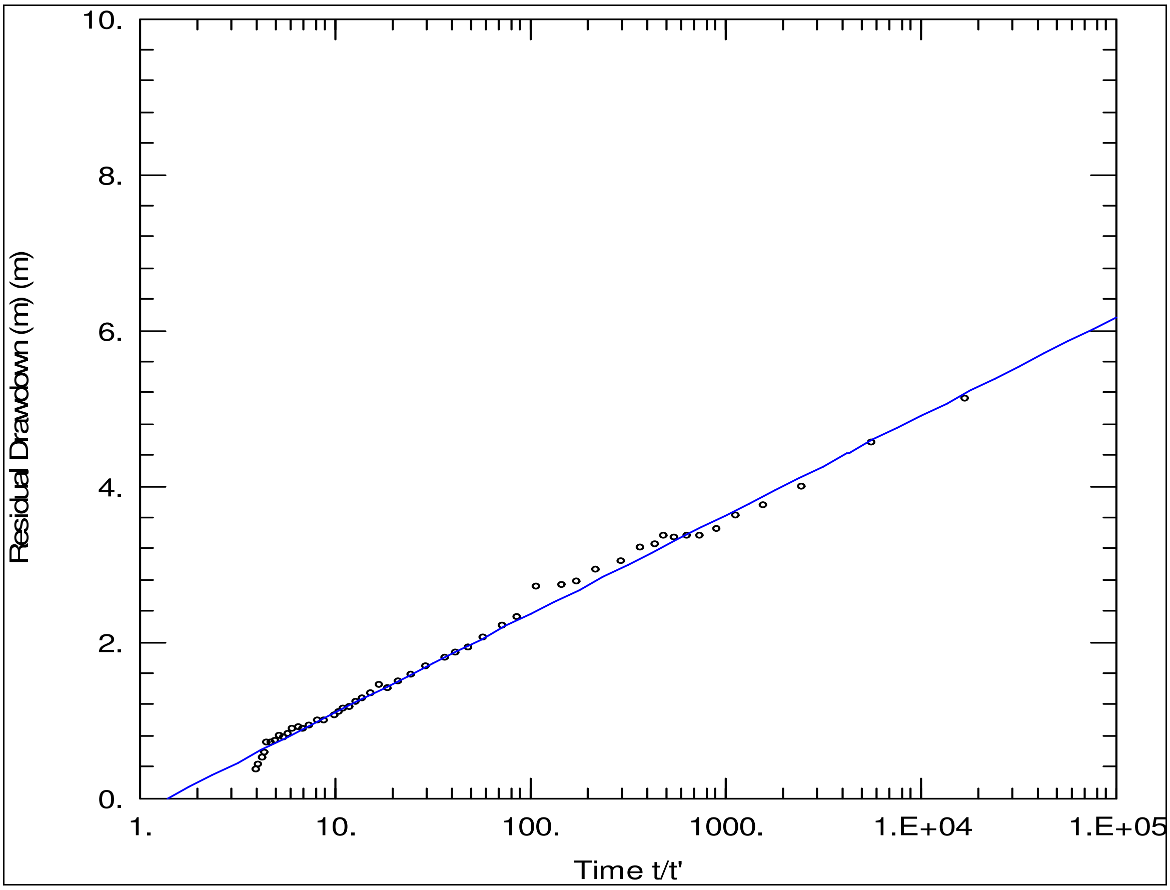

Figure 33-14 Pumping Test Results for BH10228: Theis Recovery Solution

Table 33-5 Calibration Test Data – BH10402

BH No.: 10402	**District: Ghanzi**
Date of test commencement: 16/09/2007	**Location: Ncojane**
Time of test commencemen: 1100 Hrs	**BH depth (m): 263m**
Date of test completion: 16/09/2007	**Screen Interval (m):**
Time of test completion: 1200 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 106.60m**
Temperature of water (°C):	**EC (µS/cm): pH:**

t	Depth WL (m)	Drawdown (m)	Time to fill **100L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **150L**	Pump Rate (m3/hr)
STEP	**1**				**STEP**	**2**			
15 sec	106.88	0.28			15 sec	112.32	5.72		
30 sec	107.36	0.76			30 sec	115.05	8.45		
1	107.85	1.25			1	115.45	8.85	12.80	42.19
1.5	108.24	1.64			1.5	116.00	9.40		
2	108.72	2.12			2	116.20	9.60	12.77	42.29
2.5	109.06	2.46			2.5	116.34	9.74		
3	109.75	3.15			3	116.51	9.91	13.48	40.06
4	109.80	3.20	17.85	20.17	4	116.57	9.97	13.46	40.12
5	109.70	3.10	17.98	20.02	5	116.69	10.09	13.50	40.00
6	110.00	3.40	17.95	20.06	6	116.75	10.15	13.49	40.03
7	110.34	3.74	18.01	19.99	7	116.79	10.19	13.51	39.97
8	110.54	3.94	18.01	19.99	8	116.86	10.26	13.48	40.06
9	110.88	4.28	17.95	20.06	9	116.94	10.34	13.50	40.00
10	110.97	4.37	17.98	20.02	10	117.08	10.48	13.51	39.97
11	111.04	4.44	17.96	20.04	11	117.16	10.56	13.47	40.09
12	111.14	4.54	17.97	20.03	12	117.39	10.79	13.49	40.03
15	111.44	4.84	18.00	20.00	15	117.44	10.84	13.50	40.00
Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **250L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **250L**	Pump Rate (m3/hr)
STEP	**3**				**STEP**	**4**			
15 sec	117.49	10.89			15 sec	121.49	14.89		
30 sec	117.78	11.18			30 sec	121.89	15.29		
1	117.98	11.38	15.12	59.52	1	122.21	15.61	11.67	77.12
1.5	118.17	11.57			1.5	122.54	15.94		
2	118.54	11.94	15.04	59.84	2	122.70	16.10	11.66	77.19
2.5	118.88	12.28			2.5	122.96	16.36		
3	119.01	12.41	14.98	60.08	3	123.14	16.54	11.67	77.12
4	119.26	12.66	14.96	60.16	4	123.36	16.76	11.66	77.19
5	119.43	12.83	15.00	60.00	5	123.67	17.07	11.65	77.25
6	119.77	13.17	14.97	60.12	6	123.91	17.31	11.67	77.12
7	119.94	13.34	14.95	60.20	7	124.08	17.48	11.68	77.05
8	120.09	13.49	14.99	60.04	8	124.27	17.67	11.66	77.19
9	120.24	13.64	14.96	60.16	9	124.44	17.84	11.69	76.99
10	120.37	13.77	14.96	60.16	10	124.63	18.03	11.63	77.39
11	120.56	13.96	14.97	60.12	11	124.85	18.25	11.68	77.05
12	120.78	14.18	14.99	60.04	12	124.99	18.39	11.65	77.25
15	120.99	14.39	15.01	59.96	15	125.13	18.53	11.68	77.05

Table 33-6 Step Drawdown Test Data – BH10402

BH No.: 10402	**District: Ghanzi**
Date of test commencement: 17/09/2007	**Location: Nc ojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 253m**
Date of test completion: 17/09/2007	**Screen Interval (m):**
Time of test completion:	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 106.67m**
Temperature of water (°C):	**EC (µS/cm): pH:**

STEP No.1 — STEP No.2

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **100L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **150L**	Pumping Rate (m^3/hr)	Comments
0.25	108.29	1.62			0.25	114.35	7.68			
0.5	112.47	5.80			0.5	114.50	7.83			
1	112.57	5.90			1	115.61	8.94	13.39	40.33	
1.5	112.69	6.02			1.5	115.99	9.32			
2	112.84	6.17			2	116.31	9.64	13.40	40.30	
2.5	112.93	6.26			2.5	116.45	9.78			
3	113.04	6.37			3	116.51	9.84	13.46	40.12	
4	113.14	6.47	14.14	25.46	4	116.57	9.90	13.49	40.03	
5	113.24	6.57	14.29	25.19	5	116.63	9.96	13.47	40.09	
6	113.36	6.69	14.47	24.88	6	116.69	10.02	13.51	39.97	
7	113.44	6.77	14.38	25.03	7	116.77	10.10	13.45	40.15	
8	113.50	6.83	14.40	25.00	8	116.85	10.18	13.48	40.06	
9	113.56	6.89	14.36	25.07	9	116.95	10.28	13.50	40.00	
10	113.60	6.93	14.41	24.98	10	117.00	10.33	13.50	40.00	
11	113.65	6.98	14.39	25.02	11	117.15	10.48	13.42	40.24	
12	113.70	7.03	14.36	25.07	12	117.27	10.60	13.46	40.12	
13	113.75	7.08	14.38	25.03	13	117.36	10.69	13.57	39.79	
14	113.80	7.13	14.41	24.98	14	117.44	10.77	13.41	40.27	
15	113.85	7.18	14.40	25.00	15	117.50	10.83	13.43	40.21	
20	113.88	7.21	14.35	25.09	20	117.56	10.89	13.45	40.15	
25	113.90	7.23	14.40	25.00	25	117.62	10.95	13.42	40.24	
30	113.93	7.26	14.37	25.05	30	117.68	11.01	13.49	40.03	
35	113.95	7.28	14.39	25.02	35	117.73	11.06	13.47	40.09	
40	113.97	7.30	14.36	25.07	40	117.80	11.13	13.50	40.00	
45	114.00	7.33	14.41	24.98	45	117.85	11.18	13.47	40.09	
50	114.03	7.36	14.38	25.03	50	117.96	11.29	13.44	40.18	
55	114.05	7.38	14.38	25.03	55	118.02	11.35	13.41	40.27	
60	114.08	7.41	14.36	25.07	60	118.07	11.40	13.45	40.15	
70	114.12	7.45	14.40	25.00	70	118.13	11.46	13.47	40.09	
114.17	7.50	14.39	25.02	80	118.20	11.53	13.51	39.97		
114.20	7.53	14.36	25.07	90	118.26	11.59	13.49	40.03		
114.25	7.58	14.40	25.00	100	118.34	11.67	13.45	40.15		

BH No.: 10402	**District: Ghanzi**
Date of test commencement: 17/09/2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 253m**
Date of test completion: 17/09/2007	**Screen Interval (m):**
Time of test completion: 1420 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 106.67m**
Temperature of water (°C):	**EC (mS/cm): pH:**

STEP No. **3** — STEP No. **4**

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **200L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **250L**	Pumping Rate (m^3/hr)	Comments
0.25	118.51	11.84			0.25	121.71	15.04			nm,
0.5	118.69	12.02			0.5	121.96	15.29			
1	119.01	12.34	13.10		1	122.34	15.67	12.80	70.31	
1.5	119.24	12.57			1.5	122.59	15.92			
2	119.36	12.69	13.09	55.00	2	122.73	16.06	12.88	69.88	
2.5	119.49	12.82			2.5	122.99	16.32			

3	119.57	12.90	13.00	55.38	3	123.19	16.52	12.84	70.09	
4	119.68	13.01	13.06	55.13	4	123.29	16.62	12.86	69.98	
5	119.81	13.14	13.10	54.96	5	123.43	16.76	12.81	70.26	
6	119.90	13.23	13.04	55.21	6	123.60	16.93	12.85	70.04	
7	120.01	13.34	13.08	55.05	7	123.69	17.02	12.83	70.15	
8	120.13	13.46	13.09	55.00	8	123.83	17.16	12.82	70.20	
9	120.18	13.51	13.05	55.17	9	123.95	17.28	12.85	70.04	
10	120.25	13.58	13.02	55.30	10	124.13	17.46	12.81	70.26	
11	120.30	13.63	13.06	55.13	11	124.21	17.54	12.86	69.98	
12	120.36	13.69	13.07	55.09	12	124.34	17.67	12.83	70.15	
13	120.42	13.75	13.01	55.34	13	124.50	17.83	12.81	70.26	
14	120.48	13.81	13.10	54.96	14	124.63	17.96	12.84	70.09	
15	120.55	13.88	13.03	55.26	15	124.73	18.06	12.82	70.20	
20	120.61	13.94	13.09	55.00	20	124.80	18.13	12.82	70.20	
25	120.67	14.00	13.05	55.17	25	124.87	18.20	12.85	70.04	
30	120.77	14.10	13.09	55.00	30	124.92	18.25	12.84	70.09	
35	120.85	14.18	13.07	55.09	35	125.01	18.34	12.81	70.26	
40	120.96	14.29	13.07	55.09	40	125.08	18.41	12.82	70.20	
45	121.02	14.35	13.05	55.17	45	125.14	18.47	12.81	70.26	
50	121.13	14.46	13.01	55.34	50	125.20	18.53	12.83	70.15	
55	121.17	14.50	13.09	55.00	55	125.27	18.60	12.85	70.04	
60	121.24	14.57	13.08	55.05	60	125.35	18.68	12.81	70.26	
70	121.30	14.63	13.02	55.30	70	125.47	18.80	12.84	70.09	
80	121.38	14.71	13.06	55.13	80	125.59	18.92	12.81	70.26	
90	121.43	14.76	13.03	55.26	90	125.72	19.05	12.85	70.04	
100	121.51	14.84	13.04	55.21	100	125.98	19.31	12.83	70.15	

BH No.: 10402	**District:** Ghanzi
Date of test commencement: 17/09/2007	**Location:** **Ncojane**
Time of test commencement: 0600 Hrs	**BH depth (m): 253m**
Date of test completion: 17/09/2007	**Screen Interval (m):**
Time of test completion: 1420 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 106.67m**
Temperature of water (°C):	**EC (mS/cm):** **pH:**

STEP No. 5 | STEP No. ______

TIME (min)	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill 250L**	**Pumping Rate (m3/hr)**	**TIME (min)**	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill ______L**	**Pumping Rate (m3/hr)**	**Comments**
0.25	126.33	19.66			0.25					
0.5	126.60	19.93			0.5					
1	126.99	20.32	11.84	76.01	1					
1.5	127.40	20.73			1.5					
2	127.78	21.11	11.66	77.19	2					
2.5	127.98	21.31			2.5					
3	128.39	21.72	11.68	77.05	3					
4	128.74	22.07	11.63	77.39	4					
5	129.00	22.33	11.64	77.32	5					
6	129.25	22.58	11.69	76.99	6					
7	129.40	22.73	11.66	77.19	7					
8	129.57	22.90	11.67	77.12	8					
9	129.71	23.04	11.64	77.32	9					
10	129.96	23.29	111.68	8.06	10					
11	130.13	23.46	11.63	77.39	11					
12	130.32	23.65	11.65	77.25	12					
13	130.43	23.76	11.69	76.99	13					
14	130.60	23.93	11.67	77.12	14					
15	130.71	24.04	11.64	77.32	15					
20	130.79	24.12	11.64	77.32	20					
25	130.88	24.21	11.65	77.25	25					
30	130.97	24.30	11.63	77.39	30					
35	131.09	24.42	11.66	77.19	35					
40	131.20	24.53	11.64	77.32	40					
45	131.28	24.61	11.63	77.39	45					
50	131.41	24.74	11.67	77.12	50					
55	131.53	24.86	11.58	77.72	55					

60	131.61	24.94	11.65	77.25	60					
70	131.73	25.06	11.64	77.32	70					
80	131.85	25.18	11.63	77.39	80					
90	131.95	25.28	11.68	77.05	90					
100	132.07	25.40	11.67	77.12	100					

Table 33-7 Constant Rate Test – BH10402

BH No.: 10402	**District: Ghanzi**
Date of test commencement: 21.09.2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 253m**
Date of test completion: 24/09/2007	**Screen Interval (m):**
Time of test completion: 0600 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 106.46m**
Temperature of water (°C):	**EC (mS/cm): pH:**

	Elapsed time	Depth to WL (m)	Drawdown (m)	Time to fill 250L	Pumping Rate (m3/hr)	Temp (℃)	EC (μs/cm)	pH	Manometer (cm)	Comments
	0.25	108.02	1.56							
	0.5	109.62	3.16							
	1	110.79	4.33							
	2	112.44	5.98	12.87	69.93					
	3	113.79	7.33	12.80	70.31					
	4	115.23	8.77	12.86	69.98					
	5	116.04	9.58	12.86	69.98					
	6	116.60	10.14	12.84	70.09					
	7	118.43	11.97	12.85	70.04					
	8	119.27	12.81	12.85	70.04					
	9	119.67	13.21	12.83	70.15					
	10	119.97	13.51	12.84	70.09					
	11	120.03	13.57	12.86	69.98					
	12	120.17	13.71	12.81	70.26					
	15	120.38	13.92	12.82	70.20					
	20	120.90	14.44	12.84	70.09					
	25	121.09	14.63	12.83	70.15					
	30	121.28	14.82	12.85	70.04					
	35	121.44	14.98	12.84	70.09					
	40	121.55	15.09	12.81	70.26					
	45	121.63	15.17	12.83	70.15					
	50	121.72	15.26	12.86	69.98					
	55	121.82	15.36	12.82	70.20					
	60	121.87	15.41	12.83	70.15	24.4	925.00	7.97		
	75	121.96	15.50	12.84	70.09					
	90	122.04	15.58	12.82	70.20					
	105	122.10	15.64	12.84	70.09					
	120	122.15	15.69	12.82	70.20	27.7	932.00	7.71		
	150	122.20	15.74	12.83		28.2	915.00	7.87		
	180	122.24	15.78	12.85	70.04	28.2	915.00	7.87		
	210	122.29	15.83	12.85	70.04					
	240	122.34	15.88	12.82	70.20	32.5	827.00	7.70		
	270	122.40	15.94	12.86	69.98					
	300	122.46	16.00	12.84	70.09	31.7	694.00	7.98		
	330	122.52	16.06	12.83	70.15	31.8		7.84		
	360	122.56	16.10	12.80	70.31	31.6	804.00	7.80		
	390	122.64	16.18	12.86	69.98	32.8	713.00	7.96		
	420	123.06	16.60	12.84	70.09	30.8	715.00	7.91		
	450	123.12	16.66	12.81	70.26					
8	480	123.18	16.72	12.85	70.04	30.5	783.00	7.93		
9	540	123.26	16.80	12.80	70.31	32.7	735.00	7.60		
10	600	123.32	16.86	12.86	69.98	30.1	770.00	7.87		
11	660	123.40	16.94	12.81	70.26	29.1	737.00	7.74		
12	720	123.46	17.00	12.83	70.15	28.3	767.00	7.84		
13	780	123.52	17.06	12.80	70.31	26.6	687.00	7.73		

14	840	123.56	17.10	12.82	70.20	26.1	674.00	7.85		
15	900	123.60	17.14	12.85	70.04	25.4	641.00	7.87		
16	960	123.64	17.18	12.81	70.26	25.5	678.00	7.96		
17	1020	123.68	17.22	12.84	70.09	24.0	680.00	8.01		
18	1080	123.74	17.28	12.86	69.98	23.9	667.00	7.89		
19	1140	123.86	17.40	12.80	70.31	24.0	663.00	7.98		
20	1200	123.93	17.47	12.82	70.20	21.2	658.00	7.91		
21	1260	123.98	17.52	12.85	70.04	22.7	652.00	7.96		
22	1320	124.03	17.57	12.83	70.15	23.2	652.00	7.97		
23	1380	124.09	17.63	12.84	70.09	23.7	665.00	7.96		
24	1440	124.15	17.69	12.81	70.26	23.7	666.00	7.97		
25	1500	124.18	17.72	12.81	70.26	25.6	647.00	8.10		
26	1560	124.23	17.77	12.80	70.31	26.3	652.00	7.96		
27	1620	124.28	17.82	12.85	70.04	27.8	611.00	8.07		
28	1680	124.40	17.94	12.82	70.20	28.7	588.00	7.96		
29	1740	124.36	17.90	12.83	70.15	29.8	559.00	7.88		
30	1800	124.40	17.94	12.80	70.31	29.2	575.00	7.90		
31	1860	124.45	17.99	12.84	70.09	29.2	565.00	7.79		
32	1920	124.51	18.05	12.85	70.04	29.1	574.00	7.85		
33	1980	124.56	18.10	12.81	70.26	29.0	566.00	7.75		
34	2040	124.59	18.13	12.83	70.15	29.4	574.00	7.74		
35	2100	124.64	18.18	12.80	70.31	29.3	569.00	7.49		
36	2160	124.67	18.21	12.82	70.20	28.5	573.00	7.77		
37	2220	124.76	18.30	12.80	70.31	26.5	569.00	8.03		
38	2280	124.87	18.41	12.83	70.15	26.9	574.00	7.84		
39	2340	124.92	18.46	12.81	70.26	26.2	576.00	7.87		
40	2400	124.98	18.52	12.84	70.09	26.9	571.00	7.93		
41	2460	125.03	18.57	12.85	70.04	25.6	554.00	8.02		
42	2520	125.08	18.62	12.83	70.15	24.3	561.00	7.97		
43	2580	125.15	18.69	12.83	70.15	24.4	569.00	8.07		
44	2640	125.22	18.76	12.80	70.31	24.3	573.00	7.99		
45	2700	125.28	18.82	12.84	70.09	24.1	575.00	7.95		
46	2760	125.37	18.91	12.81	70.26	24.9	559.00	7.74		
47	2820	125.46	19.00	12.85	70.04	23.7	574.00	7.65		
48	2880	125.52	19.06	12.81	70.26	23.5	565.00	7.79		
49	2940	125.56	19.10	12.82	70.20	23.7	679.00	7.94		
50	3000	125.71	19.25	12.85	70.04	24.5	699.00	7.74		
51	3060	125.76	19.30	12.82	70.20	28.7	601.00	7.89		
52	3120	125.81	19.35	12.80	70.31	29.6	583.00	7.80		
53	3180	125.85	19.39	12.80	70.31	29.1	557.00	7.86		
54	3240	125.91	19.45	12.84	70.09	30.1	659.00	7.77		
55	3300	125.96	19.50	12.82	70.20	29.1	652.00	7.69		
56	3360	126.02	19.56	12.85	70.04	28.6	555.00	7.71		
57	3420	126.11	19.65	12.83	70.15	28.7	552.00	7.72		
58	3480	126.16	19.70	12.82	70.20	28.8	552.00	7.80		
59	3540	126.22	19.76	12.81	70.26	28.8	554.00	7.77		
60	3600	126.28	19.82	12.80	70.31	28.3	553.00	7.80		
61	3660	126.35	19.89	12.81	70.26	26.6	549.00	7.81		
62	3720	126.42	19.96	12.85	70.04	25.0	558.00	7.92		
63	3780	126.49	20.03	12.84	70.09	24.2	562.00	7.86		
64	3840	126.56	20.10	12.85	70.04	23.5	566.00	8.08		
65	3900	126.63	20.17	12.82	70.20	23.8	547.00	8.04		
66	3960	126.69	20.23	12.80	70.31	25.4	545.00	8.08		
67	4020	126.75	20.29	12.83	70.15	24.7	540.00	8.21		
68	4080	126.81	20.35	12.81	70.26	25.3	534.00	7.99		
69	4140	126.87	20.41	12.85	70.04	26.8	546.00	8.48		
70	4200	126.93	20.47	12.84	70.09	27.3	559.00	7.85		
71	4260	127.02	20.56	12.84	70.09	30.1	568.00	8.14		
72	4320	127.10	20.64	12.85	70.04	30.1	567.00	7.90		

Table 33-8 Constant Rate Test Observation BH10227

BH NO : 10227	District : Ghantsi
Date of test commencement :21.09.2007	Location :Nojane
Time of test commencement :0600hrs	BH depth(m) :300m
Date of test completion:24.09.2007	Screen Interval (m)
Time of test completion :0600 hrs	Depth of pump intake (m) :
Method of water level measurement: Electrical Dipper	Description of MP
Pumping BH NO: 10402	Height of MP above ground(m) :1m
Distance to pumping BH (m):12.40m	Static Water level before test(m) :106.75m

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Comments
	0.25	107.70	0.95	
	0.5	108.69	1.94	
	1	109.05	2.30	
	2	110.12	3.37	
	3	110.59	3.84	
	4	110.66	3.91	
	5	110.84	4.09	
	6	110.94	4.19	
	7	111.03	4.28	
	8	111.06	4.31	
	9	111.08	4.33	
	10	111.13	4.38	
	11	111.17	4.42	
	12	111.22	4.47	
	15	111.28	4.53	
	20	111.32	4.57	
	25	111.46	4.71	
	30	111.66	4.91	
	35	111.80	5.05	
	40	111.92	5.17	
	45	112.01	5.26	
	50	112.10	5.35	
	55	112.19	5.44	
	60	112.25	5.50	
	75	112.42	5.67	
	90	112.53	5.78	
	105	112.64	5.89	
	120	112.68	5.93	
	150	112.80	6.05	
	180	112.95	6.20	
	210	113.01	6.26	
	240	113.09	6.34	
	270	113.11	6.36	
	300	113.15	6.40	
	330	113.21	6.46	
	360	113.28	6.53	
	390	113.31	6.56	
	420	113.35	6.60	
	450	113.39	6.64	
	480	113.41	6.66	
	540	113.45	6.70	
	600	113.49	6.74	
	660	113.51	6.76	
	720	113.53	6.78	
	780	113.57	6.82	
	840	113.60	6.85	
	900	113.63	6.88	
	960	113.66	6.91	
	1020	113.68	6.93	
	1080	113.72	6.97	
	1140	113.75	7.00	

	1200	113.77	7.02	
	1260	113.80	7.05	
	1320	113.83	7.08	
	1380	113.86	7.11	
	1440	113.91	7.16	
	1500	113.95	7.20	
	1560	113.95	7.20	
	1620	113.98	7.23	
	1680	113.98	7.23	
	1740	113.98	7.23	
	1800	113.98	7.23	
	1860	114.05	7.30	
	1920	114.08	7.33	
	1980	114.10	7.35	
	2040	114.12	7.37	
	2100	114.15	7.40	
	2160	114.18	7.43	
	2220	114.21	7.46	
	2280	114.24	7.49	
	2340	114.27	7.52	
	2400	114.30	7.55	
	2460	114.33	7.58	
	2520	114.37	7.62	
	2580	114.40	7.65	
	2640	114.43	7.68	
	2700	114.46	7.71	
	2760	114.49	7.74	
	2820	114.51	7.76	
	2880	114.54	7.79	
	2940	114.56	7.81	
	3000	114.58	7.83	
	3060	114.60	7.85	
	3120	114.62	7.87	
	3180	114.64	7.89	
	3240	114.67	7.92	
	3300	114.73	7.98	
	3360	114.76	8.01	
	3420	114.80	8.05	
	3480	114.83	8.08	
	3540	114.85	8.10	
	3600	114.88	8.13	
	3660	114.91	8.16	
	3720	114.95	8.20	
	3780	115.01	8.26	
	3840	115.04	8.29	
	3900	115.07	8.32	
	3960	115.10	8.35	
	4020	115.13	8.38	
	4080	115.16	8.41	
	4140	115.19	8.44	
	4200	115.22	8.47	
	4260	115.26	8.51	
	4320	115.31	8.56	

Table 33-9 Recovery Test Data – BH10402

BH No.: 10402	**District: Ghanzi**
Date of test commencement: 24.09.2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 257m**
Date of test completion: 25/09/2007	**Screen Interval (m):**
Time of test completion: 0600 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 106.46m**
Temperature of water (^oC):	**EC (mS/cm): pH:**

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	127.1	20.64
	0.25	125.44	18.98
	0.5	124.08	17.62
	1	123.81	17.35
	2	121.81	15.35
	3	121.57	15.11
	4	120.28	13.82
	5	119.77	13.31
	6	119.32	12.86
	7	118.84	12.38
	8	118.24	11.78
	9	116.82	10.36
	10	114.46	8
	12	112.73	6.27
	15	112	5.54
	20	111.66	5.2
	25	110.46	4
	30	109.74	3.28
	40	109.36	2.9
	50	108.99	2.53
	60	108.79	2.33
	75	108.7	2.24
	90	108.58	2.12
	105	108.45	1.99
	120	108.34	1.88

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	108.18	1.72
	180	108.07	1.61
	210	108.02	1.56
	240	107.95	1.49
	270	107.87	1.41
	300	107.82	1.36
	330	107.78	1.32
	360	107.69	1.23
	390	107.67	1.21
	420	107.61	1.15
	450	107.57	1.11
	480	107.53	1.07
	540	107.54	1.08
	600	107.47	1.01
	660	107.42	0.96
	720	107.41	0.95
	780	107.39	0.93
	840	107.36	0.9
	900	107.32	0.86
	960	107.27	0.81
	1020	107.26	0.8
	1080	107.26	0.8
	1140	107.26	0.8
	1200	107.2	0.74
	1260	107.13	0.67
	1320	107.06	0.6
	1380	106.94	0.48
	1440	106.87	0.41
	1560		
	1680		
	1800		
	1920		
	2040		

Table 33-10 Recovery Test Data – BH10227

BH No.: 10227	**District: Ghanzi**	
Date of test commencement: 25.09.2007	**Location: Ncojane**	
Time of test commencemen: 0600 Hrs	**BH depth (m):**	
Date of test completion: 26/09/2007	**Screen Interval (m):**	
Time of test completion: 0600 Hrs	**Depth of pump intake (m):m**	
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 106.75m**	
Temperature of water (^oC):	**EC (mS/cm):**	**pH:**

Clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	115.31	8.56
	0.25	114.88	8.13
	0.5	114.31	7.56
	1	113.66	6.91
	2	113.28	6.53
	3	112.91	6.16
	4	112.76	6.01
	5	112.32	5.57
	6	112.01	5.26
	7	111.89	5.14
	8	111.37	4.62
	9	111.11	4.36
	10	110.87	4.12
	12	110.54	3.79
	15	110.24	3.49
	20	110.08	3.33
	25	109.88	3.13
	30	109.44	2.69
	40	109.25	2.5
	50	109.05	2.3
	60	108.95	2.2
	75	108.81	2.06
	90	108.7	1.95
	105	108.68	1.93
	120	108.64	1.89

Clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	108.45	1.7
	180	108.37	1.62
	210	108.29	1.54
	240	108.17	1.42
	270	108.06	1.31
	300	108.01	1.26
	330	107.94	1.19
	360	107.89	1.14
	390	107.85	1.1
	420	107.83	1.08
	450	107.77	1.02
	480	107.75	1
	540	107.73	0.98
	600	107.68	0.93
	660	107.65	0.9
	720	107.63	0.88
	780	107.59	0.84
	840	107.55	0.8
	900	107.53	0.78
	960	107.52	0.77
	1020	107.52	0.77
	1080	107.52	0.77
	1140	107.48	0.73
	1200	107.34	0.59
	1260	107.27	0.52
	1320	107.19	0.44
	1380	107.13	0.38
	1440	107.02	0.27

34 BH10403

Abandoned borehole BH10403 was a replacement borehole for exploration borehole BH10211. BH10403 with site reference **P03**, Line **R3 TEM 63** and 9000m is located approximately 20 km east of Ncojane along the gravel road to Metsimantsho. BH10211 is one of three boreholes drilled at this site during exploration phase. These boreholes are BH10210, BH10211 and BH10318 (abandoned). It should be noted that this borehole is one of five boreholes located within radius of 30m and about and 20m from BH10210. Drilling at this site with 17.5 inch diameter bit was started 20 February and a total depth of 69 m was achieved by 25th February 2007. An attempt to install 15 inch casing to 69 m was made but the casings only went down to 65 m. The contractor made an attempt to pull back casing but 18 m could not be pulled out. It appears that the casings broke off from the rest due to improper welding. After unsuccessfully trying to fish out the casings, the borehole was backfilled and abandoned. A replacement borehole (BH10404) was sited 10m from BH10403 and drilling is underway at this borehole.

34.1 SITING CRITERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block and where there is probably thin dolerite sill/dyke.

35 BH10404

BH10404 is replacement borehole for abandoned borehole BH10403, drilled at site **P03**, Line **R3 TEM 63** at peg 9000m. It is located approximately 20 km east of Ncojane along the gravel road to Metsimantsho. Drilling at this site commenced on 03 March 2007 and was completed on 27 April 2007

35.1 SITING CRITERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block and where there is probable thin dolerite sill/dyke.

35.2 DRILLING RESULTS

Drilling was carried out with 17 inch drilling bit to a depth of 63 m after which 15 inch plain casings were installed and grouted. Drilling was continued from 63 to 196 m with a 15 inch drilling bit after which 12inch casings were installed and grouted to allow for further drilling. Drilling was then continued with 12 inch DTH bit to a depth of 226 m when drilling could not continue due to back pressure problems. After the Easter break a 12 inch tricone bit (drag bit) was utilised to complete the borehole to the terminal depth of 250 m. Various lithologies including fine grained sands, silcrete, mudstones, coal and fine to coarse grained sandstones were intercepted during drilling of this exploration borehole (**Figure 35-1).**

During drilling of this borehole, two water strikes were encountered. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows;

1. (198m, 730µS/cm, 72 m^3/hr)
2. (225m, 778 µS/cm., 85 m^3/hr)

The borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 250m **(Figure 35-2).** The construction of the botehole was through using 8 inch epoxy plain casings and epoxy screens. The 8 inch epoxy casings were installed between 0 to 205 m, 226 and 236 and 245 to 250.m while the screens were installed between 205 to 226 and 226 to 245, representing a zone of 40m. Borehole development was through airlift pumping and air jetting and the final blow out yield was 65 m3/hr while the electrical conductivity was 795µS/cm.

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

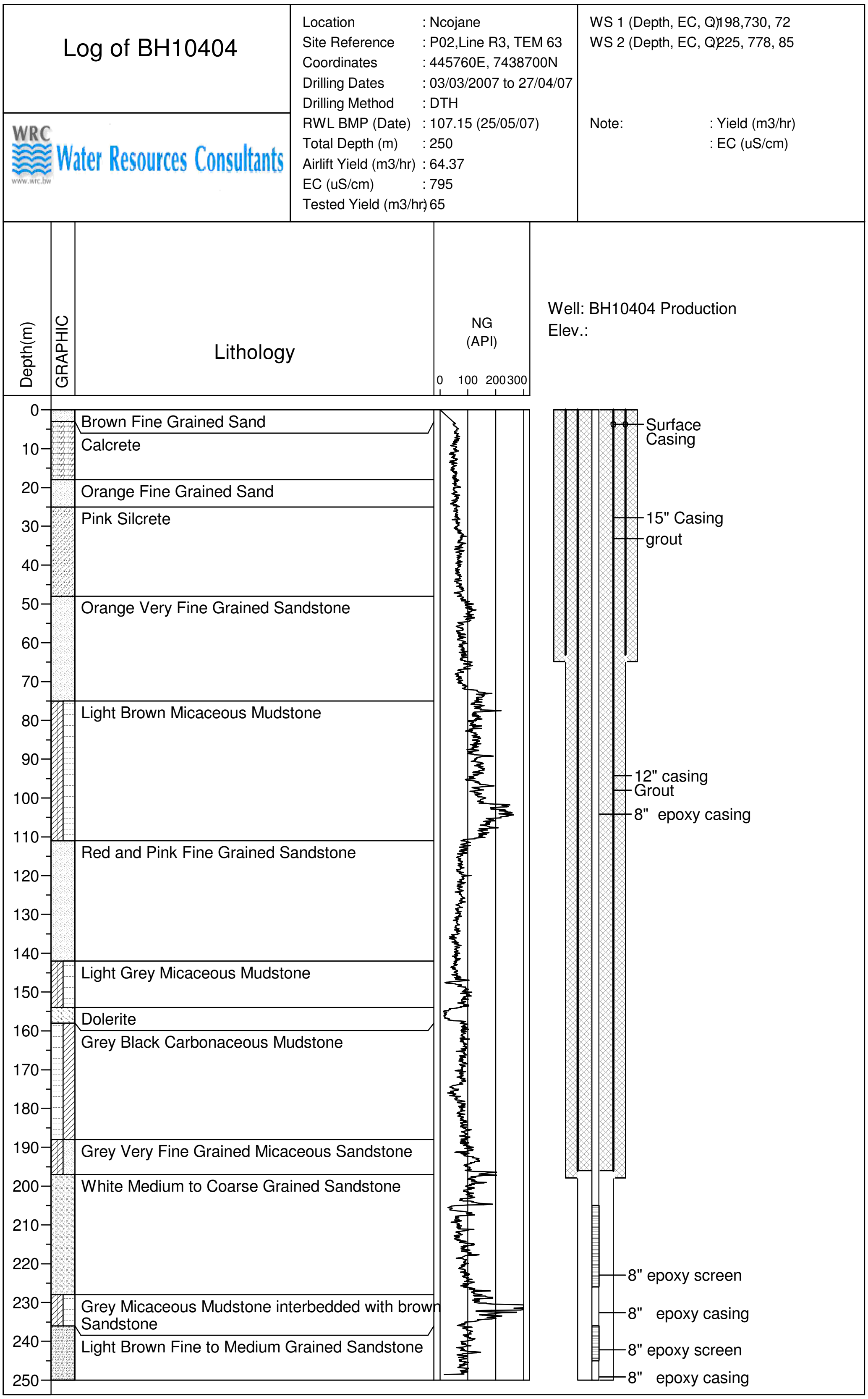

Figure 35-1 Log of BH10404

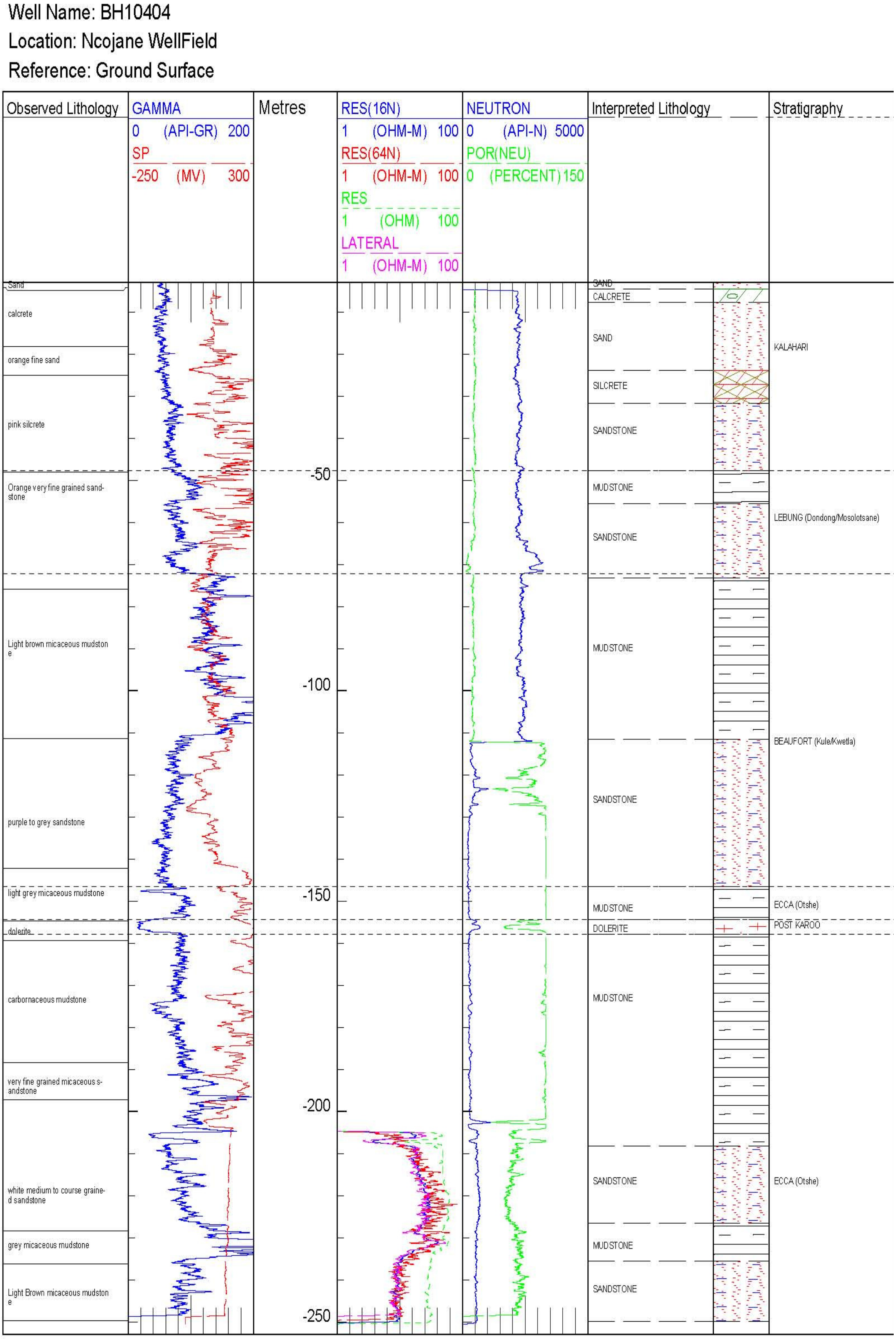

Figure 35-2 Geophysical log of BH10404

35.3 PUMP TESTING RESULTS

Test pumping operations were started on 18th July with a calibration test at BH10404. The tests carried out were calibration, step drawdown, constant rate and recovery tests. A summary of the pumping test data for BH10404 is in **Table 35-1**. As the maximum discharge rate obtained during the calibration test was only 69m^3/hr, it was decided to reduce the pump intake from 147 m to 135 m to try to improve the performance of the pump prior to conducting the step drawdown test. The collected pump testing data is presented in **Tables 35-5 to 35- 8.**

Table 35-1 Summary of Pumping Test Data BH10404

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	4.98	19.43
	2	15	11.91	40.55
	3	15	17.54	59.33
	4	15	19.19	66.48
Step Test	1	100	8.33	30
	2	100	13.08	40
	3	100	18.00	50
	4	100	21.68	60
	5	100	24.35	70
Constant Rate	1	10080	26.40	65
Recovery	1	1440	2.79*	0

Note. 0.37 Residual Drawdown*

35.3.1 Step Drawdown Test

The step drawdown test (SDT) was conducted on 19th July 2007 at discharge rates of 30, 40 50, 60 and 69 m^3/hr, with a total drawdown of 24.35 m at the end of the test. The static water level before the start of the test was 108.32 m bmp. It has to be noted that there was no improvement in the performance of the pump with reduction of the pump intake.

The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 82 m^2/d, **(Figure 35-5)**. The results of the interpreted step test data are given in **Table 35-2**.

Table 35-2 Results of Step Test Analysis BH10404

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10404	1.54E-006	1.16E-002	82	30	9.23	9.23	3.25
				40	3.05	12.28	3.25
				50	4.45	16.73	2.98
				60	2.76	19.49	3.07

The planned duration for the constant rate test of BH10404 was 7 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 35-3**) to estimate the expected total drawdown after 7 days of pumping.

35.3.2 Constant Rate and Recovery Tests

The first Constant Rate Test (CRT), was started on 21st July 2007 at a discharge rate of 70 m^3/hr, however the water level reached the pump suction on 22nd July after 23 hours of pumping. After discussions with the contractor it was found out that the pump suction was 5 m above the bottom of the pump i.e. 135 m instead of 140 m. The CRT was restarted at lower pumping rate of 65 m^3/hr on 24th July 2007 but this test also failed on 25th July after 27 hrs of pumping this time due to a breakdown of the engine. The third constant rate test (CRT) was carried out between 29th July and 5th

September 2007 at a discharge rate of 65m^3/hr and the total drawdown after 168 hrs of pumping was 26.40 m. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 2.79 m.

