GHT CONSULTING SCIENTISTS

GEOHYDROLOGICAL REPORT

GEOPHYSICAL SITING, PERCUSSION DRILLING & AQUIFER TEST PUMPING FOR THE TOWNS OF VICTORIA WEST, LOXTON, RICHMOND, HUTCHINSON & MERRIMAN

for

STABILIS DEVELOPMENT
UBUNTU MUNICIPALITY
DEPARTMENT OF WATER AFFAIRS

By

GHT CONSULTING

PROJECT TEAM
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Project No.:	203-22-bws.674	Start Date:	September 2013
Report No.:	RVN674.1/1424	Report Date:	December 2013
Report No.:	RVN674.2/1425	Report Date:	December 2013
Report No.:	RVN674.3/1426	Report Date:	December 2013
Report No.:	RVN674.4/1427	Report Date:	December 2013
Report No.:	RVN674.5/1428	Report Date:	December 2013

GHT CONSULTING SCIENTISTS

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2 December 2013 *Our Reference No.: RVN674/1424/25/26/27/28*

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FOR ATTENTION: MR. J.H.C. THERON

Dear Sir,

GEOPHYSICAL SITING, PERCUSSION DRILLING & AQUIFER TEST PUMPING FOR THE TOWNS OF VICTORIA WEST, LOXTON, RICHMOND, HUTCHINSON & MERRIMANT

It is our pleasures to enclose three copies of report RVN674/1424/25/26/27/28: "GEOPHYSICAL SITING, PERCUSSION DRILLING & AQUIFER TEST PUMPING FOR THE TOWNS OF VICTORIA WEST, LOXTON, RICHMOND, HUTCHINSON & MERRIMANT".

We trust that the report will fulfil the expectations of the Stabilis Development (Pty) Ltd, Ubuntu Municipality and the Department of Water Affairs, and we will supply any additional information if required.

Yours sincerely,

D.C. RUDOLPH (M.Sc. / Pr. Sci. Nat.)
Senior Geohydrologist

J.J.H. HOUGH (M.Sc. / Pr. Sci. Nat.)
Senior Geohydrologist

Copies: Three copies to Stabilis Development.

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- GLOSSARY OF GEOHYDROLOGICAL TERMS & ABBREVIATIONS -

Geohydrological Term	Definition
Aquifer	A water-bearing geological formation.
Aquitard	An aquitard is a geological unit that is permeable enough to transmit water in significant quantities when viewed over large and long periods, but its permeability is not sufficient to justify production boreholes being placed in it. Clays, loams and shale are typical aquitards.
Confined Aquifer	A confined aquifer is bounded above and below by an aquiclude. In a confined Aquifer, the pressure of the water is usually higher than that of the atmosphere. So that if a borehole taps the aquifer, the water in it stands above the top of the aquifer, or even above the ground surface. We then speak of a free-flowing or artesian borehole.
Contamination	The introduction of any substance into the environment by the action of man.
Diffusivity (KD/S)	The hydraulic diffusivity is the ratio of the transmissivity and the storativity of a saturated aquifer, it governs the propagation of the chances a hydraulic head in the aquifer. Diffusivity has the dimension of $lenght^2/Time$.
Fractured-rock aquifer	Groundwater occurring in within fractures and fissures in hard-rock formations. Groundwater: Refers to water filling the pores and voids in geological formations below the water table.
Groundwater Flow	The movement of water though openings and pore spaces in rock below the water table i.e. in the saturated zone. Groundwater naturally drains from higher lying areas to low lying areas such as river, lakes and oceans. The rate of flow depends on the slope of the water table and the stransmissivity of the geological formations.
Groundwater Recharge	Refers to the portion of rainfall that infiltrates the soil, percolates under gravity through the unsaturated zone (also called the Vadose zone) down to the saturated zone below the water table (also called the Phreatic zone).
Groundwater Resource	All ground water available for the beneficial use, including by man, aquatic ecosystems and the grater environment.
Groundwater Resource Units (GRU's)	Represent provisional zones defined for the purpose of assessing and managing the groundwater resources of a region, in terms of large-scale abstraction from relatively shallow (depth<300m) production boreholes. They represent areas where the broad geohydrological characteristics (i.e. water occurrence and quality, hydraulic properties, flow regime, aquifer boundary conditions etc.) are anticipated to be similar. Sometimes also called ground water management units (GMU's).
Hydraulic Conductivity (K)	The hydraulic conductivity is the constant of proportionality in Darcy's law. It is defined as the volume of water that will move through a porous medium in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow
Hydrocensus	A field survey by which all relevant information regarding groundwater is amassed. This typically includes yields, borehole equipment, groundwater levels, casing height / diameter, WGS84 coordinates, potential pollution risks, photos etc.
Intergranular Aquifer	Groundwater contained intergranular interstices of sedimentary and weathered formations.
Leaky Aquifer	A leaky aquifer, also known as a semi-confined aquifer, is an aquifer who's upper and lower boundaries is aquitards, or one boundary is an aquitard and the other is an aquiclude. Water is free to move through the aquitards, either upwards or downwards. If a leaky aquifer is in hydrological equilibrium, the water level in a borehole tapping it may coincide with the water table.
Major Aquifer System	Highly permeable formations, usually with a known or probable presence pf significant fracturing and/or intergranular porosity; may be highly productive and able to support large abstractions for public supply and other purposes; water quality is generally very good.
Minor Aquifer System	Fractured or potentially fractured rocks that do not have a high primary permeability , or other formations of variable permeability; aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow of rivers.
Non-Aquifer	A groundwater body that is essentially impermeable, does not readily transmit water and/or has water quality that renders it unfit for use.

Geohydrological Term	Definition
Non-Aquifer System	Formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities; water quality may also be such that it renders the aquifer unusable; groundwater flow through such rocks does take place and needs to be considered when assessing the risk associated with persistent pollutants.
Permeability	The ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of a aquifer under unit hydraulic gradient in unit time (expressed as m^3/m^2.d or m/d). It is an intrinsic property of the porous medium and is independent of the properties of the saturating fluid; not to be confused with hydraulic conductivity, which relates specifically to the movement of water.
Pollution	The introduction into the environment of any substance by the action of man that is, or results in, significant harmful effects to man or the environment.
Porosity	The porosity of a rock is its property of containing pores or voids. With consolidated rocks and hard rocks, a distinction is usually made between primary porosity, which is present when the rock is formed and secondary porosity, which develops later as a result of solution or fracturing.
Recharge	Groundwater recharge or deep drainage or deep percolation is a hydrologic process where water moves downward from surface water to groundwater. This process usually occurs in the vadose zone below plant roots and is often expressed as a flux to the water table surface. Recharge occurs both naturally (through the water cycle) and anthropologically (i.e. "artificial ground water recharge"), where rainwater and or reclaimed water is touted to the subsurface.
Saline Water	Water that is generally considered unsuitable for human consumption or for irrigation because of it's high content of dissolved solids.
Saturated Zone	The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere.
Specific Yield (S_y)	The specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline of the water table. The values of the specific yield range from 0.01 to 0.3 and are much higher that the storativities of confined aquifers.
Storativity Ratio	The storativity ratio is a parameter that controls the flow from the aquifer matrix blocks into the fractures of a confined fractured aquifer of the double-porosity type. Sustainable Yield: This usually refers to a yield calculated from aquifer test pumping by a professional geohydrologist. The yield refers to the recommended abstraction rate and pumping schedule for continued use.
Storativity (S)	The storativity of a saturated confines aquifer of thickness D is the volume of water released from storage per unit are of the aquifer per unit decline in the component of hydraulic head normal to that surface.
Transmissivity (KD & T)	Transmissivity is the product of the average hydraulic conductivity K and the saturated thickness of the aquifer D. Consequently, transmissivity is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer.
Unconfined Aquifer	An unconfined aquifer, also known as a water table aquifer, is bounded below by an aquiclude, but is not restricted by any confining layer above it. Its upper boundary is the water table and is free to rise and fall.
Unsaturated Zone	That part of the geological stratum above the water table where interstices and voids contain a combination of air and water; synonymous with zone of aeration or vadose zone.
Water Table	The upper surface of the saturated zone of an unconfined aquifer at which pore pressure is at atmospheric pressure, the depth to which may fluctuate seasonally.

Abbreviation	Definition
CRD	Cumulative Rainfall Departure
DWA	Department of Water Affairs
DWAE	Department of Water Affairs and Environment
DWAF	Department of Water Affairs and Forestry
EC	Electric Conductivity
GA	General Authorisation
GHT	GHT Consulting
m	Metres
m^3/a	Cubic metres per annum
m^3/d	Cubic metres per day
magl	Metres above ground level
mamsl	Metres above mean sea level
MAP	Mean annual precipitation
mbgl	Metres below ground level
mm	Millimetres
mS/cm	Milli-siemens per centimetre
mS/m	Milli-siemens per metre
SANS	South African National Standard
SVF	Saturated Volume Fluctuation
TOR	Terms of Reference
WRC	Water Research Commission

1 INTRODUCTION

GHT Consulting was appointed by Stabilis Development on behalf of Ubuntu Municipality to perform a groundwater supply project, which includes geophysical siting, percussion drilling and aquifer testing of new boreholes as well as existing boreholes for the towns of Victoria West, Loxton, Richmond, Hutchinson and Merriman.

The deliverables of the project are as are as follows:

- **Geophysical siting of thirteen (13) drilling targets [two (2) additional targets were also sited]:**
  - Victoria West: Geophysical siting of six (6) drilling targets;
  - Hutchinson: Geophysical siting of three (3) drilling targets;
  - Richmond: No geophysical siting to be performed;
  - Loxton: Geophysical siting of four (4) drilling targets; and
  - Merriman: Geophysical siting of two (2) drilling targets.
- **Percussion drilling of thirteen (13) new boreholes [three (3) boreholes were drilled additionally]:**
  - Victoria West: Six (6) boreholes were percussion drilled;
  - Hutchinson: Three (3) boreholes were percussion drilled;
  - Richmond: One (1) boreholes were percussion drilled;
  - Loxton: Four (4) boreholes were percussion drilled; and
  - Merriman: Two (2) boreholes were percussion drilled.
- **Aquifer test pumping of newly drilled boreholes as well as existing boreholes [total of twelve (12) aquifer test pumping test were performed]:**
  - Victoria West: Aquifer Test Pumping of three (3) boreholes.
  - Richmond: Aquifer Test Pumping of six (6) boreholes.
  - Merriman: Aquifer Test Pumping of one (1) borehole.
  - Loxton: Aquifer Test Pumping of two (2) boreholes.
- **Compilation of a Geohydrological Report:**
  - The geohydrological report contains all the data generated during the project as well as the conclusions and recommendations.

The locality maps of the towns can be viewed in Appendix A.

2 BACKGROUND INFORMATION

This section contains the background information of the study area, which includes the towns of Victoria West, Loxton, Richmond, Hutchinson and Merriman.

2.1 CATCHMENT

The study area is located in north western part of the Northern Cape Province. The quaternary sub-catchment for the towns is as follows:

- Victoria West is located in quaternary sub-catchment D61E;
- Loxton is located in quaternary sub-catchment D55D;
- Richmond is located in quaternary sub-catchment D61A;
- Hutchinson West is located in quaternary sub-catchment D61E; and
- Merriman is located in quaternary sub-catchment D61A.

The area as a whole is located in DWA Water Management Area 14.

2.2 CLIMATE

The study area has hot summers and cool winters, and a predominantly summer rainfall. The air temperatures range from an average maximum of 30 to 32 ^{o}C in January to an average minimum of 0 to 2 ^{o}C in July, meaning conditions with mildly hot summers and cold to very cold winters (South African Atlas of Agrohydrology and –Climatology, 1997).

The mean annual rainfall for the study area is on average 279.15 mm/a, which occurs mainly as thunderstorms but soft rains also do occur (Rainfall Station Gauge No.: 0139 658, Loxton (238.5 mm/a) & Rainfall Station Gauge No.: 0142 805, Richmond (319.8 mm/a), Surface Water Resources of South Africa, 1990).

2.3 GENERAL AQUIFER INFORMATION OF THE GRAAFF-REINET DISTRICT

The following section is based on the Groundwater Resources of South Africa Maps, DWA, 1995 as well as existing information gathered from varies geohydrological-, hydrological- and civil engineering reports (refer to Section 9, References on page 127).

2.3.1 Baseflow

The groundwater component of river flow (base flow) is negligible in the study area (refer to Figure 1 on page 12).

2.3.2 Groundwater Table Depth

The groundwater depth in the study area is approximately < 10 mbgl according to the DWA Groundwater Resources Map (refer to Figure 2 on page 13).

2.3.3 Recharge to Aquifer

The mean annual recharge of the area is between 10 - 15 mm/a (refer to Figure 3 on page 14). Therefore the study area has an estimated recharge percentage at 4.8% of MAP.

2.3.4 Drilling Depths and Success Rates

In general the recommended drilling depths below water level are 30 – 50 meters for the study area. Fractures restricted principally to a zone directly below groundwater level that consist of compacted sedimentary rocks intruded by Jurassic Jura age intrusive dolerite sills and to a lesser extent dykes structure. Storage coefficient in order of magnitude for the study area is < 0.001 for the sedimentary rocks. The qualitative indication of spatial distribution of storage media based on drilling success rate for the area is between > 60%. (Groundwater Resources of South Africa Maps, DWA, 1995).

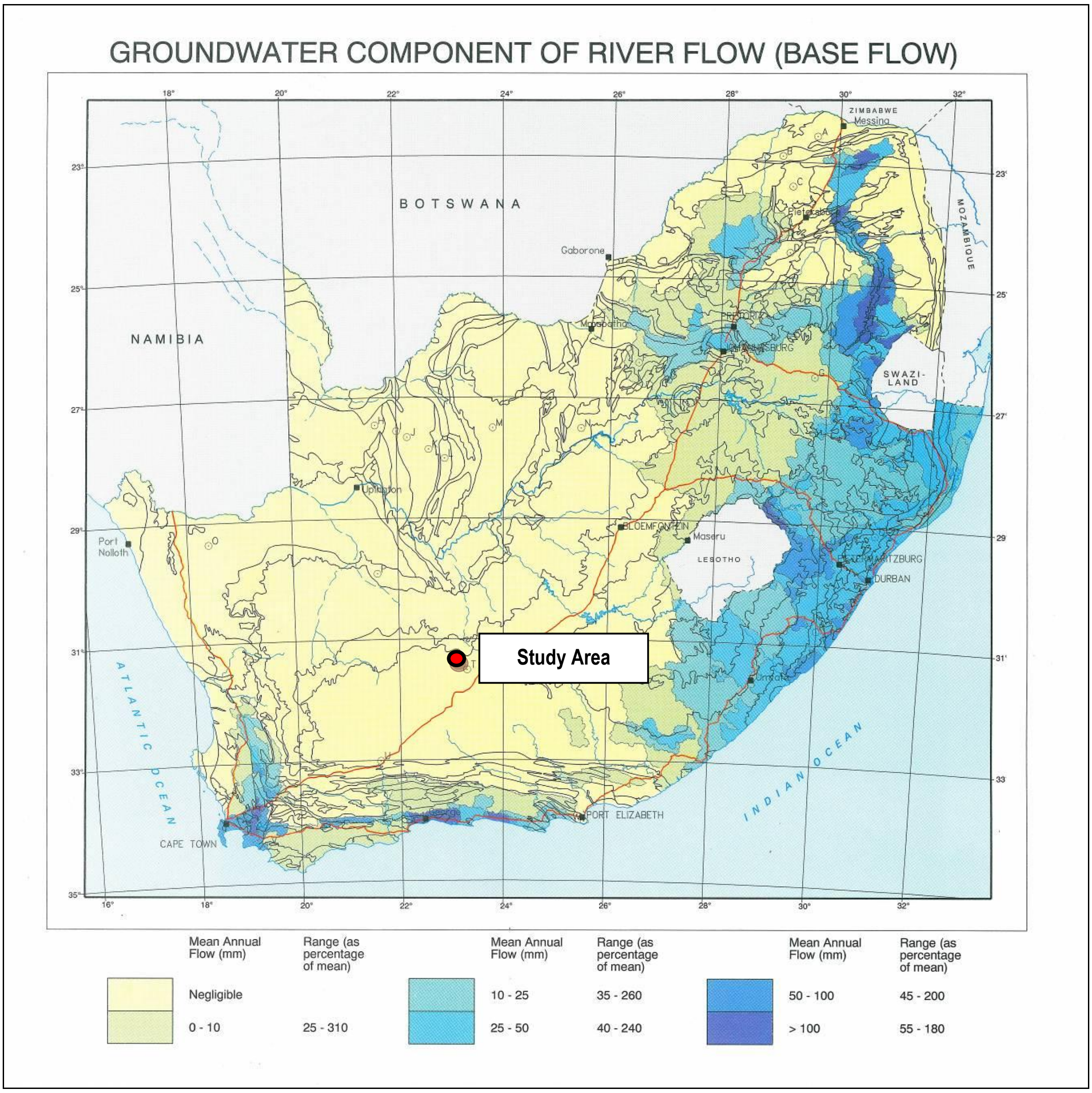


Figure 1. Groundwater component of river flow (base flow), (adapted from the Groundwater Resources of South Africa Map, DWA, 1995).

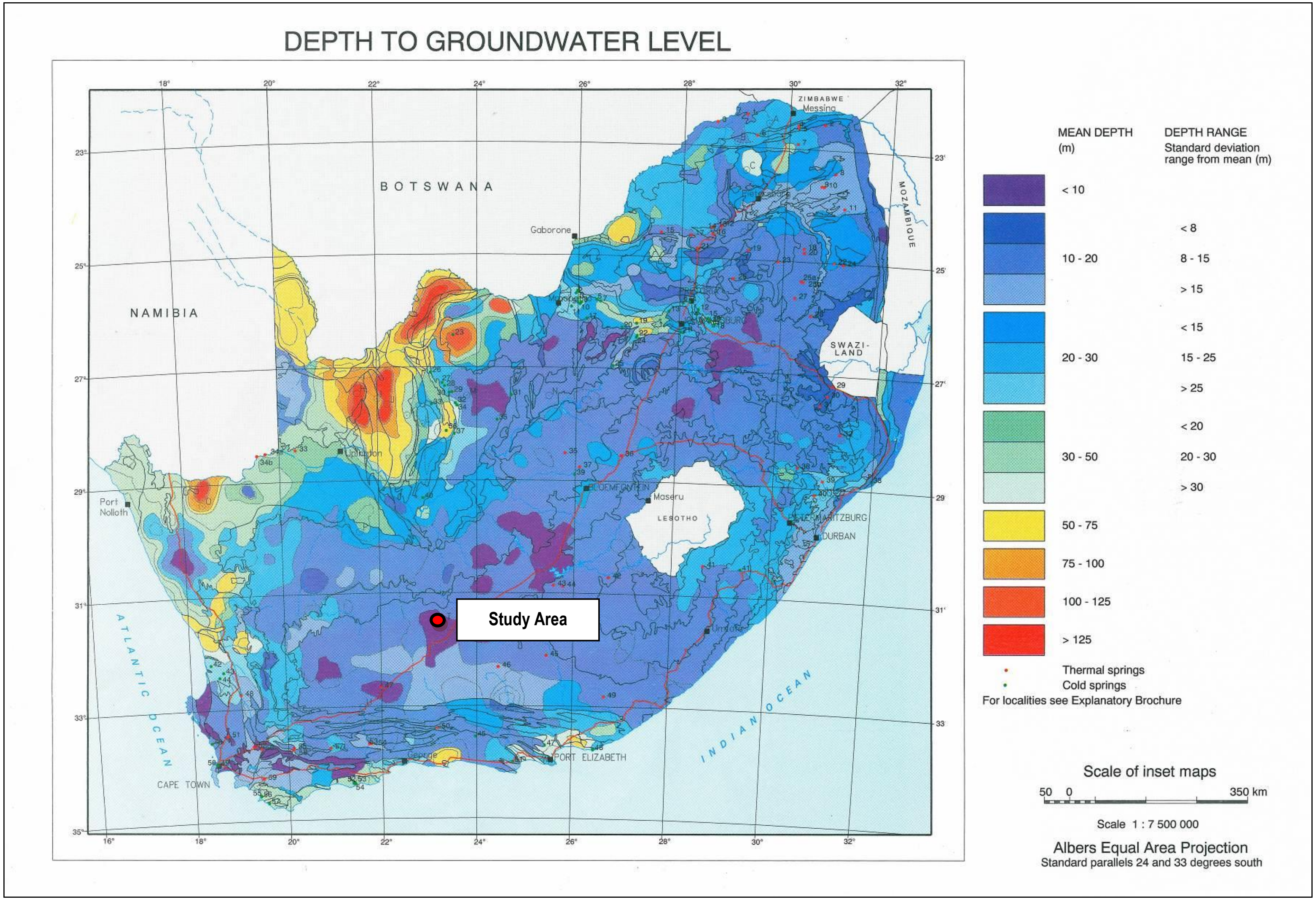


Figure 2. Depth of groundwater level (adapted from the Groundwater Resources of South Africa Map, DWA, 1995)

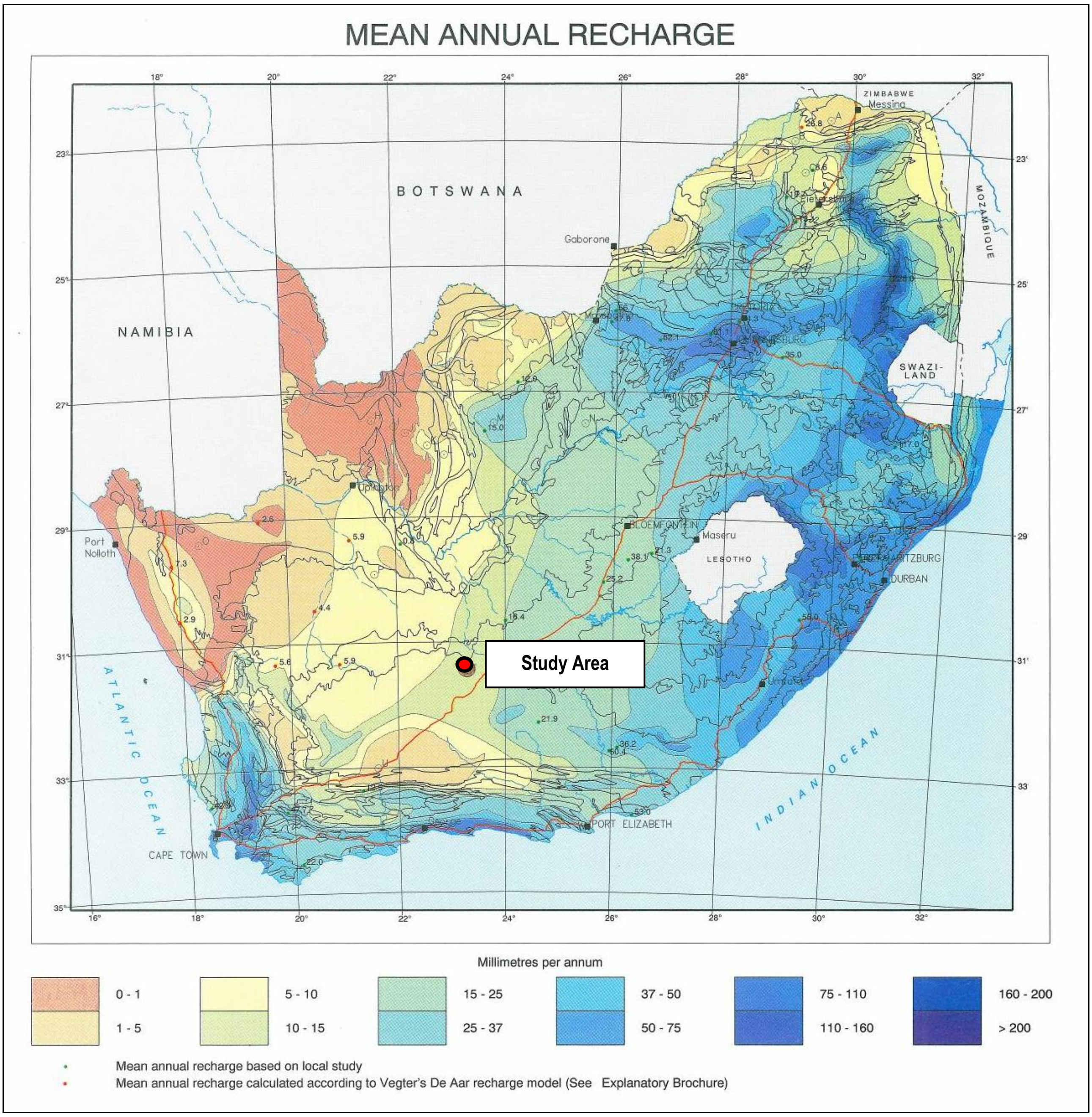


Figure 3. Mean annual recharge (adapted from the Groundwater Resources of South Africa Map, DWA, 1995).

3 GEOPHYISCAL SURVEY AND BOREHOLE SITING

This section includes the results of geophysical investigation and borehole siting for the towns of Victoria West, Loxton, Richmond, Hutchinson and Merriman.

3.1 THE MAGNETIC METHOD

The magnetic geophysical method proved an effective method for the detection of dolerite structures, which includes dykes and sills.

The normal magnetic field of the earth can be visualised as a field of a bar magnet placed at the centre of the earth. Any changes in this "normal" magnetic field superimposed by dykes, for example, can be measured by a magnetometer. These measurements (changes) in magnetism can then, through the process of modelling, be interpreted in terms of the dip, strike, depth and width of the body that causes the anomaly. Since these geological magnetic features might be remnant (i.e. permanently) magnetised, a feature, which is normally not known to the modeller, no unique solution of the model exists. By making certain reasonable assumptions about the geology, restrictions can be placed on some of the geological features of the body. The magnetic method is an extremely useful method to map of dykes, which are good groundwater exploration targets.

3.2 RESULTS OF THE FIELD GEOPHYSICAL SURVEY AND BOREHOLE SITING

A geophysical field survey was conducted at the towns of Victoria West, Loxton, Richmond, Hutchinson and Merriman. The survey included eight (8) magnetic traverse lines. A total of seventeen (16) borehole positions were sited by means of geophysical traverses and geological observations. The geophysical traverse data sheets can be viewed in Appendix B.

3.2.1 Victoria West Geophysical Survey Results

The description of the geophysical traverses of the magnetic field survey as well as the sited drilling positions for Victoria West are as follows (refer to Figure 4 on page 17):

- Traverse line VW-TV01 (refer to Figure 5 on page 18): The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 30 m. One drilling target was sited on the geological structure, namely VWP1 (East: 23.07302and South: -31.41948, WGS84).
- Traverse line VW-TV02 (refer to Figure 6 on page 19): The traverse was conducted from south to north. A potential geological (dolerite dyke) structure was observed at station 22 m. One drilling target was sited on the geological structure, namely VWP21 (East: 23.07793 and South: -31.41948, WGS84).
- Traverse line VW-TV03 (refer to Figure 7 on page 20): The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 12 m. One drilling target was sited on the geological structure, namely VWP31 (East: 23.06834 and South: -31.40636, WGS84).

- Traverse line VW-TV04 (refer to Figure 8 on page 21): The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 13 m.

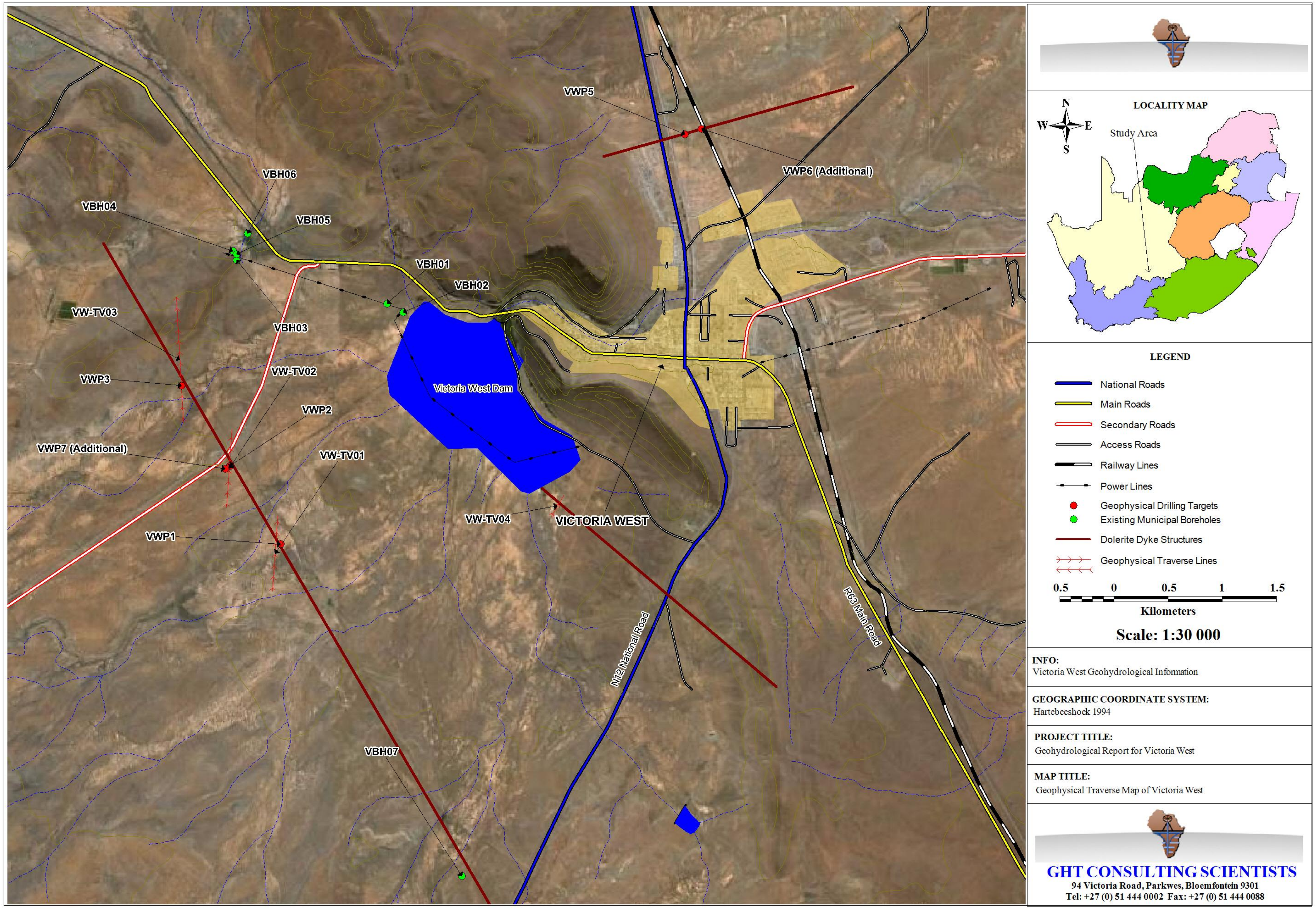
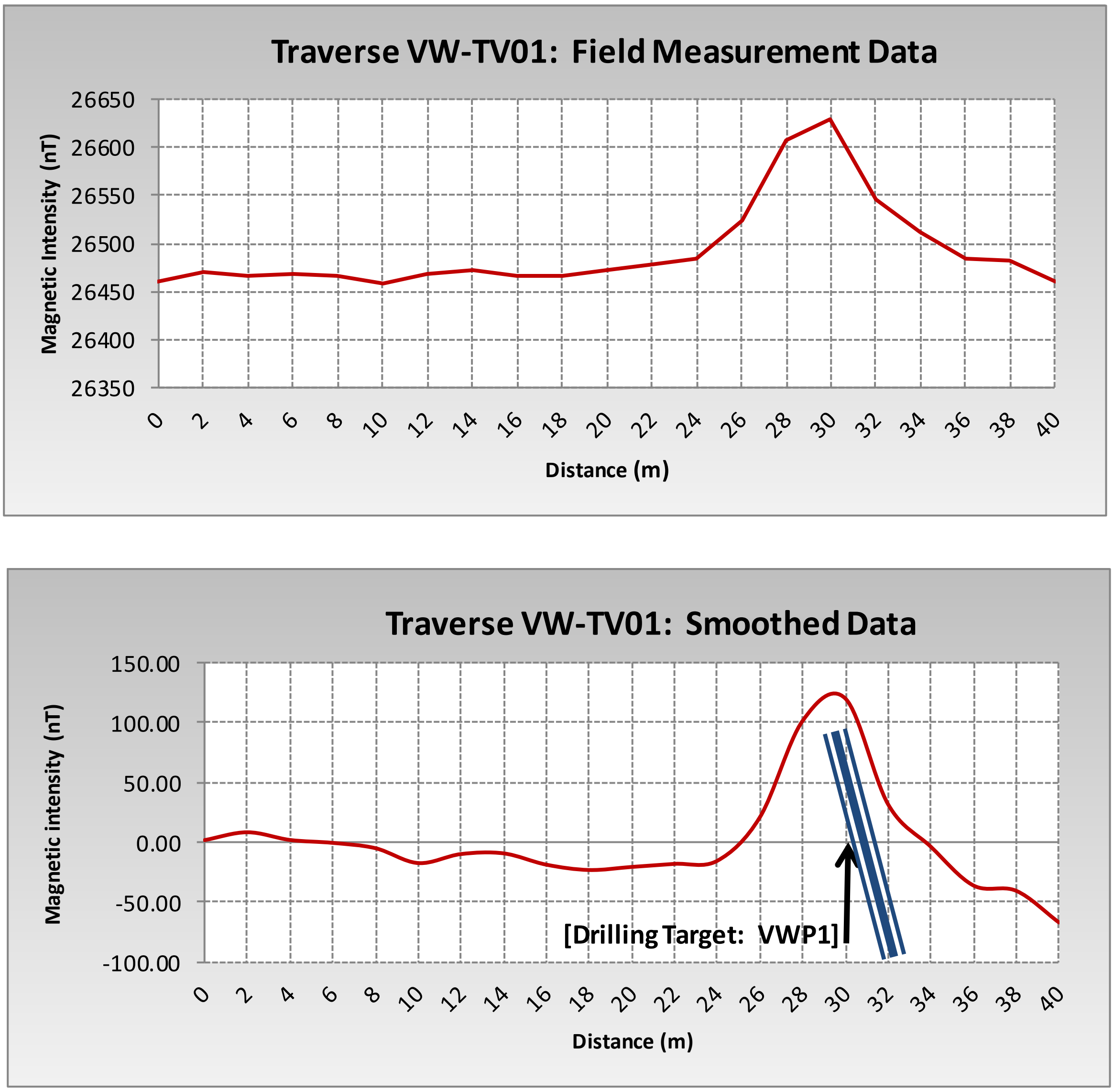


Figure 4. The locality map of the geophysical survey conducted on the commonage of Victoria West.

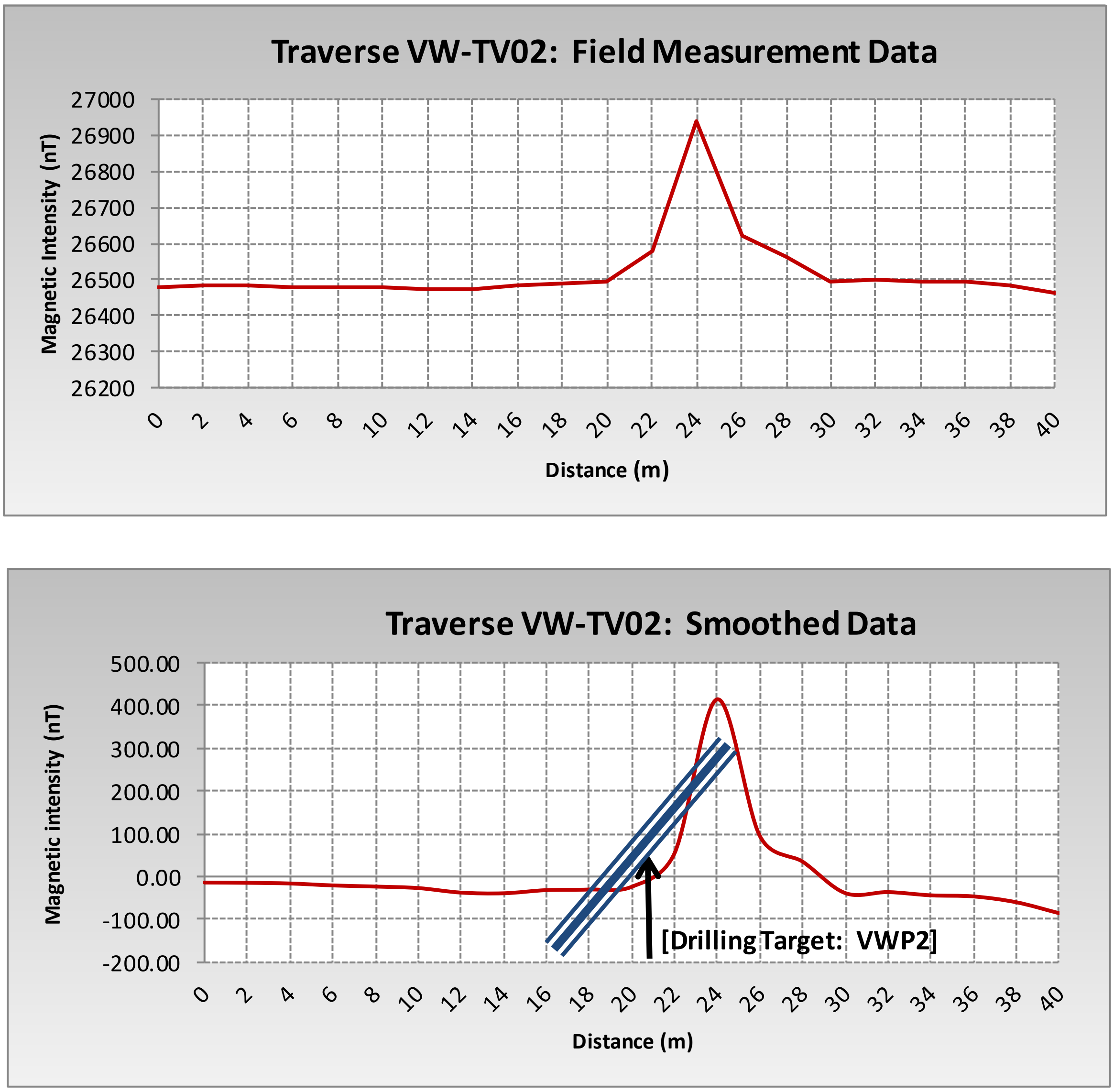
VICTORIA WEST - MAGNETIC PROFILES



Project:	Geophysical Survey	**Profile Number:**	VW-TV01
Project Number:	203-22-GHD.674	**Profile Direction:**	SW-NE
Survey Area:	Victoria West	**Station Spacing:**	2 m
Date of Survey:	10-Sep-13	**Operator:**	Mr DC Rudolph

Figure 5. Magnetic intensity graph of traverse VW-TV01. The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 30 m. One drilling target was sited on the geological structure, namely VWP1 (East: 23.07302 and South: -31.41948, WGS84).

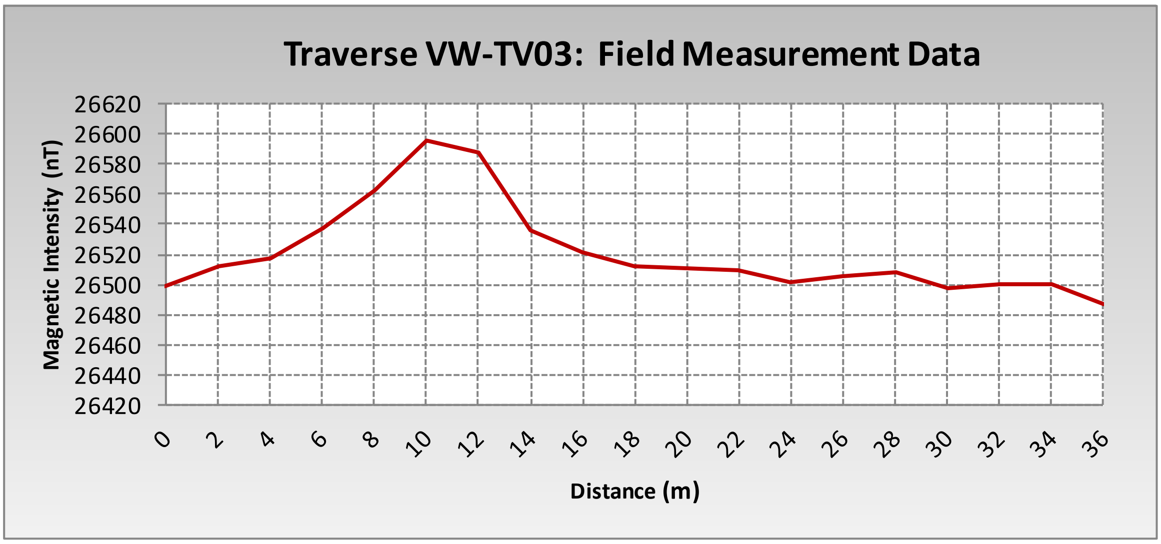
VICTORIA WEST - MAGNETIC PROFILES

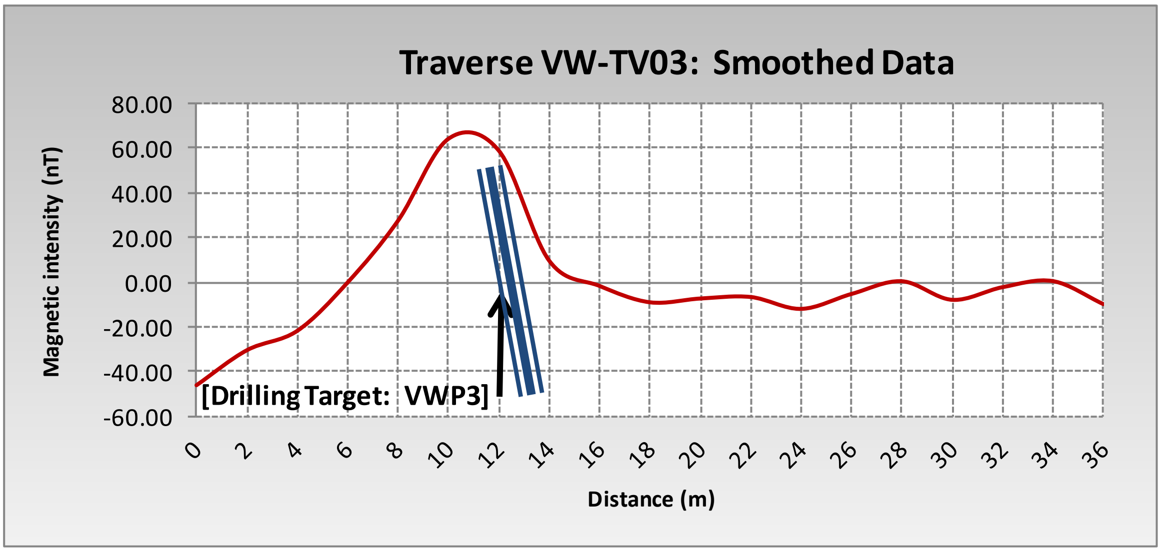


Project:	Geophysical Survey	**Profile Number:**	VW-TV02
Project Number:	203-22-GHD.674	**Profile Direction:**	S-N
Survey Area:	Victoria West	**Station Spacing:**	2 m
Date of Survey:	10-Sep-13	**Operator:**	Mr DC Rudolph

Figure 6. Magnetic intensity graph of traverse VW-TV02. The traverse was conducted from south to north. A potential geological (dolerite dyke) structure was observed at station 22 m. One drilling target was sited on the geological structure, namely VWP2 (East: 23.07793 and South: -31.41948, WGS84).

VICTORIA WEST - MAGNETIC PROFILES

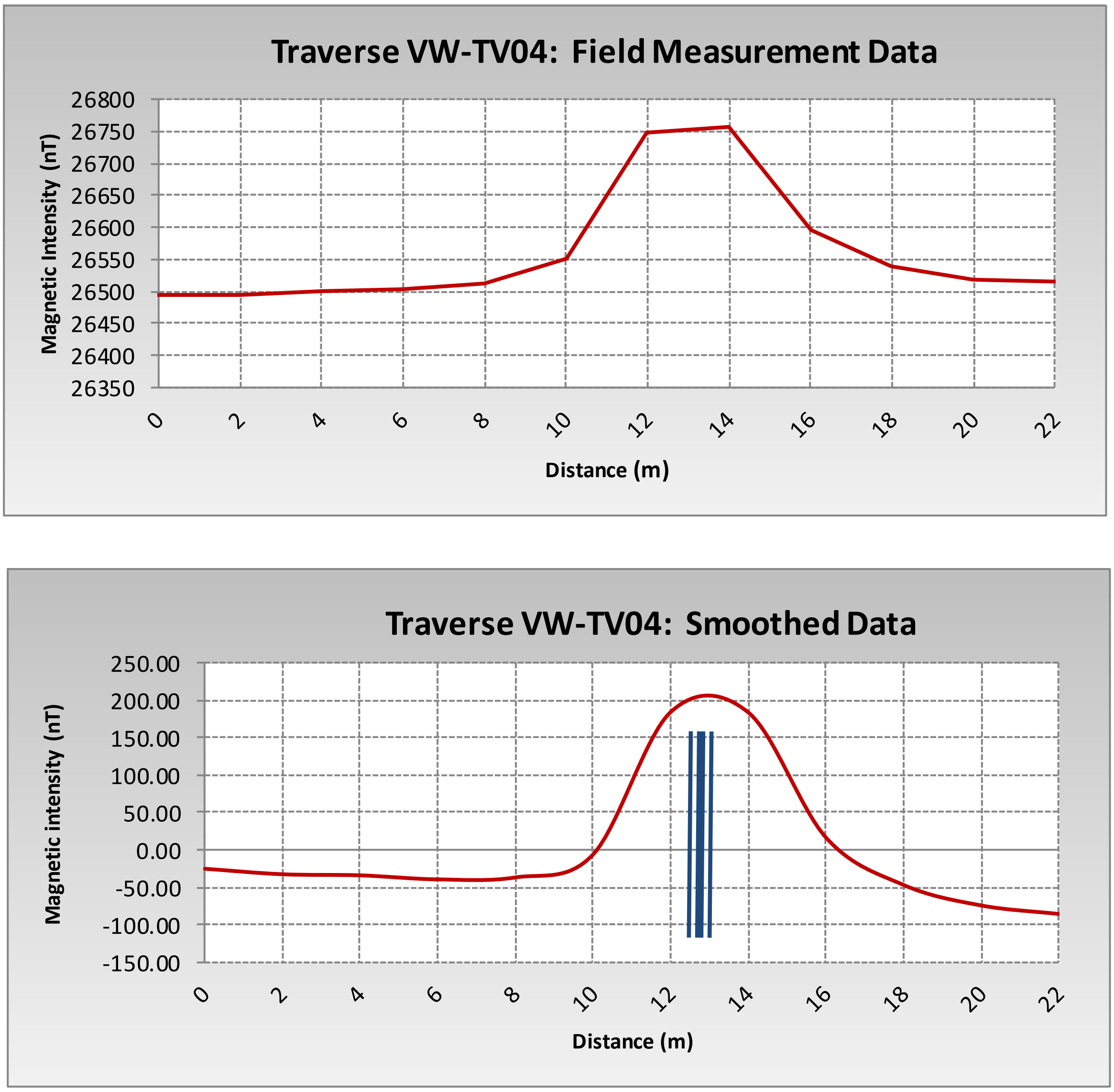




Project:	Geophysical Survey	**Profile Number:**	VW-TV03
Project Number:	203-22-GHD.674	**Profile Direction:**	S-N
Survey Area:	Victoria West	**Station Spacing:**	2 m
Date of Survey:	10-Sep-13	**Operator:**	Mr DC Rudolph

Figure 7. Magnetic intensity graph of traverse VW-TV03. The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 12 m. One drilling target was sited on the geological structure, namely VWP3 (East: 23.06834 and South: -31.40636, WGS84).

VICTORIA WEST - MAGNETIC PROFILES



Project:	Geophysical Survey	**Profile Number:**	VW-TV04
Project Number:	203-22-GHD.674	**Profile Direction:**	SW-NE
Survey Area:	Victoria West	**Station Spacing:**	2 m
Date of Survey:	10-Sep-13	**Operator:**	Mr DC Rudolph

Figure 8. Magnetic intensity graph of traverse VW-TV04. The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 13 m.

3.2.2 Loxton Geophysical Survey Results

The description of the geophysical traverses of the magnetic field survey as well as the sited drilling positions for Loxton are as follows (refer to Figure 9 on page 23):

- Traverse line L-TV01 (refer to Figure 10 on page 24): The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 30 m. One drilling target was sited on the geological structure, namely LP1 (East: 22.33423 and South: -31.48564, WGS84).
- Traverse line L-TV02 (refer to Figure 11 on page 25): The traverse was conducted from south to north. A potential geological (dolerite dyke) structure was observed at station 44 m. One drilling target was sited on the geological structure, namely LP2 (East: 22.33525 and South: -31.48257, WGS84).
- Traverse line L-TV03 (refer to Figure 12 on page 26): The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 10 m. One drilling target was sited on the geological structure, namely LP3 (East: 22.33525 and South: -31.47982, WGS84).
- Traverse line L-TV04 (refer to Figure 13 on page 27): The traverse was conducted from west to east. A potential geological (dolerite dyke) structure was observed at station 55 m. One drilling target was sited on the geological structure, namely LP4 (East: 22.33838 and South: -31.47674, WGS84).

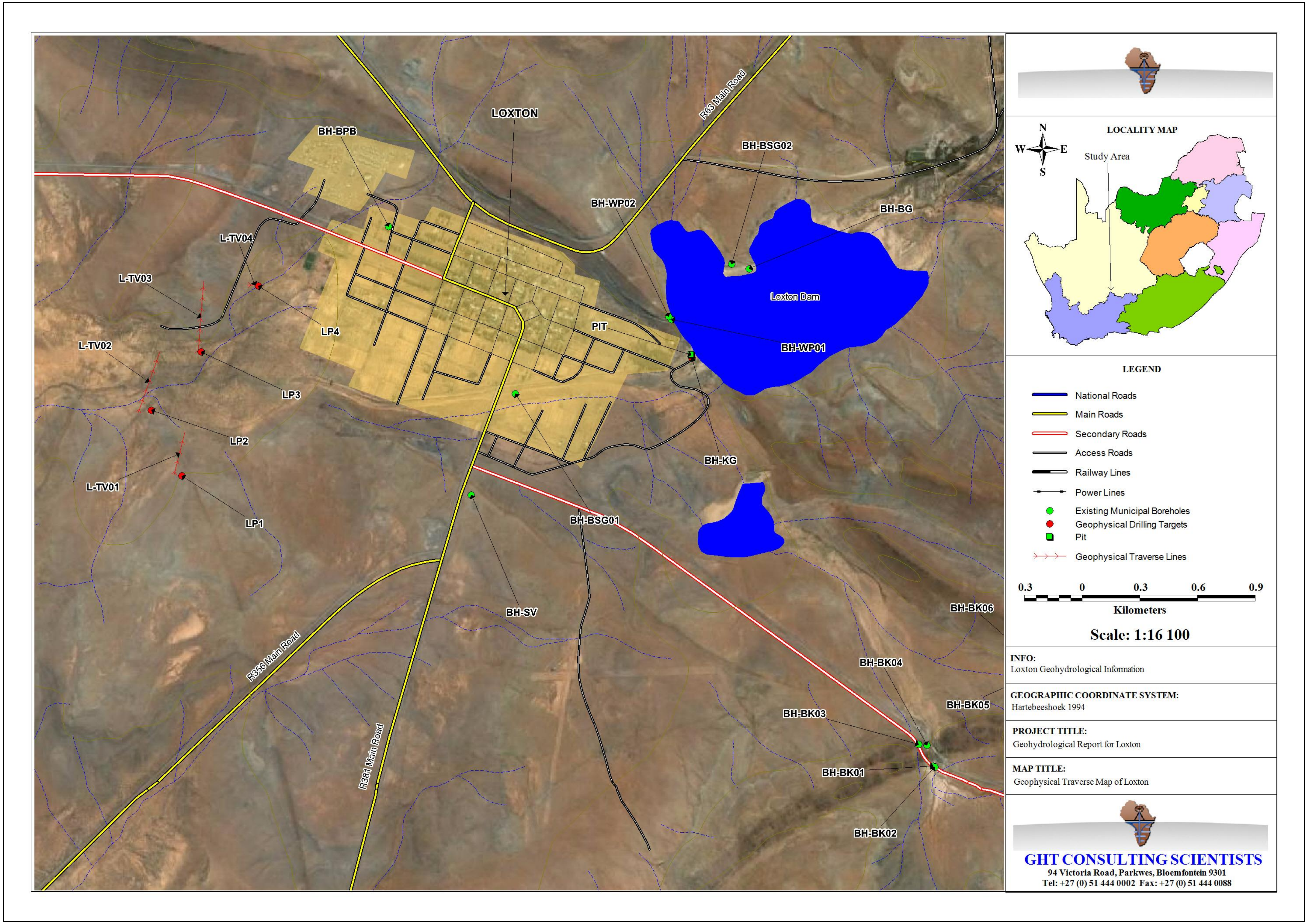
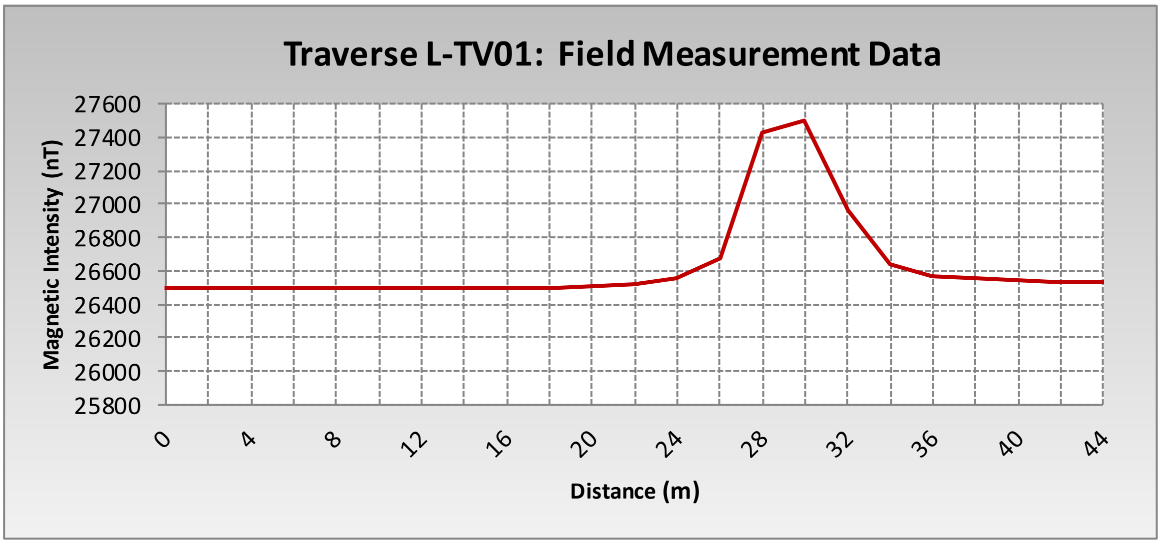
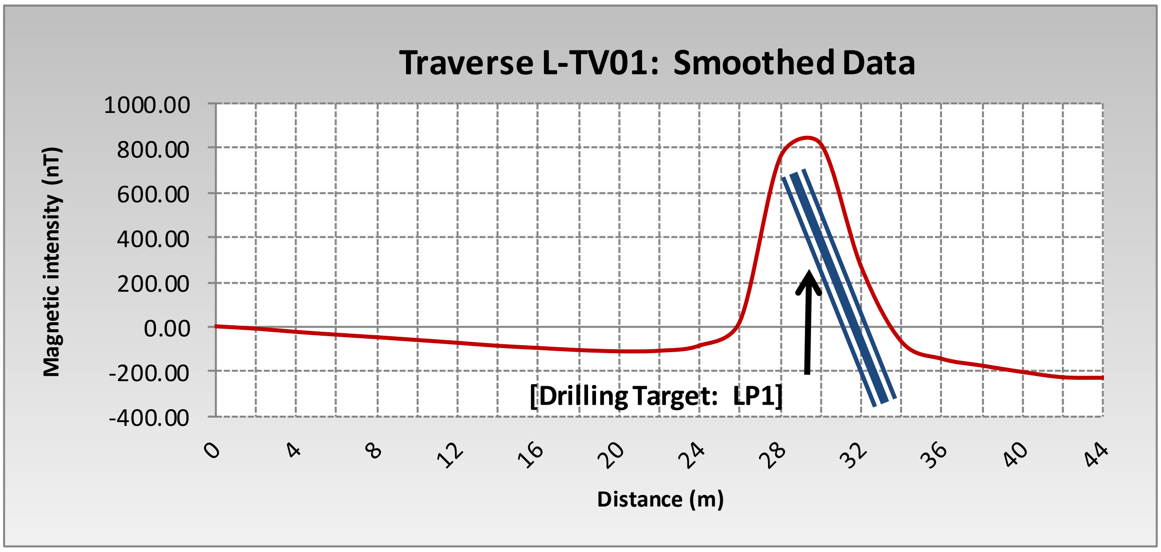


Figure 9. The locality map of the geophysical survey conducted on the commonage of Loxton.

LOXTON - MAGNETIC PROFILES

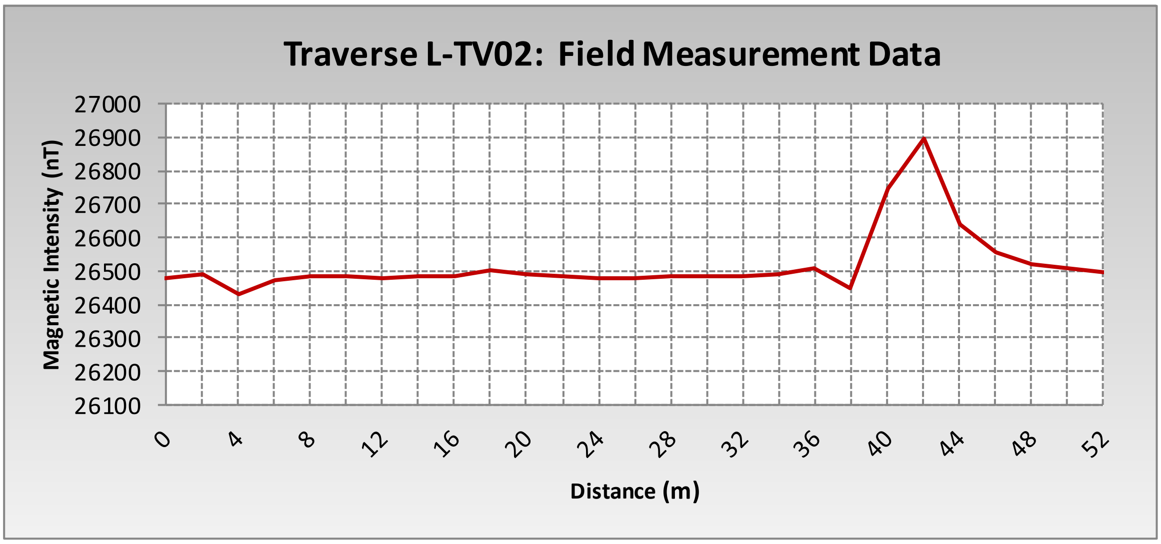


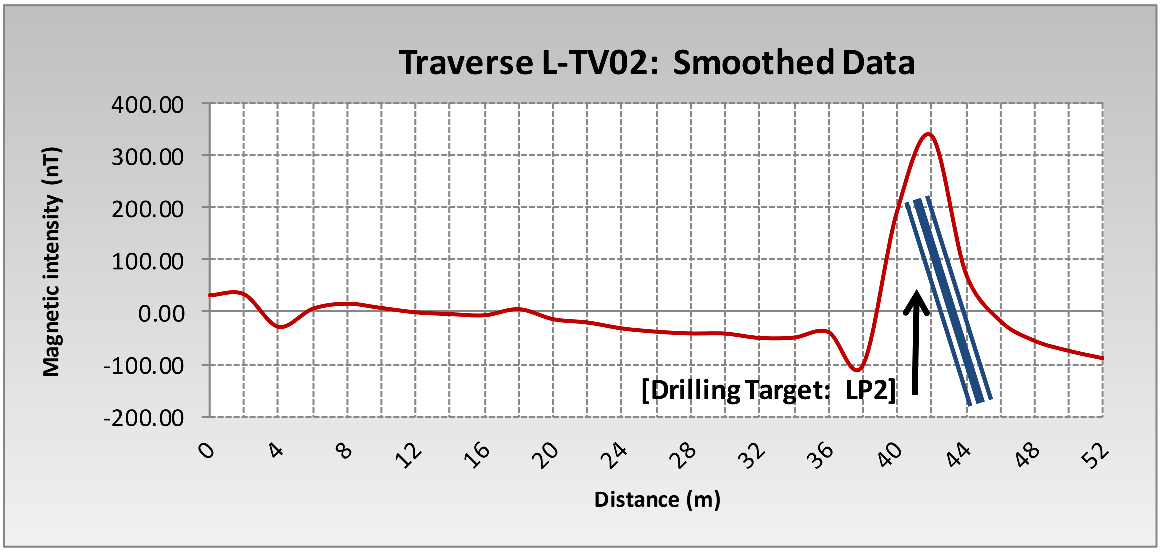


Project:	Geophysical Survey	**Profile Number:**	L-TV01
Project Number:	203-22-GHD.674	**Profile Direction:**	SW-NE
Survey Area:	Loxton	**Station Spacing:**	2 m
Date of Survey:	11-Sep-13	**Operator:**	Mr DC Rudolph

Figure 10. Magnetic intensity graph of traverse L-TV01. The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 30 m. One drilling target was sited on the geological structure, namely LP1 (East: 22.33423 and South: -31.48564, WGS84).

LOXTON - MAGNETIC PROFILES

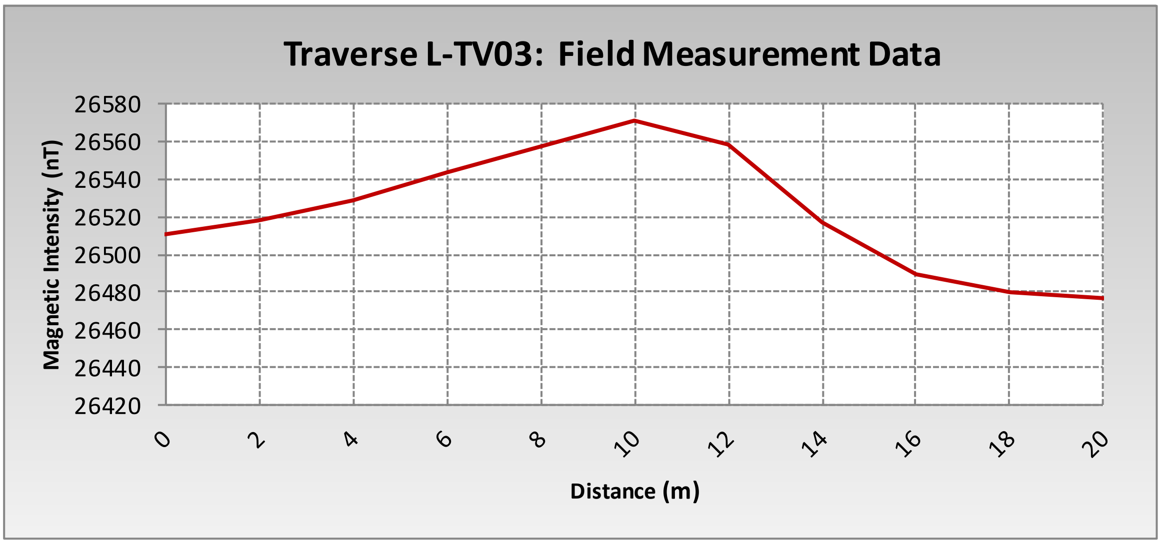


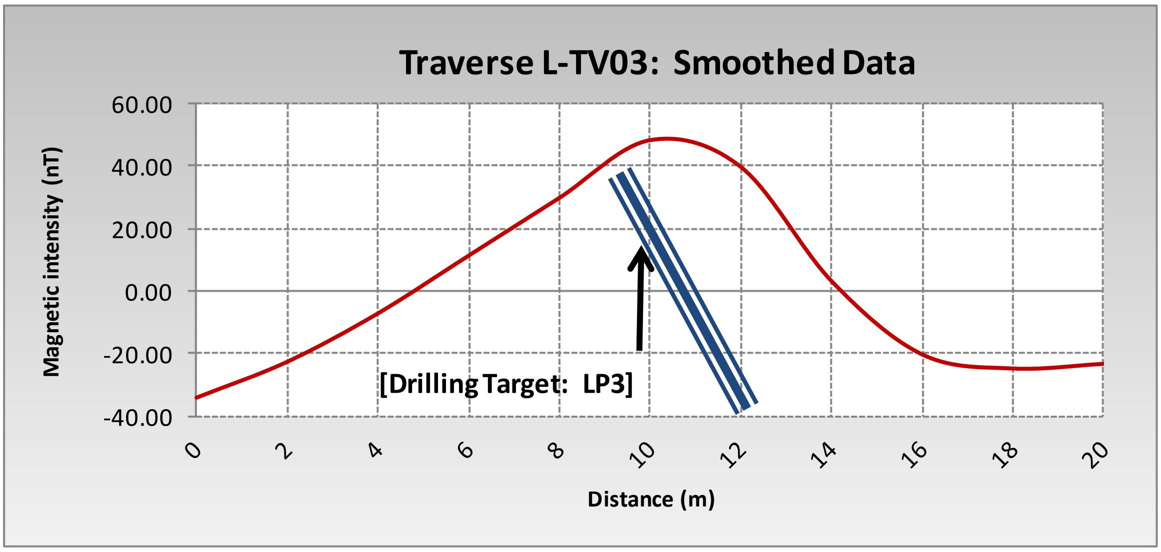


Project:	Geophysical Survey	**Profile Number:**	L-TV02
Project Number:	203-22-GHD.674	**Profile Direction:**	SW-NE
Survey Area:	Loxton	**Station Spacing:**	2 m
Date of Survey:	11-Sep-13	**Operator:**	Mr DC Rudolph

Figure 11. Magnetic intensity graph of traverse L-TV02. The traverse was conducted from south to north. A potential geological (dolerite dyke) structure was observed at station 44 m. One drilling target was sited on the geological structure, namely LP2 (East: 22.33525 and South: -31.48257, WGS84).