Transmissivity (T) values obtained by Cooper-Jacob (1946) and Hantush leaky, analytical solutions were 94 and 96 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a Transmissivity obtained was 95m^2/d. The results are summarised in **Table 35-3** and the interpreted data is presented in **Figures 35-6 to 35-8.**

35.3.3 Observation borehole BH10210

The water level response was monitored in an observation borehole (BH10210) located 15 m away from BH10404 (pumped borehole). This observation borehole is screened between 192.83 to 244.07 m bgl and the total drawdown at the end of pumping (168 hrs) was 25.15 m.

Various analytical solutions (Cooper-Jacob and Hantush Leaky,) were applied to data obtained from this observation borehole using the computer programme "Aqtesolv" and the best fit was obtained based on the Cooper Jacob and Hantush Leaky solutions. The transmissivity (T) values obtained by these two analytical solutions were 97 and 53 m^2/d respectively while the storativity values calculated from the same solution were 5.0x10^{-5} and 1.5x10^{-4} respectively. The Transmissivity obtained from recovery data using the Theis recovery method was 82 m^2/d. The results are summarised in **Table 35-3** and the interpreted data is presented in **Figures 35-9 to 35-11.**

Table 35-3 Summary of Constant Rate and Recovery Tests BH10404

BH No.	CRT Duration (hours)	Q (m^3/d)	Pumping borehole T (m^2/d)		Obs. BH No.	Observation borehole Pumping phase		Observation borehole Recovery phase	Aquifer type
			Pumping Phase	Recovery Phase		T (m^2/d)	S	T (m^2/d)	
10404	168	1560	a) 94 b) 96	c) 95	10210	a) 97 b) 53	a) 5.0E-5 b) 1.5E-4	d) 82	Confined leaky with storage

Notes:
Interpretation Techniques
a) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

35.3.3.1 Aquifer Type interpreted

The interpretation of the pump testing data indicates that the aquifer type is confined-leaky with negative (barrier) boundary

35.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. The results of chemical analyses from CSIR lab are presented in **Table 35-4**.

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC), and pH are 28.7 °C, 568 µS/cm and 7.78 respectively.

Table 35-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10404	7.8	135.5	21.4	19	33	112.5	208	17.1	0.59	<0.05	<0.05	840	6.80	5.38
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10404	<0.05	132	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in $\mu S/cm$
All units are in mg/L except pH, which has no units
HCO_3 *is calculated from alkalinity*

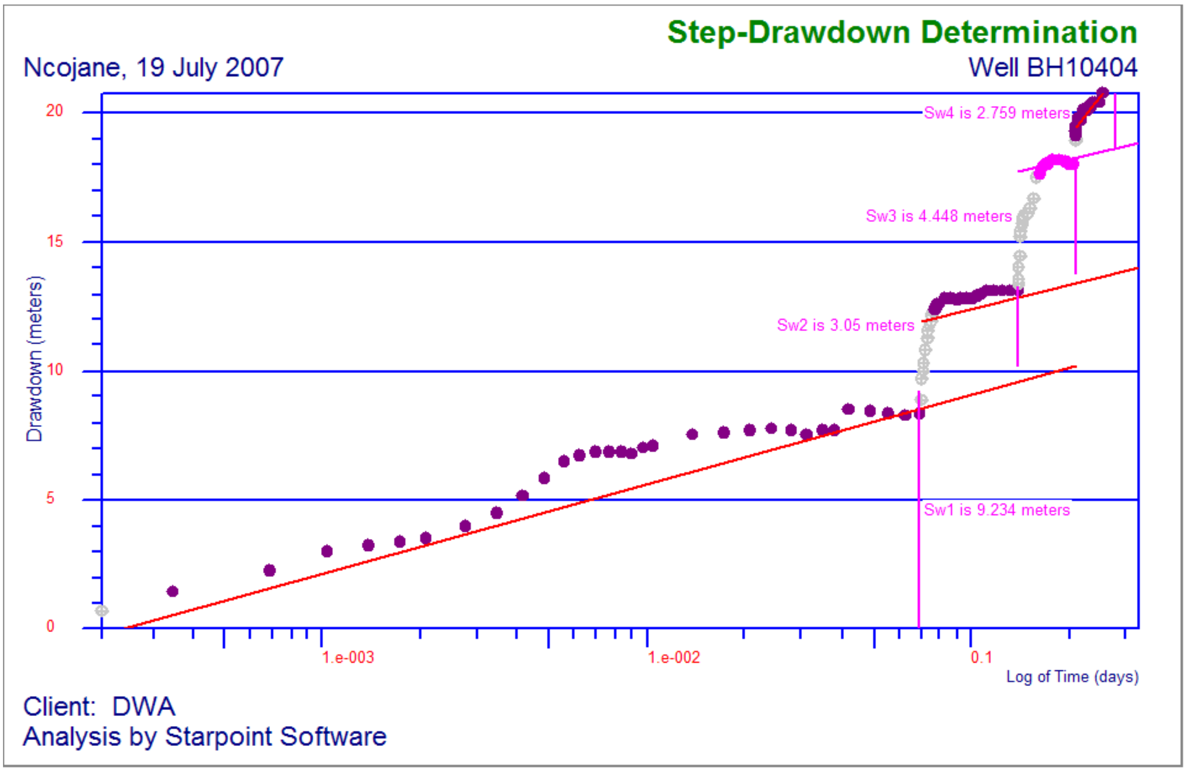

Figure 35-3 Pumping Test Results for BH10316: Step Drawdown Test - Hantush-Bierschenk (semi-log)

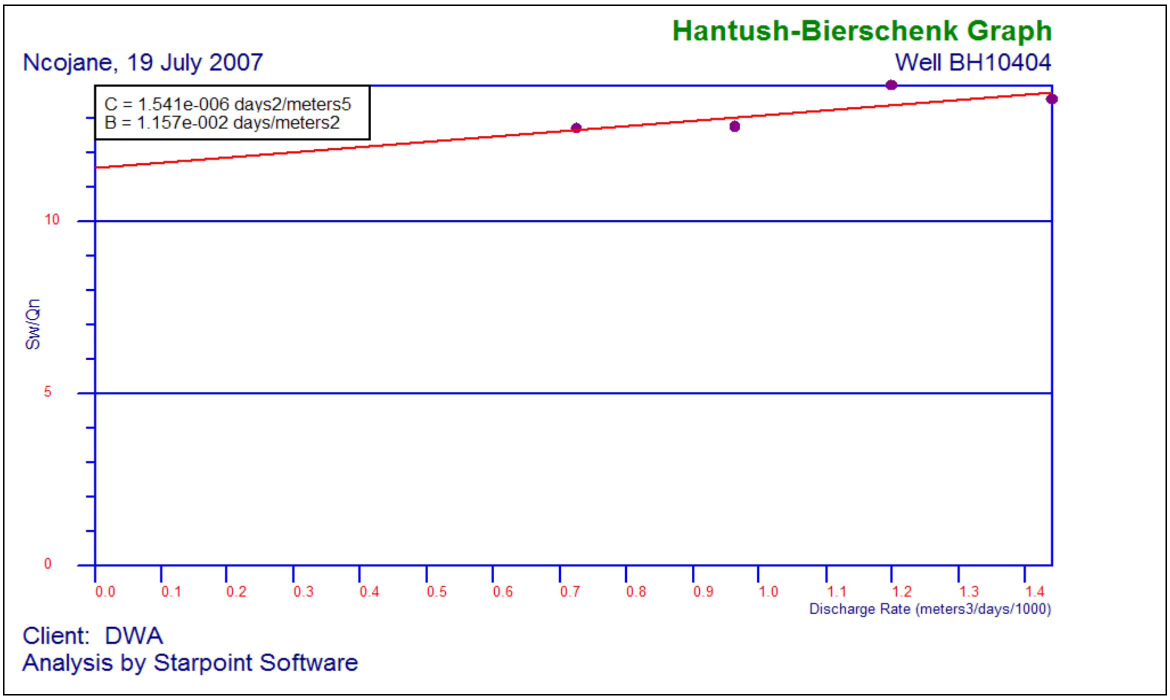

Figure 35-4 Pumping Test Results for BH10404: Step Drawdown Test – Hantush-Bierschenk

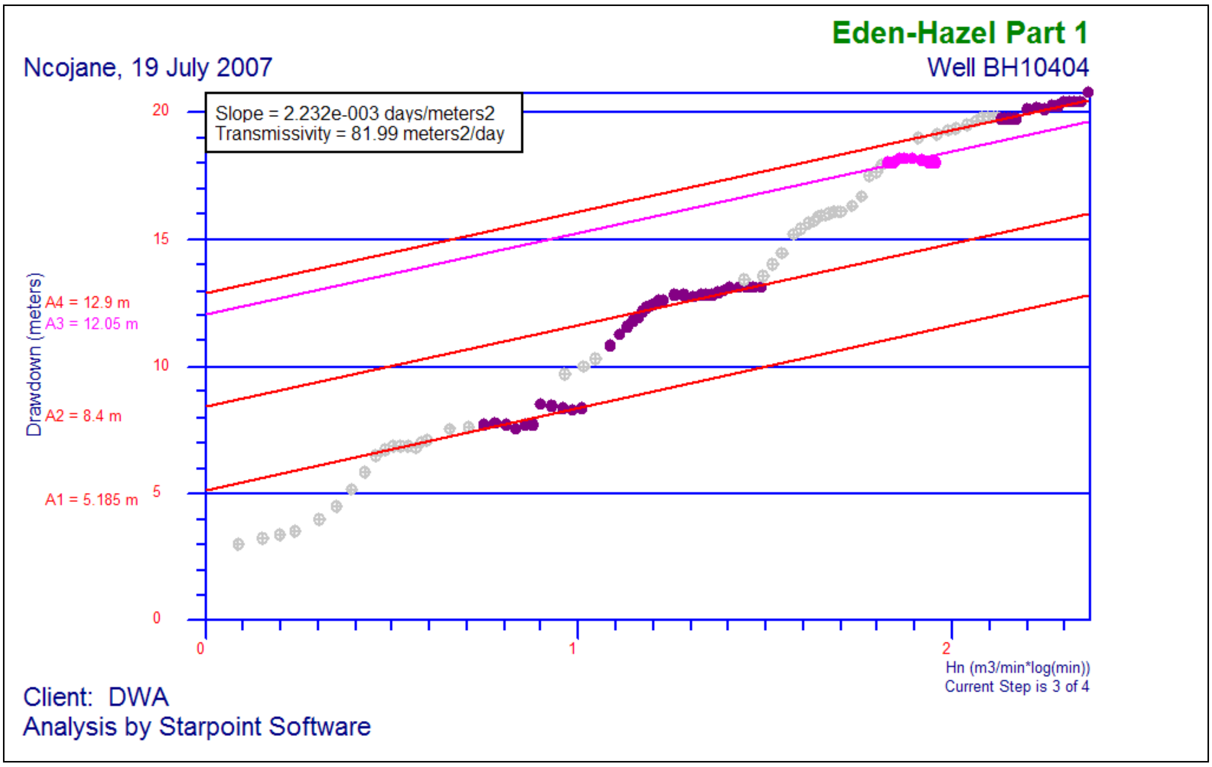

Figure 35-5 Pumping Test Results for BH10404: Step Drawdown Test – Eden-Hazel (Part 1)

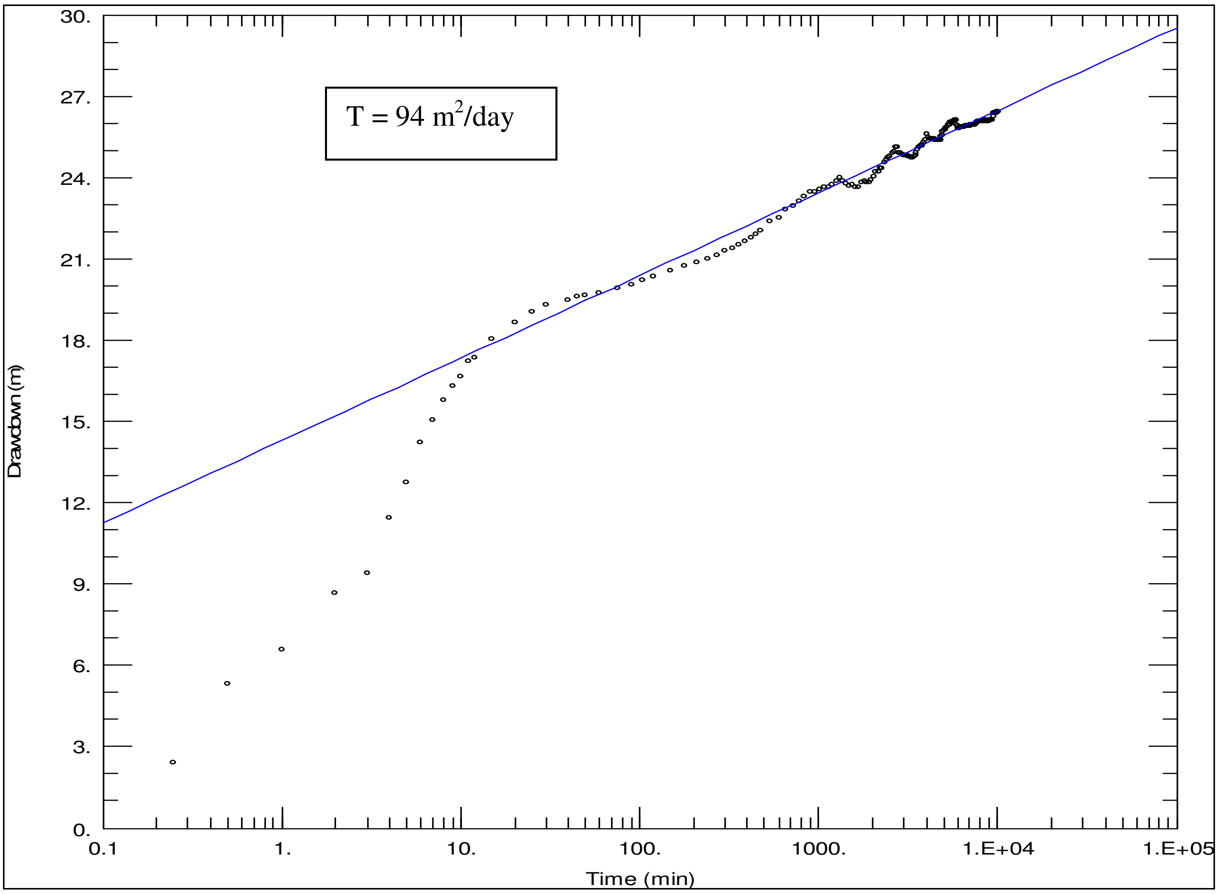

Figure 35-6 Pumping Test Results for BH10404: Cooper Jacob Solution

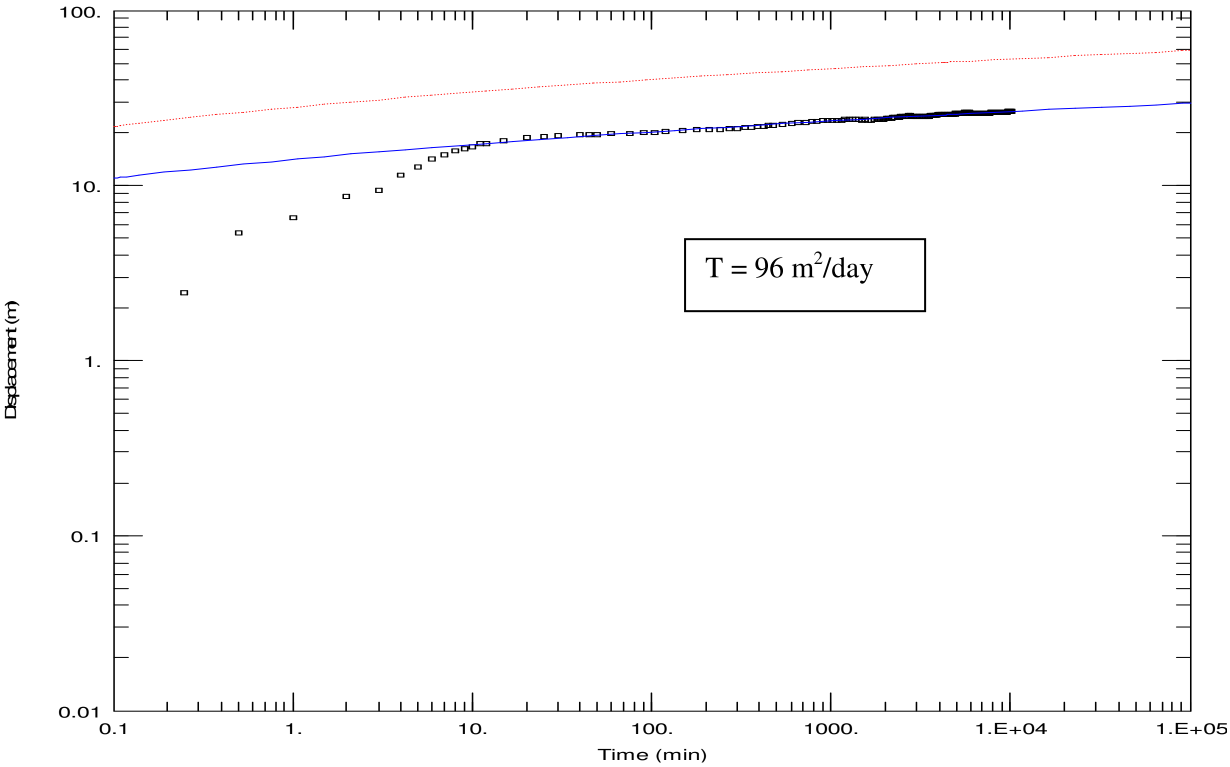

Figure 35-7 Pumping Test Results for BH10404: CRT Hantush leaky with storage in the aquitard

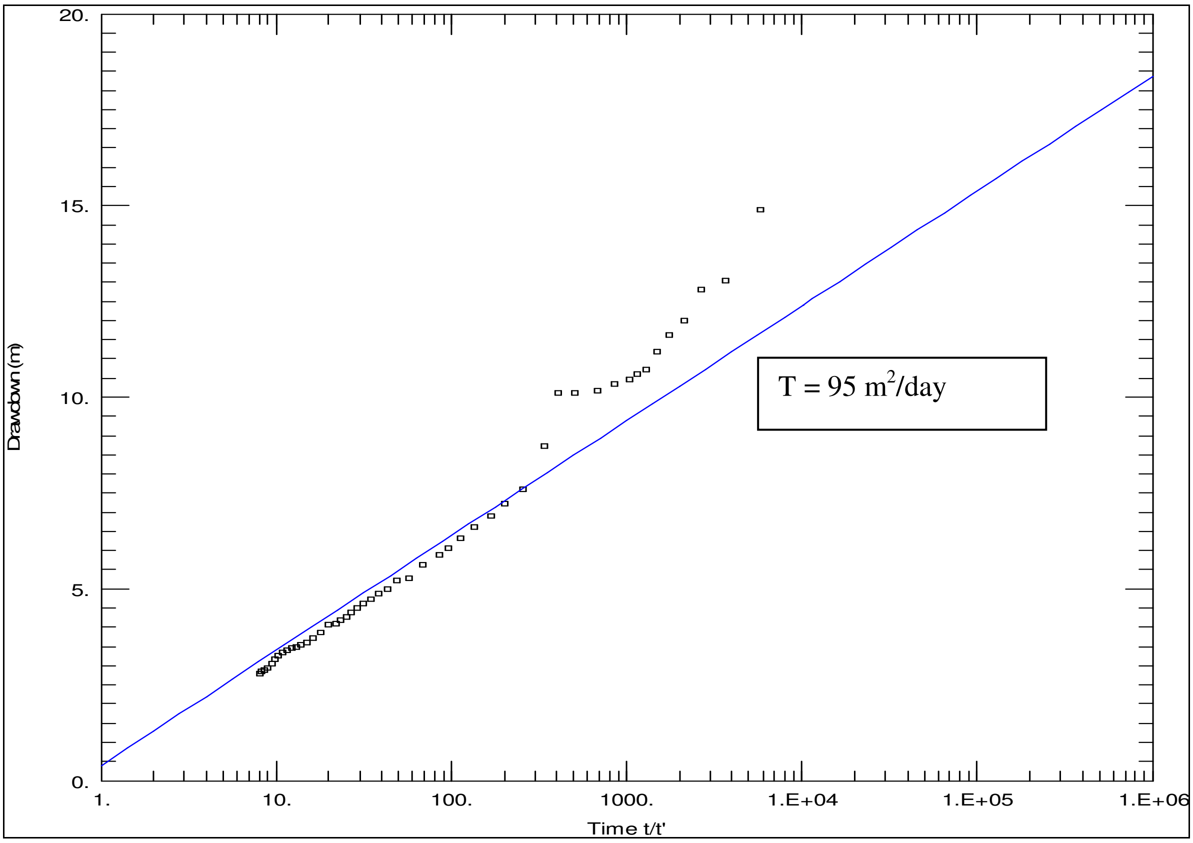

Figure 35-8 Pumping Test Results for BH10404: Theis Recovery Solution

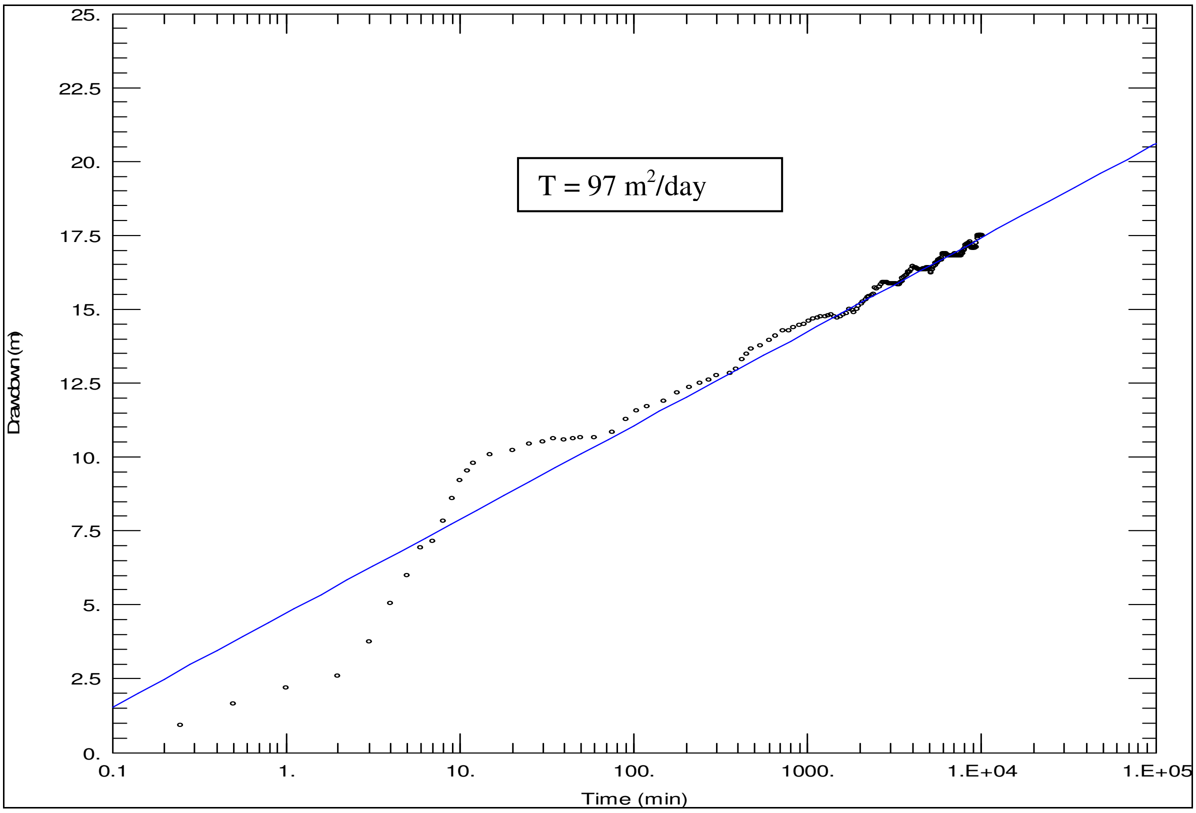

Figure 35-9 Pumping Test Results for BH10210: Cooper Jacob Solution

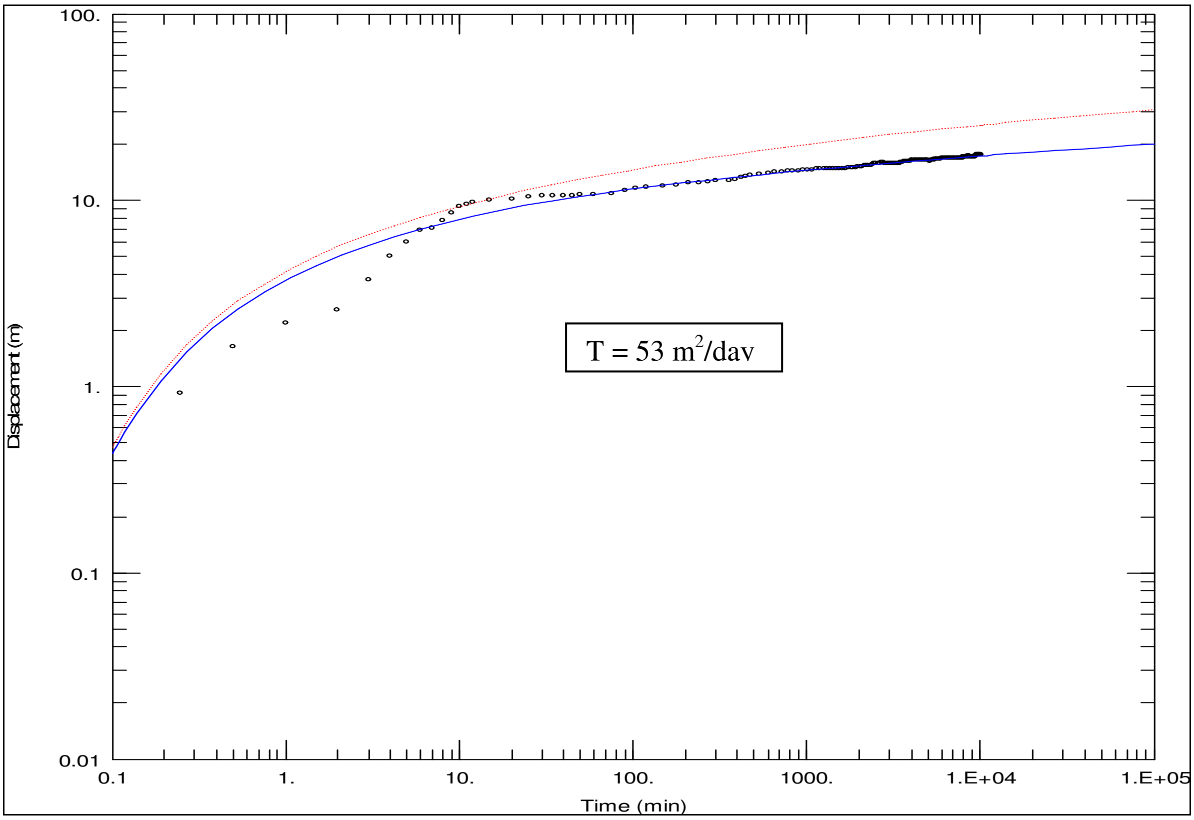

Figure 35-10 Pumping Test Results for BH10210: Hantush leaky with storage in the aquitards

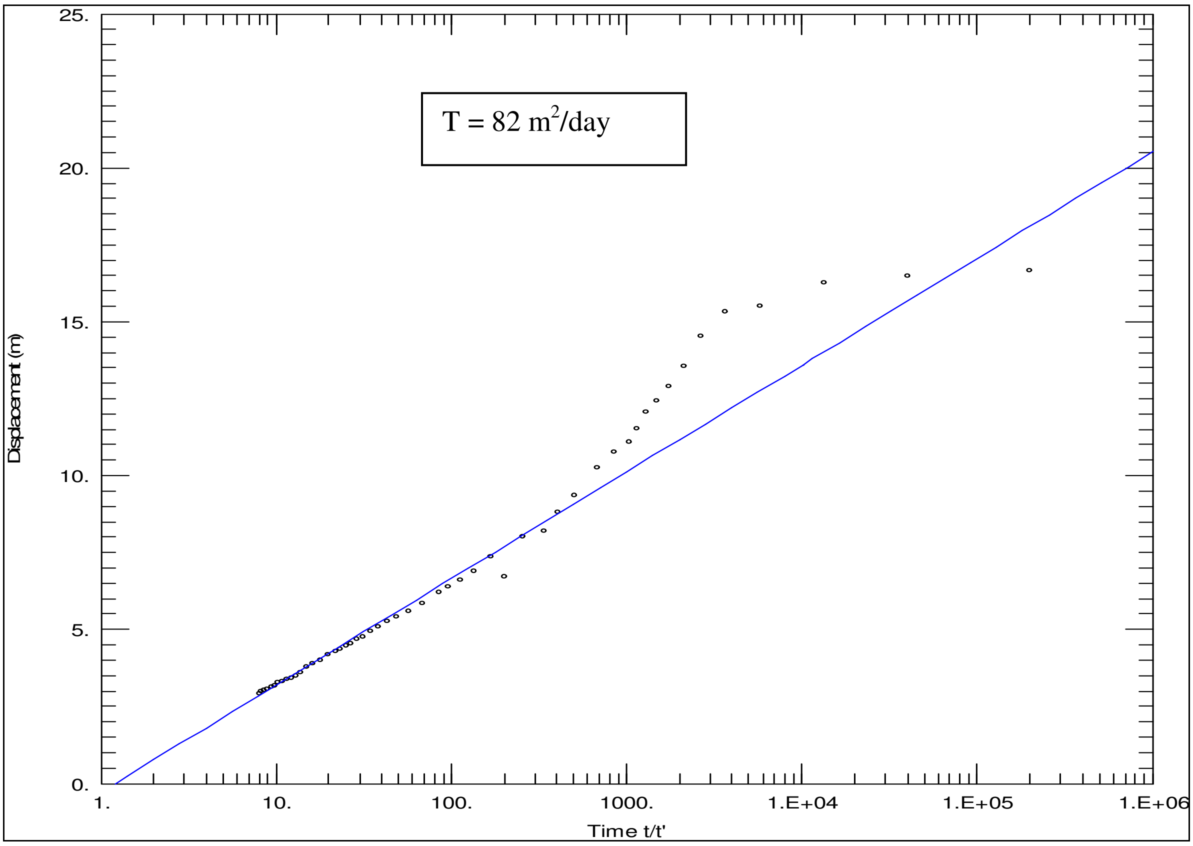

Figure 35-11 Pumping Test Results for BH10210 Theis Recovery Solution

Table 35-5 Calibration Test Data – BH10404

Commencement of test: 18.07.2007	BH No. 10404
Completion of testcasing length:18.07.2007	Casing Diameter- 203m
Casing Length	District: Ghanzi
Bh Depth: 250m	Location: Ncojane Consultant- WRC
Pump Type:9002 Orbirt Pumps	SWL- 108.34m TDS-
Water Strikes	Pump Intake-:152m pH-
Latitude	Longitude

Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **100L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **150L**	Pump Rate (m3/hr)
STEP 1					**STEP 2**				
15 sec	108.61	0.27			15 sec	113.47	5.13		
30 sec	108.81	0.47			30 sec	113.64	5.30		
1	109.78	1.44			1	116.08	7.74	11.96	45.15
2	109.94	1.60			2	117.69	9.35	12.83	42.09
3	109.81	1.47			3	118.47	10.13	13.56	39.82
4	110.24	1.90			4	118.70	10.36	13.48	40.06
5	110.44	2.10			5	118.87	10.53	13.51	39.97
6	111.26	2.92	19.74	18.24	6	119.11	10.77	13.54	39.88
7	111.83	3.49	19.68	18.29	7	119.32	10.98	13.46	40.12
8	112.05	3.71	19.66	18.31	8	119.51	11.17	13.52	39.94
9	112.55	4.21	18.44	19.52	9	119.70	11.36	13.48	40.06
10	112.77	4.43	17.51	20.56	10	119.78	11.44	13.56	39.82
11	112.99	4.65	17.84	20.18	11	119.91	11.57	13.50	40.00
12	113.12	4.78	17.86	20.16	12	120.03	11.69	13.48	40.06
15	113.32	4.98	17.86	20.16	15	120.25	11.91	13.45	40.15

Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **200L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **250L**	Pump Rate (m3/hr)
STEP 3					**STEP 4**				
15 sec	120.77	12.43			15 sec	125.90	17.56		
30 sec	121.64	13.30			30 sec	126.08	17.74		
1	122.35	14.01	13.33	54.01	1.00	126.14	17.80	14.68	61.31
2	123.15	14.81	12.98	55.47	2.00	126.30	17.96	14.79	60.85
3	124.02	15.68	12.02	59.90	3.00	125.60	17.26	14.78	60.89
4	124.46	16.12	11.83	60.86	4.00	126.77	18.43	13.74	65.50
5	124.85	16.51	12.00	60.00	5.00	127.07	18.73	13.66	65.89
6	125.08	16.74	12.02	59.90	6.00	127.12	18.78	13.45	66.91
7	125.19	16.85	11.91	60.45	7.00	127.34	19.00	13.25	67.92
8	125.33	16.99	11.97	60.15	8.00	127.35	19.01	13.06	68.91
9	125.49	17.15	12.00	60.00	9.00	127.35	19.01	13.00	69.23
10	125.57	17.23	12.00	60.00	10.00	127.35	19.01	12.98	69.34
11	125.71	17.37	11.92	60.40	11.00	127.35	19.01	13.03	69.07
12	125.73	17.39	11.99	60.05	12.00	127.36	19.02	12.99	69.28
15	125.88	17.54	11.98	60.10	15.00	127.53	19.19	13.01	69.18

Table 35-6 Step Drawdown Test Data – BH10404

Official BH No.:BH 10404	District:Ghanzi
Date of test commencement:20.07.2007	Location:Ncojane
Time of test Commencement:0700 Hrs	BH depth (m):250m
Date of test completion:20.07.2007	Screen interval (m)
Time of test Completion:1520 Hrs	Depth to pump intake (m)140m
Method of water level measurement: Electrical Dipper	Description of MP:
Observation Bh No.:	Height of MP above ground:
Distance to OB. BH (m)	Static water level before test (m):108.32
Temperature of water (^oC):	TDS/EC:

STEP No. 1						STEP No. 2					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **100L**	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **150L**	Pumping Rate (m^3/hr)	Comments
0.25	109.05	0.73				0.25					
0.5	109.78	1.46				0.5	116.69	8.37			
1	110.55	2.23	11.27	31.94		1	116.79	8.47	13.58	39.76	
1.5	111.34	3.02				1.5	117.20	8.88			
2	111.54	3.22	11.67	30.85		2	118.00	9.68	13.59	39.74	
2.5	111.67	3.35				2.5	118.33	10.01			
3	111.88	3.56	11.88	30.30		3	118.60	10.28	13.20	40.91	
4	112.31	3.99	11.73	30.69		4	119.15	10.83	13.43	40.21	
5	112.79	4.47	12.00	30.00		5	119.56	11.24	13.41	40.27	
6	113.51	5.19	12.06	29.85		6	119.85	11.53	13.38	40.36	
7	114.13	5.81	11.97	30.08		7	120.12	11.80	13.46	40.12	
8	114.80	6.48	12.02	29.95		8	120.28	11.96	13.42	40.24	
9	115.06	6.74	11.96	30.10		9	120.46	12.14	13.40	40.30	
10	115.17	6.85	11.97	30.08		10	120.59	12.27	13.44	40.18	
11	115.17	6.85	11.95	30.13		11	120.70	12.38	13.47	40.09	
12	115.17	6.85	11.92	30.20		12	120.74	12.42	13.39	40.33	
13	115.12	6.80	11.94	30.15		13	120.85	12.53	13.48	40.06	
14	115.31	6.99	11.89	30.28		14	120.88	12.56	13.50	40.00	
15	115.43	7.11	11.99	30.03		15	120.94	12.62	13.46	40.12	
20	115.83	7.51	11.93	30.18		20	121.10	12.78	13.48	40.06	
25	115.95	7.63	11.97	30.08		25	121.10	12.78	13.41	40.27	
30	116.03	7.71	11.74	30.66		30	121.09	12.77	13.39	40.33	
35	116.05	7.73	11.66	30.87		35	121.12	12.80	13.49	40.03	
40	116.04	7.72	11.96	30.10		40	121.15	12.83	13.50	40.00	
45	115.87	7.55	11.88	30.30		45	121.15	12.83	13.46	40.12	
50	115.98	7.66	11.98	30.05		50	121.20	12.88	13.58	39.76	
55	116.02	7.70	11.97	30.08		55	121.31	12.99	13.49	40.03	
60	116.86	8.54	11.99	30.03		60	121.43	13.11	13.47	40.09	
70	116.75	8.43	12.07	29.83		70	121.43	13.11	13.45	40.15	
80	116.70	8.38	11.99	30.03		80	121.42	13.10	13.42	40.24	
90	116.62	8.30	11.98	30.05		90	121.41	13.09	13.50	40.00	
100	116.65	8.33	11.99	30.03		100	121.40	13.08	13.51	39.97	

Official BH No.:BH 10404	District:Ghanzi
Date of test commencement:20.07.2007	Location:Ncojane
Time of test Commencement:0700 Hrs	BH depth (m):250m
Date of test completion:20.07.2007	Screen interval (m)
Time of test Completion:1520 Hrs	Depth to pump intake (m)140m
Method of water level measurement: Electrical Dipper	Description of MP:
Observation Bh No.:	Height of MP above ground:
Distance to OB. BH (m)	Static water level before test (m):108.32
Temperature of water (°C):	TDS/EC:

STEP No. 3						STEP No. 4					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **200L**	Pumping Rate (m^3/hr)	Comments	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **200L**	Pumping Rate (m^3/hr)	Comments
0.25	121.50	13.18				0.25	126.61	18.29			
0.5	121.55	13.23				0.5	127.00	18.68			
1	121.63	13.31	14.74	48.85		1	127.22	18.90	12.71	56.65	
1.5	121.70	13.38				1.5	127.34	19.02			
2	121.89	13.57	14.50	49.66		2	127.44	19.12	12.01	59.95	
2.5	122.30	13.98				2.5	127.60	19.28			
3	122.74	14.42	14.31	50.31		3	127.66	19.34	11.99	60.05	
4	123.50	15.18	14.42	49.93		4	127.81	19.49	12.01	59.95	
5	123.74	15.42	14.38	50.07		5	128.00	19.68	12.00	60.00	

6	123.99	15.67	14.33	50.24		6	128.09	19.77	11.97	60.15	
7	124.05	15.73	14.39	50.03		7	128.09	19.77	11.93	60.35	
8	124.16	15.84	14.40	50.00		8	128.09	19.77	12.01	59.95	
9	124.23	15.91	14.38	50.07		9	128.10	19.78	11.99	60.05	
10	124.29	15.97	14.38	50.07		10	128.07	19.75	11.97	60.15	
11	124.36	16.04	14.36	50.14		11	128.06	19.74	11.98	60.10	
12	124.40	16.08	14.39	50.03		12	128.05	19.73	11.96	60.20	
13	124.40	16.08	14.40	50.00		13	128.05	19.73	12.00	60.00	
14	124.41	16.09	14.38	50.07		14	128.04	19.72	11.93	60.35	
15	124.42	16.10	14.37	50.10		15	128.05	19.73	11.98	60.10	
20	124.63	16.31	14.38	50.07		20	128.39	20.07	11.97	60.15	
25	124.99	16.67	14.42	49.93		25	128.51	20.19	11.99	60.05	
30	125.79	17.47	14.40	50.00		30	128.45	20.13	11.96	60.20	
35	126.00	17.68	14.36	50.14		35	128.55	20.23	12.00	60.00	
40	126.24	17.92	14.40	50.00		40	128.54	20.22	12.01	59.95	
45	126.34	18.02	14.35	50.17		45	128.74	20.42	11.98	60.10	
50	126.34	18.02	14.41	49.97		50	128.74	20.42	11.97	60.15	
55	126.48	18.16	14.40	50.00		55	128.74	20.42	11.90	60.50	
60	126.47	18.15	14.38	50.07		60	128.74	20.42	12.01	59.95	
70	126.46	18.14	14.35	50.17		70	129.05	20.73	12.01	59.95	
80	126.43	18.11	14.30	50.35		80	130.09	21.77	11.99	60.05	
90	126.37	18.05	14.40	50.00		90	130.00	21.68	11.98	60.10	
100	126.32	18.00	14.39	50.03		100	130.00	21.68	11.96	60.20	

Official BH No.:BH 10404	District:Ghanzi
Date of test commencement:20.07.2007	Location:Ncojane
Time of test Commencement:0700 Hrs	BH depth (m):250m
Date of test completion:20.07.2007	Screen interval (m)
Time of test Completion:1520 Hrs	Depth to pump intake (m)140m
Method of water level measurement: Electrical Dipper	Description of MP:
Observation Bh No.:	Height of MP above ground:
Distance to OB. BH (m)	Static water level before test (m):108.32
Temperature of water (°C):	TDS/EC:

STEP No. **5** STEP No.

TIME (min)	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill 250L**	**Pumping Rate (m3/hr)**	**Comments**	**TIME (min)**	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill ____L**	**Pumping Rate (m3/hr)**	**Comments**
0.25	130.04	21.72				0.25					
0.5	129.89	21.57				0.5					
1	129.79	21.47	13.00	69.23		1					
1.5	129.79	21.47				1.5					
2	129.70	21.38	12.91	69.71		2					
2.5	129.69	21.37				2.5					
3	129.58	21.26	12.86	69.98		3					
4	129.62	21.30	12.81	70.26		4					
5	129.62	21.30	12.84	70.09		5					
6	129.62	21.30	12.83	70.15		6					
7	129.62	21.30	12.87	69.93		7					
8	129.65	21.33	12.85	70.04		8					
9	129.67	21.35	12.80	70.31		9					
10	129.67	21.35	12.83	70.15		10					
11	129.67	21.35	12.86	69.98		11					
12	129.67	21.35	12.86	69.98		12					
13	129.67	21.35	12.85	70.04		13					
14	129.67	21.35	12.87	69.93		14					
15	129.61	21.29	12.88	69.88		15					
20	129.62	21.30	12.84	70.09		20					
25	129.62	21.30	12.81	70.26		25					
30	129.62	21.30	12.79	70.37		30					
35	129.62	21.30	12.86	69.98		35					
40	129.62	21.30	12.86	69.98		40					
45	129.62	21.30	12.86	69.98		45					
50	129.62	21.30	12.80	70.31		50					

55	129.69	21.37	12.82	70.20		55					
60	129.70	21.38	12.79	70.37		60					
70	130.40	22.08	12.81	70.26		70					
80	131.22	22.90	12.80	70.31		80					
90	132.00	23.68	12.79	70.37		90					
100	132.67	24.35	12.86	69.98		100					

Table 35-7 Constant rate Test Data BH10404 (first CRT)

Official BH NO : BH 10404	District :
Date of test commencement :22.07.2007	Location : Ncojane
Time of test commencement :1000 hrs	BH depth(m) : 250
Date of test completion: 23.07.2007	Screen Interval (m)
Time of test completion :1000 hrs	Depth of pump intake (m) : 140m
Method of water level measurement: Electrical Dipper	Description of MP
OB BH NO: BH 10210	Height of MP above ground(m) :0.95m
Distance ob BH r (m): 15m	Static Water level before test(m) : 108.46m
Casing diameter (mm): 203mm	Water strike
Orifice plate diameter	Delivery pipe diameter: 127mm
Co-ordinates: 152mm	Co-ordinates:

TIME (min)	**Depth to WL (m)**	**Draw down (m)**	**Time to fill 350L**	**Q (m3/hr)**	**Temp**	**EC**	**pH**	**Monometre (cm)**	**Comments**
0.25	110.48	2.02							
0.5	113.16	4.70							
1	116.19	7.73							
2	119.28	10.82							
3	120.24	11.78							
4	121.57	13.11							
5	122.87	14.41							
6	123.51	15.05							
7	124.70	16.24							
8	125.85	17.39							
9	126.74	18.28							
10	127.24	18.78							
11	127.63	19.17							
12	127.94	19.48							
15	128.65	20.19							
20	129.45	20.99							
25	129.86	21.40							
30	130.05	21.59	12.81	70.26					
40	130.33	21.87	22.85	39.39					
45	130.33	21.87	12.82	70.20					
50	130.33	21.87	12.80	70.31					
60	130.32	21.86	12.79	70.37					
75	130.34	21.88	12.83	70.15					
90	130.34	21.88	12.80	70.31					
105	130.34	21.88	12.80	70.31					
120	130.34	21.88	12.84	70.09					
150	130.63	22.17	12.81	70.26					
180	131.04	22.58	12.79	70.37					
210	131.47	23.01	12.85	70.04					
240	131.59	23.13	12.82	70.20	30.40	636.00	7.66		
270	131.78	23.32	12.85	70.04	30.40	625.00	7.58		
300	131.93	23.47	12.80	70.31	27.40	665.00	7.72		
330	132.07	23.61	12.80	70.31	27.40	664.00	7.70		
360	132.19	23.73	12.84	70.09	28.50	651.00	7.65		
390	132.34	23.88	12.81	70.26	26.50	661.00	7.72		
420	132.45	23.99	12.85	70.04	26.00	671.00	7.52		
450	132.48	24.02	12.80	70.31	25.20	664.00	7.83		
480	132.55	24.09	12.80	70.31	22.70	681.00	7.94		
540	132.71	24.25	12.84	70.09	22.90	685.00	7.84		
600	132.90	24.44	12.81	70.26	21.40	684.00	7.93		

660	133.16	24.70	12.85	70.04	19.80	674.00	7.82		
720	133.33	24.87	12.83	70.15	24.20	667.00	7.80		
780	133.45	24.99	12.81	70.26	24.10	647.00	7.78		
840	133.59	25.13	12.80	70.31	22.80	648.00	7.82		
900	133.72	25.26	12.79	70.37	23.80	677.00	7.79		
960	133.96	25.50	12.82	70.20	22.20	653.00	7.87		
1020	134.04	25.58	12.79	70.37	21.02	673.00	7.82		
1080	134.07	25.61	12.84	70.09	23.60	647.00	7.78		
1140	134.10	25.64	12.84	70.09	21.90	679.00	8.00		
1200	134.13	25.67	12.80	70.31	20.60	719.00	8.03		
1260	134.24	25.78	12.80	70.31	21.90	691.00	7.90		
1320	134.31	25.85	12.83	70.15	25.90	649.00	7.85		
1380	134.58	26.12	12.85	70.04	25.60	659.00	7.88		
1440	134.72	26.26	12.84	70.09					

Table 35-8 Constant Rate Test – BH10404

Official BH NO : BH 10404	District :
Date of test commencement :29.07.2007	Location : Nojwane
Time of test commencement :1100 hrs	BH depth(m) : 250
Date of test completion: 05.08.2007	Screen Interval (m)
Time of test completion :1100 hrs	Depth of pump intake (m) : 155
Method of water level measurement: Electrical Dipper	Description of MP
OB BH NO: Bh 10210	Height of MP above ground(m) :0.95m
Distance ob BH r (m): 15m	Static Water level before test(m) : 109.28m
Casing diameter (mm): 203mm	Water strike
Orifice plate diameter: 152mm	Delivery pipe diameter: 127mm
Coordinates:	Co-ordinates:

	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 500L	Discharge $Q(m^3/h)$	Temp (^0C)	EC (us/cm)	pH	Manometer (cm)	Comments
	0.25	111.71	2.43							
	0.5	114.62	5.34							
	1	115.84	6.56							
	2	117.96	8.68	13.94	64.56					
	3	118.66	9.38	13.80	65.22					
	4	120.70	11.42	13.36	67.37					
	5	122.03	12.75	13.54	66.47					
	6	123.50	14.22	13.83	65.08					
	7	124.34	15.06	13.80	65.22					
	8	125.06	15.78	13.85	64.98					
	9	125.57	16.29	13.85	64.98					
	10	125.93	16.65	13.84	65.03					
	11	126.51	17.23	13.80	65.22					
	12	126.64	17.36	13.82	65.12					
	15	127.34	18.06	13.81	65.17					
	20	127.93	18.65	13.84	65.03					
	25	128.31	19.03	13.80	65.22					
	30	128.56	19.28	13.85	64.98					
	40	128.75	19.47	13.83	65.08					
	45	128.89	19.61	13.85	64.98					
	50	128.92	19.64	13.81	65.17					
	60	129.01	19.73	13.81	65.17		635.00	7.78		
	75	129.17	19.89	13.83	65.08					
	90	129.33	20.05	13.84	65.03					
	105	129.47	20.19	13.80	65.22					
	120	129.63	20.35	13.85	64.98	27.30	646.00	7.77		
	150	129.83	20.55	13.83	65.08					
	180	130.03	20.75	13.81	65.17	27.50	649.00	7.74		
	210	130.16	20.88	13.84	65.03					
	240	130.28	21.00	13.80	65.22	27.20	664.00	7.86		
	270	130.42	21.14	13.80	65.22					
	300	130.57	21.29	13.83	65.08	27.10	635.00	7.78		
	330	130.68	21.40	13.81	65.17	25.60	653.00	7.96		
	360	130.81	21.53	13.80	65.22					
	390	130.93	21.65	13.84	65.03					
	420	131.07	21.79	13.82	65.12	24.80	637.00	7.93		
	450	131.19	21.91	13.84	65.03					
	480	131.31	22.03	13.81	65.17	24.00	636.00	7.95		
	540	131.66	22.38	13.80	65.22	23.30	637.00	7.98		
10	600	131.79	22.51	13.84	65.03	22.60	633.00	7.93		
11	660	132.09	22.81	13.82	65.12	22.80	654.00	7.90		
12	720	132.24	22.96	13.80	65.22	21.40	651.00	7.91		
13	780	132.39	23.11	13.84	65.03	19.30	637.00			
14	840	132.57	23.29	13.83	65.08	18.90	664.00			
15	900	132.75	23.47	13.85	64.98	17.20	673.00	7.95		

16	960	132.74	23.46	13.83	65.08	20.20	674.00	7.84		
17	1020	132.84	23.56	13.80	65.22	18.60	668.00	7.84		
18	1080	132.90	23.62	13.82	65.12	20.20	670.00	7.85		
19	1140	132.92	23.64	13.83	65.08	19.30	652.00	7.84		
20	1200	133.00	23.72	13.81	65.17	21.20	635.00	7.92		
21	1260	133.14	23.86	13.84	65.03	22.70	644.00	7.95		
22	1320	133.27	23.99	13.82	65.12	26.00	649.00	7.98		
23	1380	133.14	23.86	13.82	65.12	27.30	659.00	7.78		
24	1440	133.05	23.77	13.80	65.22	26.00	637.00	7.72		
25	1500	132.96	23.68	13.84	65.03	29.20	629.00	7.79		
26	1560	132.99	23.71	13.84	65.03	26.20	656.00	7.81		
27	1620	132.90	23.62	13.82	65.12	28.30	649.00	7.80		
28	1680	132.90	23.62	13.85	64.98	27.20	653.00	7.70		
29	1740	133.09	23.81	13.81	65.17	28.30	617.00	7.86		
30	1800	133.15	23.87	13.80	65.22	25.50	648.00	7.88		
31	1860	133.10	23.82	13.83	65.08	23.20	649.00	7.94		
32	1920	133.10	23.82	13.81	65.17	23.00	621.00	7.83		
33	1980	133.19	23.91	13.83	65.08	20.20	639.00	7.97		
34	2040	133.32	24.04	13.82	65.12	21.70	641.00	7.98		
35	2100	133.47	24.19	13.80	65.22	21.00	637.00	7.85		
36	2160	133.50	24.22	13.82	65.12	20.10	660.00	7.80		
37	2220	133.63	24.35	13.81	65.17	21.10	662.00	7.72		
38	2280	133.63	24.35	13.81	65.17	21.70	663.00	7.81		
39	2340	133.84	24.56	13.80	65.22	19.50	679.00	7.94		
40	2400	133.93	24.65	13.81	65.17	21.60	653.00	7.96		
41	2460	134.00	24.72	13.83	65.08	22.00	635.00	7.82		
42	2520	134.04	24.76	13.80	65.22	21.20	662.00	7.95		
43	2580	134.18	24.90	13.84	65.03	21.40	690.00	7.93		
44	2640	134.24	24.96	13.81	65.17	21.00	664.00	7.90		
45	2700	134.38	25.10	13.83	65.08	23.10	691.00	7.77		
46	2760	134.38	25.10	13.80	65.22	26.00	676.00	7.76		
47	2820	134.19	24.91	13.82	65.12	27.70	685.00	7.79		
48	2880	134.19	24.91	13.84	65.03	28.80	555.00	7.89		
49	2940	134.13	24.85	13.81	65.17	28.90	653.00	7.78		
50	3000	134.09	24.81	13.82	65.12	29.30	672.00	7.80		
51	3060	134.09	24.81	13.81	65.17	30.00	659.00	7.68		
52	3120	134.10	24.82	13.84	65.03	30.30	657.00	7.68		
53	3180	134.06	24.78	13.80	65.22	28.10	676.00	7.65		
54	3240	134.06	24.78	13.83	65.08	25.20	678.00	7.84		
55	3300	134.00	24.72	13.80	65.22	23.60	686.00	7.90		
56	3360	134.00	24.72	13.85	64.98	23.00	666.00	7.82		
57	3420	134.05	24.77	13.83	65.08	22.40	672.00	7.84		
58	3480	134.10	24.82	13.81	65.17	22.10	671.00	7.87		
59	3540	134.20	24.92	13.81	65.17	22.50	671.00	7.76		
60	3600	134.30	25.02	13.82	65.12	22.50	678.00	7.80		
61	3660	134.38	25.10	13.80	65.22	21.40	694.00	7.95		
62	3720	134.42	25.14	13.85	64.98	21.10	697.00	7.96		
63	3780	134.49	25.21	13.83	65.08	21.70	695.00	7.91		
64	3840	134.46	25.18	13.81	65.17	21.80	687.00	7.82		
65	3900	134.55	25.27	13.80	65.22	21.70	684.00	7.83		
66	3960	134.64	25.36	13.79	65.26	21.10	685.00	7.78		
67	4020	134.89	25.61	13.83	65.08	21.00	676.00	7.86		
68	4080	134.87	25.59	13.82	65.12	22.10	689.00	7.82		
69	4140	134.73	25.45	13.81	65.17	24.00	687.00	7.78		
70	4200	134.68	25.40	13.84	65.03	26.50	616.00	7.83		
71	4260	134.68	25.40	13.81	65.17	26.10	685.00	7.80		
72	4320	134.68	25.40	13.80	65.22	27.00	664.00	7.64		
73	4380	134.68	25.40	13.83	65.08	27.30	673.00	7.77		
74	4440	134.68	25.40	13.83	65.08	31.10	433.00	7.72		
75	4500	134.67	25.39	13.85	64.98	31.30	646.00	7.63		
76	4560	134.67	25.39	13.82	65.12	30.10	649.00	7.80		
77	4620	134.67	25.39	13.84	65.03	28.30	655.00	7.83		
78	4680	134.67	25.39	13.83	65.08	26.50	659.00	7.75		

79	4740	134.66	25.38	13.81	65.17	25.30	675.00	7.73		
80	4800	134.67	25.39	13.81	65.17	25.00	663.00	7.79		
81	4860	134.78	25.50	13.84	65.03	24.50	687.00	7.75		
82	4920	134.84	25.56	13.82	65.12	24.00	685.00	7.75		
83	4980	134.97	25.69	13.83	65.08	21.50	665.00	7.73		
84	5040	135.00	25.72	13.80	65.22	23.30	663.00	7.90		
85	5100	135.06	25.78	13.81	65.17	22.90	674.00	7.89		
86	5160	135.11	25.83	13.84	65.03	22.60	674.00	7.82		
87	5220	135.14	25.86	13.82	65.12	22.10	698.00	7.83		
88	5280	135.14	25.86	13.80	65.22	21.30	639.00	7.90		
89	5340	135.20	25.92	13.82	65.12	20.40	669.00	7.89		
90	5400	135.23	25.95	13.84	65.03		649.00	7.83		
91	5460	135.29	26.01	13.83	65.08	18.40	664.00	7.84		
92	5520	135.29	26.01	13.84	65.03	21.80	669.00	7.73		
93	5580	135.31	26.03	13.80	65.22	25.10	591.00	7.83		
94	5640	135.33	26.05	13.81	65.17	26.20	519.00	7.80		
95	5700	135.35	26.07	13.82	65.12	28.50	662.00	7.91		
96	5760	135.35	26.07	13.84	65.03	29.70	668.00	7.87		
97	5820	135.38	26.10	13.80	65.22	30.20	670.00	7.80		
98	5880	135.38	26.10	13.81	65.17	31.30	666.00	7.82		
99	5940	135.22	25.94	13.80	65.22	32.90	644.00	7.77		
100	6000	135.16	25.88	13.83	65.08	31.60	661.00	7.86		
101	6060	135.09	25.81	13.84	65.03	29.30	680.00	7.95		
102	6120	135.10	25.82	13.80	65.22	26.90	686.00	7.97		
103	6180	135.11	25.83	13.81	65.17	24.40	688.00	7.99		
104	6240	135.14	25.86	13.82	65.12	24.40	671.00	7.89		
105	6300	135.13	25.85	13.82	65.12	23.90	664.00	7.84		
106	6360	135.14	25.86	13.84	65.03	23.60	659.00	7.82		
107	6420	135.14	25.86	13.81	65.17	23.40	665.00	7.86		
108	6480	135.14	25.86	13.83	65.08	22.10	679.00	7.91		
109	6540	135.15	25.87	13.80	65.22	23.10	657.00	7.73		
110	6600	135.16	25.88	13.85	64.98	21.20	680.00	7.96		
111	6660	135.17	25.89	13.83	65.08	21.00	669.00	7.86		
112	6720	135.17	25.89	13.80	65.22	22.70	655.00	7.77		
113	6780	135.17	25.89	13.84	65.03	21.60	683.00	7.85		
114	6840	135.18	25.90	13.79	65.26	21.90	663.00	7.76		
115	6900	135.19	25.91	13.82	65.12	19.00	677.00	7.82		
116	6960	135.19	25.91	13.80	65.22	21.00	666.00	7.89		
117	7020	135.19	25.91	13.81	65.17	21.30	662.00	7.85		
118	7080	135.21	25.93	13.83	65.08	21.80	656.00	7.90		
119	7140	135.21	25.93	13.79	65.26	21.90	670.00	7.86		
120	7200	135.21	25.93	13.80	65.22	29.40	661.00	7.63		
121	7260	135.21	25.93	13.82	65.12	29.10	674.00	7.88		
122	7320	135.21	25.93	13.81	65.17	33.40	643.00	7.70		
123	7380	135.22	25.94	13.80	65.22	30.60	675.00	7.73		
124	7440	135.22	25.94	13.83	65.08	29.40	677.00	7.75		
125	7500	135.23	25.95	13.81	65.17	29.00	685.00	7.72		
126	7560	135.23	25.95	13.82	65.12	26.70	673.00	7.98		
127	7620	135.25	25.97	13.82	65.12	25.10	678.00	7.90		
128	7680	135.29	26.01	13.80	65.22	24.70	678.00	7.88		
129	7740	135.33	26.05	13.83	65.08	23.00	687.00	7.95		
130	7800	135.33	26.05	13.81	65.17	22.10	684.00	7.87		
131	7860	135.34	26.06	13.81	65.17	21.50	686.00	7.92		
132	7920	135.34	26.06	13.80	65.22	22.60	660.00	7.75		
133	7980	135.34	26.06	13.84	65.03	22.10	658.00	7.75		
134	8040	135.35	26.07	13.81	65.17	21.70	667.00	7.82		
135	8100	135.35	26.07	13.81	65.17	22.00	666.00	8.01		
136	8160	135.35	26.07	13.81	65.17	21.70	688.00	7.98		
137	8220	135.35	26.07	13.84	65.03	21.40	674.00	7.92		
138	8280	135.36	26.08	13.80	65.22	21.30	696.00	8.04		
139	8340	135.36	26.08	13.83	65.08	21.60	682.00	7.93		
140	8400	135.36	26.08	13.81	65.17	21.80	681.00	7.84		
141	8460	135.36	26.08	13.80	65.22	22.20	664.00	7.87		

142	8520	135.39	26.11	13.82	65.12	23.70	654.00	7.87		
143	8580	135.39	26.11	13.81	65.17	27.00	677.00	7.80		
144	8640	135.36	26.08	13.80	65.22	27.20	679.00	7.83		
145	8700	135.36	26.08	13.83	65.08	27.40	682.00	7.92		
146	8760	135.36	26.08	13.81	65.17	28.20	694.00	7.81		
147	8820	135.37	26.09	13.82	65.12	30.60	648.00	7.82		
148	8880	135.37	26.09	13.84	65.03	29.70	541.00	7.80		
149	8940	135.37	26.09	13.81	65.17	28.60	542.00	7.84		
150	9000	135.37	26.09	13.82	65.12	28.70	544.00	7.83		
151	9060	135.38	26.10	13.80	65.22	28.70	560.00	7.77		
152	9120	135.38	26.10	13.83	65.08	29.10	546.00	7.81		
153	9180	135.38	26.10	13.80	65.22	30.10	536.00	7.77		
154	9240	135.39	26.11	13.81	65.17	30.10	540.00	7.79		
155	9300	135.39	26.11	13.80	65.22	30.40	577.00	7.82		
156	9360	135.39	26.11	13.84	65.03	29.80	542.00	7.81		
157	9420	135.39	26.11	13.82	65.12	30.20	541.00	7.80		
158	9480	135.52	26.24	13.80	65.22	29.20	537.00	7.86		
159	9540	135.64	26.36	13.81	65.17	28.40	577.00	7.81		
160	9600	135.65	26.37	13.83	65.08	29.10	543.00	7.82		
161	9660	135.66	26.38	13.80	65.22	29.30	562.00	7.78		
162	9720	135.66	26.38	13.84	65.03	28.10	547.00	7.80		
163	9780	135.66	26.38	13.81	65.17	28.40	548.00	7.76		
164	9840	135.67	26.39	13.80	65.22	29.80	560.00	7.79		
165	9900	135.67	26.39	13.82	65.12	28.90	546.00	7.83		
166	9960	135.67	26.39	13.84	65.03	27.10	540.00	7.82		
167	10020	135.68	26.40	13.81	65.17	28.70	577.00	7.78		
168	10080	135.68	26.40	13.82	65.12	28.70	568.00	7.78		

Table 35-9 Constant Rate Test – Observation BH10210

BH NO : 10210	District : Ghantsi
Date of test commencement :29.07.2007	Location :Ncojane
Time of test commencement :1100hrs	BH depth(m) :
Date of test completion:05.08.2007	Screen Interval (m)
Time of test completion :1100 hrs	Depth of pump intake (m) :
Method of water level measurement: Electrical Dipper	Description of MP
Pumping BH NO: 10404	Height of MP above ground(m) :1m
Distance to pumping BH (m):15m	Static Water level before test(m) :109.51m

clock	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Comments
	0.25	110.43	0.92	
	0.5	111.15	1.64	
	1	111.71	2.20	
	2	112.09	2.58	
	3	113.25	3.74	
	4	114.54	5.03	
	5	115.51	6.00	
	6	116.44	6.93	
	7	116.64	7.13	
	8	117.33	7.82	
	9	118.11	8.60	
	10	118.73	9.22	
	11	119.03	9.52	
	12	119.30	9.79	
	15	119.59	10.08	
	20	119.73	10.22	
	25	119.96	10.45	
	30	120.03	10.52	
	35	120.13	10.62	
	40	120.10	10.59	

	45	120.14	10.63	
	50	120.18	10.67	
	60	120.17	10.66	
	75	120.34	10.83	
	90	120.79	11.28	
	105	121.06	11.55	
	120	121.21	11.70	
	150	121.39	11.88	
	180	121.67	12.16	
	210	121.85	12.34	
	240	122.00	12.49	
	270	122.12	12.61	
	300	122.25	12.74	
	360	122.32	12.81	
	390	122.47	12.96	
	420	122.81	13.30	
	450	122.98	13.47	
8	480	123.16	13.65	
9	540	123.29	13.78	
10	600	123.45	13.94	
11	660	123.61	14.10	
12	720	123.79	14.28	
13	780	123.80	14.29	
14	840	123.88	14.37	
15	900	123.96	14.45	
16	960	124.01	14.50	
17	1020	124.10	14.59	
18	1080	124.17	14.66	
19	1140	124.23	14.72	
20	1200	124.24	14.73	
21	1260	124.26	14.75	
22	1320	124.28	14.77	
23	1380	124.33	14.82	
24	1440	124.25	14.74	
25	1500	124.21	14.70	
26	1560	124.26	14.75	
27	1620	124.31	14.80	
28	1680	124.35	14.84	
29	1740	124.49	14.98	
30	1800	124.46	14.95	
31	1860	124.40	14.89	
32	1920	124.52	15.01	
33	1980	124.61	15.10	
34	2040	124.69	15.18	
35	2100	124.76	15.25	
36	2160	124.82	15.31	
37	2220	124.90	15.39	
38	2280	124.93	15.42	
39	2340	124.97	15.46	
40	2400	125.01	15.50	
41	2460	125.22	15.71	
42	2520	125.21	15.70	
43	2580	125.28	15.77	
44	2640	125.34	15.83	
45	2700	125.41	15.90	
46	2760	125.41	15.90	
47	2820	125.40	15.89	
48	2880	125.40	15.89	
49	2940	125.39	15.88	
50	3000	125.36	15.85	
51	3060	125.37	15.86	
52	3120	125.37	15.86	
53	3180	125.36	15.85	

54	3240	125.36	15.85	
55	3300	125.35	15.84	
56	3360	125.35	15.84	
57	3420	125.40	15.89	
58	3480	125.45	15.94	
59	3540	125.55	16.04	
60	3600	125.59	16.08	
61	3660	125.63	16.12	
62	3720	125.68	16.17	
63	3780	125.79	16.28	
64	3840	125.72	16.21	
65	3900	125.79	16.28	
66	3960	125.83	16.32	
67	4020	125.97	16.46	
68	4080	125.97	16.46	
69	4140	125.93	16.42	
70	4200	125.90	16.39	
71	4260	125.87	16.36	
72	4320	125.87	16.36	
73	4380	125.86	16.35	
74	4440	125.86	16.35	
75	4500	125.84	16.33	
76	4560	125.84	16.33	
77	4620	125.85	16.34	
78	4680	125.87	16.36	
79	4740	125.86	16.35	
80	4800	125.86	16.35	
81	4860	125.90	16.39	
82	4920	125.91	16.40	
83	4980	125.90	16.39	
84	5040	125.91	16.40	
85	5100	125.75	16.24	
86	5160	125.77	16.26	
87	5220	125.85	16.34	
88	5280	125.90	16.39	
89	5340	125.95	16.44	
90	5400	125.99	16.48	
91	5460	126.06	16.55	
92	5520	126.08	16.57	
93	5580	126.10	16.59	
94	5640	126.12	16.61	
95	5700	126.18	16.67	
96	5760	126.20	16.69	
97	5820	126.18	16.67	
98	5880	126.18	16.67	
99	5940	126.25	16.74	
100	6000	126.36	16.85	
101	6060	126.39	16.88	
102	6120	126.39	16.88	
103	6180	126.40	16.89	
104	6240	126.38	16.87	
105	6300	126.36	16.85	
106	6360	126.36	16.85	
107	6420	126.32	16.81	
108	6480	126.31	16.80	
109	6540	126.31	16.80	
110	6600	126.31	16.80	
111	6660	126.32	16.81	
112	6720	126.31	16.80	
113	6780	126.31	16.80	
114	6840	126.30	16.79	
115	6900	126.30	16.79	
116	6960	126.36	16.85	

117	7020	126.38	16.87	
118	7080	126.36	16.85	
119	7140	126.31	16.80	
120	7200	126.32	16.81	
121	7260	126.31	16.80	
122	7320	126.30	16.79	
123	7380	126.30	16.79	
124	7440	126.31	16.80	
125	7500	126.31	16.80	
126	7560	126.32	16.81	
127	7620	126.33	16.82	
128	7680	126.37	16.86	
129	7740	126.39	16.88	
130	7800	126.46	16.95	
131	7860	126.47	16.96	
132	7920	126.49	16.98	
133	7980	126.51	17.00	
134	8040	126.55	17.04	
135	8100	126.60	17.09	
136	8160	126.66	17.15	
137	8220	126.67	17.16	
138	8280	126.70	17.19	
139	8340	126.70	17.19	
140	8400	126.71	17.20	
141	8460	126.72	17.21	
142	8520	126.75	17.24	
143	8580	126.77	17.26	
144	8640	126.73	17.22	
145	8700	126.65	17.14	
146	8760	126.60	17.09	
147	8820	126.56	17.05	
148	8880	126.60	17.09	
149	8940	126.57	17.06	
150	9000	126.57	17.06	
151	9060	126.58	17.07	
152	9120	126.58	17.07	
153	9180	126.59	17.08	
154	9240	126.60	17.09	
155	9300	126.61	17.10	
156	9360	126.61	17.10	
157	9420	126.75	17.24	
158	9480	126.88	17.37	
159	9540	126.97	17.46	
160	9600	127.00	17.49	
161	9660	127.01	17.50	
162	9720	127.01	17.50	
163	9780	127.01	17.50	
164	9840	127.01	17.50	
165	9900	127.02	17.51	
166	9960	127.02	17.51	
167	10020	127.02	17.51	
168	10080	127.02	17.51	

Table 35-10 Recovery Test Data – BH10404

Official BH NO : 10404	District :Ghanzi
Date of test commencement :05.08.2007	Location :Ncojane
Time of test commencement :1100 Hrs	BH depth(m) :250m
Date of test completion:06.08.2007	Screen Interval (m):
Time of test completion :1100 Hrs	Depth of pump intake (m):`155m
Method of water level measurement:Electrical dipper	Description of MP:
OB. BH. No.:	Height of MP above ground(m):0.95m
Dist.to Ob Bh:	Static Water level before test(m):109.28m

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	135.68	26.4
	0.25	131.43	22.15
	0.5	130.24	20.96
	1	129.44	20.16
	2	124.17	14.89
	3	122.33	13.05
	4	122.08	12.8
	5	121.29	12.01
	6	120.91	11.63
	7	120.48	11.2
	8	120.01	10.73
	9	119.88	10.6
	10	119.74	10.46
	12	119.64	10.36
	15	119.44	10.16
	20	119.41	10.13
	25	119.41	10.13
	30	118.02	8.74
	40	116.89	7.61
	50	116.51	7.23
	60	116.19	6.91
	75	115.89	6.61
	90	115.6	6.32
	105	115.33	6.05
	120	115.16	5.88

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	114.9	5.62
	180	114.57	5.29
	210	114.5	5.22
	240	114.26	4.98
	270	114.17	4.89
	300	114.02	4.74
	330	113.89	4.61
	360	113.77	4.49
	390	113.66	4.38
	420	113.56	4.28
	450	113.46	4.18
	480	113.38	4.1
	540	113.36	4.08
	600	113.13	3.85
	660	113	3.72
	720	112.88	3.6
	780	112.84	3.56
	840	112.78	3.5
	900	112.73	3.45
	960	112.68	3.4
	1020	112.62	3.34
	1080	112.54	3.26
	1140	112.46	3.18
	1200	112.34	3.06
	1260	112.22	2.94
	1320	112.15	2.87
	1380	112.14	2.86
	1440	112.07	2.79

Table 35-11 Recovery Test Data – BH10210

Official BH NO : 10210	District :Ghanzi
Date of test commencement :05.08.2007	Location :Ncojane
Time of test commencement :1100 Hrs	BH depth(m) :
Date of test completion:06.08.2007	Screen Interval (m):
Time of test completion :1100 Hrs	Depth of pump intake (m):
Method of water level measurement:Electrical Dipper	Description of MP:
OB. BH. No.:10210	Height of MP above ground(m):
Dist.to Ob Bh:	Static Water level before test(m):109.51m

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	127.02	17.51
	0.25	126.16	16.65
	0.5	126.00	16.49
	1	125.77	16.26
	2	125.01	15.50
	3	124.83	15.32
	4	124.05	14.54
	5	123.07	13.56
	6	122.40	12.89
	7	121.94	12.43
	8	121.56	12.05
	9	121.02	11.51
	10	120.60	11.09
	12	120.27	10.76
	15	119.77	10.26
	20	118.86	9.35
	25	118.32	8.81
	30	117.69	8.18
	40	117.51	8.00
	50	116.22	6.71
	60	116.89	7.38
	75	116.42	6.91
	90	116.13	6.62
	105	115.90	6.39
	120	115.71	6.20

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	115.37	5.86
	180	115.10	5.59
	210	114.91	5.40
	240	114.78	5.27
	270	114.58	5.07
	300	114.45	4.94
	330	114.27	4.76
	360	114.19	4.68
	390	114.06	4.55
	420	113.98	4.47
	450	113.87	4.36
	480	113.79	4.28
	540	113.69	4.18
	600	113.51	4.00
	660	113.39	3.88
	720	113.28	3.77
	780	113.10	3.59
	840	113.01	3.50
	900	112.93	3.42
	960	112.88	3.37
	1020	112.81	3.30
	1080	112.77	3.26
	1140	112.68	3.17
	1200	112.64	3.13
	1260	112.57	3.06
	1320	112.52	3.01
	1380	112.48	2.97
	1440	112.42	2.91

36 BH10405

BH10405 is production borehole drilled at site **P03**, Line **R3, TEM 67** and peg **13000m**. It is located approximately 20 km east of Ncojane along the gravel road to Metsimantsho. Drilling at this site commenced on 15 March 2007 and was completed on 08 May 2007.

36.1 SITING CRETERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block and with probable thin dolerite sill/dyke.

36.2 DRILLING RESULTS

Drilling was started with 17 a inch bit down to 61 m after which 15 inch plain casing was installed and grouted. Drilling was continued with a 15 inch bit from 61 to 66 m when a major breakdown occurred on the machine's engine. After the Easter break, drilling was continued from 61 to 196m with 15 inch drilling bit after which 12 inch casings were installed to allow for further drilling. Drilling was then continued with a 12 inch tricone bit (drag bit) to the terminal depth of 255 m.

Three different water strikes were encountered at various depths in this borehole in Kule/Kwetla and Ecca Groups. The first water strike with a yield of 10m^3/hr and an electrical conductivity of 950 µS/cm was encountered at 161m. The second water strike was encountered at a depth of 193 m where the yield increased to 77m^3/hr and the electrical conductivity was measured as 550µS/cm. The third and last water strike was encountered at the depth of 206 m where the yield was estimated as 92 m^3/hr and the electrical conductivity was measured as 530 µS/cm.Various lithologies including fine grained sands, silcrete, mudstones, coal and fine to coarse grained sandstones were intercepted during drilling of this exploration borehole (**Figure 36-1**).

1. (161m, 550µS/cm, 77 m^3/hr)
2. (193m, 530µS/cm, 92 m^3/hr)

The borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 255m **(Figure 36-2).** The borehole was constructed using 8 inch epoxy coated plain casings and epoxy screens. The 8 inch plain epoxy coated casings were installed from 0 to 190m, 195 to 200m and 200 to 250 while the screens were installed in two difference aquifer zones (sandstone) separated by mudstone. These zones are between 190 to 195 m and 200 m to 250 m representing a total screened zone of 55 m. Borehole development was through airlift pumping and air jetting and the final blow out yield was estimated as 78 m^3/hr while the electrical conductivity was 540 µS/cm.Verticality and alignment tests on this borehole were conducted on 16th May 2007.

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

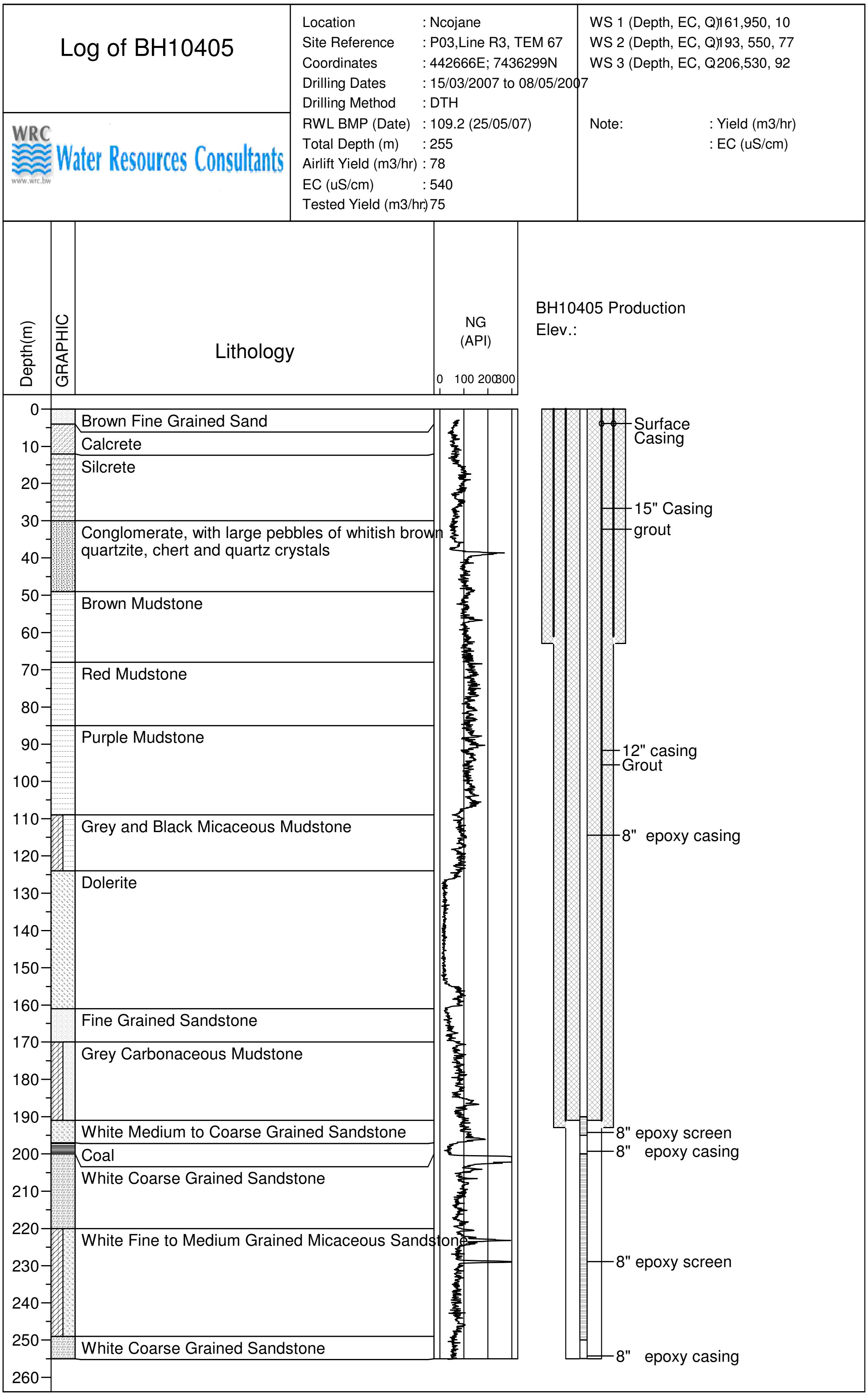

Figure 36-1 Log of BH10405

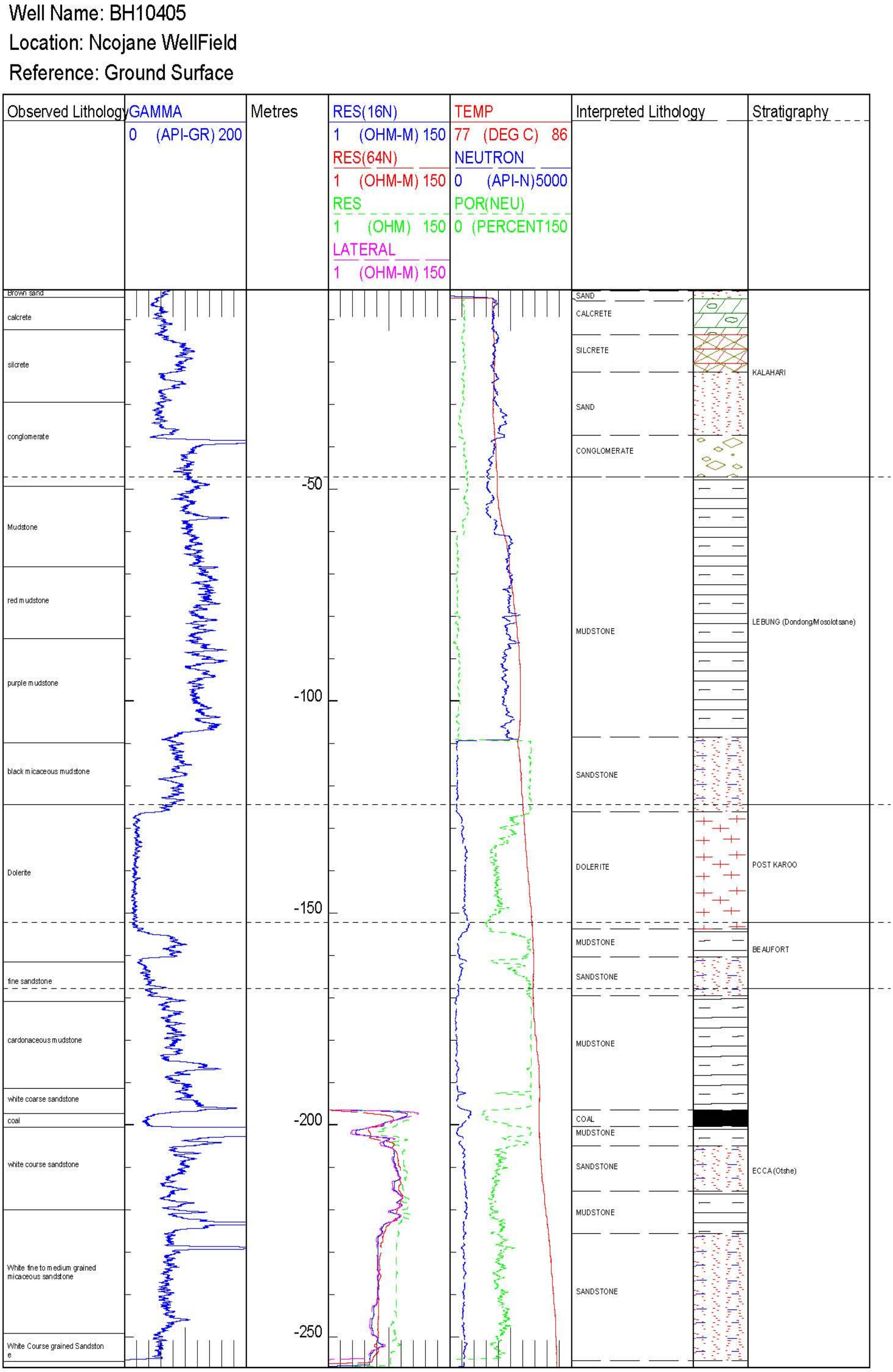

Figure 36-2 Geophysical log of BH10405

36.3 PUMP TESTING RESULTS

Test pumping operations at this borehole were started on 12th August 2007 and completed on 25th August 2007. There was a major breakdown on the engine just before the step test and this delayed the progress by 8 days while the Contractor was still fixing the engine. The tests carried out were calibration, step drawdown, constant rate and recovery tests. A summary of the pumping test data for BH10405 is presented in **Table 36-1.** The static water level at the beginning of the test was 107.26m bmp. The collected pump testing data is presented in **Tables 36-5 to 36-8.**

Table 36-1 Summary of Pumping Test Data BH10405

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	3.01	20
	2	15	5.53	40
	3	15	6.74	60
	4	15	8.99	79
Step Test	1	100	3.24	30
	2	100	5.63	45
	3	100	8.31	60
	4	100	9.85	77
Constant Rate	1	4320	12.55	75
Recovery	1	1440	0.79	0

Note. 0.37 Residual Drawdown*

36.3.1 Step Drawdown Test

The step drawdown test was carried out on 21st August 2007 after attending to the breakdown and consisted of 4 steps of 100 minutes duration at discharge rates of 30, 45, 60 and 77 m^3/hr, respectively. The static water level before the start of the test was 107.23 m bmp.

The interpreted step test data is presented in **Figures 36-3 to 36-5**. The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was194 m^2/d **(Figure 36-5).** The results of the interpreted step test data are given in **Table 36-2.**

Table 36-2 Results of Step Test Analysis BH10405

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10405	4.1E-007	4.5E-003	194	30	3.3	3.3	9.09
				45	2.05	5.35	8.41
				60	2.56	7.91	7.58
				77	1.26	10.71	7.19

The planned duration for the constant rate test at this borehole was 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time **(Figure 36-3)** to estimate the expected total drawdown after 3 days of pumping.

36.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 24th July and 6th August 2007 at a discharge rate of 65 m^3/hr and the total drawdown after 72 hrs of pumping was 26.40 m. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 0.79 m.

Transmissivity (T) values obtained from Cooper-Jacob (1946) and Hantush leaky analytical solutions were 149 and 174 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 172m^2/d was obtained. The results are summarised in **Table 36-3** and the interpreted data is presented in **Figures 36-6** to **36-8**

There is an apparent impermeable barrier interpreted in the CRT data after 2000 minutes of pumping, **Figure 36-5**. This barrier is probably caused by NW - SE trending lineament located about 200m east of BH10405.

Table 36-3 Summary of Constant Rate and Recovery Tests BH10405

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10405	72	1800	a) 149 b) 174	d) 172	Confined leaky with storage and negative boundary

Notes:
Interpretation Techniques
a) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

36.3.2.1 Aquifer Type interpreted

The interpretation of the pump testing data indicates that the aquifer type is confined-leaky with negative (barrier) boundary.