LOXTON - MAGNETIC PROFILES

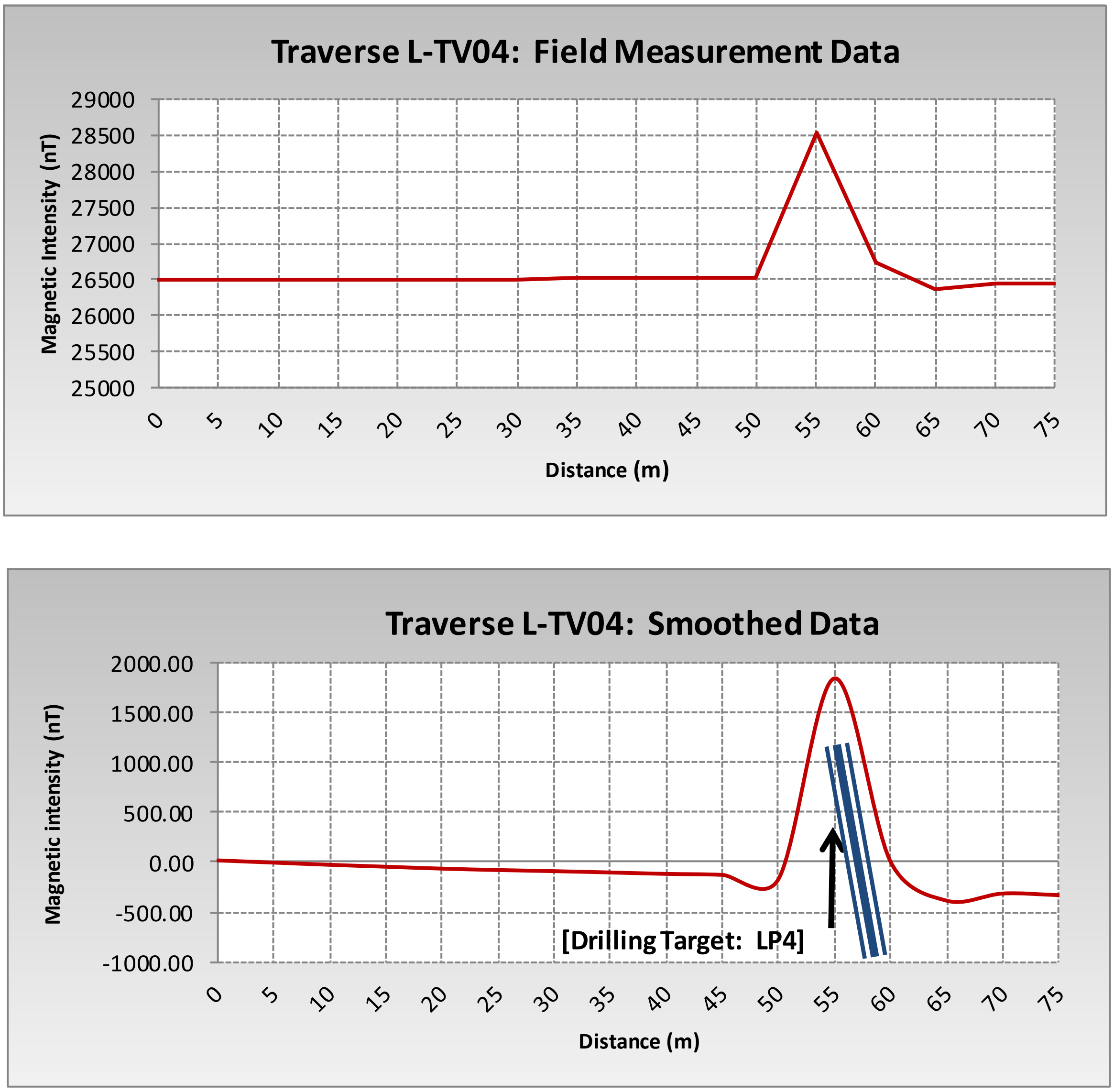




Project:	Geophysical Survey	**Profile Number:**	L-TV03
Project Number:	203-22-GHD.674	**Profile Direction:**	SW-NE
Survey Area:	Loxton	**Station Spacing:**	2 m
Date of Survey:	11-Sep-13	**Operator:**	Mr DC Rudolph

Figure 12. Magnetic intensity graph of traverse L-TV03. The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 10 m. One drilling target was sited on the geological structure, namely LP3 (East: 22.33525 and South: -31.47982, WGS84).

LOXTON - MAGNETIC PROFILES



Project:	Geophysical Survey	**Profile Number:**	L-TV04
Project Number:	203-22-GHD.674	**Profile Direction:**	W-E
Survey Area:	Loxton	**Station Spacing:**	5 m
Date of Survey:	11-Sep-13	**Operator:**	Mr DC Rudolph

Figure 13. Magnetic intensity graph of traverse L-TV04. The traverse was conducted from west to east. A potential geological (dolerite dyke) structure was observed at station 55 m. One drilling target was sited on the geological structure, namely LP4 (East: 22.33838 and South: -31.47674, WGS84).

3.2.3 Hutchinson Geophysical Survey Results

The four (4) drilling targets for Hutchinson were sited on municipal property. The drilling target localities can be viewed in Figure 14 on page 29. The drilling target information is as follows:

- Drilling target HP1 (East: 23.18805 and South: - -31.49499, WGS84). The drilling target was site according to geological observations and interpretations.
- Drilling target HP2 (East: 23.18805 and South: - -31.49499, WGS84). The drilling target was site according to geological observations and interpretations.
- Drilling target HP3 (East: 23.18805 and South: - -31.49499, WGS84). The drilling target was site according to geological observations and interpretations.
- Drilling target HP4 (East: 23.18805 and South: - -31.49499, WGS84). The drilling target was site according to geological observations and interpretations.

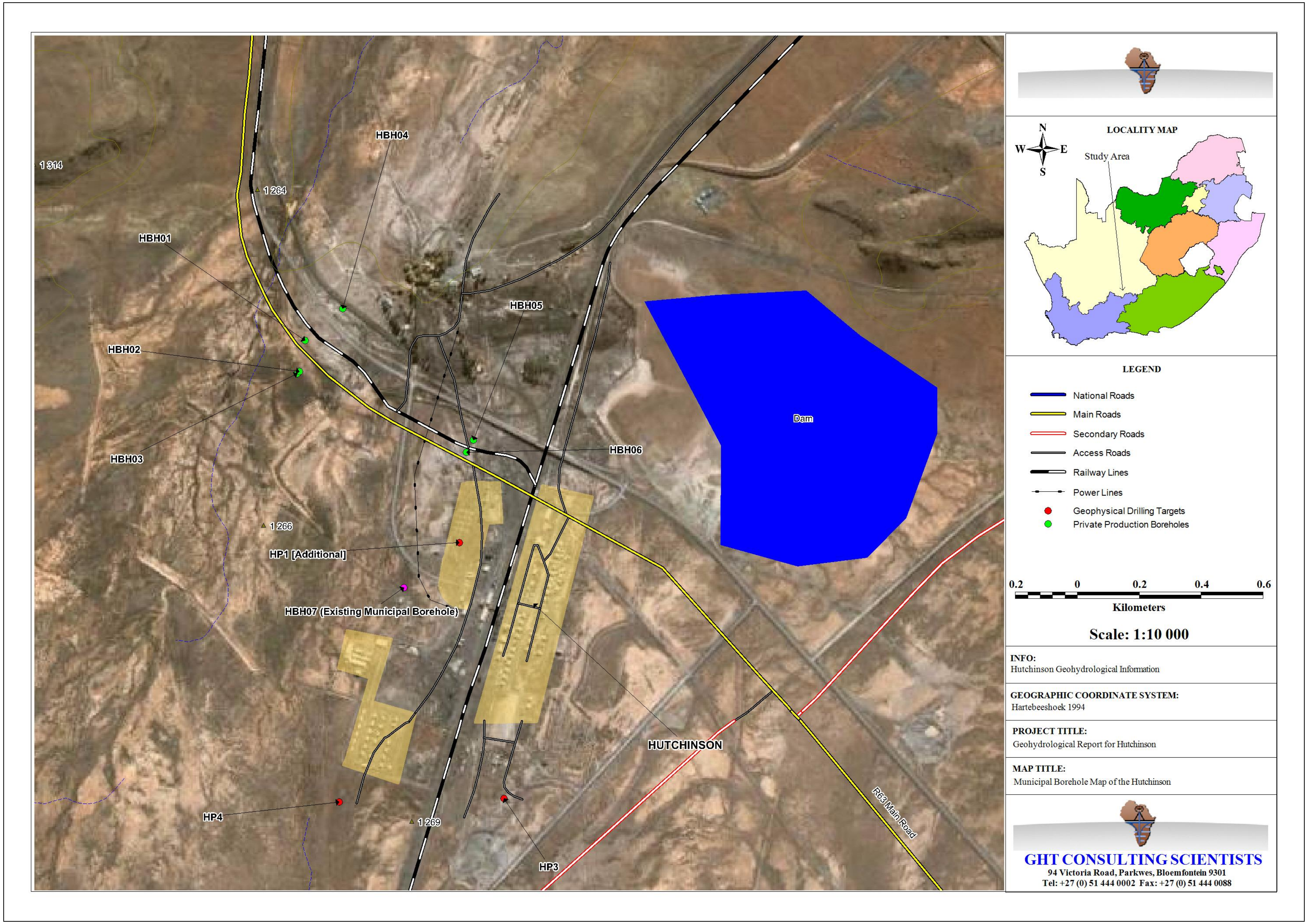


Figure 14. The locality map of the geophysical survey conducted on the commonage of Hutchinson.

3.2.4 Merriman Geophysical Survey Results

The two (2) drilling targets for Merriman were sited on municipal property. The drilling target localities can be viewed in Figure 15 on page 31. The drilling target information is as follows:

- Drilling target MP1 (East: 23.62016 and South: -31.21021, WGS84). The drilling target was site according to geological observations and interpretations.
- Drilling target MP2 (East: 23.61754 and South: -31.21202, WGS84). The drilling target was site according to geological observations and interpretations.

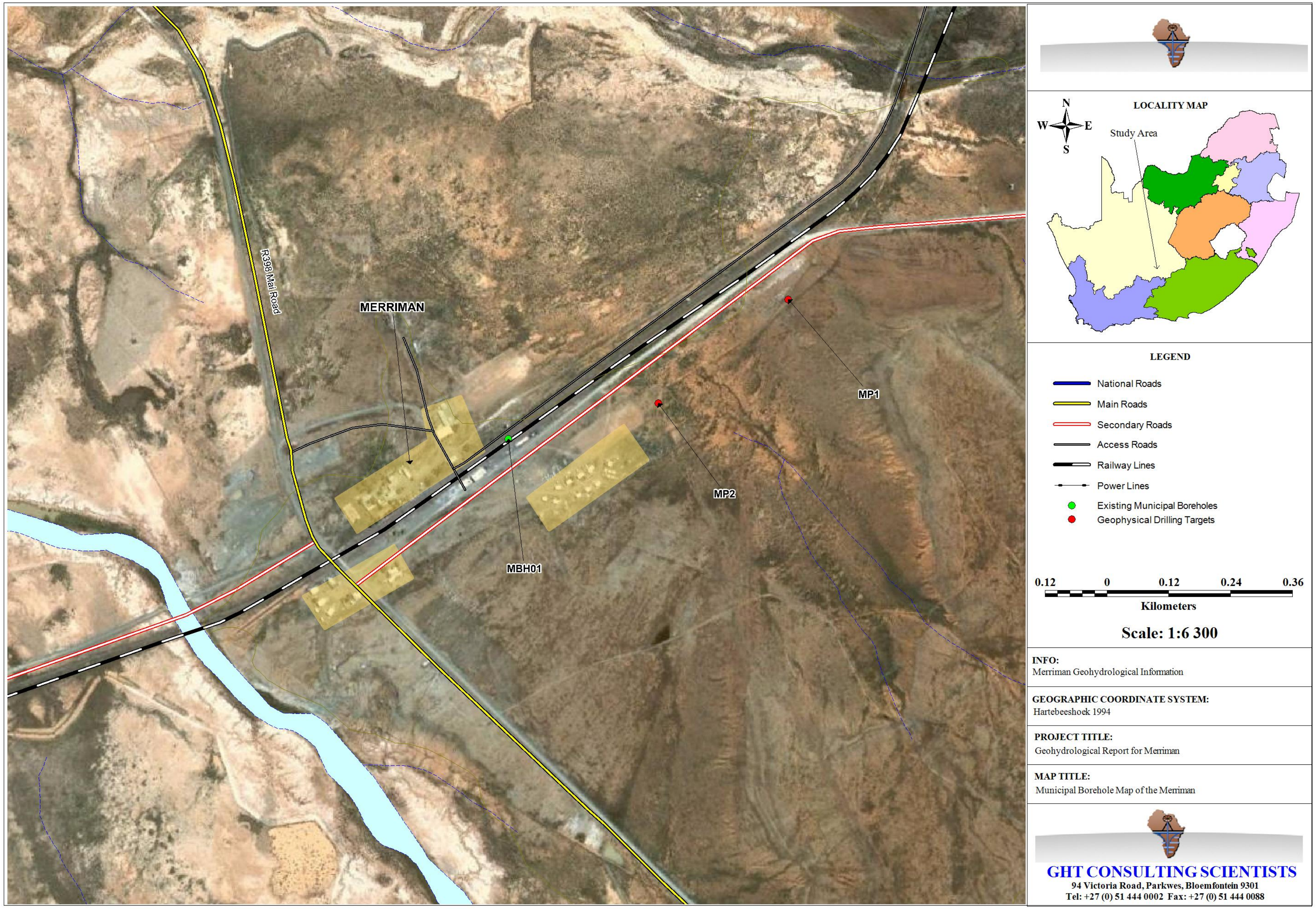


Figure 15. The locality map of the geophysical survey conducted on the commonage of Merriman.

4 GEOLOGY OF THE STUDY AREA

This section contains the general geology of the study area as well as the geological / geohydrological logging information of the sixteen (16) newly drilled boreholes information collected during the completion of the project.

4.1 LITHOSTRATIGRAPHY AND DEPOSITIONAL HISTORY

This section has been adapted from the Hydrogeology of the Main Karoo Basin, WRC Report No. TT179/02.

The lithostratigraphy of the study area consists of the Karoo Supergroup Geology as well as Surficial or Quaternary Deposits and Karoo Dolerite Intrusives of the Jurassic Jura. The lithostratigraphy of the study area is as follows:

- **Beaufort Group:**
- Adelaide Subgroup;
  - Teekloof Formation: The Teekloof Formation is sub-divided by the Oukloof and Hoedemaker Members. The sedimentary rocks of the Teekloof Formation consist of green, red and purple mudstone, shales, sandstone and subordinate sandstone, (Geological Survey Map, 3224 Graaff-Reinet, 1:250 000 Series); and
- **Late Tertiary Surficial or Quaternary Deposits:** Unconsolidated alluvium and colluvium deposits (Geological Survey Map, 3122, Victoria West, 1:250 000 Series).
- **Dolerite Intrusives (Jurassic Jura Age):** The dolerites of the area consist of sills and dyke structures (Geological Survey Map, 3122, Victoria West, 1:250 000 Series).

The borehole construction and the geological logging of the information available for existing boreholes as well the newly drilled boreholes can be viewed in Appendix C.

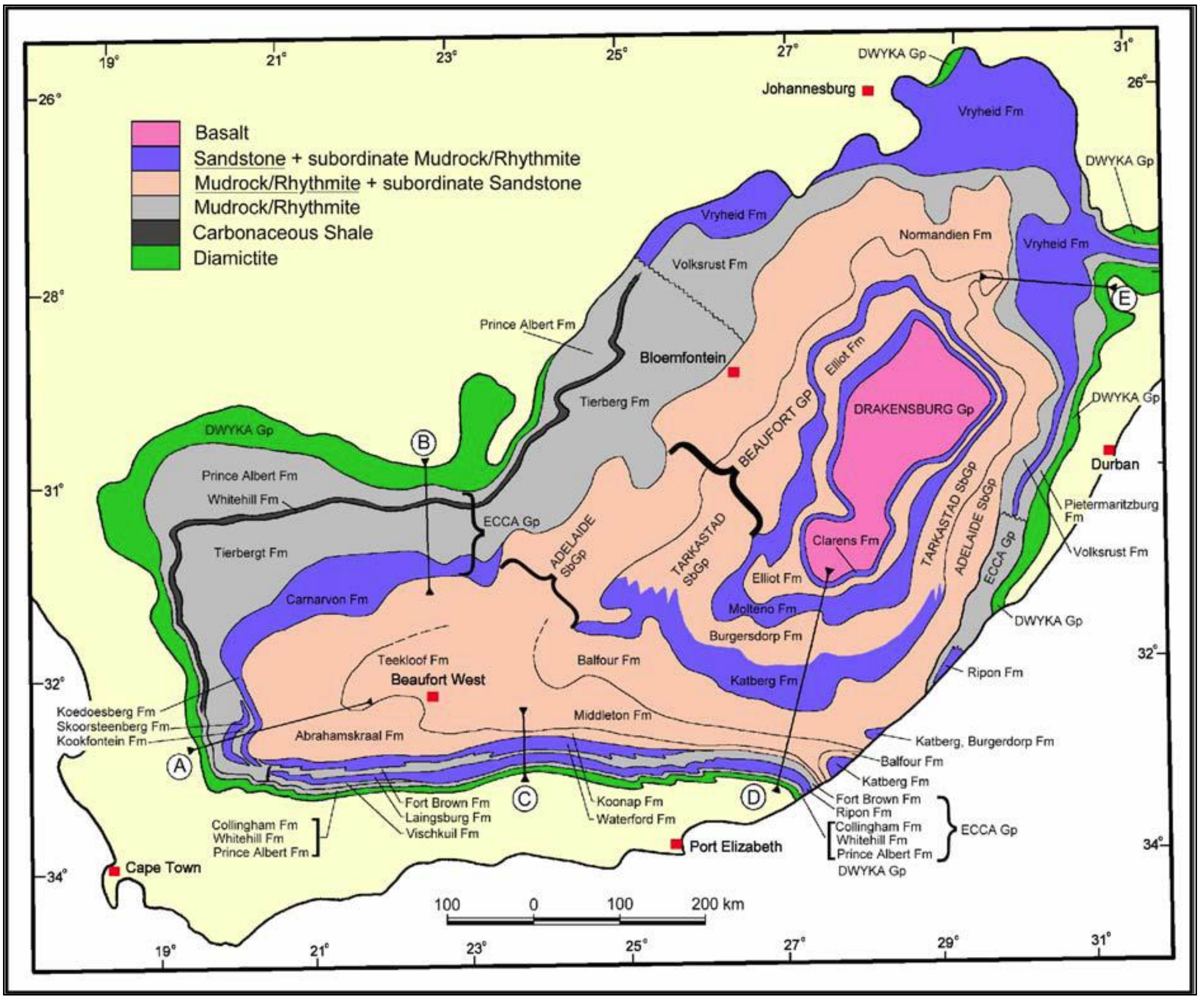


Figure 16. Schematic areal distribution of lithostratigraphic units in the Main Karoo Basin (after Johnson et al., 1997).

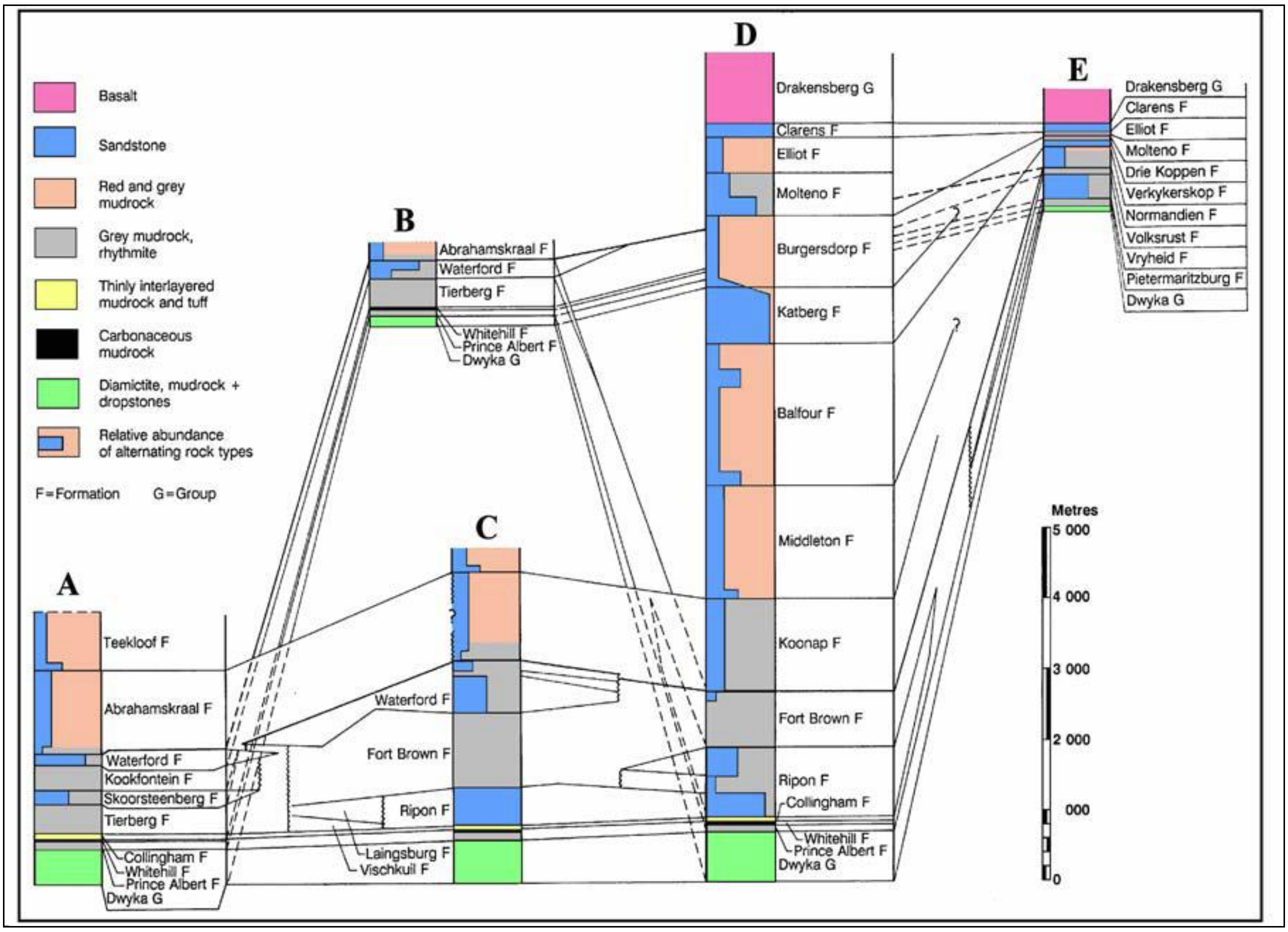


Figure 17. Generalised stratigraphy and lithology of the Karoo Supergroup of the Main Karoo Basin (Johnson et al., 1997).

4.2 ADELAIDE SUB-GROUP GEOLOGY

In the south eastern part of the basin, the late Permian Adelaide Subgroup comprises the Koonap, Middleton and Balfour Formations. In the west, the Abrahamskraal and Teekloof Formations are the approximate equivalents of the Koonap and Middleton Formations, respectively (refer to Figure 16 and Figure 17). While the Middleton and Teekloof Formations are characterised by a greater relative abundance of red mudstone compared to the underlying and (in the case of the former) overlying units, in practice the boundaries are linked to specific sandstone-rich marker units (members). Thus the arenaceous Poortjie and Oudeberg Members constitute the base of the Teekloof and Balfour Formations, respectively. In the northeastern region, only a single formation, the Normandien Formation, is present.

The Adelaide Subgroup attains a maximum thickness of about 5000m in the southeast, which decreases rapidly to about 800 m in the centre of the Basin and thereafter more gradually to around 100–200 m in the extreme north. The Koonap Formation attains a maximum thickness of about 1 300 m, the Middleton 1 600 m (although it may be as much as 2 500 m to the north of Port Elizabeth) and the Balfour 2 000 m. In the west, the Abrahamskraal and Teekloof Formations are up to 2500 m and 1400 m thick, respectively. The Normandien Formation is approximately 320 m thick in its type area (Groenewald, 1989).

In the southern and central parts of the Basin the Adelaide Subgroup consists of alternating bluish-grey, greenish-grey or greyish-red mudrock and grey, very fine to medium-grained, lithofeldspathic sandstone. In the northern part of the Basin, coarse to very coarse sandstone, or even granulestone, are also common in the Normandien Formation. Sandstone generally constitutes 20– 30% of the total thickness, but in certain areas may be as little as 10%, while some sandstone-rich intervals may in places contain up to 60 % sandstone.

Individual sandstone units are thickest in the south (averaging 6 m; maximum 60 m) and become thinner northwards, except for the extreme northeast where thick, laterally extensive units are also present in the Normandien Formation. They generally extend laterally for a few hundreds metres to a few kilometres, but many are markedly lenticular. Calcareous concretions 20-100 cm in diameter are present in some sandstone layers.

In the Daggaboersnek Member, which occurs towards the middle of the Balfour Formation in the south eastern part of the basin, the sandstones tend to be thin and tabular, possibly reflecting a lacustrine depositional environment.

Palaeocurrent data indicate that the bulk of the sediment was derived from a source area situated to the south and southeast of the Basin, with subordinate influxes from the southwest, west-northwest and northeast (refer to Figure 18 (A) on page 36). The source area situated to the south, southeast and southwest of the Basin coincides with the second major tectonic paroxysm of the Cape Fold Belt, dated at ±258 Ma (Hälbich et al., 1983). The margin of the Basin was probably close to the present South African coastline (Cole, 1998). Source areas to the west-northwest and northeast were sited on the continental regions of western Namaqualand / north-eastern Patagonia and the Mozambique Ridge / East Antarctica respectively (Cole, 1998).

Except in the lower part of the Normandien Formation, where coarsening-upward cycles of sedimentation are present, the sandstone units normally form fining-upward cycles. The cycles vary from a few metres to a few tens of metres in thickness and were probably formed by the lateral migration of meandering rivers (refer to Figure 18 (B) on page 36). The subordinate, horizontally bedded sandstone units that show no upward change in grain-size were deposited by ephemeral sheet-floods. The mudstone represents deposition in a flood plain and lacustrine environment.

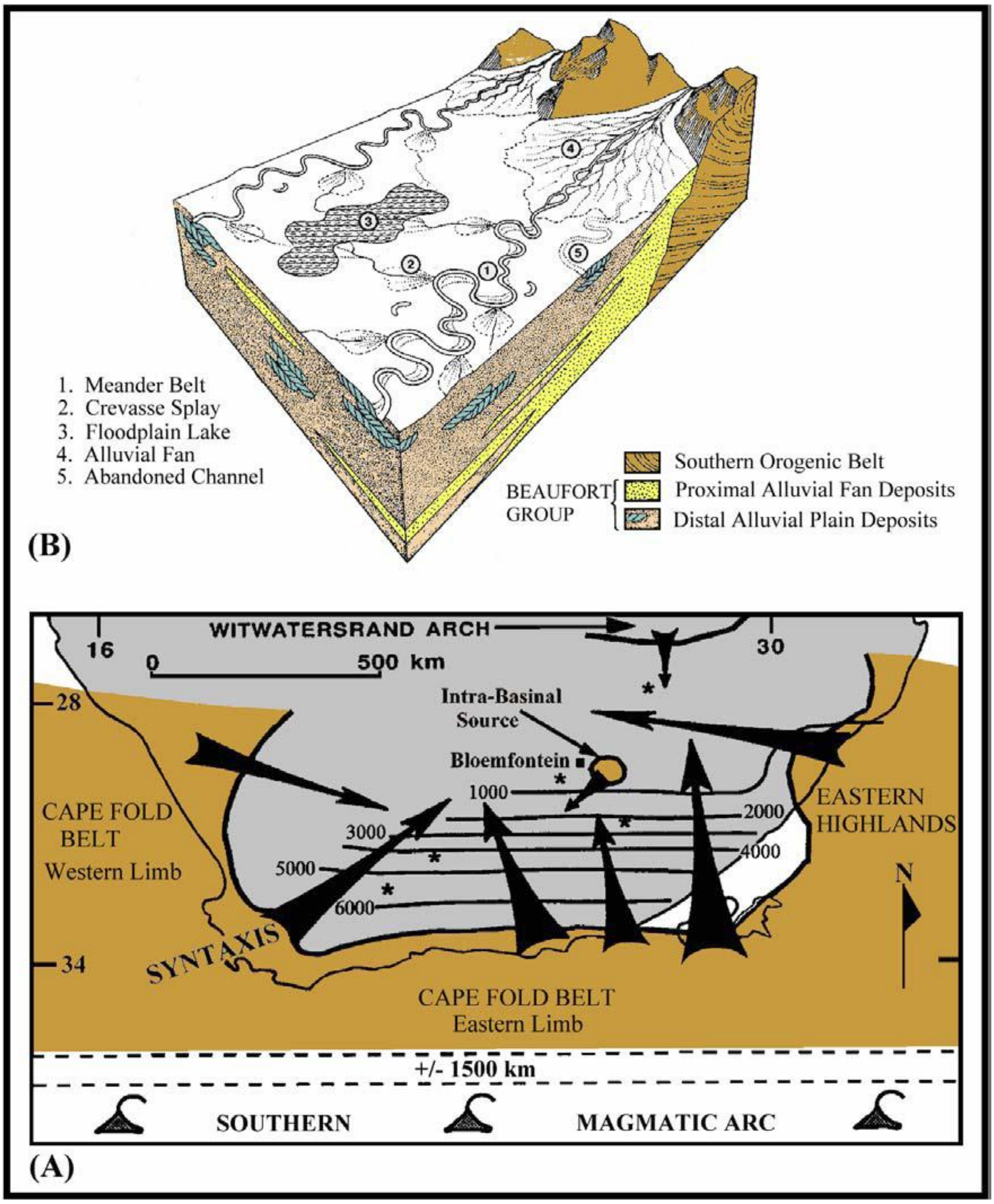


Figure 18. (A) Sediment source areas for the Beaufort Group (after Cole, 1992). (B) Depositional environment of the Beaufort Group in the Southern Karoo Basin (after Smith et al., 1993).

4.3 LATE TERTIARY SURFICIAL OR QUATERNARY DEPOSITS

The only unconsolidated deposits of any geohydrological significance in the study area occur at the confluence of the Sundays, Pienaars, Broederstroom and Gats Rivers, as well as beneath the Nqweba or Van Ryneveldspas Dam, to the north of Graaff-Reinet. The alluvium generally varies in thickness between 1 and 18m, with exceptional thickness of up to 24 m occurring in the vicinity of the Northern Borehole field. The upper 6m of these deposits are generally loamy and fine grained (silt and clay rich), and are often calcretized. The basal zone generally consists of poorly sorted and coarse grained material, including gravel and boulders which infill narrow palaeo-channels. The thickness of this coarse base unit varies over short distances and where present is 0.5 to 8m thick (Woodford, 1984). The saturated alluvium and underlying fractured bedrock form a significant aquifer system hereafter referred to as the "Graaff-Reinet Aquifer System" or GRAS.

4.4 INTRUSIVE KAROO DOLERITE

A vast volume of basaltic magma was injected into the Beaufort Group of sediments at about 150 to 180 Ma, in the form of dolerite dyke and sills, as well as eruptions of basalt lava flows. Dolerite dykes and sills have been widely targeted for the development of relatively high-yielding boreholes in the Karoo Basin (Woodford and Chevallier, 2002). High-yielding boreholes are often associated with fracturing associated with these structures. Significant water-bearing fractures are associated with the so-called 'Dalham' dolerite sheet and sill underlying the alluvium in the Northern Wellfield. Woodford (1984) also drilled a number of high yielding boreholes on dolerite dykes located to the north of Graaff-Reinet. The southern extremity of the study area in the Moordenaars catchment is formed by an arcuate shaped inclined dolerite sheet, which dips northward by 8°.

Towards the end of the Cape Orogeny a thermal dome uplift developed beneath almost the entire South African continent. Dolerite intrusions represent the roots of the volcanic system and are presumed to be of the same age as the extrusive lavas (Fitch and Miller, 1984). Extensive magmatic activity lead to dolerite dykes, inclined sheets and sills to intrude the sedimentary rocks of the Karoo Supergroup during the Jurassic period to the north of the compressional sphere of the Cape Fold Belt. The level of erosion that affected the Main Karoo basin has revealed the deep portions of the intrusive system, which displays a high degree of tectonic complexity. The Karoo intrusives can either occur as dykes (linear features), sills (horizontal or inclined sheets) or ring-complexes. The Karoo dolerite, which includes a wide range of petrological facies, consists of an interconnected network of dykes and sills and it is nearly impossible to single out any particular intrusive or tectonic event. It would, however, appear that a very large number of fractures were intruded simultaneously by magma and that the dolerite intrusive network acted as a shallow stockwork-like reservoir.

Early mapping of the dolerite intrusives was carried out by Rogers and Du Toit (1903) in the Western Cape and Du Toit (1905) in the Eastern Cape. Further contributions on their tectonic and structural aspects include Du Toit (1920), Mask (1966) and Walker and Poldervaart (1949). More recently the Geological Survey has published most of the 1:250 000 maps of the entire Karoo Basin. Detailed mapping of dolerite occurrences at specific localities in the southern Free State were conducted by Burger et al., (1981) and in the Western Karoo by Chevallier and Woodford (1999).

In the study areas sills are the most abundant dolerite appearance and may be horizontal or slightly inclined. Geophysical data indicated also the presence of dyke structure although very few in number.

4.4.1 Geometry, Structure and Mechanism of Emplacement of Dolerite Dykes

Dolerite dykes are the primary targets for groundwater exploration and it is therefore important to understand the geometry, structure and mechanisms of emplacement.

Emplacement Mode: Dolerite dykes, like many other magmatic intrusions, develop by rapid hydraulic fracturing via the propagation of a fluid-filled open fissure, resulting in a massive magmatic intrusion with a neat and transgressive contact with country rock. This fracturing mechanism is in contrast to the slow mode of hydraulic fracturing responsible for breccia-intrusions (i.e. kimberlite). For the intrusion to develop the magma pressure at the tip of the fissure must overcome the tensile strength of the surrounding rock. Dykes can develop vertically upwards or lateral along-strike over very long distances, as long as the magma pressure at the tip of the fissure is maintained. The intrusion of dolerite and basaltic dykes are therefore never accompanied by brecciation, deformation or shearing of the host-rock, at least during their propagation.

Dyke Attitude: All the dykes are sub-vertical with a dip rarely below 70 degrees. Kruger and Kok (1976) reports dips of dykes in the north eastern Free State varying between 65 to 90 degrees. The attitude of dykes often change with depth (i.e. are curved or dislocated), as observed from many detailed borehole logs. This phenomenon can be attributed to vertical offsetting as a result of vertical en-échelon segmentation or due to interconnecting of dykes between sediment layers.