36.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. The results of chemical analyses from CSIR lab are presented in **Table 36-4**. The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC) and pH are 28.7 ^{o}C, 566 μS/cm and 7.66 respectively.

Table 36-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10405	6.5	85.8	26.5	16.9	17.2	167.9	188	13.9	0.64	<0.05	<0.05	650	6.6	416
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10405	<0.05	136	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in μS/cm
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

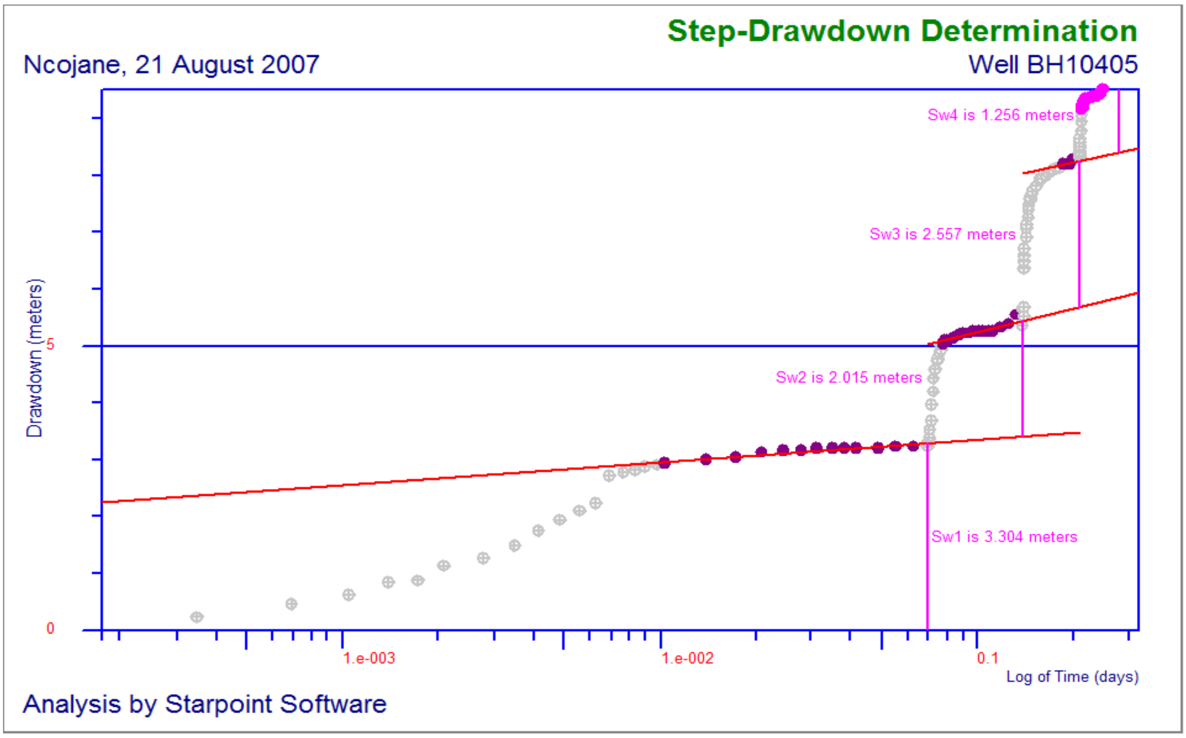

Figure 36-3 Pumping Test Results for BH10405: Step Drawdown Test - Hantush-Bierschenk (semi-log)

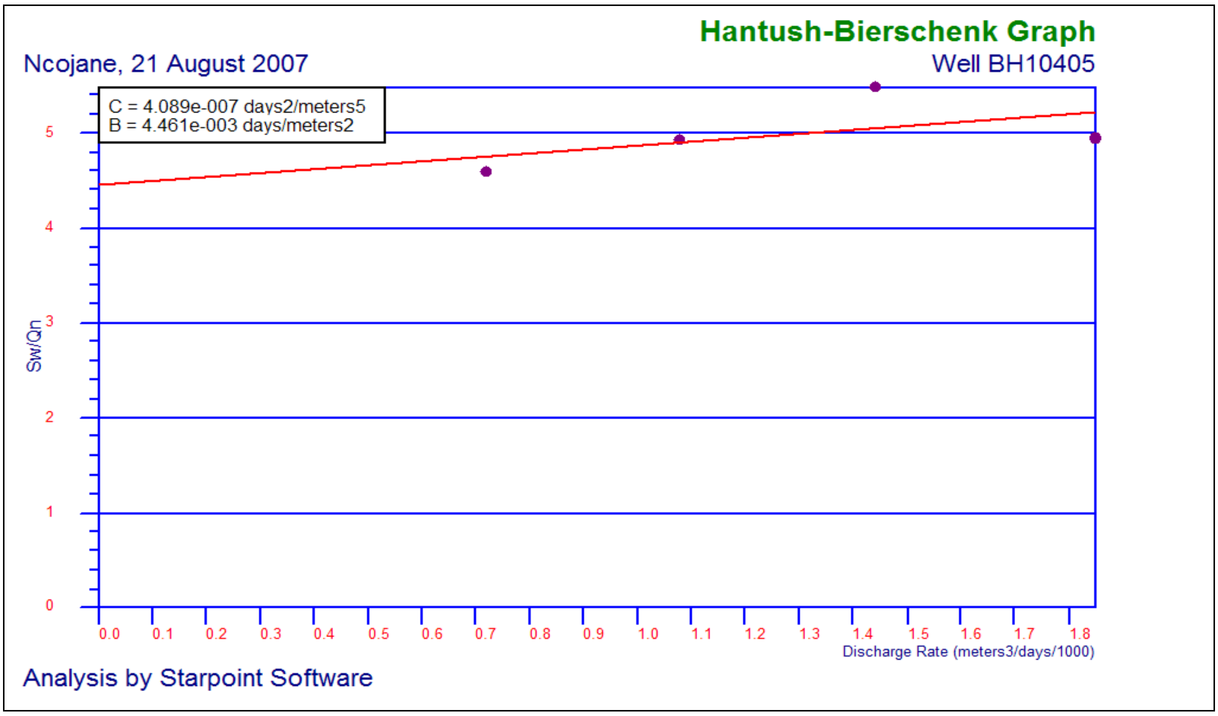

Figure 36-4 Pumping Test Results for BH10405: Step Drawdown Test – Hantush-Bierschenk

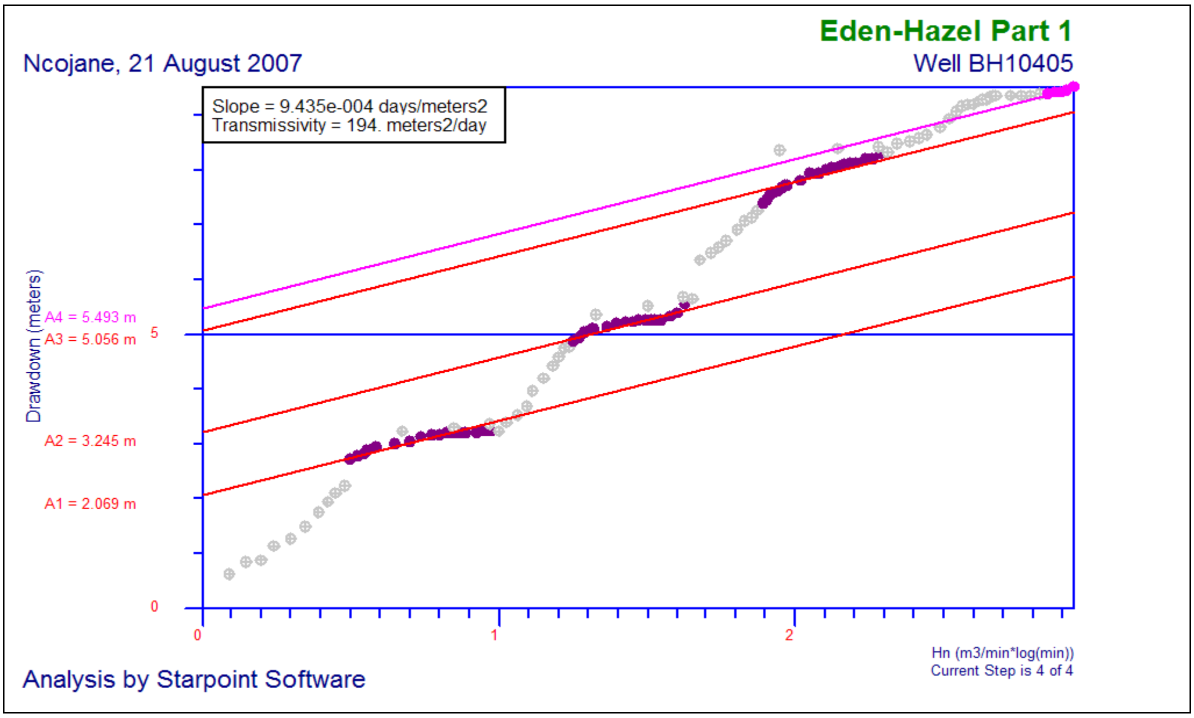

Figure 36-5 Pumping Test Results for BH10405: Step Drawdown Test – Eden-Hazel (Part 1)

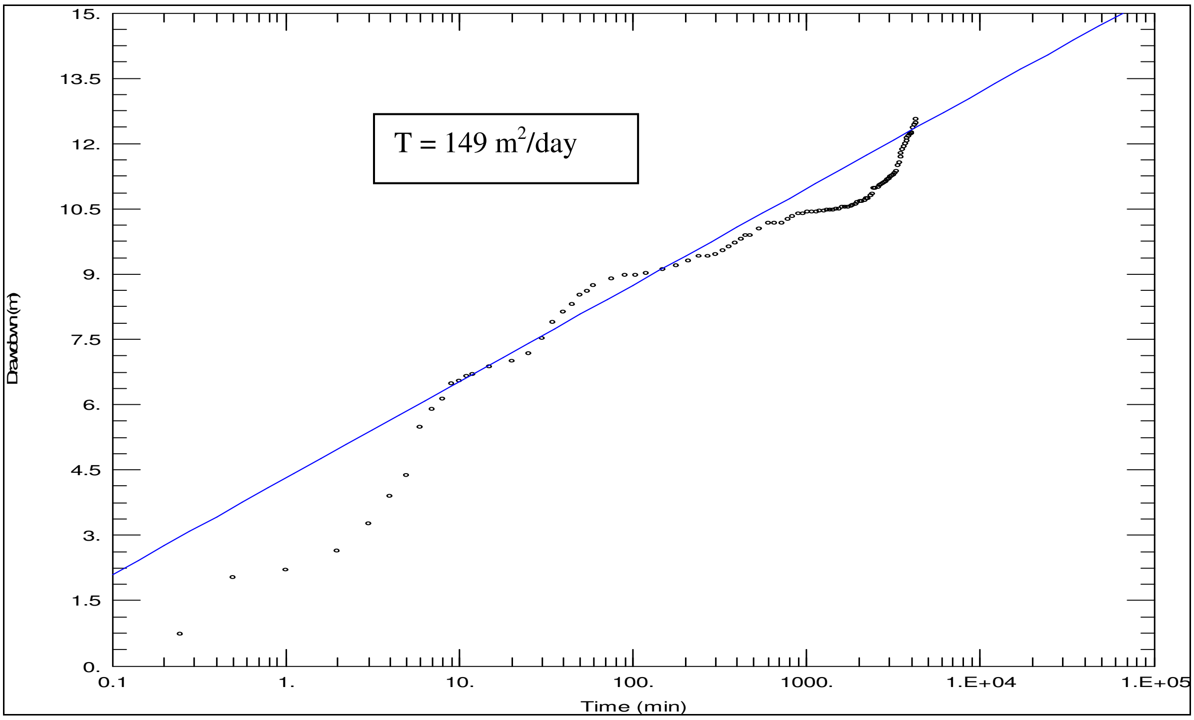

Figure 36-6 Pumping Test Results for BH10405: Cooper Jacob Solution

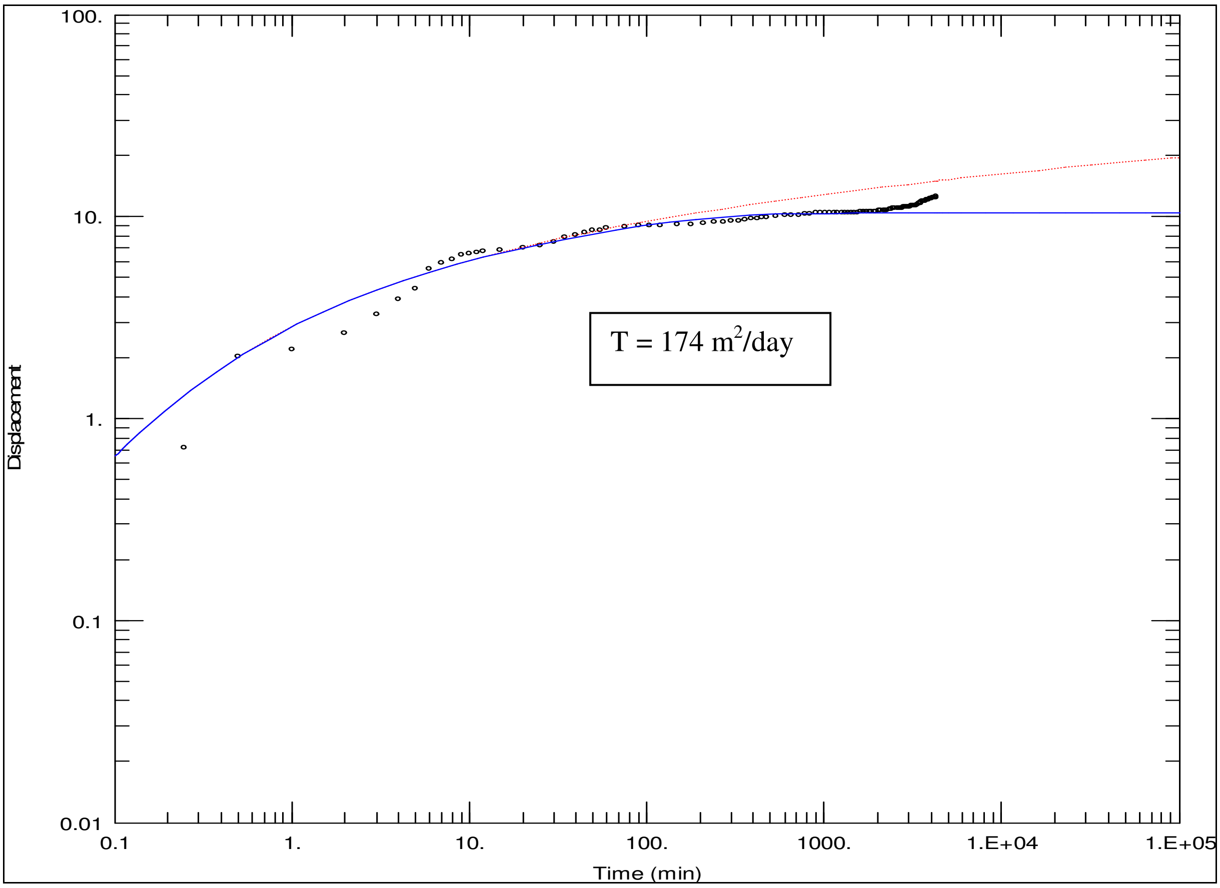

Figure 36-7 Pumping Test Results for BH10405: Hantush leaky with storage in the aquitard

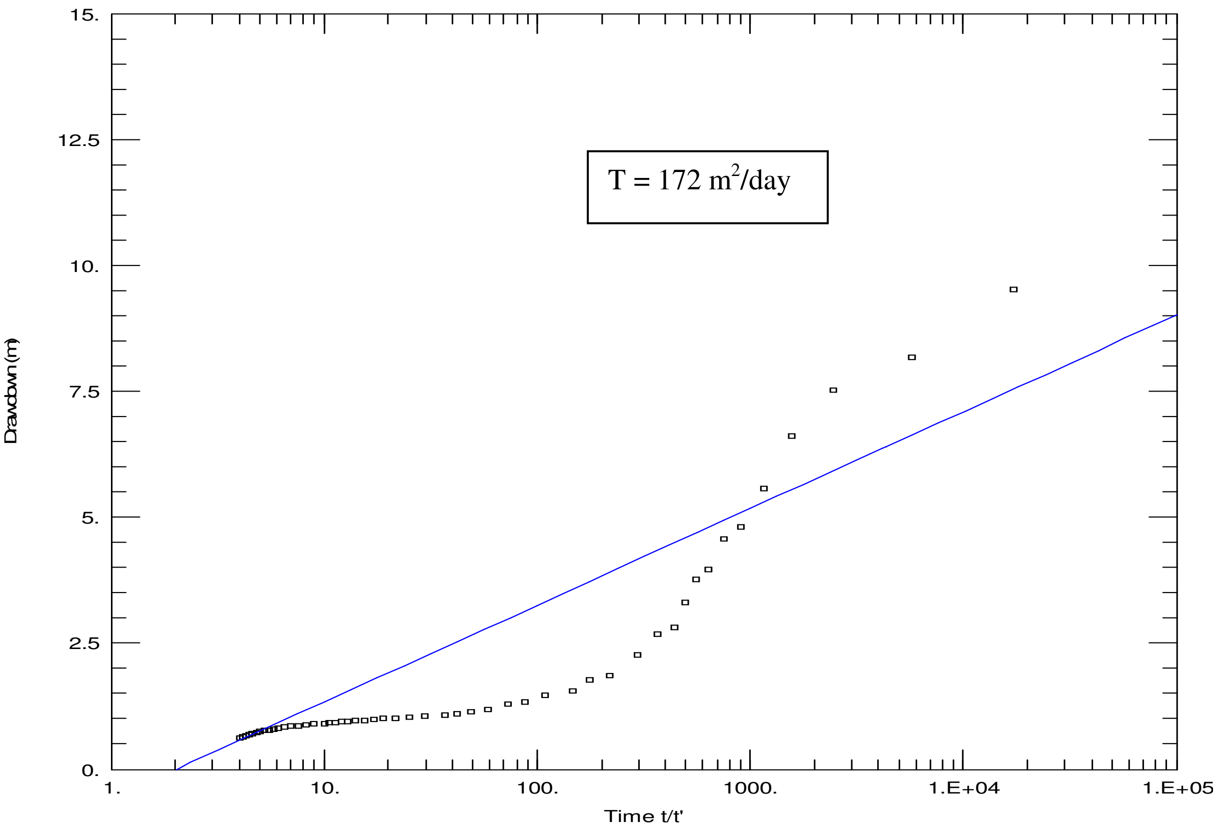

Figure 36-8 Pumping Test Results for BH10405: Theis Recovery Solution

Table 36-5 Calibration Test Data – BH10405

Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **100L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **150L**	Pump Rate (m3/hr)
STEP	**1**				**STEP**	**2**			
15 sec	107.45	0.19			15 sec	110.26	3.00		
30 sec	107.52	0.26			30 sec	110.28	3.02		
1	108.14	0.88			1	110.34	3.08	13.36	40.42
1.5		(107.26)			1.5				
2	108.23	0.97			2	110.45	3.19	13.36	40.42
2.5		(107.26)			2.5				
3	108.64	1.38			3	111.09	3.83	13.40	40.30
4	108.78	1.52	16.87	21.34	4	111.49	4.23	13.44	40.18
5	108.92	1.66	16.94	21.25	5	111.68	4.42	13.48	40.06
6	108.99	1.73	17.44	20.64	6	111.87	4.61	13.41	40.27
7	109.09	1.83	17.50	20.57	7	112.03	4.77	13.38	40.36
8	109.13	1.87	17.67	20.37	8	112.19	4.93	13.38	40.36
9	109.24	1.98	17.80	20.22	9	112.26	5.00	13.49	40.03
10	109.42	2.16	17.53	20.54	10	112.34	5.08	13.44	40.18
11	110.05	2.79	17.49	20.58	11	112.41	5.15	13.37	40.39
12	110.23	2.97	17.51	20.56	12	112.60	5.34	13.50	40.00
15	110.27	3.01	17.69	20.35	15	112.79	5.53	13.38	40.36

Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **200L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **250L**	Pump Rate (m3/hr)
STEP	**3**				**STEP**	**4**			
15 sec	112.86	5.60			15 sec	114.03	6.77		
30 sec	112.92	5.66			30 sec	114.09	6.83		
1	113.02	5.76	12.03	59.85	1	114.14	6.88	11.47	78.47
1.5			12.01	59.95	1.5		(107.26)	11.36	79.23
2	113.26	6.00	11.99	60.05	2	114.72	7.46	11.41	78.88
2.5			12.01	59.95	2.5		(107.26)	11.35	79.30
3	113.41	6.15	12.02	59.90	3	115.15	7.89	11.37	79.16
4	113.50	6.24	11.98	60.10	4	115.30	8.04	11.33	79.44
5	113.59	6.33	12.01	59.95	5	115.44	8.18	11.39	79.02
6	113.64	6.38	11.96	60.20	6	115.58	8.32	11.40	78.95
7	113.69	6.43	12.03	59.85	7	115.73	8.47	11.36	79.23
8	113.77	6.51	11.97	60.15	8	115.87	8.61	11.41	78.88
9	113.82	6.56	11.99	60.05	9	115.95	8.69	11.35	79.30
10	113.87	6.61	11.97	60.15	10	116.02	8.76	11.36	79.23
11	113.92	6.66	12.02	59.90	11	116.10	8.84	11.40	78.95
12	113.96	6.70	11.99	60.05	12	116.17	8.91	11.37	79.16
15	114.00	6.74	12.01	59.95	15	116.25	8.99	11.35	79.30

Table 36-6 Step Drawdown Test Data – BH10405

Official BH No.:BH 10405	District:Ghanzi
Date of test commencement:21.08.2007	Location:Ncojane
Time of test Commencement:0900 Hrs	BH depth (m):250m
Date of test completion:21.08.2007	Screen interval (m)
Time of test Completion:1540 Hrs	Depth to pump intake (m)155m
Method of water level measurement: Electrical Dipper	Description of MP:
Observation Bh No.:	Height of MP above ground:
Distance to OB. BH (m)	Static water level before test (m):107.23m
Temperature of water (^{o}C):	TDS/EC:

	STEP No.	**1**				STEP No.	**2**			
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **100L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **150L**	Pumping Rate (m^3/hr)	Comments
0.25	107.47	0.24			0.25	110.53	3.30			
0.5	107.70	0.47			0.5	110.58	3.35			
1	107.87	0.64			1	110.63	3.40			
1.5	108.08	0.85			1.5	110.74	3.51			
2	108.12	0.89			2	110.91	3.68	11.64	46.39	
2.5	108.37	1.14			2.5	111.20	3.97	11.96	45.15	
3	108.49	1.26			3	111.43	4.20	12.01	44.96	
4	108.72	1.49	11.90	30.25	4	111.65	4.42	11.97	45.11	
5	108.97	1.74	11.94	30.15	5	111.82	4.59	11.97	45.11	
6	109.17	1.94	11.99	30.03	6	111.96	4.73	12.00	45.00	
7	109.33	2.10	11.96	30.10	7	112.02	4.79	11.96	45.15	
8	109.46	2.23	12.01	29.98	8	112.10	4.87	12.01	44.96	
9	109.96	2.73	11.95	30.13	9	112.16	4.93	12.00	45.00	
10	110.01	2.78	11.98	30.05	10	112.23	5.00	11.99	45.04	
11	110.04	2.81	11.93	30.18	11	112.27	5.04	11.99	45.04	
12	110.06	2.83	11.95	30.13	12	112.31	5.08	11.97	45.11	
13	110.11	2.88	11.96	30.10	13	112.33	5.10	12.01	44.96	
14	110.13	2.90	12.00	30.00	14	112.34	5.11	11.98	45.08	
15	110.17	2.94	11.99	30.03	15	112.36	5.13	12.00	45.00	
20	110.23	3.00	12.03	29.93	20	112.43	5.20	11.99	45.04	
25	110.28	3.05	11.97	30.08	25	112.45	5.22	11.96	45.15	
30	110.36	3.13	12.01	29.98	30	112.47	5.24	11.99	45.04	
35	110.40	3.17	11.99	30.03	35	112.48	5.25	11.96	45.15	
40	110.40	3.17	12.02	29.95	40	112.48	5.25	11.99	45.04	
45	110.42	3.19	11.98	30.05	45	112.49	5.26	11.97	45.11	
50	110.42	3.19	12.01	29.98	50	112.49	5.26	12.01	44.96	
55	110.43	3.20	12.03	29.93	55	112.49	5.26	11.99	45.04	
60	110.44	3.21	12.03	29.93	60	112.50	5.27	12.00	45.00	
70	110.44	3.21	12.00	30.00	70	112.54	5.31	11.96	45.15	
80	110.46	3.23	11.99	30.03	80	112.63	5.40	11.96	45.15	
90	110.46	3.23	12.03	29.93	90	112.77	5.54	11.98	45.08	
100	110.47	3.24	12.00	30.00	100	112.86	5.63	12.01	44.96	

Official BH No.:BH 10405	District:Ghanzi
Date of test commencement:21.08.2007	Location:Ncojane
Time of test Commencement:0900 Hrs	BH depth (m):250m
Date of test completion:21.08.2007	Screen interval (m)
Time of test Completion:1540 Hrs	Depth to pump intake (m)155m
Method of water level measurement: Electrical Dipper	Description of MP:
Observation Bh No.:	Height of MP above ground:
Distance to OB. BH (m)	Static water level before test (m):107.23m
Temperature of water (°C):	TDS/EC:

STEP No. **3** STEP No. **4**

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **200L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **250L**	Pumping Rate (m^3/hr)	Comments
0.25	112.60	5.37			0.25	115.57	8.34			
0.5	112.74	5.51			0.5	115.60	8.37			
1	112.90	5.67			1	115.63	8.40			
1.5	113.58	6.35			1.5	115.70	8.47			
2	113.71	6.48	12.42	57.97	2	115.74	8.51	13.20	68.18	
2.5	113.58	6.35	12.01	59.95	2.5	115.81	8.58	13.01	69.18	
3	113.93	6.70	11.96	60.20	3	115.87	8.64	12.04	74.75	
4	114.13	6.90	11.98	60.10	4	116.00	8.77	12.01	74.94	
5	114.28	7.05	12.02	59.90	5	116.16	8.93	11.56	77.85	
6	114.37	7.14	12.00	60.00	6	116.27	9.04	11.56	77.85	
7	114.50	7.27	11.97	60.15	7	116.37	9.14	11.57	77.79	
8	114.60	7.37	12.01	59.95	8	116.41	9.18	11.54	77.99	
9	114.69	7.46	11.99	60.05	9	116.43	9.20	11.59	77.65	
10	114.76	7.53	11.98	60.10	10	116.47	9.24	11.58	77.72	
11	114.81	7.58	11.96	60.20	11	116.50	9.27	11.59	77.65	
12	114.85	7.62	11.96	60.20	12	116.50	9.27	11.51	78.19	
13	114.89	7.66	12.00	60.00	13	116.53	9.30	11.56	77.85	
14	114.92	7.69	11.97	60.15	14	116.57	9.34	11.59	77.65	
15	114.94	7.71	11.99	60.05	15	116.58	9.35	11.56	77.85	
20	115.04	7.81	12.01	59.95	20	116.58	9.35	11.56	77.85	
25	115.15	7.92	11.98	60.10	25	116.58	9.35	11.54	77.99	
30	115.17	7.94	12.00	60.00	30	116.59	9.36	11.57	77.79	
35	115.23	8.00	11.97	60.15	35	116.60	9.37	11.58	77.72	
40	115.27	8.04	11.98	60.10	40	116.60	9.37	11.58	77.72	
45	115.30	8.07	11.96	60.20	45	116.63	9.40	11.55	77.92	
50	115.32	8.09	12.01	59.95	50	116.65	9.42	11.56	77.85	
55	115.34	8.11	12.00	60.00	55	116.68	9.45	11.59	77.65	
60	115.36	8.13	12.00	60.00	60	116.72	9.49	11.57	77.79	
70	115.41	8.18	11.98	60.10	70	116.75	9.52	11.54	77.99	
80	115.43	8.20	11.99	60.05	80	116.88	9.65	11.55	77.92	
90	115.50	8.27	12.01	59.95	90	116.97	9.74	11.57	77.79	
100	115.54	8.31	11.97	60.15	100	117.08	9.85	11.59	77.65	

Official BH No.:BH 10404	District:Ghanzi
Date of test commencement:20.07.2007	Location:Ncojane
Time of test Commencement:0700 Hrs	BH depth (m):250m
Date of test completion:20.07.2007	Screen interval (m)
Time of test Completion:1520 Hrs	Depth to pump intake (m)140m
Method of water level measurement: Electrical Dipper	Description of MP:
Observation Bh No.:	Height of MP above ground:
Distance to OB. BH (m)	Static water level before test (m):108.32
Temperature of water (°C):	TDS/EC:

STEP No. **5** STEP No.

TIME (min)	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill 250L**	**Pumping Rate (m3/hr)**	**Comments**	**TIME (min)**	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill ______L**	**Pumping Rate (m3/hr)**	**Comments**

0.25	130.04	21.72				0.25					
0.5	129.89	21.57				0.5					
1	129.79	21.47	13.00	69.23		1					
1.5	129.79	21.47				1.5					
2	129.70	21.38	12.91	69.70		2					
2.5	129.69	21.37				2.5					
3	129.58	21.26	12.86	69.98		3					
4	129.62	21.30	12.81	70.25		4					
5	129.62	21.30	12.84	70.09		5					
6	129.62	21.30	12.83	70.14		6					
7	129.62	21.30	12.87	69.93		7					
8	129.65	21.33	12.85	70.03		8					
9	129.67	21.35	12.80	70.31		9					
10	129.67	21.35	12.83	70.14		10					
11	129.67	21.35	12.86	69.98		11					
12	129.67	21.35	12.86	69.98		12					
13	129.67	21.35	12.85	70.03		13					
14	129.67	21.35	12.87	69.93		14					
15	129.61	21.29	12.88	29.87		15					
20	129.62	21.30	12.84	70.09		20					
25	129.62	21.30	12.81	70.25		25					
30	129.62	21.30	12.79	70.36		30					
35	129.62	21.30	12.86	69.98		35					
40	129.62	21.30	12.86	69.93		40					
45	129.62	21.30	12.86	69.70		45					
50	129.62	21.30	12.80	70.31		50					
55	129.69	21.37	12.82	70.20		55					
60	129.70	21.38	12.79	70.36		60					
70	130.40	22.08	12.81	70.25		70					
80	131.22	22.90	12.80	70.31		80					
90	132.00	23.68	12.79	70.36		90					
100	132.67	24.35	12.86	69.98		100					

Table 36-7 Constant Rate Test – BH10405

Official BH NO : BH 10405	District :Ghantsi
Date of test commencement :29.07.2007	Location : Ncojane
Time of test commencement :1100 hrs	BH depth(m) : 250
Date of test completion: 05.08.2007	Screen Interval (m)
Time of test completion :1100 hrs	Depth of pump intake (m) : 155
Method of water level measurement: Electrical Dipper	Description of MP
OB BH NO: Bh 10210	Height of MP above ground(m) :0.95m
Distance ob BH r (m): 15m	Static Water level before test(m) : 107.20m
Casing diameter (mm) 203mm	Water strike
Orifice plate diameter:152mm	Delivery pipe diameter: 127mm
Co-ordinates:	Co-ordinates:

	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 250l	Q(m^3/h)	Temp (^{0}C)	EC (us/cm)	pH	Manometer (cm)	Comments
	0.25	107.92	0.72							
	0.5	109.22	2.02							
	1	109.40	2.20							
	2	109.83	2.63							
	3	110.47	3.27							
	4	111.09	3.89	11.90	75.63					
	5	111.57	4.37	12.03	74.81					
	6	112.69	5.49	11.98	75.13					
	7	113.09	5.89	12.01	74.94					
	8	113.34	6.14	11.97	75.19					
	9	113.69	6.49	11.99	75.06					
	10	113.74	6.54	11.96	75.25					
	11	113.85	6.65	11.98	75.13					
	12	113.90	6.70	12.01	74.94					
	15	114.06	6.86	11.96	75.25					
	20	114.20	7.00	11.98	75.13					
	25	114.38	7.18	12.01	74.94					
	30	114.73	7.53	11.96	75.25					
	35	115.09	7.89	12.00	75.00					
	40	115.33	8.13	11.97	75.19					
	45	115.50	8.30	11.99	75.06					
	50	115.73	8.53	11.98	75.13					
	55	115.80	8.60	11.99	75.06					
	60	115.93	8.73	12.01	74.94					
	75	116.09	8.89	11.96	75.25					
	90	116.17	8.97	12.00	75.00					
	105	116.18	8.98	11.97	75.19					
	120	116.22	9.02	11.99	75.06	29.50	559.00	7.65		
	150	116.30	9.10	11.99	75.06					
	180	116.39	9.19	11.98	75.13	28.40	561.00	7.75		
	210	116.50	9.30	12.00	75.00					
	240	116.60	9.40	11.99	75.06	29.30	579.00	7.68		
	270	116.62	9.42	12.00	75.00					
	300	116.66	9.46	11.97	75.19	28.00	566.00	7.74		
	330	116.74	9.54	11.99	75.06					
	360	116.82	9.62	11.96	75.25	27.50	577.00	7.81		
	390	116.92	9.72	11.98	75.13					
	420	117.00	9.80	12.00	75.00	26.30	570.00	7.65		
	450	117.09	9.89	12.00	75.00					
8	480	117.09	9.89	11.96	75.25	24.30	578.00	7.77		
9	540	117.24	10.04	12.00	75.00	23.60	555.00	7.73		
10	600	117.37	10.17	11.99	75.06	23.00	546.00	7.64		
11	660	117.37	10.17	11.97	75.19	22.80	588.00	7.78		
12	720	117.37	10.17	11.98	75.13	22.80	582.00	7.66		

13	780	117.46	10.26	12.00	75.00	23.00	546.00	7.63		
14	840	117.52	10.32	11.96	75.25	22.90	575.00	7.69		
15	900	117.58	10.38	11.97	75.19	21.60	584.00	7.74		
16	960	117.59	10.39	11.99	75.06	21.80	582.00	7.65		
17	1020	117.63	10.43	12.00	75.00	21.00	543.00	7.63		
18	1080	117.64	10.44	11.98	75.13	22.70	546.00	7.64		
19	1140	117.64	10.44	11.96	75.25	22.80	575.00	7.63		
20	1200	117.66	10.46	12.00	75.00	23.70	565.00	7.74		
21	1260	117.66	10.46	11.99	75.06	26.80	564.00	7.76		
22	1320	117.67	10.47	12.00	75.00	26.70	551.00	7.76		
23	1380	117.68	10.48	12.00	75.00	27.60	560.00	7.73		
24	1440	117.68	10.48	11.97	75.19	31.20	581.00	7.70		
25	1500	117.69	10.49	11.99	75.06	32.10	583.00	7.56		
26	1560	117.70	10.50	11.97	75.19	30.50	576.00	7.75		
27	1620	117.73	10.53	11.99	75.06	31.40	543.00	7.77		
28	1680	117.73	10.53	11.97	75.19	29.00	587.00	7.78		
29	1740	117.74	10.54	11.98	75.13	28.90	599.00	7.69		
30	1800	117.75	10.55	11.96	75.25	26.00	577.00	7.87		
31	1860	117.78	10.58	11.99	75.06	25.10	595.00	7.78		
32	1920	117.81	10.61	12.00	75.00	24.70	586.00	7.92		
33	1980	117.84	10.64	12.01	74.94	23.90	568.00	7.79		
34	2040	117.86	10.66	11.96	75.25	22.50	585.00	7.80		
35	2100	117.88	10.68	11.98	75.13	22.80	599.00	7.62		
36	2160	117.89	10.69	12.06	74.63	24.60	543.00	7.78		
37	2220	117.93	10.73	12.01	74.94	25.10	576.00	7.69		
38	2280	117.94	10.74	12.00	75.00	28.70	582.00	7.56		
39	2340	118.01	10.81	11.96	75.25	22.60	599.00	7.79		
40	2400	118.04	10.84	11.97	75.19	23.50	545.00	7.77		
41	2460	118.17	10.97	11.99	75.06	21.60	575.00	7.75		
42	2520	118.17	10.97	12.00	75.00	21.10	566.00	7.56		
43	2580	118.19	10.99	11.96	75.25	25.60	579.00	6.25		
44	2640	118.23	11.03	12.00	75.00	26.50	583.00	7.78		
45	2700	118.25	11.05	11.97	75.19	28.90	570.00	7.88		
46	2760	118.28	11.08	11.96	75.25	29.60	580.00	7.18		
47	2820	118.30	11.10	12.00	75.00	31.60	563.00	7.92		
48	2880	118.33	11.13	11.98	75.13	31.80	555.00	7.77		
49	2940	118.37	11.17	11.97	75.19	30.90	568.00	7.56		
50	3000	118.39	11.19	11.97	75.19	31.30	548.00	7.56		
51	3060	118.43	11.23	11.98	75.13	31.20	569.00	7.80		
52	3120	118.45	11.25	11.96	75.25	31.50	566.00	7.69		
53	3180	118.48	11.28	11.99	75.06	27.90	578.00	7.75		
54	3240	118.52	11.32	11.96	75.25	28.80	580.00	7.18		
55	3300	118.56	11.36	11.99	75.06	25.20	573.00	7.82		
56	3360	118.70	11.50	11.98	75.13	24.20	573.00	7.73		
57	3420	118.75	11.55	11.96	75.25	24.60	562.00	7.62		
58	3480	118.88	11.68	11.98	75.13	25.10	582.00	7.45		
59	3540	118.97	11.77	11.97	75.19	25.60	557.00	7.67		
60	3600	119.06	11.86	11.98	75.13	23.90	573.00	7.56		
61	3660	119.13	11.93	11.96	75.25	22.90	565.00	7.77		
62	3720	119.19	11.99	12.00	75.00	22.70	555.00	7.47		
63	3780	119.25	12.05	11.98	75.13	21.70	583.00	7.81		
64	3840	119.33	12.13	11.96	75.25	20.70	577.00	7.92		
65	3900	119.37	12.17	11.98	75.13	20.80	520.00	7.89		
66	3960	119.42	12.22	11.97	75.19	20.20	572.00	7.85		
67	4020	119.43	12.23	11.99	75.06	20.40	553.00	7.62		
68	4080	119.46	12.26	11.96	75.25	21.50	562.00	7.96		
69	4140	119.56	12.36	11.97	75.19	22.30	573.00	7.86		
70	4200	119.62	12.42	11.98	75.13	23.00	584.00	7.88		
71	4260	119.68	12.48	11.97	75.19	24.90	578.00	7.84		
72	4320	119.75	12.55	11.99	75.06	22.70	566.00	7.76		

Table 36-8 Recovery Test Data – BH10405

Official BH NO : 10405	District :Ghanzi
Date of test commencement :24.08.2007	Location :Ncojane
Time of test commencement :1200 Hrs	BH depth(m) :250m
Date of test completion:25.08.2007	Screen Interval (m):
Time of test completion :1800 Hrs	Depth of pump intake (m):`155m
Method of water level measurement: Electrical dipper	Description of MP:
OB. BH. No.:	Height of MP above ground(m):0.95m
Dist.to Ob Bh:	Static Water level before test(m):107.20m

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	119.75	12.55
	0.25	118.64	11.44
	0.5	116.72	9.52
	1	115.38	8.18
	2	114.73	7.53
	3	113.8	6.6
	4	112.77	5.57
	5	112.01	4.81
	6	111.78	4.58
	7	111.17	3.97
	8	110.96	3.76
	9	110.5	3.3
	10	110.01	2.81
	12	109.88	2.68
	15	109.47	2.27
	20	109.06	1.86
	25	108.97	1.77
	30	108.76	1.56
	40	108.66	1.46
	50	108.54	1.34
	60	108.49	1.29
	75	108.39	1.19
	90	108.34	1.14
	105	108.3	1.1
	120	108.27	1.07

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	108.25	1.05
	180	108.24	1.04
	210	108.22	1.02
	240	108.21	1.01
	270	108.19	0.99
	300	108.17	0.97
	330	108.16	0.96
	360	108.15	0.95
	390	108.14	0.94
	420	108.13	0.93
	450	108.12	0.92
	480	108.11	0.91
	540	108.1	0.9
	600	108.08	0.88
	660	108.06	0.86
	720	108.05	0.85
	780	108.03	0.83
	840	108.01	0.81
	900	107.99	0.79
	960	107.98	0.78
	1020	107.96	0.76
	1080	107.94	0.74
	1140	107.92	0.72
	1200	107.9	0.7
	1260	107.88	0.68
	1320	107.87	0.67
	1380	107.85	0.65
	1440	107.82	0.62

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37 BH10406

BH10406 is an abandoned borehole with site number **P05**, Line **L1, TEM 302**. The borehole is located about 27 km east of Ncojane along the gravel road to Metsimantsho and about 10m soutrh of abandoned borehile BH10409. Drilling at this site commenced on 28 April 2007 with 17 inch DTH bit to a depth of 61 m after which 15 inch plain casing was installed and grouted. The borehole was then cased using 12 inch casings and cement grouted to seal the Kule/Kwetla formations. The borehole was abandoned on the 21st May 2007 at 197 m since the 12 inch bit could not be recovered. It has to be noted the fishing tool also broke into the same borehole.

An attempt to replace BH10406 was through drilling BH10409 about 10m away from abandoned borehole. BH10409 was also abandoned after drilling only 20m and details of this borehole are in chapter 40.

37.1 SITING CRITERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block with thin dolerite sill/dyke.

38 BH10407

BH10407 is a production borehole drilled at site **P04**, Line **L1, TEM 296** and peg **13000m**. It is located approximately 22 km south east of Ncojane, south of the Ncojane – Metsimantsho road. Drilling at this site commenced on 10th May 2007 and was completed at 249 m on 31st May 2007.

38.1 SITING CRETERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block and with probable thin dolerite sill/dyke.

38.2 DRILLING RESULT

Drilling of this borehole was started with a 17 inch drilling bit down to 60m and 15 inch plain casing was installed and cement grouted down to 60m. A 15 inch bit was then used to drill from 60m to 193m between the 15th May 2007 and 26th May 2007 though there was a major breakdown for 7 days . Various lithologies including fine grained sands, silcrete, mudstones, coal and fine to coarse grained sandstones were intercepted during drilling of this borehole (**Figure 38-1).**

Two water strikes were encountered at various depths during drilling of this borehole. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for these water strikes are as follows:

1. (205m, 520µS/cm, 70 m^3/hr
2. (232m, 520µS/cm, 115 m^3 /hr)
3.

The borehole was geophysically logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes to a depth of 250m **(Figure 38-2).** The borehole, was then constructed using 8 inch epoxy coated plain casings and screens. The 8 inch epoxy casings were installed from 0 to 198m and 243 to 246 m while the screens were installed from 198 to 243 m. The total screened zone is 45 m. Borehole development was through airlift pumping and air jetting and the final blow out yield was estimated as 70m^3/hr while the electrical conductivity was 540 µS/cm. The verticality and alignment test were conducted on the 2nd of June 2007.