Dyke Width: The average thickness of Karoo dolerite dykes ranges between 2 and 10 m (Woodford and Chevallier, 2001). In general, the width of a dyke is a function of its length. In other words, the wider a dyke is, the longer it will be (this probably also applies to the vertical extension of the feature). For example, the major E-W dykes of Western Karoo Domain can attain widths of up to 70 m, while the Middelburg dyke is 80 m wide. The radiating E-W dykes of Eastern Karoo have widths of up to300 m in places. No relationship has been found between trend and thickness (Woodford and Chevallier, 2001).

En-échelon Pattern: Dolerite dykes often exhibit an en-échelon pattern along strike, which are clearly detected by mapping. This is especially the case with the E-W shear dykes and their associated riedel-shears. Displacements in the vertical section also occur, often associated with horizontal, transgressive fracturing. These offsets are often observed, except through drilling.

Dyke Related Fracturing: The country rock is often fractured during and after dyke emplacement. These fractures form a set of master joints parallel to its strike over a distance that does not vary greatly with the thickness of the dyke (between 5 and 15 m). The dolerite dykes are also affected by thermal- or columnar- jointing perpendicular to their margins. These thermal joints also ex tends into the host rock over a distance not exceeding 0.3 to 0.5 m from the contact. Van Wyk (1963) observed two types of jointing associated with dyke intrusions in a number of coal mines in the Vryheid Dundee area, namely:

- Three sets of pervasive-thermal, columnar joints that are approximately 120 degrees apart; and
- Joints parallel to the contact, confined mainly to the host rock alongside the dyke.

Many cases of tectonic reactivation of the dolerite have been observed in the Loxton-Victoria West area (Woodford and Chevallier, 2001), especially on the N-S dykes that have been reactivated by cretaceous kimberlite activity or by more recent master jointing. Reactivation often results in sub-vertical fissures within the country rock and/or dyke itself, which are commonly highly weathered and filled with secondary calcite/calcrete (width of up to 150 mm) uplifting or brecciation of the sediment along the dyke contact. Deformation and Contact Metamorphism of Host Rock: Localised upwarping of the country rock is often observed adjacent to dipping dykes. Hydraulic fissure propagation, as mentioned above, cannot be responsible for this phenomena, as the magma would have to be cool and become viscous in order cause such deformation. This upwarping of the country rock is commonly a near-surface phenomenon related to supergene formation of clays with a high expansion coefficient resulting in the ‘swelling’ of rock mass. In nearly every case, the dolerite magma shows marked chilling against the sediments into which it has been injected. The chill zone generally exhibits the effects of contact metamorphism, where argillites are altered to hornfels or lydianite and arenaceous units are crystallised to quartzite. Enslin (1951) and Van Wyk (1963) state that the jointed contact zone is less than 30 c wide, irrespectively of dyke thickness.

Petrography and Dyke Weathering: The effect of variable cooling of dykes following intrusion is also apparent in the way which dykes weather in the Western Karoo, namely:

- Thick dykes (>8 m) generally exhibit a prominent chill-margin containing a fine grained, porphyritic, melanocratic dolerite that weathers to produce well-rounded, small, white-speckled boulders (i.e. spheriodal weathering). This zone is normally only 0.5 to 1.5 m wide and exhibits well-developed thermal-shrinkage joints. The central portion of such dykes consist of medium to coarse grained, mesocratic and occasionally leucocratic dolerite that decomposes to a uniform ‘gravely’ material, which exhibits an exfoliation type of pattern. Sporadic fractures or meta-sedimentary veins are encountered in this zone and they often do not extend into the country rock. Magnetic traverses across these features normally produce two distinctive peaks.

Thin dykes (<3 m) commonly consist of fine-grained, porphyritic, melanocratic dolerite (Vandoolaeghe, 1979). These tend to be more resistant to weathering than the thicker dykes and in outcrop exhibit a uniform pattern of shrinkage-joints. The dyke weathers to produce small rounded, white-speckled boulders set in finer angular groundmass.

4.5 GEOHYDROLOGICAL IMPLICATIONS OF GEOLOGY

This section describes the general geohydrological implications of Karoo geology in terms of the sedimentary rocks and the younger intrusive dolerites.

4.5.1 Sediments

Van Wyk (1963) and Vegter (1992) state that the porosity and permeability of the Karoo sediments appears to be highest in the near-surface (i.e. the upper 30 m), which generally corresponds to the weathered zone. There is no clear relation, however, between the occurrence of groundwater and the weathering of the different Karoo lithologies. In this regard, the following generalisation may be stated:

- Dwyka diamictite may represent potential ‘weathered’ aquifers due to their low resistance to weathering;
- Weathering of Karoo shale and mudrock produces clays, which often reduces the permeability of the sediments; and
- Karoo sandstone is highly resistant to weathering and thus these processes are unlikely to direct affect the hydraulic properties of these rocks.

Composite alluvial-weathered bedrock aquifers are commonly developed along the major drainage systems.

It must be noted that low to medium yielding boreholes in the order of 0.5 to 3 L/s can be drilled in sedimentary rocks. No proven geophysical technique currently exists that can locate fractures. Therefore these fracture systems in sedimentary rocks are only discovered by coincidence.

With the exception of alluvium and other poorly consolidated deposits, primary porosity is almost non-existent in rocks in the area of Graaff-Reinet. Most of the aquifers rely on secondary (fracture) porosity. Targets for drilling in Northern Well Field are provided by (1.) thick alluvium, (2.) alternating lithologies, especially where accompanied by folding and or fracturing, and (3.) dolerite sills with adjacent altered contact zones (See Section 4.5.2 for dolerite intrusions).

Targets for drilling in Mimosadale are provided by (1.) alternating sedimentary lithologies, and (2.) folding and fracturing of alternating lithologies through the result of tectonic deformation.

4.5.2 Dolerite Intrusions

Extensive weathered zones often develop in dolerite sills that are situated in low lying and well drained areas – 'similar to weathered basins' described in other crystalline basement rocks (Enslin, 1943; Wright and Burgess, 1992). These localised, shallow intergranular aquifers are capable of storing large volumes of groundwater. Although abstraction from these dense-massive structures are only possible where extensive weathering has occurred at depth (below the aquifer water table).

Dolerite ring-dykes and inclined sheets seldom form negative features of the landscape, as they are more resistant to weathering. The hydrological properties weathered dolerite rings and inclined sheets seem very variable. Vegter (1995) states that the upper or lower contact sills located within the weathered zone, i.e. 20 to 50 mbgl, are favourable zones for striking groundwater. Recent extensive exploration drilling along dolerite inclined sheets and ring dykes in the Victoria West area (Chevallier et al., 2001), shows that the contact between the sediment and the dolerite within the first 50 m below surface did not yield significant volumes of groundwater.

The contact between dolerite dykes and the host rock, within the weathered zone, remains the most important target for groundwater exploration (Vegter, 1995 & Smart, 1998).

4.6 HYDROSTRATIGRAPHY OF THE BEAUFORT GROUP

The main sediment source area for the Beaufort rocks lay along the high-lying, southern margin of the Basin. The coarser grained rocks are, therefore, found near the Cape Fold Belt (alluvial fan and braided stream environments), while mudstone, shale and fine-grained sandstones dominate the more distal central and northern portion (meandering river and floodplain environment) of the Basin. The sedimentary units in the Group therefore usually have very low primary permeabilities. The geometry of these aquifers is complicated by the lateral migration of meandering streams over a floodplain. Aquifers in the Beaufort Group will thus not only be multi-layered, but also multi-porous with variable thicknesses.

The contact plane between two different sedimentary layers will cause a discontinuity in the hydraulic properties of the composite aquifer. The pumping of a multi-layered aquifer will thus cause the piezometric pressure in the more permeable layers to drop faster than in the less permeable layers. It is therefore possible to completely extract the more permeable layers of the multi-layered Beaufort aquifers, without materially affecting the piezometric pressure in the less permeable layers. This complex behaviour of aquifers in the Beaufort Group is further complicated by the fact that many of the coarser, and thus more permeable, sedimentary bodies are lens-shaped. The life-span of a high-yielding borehole in the Beaufort Group may therefore be limited, if the aquifer is not recharged frequently.

4.1 GEOLOGICAL LOGS AND BOREHOLE CONSTRUCTION OF THE NEWLY DRILLED BOREHOLES

As mentioned earlier sixteen (16) boreholes were percussion drilled during the course of the project. The geology of the study area consists of the sedimentary rocks of the Karoo Supergroup and more specifically the Beaufort Group, which contains sedimentary rocks such sandstones, shales and mudstones. The whole sedimentary sequence has been intruded by magmatic features such as dolerite dykes and sills.

4.1.1 Victoria West: Geological / Hydrogeological Logging

The results of the percussion drilling and geological / hydrogeological logging are as follows for Victoria West (refer to Appendix C for the geological logs, geohydrological information and borehole construction):

- Drilling Target VWP1 (Borehole Number: VBH08) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of dark grey dolerite (dyke structure). The groundwater strikes were encountered at the depths 26 mbgl and 49 mbgl. The blow yield of the borehole was estimated at 2 900 L/h. The borehole was not recommended for aquifer test pumping due to low yield.
- Drilling Target VWP2 (Borehole Number: VBH09) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl. The geology consisted of light grey shales. A groundwater strike was encountered at the depth of 24 mbgl. The blow yield of the borehole was estimated at 400 L/h. The borehole was not recommended for aquifer test pumping due to low yield.
- Drilling Target VWP3 (Borehole Number: VBH10) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of light grey shales. The groundwater strikes were encountered at the depths 28 mbgl and 44 mbgl. The blow yield of the borehole was estimated at 3 200 L/h. The borehole was not recommended for aquifer test pumping due to low yield.
- Drilling Target VWP5 (Borehole Number: VBH11) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of light grey shales and dolerite bits at the end of borehole area. The groundwater strikes were encountered at the depths 42 mbgl and 68 mbgl. The blow yield of the borehole was estimated at 15 000 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.
- Drilling Target VWP6 (Borehole Number: VBH12) was exploited by percussion drilling. The borehole was drilled to a depth of 90 mbgl and equipped with a sanitary seal. The geology consisted of light grey shales and dark grey dolerite. The groundwater strikes were encountered at the depths 32 mbgl and 78 mbgl. The blow yield of the borehole was estimated at 18 000 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.
- Drilling Target VWP7 (Borehole Number: VBH13) was exploited by percussion drilling. The borehole was drilled to a depth of 60 mbgl. The geology consisted of light grey shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.

The photos of the newly drilled boreholes of Victoria West can be viewed below:

Photo 1. Newly drilled borehole VBH08 (VWP01).

Photo 2. Geological logs of borehole VBH08 (VWP01).

Photo 3. Newly drilled borehole VBH09 (VWP02).

Photo 4. Geological logs of borehole VBH09 (VWP02).

Photo 5. Newly drilled borehole VBH10 (VWP03).

Photo 6. Geological logs of borehole VBH10 (VWP03).

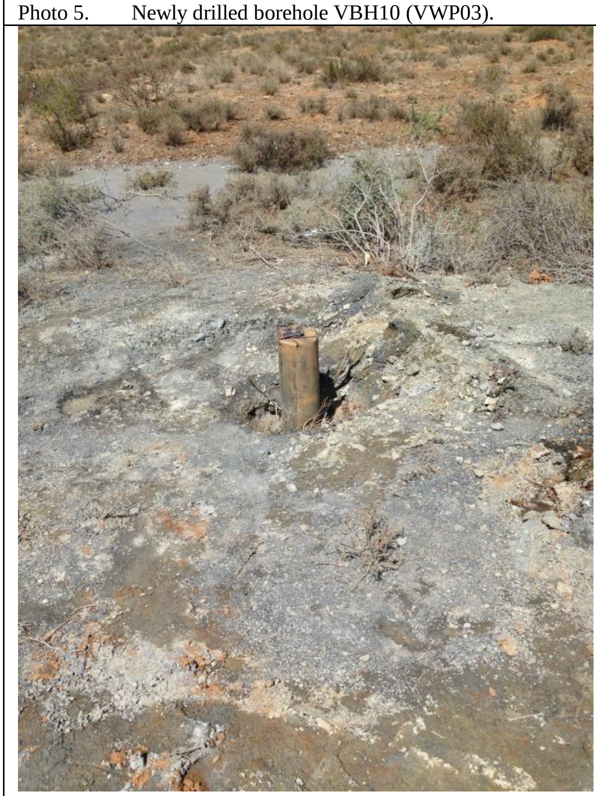


Photo 7. Newly drilled borehole VBH11 (VWP05).

Photo 8. Geological logs of borehole VBH11 (VWP05).

Photo 9. Newly drilled borehole VBH12 (VWP06).

Photo 10. Geological logs of borehole VBH12 (VWP06).

Photo 11. Newly drilled borehole VBH13 (VWP07).

Photo 12. Geological logs of borehole VBH13 (VWP07).

4.1.2 Loxton: Geological / Hydrogeological Logging

The results of the percussion drilling and geological / hydrogeological logging are as follows for Loxton (refer to Appendix C for the geological logs, geohydrological information and borehole construction):

- Drilling Target LP1 (Borehole Number: LBH01) was exploited by percussion drilling. The borehole was drilled to a depth of 90 mbgl and equipped with a sanitary seal. The geology consisted of light grey and purple shales. The groundwater strikes were encountered at the depths 54 mbgl and 57 mbgl. The blow yield of the borehole was estimated at 6 000 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.

- Drilling Target LP2 (Borehole Number: LBH02) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of light grey and black carbonaceous shales. The groundwater strikes were encountered at the depths 36 mbgl and 54 mbgl. The blow yield of the borehole was estimated at 5 400 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.
- Drilling Target LP3 (Borehole Number: LBH03) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl. The geology consisted of light grey and purple shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.
- Drilling Target LP4 (Borehole Number: LBH04) was exploited by percussion drilling. The borehole was drilled to a depth of 90 mbgl. The geology consisted of light grey shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.

The photos of the newly drilled boreholes of Loxton can be viewed below:

Photo 13. Newly drilled borehole LBH01 (LP01).

Photo 14. Geological logs of borehole LBH01 (LP01).

Photo 15. Newly drilled borehole LBH02 (LP02).

Photo 16. Geological logs of borehole LBH02 (LP02).

Photo 17. Newly drilled borehole LBH03 (LP03).

Photo 18. Geological logs of boreholeLBH03 (LP03).

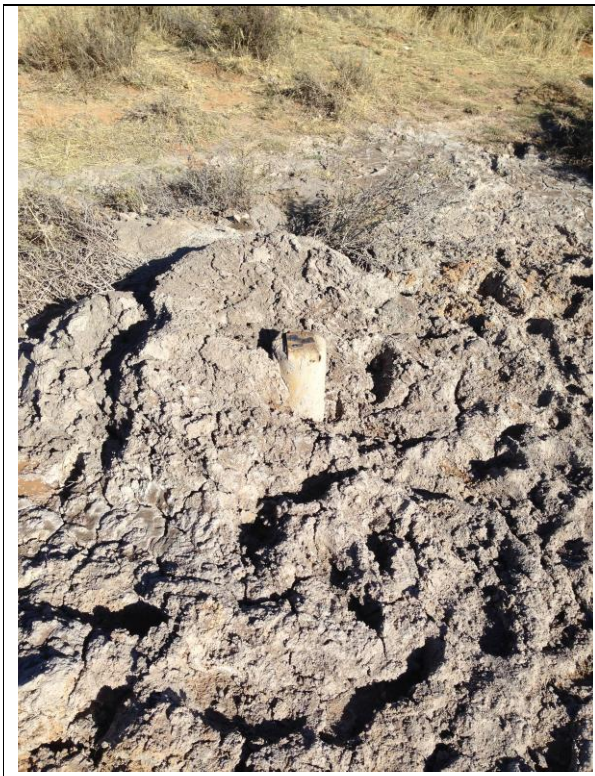


Photo 19. Newly drilled borehole LBH04 (LP04).

Photo 20. Geological logs of borehole LBH04 (LP04).

4.1.3 Richmond: Geological / Hydrogeological Logging

The results of the percussion drilling and geological / hydrogeological logging are as follows for Richmond (refer to Appendix C for the geological logs, geohydrological information and borehole construction):

- Existing municipal production borehole RBH04 re-drilled due to blockages in the original borehole caused by poor borehole construction. The borehole was drilled to a depth of 62 mbgl and equipped with a sanitary seal. The geology consisted of light brown and light grey shales. The groundwater strikes were encountered at the depths 25 mbgl and 28 mbgl. The blow yield of the borehole was estimated at 10 500 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.

The photos of the newly drilled borehole of Richmond can be viewed below:

Photo 21. Re-drilled municipal production borehole RBH04.

Photo 22. Geological logs of re-drilled borehole RBH04.

4.1.4 Hutchinson: Geological / Hydrogeological Logging

The results of the percussion drilling and geological / hydrogeological logging are as follows for Hutchinson (refer to Appendix C for the geological logs, geohydrological information and borehole construction):

- Drilling Target HP1 (Borehole Number: HBH08) was exploited by percussion drilling. The borehole was drilled to a depth of 60 mbgl. The geology consisted of light grey shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.
- Drilling Target HP3 (Borehole Number: HBH09) was exploited by percussion drilling. The borehole was drilled to a depth of 70 mbgl and equipped with a sanitary seal. The geology consisted of light grey and purple shales. A groundwater strike was

encountered at a depth of 48 mbgl. The blow yield of the borehole was estimated at 200 L/h. The borehole was not recommended for aquifer test pumping due to low yield.

- Drilling Target HP4 (Borehole Number: VBH10) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of light grey and purple shales. A groundwater strike was encountered at a depth of 65 mbgl. The blow yield of the borehole was estimated at 3 000 L/h. The borehole was not recommended for aquifer test pumping due to low yield.

The photos of the newly drilled borehole of Hutchinson can be viewed below:

Photo 23. Newly drilled borehole HBH08 (HP01).

Photo 24. Geological logs of borehole HBH08 (HP01).

Photo 25. Newly drilled borehole HBH09 (HP03).

Photo 26. Geological logs of borehole HBH09 (HP03).

Photo 27. Newly drilled borehole HBH10 (HP04).

Photo 28. Geological logs of borehole HBH10 (HP04).

4.1.5 Merriman: Geological / Hydrogeological Logging

The results of the percussion drilling and geological / hydrogeological logging are as follows for Merriman (refer to Appendix C for the geological logs, geohydrological information and borehole construction):

- Drilling Target MP1 (Borehole Number: MBH02) was exploited by percussion drilling. The borehole was drilled to a depth of 70 mbgl and equipped with a sanitary seal. The geology consisted of light grey shales. A groundwater strike was encountered at a depth of 54 mbgl. The blow yield of the borehole was estimated at 3 000 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality due to low volume water needs of Merriman (26 households).

- Drilling Target MP2 was exploited by percussion drilling. The borehole was drilled to a depth of 70 mbgl. The geology consisted of light grey shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.

The photos of the newly drilled borehole of Hutchinson can be viewed below:

Photo 29. Newly drilled borehole MBH02 (MP01).

Photo 30. Geological logs of borehole MBH02 (MP01).

Photo 31. Newly drilled borehole MP02.

Photo 32. Geological logs of borehole MP02

5 GENERAL BOREHOLE INFORMATION

This section contains the general borehole information of the existing municipal boreholes as well as the newly drilled boreholes for the towns of Victoria West, Loxton, Richmond, Hutchinson and Merriman.

5.1 VICTORIA WEST BOREHOLE INFORMATION

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Victoria West. The general borehole information tables can be perused in Table 1 on page 55. The locality map of the municipal boreholes can be viewed in Figure 19 on page 56.

The summary of the general borehole information for Victoria West is as follows:

- The commonage contains seven (7) existing municipal boreholes namely, VBH01, VBH02, VBH03, VBH04, VBH05, VBH06 and VBH07. Three (3) boreholes are currently in use for abstraction purposes. The utilised boreholes include VBH01, VBH02 and VBH07.
- Six (6) new boreholes were drilled namely, VBH08, VBH09, VBH10, VBH11, VBH12 and VBH13.
- The following boreholes have been aquifer test pumped to determine their sustainable yields and groundwater quality namely VBH01, VBH11 and VBH12.
- The descriptions of the current state of the existing borehole equipment can be viewed in Appendix D.

The photos of the existing Victoria West municipal boreholes can be viewed below:

Photo 33. Existing municipal borehole VBH01.

Photo 34. Existing municipal borehole VBH02.

Photo 35. Existing municipal borehole VBH03.

Photo 36. Existing municipal borehole VBH04.

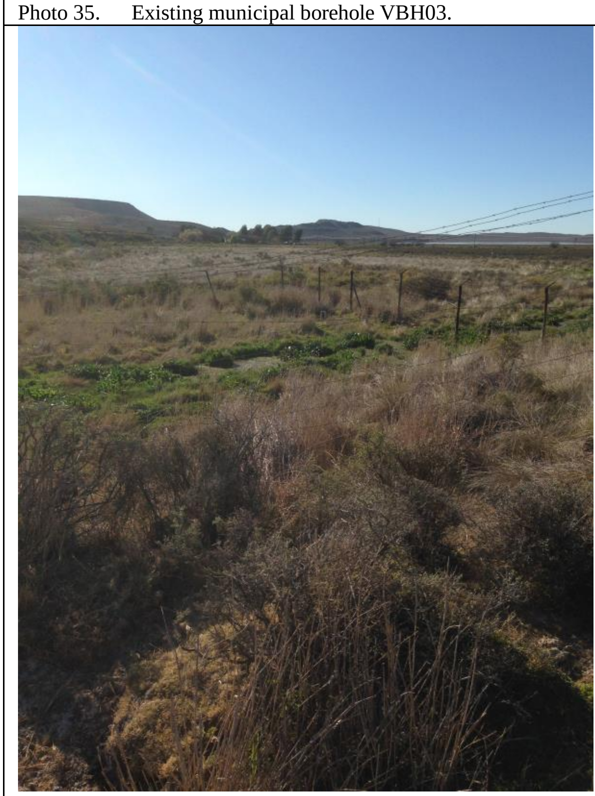


Photo 37. Existing municipal borehole VBH05.

Photo 38. Existing municipal borehole VBH06.

Photo 39. Existing municipal borehole VBH07.

Table 1. Victoria West: General borehole information of the municipal boreholes.

VICTORIA WEST: GENERAL BOREHOLE INFORMATION TABLE (I)

No.	Borehole Number	Site Name / Site Description	Photo No.	Date	Coordinates Longitude (East)	Coordinates Latitude (South)	Elevation (mamsl)	Static Water Level (mbgl)	Aquifer Test Pumped? & Other Rehabilitation Comments
1.)	VBH01	Municipal Borehole.	33	25-Sep-13	23.08833	-31.39956	n/a	1.40	Unknown.
2.)	VBH02	Municipal Borehole.	34	25-Sep-13	23.08993	-31.40031	n/a	n/a	Unknown.
3.)	VBH03	Municipal Borehole.	35	25-Sep-13	23.07371	-31.39593	n/a	n/a	Unknown.
4.)	VBH04	Municipal Borehole.	36	25-Sep-13	23.07336	-31.39519	n/a	n/a	Unknown.
5.)	VBH05	Municipal Borehole.	37	25-Sep-13	23.07369	-31.39545	n/a	n/a	Unknown.
6.)	VBH06	Municipal Borehole.	38	25-Sep-13	23.07477	-31.39372	n/a	n/a	Unknown.
7.)	VBH07	Municipal Borehole (Martin).	39	25-Sep-13	23.09552	-31.44707	n/a	n/a	Unknown.
8.)	VBH08 [VWP1]	Newly Drilled Municipal Borehole.	1	22-Sep-13	23.07793	-31.41948	n/a	n/a	Low yielding. Not to be tested.
9.)	VBH09 [VWP2]	Newly Drilled Municipal Borehole.	3	21-Sep-13	23.07302	-31.41302	n/a	n/a	Dry. Not to be tested.
10.)	VBH10 [VWP3]	Newly Drilled Municipal Borehole.	5	24-Sep-13	23.06834	-31.40636	n/a	n/a	Low yielding. Not to be tested.
11.)	VBH11 [VWP5]	Newly Drilled Municipal Borehole.	7	09-Oct-13	23.11734	-31.38559	n/a	17.52	To be tested.
12.)	VBH12 [VWP6]	Newly Drilled Municipal Borehole.	9	09-Oct-13	23.11899	-31.38511	n/a	20.76	To be tested.
13.)	VBH13 [VWP7]	Newly Drilled Municipal Borehole.	11	30-Oct-13	23.07257	-31.41325	n/a	n/a	Dry. Not to be tested.

VICTORIA WEST: GENERAL BOREHOLE INFORMATION TABLE (II)

No.	Borehole Number	Site Name / Site Description	Casing / Block Height (mm)	Casing Depth (mbgl)	Borehole Diameter (mm)	Borehole Depth (m)	Borehole Equipment	Current State of Borehole
1.)	VBH01	Municipal Borehole.	220	3.30	190	58.50	Submersible Pump (50 mm Outlet Pipe).	Currently in use.
2.)	VBH02	Municipal Borehole.	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Currently in use.
3.)	VBH03	Municipal Borehole.	n/a	n/a	n/a	n/a	None.	Not Utilised.
4.)	VBH04	Municipal Borehole.	n/a	n/a	n/a	n/a	None.	Not Utilised.
5.)	VBH05	Municipal Borehole.	n/a	n/a	n/a	n/a	None.	Not Utilised.
6.)	VBH06	Municipal Borehole.	n/a	n/a	n/a	n/a	None.	Not Utilised.
7.)	VBH07	Municipal Borehole (Martin).	n/a	n/a	n/a	n/a	Submersible Pump (80 mm Outlet Pipe).	Currently in use.
8.)	VBH08 [VWP1]	Newly Drilled Municipal Borehole.	n/a	13.00	170	80.00	None.	New borehole. Not Utilised.
9.)	VBH09 [VWP2]	Newly Drilled Municipal Borehole.	n/a	12.00	170	80.00	None.	New borehole. Not Utilised.
10.)	VBH10 [VWP3]	Newly Drilled Municipal Borehole.	n/a	12.00	170	80.00	None.	New borehole. Not Utilised.
11.)	VBH11 [VWP5]	Newly Drilled Municipal Borehole.	n/a	12.00	170	79.74	None.	New borehole. Not Utilised.
12.)	VBH12 [VWP6]	Newly Drilled Municipal Borehole.	150	12.00	170	90.60	None.	New borehole. Not Utilised.
13.)	VBH13 [VWP7]	Newly Drilled Municipal Borehole.	n/a	12.00	170	60.00	None.	New borehole. Not Utilised.

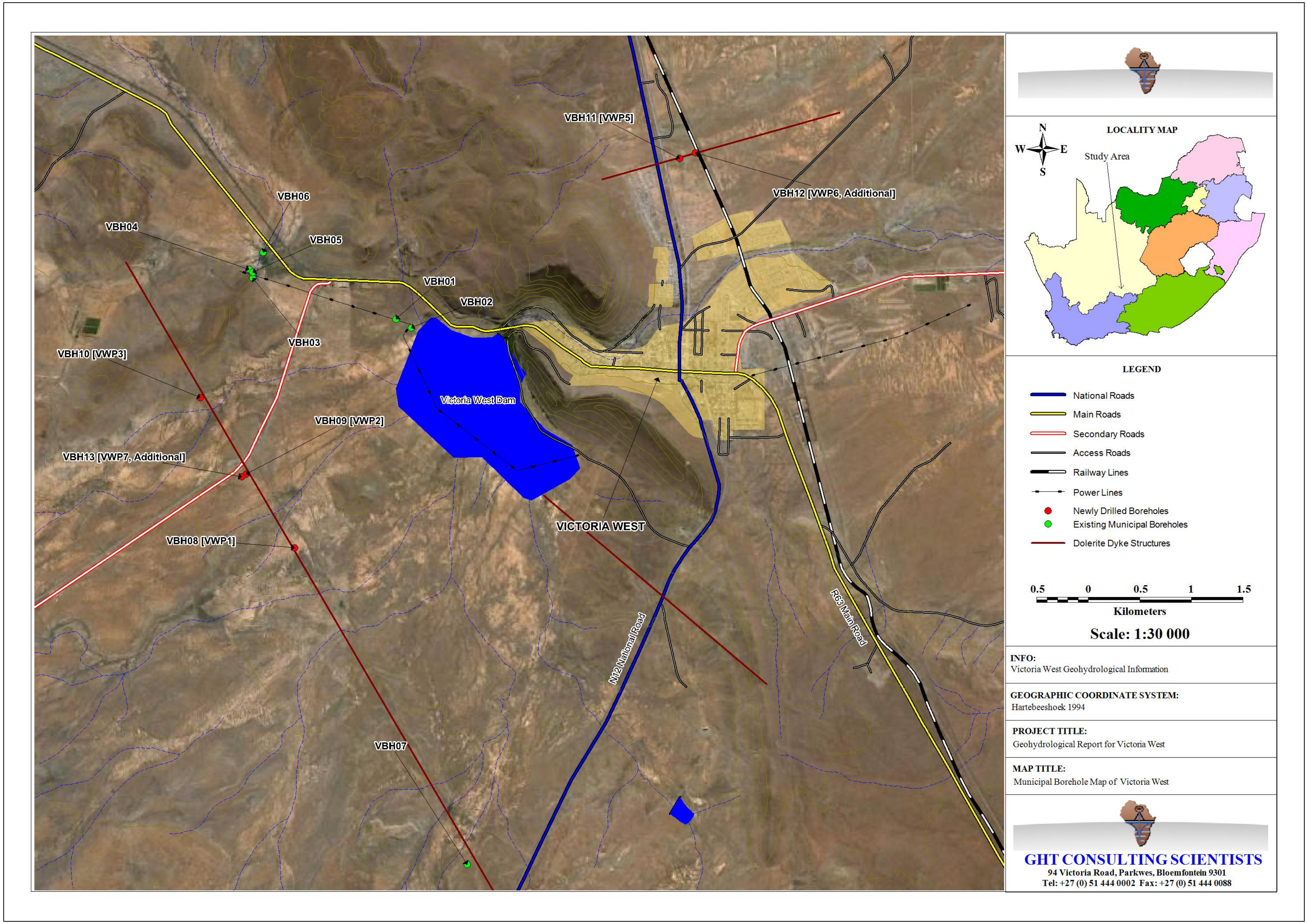


Figure 19. Locality map of the municipal boreholes of the Victoria West.

5.2 LOXTON BOREHOLE INFORMATION

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Loxton. The general borehole information tables can be perused in Table 2 on page 61. The locality map of the municipal boreholes can be viewed in Figure 20 on page 62.

The summary of the general borehole information for Loxton is as follows:

- The commonage contains fourteen (14) existing municipal boreholes and a Pit namely, BH-BG, BH-BK01, BH-BK02, BH-BK03, BH-BK04, BH-BK05, BH-BK06, BH-BPB, BH-KG, PIT, BH-SV, BH-WP01, BH-WP02, BH-BSG01 and BH-BSG02. Six (6) boreholes and the Pit are currently in use for abstraction purposes. The utilised boreholes include BH-BG, BH-BK01, BH-BK03, BH-BK05, BH-BPB, PIT and BH-BSG01.
- Four (4) new boreholes were drilled namely, LBH01, LBH02, LBH03 and LBH04.
- The following boreholes have been aquifer test pumped to determine their sustainable yields and groundwater quality namely LBH01 and LBH02.

The photos of the existing Loxton municipal boreholes can be viewed below:

Photo 40. Existing municipal borehole (Brakgat) BH-BG.

Photo 41. Existing Municipal Borehole BH-BK01.

Photo 42. Existing municipal borehole BH-BK02.

Photo 43. Existing municipal borehole BH-BK03.

Photo 44. Existing municipal borehole BH-BK04.

Photo 45. Existing municipal borehole BH-BK05

Photo 46. Existing municipal borehole BH-BK06

Photo 47. Existing municipal borehole BH-KG.

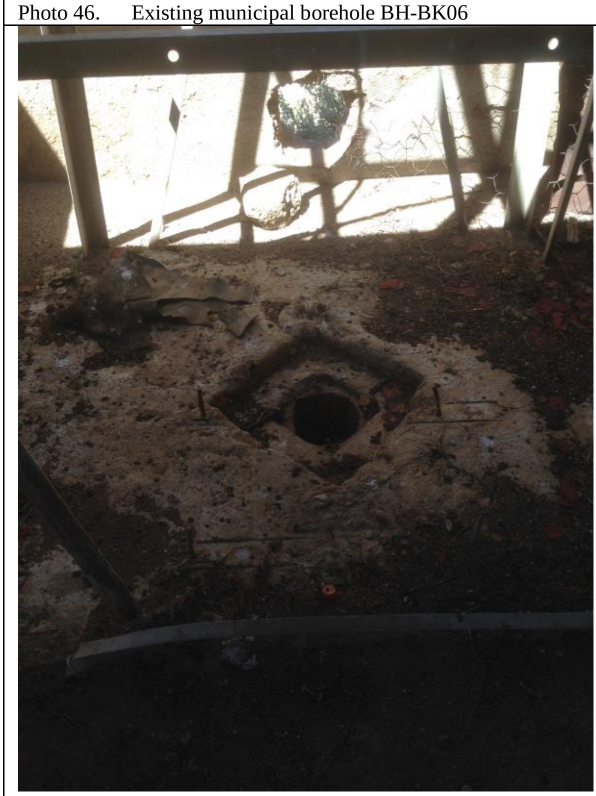


Photo 48. Existing municipal borehole BH-WP01.

Photo 49. Existing municipal borehole BH-WP02


Photo 50. Existing municipal borehole BH-BSG01.


Photo 51. Existing municipal borehole BH-BSG02.

Table 2. Loxton: General borehole information of the municipal boreholes.