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

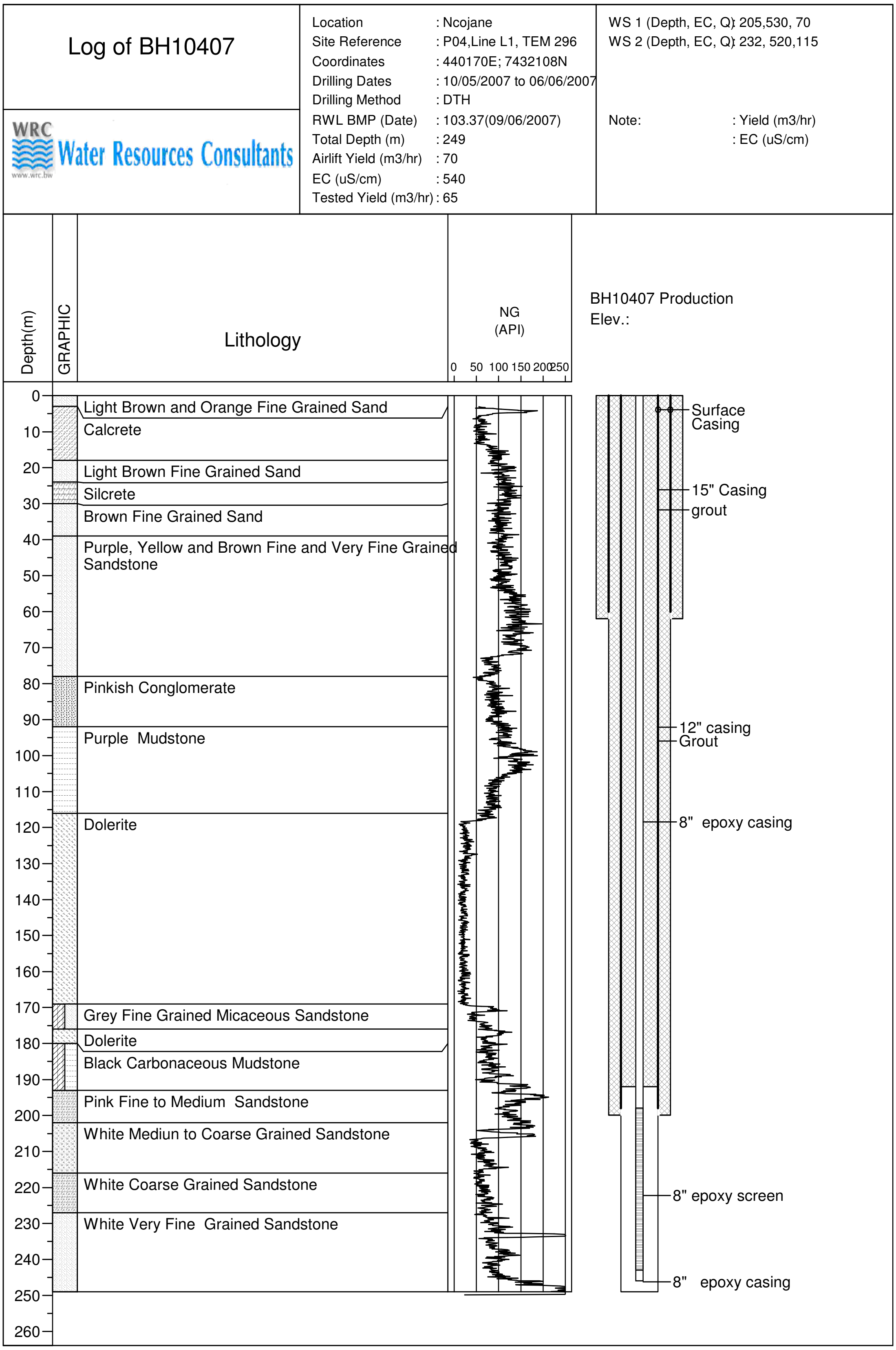

Figure 38-1 Log of BH10407

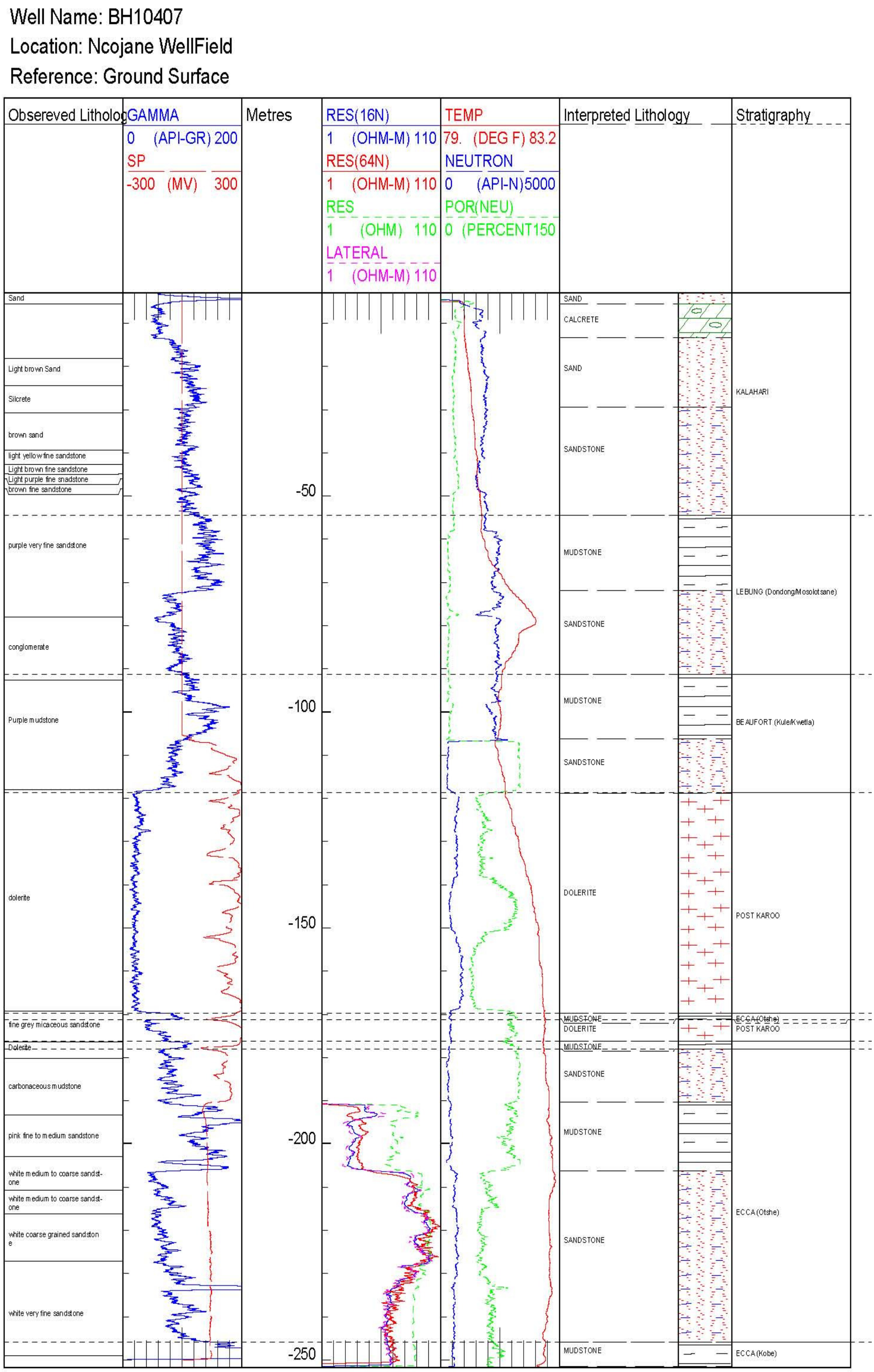

Figure 38-2 Geophysical log of BH10407

38.3 PUMP TESTING RESULTS

Test pumping operations at BH10407 were started on 31st August 2007 and were completed on 6th September 2007 after breakdown of the engine during CRT (60 hours). The tests carried out were calibration, step drawdown, constant rate and recovery tests. A summary of the pumping test data for BH10407 is in **Table 38-1.** The static water level at the beginning of the test was 104.30m bmp. The collected pump testing data is presented in **Tables 38-5 to 38-9**.

Table 38-1 Summary of Pumping Test Data BH10407

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	6.13	20
	2	15	8.74	35
	3	15	14.96	50
	4	15	17.97	65
	5	15	1947	77
Step Test	1	100	7.95	30
	2	100	12.13	40
	3	100	16.67	50
	4	100	20.10	65
	5	100	26.29	77
Constant Rate	1	3600	21.55	65
Recovery	1	1440	0.57	0

Note. 0.57 Residual Drawdown*

38.3.1 Step Drawdown Test

The step drawdown test was carried out on 1th September 2007 and consisted of 5 steps of 100 minutes duration at pumping rates of 30, 40 50, 65 and 77 m^3/hr, respectively. The static water level before the start of the test was 104.34 m bmp. The plots are presented in **Figures 38-3 to 38-5**.

The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 73m^2/d (**Figure 38-5**). The results of the interpreted step test data are given in **Table 38-2**.

Table 38-2 Results of Step Test Analysis BH10407

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10407	2.97E-003	2.80E-006	73	30	3.01	3.01	9.97
				40	2.67	5.68	7.04
				50	3.56	9.24	5.41
				65	1.23	10.47	6.21
				77	4.32	14.79	5.21

The planned duration for the constant rate test at this borehole was 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 38-3**) to estimate the expected total drawdown after 3 days of pumping.

38.3.2 Constant Rate and Recovery Tests

The constant rate test (CRT) was carried out between 2nd September and 6th September 2007 at a discharge rate of 65m^3/hr and the total drawdown after 60 hrs of pumping was 21.55 m. The CRT lasted for 60hours instead of 72hours due the breakdown and a 24 hour recovery monitoring period was started immediately after the breakdown. The residual drawdown at the end of Recovery test was 0.57m.

Data from the pumping borehole was interpreted using Cooper-Jacob (1946) and Hantush leaky analytical solutions using the computer programme "Aqtesolv". Transmissivity (T) values obtained by these two analytical solutions were 146 and 143 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a T value of 143m^2/d was obtained. The results are summarised in **Table 38-3** and the interpreted data is presented in **Figures 38-6** to **38-8**.

There is an apparent impermeable barrier interpreted in the CRT data after 1100 minutes of pumping, **Figure 38-6**. This barrier is probably caused by a NW - SE trending lineament located about 700m east of BH10407.

Table 38-3 Summary of Constant Rate and Recovery Tests BH10407

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10407	60	1560	a) 146 b) 149	d) 143	Confined and leaky

Notes:
<u>Interpretation Techniques</u>
a) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

38.3.2.1 <u>Aquifer Type interpreted</u>

The interpretation of the pump testing data indicates that the aquifer type is confined-leaky with negative (barrier) boundary.

38.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. The results of chemical analyses from CSIR lab are presented in **Table 38-4**. The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC) and pH are 26.0 °C, 574 µS/cm and 7.85 respectively.

Table 38-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10407	8.3	139.5	22.7	19.7	31.3	116.1	219	13.9	0.64	<0.05	<0.05	860	6.7	550
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10407	<0.05	138	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in µS/cm
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

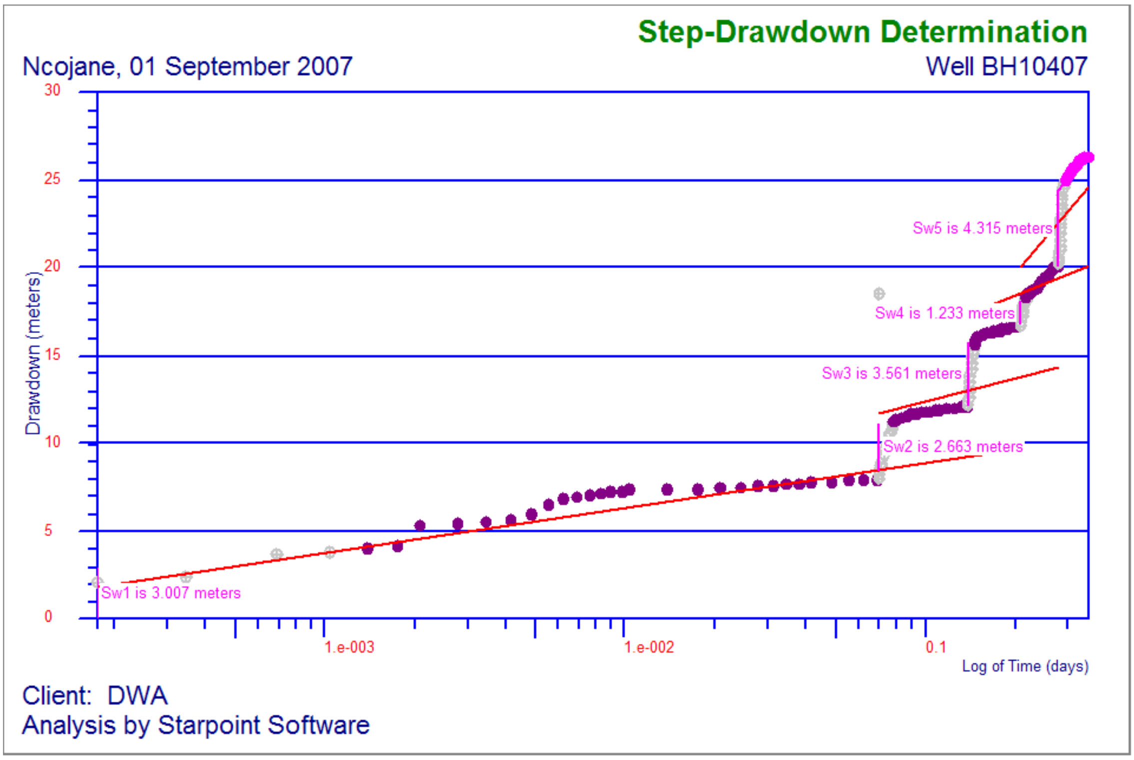

Figure 38-3 Pumping Test Results for BH10407: Step Drawdown Test - Hantush-Bierschenk (semi-log)

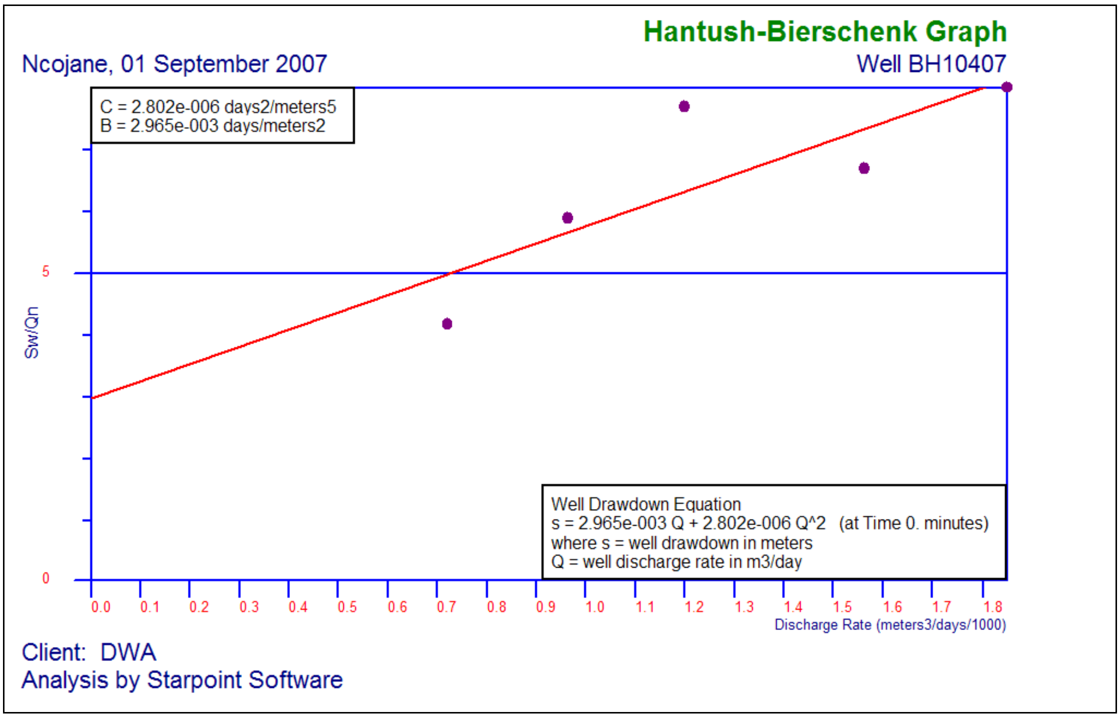

Figure 38-4 Pumping Test Results for BH10407: Step Drawdown Test – Hantush-Bierschenk

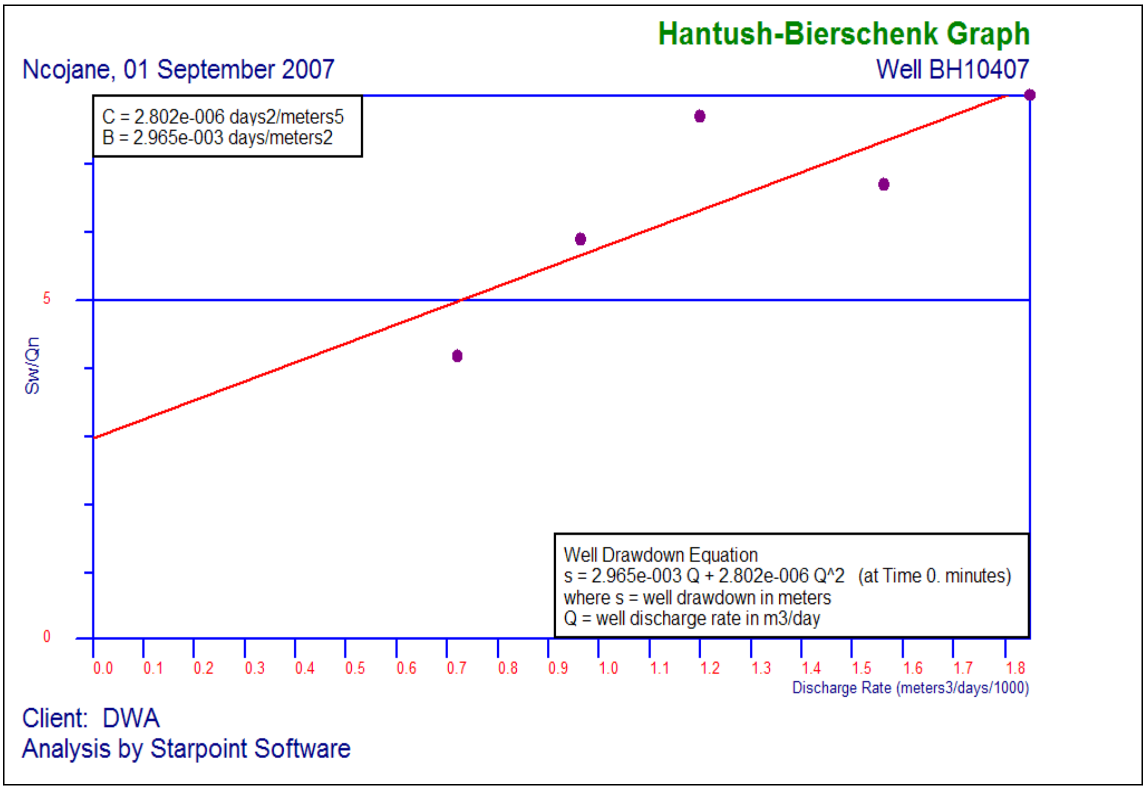

Figure 38-5 Pumping Test Results for BH10407: Step Drawdown Test – Eden-Hazel (Part 1)

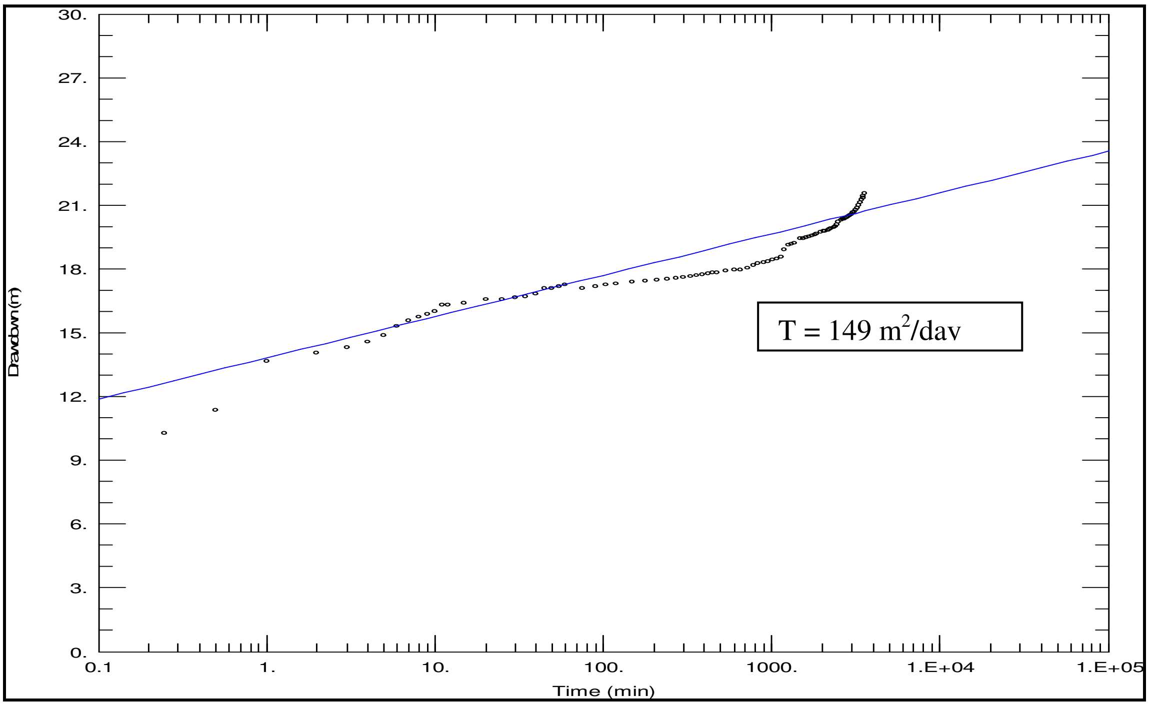

Figure 38-6 Pumping Test Results for BH10407: Theis Solution

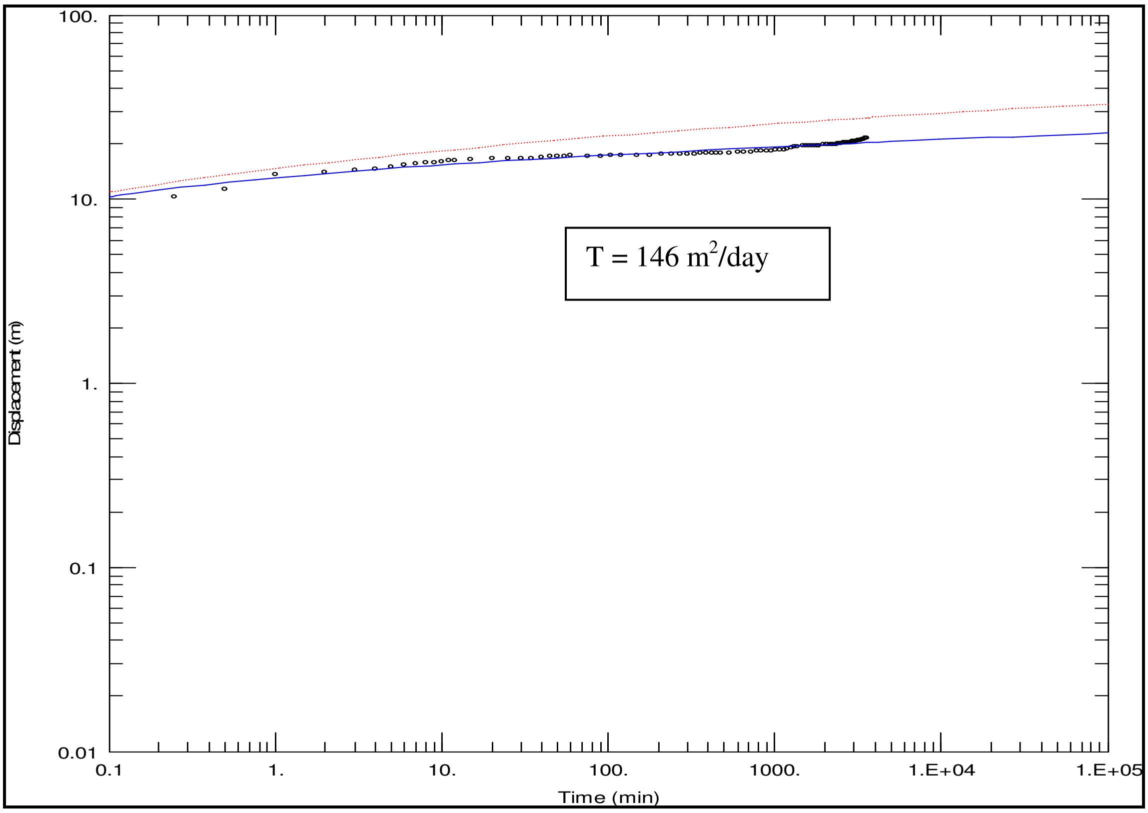

Figure 38-7 Pumping Test Results for BH10407: CRT Cooper Jacob Solution

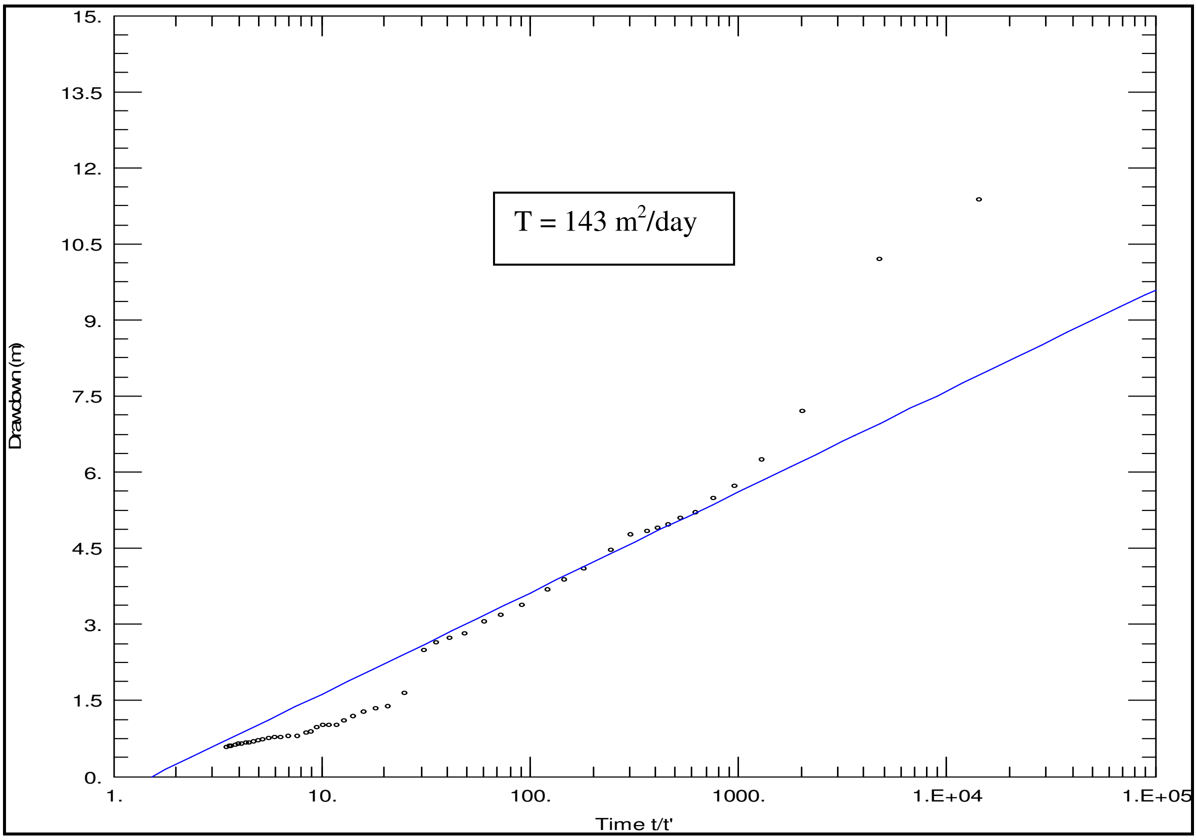

Figure 38-8 Pumping Test Results for BH10407: Theis Recovery Solution

Table 38-5 Calibration Test Data – BH10407

BH No.: 10407	**District: Ghanzi**
Date of test commencement: 31/08/2007	**Location: Ncojane**
Time of test commencemen: 0700 Hrs	**BH depth (m): 243m**
Date of test completion: 31/08/2007	**Screen Interval (m):**
Time of test completion: 0815 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 104.30m**
Temperature of water (^{o}C):	**EC (mS/cm): pH:**

Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **100L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **150L**	Pump Rate (m3/hr)
STEP	**1**				**STEP**	**2**			
15 sec	105.37	1.07			15 sec	110.50	6.20		
30 sec	106.56	2.26			30 sec	111.20	6.90		
1	108.56	4.26			1	111.52	7.22	15.50	34.84
1.5	108.43	4.13			1.5	111.85	7.55		
2	108.54	4.24			2	112.15	7.85	15.41	35.04
2.5	108.61	4.31			2.5	112.29	7.99		
3	108.69	4.39			3	112.45	8.15	15.37	35.13
4	108.78	4.48			4	112.55	8.25	15.40	35.06
5	108.85	4.55	18.09	19.90	5	112.63	8.33	15.36	35.16
6	109.04	4.74	17.98	20.02	6	112.66	8.36	15.38	35.11
7	109.39	5.09	18.03	19.97	7	112.71	8.41	15.40	35.06
8	109.63	5.33	17.99	20.01	8	112.74	8.44	15.37	35.13
9	110.04	5.74	18.00	20.00	9	112.79	8.49	15.41	35.04
10	110.19	5.89	17.96	20.04	10	112.85	8.55	15.36	35.16
11	110.30	6.00	17.98	20.02	11	112.93	8.63	15.41	35.04
12	110.37	6.07	17.98	20.02	12	112.99	8.69	15.39	35.09
15	110.43	6.13	18.08	19.91	15	113.04	8.74	15.42	35.02

Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **200L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **250L**	Pump Rate (m3/hr)
STEP	**3**				**STEP**	**4**			
15 sec	113.99	9.69			15 sec	119.3	15.00		
30 sec	115.89	11.59			30 sec	110.7	6.40		
1	117.04	12.74	13.45	53.53	1	120.21	15.91	14.00	64.29
1.5	117.39	13.09			1.5	120.59	16.29		
2	117.70	13.40	14.43	49.90	2	120.88	16.58	13.77	65.36
2.5	117.93	13.63			2.5	121.11	16.81		
3	118.13	13.83	14.38	50.07	3	121.34	17.04	13.84	65.03
4	118.40	14.10	14.40	50.00	4	121.56	17.26	13.79	65.26
5	118.56	14.26	14.36	50.14	5	121.71	17.41	13.80	65.22
6	118.71	14.41	14.41	49.97	6	121.80	17.50	13.82	65.12
7	118.78	14.48	14.35	50.17	7	121.88	17.58	13.78	65.31
8	118.89	14.59	14.39	50.03	8	121.95	17.65	13.80	65.22
9	118.97	14.67	14.37	50.10	9	122.04	17.74	13.83	65.08
10	119.06	14.76	14.38	50.07	10	122.09	17.79	13.81	65.17
11	119.13	14.83	14.40	50.00	11	122.17	17.87	13.84	65.03
12	119.19	14.89	14.36	50.14	12	122.22	17.92	13.79	65.26
15	119.26	14.96	14.40	50.00	15	122.27	17.97	13.82	65.12

Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **250L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **250L**	Pump Rate (m3/hr)
STEP	**5**				**STEP**	**6**			
15 sec	122.30	18.00			15 sec				
30 sec	122.62	18.32			30 sec				
1	122.80	18.50	12.04	74.75	1				

1.5	122.89	18.59			1.5					
2	122.96	18.66	11.77	76.47	2					
2.5	123.01	18.71			2.5					
3	123.07	18.77	11.72	76.79	3					
4	123.17	18.87	11.68	77.05	4					
5	123.22	18.92	11.67	77.12	5					
6	123.27	18.97	11.68	77.05	6					
7	123.33	19.03	11.69	76.99	7					
8	123.39	19.09	11.66	77.19	8					
9	123.46	19.16	11.67	77.12	9					
10	123.53	19.23	11.66	77.19	10					
11	123.60	19.30	11.67	77.12	11					
12	123.67	19.37	11.68	77.05	12					
15	123.77	19.47	11.66	77.19	15					

Table 38-6 Step Drawdown Test Data – BH10407

BH No.: 10407	**District: Ghanzi**
Date of test commencement: 01/09/2007	**Location: Ncojane**
Time of test commencemen: 0630 Hrs	**BH depth (m): 243m**
Date of test completion: 01/09/2007	**Screen Interval (m):**
Time of test completion: 1450 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 104.34m**
Temperature of water (^oC):	**EC (mS/cm): pH:**

STEP No. **1**					STEP No. **2**					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **100L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **150L**	Pumping Rate (m^3/hr)	Comments
0.25	106.45	2.11			0.25	112.36	8.02			
0.5	106.75	2.41			0.5	112.59	8.25			
1	108.09	3.75			1	112.77	8.43	13.53	39.91	
1.5	108.20	3.86			1.5	122.89	18.55			
2	108.33	3.99			2	112.99	8.65	13.47	40.09	
2.5	108.49	4.15			2.5	113.13	8.79	13.49	40.03	
3	109.62	5.28	12.19	29.53	3	113.23	8.89	13.51	39.97	
4	109.77	5.43	12.00	30.00	4	113.58	9.24	13.45	40.15	
5	109.85	5.51	11.99	30.03	5	113.79	9.45	13.49	40.03	
6	110.00	5.66	12.01	29.98	6	113.98	9.64	13.47	40.09	
7	110.36	6.02	11.98	30.05	7	114.33	9.99	13.44	40.18	
8	110.82	6.48	11.96	30.10	8	114.69	10.35	13.50	40.00	
9	111.17	6.83	11.96	30.10	9	114.87	10.53	13.49	40.03	
10	111.31	6.97	12.01	29.98	10	114.98	10.64	13.48	40.06	
11	111.43	7.09	11.97	30.08	11	115.19	10.85	13.46	40.12	
12	111.52	7.18	12.00	30.00	12	115.34	11.00	13.47	40.09	
13	111.58	7.24	11.99	30.03	13	115.50	11.16	13.45	40.15	
14	111.61	7.27	11.97	30.08	14	115.59	11.25	13.47	40.09	
15	111.66	7.32	12.02	29.95	15	115.68	11.34	13.50	40.00	
20	111.71	7.37	11.85	30.38	20	115.75	11.41	13.49	40.03	
25	111.75	7.41	12.00	30.00	25	115.88	11.54	13.45	40.15	
30	111.79	7.45	11.96	30.10	30	115.97	11.63	13.50	40.00	
35	111.85	7.51	11.97	30.08	35	116.04	11.70	13.50	40.00	
40	111.91	7.57	12.01	29.98	40	116.09	11.75	13.44	40.18	
45	111.96	7.62	12.00	30.00	45	116.12	11.78	13.47	40.09	
50	112.01	7.67	12.00	30.00	50	116.16	11.82	13.50	40.00	
55	112.06	7.72	11.99	30.03	55	116.20	11.86	13.49	40.03	
60	112.11	7.77	11.93	30.18	60	116.25	11.91	13.46	40.12	
70	112.16	7.82	12.00	30.00	70	116.29	11.95	13.48	40.06	
80	112.21	7.87	11.98	30.05	80	116.36	12.02	13.50	40.00	
90	112.25	7.91	11.96	30.10	90	116.42	12.08	13.50	40.00	
100	112.29	7.95	11.99	30.03	100	116.47	12.13	13.47	40.09	

BH No.: 10407	**District: Ghanzi**
Date of test commencement: 01/09/2007	**Location: Ncojane**
Time of test commencemen: 0630 Hrs	**BH depth (m): 243m**
Date of test completion: 01/09/2007	**Screen Interval (m):**
Time of test completion: 1450 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 104.34m**
Temperature of water (°C):	**EC (mS/cm): pH:**

STEP No. **3** / STEP No. **4**

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **200L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **250L**	Pumping Rate (m^3/hr)	Comments
0.25	116.57	12.23			0.25	121.11	16.77			
0.5	116.71	12.37			0.5	121.31	16.97			
1	116.93	12.59	13.99		1	121.47	17.13	13.96		
1.5	117.29	12.95			1.5	121.61	17.27			
2	117.51	13.17	14.40	50.00	2	121.79	17.45	13.86	64.94	
2.5	117.81	13.47			2.5	121.85	17.51			
3	118.21	13.87	14.33	50.24	3	121.97	17.63	13.84	65.03	
4	118.63	14.29	14.37	50.10	4	122.10	17.76	13.80	65.22	
5	118.90	14.56	14.36	50.14	5	122.15	17.81	13.85	64.98	
6	119.26	14.92	14.40	50.00	6	122.21	17.87	13.82	65.12	
7	119.48	15.14	14.38	50.07	7	122.26	17.92	13.84	65.03	
8	119.71	15.37	14.40	50.00	8	122.31	17.97	13.81	65.17	
9	119.89	15.55	14.39	50.03	9	122.37	18.03	13.84	65.03	
10	119.99	15.65	14.34	50.21	10	122.44	18.10	13.80	65.22	
11	120.11	15.77	14.41	49.97	11	122.49	18.15	13.83	65.08	
12	120.22	15.88	14.37	50.10	12	122.55	18.21	13.80	65.22	
13	120.31	15.97	14.34	50.21	13	122.67	18.33	13.85	64.98	
14	120.36	16.02	14.39	50.03	14	122.79	18.45	13.81	65.17	
15	120.40	16.06	14.41	49.97	15	122.87	18.53	13.84	65.03	
20	128.48	24.14	14.35	50.17	20	122.92	18.58	13.83	65.08	
25	120.54	16.20	14.40	50.00	25	123.00	18.66	13.80	65.22	
30	120.59	16.25	14.39	50.03	30	123.08	18.74	13.85	64.98	
35	120.63	16.29	14.37	50.10	35	123.14	18.80	13.82	65.12	
40	120.66	16.32	14.40	50.00	40	123.23	18.89	13.84	65.03	
45	120.71	16.37	14.40	50.00	45	123.39	19.05	13.81	65.17	
50	120.74	16.40	14.35	50.17	50	123.51	19.17	13.85	64.98	
55	120.77	16.43	14.38	50.07	55	123.64	19.30	13.82	65.12	
60	120.83	16.49	14.37	50.10	60	123.79	19.45	13.80	65.22	
70	120.88	16.54	14.40	50.00	70	123.93	19.59	13.80	65.22	
80	120.92	16.58	14.36	50.14	80	124.23	19.89	13.83	65.08	
90	120.97	16.63	14.40	50.00	90	124.36	20.02	13.81		
100	121.01	16.67	14.37	50.10	100	124.44	20.10			

BH No.: 10407	**District: Ghanzi**
Date of test commencement: 01/09/2007	**Location: Ncojane**
Time of test commencemen: 0630 Hrs	**BH depth (m): 243m**
Date of test completion: 01/09/2007	**Screen Interval (m):**
Time of test completion: 1450 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 104.34m**
Temperature of water (°C):	**EC (mS/cm): pH:**

STEP No. **5** / STEP No.