LOXTON: GENERAL BOREHOLE INFORMATION TABLE (I)

No.	Borehole Number	Site Name / Site Description	Photo No.	Date	Coordinates Longitude (East)	Coordinates Latitude (South)	Elevation (mamsl)	Static Water Level (mbgl)	Aquifer Test Pumped? & Other Rehabilitation Comments
1.)	BH-BG	Brakgat Borehole.	40	25-Sep-13	22.36535	-31.47593	n/a	9.44	Yes (2004).
2.)	BH-BK01	Bokpoort 1 Borehole.	41	25-Sep-13	22.37557	-31.49923	n/a	19.05	Yes (2004).
3.)	BH-BK02	Bokpoort 2 Borehole.	42	25-Sep-13	22.37563	-31.49927	n/a	24.61	Yes (2004).
4.)	BH-BK03	Bokpoort 3 Borehole.	43	25-Sep-13	22.37475	-31.49820	n/a	40.10	Yes (2004).
5.)	BH-BK04	Bokpoort 4 Borehole.	44	25-Sep-13	22.37520	-31.49825	n/a	41.04	Yes (2004).
6.)	BH-BK05	Bokpoort 5 Borehole.	45	25-Sep-13	22.38140	-31.49476	n/a	n/a	Unknown.
7.)	BH-BK06	Bokpoort 6 Borehole.	46	25-Sep-13	22.38142	-31.49461	n/a	n/a	Unknown.
8.)	BH-BPB	Cemetery Borehole.	n/a	25-Sep-13	22.34553	-31.47395	n/a	n/a	No.
9.)	BH-KG	Kruitgat Borehole.	n/a	25-Sep-13	22.36222	-31.48010	n/a	4.75	Yes (2004).
10.)	PIT	A pit located next to BH-KG.	47	25-Sep-13	22.36218	-31.47996	n/a	n/a	Unknown.
11.)	BH-SV	Skietveld Borehole.	n/a	25-Sep-13	22.35011	-31.48654	n/a	n/a	Unknown.
12.)	BH-WP01	Wind-Pump by Dam.	49	25-Sep-13	22.36108	-31.47831	n/a	n/a	Unknown.
13.)	BH-WP02	Wind-Pump by Dam.	49	25-Sep-13	22.36094	-31.47817	n/a	n/a	Unknown.
14.)	BH-BSG01	Ben se Gat 1 Borehole.	50	25-Sep-13	22.35252	-31.48179	n/a	n/a	Unknown.
15.)	BH-BSG02	Ben se Gat 2 Borehole.	51	25-Sep-13	22.36439	-31.47570	n/a	n/a	Unknown.
16.)	LBH01 [LP1]	Newly Drilled Municipal Borehole.	13	14-Oct-13	22.33423	-31.48564	n/a	5.10	To be tested.
17.)	LBH02 [LP2]	Newly Drilled Municipal Borehole.	15	16-Oct-13	22.33253	-31.48257	n/a	2.09	To be tested.
18.)	LBH03 [LP3]	Newly Drilled Municipal Borehole.	17	28-Sep-13	22.33525	-31.47982	n/a	n/a	Dry. Not to be tested.
19.)	LBH04 [LP4]	Newly Drilled Municipal Borehole.	19	25-Sep-13	22.33838	-31.47674	n/a	n/a	Dry. Not to be tested.

LOXTON: GENERAL BOREHOLE INFORMATION TABLE (II)

No.	Borehole Number	Site Name / Site Description	Casing / Block Height (mm)	Casing Depth (mbgl)	Borehole Diameter (mm)	Borehole Depth (m)	Borehole Equipment	Current State of Borehole
1.)	BH-BG	Brakgat Borehole.	20	2.53	165	55.68	Submersible Pump (65 mm Outlet Pipe).	Main Production Borehole. Utilised.
2.)	BH-BK01	Bokpoort 1 Borehole.	35	3.14	165	36.14	Submersible Pump (50 mm Outlet Pipe).	Utilised.
3.)	BH-BK02	Bokpoort 2 Borehole.	6	1.65	165	75.50	None.	Not Utilised.
4.)	BH-BK03	Bokpoort 3 Borehole.	30	3.20	165	87.60	Submersible Pump (50 mm Outlet Pipe).	Utilised.
5.)	BH-BK04	Bokpoort 4 Borehole.	10	3.15	165	110.80	None currently. Pump oversized.	Low Yielding Borehole. Recommended For Re-Testing.
6.)	BH-BK05	Bokpoort 5 Borehole.	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Utilised.
7.)	BH-BK06	Bokpoort 6 Borehole.	n/a	n/a	n/a	n/a	None.	Not Utilised.
8.)	BH-BPB	Cemetery Borehole.	n/a	n/a	n/a	n/a	Wind-pump.	Unknown.
9.)	BH-KG	Kruitgat Borehole.	21	5.50	165	45.20	None.	Not Utilised.
10.)	PIT	A pit located next to BH-KG.	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Utilised.
11.)	BH-SV	Skietveld Borehole.	n/a	n/a	n/a	n/a	None.	Not Utilised.
12.)	BH-WP01	Wind-Pump by Dam.	n/a	n/a	n/a	n/a	Wind-pump.	Wind-Pump Broken. Not Utilised.
13.)	BH-WP02	Wind-Pump by Dam.	n/a	n/a	n/a	n/a	None.	Borehole Blocked.
14.)	BH-BSG01	Ben se Gat 1 Borehole.	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Utilised.
15.)	BH-BSG02	Ben se Gat 2 Borehole.	n/a	n/a	n/a	n/a	None.	Not Utilised.
16.)	LBH01 [LP1]	Newly Drilled Municipal Borehole.	90	12.50	170	90.30	None.	New borehole. Not Utilised.
17.)	LBH02 [LP2]	Newly Drilled Municipal Borehole.	240	13.70	170	76.00	None.	New borehole. Not Utilised.
18.)	LBH03 [LP3]	Newly Drilled Municipal Borehole.	n/a	10.00	170	80.00	None.	New borehole. Not Utilised.
19.)	LBH04 [LP4]	Newly Drilled Municipal Borehole.	n/a	12.00	170	90.00	None.	New borehole. Not Utilised.

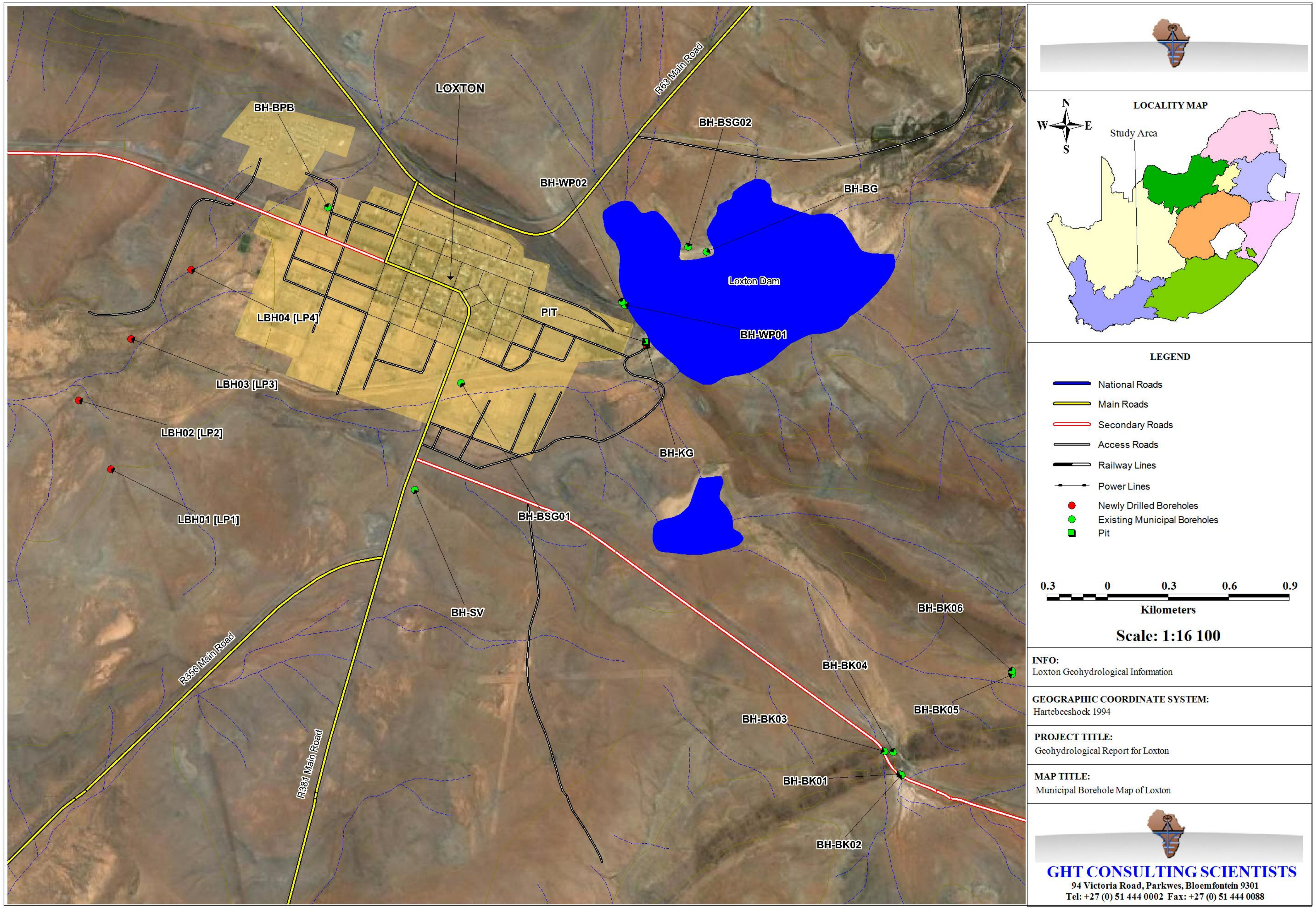


Figure 20. Locality map of the municipal boreholes of the Loxton.

5.3 RICHMOND BOREHOLE INFORMATION

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Richmond. The general borehole information tables can be perused in Table 3 on page 65. The locality map of the municipal boreholes can be viewed in Figure 21 on page 66.

The summary of the general borehole information for Richmond is as follows:

- The commonage contains six (6) existing municipal boreholes namely, RBH01, RBH02, RBH03, RBH04, RBH05 and RBH06. Five (5) boreholes are currently in use for abstraction purposes. The utilised boreholes includes and RBH01, RBH02, RBH03, RBH05 and RBH06.
- Borehole RBH04 has collapsed at 26 mbgl due to poor borehole construction and was re-drilled and constructed properly.
- The following boreholes have been aquifer test pumped to determine their sustainable yields and groundwater quality namely RBH01, RBH02, RBH03, RBH04, RBH05 and RBH06.
- The descriptions of the current state of the existing borehole equipment can be viewed in Appendix D.

The photos of the existing Richmond municipal boreholes can be viewed below:

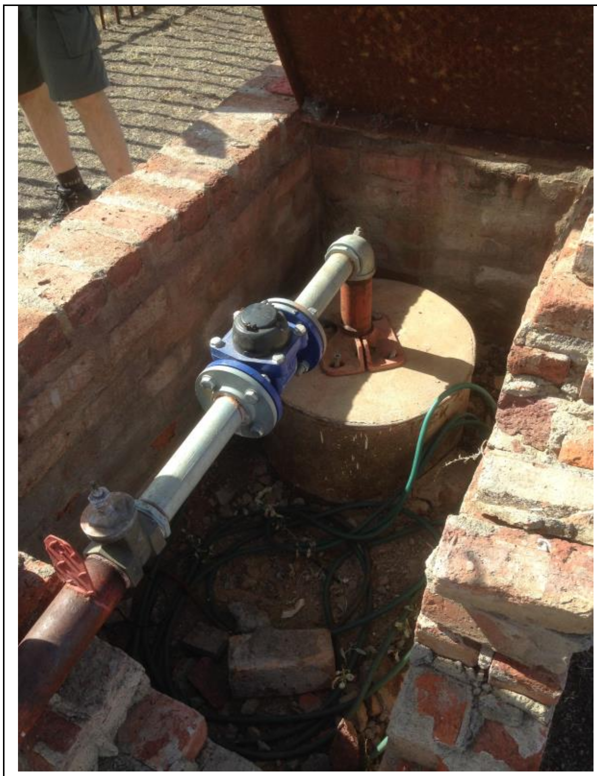


Photo 52. Existing municipal borehole RBH01.

Photo 53. Existing municipal borehole RBH02.

Photo 54. Existing municipal borehole RBH03.

Photo 55. Existing municipal borehole RBH04.

Photo 56. Existing municipal borehole RBH05.

Photo 57. Existing municipal borehole RBH06.

Table 3. Richmond: General borehole information of the municipal boreholes.

RICHMOND: GENERAL BOREHOLE INFORMATION TABLE (I)

No.	Borehole Number	Site Name / Site Description	Photo No.	Date	Coordinates Longitude (East)	Coordinates Latitude (South)	Elevation (mamsl)	Static Water Level (mbgl)	Aquifer Test Pumped? & Other Rehabilitation Comments
1.)	RBH01	Municipal Borehole.	52	26-Sep-13	23.95822	-31.40936	n/a	5.77	To be tested.
2.)	RBH02	Municipal Borehole.	53	26-Sep-13	23.96151	-31.40968	n/a	4.97	To be tested.
3.)	RBH03	Municipal Borehole.	54	26-Sep-13	23.95974	-31.41039	n/a	5.43	To be tested.
4.)	RBH04	Municipal Borehole. (Re-Drilled)	55	26-Sep-13	23.95659	-31.41192	n/a	5.71	To be tested.
5.)	RBH05	Municipal Borehole (Hangtoring).	56	26-Sep-13	23.95773	-31.41495	n/a	4.77	To be tested.
6.)	RBH06	Municipal Borehole.	21 & 57	26-Sep-13	23.95184	-31.41343	n/a	8.88	To be tested.

RICHMOND: GENERAL BOREHOLE INFORMATION TABLE (II)

No.	Borehole Number	Site Name / Site Description	Casing / Block Height (mm)	Casing Depth (mbgl)	Borehole Diameter (mm)	Borehole Depth (m)	Borehole Equipment	Current State of Borehole
1.)	RBH01	Municipal Borehole.	410	6.44	120	57.28	Submersible Pump (75 mm Outlet Pipe).	Utilised.
2.)	RBH02	Municipal Borehole.	250	6.46	160	59.40	Submersible Pump (50 mm Outlet Pipe).	Utilised.
3.)	RBH03	Municipal Borehole.	220	6.50	160	59.00	Submersible Pump (50 mm Outlet Pipe).	Utilised.
4.)	RBH04	Municipal Borehole. (Re-Drilled)	300	27.26	165	66.90	None.	Not Utilised. Borehole was re-drilled.
5.)	RBH05	Municipal Borehole (Hangtoring).	200	2.42	155	37.28	Submersible Pump (50 mm Outlet Pipe).	Utilised.
6.)	RBH06	Municipal Borehole.	200	3.05	200	54.14	Submersible Pump (50 mm Outlet Pipe).	Utilised.

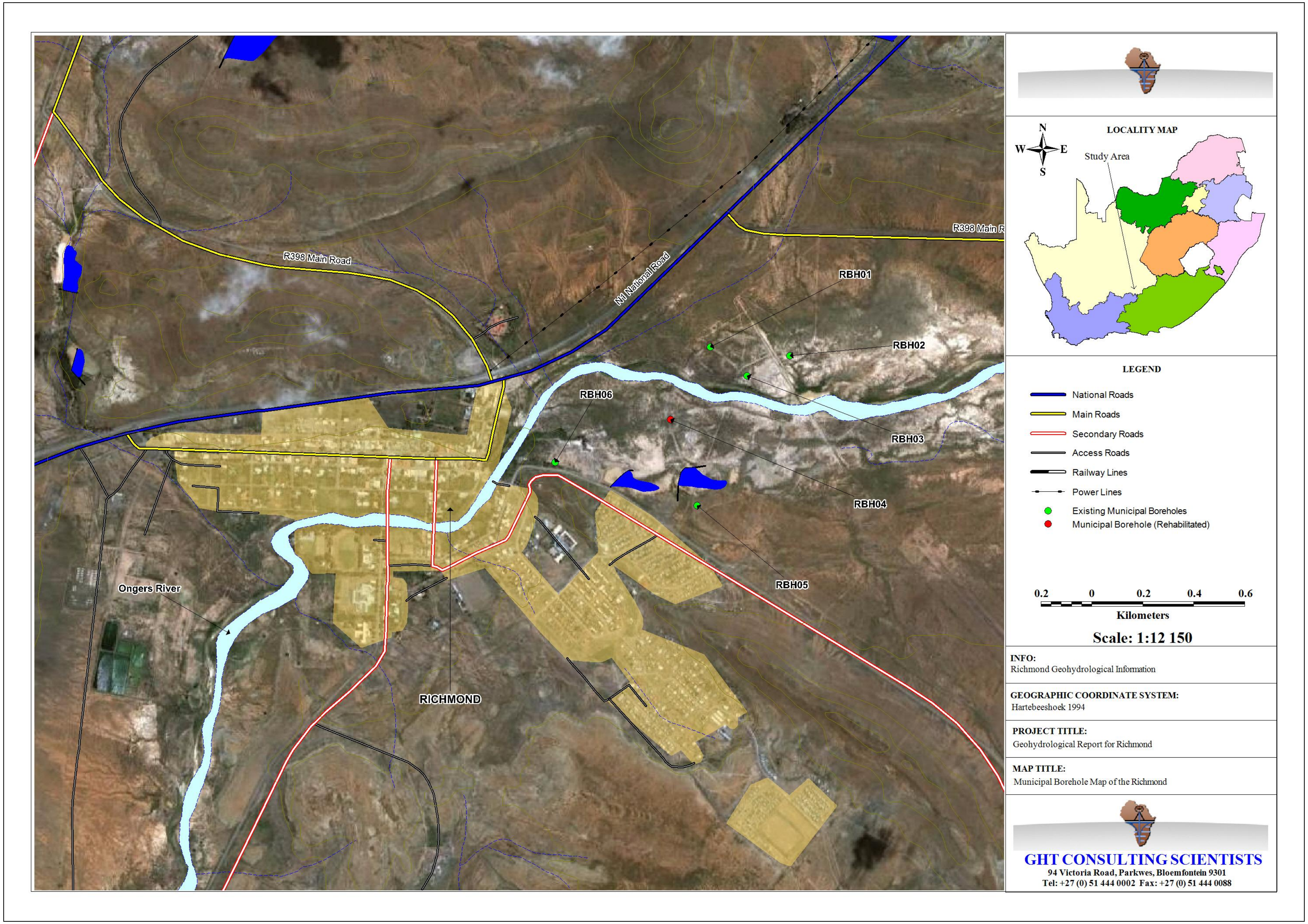


Figure 21. Locality map of the municipal boreholes of the Richmond.

5.4 HUTCHINSON BOREHOLE INFORMATION

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Hutchinson. The general borehole information tables can be perused in Table 4 on page 70. The locality map of the municipal boreholes can be viewed in Figure 22 on page 71.

The summary of the general borehole information for Hutchinson is as follows:

- The commonage contains six (6) private boreholes utilised for municipal water production purposes namely, HBH01, HBH02, HBH03, HBH04, HBH05 and HBH06. Six (6) private boreholes are currently in use for abstraction purposes. Municipal borehole HBH07 is also utilised for water abstraction purposes.
- Three (3) new boreholes were drilled namely, HBH08, HBH09 and HBH10 but were found to be dry and therefore not recommended for aquifer test pumping.

"The photos of the existing Hutchinson municipal boreholes can be viewed below:

Photo 58. Existing municipal borehole HBH01.

Photo 59. Existing municipal borehole HBH02.

Photo 60. Existing municipal borehole HBH03.

Photo 61. Existing municipal borehole HBH04.

Photo 62. Existing municipal borehole HBH05.

Photo 63. Existing municipal borehole HBH06.

 Photo 64. Existing municipal borehole HBH07.	

Table 4. Hutchinson: General borehole information of the municipal boreholes.

HUTCHINSON: GENERAL BOREHOLE INFORMATION TABLE (I)

No.	Borehole Number	Site Name / Site Description	Photo No.	Date	Coordinates Longitude (East)	Coordinates Latitude (South)	Elevation (mamsl)	Static Water Level (mbgl)	Aquifer Test Pumped? & Other Rehabilitation Comments
1.)	HBH01	Private Borehole (BH27).	58	25-Sep-13	23.18264	-31.48900	n/a	n/a	Unknown.
2.)	HBH02	Private Borehole.	59	25-Sep-13	23.18247	-31.48991	n/a	n/a	Unknown.
3.)	HBH03	Private Borehole.	60	25-Sep-13	23.18240	-31.48997	n/a	n/a	Unknown.
4.)	HBH04	Private Borehole.	61	25-Sep-13	23.18391	-31.48806	n/a	n/a	Unknown.
5.)	HBH05	Private Borehole.	62	25-Sep-13	23.18846	-31.49196	n/a	n/a	Unknown.
6.)	HBH06	Private Borehole.	63	25-Sep-13	23.18823	-31.49232	n/a	n/a	Unknown.
7.)	HBH07	Municipal Borehole.	64	25-Sep-13	23.18618	-31.49631	n/a	n/a	Unknown.
8.)	HBH08 [HP1]	Newly Drilled Municipal Borehole.	23	29-Sep-13	23.18805	-31.49499	n/a	n/a	Dry. Not to be tested.
9.)	HBH09 [HP3]	Newly Drilled Municipal Borehole.	25	29-Sep-13	23.18972	-31.50254	n/a	n/a	Dry. Not to be tested.
10.)	HBH10 [HP4]	Newly Drilled Municipal Borehole.	27	28-Sep-13	23.18410	-31.50263	n/a	n/a	Dry. Not to be tested.

HUTCHINSON: GENERAL BOREHOLE INFORMATION TABLE (II)

No.	Borehole Number	Site Name / Site Description	Casing / Block Height (mm)	Casing Depth (mbgl)	Borehole Diameter (mm)	Borehole Depth (m)	Borehole Equipment	Current State of Borehole
1.)	HBH01	Private Borehole (BH27).	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Utilised.
2.)	HBH02	Private Borehole.	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Utilised.
3.)	HBH03	Private Borehole.	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Utilised.
4.)	HBH04	Private Borehole.	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Utilised.
5.)	HBH05	Private Borehole.	n/a	n/a	n/a	n/a	Submersible Pump (70 mm Outlet Pipe).	Utilised.
6.)	HBH06	Private Borehole.	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Utilised.
7.)	HBH07	Municipal Borehole.	n/a	n/a	n/a	n/a	Submersible Pump.	Utilised.
8.)	HBH08 [HP1]	Newly Drilled Municipal Borehole.	n/a	6.00	170	60.00	None.	New borehole. Not Utilised. Dry.
9.)	HBH09 [HP3]	Newly Drilled Municipal Borehole.	n/a	12.00	170	70.00	None.	New borehole. Not Utilised. Dry.
10.)	HBH10 [HP4]	Newly Drilled Municipal Borehole.	n/a	12.00	170	80.00	None.	New borehole. Not Utilised. Dry.

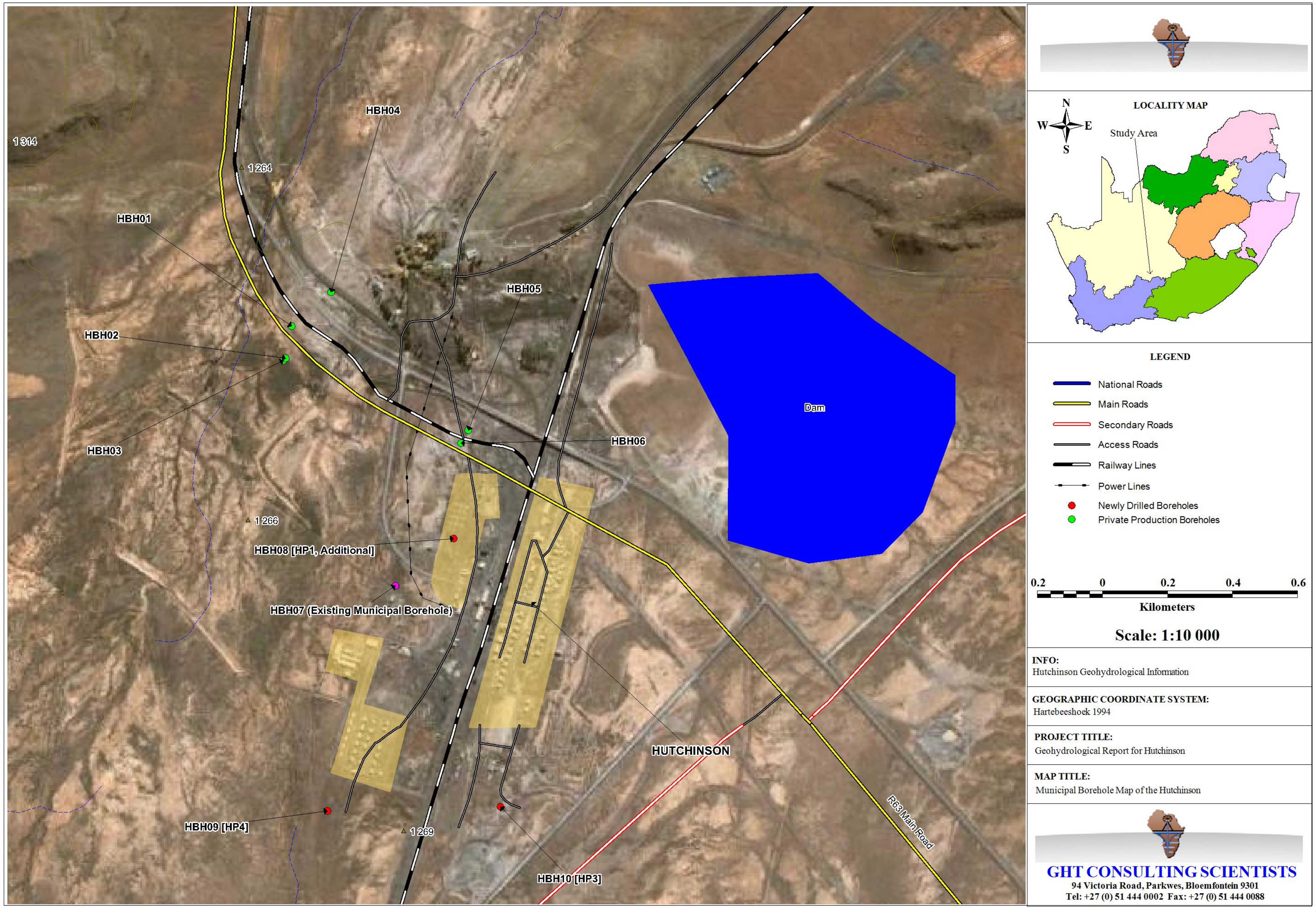


Figure 22. Locality map of the municipal boreholes of the Hutchinson.

5.5 MERRIMAN BOREHOLE INFORMATION

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Merriman. The general borehole information tables can be perused in Table 5 on page 73. The locality map of the municipal boreholes can be viewed in Figure 23 on page 74.

The summary of the general borehole information for Merriman is as follows:

- The commonage contains one (1) existing municipal borehole namely MBH01. Borehole MBH01 is currently in use for abstraction purposes.
- One (1) new borehole was drilled namely, MBH02. The borehole has been aquifer test pumped to determine their sustainable yields and groundwater quality.

The photos of the existing Merriman municipal boreholes can be viewed below:

Photo 65. Existing municipal borehole MBH01.

Table 5. Merriman: General borehole information of the municipal boreholes.

MERRIMAN: GENERAL BOREHOLE INFORMATION TABLE (I)

No.	Borehole Number	Site Name / Site Description	Photo No.	Date	Coordinates Longitude (East)	Coordinates Latitude (South)	Elevation (mamsl)	Static Water Level (mbgl)	Aquifer Test Pumped? & Other Rehabilitation Comments
1.)	MBH01	Municipal Borehole.	65	26-Sep-13	23.61449	-31.21264	n/a	n/a	Unknown.
2.)	MBH02 [MP01]	Newly Drilled Municipal Borehole.	29	02-Oct-13	23.62016	-31.21021	n/a	11.57	To be tested.

MERRIMAN: GENERAL BOREHOLE INFORMATION TABLE (II)

No.	Borehole Number	Site Name / Site Description	Casing / Block Height (mm)	Casing Depth (mbgl)	Borehole Diameter (mm)	Borehole Depth (m)	Borehole Equipment	Current State of Borehole
1.)	MBH01	Municipal Borehole.	n/a	n/a	n/a	n/a	Submersible Pump (50 mm Outlet Pipe).	Utilised.
2.)	MBH02 [MP01]	Newly Drilled Municipal Borehole.	170	12.37	170	71.02	None.	New borehole. Not Utilised.

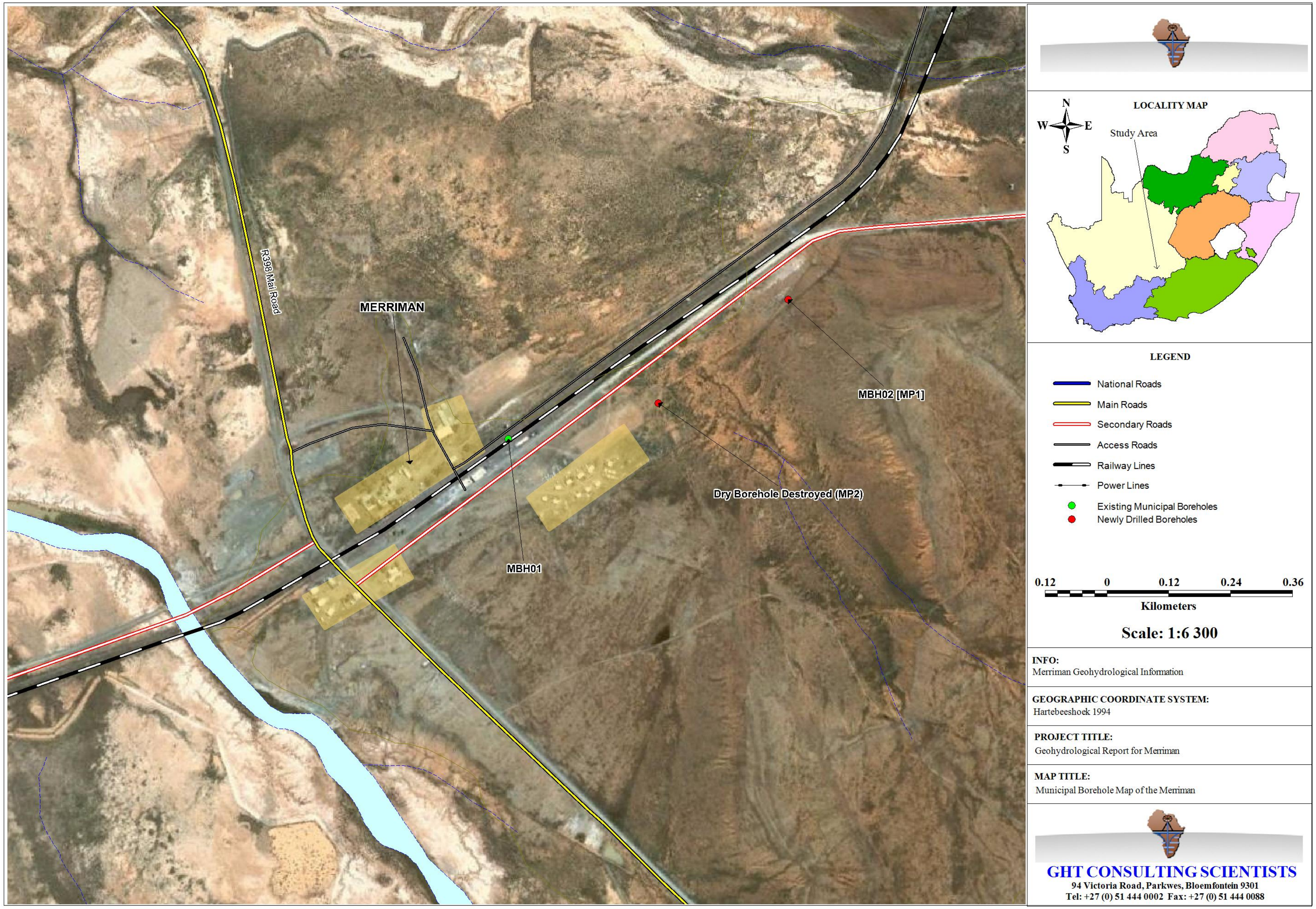


Figure 23. Locality map of the municipal boreholes of the Merriman.

6 AQUIFER TEST PUMPING ANALYSES

Aquifer test pumping was performed on the newly drilled and existing boreholes to determine their sustainable yields for water supply purposes. The aquifer test pumping data sheets can be viewed In Appendix E. The recovery curves of the aquifer tested borehole can be viewed in Appendix F.

The following hydraulic aquifer test pumping methods were performed:

- Calibration Test;
- Stepped Discharge Test;
- Constant Discharge Test; and
- Recovery Test.

6.1 AQUIFER TEST PUMPING

This section contains the description and results of the performed aquifer tests.

6.1.1 Calibration Test

This type of test involves the determination of the actual rate of inflow into the borehole from the surrounding geological formations. It is achieved by abstracting all the water that flows into the borehole. Eventually, when the borehole is empty, it is only the water that flows into the borehole that is abstracted. If this rate of abstraction is measured, it represents the rate at which the water enters the borehole from the aquifer, i.e. the actual yield of the aquifer.

The calibration tests were conducted over a 60 minute period.

6.1.2 Stepped Discharge Test

The step drawdown test is a single-well test and it is performed to evaluate the productivity of a borehole. It also gives an indication of the optimum yield at which the borehole can be subjected to constant discharge testing, if required. The results of a step drawdown test will indicate whether further pump testing in the form of a constant discharge test is warranted or whether the borehole is judged to be sufficiently weak (potential yield less than 0.5 L/s) to make a utilisation recommendation without further testing. If the result of the stepped discharge test is positive, then a constant rate-pumping test must be performed.

In performing a step discharge test, the borehole is subjected to three or more sequentially higher pumping rates, which is maintained for an equal length of time. The test is done by pumping the borehole at a low constant discharge rate until the drawdown stabilises. The constant discharge rate is then increased and the borehole is pumped until the drawdown stabilises again. The pumping rate is then increased again and the process is repeated. The time per pumping rate should be between 60 and 120 min. (Hobbs and Marais, 1997).

A step length of 100 min. is recommended for the test. The drawdown in the borehole in response to each of the pumping rates must be measured and recorded in accordance with a prescribed time schedule.

The following constant discharge rates were recommended by means of the data generated by the step drawdown test:

- The discharge rate for the constant rate test at VBH01 was recommended at 3.50 L/s.
- The discharge rate for the constant rate test at VBH11 was recommended at 6.10 L/s.
- The discharge rate for the constant rate test at VBH12 was recommended at 4.50 L/s.
- The discharge rate for the constant rate test at LBH01 was recommended at 1.30 L/s.
- The discharge rate for the constant rate test at LBH02 was recommended at 8.50 L/s.
- The discharge rate for the constant rate test at RBH01 was recommended at 8.00 L/s.
- The discharge rate for the constant rate test at RBH02 was recommended at 6.00 L/s.
- The discharge rate for the constant rate test at RBH03 was recommended at 15.00 L/s.
- The discharge rate for the constant rate test at RBH04 was recommended at 1.30 L/s.
- The discharge rate for the constant rate test at RBH05 was recommended at 8.00 L/s.
- The discharge rate for the constant rate test at RBH06 was recommended at 6.50 L/s.
- The discharge rate for the constant rate test at MBH02 was recommended at 1.50 L/s.

6.1.3 Constant Rate Discharge Test

The constant discharge test is used to determine an aquifer’s hydraulic parameters like transmissivity, storativity (if an observation well exists) and a conceptual model of the aquifer’s hydraulic scenario, for example the presence of impermeable or recharge boundaries. The test involves monitoring the drawdown in the borehole while the discharge is kept constant. A description of the various methods used to analyse the data obtained from constant discharge tests is given in Kruseman and De Ridder (1991). The duration of the constant rate test may be determined by the information and level of reliability required (Weaver, 1993). It is common practice to run the test for about eight hours for boreholes to be equipped with hand, solar or wind driven pumps, and for forty-eight to seventy-two hours for boreholes to be equipped with electricity or diesel driven pumps, which are to be operated on a daily basis.

The aquifer test pumping data sheets can be viewed In Appendix E.

The following results where obtain by means of the constant rate discharge tests:

- The test on VBH01 was conducted over a 48-hour period with an abstraction rate of 3.50 L/s during which a drawdown of 5.62 m was achieved. The pump inlet was installed at a depth of 54.36 mbgl. The available drawdown for the aquifer test was calculated at 57.02 m.
- The test on VBH11 (VWP05) was conducted over a 48-hour period with an abstraction rate of 6.10 L/s during which a drawdown of 42.91 m was achieved. The pump inlet was installed at a depth of 74.50 mbgl. The available drawdown for the aquifer test was calculated at 53.94 m.
- The test on VBH12 (VWP06) was conducted over a 48-hour period with an abstraction rate of 4.50 L/s during which a drawdown of 28.22 m was achieved. The pump inlet was installed at a depth of 87.50 mbgl. The available drawdown for the aquifer test was calculated at 62.41 m.

- The test on LBH01 (LP01) was conducted over a 13-hour period with an abstraction rate of 1.30 L/s during which a drawdown of 82.34 m was achieved. The pump inlet was installed at a depth of 87.50 mbgl. The available drawdown for the aquifer test was calculated at 78.62 m.
- The test on LBH02 (LP02) was conducted over a 48-hour period with an abstraction rate of 8.50 L/s during which a drawdown of 25.71 m was achieved. The pump inlet was installed at a depth of 72.50 mbgl. The available drawdown for the aquifer test was calculated at 69.96 m.
- The test on RBH01 was conducted over a 48-hour period with an abstraction rate of 8.0 L/s during which a drawdown of 7.83 m was achieved. The pump inlet was installed at a depth of 54.36 mbgl. The available drawdown for the aquifer test was calculated at 50.33 m.
- The test on RBH02 was conducted over a 48-hour period with an abstraction rate of 6.00 L/s during which a drawdown of 9.46 m was achieved. The pump inlet was installed at a depth of 54.36 mbgl. The available drawdown for the aquifer test was calculated at 49.29 m.
- The test on RBH03 was conducted over a 48-hour period with an abstraction rate of 15.00 L/s during which a drawdown of 9.06 m was achieved. The pump inlet was installed at a depth of 54.36 mbgl. The available drawdown for the aquifer test was calculated at 48.57 m.
- The test on RBH04 was conducted over a 24-hour period with an abstraction rate of 1.30 L/s during which a drawdown of 46.84 m was achieved. The pump inlet was installed at a depth of 63.36 mbgl. The available drawdown for the aquifer test was calculated at 57.60 m.
- The test on RBH05 was conducted over a 48-hour period with an abstraction rate of 8.00 L/s during which a drawdown of 5.54 m was achieved. The pump inlet was installed at a depth of 33.36 mbgl. The available drawdown for the aquifer test was calculated at 28.26 m.
- The test on RBH06 was conducted over a 20-hour period with an abstraction rate of 6.50 L/s during which a drawdown of 3.80 m was achieved. The pump inlet was installed at a depth of 51.41 mbgl. The available drawdown for the aquifer test was calculated at 41.76 m.
- The test on MBH02 (MP01) was conducted over a 20-hour period with an abstraction rate of 1.50 L/s during which a drawdown of 54.79 m was achieved. The pump inlet was installed at a depth of 68.96 mbgl. The available drawdown for the aquifer test was calculated at 57.39 m.

6.1.4 Recovery Test

The recovery test can be used to calculate an aquifer's hydraulic parameters, to establish whether recharge has taken place during or shortly after the constant discharge test and whether the storativity values vary throughout the aquifer (Driscoll, 1986). It can also give an indication of the extent of the aquifer, or the extent and connectiveness of fractures. The Geological Society of South Africa recommends this test to be continued until: the water level in the borehole recovers to its pre-pumping level; the water level recovers to less than 5% of the total drawdown experienced during the constant rate test; three readings in succession are identical; or the test is carried out for half the length of time of the constant discharge test (Weaver, 1993). In order to establish whether the aquifer has been significantly dewatered during the constant discharge test, and in order to accurately apply the recovery test data for estimating sustainable borehole yields, it may be preferable to monitor recovery water levels for at least the same duration as the constant discharge test.

In general, the conducting of these tests is well-known procedures among geohydrologists and poses no problem in the field. A serious problem, however, is that all these tests are performed in open boreholes (no piezometers installed) and that the results are analysed with typical porous flow models like the Theis and Cooper Jacob method.

The following results where obtain by means of the recovery tests:

Recovery Test Method (Kirchner, 1991): This method involves calculating the maximum number of hours a borehole should be pumped each day at the tested rate, and it is based on the time it takes for the water level in a pumped borehole to return to the original rest water level (prior to pumping). Borehole water level measurements during the recovery period following a constant discharge pump test are plotted on semi-log graph paper against the time since pumping began (t), divided by the time since pumping was stopped (t').

The following formula is then used to determine the maximum number of hours (h) a borehole should be pumped for each day, at the pumping rate of the preceding test:

$$h = 24 - \left(24/x\right)$$

where:

- x = the x-axis intercept of the residual drawdown versus recovery plot (t/t') on semi-log graph paper after a constant discharge pumping test. Residual drawdown is the water level in a borehole after pumping has ceased.

If, for example, the aquifer is recharged and complete recovery has occurred at e.g. t/t" = 3, then the pumping time was twice the recovery time. That means the borehole can be pumped for 16 h/d at the same hourly rate that the hole was pumped during the test. Whether the same quantity of water per day may be abstracted at a higher rate in a shorter period depends on the results of the step tests.

A complete recovery at e.g. t/t" = 1.6 indicates that the abstraction rate of the pumping test cannot be maintained for longer periods. In this case, a recovery time of 24/1.6 = 15 h/d and a corresponding pumping time of 9 h/d must be regarded as more adequate. Theoretically zero residual drawdown should occur at t/t' = 2 if the abstraction rate equals lateral recharge (Kirchner, 1991). In this case, the recovery time for the borehole is equal to the preceding pumping time and a 12-hour pumping day can be maintained. A more rapid recovery may be observed if either vertical recharge has occurred or if storativity is different during pumping and recovery due to air entrapment or elastic deformation of the aquifer (Driscoll, 1986). A longer recovery time or incomplete recovery would indicate a limited extent of the aquifer or lower permeability boundaries.

A major problem in applying the recovery method is when incomplete or rapid recovery is experienced. Recovery readings are seldom taken for a longer period than the pumping period, that is beyond t/t' = 2, hence extrapolations are necessary. Extrapolations can produce non-unique t/t' intercepts, which may have serious implications for yield derivations. For example, if intercepts could fall between 1.01 and 1.1 from a pumping rate of 4 L/s, which is a very plausible range given the standard error of slope extrapolations, yields of 3.4 to 31.4 m 3 /day would be calculated. Extrapolations may also produce a t/t' value which is less than one, which gives a negative yield recommendation using equation 1. Under these circumstances it does not necessarily mean that the borehole cannot yield anything at all on a sustainable basis. Rather it indicates that partial dewatering of the aquifer took place during the constant discharge test, or that the aquifer is bounded by formations with relatively low permeabilities. While these may be good reasons to be cautious in recommending a long-term abstraction rate, they are not reasons to abandon the borehole altogether. In cases where rapid recovery occurs due to leakage from overlying material or variations in storativity, relatively high t/t' values may be obtained. This results in the calculation of large yield values. Since the extent of storage in these horizons is not taken into account, the sustainability of these yields would be uncertain.

It is also necessary to examine the assumption that recovery time is related to the preceding pumping rate. Could a borehole pumped at a low rate relative to its potential require just as long to recover than if it were pumped at a higher rate? If a low rate was selected, a low pressure gradient would be induced in the fractures, which would limit their rate of replenishment from the surrounding matrix. Consequently, similar t/t' intercept values may be obtained irrespective of the preceding pumping rate.

The implication is that a much lower yield value would be calculated relative to that which would have been calculated from a high pumping rate recovery test. The application of this method should possibly be restricted to tests where the pumping rate is close to the borehole's capacity and where the recovery is complete. The implication is that a much lower yield value would be calculated relative to that which would have been calculated from a high pumping rate recovery test. The application of this method should possibly be restricted to tests where the pumping rate is close to the borehole's capacity and where the recovery is complete.

The recovery curves of the aquifer tested borehole can be viewed in Appendix F.

The following results were obtained by utilising the Kirchner Recovery Test Method for the aquifer tested boreholes:

- Production borehole VBH01 recovered to 92.21% of the initial static water level within 3-minutes after the termination of the constant rate discharged test.
- Production borehole VBH11 recovered to 90.83% of the initial static water level within 38-hours after the termination of the constant rate discharged test.
- Production borehole VBH12 recovered to 90.89% of the initial static water level within 36-hours after the termination of the constant rate discharged test.
- Production borehole LBH01 recovered to 72.66% of the initial static water level within 13-hours after the termination of the constant rate discharged test.
- Production borehole LBH02 recovered to 95.22% of the initial static water level within 1-hour after the termination of the constant rate discharged test.
- Production borehole RBH01 recovered to 90.80% of the initial static water level within 3.5-hours after the termination of the constant rate discharged test.
- Production borehole RBH02 recovered to 94.50% of the initial static water level within 20-minutes after the termination of the constant rate discharged test.
- Production borehole RBH03 recovered to 90.40% of the initial static water level within 1.5-hours after the termination of the constant rate discharged test.
- Production borehole RBH04 recovered to 94.92% of the initial static water level within 10-minutes after the termination of the constant rate discharged test.

- Production borehole RBH05 recovered to 92.06% of the initial static water level within 22-hours after the termination of the constant rate discharged test.
- Production borehole RBH06 recovered to 90.79% of the initial static water level within 4-hours after the termination of the constant rate discharged test.
- Production borehole MBH02 recovered to 91.82% of the initial static water level within 15-minutes after the termination of the constant rate discharged test.

6.2 AQUIFER TEST PUMPING ANALYSIS

The data obtained from the various pump tests were analysed with the FC-Method developed by Prof. Gerrit van Tonder from the Institute for Groundwater Studies (IGS) at the University of the Free State (UFS).

6.2.1 Theory of the Estimation of Sustainable Yields of Boreholes in Fractured Rock Aquifers

This section is based on WRC Report No.: 1116/1/02 titled, Manual on Pump Test Analysis in Fractured-Rock Aquifers (Van Tonder et al., 2002).

6.2.1.1 Introduction

An increasing number of boreholes in Southern Africa have dried up during the past years, in spite of favourable hydrologic conditions. An investigation of reliable estimates for the sustainable yield of the boreholes was therefore required. Overestimation of the borehole yield was due to the application of improper extrapolation of drawdown curves, which ignored barrier boundaries and neglected parameter uncertainties arising from the imperfect knowledge of the effective aquifer properties. Sami and Murray (1998) give a summary of methods that are commonly used in SA to estimate the sustainable yield of a borehole and the methods include:

- The Recovery Method;
- The late T-method;
- The Drawdown-to-boundary Method; and
- The Distance-to-boundary Method.

Naafs (1999) compared the methods above using the FC-method (Van Tonder et al., 1998) and found that the Recovery method and the late T-method are not to be used because they gave a too high sustainable yield in most of the cases tested. Naafs adapted the late T-method by introducing a variable available drawdown. In the case of this adapted late T-method, it yielded very similar results if compared to the Drawdown-to-boundary and Distance-to-boundary methods. Both the adapted late T-method and the Drawdown to-boundary methods are special cases of the FC-method.

The following sections show how to estimate the sustainable yield of a borehole by quantifying the effects of no-flow boundaries as well as the uncertainties in the values of transmissivity, storativity and distances to the boundaries.

6.2.1.2 Estimation of the Sustainable Yield of a Borehole

The ratio of drawdown s to pumping rate Q is a constant for a well (if corrected for well losses). This constant only depends on the aquifer properties transmissivity T and storativity

S: If t_{long} describes the maximum operation time in which the drawdown s shall not exceed a maximum drawdown $s_{available}$, the extrapolation of the measured pumping test drawdown can be used to determine the sustainable yield $Q_{sustainable}$:

$$Q_{Sustainabl} = Q_{PumpingTest} = \frac{S_{Available}(t = t_{long})}{S_{PumpTest}(t = t_{long})}$$

The available drawdown is, for instance, the position of the main water strike in the borehole. If the drawdown exceeds this position, a drastic decrease in the yield of the borehole occurs and it may dry up. The problem of extrapolating the drawdown measured during the pumping test from the time of the end of the pumping test to a time t_{long} of around two to five years, remains. This extrapolation is traditionally done by applying the Theis solution. A more sophisticated extrapolation of the pumping test drawdown beyond the time of the end of the measurement is obtained by using a Taylor series expansion based on the extrapolation of the measured drawdown curve including drawdown derivatives, and by accounting for boundaries.

6.2.1.3 Extrapolation of Pumping Test Drawdown

The drawdown measured during a pumping test is the sum of the drawdowns due to the production well, s_{Well}, and the boundaries, $s_{Boundary}$:

$$S(t = t_{long}) = S_{Well} + S_{Boundary}$$

The drawdown due to the production well (s_{Well}) is extrapolated by a Taylor series expansion around the late measurement points of the drawdown at $t \approx t_{EOP}$ (subscript EOP denotes end of pumping test). The Taylor series expansion is performed with respect to the logarithm of time, $\log_{10}$. A second order approximation is assumed to be sufficient:

$$S_{Well}(t = t_{long}) \approx s(t = t_{EOP}) + \frac{\partial s}{\partial \log t}\Big|_{t=t_{EOP}} (\log t_{long} - \log t_{EOP}) + \frac{1}{2}\frac{\partial^2 s}{\partial (\log t)^2}\Big|_{t=t_{EOP}} (\log t_{long} - \log t_{EOP})^2$$

The time t_{EOP} has to be large enough to ensure that the drawdown has already passed the early time flow behaviour that is due to well bore storage, fracture flow and double porosity effects. This can clearly be monitored by looking at the derivative plot $\partial s/\partial \log t$ (Van Tonder, 1998; Bourdet et al., 1984). Usually, the effect of the boundaries can only be seen at very late times of the pumping test. The extrapolation of the above equation therefore does not in general include boundary information.

For simple geometries of the boundaries, image well theory is applied to analyse the effects of the boundaries on the drawdown ($s_{Boundary}$).

The analytical expressions and the simplified boundary configurations already yield far better estimates of the sustainable yield than the traditional Theis extrapolation, which assumes an aquifer of infinite extent. The estimate can be improved further by taking into account uncertainties in the required parameters like the late time transmissivity T, storativity S and the distances to the boundaries a and b.

6.2.1.4 Risk Analysis by Uncertainty Propagation

Kunstmann and Kinzelbach (1998) showed computational efficient methods of quantifying uncertainties in groundwater modelling. The Gaussian Error Propagation method can easily and most advantageously be applied to analytical formulas. It is applied to the drawdown equations presented and described below.

The drawdown in the pumping well is a function of the parameters t, Q, T, S, a and b, where a and b are the distances to boundaries. It is assumed that the latter four parameters are not known perfectly, but are within a range around their mean values:

$$T = \hat{T} \pm \sigma_T ,\ S = \hat{S} \pm \sigma_S ,\ a = \hat{a} \pm \sigma_a ,\ b = \hat{b} \pm \sigma_b$$

The mean drawdown $\hat{s}$ can be approximated by evaluating the drawdown equations at the mean values of the input parameters:

$$\hat{s} = s(\hat{T}, \hat{S}, \hat{a}, \hat{b})$$

The standard deviation (describing the uncertainty of the drawdown) can be approximated by the following formula:

$$\sigma \approx \sqrt{\left(\frac{\partial s}{\partial T}\Big|_{T=\hat{T}}\right)^2 \sigma_T{}^2 + \left(\frac{\partial s}{\partial S}\Big|_{S=\hat{S}}\right)\sigma_S{}^2 + \left(\frac{\partial s}{\partial a}\Big|_{a=\hat{a}}\right)^2 \sigma_a{}^2 + \left(\frac{\partial s}{\partial b}\Big|_{b=\hat{b}}\right)^2 \sigma_b{}^2}$$

σ_s is required at the extrapolation time t_{long}, since the uncertainty of the extrapolated drawdown is of interest. The above shows that the uncertainty σ_s is determined by the input parameter uncertainties σ_T, σ_S, σ_a, σ_b, and the sensitivities $\partial s/\partial T$, $\partial s/\partial S$, $\partial s/\partial a$, $\partial s/\partial b$.

The sensitivity of the drawdown with respect to the parameters is the sum of the sensitivity of the well drawdown and the sensitivity of the image wells, i.e. the boundary drawdown. In case of the transmissivity, for instance, this can be written as:

$$\frac{\partial}{\partial T}\Big|_{t=t_{long}} = \frac{\partial s_{Well}}{\partial T}\Big|_{t=t_{long}} + \frac{\partial s_{Boundary}}{\partial T}\Big|_{t=t_{long}}$$

The well drawdown is extrapolated by a second order Taylor series expansion from the end of the pumping test to the time t_{long} (that describes the maximum operation period of the borehole in the case of no recharge). Since the extrapolated well drawdown is based on a measured drawdown curve, its sensitivity with respect to the parameters cannot be calculated. The sensitivity of s_{Well} is therefore approximated by assuming a Theis sensitivity, e.g.

$$\frac{\partial s_{Well}}{\partial T}\Big|_{t_{long}} \approx \frac{\partial s_{Theis}}{\partial T}\Big|_{t_{long}}$$

The analytical expression of the Theis sensitivity can easily be evaluated by a finite difference approximation. The uncertainty of the extrapolated drawdown s σ can now be included in the estimation of the sustainable yield. The available drawdown has to be corrected by the uncertainty of the drawdown that arises from the imperfect knowledge of the aquifer parameters and the distances to the boundaries:

$$s'_{available} = s_{available} - 2\sigma_s$$

This leads to a risk-oriented estimate of the sustainable yield.

A correction of the available drawdown by two standard deviations yields a probability of 95.5% for not exceeding the available drawdown (assuming a normal distribution for the uncertain s). A correction by one standard deviation still yields a safety of 68.3%. The owner of the borehole has to decide on the safety requirement (i.e. the probability of failure). In this manner a conservative and therefore sustainable yield should be estimated.

Application of this methodology required the determination of T and S. These parameters can be estimated by the interpretation of the drawdown curve. Moreover, to get an estimate of the available drawdown and the water strikes, the flow regime behaviour has to be investigated to identify the main fractures and the water strikes. In the following section we present a new, heuristic approach for the identification of T and S and a way to obtain a better knowledge on the flow regime.

6.3 ABSTRACTION RECOMMENDATIONS AND MANAGEMENT OPTIONS

The following sustainable abstraction rate and pump schedule is recommended for the aquifer tested boreholes of Ubuntu Municipality, (refer to Table 6 on page 84):

Table 6. Recommended sustainable abstraction rates and pump schedules for the aquifer tested boreholes.

Borehole Name	Abstraction Options	Duty Cycle (h/d)	Abstraction Rate (L/s)	Abstraction Volume (L/h)	Abstraction Volume (L/d)	Abstraction Volume (m^3/d)	Abstraction Volume (m^3/month)	Abstraction Volume (m^3/a)	Pump Installation Depth (mbgl)	Critical Water Level (mbgl)	Recommendations / Comments
VBH01 (Victoria West)	Recommended Abstraction Rate*	12.0	2.20	7 920	95 040	95	2 851	34 690	30.0	n/a	The groundwater of borehole VBH01 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to EC (186.0 mS/m), Na (204.0 mg/L) and Total Hardness (610.3 mg/L). Borehole is conditionally recommended for abstraction if water is chlorinated and mixed or treated to a concentration acceptable to the SANS241-1:2011 Standard (EC < 170 mS/m, Na < 200 mg/L & Total Hardness < 300 mg/L). Recommended pump installation depth is 30 mbgl.
VBH11 (Victoria West)	Recommended Abstraction Rate*	12.0	2.10	7 560	90 720	91	2 722	33 113	75.0	45.0	The groundwater of borehole VBH11 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to As (Arsenic, As = 0.095 mg/L). Borehole is conditionally recommended for abstraction if water is chlorinated and mixed or treated to a concentration acceptable to the SANS241-1:2011 Standard (As < 0.01mg/L). Recommended pump installation depth is 75 mbgl.
VBH12 (Victoria West)	Recommended Abstraction Rate*	12.0	1.70	6 120	73 440	73	2 203	26 806	85.0	30.0	The groundwater of borehole VBH12 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to As (Arsenic, As = 0.104 mg/L). Borehole is conditionally recommended for abstraction if water is chlorinated and mixed or treated to a concentration acceptable to the SANS241-1:2011 Standard (As < 0.01mg/L). Recommended pump installation depth is 85 mbgl.
LBH01 (Loxton)	Recommended Abstraction Rate*	12.0	0.30	1 080	12 960	13	389	4 730	60.0	57.0	Borehole LBH01 has a low sustainable yield and a poor water quality. Not recommended for abstraction.
LBH02 (Loxton)	Recommended Abstraction Rate*	12.0	3.60	12 960	155 520	156	4 666	56 765	60.0	35.0	The groundwater of borehole LBH02 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to EC (624.0 mS/m), Na (952.9 mg/L), Ca (227.2), Mg (220.6 mg/L), Cl (1109.4 mg/L), SO4 (1323.0 mg/L) and Total Hardness (1472.4 mg/L). Borehole is conditionally recommended for abstraction if the water abstracted is treated to ensure that the water quality complies with SANS214-1:2011 water quality standards (EC < 170 mS/m, Na < 200 mg/L, Ca < 150, Mg < 100 mg/L, Cl < 300 mg/L, SO4 , 500 mg/L & Total Hardness , 300 mg/L). Treatment options for elevated electrical conductivity values (EC), sodium (Na) and total hardness (T.Hard) concentrations include methods such as reverse osmosis or electro-dialysis, distillation or demineralisation with a mixed bed resin or ion-exchange process. All large scale salt removal processes require high levels of operator and maintenance skills as processes are easily fouled by suspended matter or hard water. The concentrated brine produced may present disposal problems. Treatment options for elevated magnesium (Mg) concentrations include lime softening followed by re-carbonation. Other techniques that can be utilised include ion-exchange resins or precipitation of magnesium at a high pH. Methods to remove magnesium from water also require skilled operation and high maintenance (DWAF, Quality of Domestic Water Supply, Volume 1: Assessment Guide. WRC Report No.: TT101/98, 1998).
RBH01 (Richmond)	Recommended Abstraction Rate*	12.0	5.20	18 720	224 640	225	6 739	81 994	33.0	29.8	The groundwater of borehole RBH01 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 33 mbgl. The estimated duty cycle recommended with the current pump installed is 10-hours a day at 5.80 L/s.
RBH02 (Richmond)	Recommended Abstraction Rate*	12.0	1.80	6 480	77 760	78	2 333	28 382	33.0	13.1	The groundwater of borehole RBH02 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 33 mbgl. The estimated duty cycle recommended with the current pump installed is 16-hours a day at 1.50 L/s.
RBH03 (Richmond)	Recommended Abstraction Rate*	12.0	6.30	22 680	272 160	272	8 165	99 338	35.0	14.8	The groundwater of borehole RBH03 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 35 mbgl. The estimated duty cycle recommended with the current pump installed is 24-hours a day at 2.5 L/s. The current pump is undersized for the borehole safe yield volume.
RBH04 (Richmond)	Recommended Abstraction Rate*	12.0	0.10	360	4 320	4	130	1 577	35.0		Low sustainable yield. Not recommended for abstraction with a motorised installation.
RBH05 (Richmond)	Recommended Abstraction Rate*	12.0	2.80	10 080	120 960	121	3 629	44 150	35.0	10.7	The groundwater of borehole RBH05 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 35 mbgl. The estimated duty cycle recommended with the current pump installed is 6-hours a day at 3.90 L/s.
RBH06 (Richmond)	Recommended Abstraction Rate*	12.0	5.00	18 000	216 000	216	6 480	78 840	35.0	23.3	The groundwater of borehole RBH06 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 35 mbgl. The estimated duty cycle recommended with the current pump installed is 9-hours a day at 5.70 L/s.
MBH02 (Merriman)	Recommended Abstraction Rate*	12.0	0.40	1 440	17 280	17	518	6 307	60.0	41.6	The groundwater of borehole MBH02 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to EC (321.0 mS/m), Na (382.9 mg/L), Ca (197.2 mg/L) and Cl (971.7 mg/L).). Borehole is conditionally recommended for abstraction if the water abstracted is treated to ensure that the water quality complies with SANS214-1:2011 water quality standards (EC < 170 mS/m, Na < 200 mg/L, Ca < 150, Cl < 300 mg/L, & Total Hardness , 300 mg/L). Treatment options for elevated electrical conductivity values (EC), sodium (Na) and total hardness (T.Hard) concentrations include methods such as reverse osmosis or electro-dialysis, distillation or demineralisation with a mixed bed resin or ion-exchange process. All large scale salt removal processes require high levels of operator and maintenance skills as processes are easily fouled by suspended matter or hard water. The concentrated brine produced may present disposal problems. (DWAF, Quality of Domestic Water Supply, Volume 1: Assessment Guide. WRC Report No.: TT101/98, 1998).

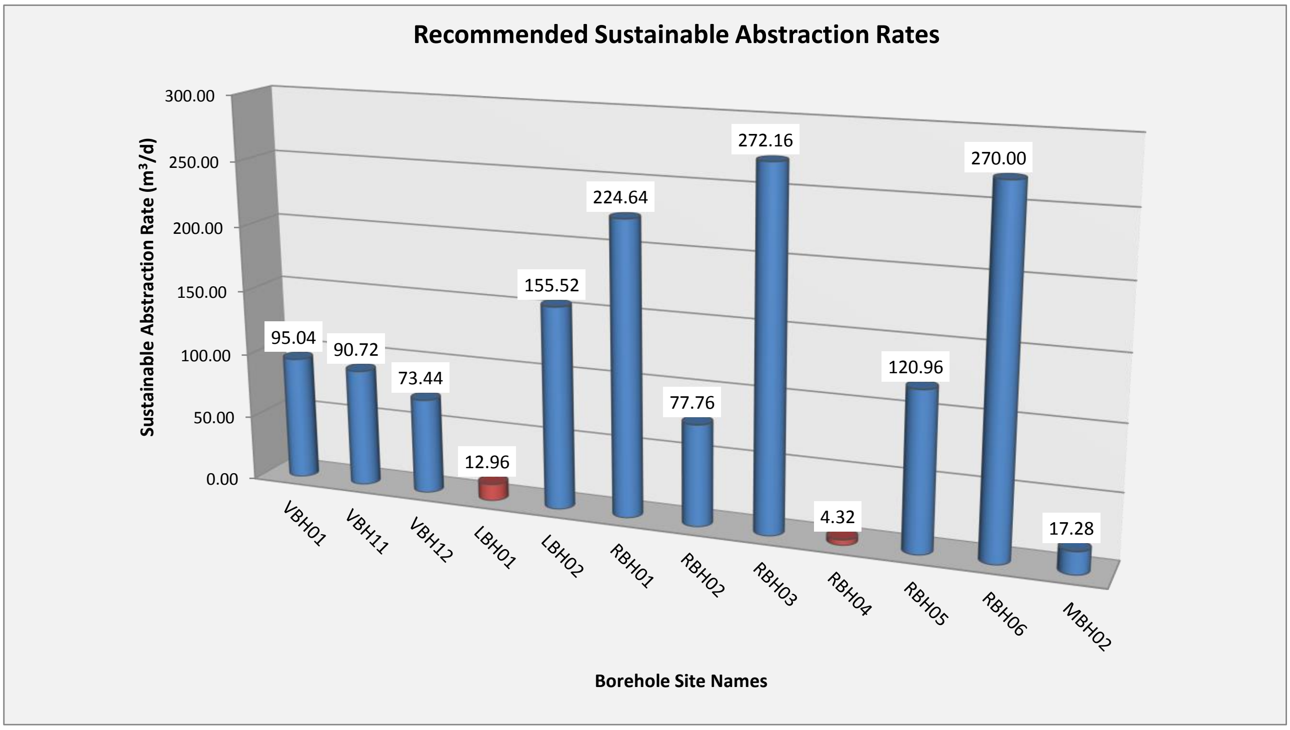


Figure 24. Recommended sustainable abstraction rates of the aquifer tested boreholes of Ubuntu Municipality.

The following sustainable yields are recommended for the aquifer test pumped boreholes of Ubuntu Municipality (refer to Table 6 on page 84):

Victoria West: Recommended Abstraction Rates

- The recommended sustainable abstraction rate for borehole VBH01 (Victoria West) is calculated at 2.20 L/s (95.0 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole VBH01 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to EC (186.0 mS/m), Na (204.0 mg/L) and Total Hardness (610.3 mg/L). Borehole is conditionally recommended for abstraction if water is chlorinated and mixed or treated to a concentration acceptable to the SANS241-1:2011 Standard (EC < 170 mS/m, Na < 200 mg/L & Total Hardness < 300 mg/L). Recommended pump installation depth is 30 mbgl.
- The recommended sustainable abstraction rate for borehole VBH11 (Victoria West) is calculated at 2.10 L/s (91.0 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole VBH11 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to As (Arsenic, As = 0.095 mg/L). Borehole is conditionally recommended for abstraction if water is chlorinated and mixed or treated to a concentration acceptable to the SANS241-1:2011 Standard (As < 0.01 mg/L). Recommended pump installation depth is 75 mbgl.
- The recommended sustainable abstraction rate for borehole VBH12 (Victoria West) is calculated at 1.70 L/s (73 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole VBH12 is classified as "ARS, above recommended standard" (inorganic water

quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to As (Arsenic, As = 0.104 mg/L). Borehole is conditionally recommended for abstraction if water is chlorinated and mixed or treated to a concentration acceptable to the SANS241-1:2011 Standard (As < 0.01 mg/L). Recommended pump installation depth is 85 mbgl.

- It is recommended that additional groundwater exploration be conducted on the dolerite dyke structure on which VBH11 and VBH12 is located to the north east of Victoria West. It is also recommended that additional groundwater exploration be conducted on the dolerite structure on which VBH07 is located to the south of Victoria West. Treatment of the reservoir water or mixing options for EC (Electrical Conductivity) is also recommended for investigation.

Loxton: Recommended Abstraction Rates

- The recommended sustainable abstraction rate for borehole LBH01 (Loxton) is calculated at 0.30 L/s (13 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). Borehole LBH01 has a low sustainable yield and a poor water quality. Not recommended for abstraction.
- The recommended sustainable abstraction rate for borehole LBH02 (Loxton) is calculated at 3.60 L/s (156 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole LBH02 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to EC (624.0 mS/m), Na (952.9 mg/L), Ca (227.2), Mg (220.6 mg/L), Cl (1109.4 mg/L), SO4 (1323.0 mg/L) and Total Hardness (1472.4 mg/L). Borehole is conditionally recommended for abstraction if the water abstracted is treated to ensure that the water quality complies with SANS214-1:2011 water quality standards (EC < 170 mS/m, Na < 200 mg/L, Ca < 150, Mg < 100 mg/L, Cl < 300 mg/L, SO4 , 500 mg/L & Total Hardness , 300 mg/L). Treatment options for elevated electrical conductivity values (EC), sodium (Na) and total hardness (T.Hard) concentrations include methods such as reverse osmosis or electro-dialysis, distillation or demineralisation with a mixed bed resin or ion-exchange process. All large scale salt removal processes require high levels of operator and maintenance skills as processes are easily fouled by suspended matter or hard water. The concentrated brine produced may present disposal problems. Treatment options for elevated magnesium (Mg) concentrations include lime softening followed by re-carbonation. Other techniques that can be utilised include ion-exchange resins or precipitation of magnesium at a high pH. Methods to remove magnesium from water also require skilled operation and high maintenance (DWAF, Quality of Domestic Water Supply, Volume 1: Assessment Guide. WRC Report No.: TT101/98, 1998).
- It is recommended that the feasibility of a water treatment plant for Loxton be investigated as the water of the reservoir is not of a SANS241:2011 quality and is unsuitable for use according to existing water quality data. Potentially sustainable groundwater volume is not the problem if the water bearing structure on, which LBH02 is further developed by groundwater exploration.