TIME (min)	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill 250L**	**Pumping Rate (m3/hr)**	**TIME (min)**	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill ______L**	**Pumping Rate (m3/hr)**	**Comments**
0.25	124.56	20.22			0.25					
0.5	124.67	20.33			0.5					

1	124.86	20.52	11.72	76.79	1					
1.5	124.94	20.60			1.5					
2	125.19	20.85	11.68	77.05	2					
2.5	125.39	21.05			2.5					
3	125.57	21.23	11.66	77.19	3					
4	125.94	21.60	11.68	77.05	4					
5	126.31	21.97	11.67	77.12	5					
6	126.63	22.29	11.69	76.99	6					
7	126.87	22.53	11.66	77.19	7					
8	127.11	22.77	11.67	77.12	8					
9	127.41	23.07	11.70	76.92	9					
10	127.74	23.40	11.68	77.05	10					
11	127.94	23.60	11.66	77.19	11					
12	128.31	23.97	11.69	76.99	12					
13	128.53	24.19	11.67	77.12	13					
14	128.77	24.43	11.70	76.92	14					
15	128.91	24.57	11.68	77.05	15					
20	129.17	24.83	11.69	76.99	20					
25	129.34	25.00	11.69	76.99	25					
30	129.51	25.17	11.70	76.92	30					
35	129.65	25.31	11.67	77.12	35					
40	129.78	25.44	11.69	76.99	40					
45	129.87	25.53	11.70	76.92	45					
50	129.96	25.62	11.70	76.92	50					
55	130.11	25.77	11.69	76.99	55					
60	130.24	25.90	11.67	77.12	60					
70	130.38	26.04	11.68	77.05	70					
80	130.47	26.13	11.70	76.92	80					
90	130.59	26.25	11.66	77.19	90					
100	130.63	26.29	11.70	76.92	100					

Table 38-7 Constant Rate Test – BH10407

BH No.: 10407						**District: Ghanzi**				
Date of test commencement: 02.09.2007						**Location: Ncojane**				
Time of test commencemen: 0700 Hrs						**BH depth (m): 243m**				
Date of test completion: 05/09/2007						**Screen Interval (m):**				
Time of test completion: 0700 Hrs						**Depth of pump intake (m):155m**				
Method of water level measurement: Electrical Dipper						**Static water level before test (m): 104.60m**				
Temperature of water (^oC):						**EC (mS/cm):**			**pH:**	
	Elapsed time	Depth to	Drawdown	Time to fill		Temp	EC		Manometer	
	(min)	Water (m)	(m)	250l	Q(m^3/h)	(^0C)	(us/cm)	pH	(cm)	Comments
	0.25	114.88	10.28							
	0.5	115.95	11.35							
	1	118.25	13.65							
	2	118.65	14.05	13.47	66.82					
	3	118.90	14.30	13.85	64.98					
	4	119.18	14.58	13.77	65.36					
	5	119.49	14.89	13.81	65.17					
	6	119.89	15.29	13.79	65.26					
	7	120.15	15.55	13.84	65.03					
	8	120.34	15.74	13.80	65.22					
	9	120.48	15.88	13.79	65.26					
	10	120.60	16.00	13.82	65.12					
	11	120.89	16.29	13.81	65.17					
	12	120.90	16.30	13.84	65.03					
	15	120.98	16.38	13.80	65.22					
	20	121.15	16.55	13.81	65.17					
	25	121.17	16.57	13.80	65.22					
	30	121.24	16.64	13.82	65.12					
	35	121.31	16.71							
	40	121.44	16.84	13.84	65.03					
	45	121.67	17.07	13.79	65.26					
	50	121.70	17.10	13.81	65.17					
	55	121.79	17.19							
	60	121.84	17.24	13.84	65.03	27.10	600.00	7.87		
	75	121.70	17.10	13.85	64.98					
	90	121.79	17.19	13.81	65.17					
	105	121.84	17.24	13.80	65.22					
	120	121.90	17.30	13.81	65.17	28.00	601.00	7.85		
	150	121.98	17.38	13.82	65.12					
	180	122.03	17.43	13.84	65.03	28.50	593.00	7.88		
	210	122.07	17.47	13.79	65.26					
	240	122.13	17.53	13.81	65.17	30.90	593.00	7.96		
	270	122.17	17.57	13.84	65.03					
	300	122.21	17.61	13.80	65.22	32.50	581.00	7.67		
	330	122.25	17.65	13.82	65.12					
	360	122.28	17.68	13.79	65.26	31.20	596.00	7.69		
	390	122.32	17.72	13.84	65.03	31.50				
	420	122.37	17.77	13.81	65.17	31.50	583.00	7.97		
	450	122.42	17.82	13.83	65.08					
8	480	122.44	17.84	13.84	65.03	30.60	588.00	7.67		
9	540	122.49	17.89	13.80	65.22	30.00	597.00	7.68		
10	600	122.54	17.94	13.81	65.17	29.20	5.86	7.84		
11	660	122.57	17.97	13.79	65.26	28.20	589.00	7.93		
12	720	122.64	18.04	13.84	65.03	25.90	596.00	7.78		
13	780	122.77	18.17	13.80	65.22	23.00	600.00	7.96		
14	840	122.84	18.24	13.82	65.12	24.40	596.00	7.82		
15	900	122.89	18.29	13.83	65.08	22.20	577.00	7.95		
16	960	122.96	18.36	13.85	64.98	24.60	578.00	7.87		
17	1020	123.03	18.43	13.47	66.82	25.00	565.00	7.81		

18	1080	123.09	18.49	13.82	65.12	24.60	580.00	7.96		
19	1140	123.16	18.56	13.80	65.22	24.50	578.00	7.91		
20	1200	123.49	18.89	13.84	65.03	23.60	556.00	7.83		
21	1260	123.74	19.14	13.81	65.17	22.70	579.00	7.80		
22	1320	123.78	19.18	13.82	65.12	21.40	563.00	7.79		
23	1380	123.83	19.23	13.19	68.23	20.90	577.00	7.99		
24	1440	124.80	20.20	13.84	65.03	24.60	590.00	7.88		
25	1500	124.05	19.45	13.82	65.12	26.40	578.00	7.91		
26	1560	124.05	19.45	13.81	65.17	27.80	589.00	7.83		
27	1620	124.07	19.47	13.80	65.22	28.50	593.00	7.92		
28	1680	124.10	19.50	13.84	65.03	29.90	572.00	7.81		
29	1740	124.14	19.54	13.82	65.12	33.20	555.00	7.69		
30	1800	124.20	19.60	13.79	65.26	33.10	545.00	7.66		
31	1860	124.24	19.64	13.85	64.98	32.70	547.00	7.62		
32	1920	128.28	23.68	13.80	65.22	34.60	549.00	7.70		
33	1980	124.32	19.72	13.82	65.12	32.50	556.00	7.84		
34	2040	124.36	19.76	13.84	65.03	31.70	554.00	7.73		
35	2100	124.39	19.79	13.81	65.17	27.20	564.00	7.95		
36	2160	124.42	19.82	13.82	65.12	25.40	570.00	7.97		
37	2220	124.46	19.86	13.80	65.22	24.90	566.00	7.93		
38	2280	124.49	19.89	13.84	65.03	24.50	568.00	7.87		
39	2340	124.53	19.93	13.79	65.26	24.60	571.00	7.96		
40	2400	124.61	20.01	13.82	65.12	25.40	550.00	7.76		
41	2460	124.68	20.08	13.83	65.08	22.90	551.00	8.14		
42	2520	124.79	20.19	13.81	65.17	23.50	582.00	8.26		
43	2580	124.88	20.28	13.82	65.12	22.70	559.00	8.17		
44	2640	124.92	20.32	13.85	64.98	24.40	586.00	7.84		
45	2700	124.95	20.35	13.47	66.82	23.60	581.00	7.77		
46	2760	124.98	20.38	13.81	65.17	23.40	589.00	7.87		
47	2820	125.04	20.44	13.83	65.08	23.70	580.00	7.92		
48	2880	125.07	20.47	13.84	65.03	24.70	583.00	7.96		
49	2940	125.10	20.50	13.82	65.12	27.30	567.00	7.93		
50	3000	125.16	20.56	13.80	65.22	29.80	555.00	7.77		
51	3060	125.23	20.63	13.79	65.26	30.50	560.00	7.72		
52	3120	125.29	20.69	13.83	65.08	29.80	562.00	7.83		
53	3180	125.37	20.77	13.80	65.22	33.30	541.00	7.65		
54	3240	125.44	20.84	13.84	65.03	32.20	565.00	8.21		
55	3300	125.61	21.01	13.82	65.12	30.40	557.00	7.95		
56	3360	125.73	21.13	13.47	66.82	30.60	575.00	7.79		
57	3420	125.85	21.25	13.80	65.22	29.60	581.00	7.88		
58	3480	125.94	21.34	13.82	65.12	28.90	572.00	7.79		
59	3540	126.04	21.44	13.81	65.17	26.90	582.00	8.01		
60	3600	126.15	21.55	13.80	65.22	26.00	574.00	7.85		

Table 38-8 Recovery Test Data – BH10407

BH No.: 10407	District: Ghanzi
Date of test commencement: 05.09.2007	Location: Ncojane
Time of test commencemen: 1945 Hrs	BH depth (m): 243m
Date of test completion: 06/09/2007	Screen Interval (m):
Time of test completion: 1945 Hrs	Depth of pump intake (m):155m
Method of water level measurement: Electrical Dipper	Static water level before test (m): 104.60m
Temperature of water (°C):	EC (mS/cm): pH:

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0		
	0.25		
	0.5	115.97	11.37
	1	114.79	10.19
	2	111.79	7.19
	3	110.84	6.24
	4	110.32	5.72
	5	110.08	5.48
	6	109.79	5.19
	7	109.69	5.09
	8	109.55	4.95
	9	109.49	4.89
	10	109.42	4.82
	12	109.36	4.76
	15	109.07	4.47
	20	108.7	4.1
	25	108.47	3.87
	30	108.27	3.67
	40	107.98	3.38
	50	107.78	3.18
	60	107.64	3.04
	75	107.41	2.81
	90	107.32	2.72
	105	107.23	2.63
	120	107.09	2.49

WL at end of test: 126.15m
Total Drawdown: 21.65m
Final discharge rate 65 (m^3/hr)

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	106.23	1.63
	180	105.98	1.38
	210	105.93	1.33
	240	105.88	1.28
	270	105.79	1.19
	300	105.69	1.09
	330	105.62	1.02
	360	105.6	1
	390	105.6	1
	420	105.57	0.97
	450	105.48	0.88
	480	105.45	0.85
	540	105.4	0.8
	600	105.4	0.8
	660	105.38	0.78
	720	105.36	0.76
	780	105.34	0.74
	840	105.33	0.73
	900	105.3	0.7
	960	105.28	0.68
	1020	105.27	0.67
	1080	105.26	0.66
	1140	105.25	0.65
	1200	105.24	0.64
	1260	105.22	0.62
	1320	105.2	0.6
	1380	105.19	0.59
	1440	105.17	0.57

39 BH10408

BH10408 is an abandoned borehole drilled at site **P06**, Line **L1, TEM 294** and peg **15000m**. The borehole is located approximately 30 km south east of Ncojane and 10m east of replacement borehole BH10411. Drilling at this site commenced on 18th May 2007 and abandoned on 31st May 2007. Drilling started with 12 inch DTH bit from 5 to 60m. The borehole was reamed with a 17 inch DHT bit from 21 to 60 m and then cased down to 60m with the 15 inch casing followed by cement grouting the annular space. Drilling continued with a 12.5 inch bit from 60 to 107 m and reamed from 60 to 144 m using 15 inch bit when drilling bit broke into the borehole. Fishing of the shunk bit was not attempted before the contractor demobilised. BH10408 was later replaced by BH10411, which was drilled about 10m west of BH10408. Drilling of replacement was succefully completed and detailed are in chapter 42 of this report..

39.1 SITING CRITERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block and with probable thin dolerite sill/dyke.

40 BH10409

BH10409 is a replacement borehole for the abandoned borehole BH10406, drilled at site **P05**, Line **L1** within 10m of the abandoned borehole BH10406. Drilling at this site commenced on the 22nd May 2007 with a 17 inch drilling bit and was stopped at a depth of 20m on the 24th May 2007 due to a breakdown of the hydraulic pump. Contractors left site on the 31st May 2007 to service the drilling rig and continuation of drilling never took place, rendering the borehole abandoned at the end of drilling activities.

40.1 SITING CRITERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block and with probable thin dolerite sill/dykes.

41 BH10410

BH10410 is a production borehole drilled at site **P08**, Line **L2, TEM 316** and peg **13000m**. It is located about 29 km south east of Ncojane. Drilling at this site started on the 7th June 2007 and was completed on 23rd July 2007 at a depth of 263 m.

41.1 SITING CRITERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block and with probable thin dolerite sill/dyke.

41.2 DRILLING RESULTS

Drilling of this borehole was started with a 17 inch drilling bit down to a depth of 70 m after which 15 inch plain casings were installed and cement grouted down to 70 m. Drilling was then continued from 70 m to 191 m using a 15 inch drilling bit. At this depth (191 m) 12 inch plain casings were installed and cement grouted. Drilling from 191 m to the terminal depth of 263 m was through the use an 8 tricone bit after which the borehole was reamed to the same depth (263 m) with a 12 inch tricone bit. Various lithologies including fine grained sands, silcrete, mudstones, coal and fine to coarse grained sandstones were intercepted during drilling of this borehole (**Figure 41-1**).

During drilling of this borehole, two water strikes were encountered. The depths, conductivities and yields (measured on a 90^{O} V-notch weir) for the water strikes are as follows:

1. (185m, 1003µS/cm (TDS ~ 652 mg/L, 9 m^3/hr)
2. (201m, 1000 µS/cm (TDS ~ 650 mg/L, 51 m^3/hr)
3. (226m, 780 µS/cm (TDS ~ 507 mg/L), 114 m^3 /hr

Borehole geophysical logging was conducted prior to borehole design in order to optimise screen placement **(Figure 41-2).** The borehole was constructed with 8 inch epoxy coated casings and screens with the screens placed between 213 and 258 m. Borehole development was through airlift pumping and air jetting. The final blow out yield after borehole construction and development was 74 m^3/hr which is less than the blow out yield obtained prior to screen placement. This reduction in the yield probably due to a combination of sealing off the top water strikes and percentage open area of the screens. The final the electrical conductivity was measured as 630µS/cm (TDS ~ 410 mg/L).

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

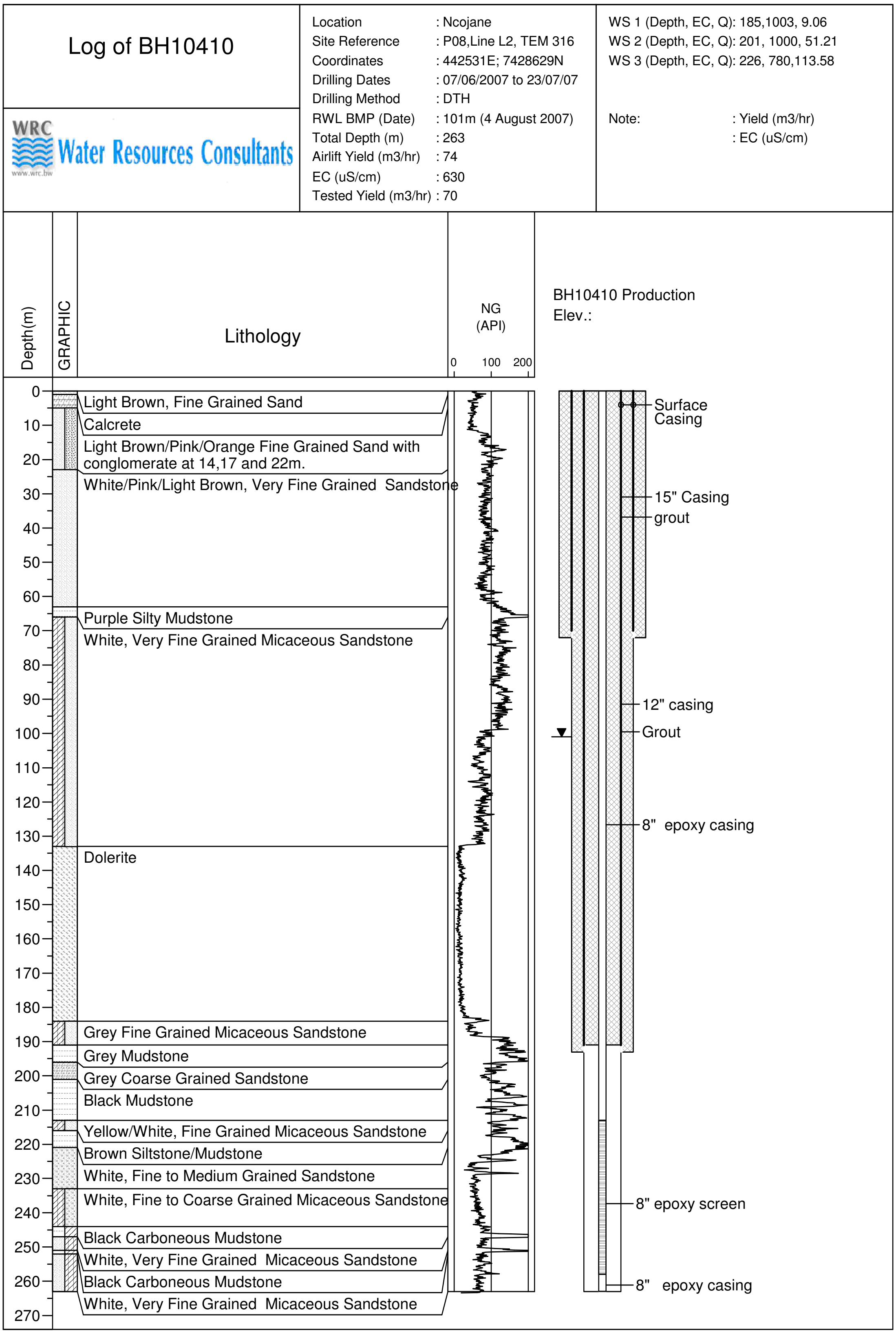

Figure 41-1 Log of BH10410

Well Name: BH10410

Location: Ncojane WellField

Reference: Ground Surface

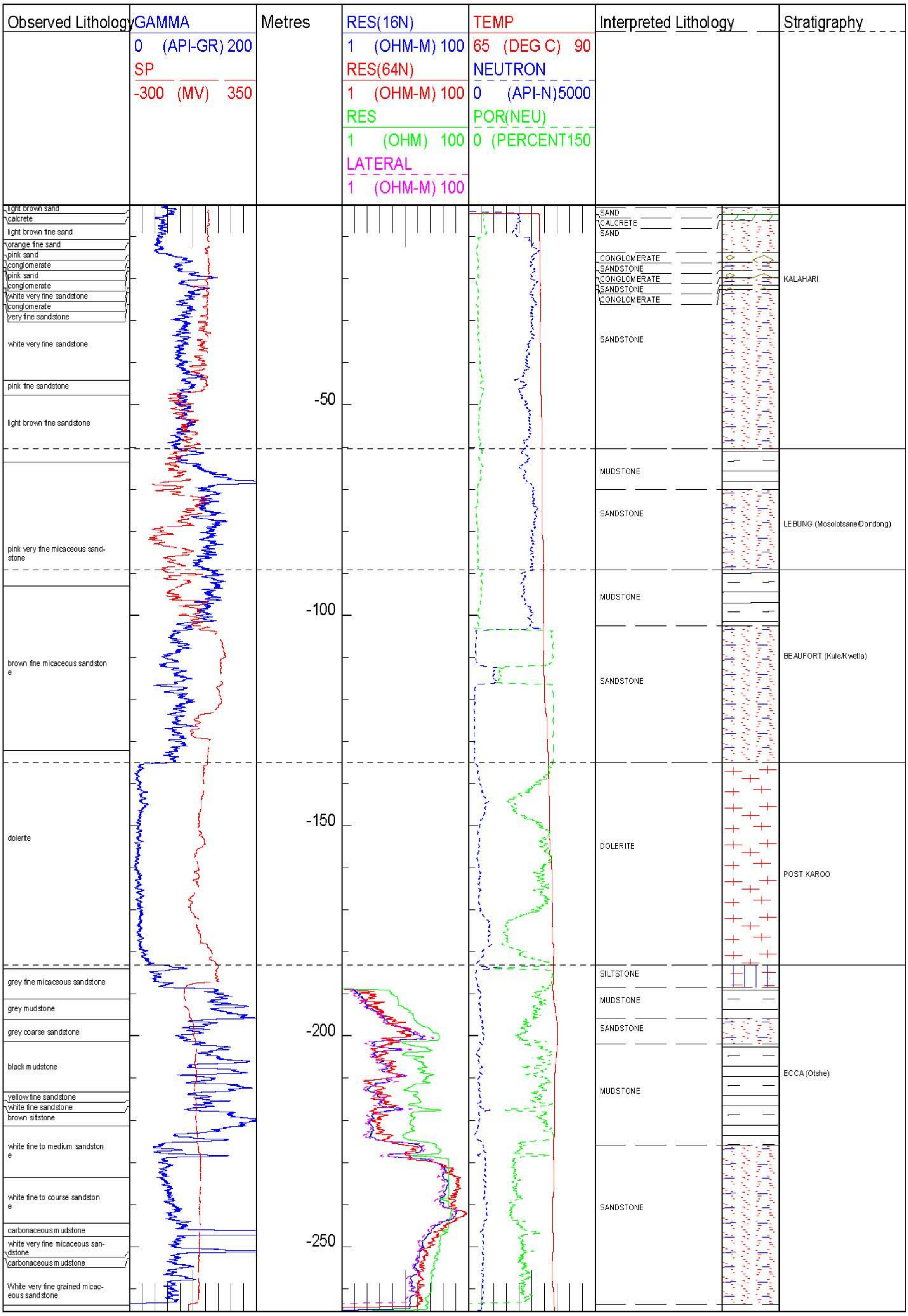

Figure 41-2 Geophysical log of BH10410

41.3 PUMP TESTING RESULTS

Test pumping at this borehole operations were started on 9th September 2007 with a calibration test at BH10410. The tests carried out were calibration, step drawdown, constant rate and recovery tests. The static water level before the start of the test was 101.17 m bmp. A summary of the pumping test data for BH10410 is in **Table 41-1**. The collected pump testing data is presented in **Tables 41-5 to 41-9**.

Table 41-1 Summary of Pumping Test Data BH10410

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	5.91	20
	2	15	9.35	40
	3	15	14.23	60
	4	15	19.97	78
Step Test	1	100	8.06	25
	2	100	11.10	40
	3	100	15.52	55
	4	100	21.24	70
	5	100	31.24	77
Constant Rate	1	4320	25.75	70
Recovery	1	1440	1.56*	0

Note. 0.37 Residual Drawdown*

41.3.1 Step Drawdown Test

The step drawdown test (SDT) was conducted on 10th September 2007 at discharge rates of 25, 40 55, 70 and 77 m^3/hr, with a total drawdown of 31.24 m at the end of the test. The static water level before the start of the test was 101.23 m bmp. The plots are presented in **Figures 41-3 to 41-5.**

The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method was 68m^2/d (**Figure 41-5**). The results of the interpreted step test data are given in **Table 41-2**.

Table 41-2 Results of Step Test Analysis BH10410

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10410	1.19E-002	4.40E-007	68	25	8.36	8.36	2.99
				40	2.15	10.51	3.81
				55	3.69	14.20	3.87
				70	5.39	19.59	3.57
				77	7.90	27.49	2.80

The planned duration for the constant rate test of BH10410 was 3 days and the step drawdown test data was used to select the optimal pumping rate. Straight lines were drawn on the latter slopes of the semi-logarithmic plot of drawdown versus time (**Figure 41-3**) to estimate the expected total drawdown after 3 days of pumping

41.3.2 Constant Rate and Recovery Tests

Constant rate test (CRT) was carried out between 13th and 17th September 2007 at a discharge rate of 70 m^3/hr and the total drawdown after 72 hrs of pumping was 25.75 m. The CRT test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 1.56 m.

Transmissivity (T) values obtained by Cooper-Jacob (1946) and Hantush leaky analytical solutions were 90 and 83 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a transmissivity value of 85m^2/d was obtained. The results are summarised in **Table 41-3** and the interpreted data is presented in **Figures 41-6 to 41-8**. There is an apparent impermeable barrier interpreted in the CRT data after 2400 minutes of pumping, **Figure 41-6**.

Table 41-3 Summary of Constant Rate and Recovery Tests BH10410

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10410	72	1680	a) 90 b) 83	d) 85	Confined leaky with storage and negative boundary

Notes:
<u>Interpretation Techniques</u>
a) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

41.3.2.1 <u>Aquifer Type interpreted</u>

The interpretation of the pump testing data indicates that the aquifer type is confined-leaky with negative (barrier) boundary.

41.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none acidified) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. The results of chemical analyses from CSIR lab are presented in **Table 41-4.**

The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC) and pH are 22.4 °C, 704 µS/cm and 7.99 respectively.

Table 41-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10410	7.5	112.0	21.8	16.3	21.1	77.8	235	<0.2	0.69	<0.05	<0.05	720	6.9	461
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10410	0.1	74	<0.1	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in µS/cm
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

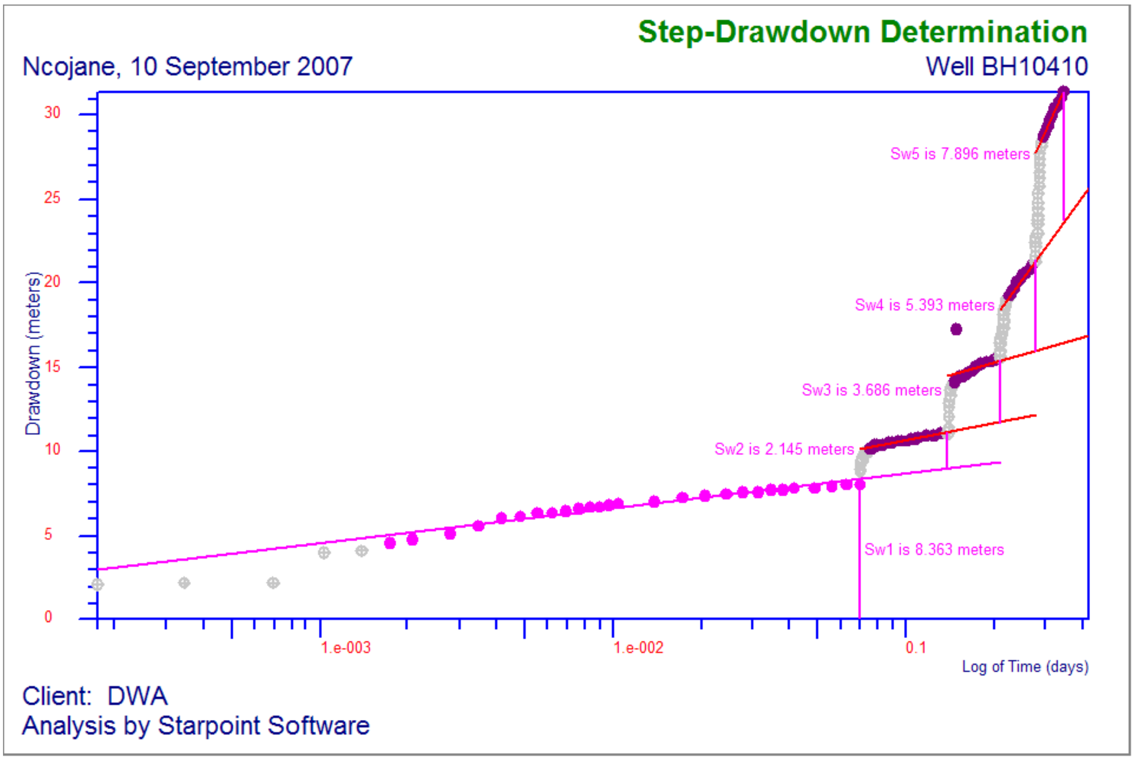

Figure 41-3 Pumping Test Results for BH10410: Step Drawdown Test - Hantush-Bierschenk (semi-log)

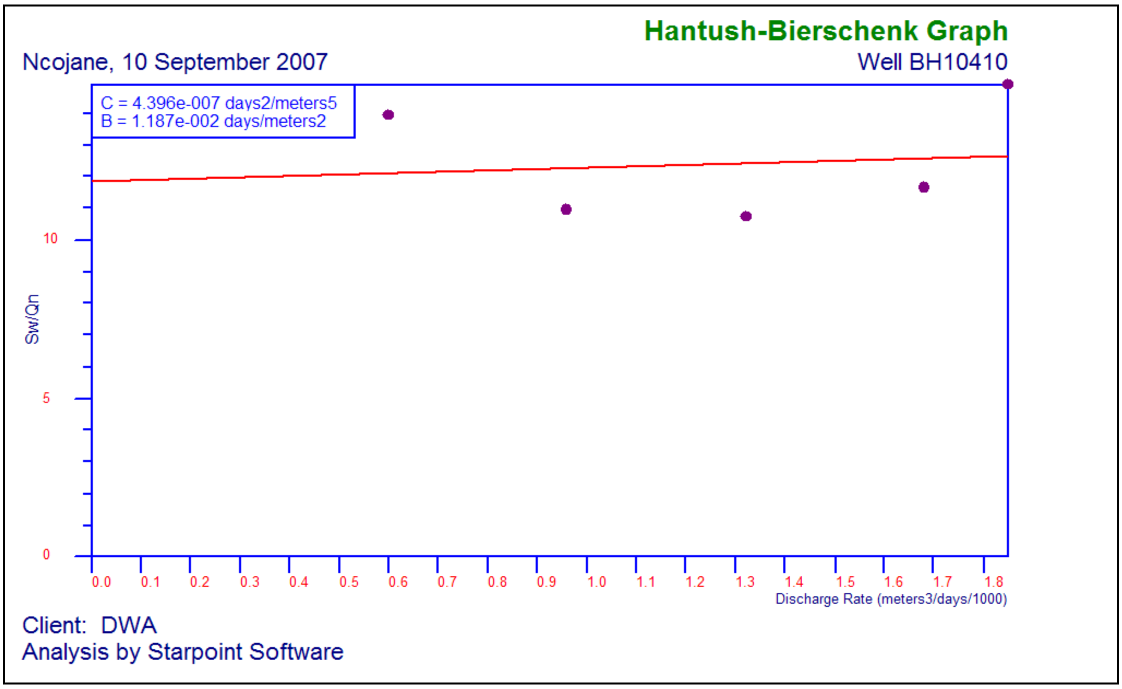

Figure 41-4 Pumping Test Results for BH10410: Step Drawdown Test – Hantush-Bierschenk

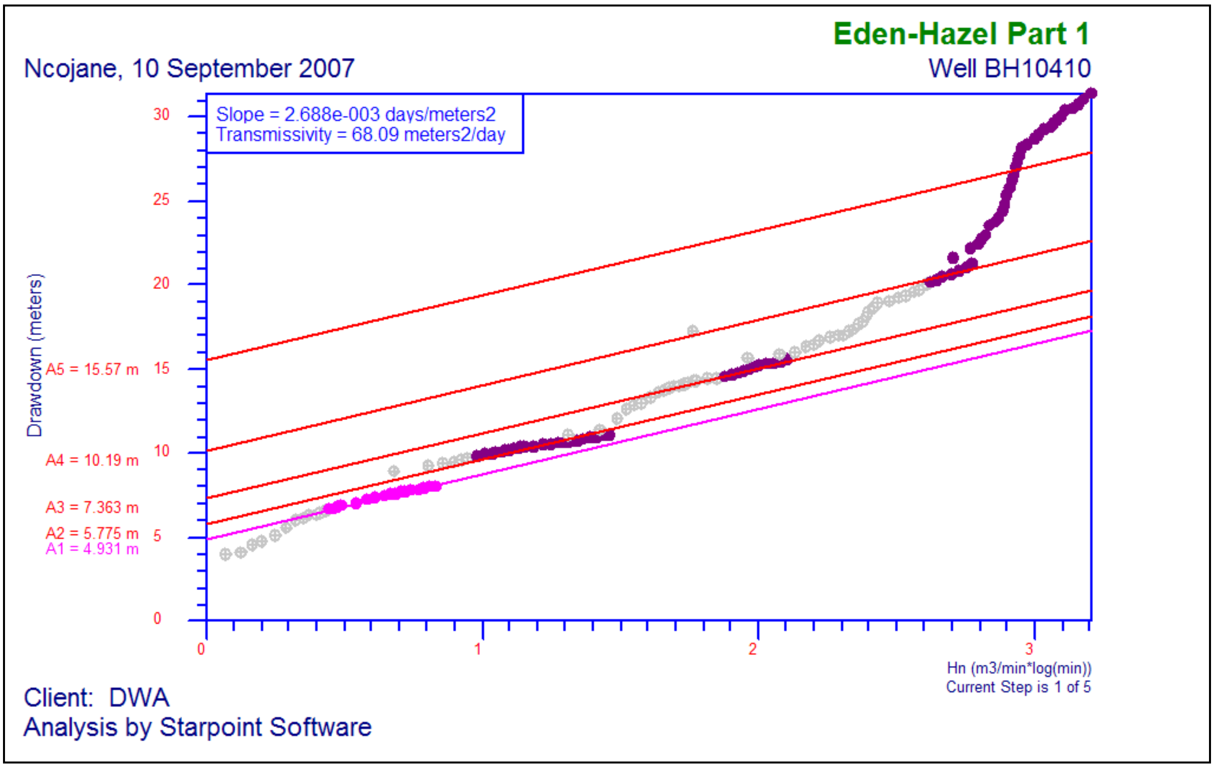

Figure 41-5 Pumping Test Results for BH10410: Step Drawdown Test – Eden-Hazel (Part 1)

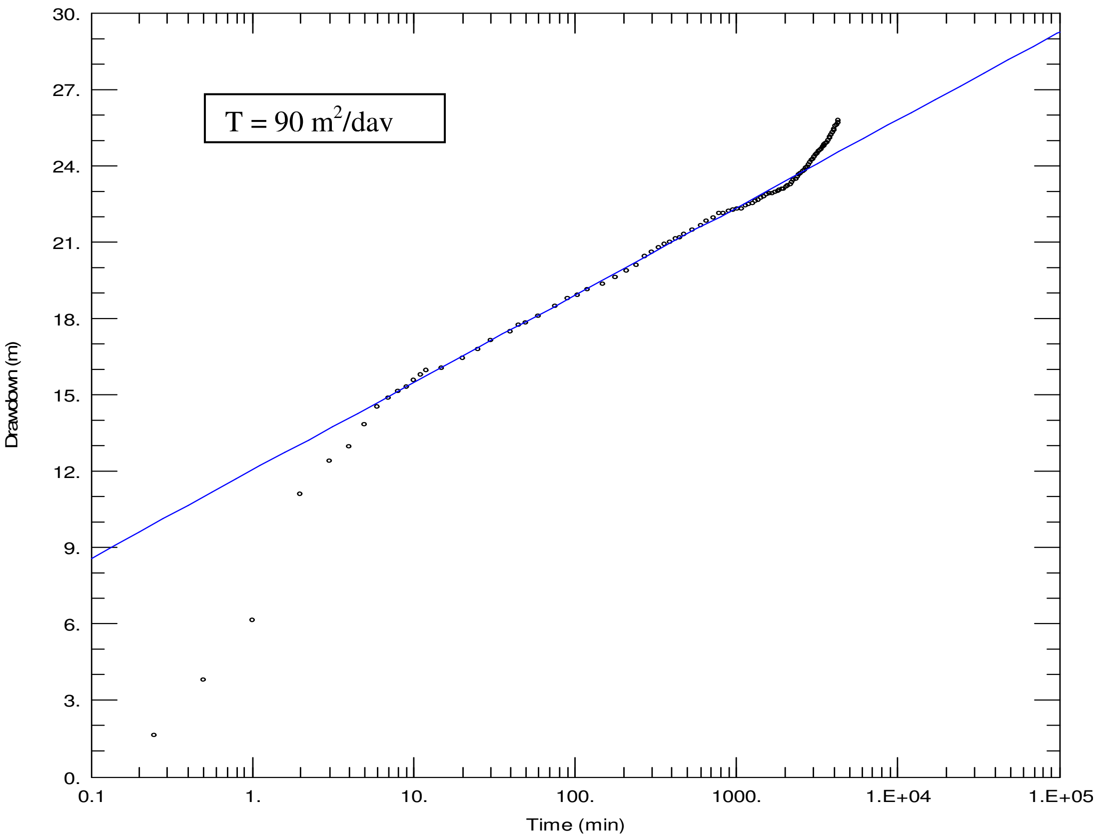

Figure 41-6 Pumping Test Results for BH10410: Cooper Jacob Solution

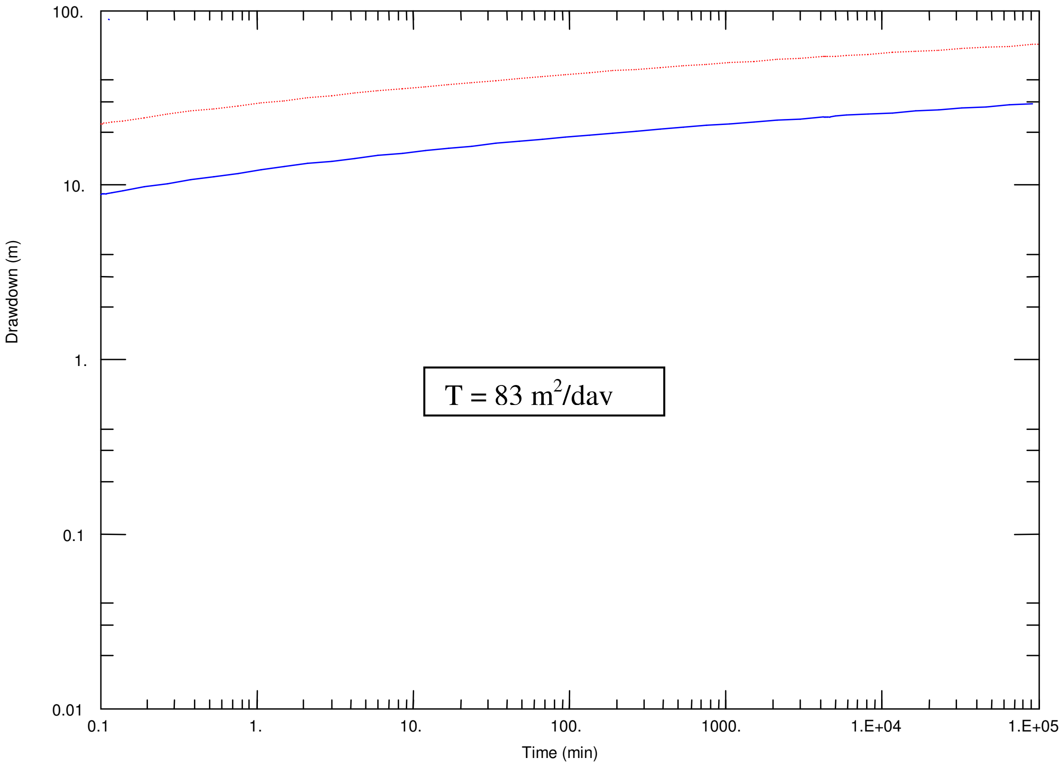

Figure 41-7 Pumping Test Results for BH10410: CRT Hantush leaky with storage in the Aquitard

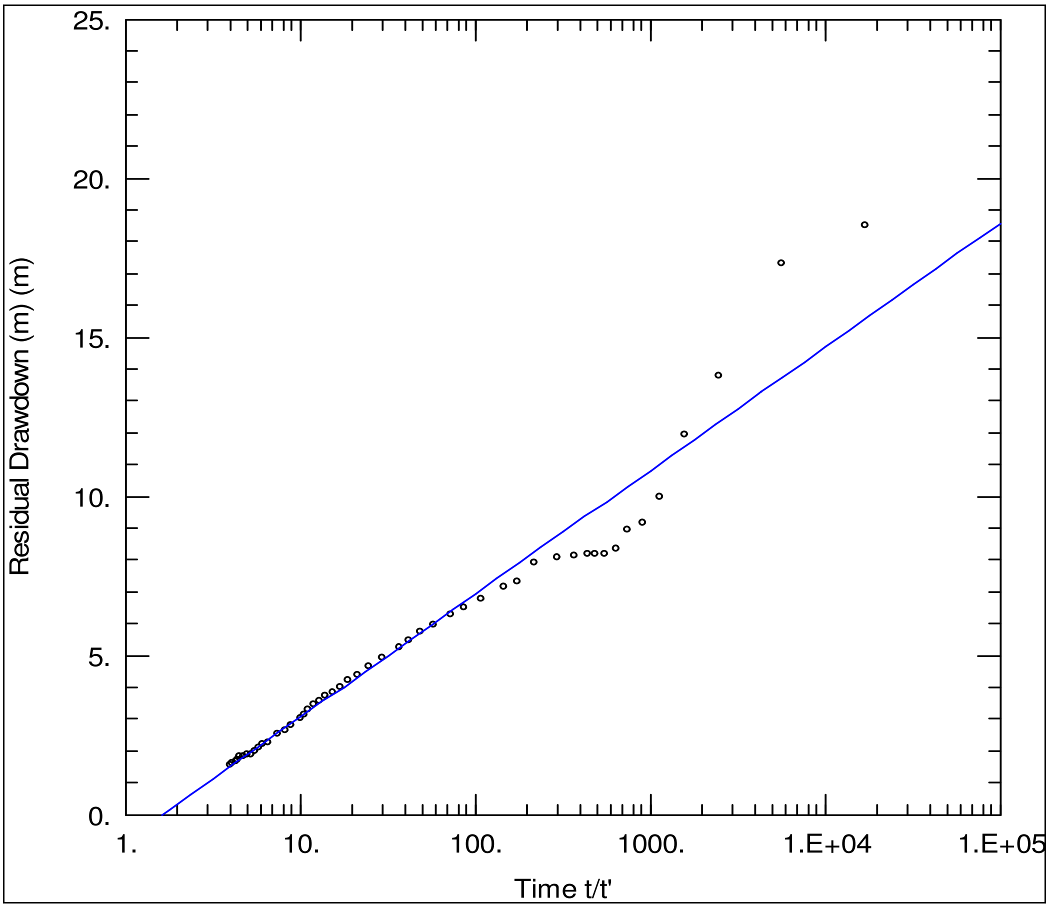

Figure 41-8 Pumping Test Results for BH10410: Theis Recovery Solution

Table 41-5 Calibration Test Data – BH10410

BH No.: 10410					**District: Ghanzi**				
Date of test commencement: 09/09/2007					**Location: Ncojane**				
Time of test commencement: 1100 Hrs					**BH depth (m): 263m**				
Date of test completion: 09/09/2007					**Screen Interval (m):**				
Time of test completion: 1200 Hrs					**Depth of pump intake (m):155m**				
Method of water level measurement: Electrical Dipper					**Static water level before test (m): 101.17m**				
Temperature of water (°C):					**EC (mS/cm):**			**pH:**	
Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **100L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **150L**	Pump Rate (m3/hr)
STEP 1					**STEP 2**				
15 sec	103.05	1.88			15 sec	107.16	5.99		
30 sec	103.83	2.66			30 sec	107.58	6.41		
1	105.06	3.89			1	107.69	6.52	13.73	39.33
1.5	105.51	4.34			1.5	107.81	6.64		
2	105.60	4.43			2	107.90	6.73	13.61	39.68
2.5	105.69	4.52			2.5	107.94	6.77		
3	105.74	4.57	18.20	19.78	3	108.00	6.83	13.47	40.09
4	105.74	4.57	18.06	19.93	4	108.31	7.14	13.52	39.94
5	105.85	4.68	17.79	20.24	5	109.04	7.87	13.39	40.33
6	105.96	4.79	17.96	20.04	6	109.55	8.38	13.44	40.18
7	106.12	4.95	17.95	20.06	7	109.78	8.61	13.51	39.97
8	106.23	5.06	17.94	20.07	8	109.86	8.69	13.50	40.00
9	106.36	5.19	17.99	20.01	9	109.89	8.72	13.49	40.03
10	106.49	5.32	17.98	20.02	10	110.18	9.01	13.46	40.12
11	106.77	5.60	17.95	20.06	11	110.26	9.09	13.50	40.00
12	106.94	5.77	17.97	20.03	12	110.39	9.22	13.48	40.06
15	107.08	5.91	17.98	20.02	15	110.52	9.35	13.50	40.00
Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **200L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **250L**	Pump Rate (m3/hr)
STEP 3					**STEP 4**				
15 sec	110.67	9.50			15 sec	115.67	14.50		
30 sec	110.79	9.62			30 sec	115.82	14.65		
1	111.42	10.25	12.37	58.21	1	116.06	14.89	11.88	75.76
1.5	111.91	10.74			1.5	116.39	15.22		
2	112.59	11.42	12.16	59.21	2	116.59	15.42	11.66	77.19
2.5	113.20	12.03			2.5	116.79	15.62		
3	113.75	12.58	12.02	59.90	3	117.01	15.84	11.51	78.19
4	113.87	12.70	11.98	60.10	4	117.51	16.34	11.48	78.40
5	113.91	12.74	11.99	60.05	5	117.89	16.72	11.49	78.33
6	113.98	12.81	11.98	60.10	6	118.36	17.19	11.53	78.06
7	114.18	13.01	12.00	60.00	7	118.77	17.60	11.50	78.26
8	114.36	13.19	11.96	60.20	8	119.09	17.92	11.52	78.13
9	114.56	13.39	11.99	60.05	9	119.48	18.31	11.49	78.33
10	114.79	13.62	12.01	59.95	10	119.93	18.76	11.51	78.19
11	114.92	13.75	11.95	60.25	11	120.26	19.09	11.54	77.99
12	115.11	13.94	12.01	59.95	12	120.71	19.54	11.48	78.40
15	115.40	14.23	11.99	60.05	15	121.14	19.97	11.50	78.26

Table 41-6 Step Drawdown Test Data – BH10410

BH No.: 10410	District: Ghanzi
Date of test commencement: 10/09/2007	Location: Ncojane
Time of test commencemen: 0600 Hrs	BH depth (m): 263m
Date of test completion: 10/09/2007	Screen Interval (m):
Time of test completion: 1420 Hrs	Depth of pump intake (m):155m
Method of water level measurement: Electrical Dipper	Static water level before test (m): 101.23m
Temperature of water (°C):	EC (mS/cm): pH:

STEP No. 1					STEP No. 2					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **100L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **150L**	Pumping Rate (m^3/hr)	Comments
0.25	103.30	2.07			0.25	110.02	8.79			
0.5	103.37	2.14			0.5	110.13	8.90			
1	103.42	2.19			1	110.45	9.22	13.56	39.82	
1.5	105.20	3.97			1.5	110.62	9.39			
2	105.34	4.11			2	110.71	9.48	13.49	40.03	
2.5	105.77	4.54			2.5	110.78	9.55	13.52	39.94	
3	106.04	4.81	13.69	26.30	3	110.90	9.67	13.50	40.00	
4	106.33	5.10	14.60	24.66	4	111.03	9.80	13.47	40.09	
5	106.79	5.56	14.40	25.00	5	111.17	9.94	13.50	40.00	
6	107.23	6.00	14.38	25.03	6	111.21	9.98	13.47	40.09	
7	107.32	6.09	14.39	25.02	7	111.27	10.04	13.46	40.12	
8	107.53	6.30	14.41	24.98	8	111.31	10.08	13.50	40.00	
9	107.58	6.35	14.33	25.12	9	111.34	10.11	13.45	40.15	
10	107.69	6.46	14.39	25.02	10	111.39	10.16	13.49	40.03	
11	107.79	6.56	14.34	25.10	11	111.47	10.24	13.50	40.00	
12	107.87	6.64	14.35	25.09	12	111.53	10.30	13.47	40.09	
13	107.96	6.73	14.40	25.00	13	111.56	10.33	13.46	40.12	
14	108.02	6.79	14.31	25.16	14	111.59	10.36	13.48	40.06	
15	108.13	6.90	14.38	25.03	15	111.63	10.40	13.50	40.00	
20	108.25	7.02	14.30	25.17	20	111.65	10.42	13.49	40.03	
25	108.48	7.25	14.40	25.00	25	111.69	10.46	13.49	40.03	
30	108.62	7.39	14.34	25.10	30	111.74	10.51	13.46	40.12	
35	108.68	7.45	14.39	25.02	35	111.79	10.56	13.45	40.15	
40	108.76	7.53	14.35	25.09	40	111.84	10.61	13.50	40.00	
45	108.84	7.61	14.40	25.00	45	111.88	10.65	13.47	40.09	
50	108.90	7.67	14.32	25.14	50	111.93	10.70	13.49	40.03	
55	108.95	7.72	14.37	25.05	55	112.01	10.78	13.45	40.15	
60	108.99	7.76	14.39	25.02	60	112.07	10.84	13.50	40.00	
70	109.07	7.84	14.36	25.07	70	112.13	10.90	13.48	40.06	
80	109.15	7.92	14.40	25.00	80	112.18	10.95	13.50	40.00	
90	109.27	8.04	14.38	25.03	90	112.25	11.02	13.48	40.06	

BH No.: 10410	**District: Ghanzi**
Date of test commencement: 10/09/2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 263m**
Date of test completion: 10/09/2007	**Screen Interval (m):**
Time of test completion: 1420 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 101.23m**
Temperature of water (°C):	**EC (mS/cm): pH:**

STEP No. 3					STEP No. 4					
TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **200L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **250L**	Pumping Rate (m^3/hr)	Comments
0.25					0.25	116.80	15.57			
0.5					0.5	116.89	15.66			
1	112.67	11.44	15.67		1	117.09	15.86	13.94		

1.5	113.35	12.12			1.5	117.28	16.05			
2	113.87	12.64	13.31	54.09	2	117.52	16.29	13.87	64.89	
2.5	114.13	12.90			2.5	117.67	16.44			
3	114.22	12.99	13.06	55.13	3	117.90	16.67	12.84	70.09	
4	114.58	13.35	13.06	55.13	4	118.14	16.91	12.86	69.98	
5	114.84	13.61	13.04	55.21	5	118.20	16.97	12.85	70.04	
6	115.01	13.78	13.12	54.88	6	118.29	17.06	12.83	70.15	
7	115.11	13.88	13.10	54.96	7	118.42	17.19	12.84	70.09	
8	115.19	13.96	13.09	55.00	8	118.62	17.39	12.86	69.98	
9	115.24	14.01	13.06	55.13	9	118.89	17.66	12.85	70.04	
10	115.33	14.10	13.00	55.38	10	119.05	17.82	12.84	70.09	
11	115.38	14.15	13.12	54.88	11	119.36	18.13	12.83	70.15	
12	115.44	14.21	13.09	55.00	12	119.58	18.35	12.86	69.98	
13	118.50	17.27	13.11	54.92	13	119.79	18.56	12.85	70.04	
14	115.55	14.32	13.08	55.05	14	119.94	18.71	12.80	70.31	
15	115.59	14.36	13.06	55.13	15	120.11	18.88	12.83	70.15	
20	115.64	14.41	13.03	55.26	20	120.29	19.06	12.85	70.04	
25	115.71	14.48	13.05	55.17	25	120.44	19.21	12.80	70.31	
30	115.78	14.55	13.02	55.30	30	120.58	19.35	12.80	70.31	
35	115.90	14.67	13.06	55.13	35	120.79	19.56	12.88	69.88	
40	116.01	14.78	13.06	55.13	40	120.94	19.71	12.84	70.09	
45	116.12	14.89	13.08	55.05	45	121.23	20.00	12.85	70.04	
50	116.21	14.98	13.10	54.96	50	121.39	20.16	12.80	70.31	
55	116.31	15.08	13.05	55.17	55	121.56	20.33	12.83	70.15	
60	116.42	15.19	13.09	55.00	60	121.71	20.48	12.82	70.20	
70	116.51	15.28	13.08	55.05	70	121.87	20.64	12.80	70.31	
80	116.59	15.36	13.06	55.13	80	122.05	20.82	12.85	70.04	
90	116.68	15.45	13.07	55.09	90	122.29	21.06	12.81	70.26	
100	116.75	15.52	13.08	55.05	100	122.47	21.24	12.83	70.15	

BH No.: 10410	**District: Ghanzi**
Date of test commencement: 10/09/2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 263m**
Date of test completion: 10/09/2007	**Screen Interval (m):**
Time of test completion: 1420 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 101.23m**
Temperature of water (^oC):	**EC (mS/cm):** **pH:**

	STEP No. 5					STEP No.				
TIME (min)	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill 250L**	**Pumping Rate (m3/hr)**	**TIME (min)**	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill ______L**	**Pumping Rate (m3/hr)**	**Comments**
0.25	122.55	21.32			0.25					
0.5	122.89	21.66			0.5					
1	123.37	22.14	11.77	76.47	1					
1.5	123.60	22.37			1.5					
2	123.98	22.75	11.60	77.59	2					
2.5	124.22	22.99			2.5					
3	124.74	23.51	11.58	77.72	3					
4	124.98	23.75	11.53	78.06	4					
5	125.18	23.95	11.57	77.79	5					
6	125.68	24.45	11.56	77.85	6					
7	126.03	24.80	11.53	78.06	7					
8	126.55	25.32	11.57	77.79	8					
9	126.99	25.76	11.55	77.92	9					
10	127.47	26.24	11.51	78.19	10					
11	127.83	26.60	11.54	77.99	11					
12	128.22	26.99	11.52	78.13	12					
13	128.61	27.38	11.58	77.72	13					
14	128.92	27.69	11.54	77.99	14					
15	129.36	28.13	11.57	77.79	15					
20	129.61	28.38	11.56	77.85	20					

25	129.88	28.65	11.51	78.19	25					
30	130.18	28.95	11.53	78.06	30					
35	130.49	29.26	11.51	78.19	35					
40	130.65	29.42	11.52	78.13	40					
45	130.87	29.64	11.56	77.85	45					
50	131.09	29.86	11.55	77.92	50					
55	131.31	30.08	11.51	78.19	55					
60	131.58	30.35	11.52	78.13	60					
70	131.77	30.54	11.57	77.79	70					
80	131.96	30.73	11.53	78.06	80					
90	132.26	31.03	11.51	78.19	90					
100	132.57	31.34	11.57	77.79	100					

Table 41-7 Constant Rate Test (first test)

BH No.: 10410	**District: Ghanzi**
Date of test commencement: 11.09.2007	**Location: Ncojane**
Time of test commencemen: 0700 Hrs	**BH depth (m): 263m**
Date of test completion: 11/09/2007	**Screen Interval (m):**
Time of test completion: 1200 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 101.75m**
Temperature of water (°C):	**EC (mS/cm):** **pH:**

	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 250l	$Q(m^3/h)$	Temp (°C)	EC (us/cm)	pH	Manometer (cm)	Comments
	0.25									
	0.5									
	1	104.93	3.18	12.89	69.82					
	2	100.05	(1.70)	12.86	69.98					
	3	112.13	10.38	12.85	70.04					
	4	115.59	13.84	12.87	69.93					
	5	116.19	14.44	12.81	70.26					
	6	116.58	14.83	12.84	70.09					
	7	116.63	14.88	12.85	70.04					
	8	116.70	14.95	12.83	70.15					
	9	116.90	15.15	12.81	70.26					
	10	117.18	15.43	12.85	70.04					
	11	117.32	15.57	12.84	70.09					
	12	117.40	15.65	12.82	70.20					
	15	117.66	15.91	12.85	70.04					
	20	118.17	16.42	12.80	70.31					
	25	118.44	16.69	12.83	70.15					
	30	118.60	16.85	12.85	70.04					
	35									
	40	118.72	16.97	12.81	70.26					
	45	118.79	17.04	12.86	69.98					
	50	118.87	17.12	12.82	70.20					
	55									
	60	118.95	17.20	12.85	70.04					
	75	119.09	17.34	12.84	70.09	26.80	706.00	8.10		
	90	119.27	17.52	12.83	70.15					
	105	119.41	17.66	12.80	70.31					
	120	119.73	17.98	12.82	70.20	27.50	695.00	8.08		
	150	119.96	18.21	12.82	70.20					
	180	120.28	18.53	12.85	70.04		690.00	7.97		
	210	120.51	18.76	12.81	70.26					
	240	120.77	19.02	12.84	70.09		728.00	8.02		
	270	120.94	19.19	12.80	70.31					
	300	121.21	19.46	12.86	69.98		713.00	7.93		

Table 41-8 Constant Rate Test – BH10410 (second test)

BH No.: 10410	**District: Ghanzi**
Date of test commencement: 13.09.2007	**Location: Ncojane**
Time of test commencement: 0600 Hrs	**BH depth (m): 263m**
Date of test completion: 16/09/2007	**Screen Interval (m):**
Time of test completion: 0600 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 101.52m**
Temperature of water (°C):	**EC (mS/cm): pH:**

	Elapsed time (min)	Depth to Water (m)	Drawdown (m)	Time to fill 250l	Q(m³/h)	Temp (°C)	EC (us/cm)	pH	Manometer (cm)	Comments
	0.25	103.15	1.63							
	0.5	105.34	3.82							
	1	107.68	6.16							
	2	112.62	11.10	12.60	71.43					
	3	113.92	12.40	12.77	70.48					
	4	114.47	12.95	12.88	69.88					
	5	115.36	13.84	12.86	69.98					
	6	116.04	14.52	12.80	70.31					
	7	116.39	14.87	12.83	70.15					
	8	116.65	15.13	12.84	70.09					
	9	116.84	15.32	12.82	70.20					
	10	117.10	15.58	12.81	70.26					
	11	117.32	15.80	12.83	70.15					
	12	117.49	15.97	12.85	70.04					
	15	117.55	16.03	12.82	70.20					
	20	117.97	16.45	12.86	69.98					
	25	118.30	16.78	12.81	70.26					
	30	118.63	17.11	12.84	70.09					
	35									
	40	118.98	17.46	12.80	70.31					
	45	119.24	17.72	12.85	70.04					
	50	119.34	17.82	12.82	70.20					
	55									
	60	119.60	18.08	12.80	70.31	26.20	669.00	7.99		
	75	119.99	18.47	12.82	70.20					
	90	120.30	18.78	12.86	69.98					
	105	120.44	18.92	12.81	70.26					
	120	120.63	19.11	12.83	70.15	24.80	692.00	8.18		
	150	120.87	19.35	12.84	70.09					
	180	121.14	19.62	12.86	69.98	26.40	686.00	8.14		
	210	121.37	19.85	12.82	70.20					
	240	121.58	20.06	12.81	70.26	30.20	602.00	8.04		
	270	121.95	20.43	12.80	70.31					
	300	122.12	20.60	12.83	70.15	31.70	694.00	7.98		
	330	122.28	20.76	12.85	70.04					
	360	122.42	20.90	12.80	70.31	31.90	664.00	7.92		
	390	122.51	20.99	12.80	70.31					
	420	122.62	21.10	12.84	70.09	31.30	679.00	7.97		
	450	122.70	21.18	12.81	70.26					
8	480	122.80	21.28	12.85	70.04	31.30	675.00	7.87		
9	540	123.01	21.49	12.80	70.31	29.30	716.00	8.05		
10	600	123.16	21.64	12.82	70.20	28.90	741.00	8.10		
11	660	123.33	21.81	12.85	70.04	28.50	716.00	7.96		
12	720	123.47	21.95	12.81	70.26	28.70	721.00	7.97		
13	780	123.64	22.12	12.80	70.31	25.60	720.00	8.04		
14	840	123.66	22.14	12.85	70.04	25.50	708.00	7.81		
15	900	123.71	22.19	12.82	70.20	25.30	703.00	7.92		
16	960	123.75	22.23	12.81	70.26	24.00	687.00	7.93		
17	1020	123.80	22.28	12.80	70.31	24.50	689.00	7.98		

18	1080	123.82	22.30	12.82	70.20	24.30	690.00	8.08		
19	1140	123.94	22.42	12.80	70.31	23.50	693.00	8.00		
20	1200	123.98	22.46	12.81	70.26	23.00	697.00	8.06		
21	1260	124.02	22.50	12.85	70.04	22.80	675.00	8.10		
22	1320	124.10	22.58	12.83	70.15	22.70	685.00	8.11		
23	1380	124.18	22.66	12.84	70.09	22.30	694.00	8.05		
24	1440	124.24	22.72	12.85	70.04	21.30	723.00	8.35		
25	1500	124.27	22.75	12.81	70.26	21.70	711.00	8.15		
26	1560	124.37	22.85	12.81	70.26	24.50	715.00	8.18		
27	1620	124.40	22.88	12.86	69.98	29.20	672.00	7.96		
28	1680	124.40	22.88	12.82	70.20	27.60	720.00	8.13		
29	1740	124.46	22.94	12.85	70.04	28.90	723.00	8.07		
30	1800	124.53	23.01	12.81	70.26	29.70	721.00	7.98		
31	1860	124.56	23.04	12.83	70.15	29.60	712.00	7.91		
32	1920	124.58	23.06	12.86	69.98	30.20	729.00	7.95		
33	1980	124.60	23.08	12.84	70.09	29.60	708.00	7.99		
34	2040	124.68	23.16	12.82	70.20	29.50	712.00	7.97		
35	2100	124.71	23.19	12.81	70.26	29.00	662.00	8.02		
36	2160	124.76	23.24	12.83	70.15	28.00	724.00	8.10		
37	2220	124.86	23.34	12.80	70.31	26.30	724.00	8.06		
38	2280	124.93	23.41	12.84	70.09	25.90	710.00	7.91		
39	2340	124.99	23.47	12.83	70.15	24.10	720.00	8.16		
40	2400	125.07	23.55	12.82	70.20	23.70	718.00	8.02		
41	2460	125.16	23.64	12.82	70.20	21.60	719.00	8.21		
42	2520	125.21	23.69	12.84	70.09	21.30	721.00	8.02		
43	2580	125.27	23.75	12.81	70.26	21.80	718.00	8.02		
44	2640	125.33	23.81	12.80	70.31	21.50	720.00	8.14		
45	2700	125.41	23.89	12.83	70.15	23.10	713.00	7.98		
46	2760	125.48	23.96	12.82	70.20	21.70	711.00	8.13		
47	2820	125.56	24.04	12.84	70.09	23.20	722.00	7.96		
48	2880	125.64	24.12	12.80	70.31	22.70	718.00	8.03		
49	2940	125.71	24.19	12.86	69.98	23.60	710.00	8.01		
50	3000	125.78	24.26	12.81	70.26	26.90	714.00	7.90		
51	3060	125.86	24.34	12.82	70.20	26.50	702.00	8.02		
52	3120	125.92	24.40	12.83	70.15	27.60	721.00	8.01		
53	3180	126.00	24.48	12.83	70.15	27.90	717.00	8.05		
54	3240	126.06	24.54	12.85	70.04	30.00	726.00	8.03		
55	3300	126.11	24.59	12.84	70.09	30.30	727.00	8.14		
56	3360	126.15	24.63	12.80	70.31	31.70	767.00	7.91		
57	3420	126.23	24.71	12.80	70.31	31.60	756.00	7.98		
58	3480	126.27	24.75	12.82	70.20	30.90	766.00	7.93		
59	3540	126.32	24.80	12.85	70.04	29.10	691.00	7.95		
60	3600	126.38	24.86	12.81	70.26	28.20	665.00	8.05		
61	3660	126.43	24.91	12.84	70.09	25.80	727.00	8.13		
62	3720	126.51	24.99	12.83	70.15	26.80	713.00	8.13		
63	3780	126.58	25.06	12.80	70.31	24.90	705.00	8.10		
64	3840	126.65	25.13	12.86	69.98	30.40	695.00	7.89		
65	3900	126.73	25.21	12.85	70.04	25.10	707.00	8.03		
66	3960	126.81	25.29	12.81	70.26	24.60	697.00	8.14		
67	4020	126.88	25.36	12.84	70.09	23.20	725.00	8.38		
68	4080	126.96	25.44	12.82	70.20	25.00	711.00	7.98		
69	4140	127.05	25.53	12.83	70.15	23.10	713.00	7.83		
70	4200	127.12	25.60	12.80	70.31	22.90	727.00	7.95		
71	4260	127.20	25.68	12.84	70.09	22.60	731.00	7.89		
72	4320	127.27	25.75	12.81	70.26	22.40	704.00	7.99		

Table 41-9 Recovery Test Data – BH10410

BH No.: 10410	**District: Ghanzi**
Date of test commencement: 16.09.2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 263m**
Date of test completion: 17/09/2007	**Screen Interval (m):**
Time of test completion: 0600 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 101.52m**
Temperature of water (°C):	**EC (mS/cm): pH:**

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	127.27	25.75
	0.25	122.24	20.72
	0.5	120.04	18.52
	1	118.84	17.32
	2	115.31	13.79
	3	113.43	11.91
	4	111.49	9.97
	5	110.7	9.18
	6	110.44	8.92
	7	109.84	8.32
	8	109.72	8.2
	9	109.7	8.18
	10	109.68	8.16
	12	109.66	8.14
	15	109.61	8.09
	20	109.44	7.92
	25	108.84	7.32
	30	108.68	7.16
	40	108.29	6.77
	50	108.02	6.5
	60	107.79	6.27
	75	107.47	5.95
	90	107.23	5.71
	105	106.98	5.46
	120	106.78	5.26

WL at end of test: 128.27m

Total Drawdown: 25.75m

Final discharge rate 70 (m^3/hr)

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	106.44	4.92
	180	106.18	4.66
	210	105.92	4.4
	240	105.74	4.22
	270	105.54	4.02
	300	105.37	3.85
	330	105.23	3.71
	360	105.08	3.56
	390	104.99	3.47
	420	104.83	3.31
	450	104.64	3.12
	480	104.56	3.04
	540	104.34	2.82
	600	104.16	2.64
	660	104.04	2.52
	720	108.91	7.39
	780	103.8	2.28
	840	103.7	2.18
	900	103.62	2.1
	960	103.53	2.01
	1020	103.4	1.88
	1080	103.4	1.88
	1140	103.36	1.84
	1200	103.32	1.8
	1260	103.22	1.7
	1320	103.18	1.66
	1380	103.13	1.61
	1440	103.08	1.56

42 BH10411

BH10411 drilled at site **P06**, Line **L1, TEM 294** and peg **15000m** is a replacement borehole situated about 10m west of abandoned BH10408. This borehole is located approximately 28 km south east of Ncojane. Drilling at this site started on the 28th July 2007 and was completed on 7th September 2007 at a depth of 266 m. Initially, the recorded depth of the borehole was 255m, however after geophysical logging and recalculation of casings installed it was established that the exact depth was 266m.

42.1 SITING CRETERIA AND DRILLING OBJECTIVES

This production borehole was drilled on the area underlain by a thick sequence of the Otshe Sandstone units which proved to have the best potential for wellfield development in terms sustainable yields and groundwater quality in Ncojane Block and with probable thin dolerite sill/dyke.

42.2 DRILLING RESULTS

. Drilling of this borehole was started with a 17 inch drilling bit down to a depth of 60 m after which 15 inch plain casings were installed and cement grouted down to 60 m. Drilling was then continued from 60 m to 189 m using a 15 inch drilling bit. At this depth, (189 m) 12 inch plain casings were installed and cement grouted. Drilling from 189 m to the depth of 255 m was through the use of an 8 inch tricone bit after which the borehole was reamed to the depth 266 m with a 12 inch tricone bit.

Two water strikes were encountered at the depths of 168m and 202m with electrical conductivities of 1190µS/cm (TDS ~ 578 mg/L), and 550 µS/cm (TDS ~ 280 mg/L) respectively. The blow out yields were 2.9 m^3/hr and 63 m^3 /hr respectively (measured on the 90° V – notch). Various lithologies including fine grained sands, silcrete, mudstones, coal and fine to coarse grained sandstones were intercepted during drilling of this production borehole A graphical representation of borehole construction, lithological information and water strikes is given in **Figure 42-1.**

1 (168m, 1190µS/cm, 2.9 m^3/hr)
2 (202m, 550 µS/cm, 63 m^3 /hr)

The initial logging of this borehole was unsuccessful as the boreholes was logged only down to 218m instead of 266 m and therefore screen placement and borehole design were based on geological log. The borehole was later re-logged using natural gamma, resistivity (16 and 64 inch), spontaneous potential, neutron and temperature probes after borehole construction **(Figure 42-2)**. The borehole was constructed with 8 inch epoxy coated casings and screens with the screens placed between 211 and 261 m. Borehole development was through airlift pumping and air jetting and the final blow out yield after borehole development was 37 m^3/hr. This yield is less than the blow out yield obtained prior to screen placement and the reduction in the yield could probably be due to a combination of sealing off the upper water strike and percentage open area of the screens. The final electrical conductivity was measured as 630µS/cm (TDS ~ 410 mg/L).

After successfully carrying out verticality and alignment tests, the borehole was capped and a cement slab was constructed.

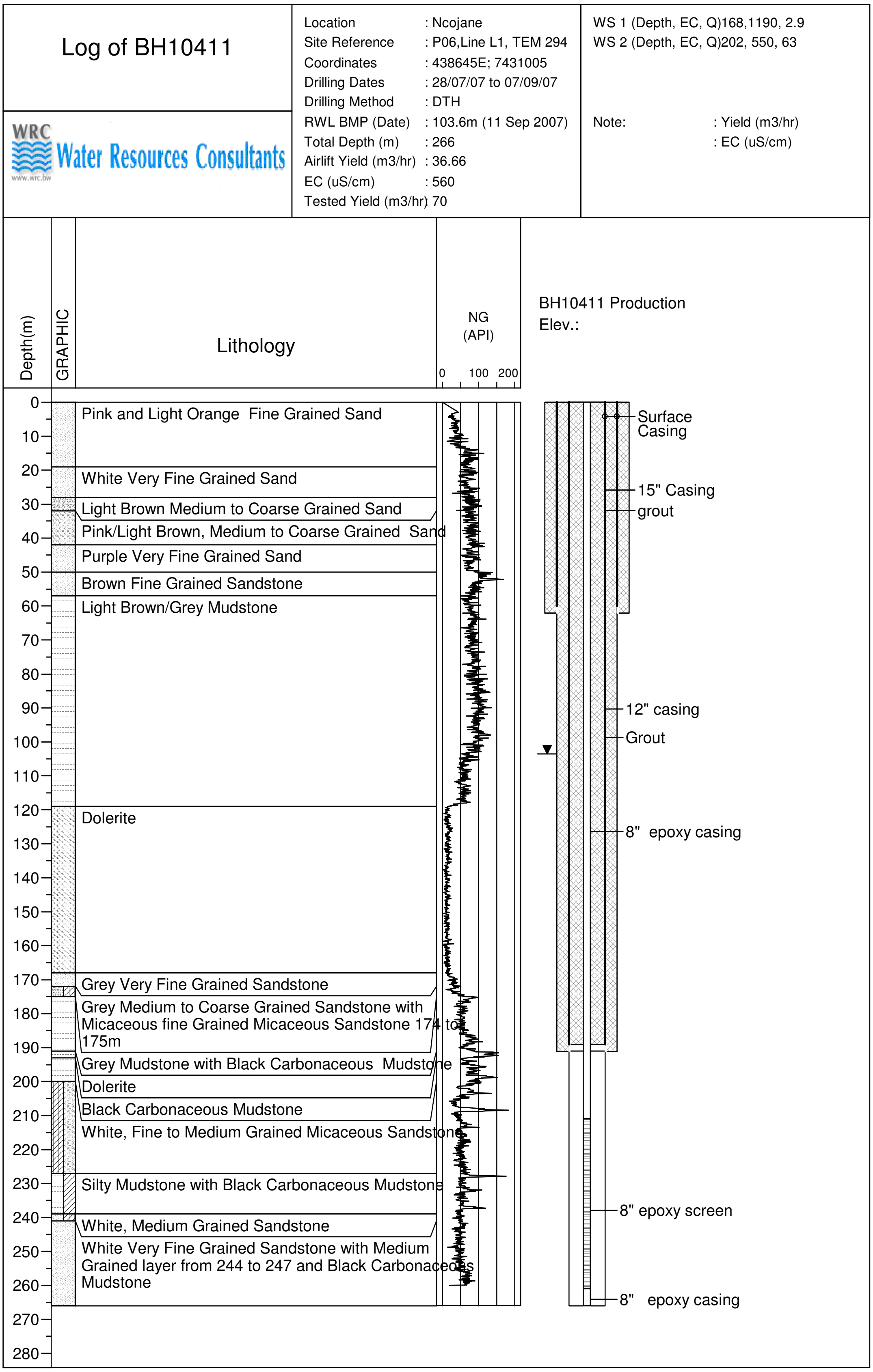

Figure 42-1 Log of BH10411

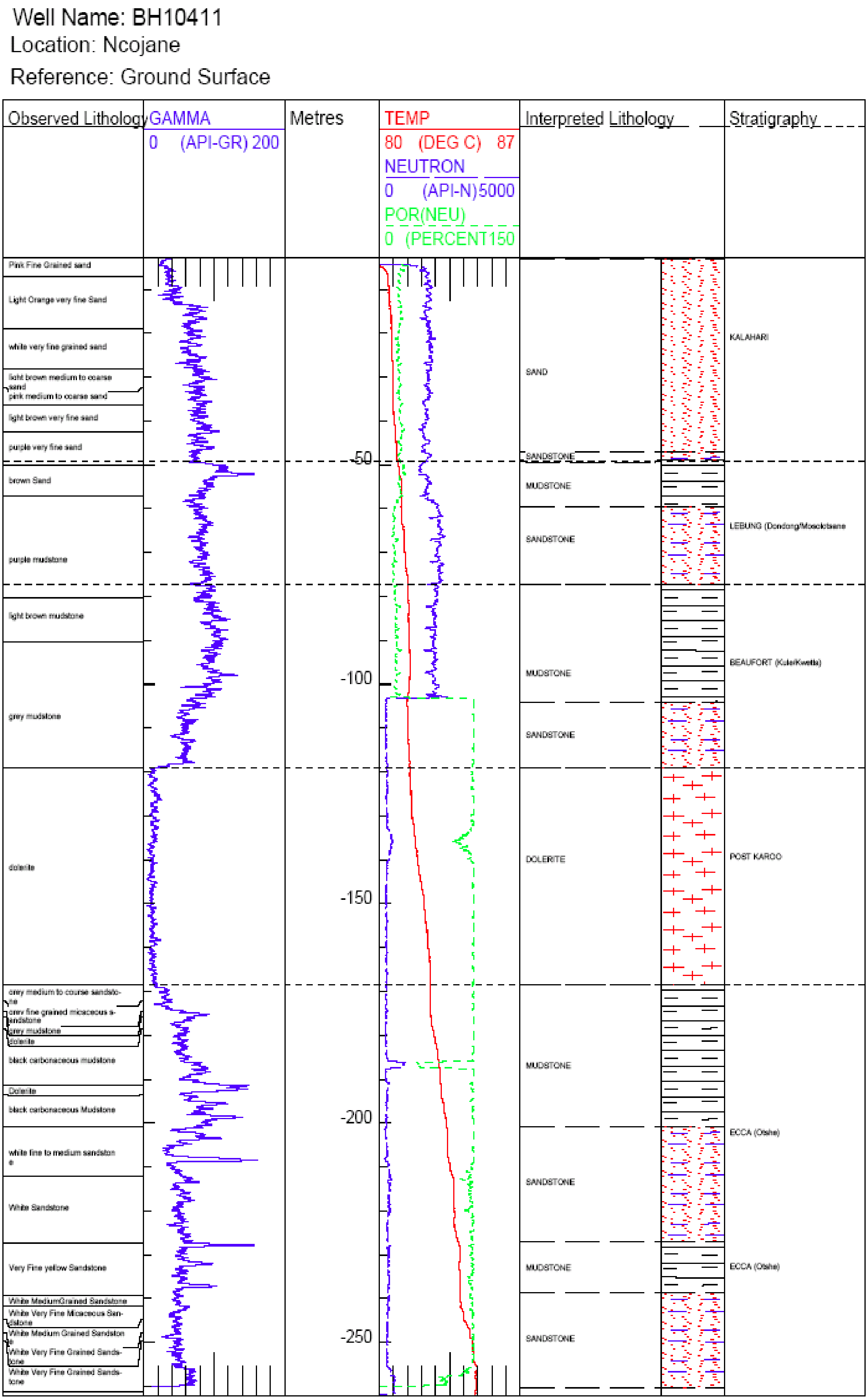

Figure 42-2 Geophysical log of BH10411

42.3 PUMP TESTING RESULTS

The last production borehole, BH10411 (sixth) for the Matsheng Project was tested between 12th October and 18th October 2007. The tests carried out were step drawdown test (SDT), constant rate test (CRT) and recovery monitoring **(Table 42-1).** The static water level at the beginning of the test was 103.13m bmp. The collected pump testing data is presented in **Tables 42-5 to 42-8**.

Table 42-1 Summary of Pumping Test Data BH1041

Test	No.	Duration [min]	Total Drawdown [m]	Discharge [m^3/hr]
Calibration	1	15	6.72	20
	2	15	11.74	40
	3	15	16.70	60
	4	15	21.75	78
Step Test	1	100	6.80	20
	2	100	10.09	35
	3	100	14.31	50
	4	100	19.87	65
	5	100	25.90	78
Constant Rate	1	4320	22.36	70
Recovery	1	1440	0.37*	0

Note. 0.37 Residual Drawdown*

42.3.1 Step Drawdown Test

The step drawdown test (SDT) was conducted on 13th October 2007 at discharge rates of 25, 35 50, 65 and 78 m^3/hr, with a total drawdown of 25.90 m at the end of the test. The static water level before the start of the test was 103.18 m bmp. The plots are presented in **Figures 42-3 to 42-5**.

The transmissivity value calculated from the step drawdown test data using the Eden-Hazel (1973) method is 68 m^2/d **(Figure 42-5)**. The results of the interpreted step test data are given in **Table 42-2**.

Table 42-2 Results of Step Test Analysis BH10411

BH	B (d/m^2)	C (d^2/m^5)	T (m^2/d)	Q (m^3/hr)	ΔS (m)	s_w (m)	Q/s_w (m^3/hr/m)
10411	1.06E-002	8.84E-007	61	20	6.86	6.86	2.92
				35	3.00	9.86	3.55
				50	3.66	13.52	3.70
				65	4.77	18.29	3.55
				78	5.36	23.65	3.30

42.3.2 Constant Rate and Recovery Tests

Constant rate test (CRT) was carried out between 14th and 17th October 2007 at a discharge rate of 70 m^3/hr and the total drawdown after 72 hrs of pumping was 22.36 m. This test was followed by a 24 hour recovery monitoring period at the end of which the residual drawdown was 2.21 m.

Transmissivity (T) values obtained by Cooper-Jacob (1946) and Hantush leaky, analytical solutions were 185 and 141 m^2/d respectively. The recovery data was analysed using the Theis recovery solution and a transmissivity value of 189m^2/d was obtained. The results are summarised in **Table 42-3** and the interpreted data are presented in **Figures 42-6** to **42-8**. There is an apparent impermeable barrier interpreted in the CRT data after 1100 minutes of pumping, **Figure 42-6**.

Table 42-3 Summary of Constant Rate and Recovery Tests BH10411

BH No.	CRT Duration (hours)	Q (m^3/d)	T (m^2/d)		Aquifer type
			Pumping Phase	Recovery Phase	
10411	72	1680	a) 185 b) 141	c) 189	Confined leaky with storage and negative boundary

Notes:
Interpretation Techniques
b) Theis
b) Cooper-Jacob
c) Hantush (Leaky without aquitard storage)
d) Theis Modified Recovery

42.3.2.1 Aquifer Type interpreted

The interpretation of the pump testing data indicates that the aquifer type is confined-leaky with negative (barrier) boundary.

42.4 WATER CHEMISTRY RESULTS

During the CRT, a set of water samples (acidified and none) were collected for chemical analysis. Samples collected were submitted to the CSIR laboratory in Stellenbosch, South Africa for analysis for most of the BOS 32:2000 listed determinants. The results of chemical analyses from CSIR lab are presented in **Table 42-4**. The well head chemical analysis at the end of pumping for temperature, electrical conductivity (EC) and pH are 25.6 ^oC, 562 µS/cm and 8.30 respectively.

Table 42-4 Chemistry Results from the CSIR Laboratory analysis.

	K	Na	Ca	Mg	SO_4	Cl	Alkalinity	NO_3	F	Fe	Mn	EC	pH	TDS
BH10411	7.5	90.9	26.7	19.9	19.5	62.5	215	17.6	0.6	<0.05	<0.05	690	7.60	442
Class II	50	200	150	70	250	200		45	1	0.3	0.1	1500	5.5 - 9.5	1000
Class III	100	400	200	100	400	600		45	1.5	2	0.5	3100	5 - 10	2000

	NH_4	Hardness	Al	As	Cd	Cr	Co	Cu	Pb	Ni	Zn	CN
BH10411	<0.05	148	0.3	<0.01	<0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Class II	1	200	0.2	0.01	0.003	0.05	0.5	1	0.01	0.02	5	0.07
Class III	2	500	0.2	0.01	0.003	0.05	1	1	0.01	0.02	10	0.07

Notes:
BOS32:2000 is Botswana Bureau of Standard on water quality and drinking water specifications (maximum allowable)
EC is in µS/cm
All units are in mg/L except pH, which has no units
HCO_3 is calculated from alkalinity

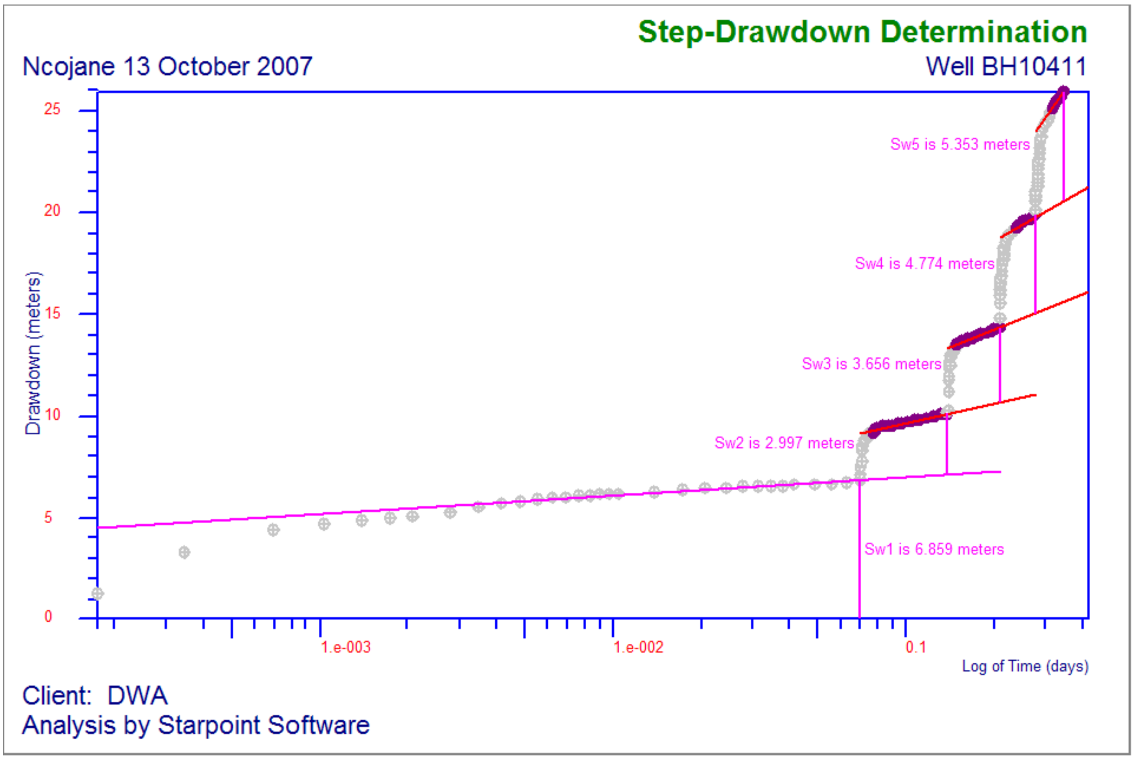

Figure 42-3 Pumping Test Results for BH10411tep Drawdown Test - Hantush-Bierschenk (semi-log)

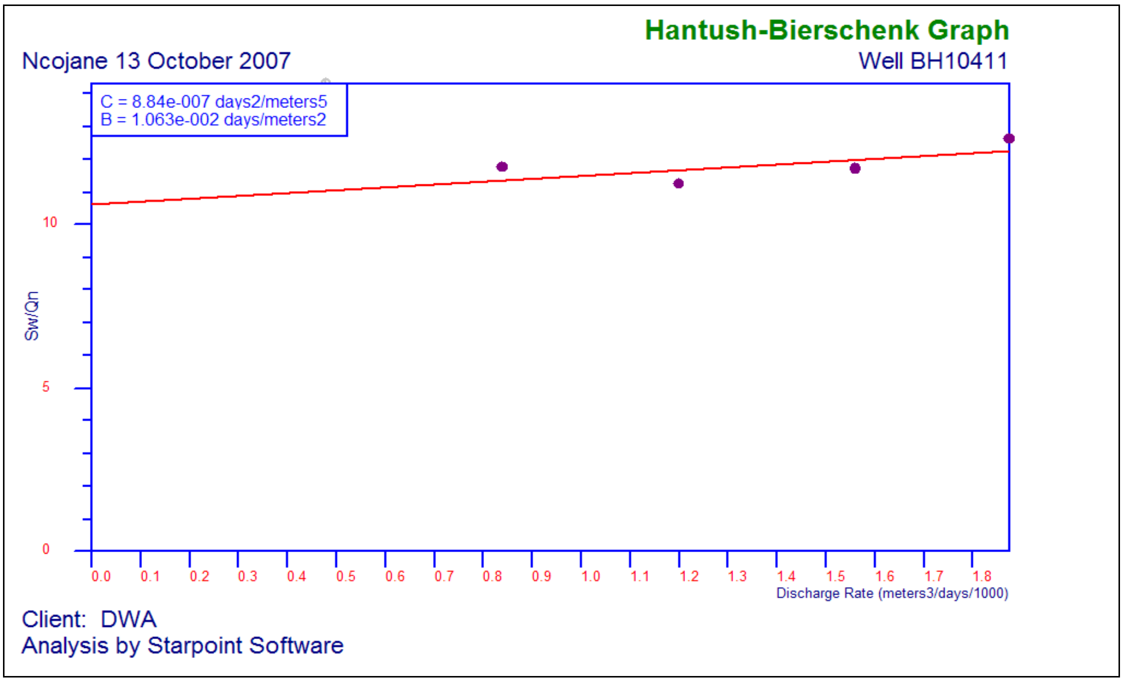

Figure 42-4 Pumping Test Results for BH10411: Step Drawdown Test – Hantush-Bierschenk

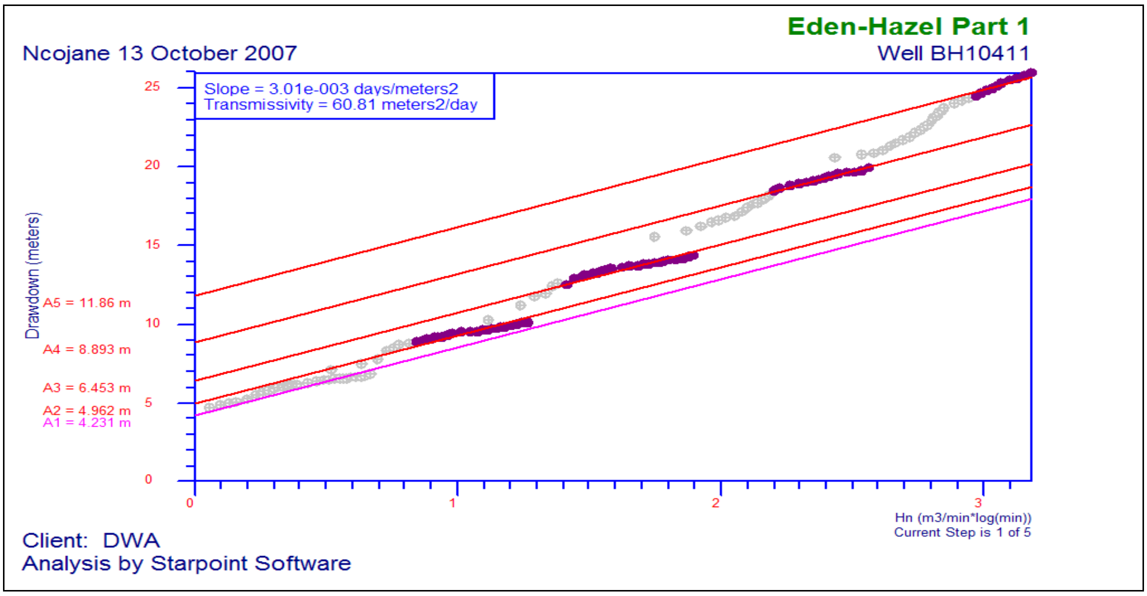

Figure 42-5 Pumping Test Results for BH10411: Step Drawdown Test – Eden-Hazel (Part 1)