Richmond: Recommended Abstraction Rates

- The recommended sustainable abstraction rate for borehole RBH01 (Richmond) is calculated at 5.20 L/s (225 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole RBH01 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 33 mbgl. The estimated duty cycle recommended with the current pump installed is 10-hours a day at 5.80 L/s.

- The recommended sustainable abstraction rate for borehole RBH02 (Richmond) is calculated at 1.80 L/s (78 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole RBH02 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 33 mbgl. The estimated duty cycle recommended with the current pump installed is 16-hours a day at 1.50 L/s.
- The recommended sustainable abstraction rate for borehole RBH03 (Richmond) is calculated at 6.30 L/s (272 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole RBH03 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 35 mbgl. The estimated duty cycle recommended with the current pump installed is 24-hours a day at 2.5 L/s. The current pump is undersized for the borehole safe yield volume.
- The recommended sustainable abstraction rate for borehole RBH04 (Richmond) is calculated at 0.10 L/s (4 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). Low sustainable yield. Not recommended for abstraction with a motorised installation.
- The recommended sustainable abstraction rate for borehole RBH05 (Richmond) is calculated at 2.80 L/s (121 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole RBH05 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 35 mbgl. The estimated duty cycle recommended with the current pump installed is 6-hours a day at 3.90 L/s.
- The recommended sustainable abstraction rate for borehole RBH06 (Richmond) is calculated at 5.0 L/s (216 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole RBH06 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 35 mbgl. The estimated duty cycle recommended with the current pump installed is 9-hours a day at 5.70 L/s.
- The production boreholes in Richmond are currently utilised 24-hours a day. It is recommended that a 13-hour duty cycle be adhered to with 11-hours of recovery per day. It is also recommended that the undersized pump at production borehole RBH03 be replaced to add additional water volume to the water system. Groundwater monitoring is also recommended at borehole RBH04 that will not be utilised for abstraction due to a low sustainable yield. If the groundwater level of the monitoring borehole reaches 17 mbgl, which is the geometric mean of the critical water level of the

borehole field, it is recommended that the duty cycles of the production boreholes be reduced to ensure the sustainable abstraction.

Merriman: Recommended Abstraction Rates

- The recommended sustainable abstraction rate for borehole MBH02 (Merriman) is calculated at 0.4 L/s (17 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time (refer to Table 6 and Figure 24 on pages 84 and 85). The groundwater of borehole MBH02 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to EC (321.0 mS/m), Na (382.9 mg/L), Ca (197.2 mg/L) and Cl (971.7 mg/L).). Borehole is conditionally recommended for abstraction if the water abstracted is treated to ensure that the water quality complies with SANS214-1:2011 water quality standards (EC < 170 mS/m, Na < 200 mg/L, Ca < 150, Cl < 300 mg/L, & Total Hardness , 300 mg/L). Treatment options for elevated electrical conductivity values (EC), sodium (Na) and total hardness (T.Hard) concentrations include methods such as reverse osmosis or electro-dialysis, distillation or demineralisation with a mixed bed resin or ion-exchange process. All large scale salt removal processes require high levels of operator and maintenance skills as processes are easily fouled by suspended matter or hard water. The concentrated brine produced may present disposal problems. (DWAF, Quality of Domestic Water Supply, Volume 1: Assessment Guide. WRC Report No.: TT101/98, 1998).
- It is recommended that the groundwater of MBH02 at Merriman be treated on small scale before utilisation by the small community.

It is also recommended that groundwater monitoring be implemented to manage the groundwater resources in a sustainable and responsible manner and to prevent dewatering of the aquifer as well as to monitor the water quality over a prolonged period. The groundwater resource monitoring for the newly drilled and tested boreholes are as follows:

- The rest or static water levels as well as pump water levels of the newly drilled production boreholes are to be measured at two monthly. The abstraction volumes are also to be measured by means of a flow meter. The decline in groundwater levels are not necessarily due to abstraction but could also be a function of seasonal change such extended drought or dry periods. Therefore should drastic declines in static or pump water levels occur, the abstraction rates will have to be decreased to ensure sustainable utilisation according to seasonal rainfall if necessary.
- The recommended abstraction boreholes must be equipped with conduit pipes to ensure that groundwater level measurements can be taken even when the boreholes are equipped. It further recommended that the abstraction boreholes be equipped with flow meters to measure and record the abstracted flow volumes.
- Monthly rainfall records are to be compiled if unavailable from South African Weather Services to determine recharge to aquifer in relation to groundwater level elevation.
- Groundwater quality is generally fairly stable and chances occur slowly (dictated by groundwater flow paths and velocities) except for bacteriological constituents. For this reason samples are normally taken as grab samples and typically at a reduced frequency compared to surface water samples. Groundwater sampling should at least be undertaken bi-annually to account for seasonality. For the first year monthly sampling should be performed to determine a baseline groundwater quality for the borehole fields (DWA, Water Monitoring Systems, Best Practice Guidelines G3, 2007).

- A monitoring protocol or management plan should be drafted according to DWA, Water Monitoring Systems, Best Practice Guidelines G3, 2007.

7 GROUNDWATER QUALITY RESULTS

The sampling of the boreholes was conducted after the completion of the aquifer test pumping. The sample was analysed for inorganic as well as bacteriological constituents. The parameters analysed for was specified by DWA under the SANS241-1:2011 Standards.

7.1 HYDROCHEMICAL IMAGING

Tables of data are the most common form in which the results of an analysis of water chemistry are reported. The data can be expressed in milligrams per litre (mg/L), milliequivalents per litre (meq/L) or millimoles per litre. For many purposes, the data may be also displayed in graphical form.

Water classification diagrams are useful for studying the distribution of water types in an area. Topographic features, rock types, or surface activities (anthropogenic influences) may influence the water type. Water classification is useful for regional groundwater studies, particularly to delineate the distribution of groundwater types and identify areas where poor quality water may occur. Such delineation of the water quality distribution in space lends itself to hydro-chemical mapping and quality classification.

Any form of hydro-chemical classification assumes that the water is in equilibrium in its environment. The nature of the classification plots is such that many points are plotted together for visual comparison of the water types.

7.1.1 Piper Diagram

According to Fetter (1994) the major ionic species in most natural waters are Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-} and CO_3^{2-} and SO_4^{2-}. A trilinear diagram can show the percentage composition of three ions. By grouping Na^{+} and K^{+} together, the major cations can be displayed on one trilinear diagram. Likewise, if CO_3^{2-} and HCO_3^{-} are grouped there are also three groups of the major anions. Figure 26 shows the form of a trilinear diagram that is commonly used in water-chemistry studies (Piper, 1944). Analyses are plotted on the basis of the percent of each cation (or anion).

Each apex of a triangle represents a 100% concentration of one of the three constituents. If a sample has two constituent groups present, then the point representing the percentage of each would be plotted on the line between the apexes for those two groups. If all three constituent groups are present, the analyses would fall in the interior field. The diamond-shaped field between the two triangles is used to represent the composition of water with respect to both cations and anions.

The cation point is projected onto the diamond-shaped field parallel to the side of the triangle labelled magnesium and the anion point is similarly projected parallel to the side of the triangle labelled sulphate. The intersection of the two lines is plotted as a point on the diamond-shaped field.

As water flows through an aquifer it assumes a diagnostic chemical composition as a result of interaction with the lithological framework. The term hydro-chemical facies is used to describe the bodies of groundwater, in an aquifer, that differ in their chemical composition. The facies are a function of the lithology, solution kinetics and flow patterns of the aquifer.

(Black, 1960 & 1966). Hydro-chemical facies can be classified on the basis of the dominant ions in the facies by means of the trilinear diagram (refer to page 92, Figure 26).

The points for both cations and anions are plotted on the appropriate tri-axial diagrams on page 93, Figure 28. The positions of these points are projected onto the diamond-shaped field and the intersection of the projected lines is plotted.

The following classification may be introduced, which permits groundwater being placed within one of the four major categories, represented on the central diamond-shaped diagram, namely (refer to page 91, Figure 25).

- Recent groundwater having a high $Ca/MgHCO_3$ content;
- A dynamic regime containing $NaHCO_3$ groundwater;
- Stagnant groundwater conditions characterised by $Ca/MgCl_2$ and $Ca/MgSO_4$ groundwater; and
- Old or mature groundwater enriched in Na^+ and Cl^-.

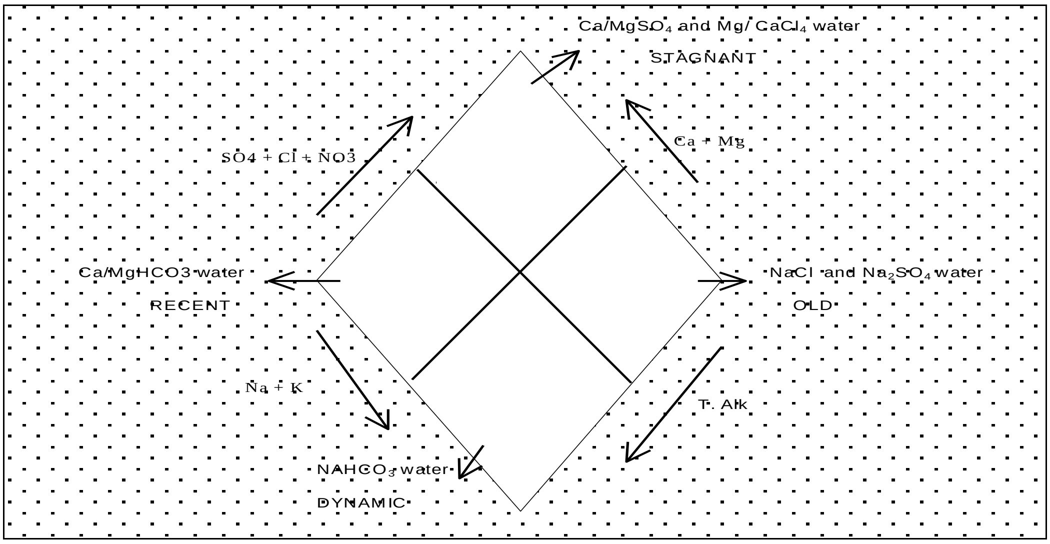


Figure 25. Classification of the diamond-shaped field of the trilinear diagram.

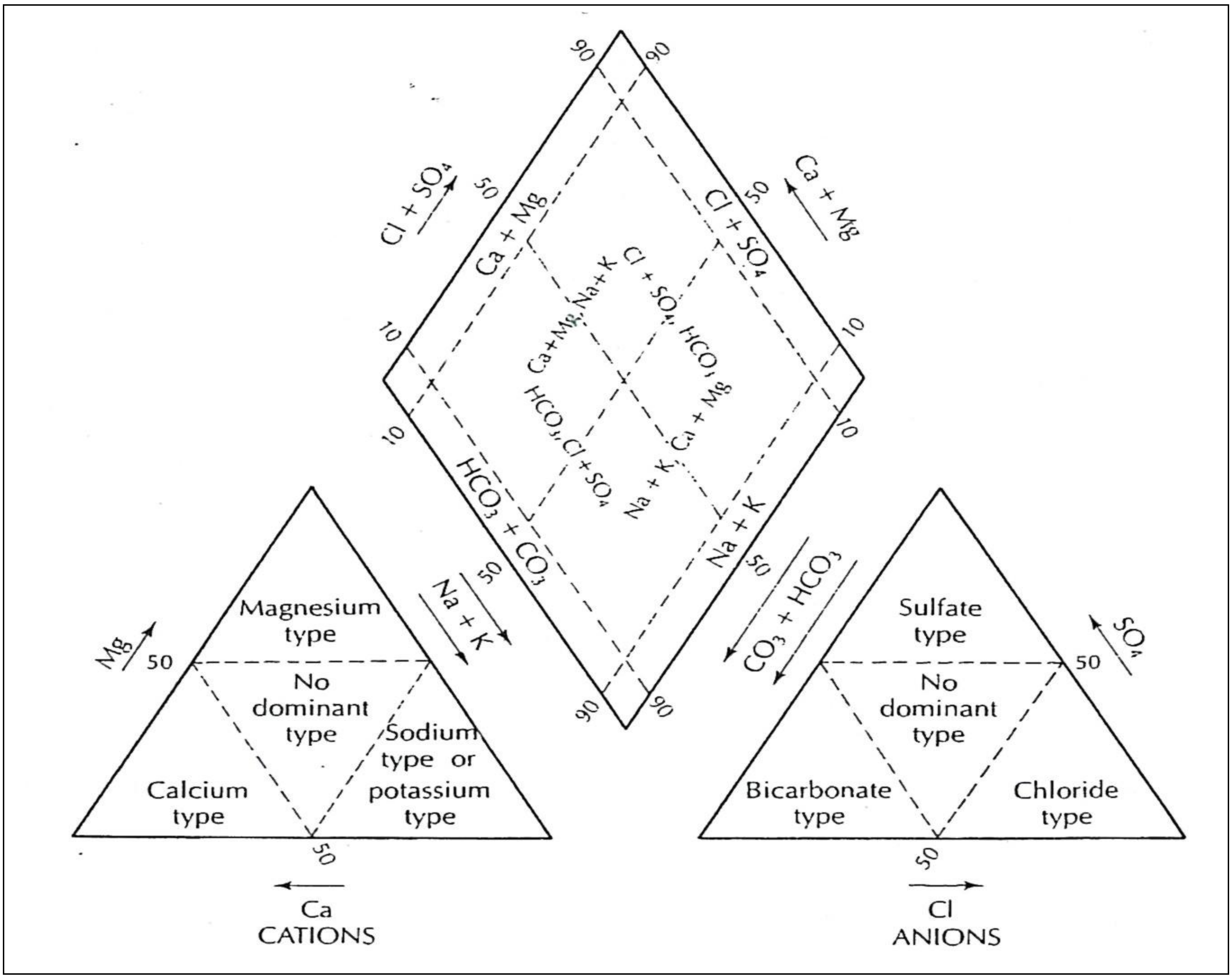


Figure 26. Hydro-Geochemical classification system for natural waters using the Piper Diagram.

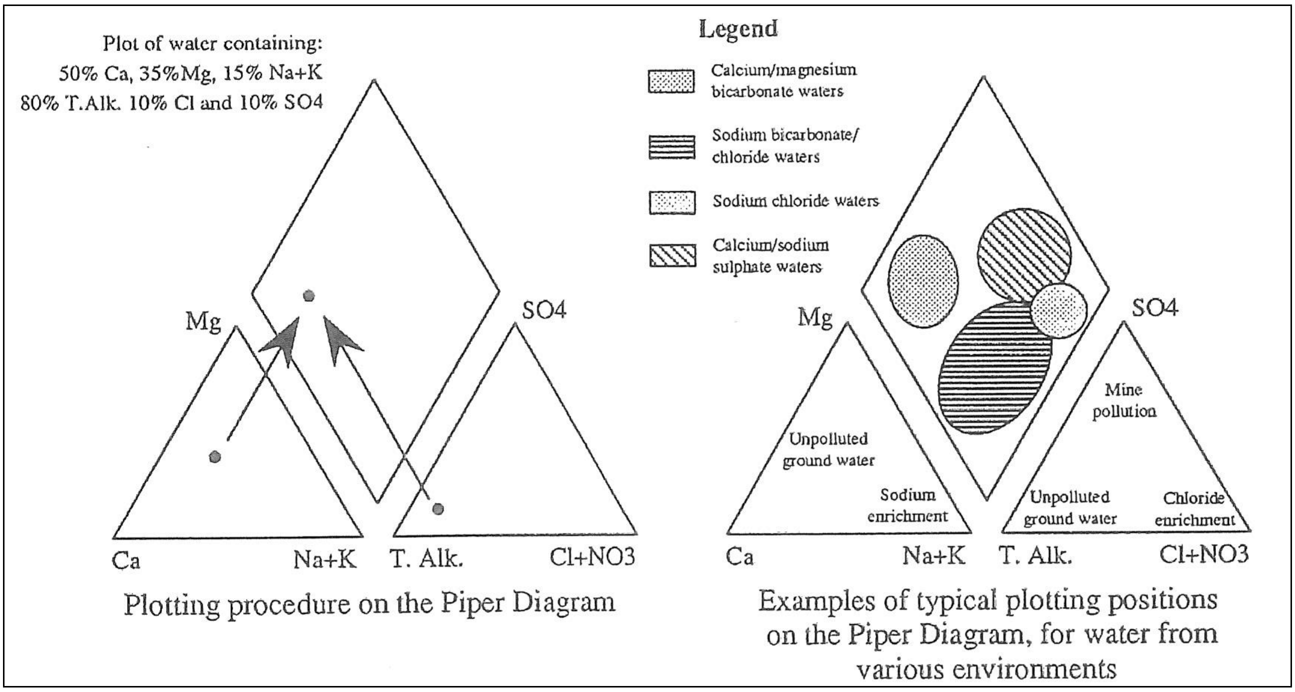


Figure 27. Hydro-Geochemical classification system for natural waters using the Piper Diagram.

7.1.1.1 Piper Diagram Description of the Tested Boreholes of Victoria West

The piper diagram description of the groundwater of the aquifer tested boreholes is as follows (refer to Figure 28 on page 93):

- General Water Type Description: The groundwater of Victoria West is of the calcium / magnesium bicarbonate and sodium bicarbonate/chloride type, which is also described as dynamic waters.
- Cation Type Description: The cations of the groundwater of boreholes VBH11 and VBH12 are of sodium / potassium type, while the cations of the groundwater of borehole VBH01 displays no particular dominant cations.
- Anion Type Description: The anions of the groundwater of boreholes VBH11 and VBH12 are of the bicarbonate type, while the anions of the groundwater of borehole VBH01 displays no particular dominant anions.

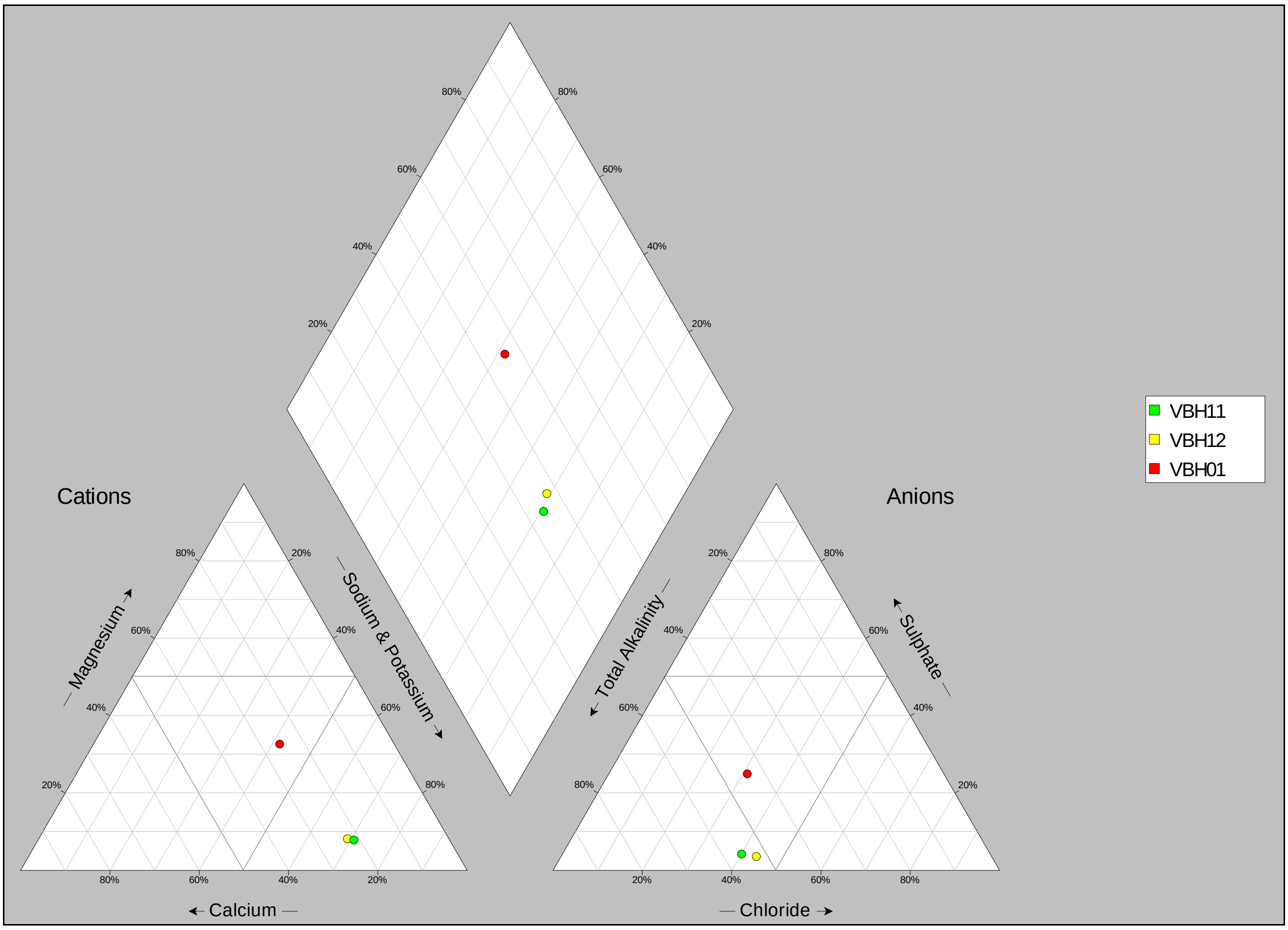


Figure 28. Piper diagram of the groundwater chemistry of the aquifer tested boreholes of Victoria West.

7.1.1.2 Piper Diagram Description of the Tested Boreholes of Loxton

The piper diagram description of the groundwater of the aquifer tested boreholes is as follows (refer to Figure 29 on page 94):

- General Water Type Description: The groundwater of Loxton is of the calcium / sodium sulphate type, which is also described as old and stagnant waters.

- Cation Type Description: The cations of the groundwater of borehole LBH01 is of the calcium type, while the cations of the groundwater of borehole LBH02 is of the sodium / potassium type:
- Anion Type Description: The anions of the groundwater of borehole LBH01 is of the sulphate type, while the anions of the groundwater of borehole LBH02 displays no particular dominant anions.

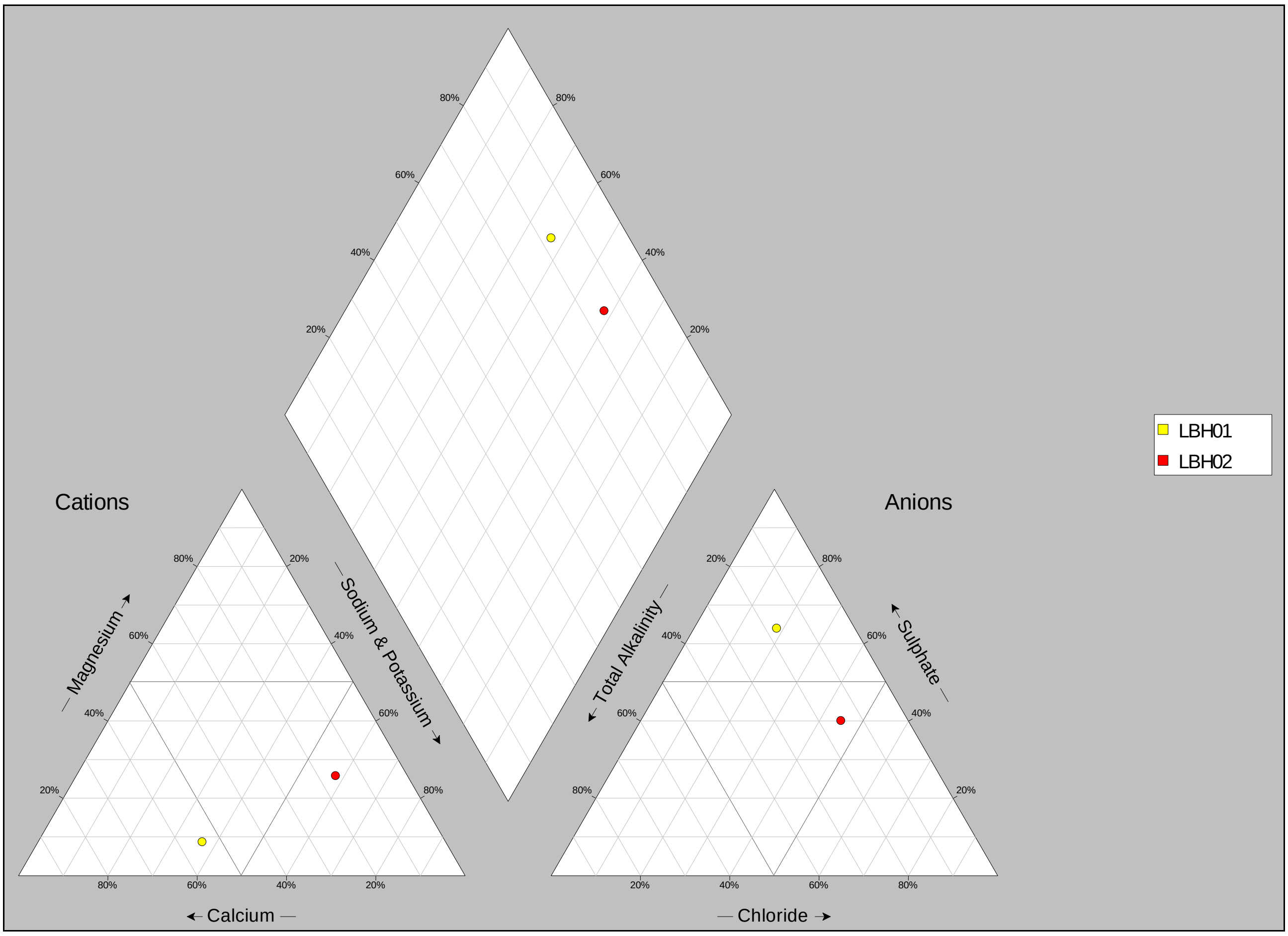


Figure 29. Piper diagram of the groundwater chemistry of the aquifer tested boreholes of Loxton.

7.1.1.3 Piper Diagram Description of the Tested Boreholes of Richmond

The piper diagram description of the groundwater of the aquifer tested boreholes is as follows (refer to Figure 30 on page 95):

- General Water Type Description: The groundwater of Richmond is of the calcium / magnesium type, which is also described as recent waters.
- Cation Type Description: The cations of the groundwater of the aquifer tested boreholes displays borehole no particular dominant anions.
- Anion Type Description: The anions of the groundwater of the aquifer tested boreholes are of the bicarbonate type.

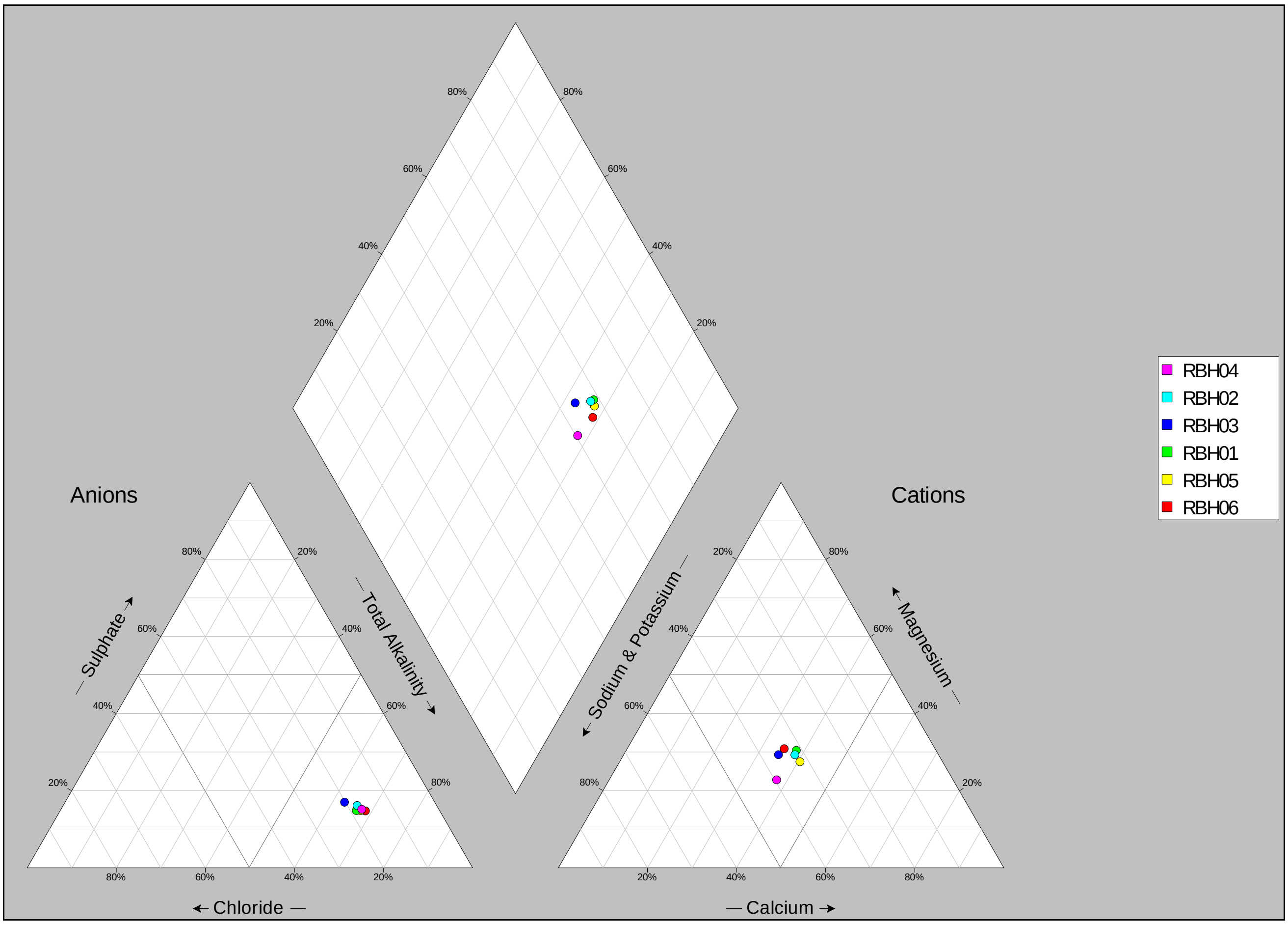


Figure 30. Piper diagram of the groundwater chemistry of the aquifer tested boreholes of Richmond.

7.1.1.4 Piper Diagram Description of the Tested Boreholes of Merriman

The piper diagram description of the groundwater of the aquifer tested boreholes is as follows (refer to Figure 31 on page 96):

- General Water Type Description: The groundwater of Merriman is of the calcium / sodium sulphate type, which is also described as old and stagnant waters.
- Cation Type Description The cations of the groundwater of borehole MBH02 is of the sodium / potassium type:
- Anion Type Description: The anions of the groundwater of borehole MBH02 is of the chloride type.

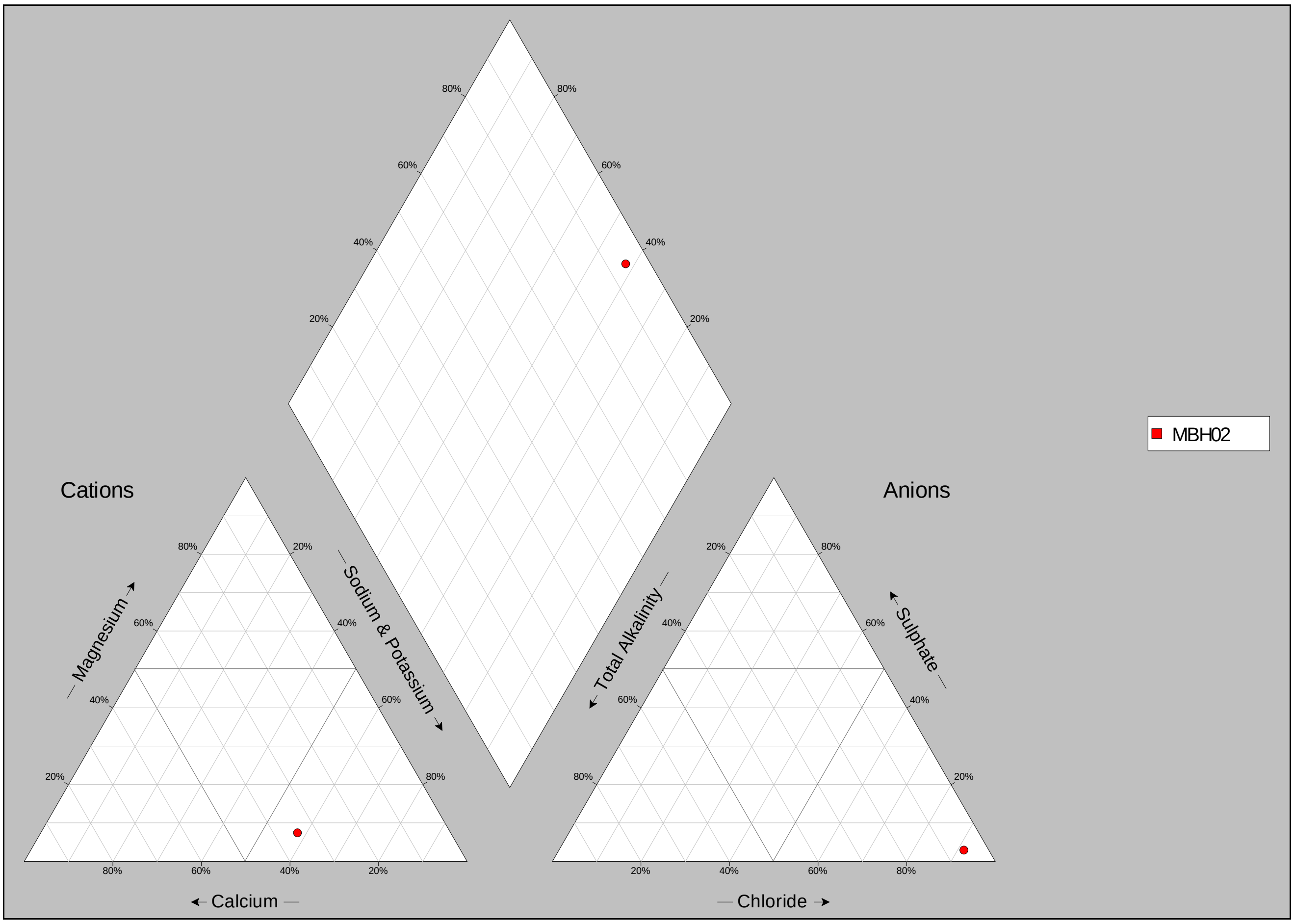


Figure 31. Piper diagram of the groundwater chemistry of the aquifer tested boreholes of Merriman.