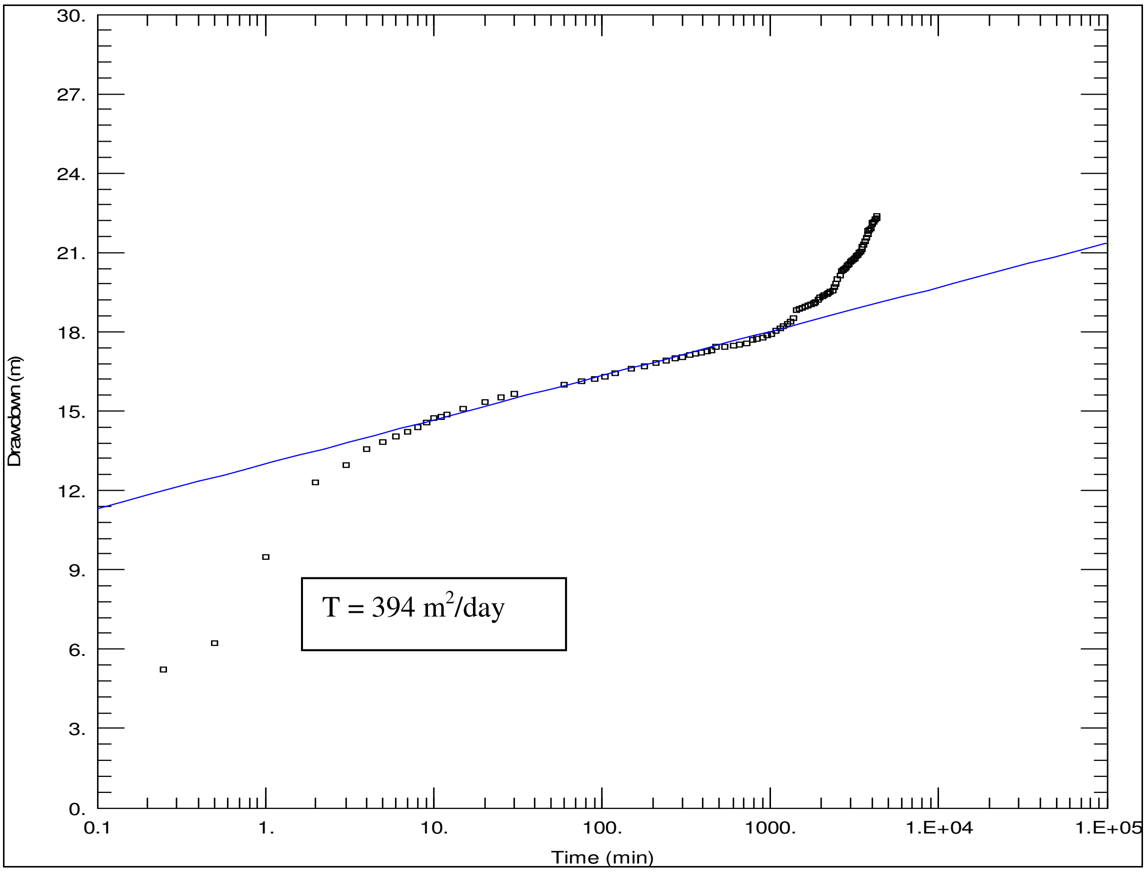

Figure 42-6 Pumping Test Results for BH10411: Theis Solution

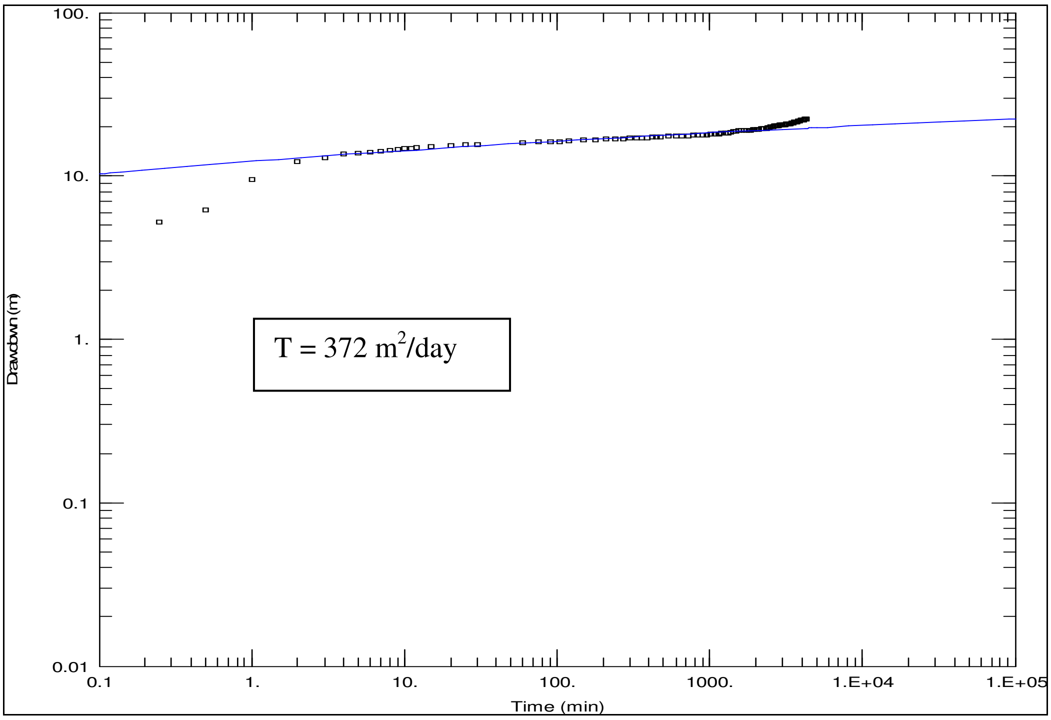

Figure 42-7 Pumping Test Results for BH10411: Hantush leaky with storage in the Aquitard

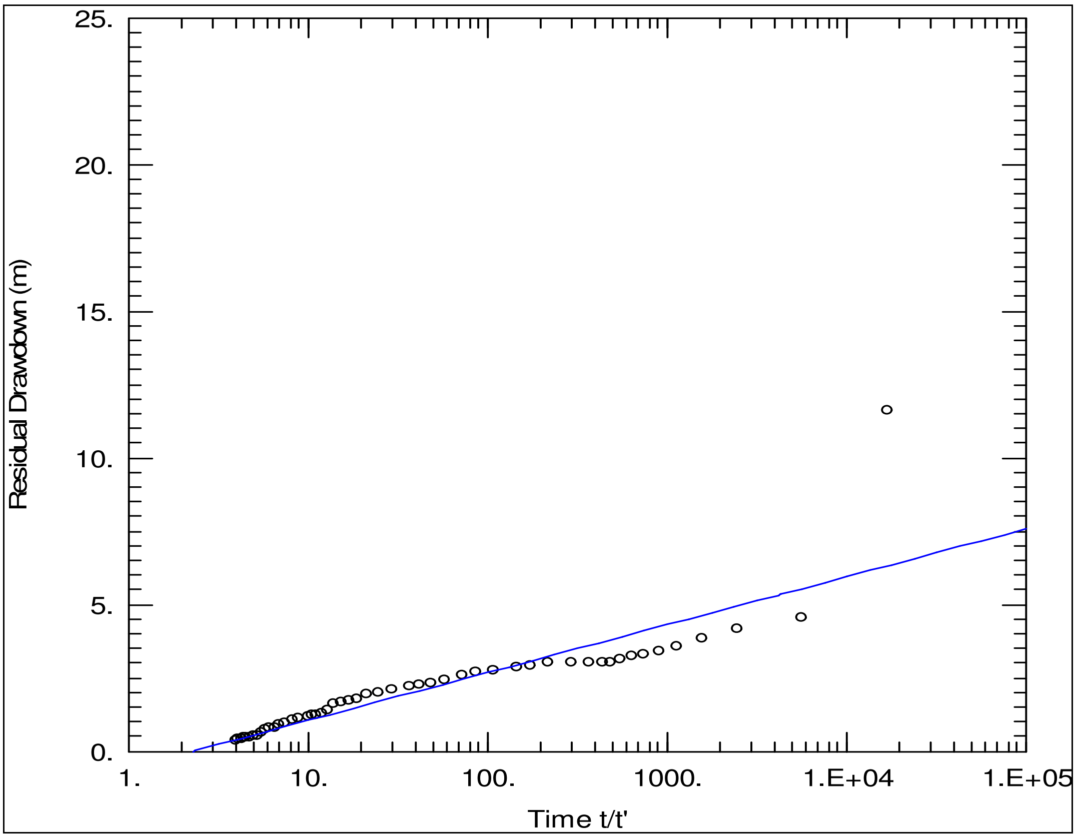

Figure 42-8 Pumping Test Results for BH10411: Theis Recovery Solution

Table 42-5 Calibration Test Data – BH10411

BH No.: 10411	District: Ghanzi
Date of test commencement: 12/10/2007	Location: Ncojane
Time of test commencemen: 0600 Hrs	BH depth (m): 262m
Date of test completion: 12/10/2007	Screen Interval (m):
Time of test completion: 0700 Hrs	Depth of pump intake (m):155m
Method of water level measurement: Electrical Dipper	Static water level before test (m): 103.13m
Temperature of water (°C):	EC (mS/cm): pH:

Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **100L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **150L**	Pump Rate (m3/hr)
STEP 1					**STEP 2**				
15 sec	104.44	1.31	17.44	20.64	15 sec	110.52	7.39	14.01	38.54
30 sec	105.58	2.45	17.86	20.16	30 sec	111.14	8.01	13.61	39.68
1	106.28	3.15	17.91	20.10	1	111.69	8.56	13.34	40.48
1.5	106.68	3.55	18.02	19.98	1.5	111.97	8.84	13.48	40.06
2	106.97	3.84	18.02	19.98	2	112.15	9.02	13.49	40.03
2.5	107.27	4.14	17.96	20.04	2.5	112.22	9.09	13.50	40.00
3	107.52	4.39	17.98	20.02	3	112.37	9.24	13.49	40.03
4	107.94	4.81	17.97	20.03	4	112.69	9.56	13.50	40.00
5	108.20	5.07	18.01	19.99	5	112.87	9.74	13.52	39.94
6	108.68	5.55	17.99	20.01	6	113.09	9.96	13.48	40.06
7	108.99	5.86	17.96	20.04	7	113.23	10.10	13.51	39.97
8	109.09	5.96	17.95	20.06	8	113.50	10.37	13.50	40.00
9	109.18	6.05	18.00	20.00	9	113.86	10.73	13.51	39.97
10	109.27	6.14	17.98	20.02	10	113.92	10.79	13.48	40.06
11	109.33	6.20	17.96	20.04	11	114.19	11.06	13.49	40.03
12	109.49	6.36	17.99	20.01	12	114.48	11.35	13.47	40.09
15	109.85	6.72	17.95	20.06	15	114.87	11.74	13.50	40.00

Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **200L**	Pump Rate (m3/hr)	Time (min)	Depth WL (m)	Drawdown (m)	Time to fill **250L**	Pump Rate (m3/hr)
STEP 3					**STEP 4**				
15 sec	115.09	11.96	12.08	59.60	15 sec	120.29	17.16	11.51	78.19
30 sec	115.28	12.15	12.10	59.50	30 sec	120.58	17.45	11.47	78.47
1	115.44	12.31	12.03	59.85	1	120.95	17.82	11.53	78.06
1.5	115.89	12.76	11.99	60.05	1.5	121.15	18.02	11.53	78.06
2	116.11	12.98	11.98	60.10	2	121.49	18.36	11.51	78.19
2.5	116.42	13.29	11.96	60.20	2.5	121.85	18.72	11.49	78.33
3	116.77	13.64	12.01	59.95	3	122.29	19.16	11.50	78.26
4	117.04	13.91	12.01	59.95	4	122.50	19.37	11.48	78.40
5	117.32	14.19	11.99	60.05	5	122.76	19.63	11.49	78.33
6	117.68	14.55	11.96	60.20	6	123.07	19.94	11.53	78.06
7	118.00	14.87	11.97	60.15	7	123.34	20.21	11.54	77.99
8	118.26	15.13	11.98	60.10	8	123.59	20.46	11.50	78.26
9	118.64	15.51	11.97	60.15	9	123.78	20.65	11.50	78.26
10	118.96	15.83	12.01	59.95	10	124.01	20.88	11.53	78.06
11	119.19	16.06	12.00	60.00	11	124.28	21.15	11.51	78.19
12	119.46	16.33	11.96	60.20	12	124.42	21.29	11.49	78.33
15	119.83	16.70	12.00	60.00	15	124.88	21.75	11.52	78.13

Table 42-6 Step Drawdown Test Data – BH10411

BH No.: 10411	**District: Ghanzi**
Date of test commencement: 13/10/2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 262m**
Date of test completion: 13/10/2007	**Screen Interval (m):**
Time of test completion:	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 103.18m**
Temperature of water (°C):	**EC (mS/cm): pH:**

STEP No. **1** STEP No. **2**

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **100L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **150L**	Pumping Rate (m^3/hr)	Comments
0.25	104.40	1.22			0.25	110.12	6.94	16.01	33.73	
0.5	106.50	3.32			0.5	110.27	7.09	15.66	34.48	
1	107.61	4.43			1	110.68	7.50	15.54	34.75	
1.5	107.90	4.72	17.48	20.59	1.5	110.93	7.75	15.46	34.93	
2	108.01	4.83	17.88	20.13	2	111.45	8.27	15.44	34.97	
2.5	108.14	4.96	18.01	19.99	2.5	111.69	8.51	15.40	35.06	
3	108.28	5.10	17.97	20.03	3	111.87	8.69	15.43	35.00	
4	108.42	5.24	17.98	20.02	4	111.97	8.79	15.41	35.04	
5	108.73	5.55	17.96	20.04	5	112.08	8.90	15.39	35.09	
6	108.85	5.67	18.00	20.00	6	112.17	8.99	15.36	35.16	
7	108.97	5.79	18.00	20.00	7	112.20	9.02	15.40	35.06	
8	109.09	5.91	17.95	20.06	8	112.24	9.06	15.38	35.11	
9	109.13	5.95	17.99	20.01	9	112.28	9.10	15.36	35.16	
10	109.19	6.01	17.97	20.03	10	112.33	9.15	15.42	35.02	
11	109.22	6.04	17.98	20.02	11	112.36	9.18	15.38	35.11	
12	109.27	6.09	18.01	19.99	12	112.42	9.24	15.41	35.04	
13	109.31	6.13	17.96	20.04	13	112.46	9.28	15.36	35.16	
14	109.34	6.16	17.96	20.04	14	112.53	9.35	15.39	35.09	
15	109.38	6.20	17.99	20.01	15	112.57	9.39	15.42	35.02	
20	109.45	6.27	17.97	20.03	20	112.66	9.48	15.37	35.13	
25	109.55	6.37	17.95	20.06	25	112.69	9.51	15.40	35.06	
30	109.62	6.44	17.98	20.02	30	112.72	9.54	15.38	35.11	
35	109.65	6.47	17.96	20.04	35	112.75	9.57	15.37	35.13	
40	109.70	6.52	17.99	20.01	40	112.79	9.61	15.40	35.06	
45	109.72	6.54	17.97	20.03	45	112.85	9.67	15.39	35.09	
50	109.75	6.57	17.99	20.01	50	112.90	9.72	15.37	35.13	
55	109.77	6.59	18.00	20.00	55	112.94	9.76	15.36	35.16	
60	109.79	6.61	18.01	19.99	60	112.99	9.81	15.38	35.11	
70	109.83	6.65	17.95	20.06	70	113.08	9.90	15.37	35.13	
80	109.85	6.67	17.98	20.02	80	113.15	9.97	15.41	35.04	
90	109.87	6.69	17.96	20.04	90	113.22	10.04	15.41	35.04	
100	109.98	6.80	18.01	19.99	100	113.27	10.09	15.39	35.09	

BH No.: 10411	**District: Ghanzi**
Date of test commencement: 13/10/2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 262m**
Date of test completion: 13/10/2007	**Screen Interval (m):**
Time of test completion: 1420 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 103.18m**
Temperature of water (°C):	**EC (mS/cm): pH:**

STEP No. **3** STEP No. **4**

TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **200L**	Pumping Rate (m^3/hr)	TIME (min)	Depth to WL (m)	Drawdown (m)	Time to fill **250L**	Pumping Rate (m^3/hr)	Comments
0.25	113.32	10.14	15.06	47.81	0.25	117.99	14.81	13.67	65.84	
0.5	113.40	10.22	15.41	46.72	0.5	118.70	15.52	13.77	65.36	
1	114.34	11.16	15.08	47.75	1	119.14	15.96	13.79	65.26	

1.5	114.94	11.76	14.66	49.11	1.5	119.34	16.16	13.83	65.08	
2	115.12	11.94	14.52	49.59	2	119.69	16.51	13.79	65.26	
2.5	115.55	12.37	14.38	50.07	2.5	119.78	16.60	13.80	65.22	
3	115.72	12.54	14.35	50.17	3	119.90	16.72	13.84	65.03	
4	115.69	12.51	14.38	50.07	4	120.07	16.89	13.82	65.12	
5	116.03	12.85	14.41	49.97	5	120.33	17.15	13.81	65.17	
6	116.15	12.97	14.38	50.07	6	120.60	17.42	13.82	65.12	
7	116.27	13.09	14.36	50.14	7	120.73	17.55	13.78	65.31	
8	116.33	13.15	14.35	50.17	8	120.89	17.71	13.85	64.98	
9	116.38	13.20	14.40	50.00	9	121.01	17.83	13.79	65.26	
10	116.45	13.27	14.39	50.03	10	121.18	18.00	13.78	65.31	
11	116.51	13.33	14.36	50.14	11	121.30	18.12	13.83	65.08	
12	116.56	13.38	14.41	49.97	12	121.44	18.26	13.85	64.98	
13	116.60	13.42	14.37	50.10	13	121.58	18.40	13.81	65.17	
14	116.66	13.48	14.39	50.03	14	121.70	18.52	13.80	65.22	
15	116.69	13.51	14.35	50.17	15	121.79	18.61	13.84	65.03	
20	116.78	13.60	14.38	50.07	20	121.94	18.76	13.83	65.08	
25	116.84	13.66	14.40	50.00	25	122.09	18.91	13.82	65.12	
30	116.89	13.71	14.39	50.03	30	122.20	19.02	13.82	65.12	
35	116.95	13.77	14.40	50.00	35	122.28	19.10	13.80	65.22	
40	117.00	13.82	14.37	50.10	40	122.38	19.20	13.81	65.17	
45	117.04	13.86	14.38	50.07	45	122.47	19.29	13.79	65.26	
50	117.09	13.91	14.35	50.17	50	122.55	19.37	13.78	65.31	
55	117.14	13.96	14.39	50.03	55	122.63	19.45	13.79	65.26	
60	117.20	14.02	14.36	50.14	60	122.70	19.52	13.84	65.03	
70	117.29	14.11	14.38	50.07	70	122.78	19.60	13.83	65.08	
80	117.37	14.19	14.40	50.00	80	122.86	19.68	13.80	65.22	
90	117.44	14.26	14.37	50.10	90	122.93	19.75	13.84	65.03	
100	117.49	14.31	14.35	50.17	100	123.05	19.87	13.82	65.12	

BH No.: 10411	**District: Ghanzi**
Date of test commencement: 13/10/2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 262m**
Date of test completion: 13/10/2007	**Screen Interval (m):**
Time of test completion: 1420 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 103.18m**
Temperature of water (^oC):	**EC (mS/cm):** **pH:**
STEP No. **5**	STEP No.

TIME (min)	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill 250L**	**Pumping Rate (m3/hr)**	**TIME (min)**	**Depth to WL (m)**	**Drawdown (m)**	**Time to fill ______L**	**Pumping Rate (m3/hr)**	**Comments**
0.25	123.30	20.12	11.58	77.72	0.25					
0.5	123.70	20.52	11.48	78.40	0.5					
1	123.90	20.72	11.47	78.47	1					
1.5	124.01	20.83	11.50	78.26	1.5					
2	124.25	21.07	11.49	78.33	2					
2.5	124.47	21.29	11.50	78.26	2.5					
3	124.69	21.51	11.49	78.33	3					
4	124.90	21.72	11.51	78.19	4					
5	125.03	21.85	11.52	78.13	5					
6	125.34	22.16	11.53	78.06	6					
7	125.49	22.31	11.52	78.13	7					
8	125.69	22.51	11.54	77.99	8					
9	125.81	22.63	11.50	78.26	9					
10	126.09	22.91	11.51	78.19	10					
11	126.21	23.03	11.49	78.33	11					
12	126.37	23.19	11.47	78.47	12					
13	126.58	23.40	11.52	78.13	13					
14	126.75	23.57	11.50	78.26	14					

15	126.91	23.73	11.45	78.60	15						
20	127.17	23.99	11.53	78.06	20						
25	127.33	24.15	11.50	78.26	25						
30	127.51	24.33	11.50	78.26	30						
35	127.67	24.49	11.49	78.33	35						
40	127.82	24.64	11.51	78.19	40						
45	127.99	24.81	11.53	78.06	45						
50	128.13	24.95	11.49	78.33	50						
55	128.27	25.09	11.47	78.47	55						
60	128.50	25.32	11.46	78.53	60						
70	128.67	25.49	11.50	78.26	70						
80	128.80	25.62	11.53	78.06	80						
90	128.96	25.78	11.48	78.40	90						
100	129.08	25.90	11.46	78.53	100						

Table 42-7 Constant Rate Test – BH10411

BH No.: 10411						District: Ghanzi				
Date of test commencement: 15.10.2007						Location: Ncojane				
Time of test commencemen: 0600 Hrs						BH depth (m):262 m				
Date of test completion: 18/10/2007						Screen Interval (m):				
Time of test completion: 0600 Hrs						Depth of pump intake (m):155m				
Method of water level measurement: Electrical Dipper						Static water level before test (m): 103.39m				
Temperature of water (^oC):						EC (mS/cm):			pH:	
	Elapsed time	Depth to	Drawdown	Time to fill		Temp	EC		Manometer	
	(min)	Water (m)	(m)	250l	Q(m^3/h)	(^0C)	(us/cm)	pH	(cm)	Comments
	0.25	108.64	5.25							
	0.5	109.60	6.21							
	1	112.88	9.49	12.94	69.55					
	2	115.71	12.32	12.90	69.77					
	3	116.37	12.98	12.84	70.09					
	4	116.95	13.56	12.80	70.31					
	5	117.23	13.84	12.86	69.98					
	6	117.43	14.04	12.81	70.26					
	7	117.60	14.21	12.84	70.09					
	8	117.77	14.38	12.85	70.04					
	9	117.95	14.56	12.79	70.37					
	10	118.13	14.74	12.83	70.15					
	11	118.18	14.79	12.82	70.20					
	12	118.27	14.88	12.81	70.26					
	15	118.48	15.09	12.83	70.15					
	20	118.72	15.33	12.79	70.37					
	25	118.89	15.50	12.86	69.98					
	30	119.02	15.63	12.83	70.15					
	35									
	40	119.20	15.81	12.81	70.26					
	45	119.23	15.84	12.80	70.31					
	50	119.25	15.86	12.82	70.20					
	55									
	60	119.37	15.98	12.79	70.37	26.2	527.00	7.34		
	75	119.50	16.11	12.85	70.04					
	90	119.60	16.21	12.83	70.15					
	105	119.68	16.29	12.81	70.26					
	120	119.82	16.43	12.86	69.98	26.9	537.00	7.51		
	150	119.98	16.59	12.79	70.37					
	180	120.10	16.71	12.83	70.15	27.1	540.00	7.35		
	210	120.22	16.83	12.80	70.31					
	240	120.30	16.91	12.81	70.26	28.3	551.00	7.47		
	270	120.37	16.98	12.79	70.37					
	300	120.45	17.06	12.85	70.04	29.9	549.00	7.44		
	330	120.50	17.11	12.83	70.15					
	360	120.54	17.15	12.80	70.31	32.4	547.00	7.58		
	390	120.60	17.21	12.81	70.26					
	420	120.65	17.26	12.85	70.04	31.7	535.00	7.71		
	450	120.69	17.30	12.80	70.31					
8	480	120.80	17.41	12.82	70.20	33.3	555.00	7.67		
9	540	120.84	17.45	12.81	70.26					
10	600	120.88	17.49	12.80	70.31	31.5	529.00	7.68		
11	660	120.92	17.53	12.85	70.04					
12	720	120.95	17.56	12.81	70.26	29.0	524.00	7.78		
13	780	121.09	17.70	12.82	70.20					
14	840	121.14	17.75	12.80	70.31	27.7	5.43	7.85		
15	900	121.17	17.78	12.79	70.37					
16	960	121.24	17.85	12.84	70.09	25.4	540.00	8.07		
17	1020	121.32	17.93	12.85	70.04	28.0	547.00	8.18		

18	1080	121.41	18.02	12.81	70.26	32.0	555.00	8.22		
19	1140	121.53	18.14	12.86	69.98	31.4	528.00	7.85		
20	1200	121.62	18.23	12.79	70.37	33.1	539.00	8.02		
21	1260	121.70	18.31	12.82	70.20	25.0	534.00	8.15		
22	1320	121.79	18.40	12.85	70.04	25.3	555.00	8.05		
23	1380	121.91	18.52	12.80	70.31	25.5	529.00	8.19		
24	1440	122.22	18.83	12.81	70.26	26.4	531.00	8.27		
25	1500	122.26	18.87	12.82	70.20	27.0	528.00	8.20		
26	1560	122.30	18.91	12.79	70.37	27.3	551.00	8.15		
27	1620	122.34	18.95	12.80	70.31	30.8	517.00	7.87		
28	1680	122.38	18.99	12.84	70.09	29.3	535.00	8.08		
29	1740	122.42	19.03	12.79	70.37	29.9	522.00	7.94		
30	1800	122.48	19.09	12.80	70.31	30.8	532.00	7.96		
31	1860	122.53	19.14	12.82	70.20	31.1	527.00	7.95		
32	1920	122.61	19.22	12.84	70.09	32.3	549.00	8.03		
33	1980	122.68	19.29	12.80	70.31	32.1	547.00	8.05		
34	2040	122.73	19.34	12.81	70.26	32.6	545.00	8.09		
35	2100	122.77	19.38	12.84	70.09	30.8	550.00	8.07		
36	2160	122.82	19.43	12.79	70.37	32.3	548.00	8.08		
37	2220	122.86	19.47	12.81	70.26	32.7	560.00	8.03		
38	2280	122.90	19.51	12.85	70.04	28.4	551.00	8.23		
39	2340	122.95	19.56	12.80	70.31	28.5	558.00	8.20		
40	2400	123.08	19.69	12.82	70.20	29.8	562.00	8.28		
41	2460	123.21	19.82	12.85	70.04	27.3	541.00	8.39		
42	2520	123.37	19.98	12.84	70.09	27.0	545.00	8.31		
43	2580	123.52	20.13	12.84	70.09	26.8	550.00	8.43		
44	2640	123.69	20.30	12.79	70.37	27.1	542.00	8.48		
45	2700	123.74	20.35	12.80	70.31	26.5	549.00	8.45		
46	2760	123.78	20.39	12.82	70.20	26.0	547.00	8.05		
47	2820	123.83	20.44	12.79	70.37	25.2	549.00	8.32		
48	2880	123.90	20.51	12.81	70.26	25.2	542.00	8.24		
49	2940	123.96	20.57	12.82	70.20	26.5	540.00	8.20		
50	3000	124.05	20.66	12.80	70.31	26.2	548.00	8.18		
51	3060	124.09	20.70	12.84	70.09	28.9	574.00	8.21		
52	3120	124.13	20.74	12.81	70.26	32.5	541.00	8.10		
53	3180	124.18	20.79	12.80	70.31	32.7	532.00	8.15		
54	3240	124.24	20.85	12.79	70.37	31.1	544.00	8.23		
55	3300	124.31	20.92	12.83	70.15	32.2	557.00	8.09		
56	3360	124.37	20.98	12.82	70.20	32.0	543.00	8.05		
57	3420	124.43	21.04	12.85	70.04	31.5	535.00	8.01		
58	3480	124.50	21.11	12.85	70.04	31.8	559.00	8.07		
59	3540	124.61	21.22	12.79	70.37	31.2	549.00	8.10		
60	3600	124.70	21.31	12.84	70.09	29.3	548.00	8.12		
61	3660	124.83	21.44	12.81	70.26	29.1	570.00	8.16		
62	3720	124.95	21.56	12.80	70.31	28.3	552.00	8.13		
63	3780	125.07	21.68	12.83	70.15	28.0	541.00	8.04		
64	3840	125.19	21.80	12.83	70.15	27.8	534.00	8.17		
65	3900	125.25	21.86	12.79	70.37	25.8	557.00	8.25		
66	3960	125.30	21.91	12.80	70.31	26.4	543.00	8.07		
67	4020	125.48	22.09	12.84	70.09	26.2	533.00	8.01		
68	4080	125.52	22.13	12.85	70.04	25.3	551.00	8.04		
69	4140	125.56	22.17	12.82	70.20	24.2	556.00	8.27		
70	4200	125.62	22.23	12.80	70.31	25.3	548.00	8.22		
71	4260	125.68	22.29	12.81	70.26	24.2	551.00	8.26		
72	4320	125.75	22.36	12.79	70.37	25.6	562.00	8.30		

Table 42-8 Recovery Test Data – BH10411

BH No.: 10402	**District: Ghanzi**
Date of test commencement: 24.09.2007	**Location: Ncojane**
Time of test commencemen: 0600 Hrs	**BH depth (m): 253m**
Date of test completion: 25/09/2007	**Screen Interval (m):**
Time of test completion: 0600 Hrs	**Depth of pump intake (m):155m**
Method of water level measurement: Electrical Dipper	**Static water level before test (m): 106.46m**
Temperature of water (ºC):	**EC (mS/cm): pH:**

clock time	Elapsed time (m)	Depth to water level (m)	Residual Drawdown (m)
	0	125.75	22.36
	0.25	123.22	19.83
	0.5	115.02	11.63
	1	107.95	4.56
	2	107.57	4.18
	3	107.2	3.81
	4	106.95	3.56
	5	106.8	3.41
	6	106.66	3.27
	7	106.6	3.21
	8	106.51	3.12
	9	106.42	3.03
	10	106.42	3.03
	12	106.4	3.01
	15	106.39	3
	20	106.38	2.99
	25	106.3	2.91
	30	106.23	2.84
	40	106.13	2.74
	50	106.07	2.68
	60	105.99	2.6
	75	105.83	2.44
	90	105.7	2.31
	105	105.66	2.27
	120	105.6	2.21

WL at end of test: 125.75

Total Drawdown:22.36 m

Final discharge rate:70.36 (m^3/hr)

clock time	Elapsed time (min)	Depth to Water level (m)	Residual Drawdown (m)
-	150	105.47	2.08
	180	105.36	1.97
	210	105.3	1.91
	240	105.18	1.79
	270	105.1	1.71
	300	105.07	1.68
	330	105.01	1.62
	360	104.8	1.41
	390	104.67	1.28
	420	104.64	1.25
	450	104.61	1.22
	480	104.58	1.19
	540	104.5	1.11
	600	104.44	1.05
	660	104.36	0.97
	720	104.3	0.91
	780	104.2	0.81
	840	104.16	0.77
	900	104.1	0.71
	960	104.01	0.62
	1020	103.92	0.53
	1080	103.9	0.51
	1140	103.87	0.48
	1200	103.85	0.46
	1260	103.83	0.44
	1320	103.81	0.42
	1380	103.78	0.39
	1440	103.76	0.37

APPENDIX A

Details of Completed Boreholes

APPENDIX B

Manual Water Level Monitoring Data

APPENDIX B. MANUAL GROUNDWATER LEVEL MONITORING DATA

MP elev =		1151.3
BH9135		
Date	W.L (mbmp)	W.L (m.amsl)
05-Mar-05	113.370	1037.930
25-Apr-05	113.337	1037.963
31-May-05	113.327	1037.973
29-Jun-05	113.385	1037.915
29-Jul-05	113.406	1037.894
01-Sep-05	113.415	1037.885
29-Nov-05	113.406	1037.894
11-Feb-06	113.441	1037.859
04-May-06	113.405	1037.895
21-Jun-06	113.398	1037.902
05-Sep-06	113.514	1037.786
25-11-06	113.500	1037.800
30-01-07	113.417	1037.883
03-Jun-07	113.480	1037.820
08-Jan-07	113.423	1037.877
31-Oct-07	113.426	1037.874

MP elev =		1249.000
BH8545		
Date	W.L (mbmp)	W.L (m.amsl)
04-Mar-05	126.885	1122.115
28-May-05	126.896	1122.104
30-Jun-05	126.99	1122.010
27-Jul-05	126.975	1122.025
01-Sep-05	126.885	1122.115
30-Nov-05	126.852	1122.148
09-Feb-06	126.8	1122.200
03-May-06	126.85	1122.150
20-Jun-06	126.83	1122.170
31-Jul-07	126.995	1122.005
03-Sep-06	126.91	1122.090
24-Nov-06	126.87	1122.130
31-Jan-07	126.88	1122.120
07-Mar-07	126.89	1122.110
31-Oct-07	126.999	1122.001

MP elev =		1222.000
BH9236		
Date	W.L (mbmp)	W.L (m.amsl)
05-Mar-05	156.70	1065.300
25-Apr-05	156.76	1065.243
30-May-05	156.79	1065.212
27-Jun-05	156.82	1065.185
30-Jul-05	156.85	1065.155
04-Sep-05	156.85	1065.153
28-Nov-05	156.91	1065.095
12-Feb-06	156.91	1065.089
04-May-06	156.90	1065.100
20-Jun-06	156.90	1065.103
05-Sep-06	156.88	1065.120
25-Nov-06	156.80	1065.200
30-Jan-07	156.93	1065.067
03-May-07	156.92	1065.080
31-Oct-07	157.02	1064.980

MP elev =		1173.000
BH9240		
Date	W.L (mbmp)	W.L (m.amsl)
05-Mar-05	134.785	1038.215
01-Sep-05	134.72	1038.280
28-Nov-05	134.767	1038.233
27-Jan-06	134.78	1038.220
04-May-06	134.733	1038.267
20-Jun-06	134.725	1038.275
05-Sep-06	134.813	1038.187
24-Nov-06	134.74	1038.260
02-Jan-07	134.76	1038.240
07-Mar-07	134.82	1038.180
31-Jul-07	134.82	1038.180
01-Nov-07	134.85	1038.150

MP elev =		1200.000
BH9243		
Date	W.L (mbmp)	W.L (m.amsl)
04-Mar-05	110.805	1089.20
24-Apr-05	110.8	1089.20
28-Jun-05	110.92	1089.08
28-Jul-05	110.927	1089.07
03-Sep-05	110.894	1089.11
29-Nov-05	110.73	1089.27
04-May-06	110.849	1089.15
04-Sep-06	110.858	1089.14
25-Nov-06	110.847	1089.15
06-Mar-07	110.893	1089.11
31-Oct-07	110.891	1089.11

MP elev =		1186.000
BH9291		
Date	W.L (mbmp)	W.L (m.amsl)
04-Mar-05	131.38	1054.63
23-Apr-05	131.39	1054.61
27-May-05	131.40	1054.60
30-Jun-05	131.46	1054.54
27-Jul-05	131.46	1054.54
01-Sep-05	131.43	1054.58
30-Nov-05	131.41	1054.59
08-Feb-06	131.42	1054.58
03-May-06	131.43	1054.57
20-Jun-06	131.48	1054.52
03-Sep-06	131.45	1054.56
24-Nov-06	131.49	1054.51
02-Jan-07	131.48	1054.52
07-Mar-07	131.49	1054.51
01-Nov-07	131.54	1054.46

APPENDIX B. MANUAL GROUNDWATER LEVEL MONITORING DATA

MP elev =		1177.77
BH9237		
Date	W.L (mbmp)	W.L (m.amsl)
04-Mar-05	129.485	1048.29
25-Apr-05	129.487	1048.28
30-May-05	129.518	1048.25
29-Jun-05	129.568	1048.20
29-Jul-05	129.545	1048.23
02-Sep-05	129.548	1048.22
30-Nov-05	129.683	1048.09
26-Jan-06	129.628	1048.14
05-Sep-06	129.63	1048.14
25-Nov-06	129.59	1048.18
30-Jan-07	129.537	1048.23
03-Jul-07	129.49	1048.28
01-Aug-07	129.62	1048.15
01-Nov-07	129.6	1048.17

MP elev =		1192.000
BH9239		
Date	W.L (mbmp)	W.L (m.amsl)
04-Mar-05	135.92	1056.08
28-May-05	135.96	1056.04
30-Jun-05	135.995	1056.005
04-Mar-05	135.92	1056.08
23-Apr-05	135.925	1056.075
28-May-05	135.96	1056.04
30-Jun-05	135.995	1056.005
27-Jul-05	135.96	1056.04
01-Sep-05	135.982	1056.018
30-Nov-05	135.936	1056.064
26-Jan-06	135.999	1056.001
03-May-06	135.922	1056.078
20-Jun-06	135.965	1056.035
04-Sep-06	135.981	1056.019
24-Nov-06	135.941	1056.059
31-Jan-07	135.99	1056.01
07-Mar-07	135.975	1056.025
11-Jun-07	135.97	1056.03
31-Jul-07	135.975	1056.025
01-Nov-07	135.98	1056.02

MP elev =		1186.720
BH9217		
Date	W.L (mbmp)	W.L (m.amsl)
03-Mar-05	72.86	1113.86
22-Apr-05	72.836	1113.88
01-Jun-05	72.954	1113.77
30-Jun-05	72.951	1113.77
01-Aug-05	72.893	1113.83
31-Aug-05	72.894	1113.83
30-Nov-05	72.835	1113.89
13-Feb-06	72.828	1113.89
03-May-06	72.78	1113.94
14-Jun-06	72.808	1113.91
23-Aug-06	72.78	1113.94
16-Nov-06	72.69	1114.03
11-Feb-07	72.723	1114.00

MP elev =		1233.00
BH9294		
Date	W.L (mbmp)	W.L (m.amsl)
05-Mar-05	129.37	1103.64
04-Sep-05	129.35	1103.65
28-Nov-05	129.35	1103.66
12-Feb-06	129.35	1103.65
28-Apr-06	129.36	1103.64
20-Jun-06	129.36	1103.65
02-Sep-06	129.30	1103.70
25-Nov-06	129.29	1103.72
30-Jan-07	129.29	1103.71
03-May-07	129.31	1103.69
31-Oct-07	129.29	1103.71

MP elev =		1226.900
BH6326		
Date	W.L (mbmp)	W.L (m.amsl)
03-Mar-05	33.665	1193.24
22-Apr-05	33.612	1193.29
01-Jun-05	33.616	1193.28
30-Jun-05	33.633	1193.27
01-Aug-05	33.68	1193.22
31-Aug-05	33.665	1193.24
30-Nov-05	33.662	1193.24
13-Feb-06	33.665	1193.24
28-Apr-06	33.635	1193.27
12-Jun-06	33.635	1193.27
23-Aug-06	33.63	1193.27
15-Nov-06	33.58	1193.32
26-Jan-07	33.6	1193.30
09-Mar-07	33.65	1193.25
03-Nov-07	33.62	1193.28

MP elev =		1268.500
BH 8346		
Date	W.L (mbmp)	W.L (m.amsl)
09-Mar-05	94.75	1173.750
26-Apr-05	94.634	1173.866
01-Jul-05	94.393	1174.107
05-Sep-05	94.13	1174.370
01-Dec-05	93.83	1174.670
16-Feb-06	93.691	1174.809
01-May-06	93.548	1174.952
14-Jun-06	93.482	1175.018
01-Sep-06	93.28	1175.220
23-Jan-07	92.87	1175.630

APPENDIX B. MANUAL GROUNDWATER LEVEL MONITORING DATA

MP elev =		1215.000
BH 9241		
Date	W.L (mbmp)	W.L (m.amsl)
04-Mar-05	136.09	1078.91
31-May-05	136.065	1078.94
28-Jun-05	136.19	1078.81
27-Jul-05	136.197	1078.80
03-Sep-05	136.195	1078.81
29-Nov-05	136.205	1078.80
04-May-06	136.205	1078.80
04-Sep-06	136.195	1078.81
25-Nov-06	136.198	1078.80
03-Jun-07	136.253	1078.75

MP elev =		1182.000
BH 9244		
Date	W.L (mbmp)	W.L (m.amsl)
04-Mar-05	152.935	1029.07
23-Apr-05	152.989	1024.78
27-May-05	152.996	1024.77
27-Jul-05	153.02	1028.98
03-Sep-05	152.987	1029.01
29-Nov-05	152.931	1029.07
08-Feb-06	152.868	1029.13
03-May-06	152.88	1029.12
20-Jun-06	152.829	1029.17
03-Sep-06	152.92	1029.08
24-Nov-06	152.788	1029.21
02-Jan-07	152.8	1029.20
01-Nov-07	152.812	1029.19

MP elev =		1201.000
BH 9297		
Date	W.L (mbmp)	W.L (m.amsl)
04-Mar-05	151.76	1049.24
25-Apr-05	151.756	1049.244
01-Jun-05	151.761	1049.239
27-Jun-05	151.75	1049.25
30-Jul-05	151.753	1049.247
04-Sep-05	151.805	1049.195
29-Nov-05	151.783	1049.217
26-Jan-06	151.715	1049.285
03-May-06	153.055	1047.945
20-Jun-06	152.869	1048.131
05-Sep-06	152.752	1048.248
30-Jan-07	152.8	1103.05
03-Jul-07	152.82	1103.03

MP elev =		1242.150
BH 9295		
Date	W.L (mbmp)	W.L (m.amsl)
05-Mar-05	132.095	1110.055
25-Apr-05	132.005	1110.145
21-May-05	132.11	1110.04
05-Jul-05	132.295	1109.855
30-Jul-05	132.352	1109.798
04-Sep-05	132.3	1109.85
28-Nov-05	132.73	1109.42
29-Jan-06	132.728	1109.422
28-Apr-06	132.596	1109.554
14-Jun-06	132.53	1109.62
18-Nov-06	132.405	1051.865
26-Jan-07	132.39	1051.88
03-Jul-07	132.395	1051.875
01-Nov-07	132.42	1051.85

MP elev =		1184.270
BH 9218		
Date	W.L (mbmp)	W.L (m.amsl)
03-Mar-05	70.03	1114.240
22-Apr-05	70.01	1114.265
01-Jun-05	70.01	1114.265
30-Jun-05	70.05	1114.225
01-Aug-05	70.07	1114.203
31-Aug-05	70.00	1114.269
30-Nov-05	70.00	1114.270
13-Feb-06	70.00	1114.272
06-May-06	69.95	1114.320
14-Jun-06	69.97	1114.300
16-Nov-06	69.90	1114.370
26-Jan-07	72.32	1111.946
03-Sep-07	72.33	1111.940
03-Nov-07	72.32	1111.949

MP elev =		1187.500
BH 6342		
Date	W.L (mbmp)	W.L (m.amsl)
30-Jun-05	62.53	1124.98
01-Aug-05	62.49	1125.01
31-Aug-05	62.53	1124.98
30-Nov-05	62.50	1125.00
13-Feb-06	62.49	1125.02
03-May-06	62.42	1125.08
14-Jun-06	62.39	1125.11
16-Nov-06	62.32	1125.18
26-Jan-07	62.30	1125.21
03-Sep-07	62.26	1125.24
03-Nov-07	62.23	1125.27