7.1.2 Expanded Durov Diagram

Water types are classified in terms of the major cations and anions. These are ratioed so that plotting the results on a classification diagram can compare relative abundance, rather than absolute values. In this project the Expanded Durov diagram was used. This diagram can be divided into nine fields, each of which represents a particular water type. The water type is named after the dominant cation and anions, which define the field.

This diagram uses similar ratio techniques to plot the concentrations of the major ions, however triangular diagrams are used, three for the anions and three for the cations, on each triangle the sum of the ions adds up to 50% and the ions are plotted in different combinations. The result is a plot with nine fields for classification, these fields give better splitting than the Piper diagram and the plot is sometimes preferred. The nine fields shown in Figure 33 on page 98 can be described as follows:

- **Field 1:** HCO_3^- and Ca^{2+} water. This water type is often a recently recharged or recharging water;
- **Field 2:** HCO_3^- and Mg^{2+} dominant or HCO_3^- and Ca^{2+} and Mg^{2+} important, indicates water often associated with dolomite or mafic igneous rocks;
- **Field 3:** HCO_3^- and Na^+ dominant, often indicates ion exchanged water;
- **Field 4:** SO_4^{2-} (or indiscriminate) and Ca^{2+} dominant, may be a recharge water in lavas or associated gypsum deposits;

- **Field 5:** No dominant anions or cations, indicates water resulting from dissolution or mixing;
- **Field 6:** SO_4^{2-} (or indiscriminate) Na^+ dominant, is a water type not frequently found and may be due to mixing influences;
- **Field 7:** Cl^- and Ca^{2+} dominant is not a common water type unless reverse ion exchange is taking place;
- **Field 8:** Cl^- and no dominant cations suggests that reverse ion exchange is taking place; and
- **Field 9:** Cl^- and Na^+ dominant, frequently indicates an end point water in a water evolution sequence.

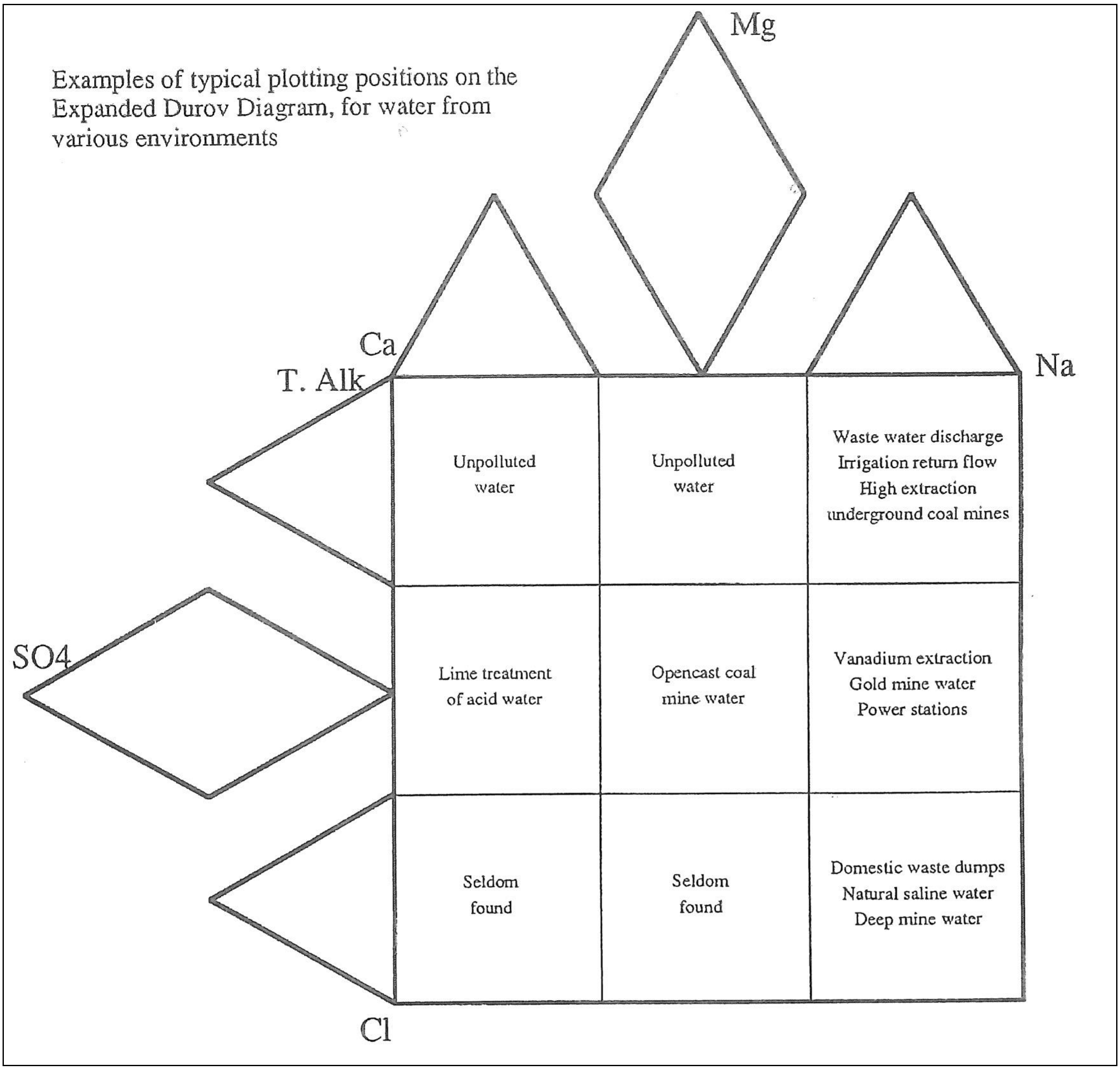


Figure 32. Hydro-Geochemical classification system for natural waters using the Expanded Durov Diagram.

7.1.2.1 Expanded Durov Diagram Description of the Tested Boreholes of Victoria West

The expanded durov diagram description of the groundwater of the aquifer tested boreholes is as follows (refer to Figure 33 on page 98):

- **Field 3:** HCO_3^- and Na^+ dominant, often indicates ion exchanged water. The following boreholes are displayed within field 3: VBH11 and VBH12.
- **Field 5:** No dominant anions or cations, indicates water resulting from dissolution or mixing. The following borehole is displayed within field 5: VBH01

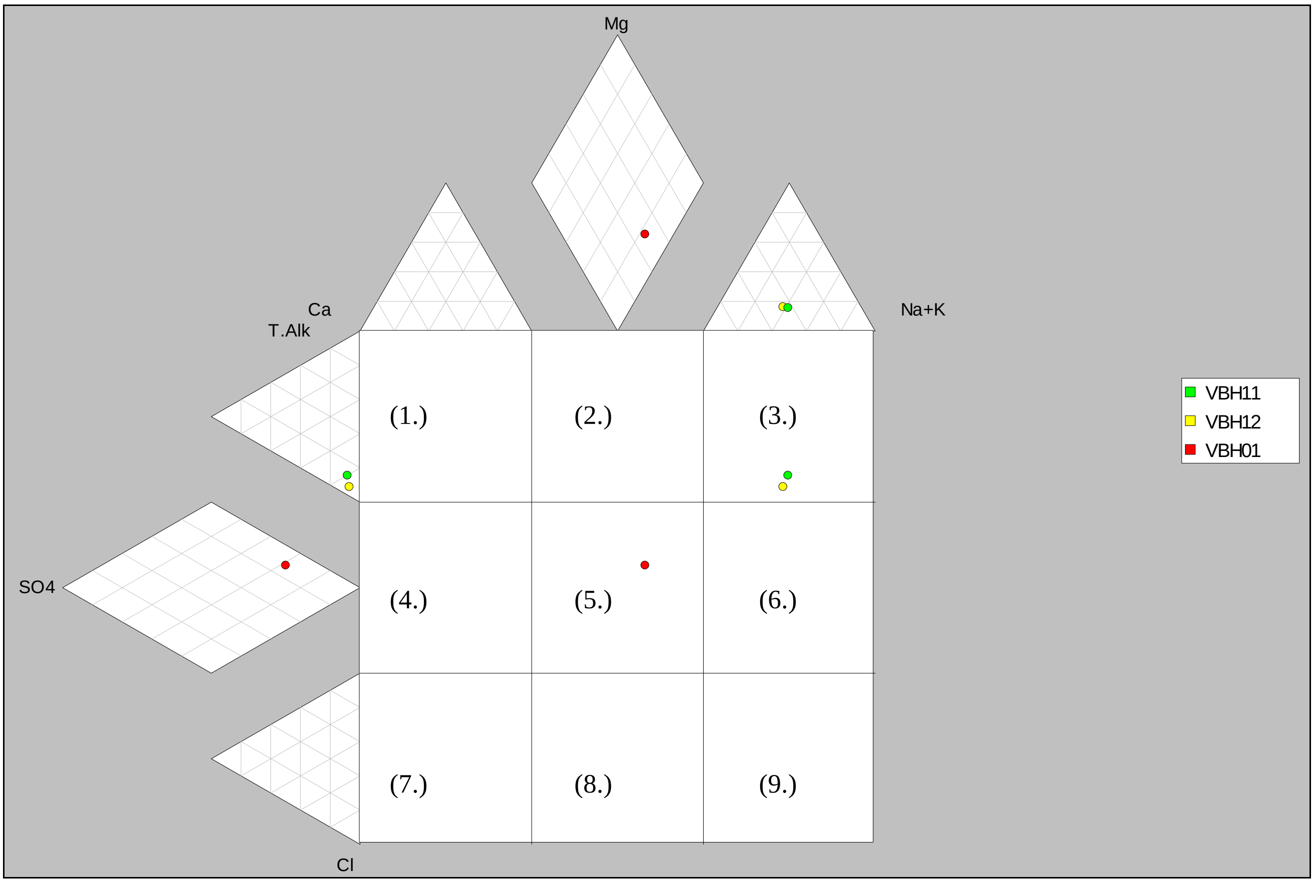


Figure 33. Expanded Durov diagram of the groundwater chemistry of the aquifer tested boreholes of Victoria West.

7.1.2.2 Expanded Durov Diagram Description of the Tested Boreholes of Loxton

The expanded durov diagram description of the groundwater of the aquifer tested boreholes is as follows (refer to Figure 34 on page 99):

- **Field 4:** SO_4^{2-} (or indiscriminate) and Ca^{2+} dominant, may be a recharge water in lavas or associated gypsum deposits. The following borehole is displayed within field 4: LBH01.
- **Field 6:** SO_4^{2-} (or indiscriminate) Na^+ dominant, is a water type not frequently found and may be due to mixing influences. The following borehole is displayed within field 6: LBH02.

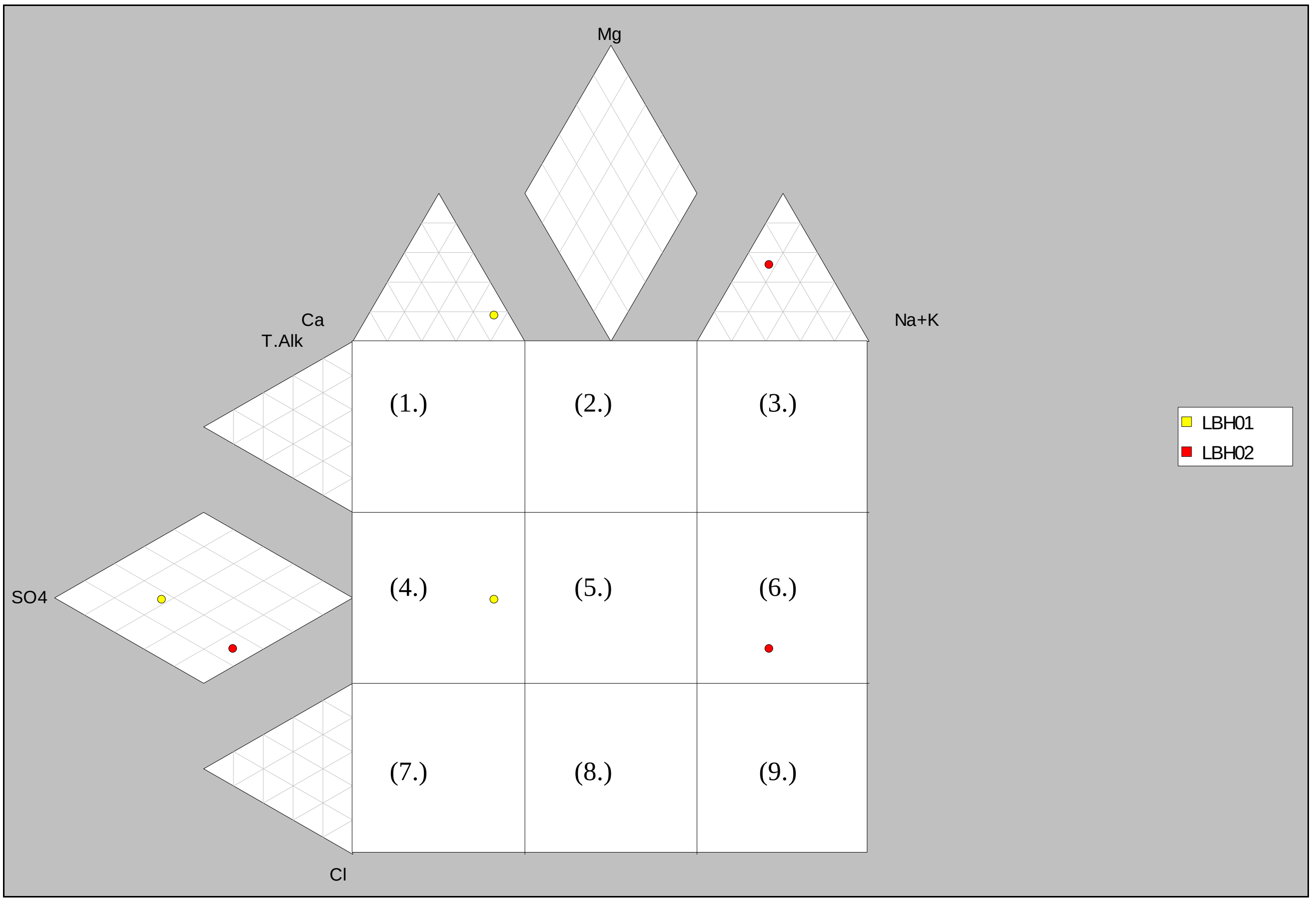


Figure 34. Expanded Durov diagram of the groundwater chemistry of the aquifer tested boreholes of Loxton.

7.1.2.3 Expanded Durov Diagram Description of the Tested Boreholes of Richmond

The expanded durov diagram description of the groundwater of the aquifer tested boreholes is as follows (refer to Figure 35 on page 100):

- **Field 2:** HCO_3^- and Mg^{2+} dominant or HCO_3^- and Ca^{2+} and Mg^{2+} important, indicates water often associated with dolomite or mafic igneous rocks. The following boreholes are displayed within field 2: RBH01, RBH02, RBH03, RBH04, RBH05 and RBH06.

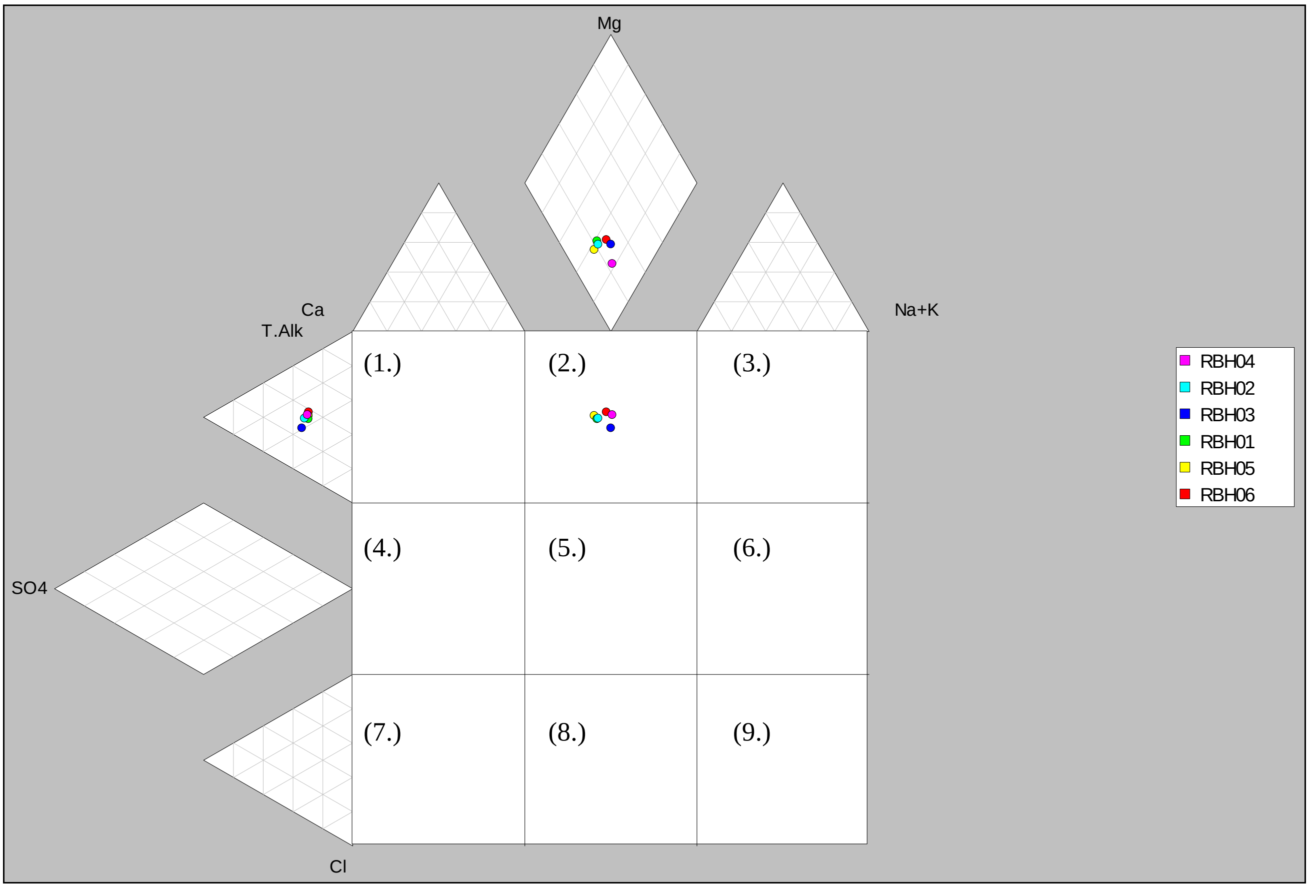


Figure 35. Expanded Durov diagram of the groundwater chemistry of the aquifer tested boreholes of Richmond.

7.1.2.4 Expanded Durov Diagram Description of the Tested Boreholes of Merriman

The expanded durov diagram description of the groundwater of the aquifer tested boreholes is as follows (refer to Figure 36 on page 101):

Field 9: Cl^- and Na^+ dominant, frequently indicates an end point water in a water evolution sequence and are thus old stagnant water. The following boreholes are displayed within field 9: MBH02.

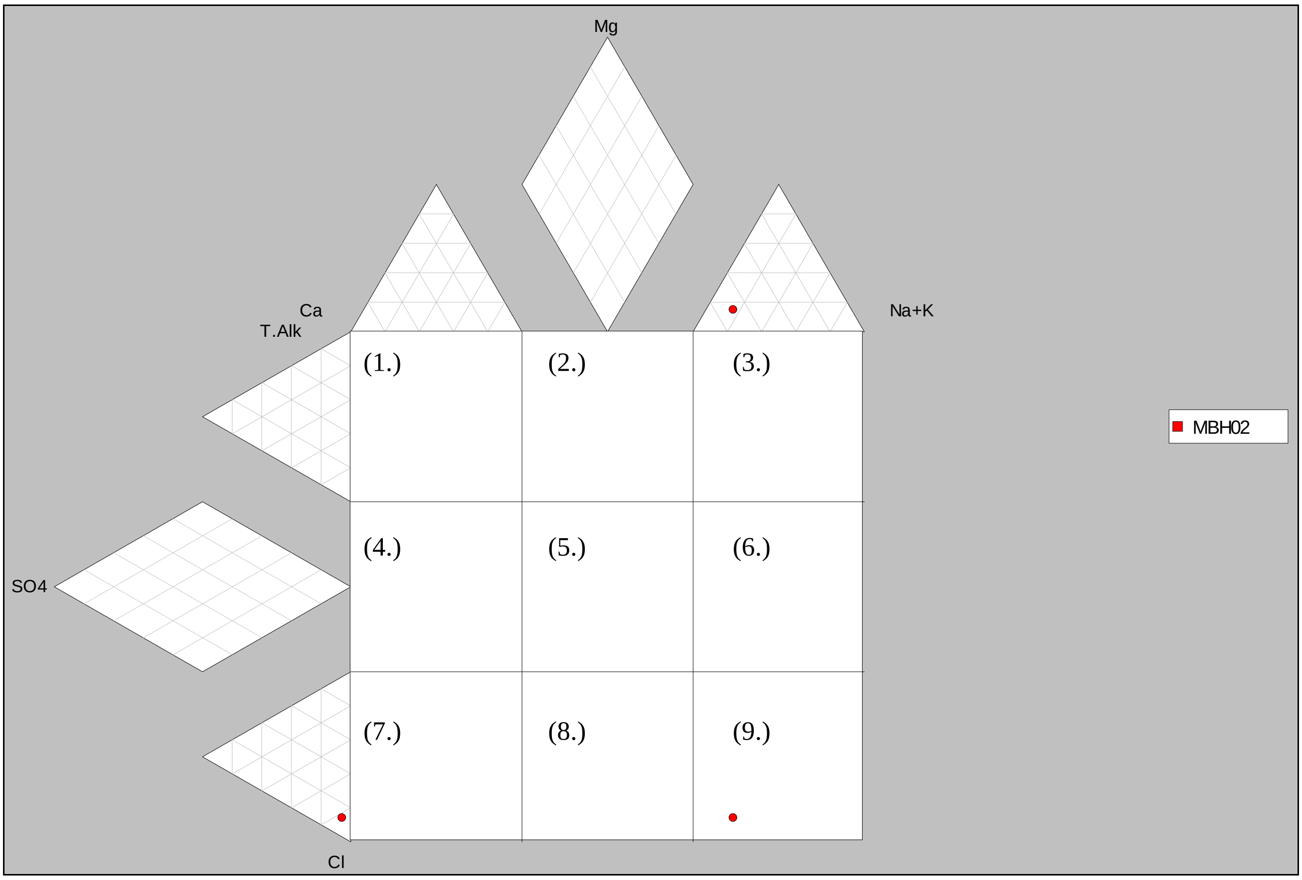


Figure 36. Expanded Durov diagram of the groundwater chemistry of the aquifer tested boreholes of Merriman.

7.2 GROUNDWATER QUALITY STANDARDS

The description of the water quality classes as well as their ranges can be viewed in Table 7 and Table 8, respectively. The SANS241-1:2011 & SANS241:2006 standards can studied respectively in Table 9 on page 104 and Table 10 on page 105.

Table 7. Description of water quality classes (DWAF, Quality of Domestic Water Supply, Volume 1: Assessment Guide. WRC Report No.: TT101/98, 1998).

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

Table 8. Water quality class ranges (DWAF, Quality of Domestic Water Supply, Volume 1: Assessment Guide. WRC Report No.: TT101/98, 1998).

PARAMETER	CLASS 0	CLASS 1	CLASS 2	CLASS 3	CLASS 4
~ Microbiological Quality ~					
Faecal Coliforms	0	0 - 1	1 - 10	10 - 100	> 100
Total Coliforms	0	0 - 10	10 - 100	100 - 1 000	> 1 000
~ Physical Quality ~					
Electrical Conductivity (mS/m)	< 70	70 - 150	150 - 370	370 - 520	> 520
pH	5 - 9.5	4.5 - 5 & 9.5 - 10	4 - 4.5 & 10 - 10.5	3 - 4 & 10.5 - 11	< 3 & >11
Total Dissolved Solids [TDS] mg/L	< 450	450 - 1 000	1 000 - 2 400	2 400 - 3 400	> 3 400
Turbidity	< 0.1	0.1 - 1	1 - 20	20 - 50	> 50
~ Chemical Quality ~					
Arsenic [As] (mg/L)	< 0.010	0.01 - 0.05	0.05 - 0.2	0.2 - 2.0	> 2
Cadmium [Cd] (mg/L)	< 0.003	0.003 - 0.005	0.005 - 0.020	0.020 - 0.050	> 0.050
Calcium [Ca] (mg/L)	0 - 80	80 - 150	150 - 300	> 300	~
Chloride [Cl] (mg/L)	< 100	100 - 200	200 - 600	600 - 1 200	> 1 200
Copper [Cu] (mg/L)	0 - 1	1 - 1.3	1.3 - 2.0	2.0 - 15	> 15
Fluoride [F] (mg/L)	< 0.7	0.7 - 1.0	1 - 1.5	1.5 - 3.5	> 3.5
Iron [Fe] (mg/L)	< 0.5	0.5 - 1	1 - 5	5 - 10	> 10
Total Hardness	0 - 200	200 - 300	300 - 600	> 600	~
Magnesium [Mg] (mg/L)	< 70	70 - 100	100 - 200	200 - 400	> 400
Manganese [Mn] (mg/L)	0 - 0.1	0.1 - 0.4	0.4 - 4	4 - 10	> 10
Nitrate [N] (mg/L)	< 6	6 - 10	10 - 20	20 - 40	> 40
Nitrite [N] (mg/L)	< 6	6 - 10	10 - 20	20 - 40	> 40
Potassium [K] (mg/L)	< 25	25 - 50	50 - 100	100 - 500	> 500
Sodium [Na] (mg/L)	< 100	100 - 200	200 - 400	400 - 1 000	> 1 000
Sulphate [SO_4] (mg/L)	< 200	200 - 400	400 - 600	600 - 1 000	> 1 000
Boron [B] (mg/L)	0 - 0.5	0.5 - 2	2 - 4	4 - 6	> 6
Zinc [Zn] (mg/L)	< 3	3 - 5	5 - 10	10 - 20	> 20

Table 9. SANS241-1:2011 physical, organoleptic and chemical requirements.

SANS 241-1:2011 - TABLE I: PHYSICAL, ORGANOLEPTIC & CHEMICAL REQUIREMENTS			
Determinand	**Risk**	**Unit**	**Standard limits [a] (Class I)**
Physical and aesthetic determinands			
Free chlorine	Chronic health	mg/L	≤ 5
Monochloramine	Chronic health	mg/L	≤ 3
Colour	Aesthetic	mg/L Pt-Co	≤ 15
Conductivity at 25 °C	Aesthetic	mS/m	≤ 170
Odour or taste	Aesthetic	-	Inoffensive
Total dissolved solids	Aesthetic	mg/L	≤ 1 200
Turbidity [b]	Operational	NTU	≤ 1
	Aesthetic	NTU	≤ 5
pH at 25 °C [c]	Operational	pH units	≥ 5 to ≤ 9,7
Chemical determinands — macro-determinands			
Nitrate as N [d]	Acute health - 1	mg/L	≤ 11
Nitrite as N [d]	Acute health - 1	mg/L	≤ 0,9
Sulfate as SO_4^{2-}	Acute health - 1	mg/L	≤ 500
	Aesthetic	mg/L	≤ 250
Fluoride as F^-	Chronic health	mg/L	≤ 1,5
Ammonia as N	Aesthetic	mg/L	≤ 1,5
Chloride as Cl^-	Aesthetic	mg/L	≤ 300
Sodium as Na	Aesthetic	mg/L	≤ 200
Zinc as Zn	Aesthetic	mg/L	≤ 5
Chemical determinands — micro-determinands			
Antimony as Sb	Chronic health	µg/L	≤ 20
Arsenic as As	Chronic health	µg/L	≤ 10
Cadmium as Cd	Chronic health	µg/L	≤ 3
Total chromium as Cr	Chronic health	µg/L	≤ 50
Cobalt as Co	Chronic health	µg/L	≤ 500
Copper as Cu	Chronic health	µg/L	≤ 2 000
Cyanide (recoverable) as CN^-	Acute health - 1	µg/L	≤ 70
Iron as Fe	Chronic health	µg/L	≤ 2 000
	Aesthetic	µg/L	≤ 300
Lead as Pb	Chronic health	µg/L	≤ 10
Manganese as Mn	Chronic health	µg/L	≤ 500
	Aesthetic	µg/L	≤ 100
Mercury as Hg	Chronic health	µg/L	≤ 6
Nickel as Ni	Chronic health	µg/L	≤ 70
Selenium as Se	Chronic health	µg/L	≤ 10
Uranium as U	Chronic health	µg/L	≤ 15
Vanadium as V	Chronic health	µg/L	≤ 200
Aluminium as Al	Operational	µg/L	≤ 300

SANS 241-1:2011 - TABLE II: PHYSICAL, ORGANOLEPTIC & CHEMICAL REQUIREMENTS			
Determinand	**Risk**	**Unit**	**Standard limits [a] (Class I)**
Chemical determinands-organic determinands			
Total organic carbon as C	Chronic health	mg/L	≤10
Trihalomethanes			
Chloroform	Chronic health	mg/L	≤ 0,3
Bromoform	Chronic health	mg/L	≤ 0,1
Dibromochloromethane	Chronic health	mg/L	≤ 0,1
Bromodichloromethane	Chronic health	mg/L	≤ 0,06
Microcystin as LR [e]	Chronic health	µg/L	≤1
Phenols	Aesthetic	µg/L	≤10

[a] The health-related standards are based on the consumption of 2 L of water per day by a person of a mass of 60 kg over a period of 70 years.

[b] Values in excess of those given in column 4 may negatively impact disinfection.

[c] Low pH values can result in structural problems in the distribution system.

[d] This is equivalent to nitrate at 50 mg $N03^-$/Land nitrite as 3 mg $N02^-$/L.

[e] Microcystin only needs to be measured where an algal bloom (> 20 000 cyanobacteria cells per

Table 10. SANS241:2006 physical, organoleptic and chemical requirements.

SANS 241:2006 - TABLE I: PHYSICAL, ORGANOLEPTIC & CHEMICAL REQUIREMENTS				
Determinand	**Unit**	**Class I (recommended operational limit)**	**Class II (max. allowable for limited duration)**	**Class II water consumption period,[a] max.**
Physical and organoleptic requirements				
Colour (aesthetic)	mg/L pt	< 20	20-50	No limit[b]
Conductivity at 25 °C (aesthetic)	mS/m	< 150	150-370	7 years
Dissolved solids (aesthetic)	mg/L	< 1 000	1 000-2 400	7 years
Odour (aesthetic)	TON	<5	5-10	No limit[b]
pH value at 25 °C (aesthetic/operational)	pH units	5,0 - 9,5	4,0 - 10,0	No limit[c]
Taste (aesthetic)	FTN	< 5	5-10	No limit
Turbidity (aesthetic/operational/indirect health)	NTU	< 1	1-5	No limit[d]
Chemical requirements — macro-determinand				
Ammonia as N (operational)	mg/L	< 1,0	1,0-2,0	No limit[d]
Calcium as Ca (aesthetic/operational)	mg/L	< 150	150-300	7 years
Chloride as Cl^- (aesthetic)	mg/L	< 200	200-600	7 years
Fluoride as F^- (health)	mg/L	< 1,0	1,0-1,5	1 year
Magnesium as Mg (aesthetic/health)	mg/L	< 70	70- 100	7 years
(Nitrate and nitrite) as N (health)	mg/L	< 10	10-20	7 years
Potassium as K (operational/health)	mg/L	< 50	50- 100	7 years
Sodium as Na (aesthetic/health)	mg/L	< 200	200-400	7 years
Sulfate as $S0_4^=$ (health)	mg/L	< 400	400-600	7 years
Zinc as Zn (aesthetic/health)	mg/L	< 5,0	5,0- 10	1 year

SANS 241:2006 - TABLE II: PHYSICAL, ORGANOLEPTIC & CHEMICAL REQUIREMENTS				
Determinand	**Unit**	**Class I (recommended operational limit)**	**Class II (max. allowable for limited duration)**	**Class II water consumption period," max.**
Chemical requirements — mlcro-determlnand				
Aluminium as AI (health)	mg/L	< 300	300-500	1 year
Antimony as Sb (health)	mg/L	< 10	10-50	1 year
Arsenic as As (health)	mg/L	< 10	10-50	1 year
Cadmium as Cd (health)	mg/L	<5	5- 10	6 months
Total Chromium as Cr (health)	mg/L	< 100	100-500	3 months
Cobalt as Co (health)	mg/L	< 500	500-1 000	1 year
Copper as Cu (health)	mg/L	< 1 000	1 000-2 000	1 year
Cyanide (recoverable) as CW (health)	mg/L	<50	50-70	1 week
Iron as Fe (aesthetic/ operational)	mg/L	< 200	200-2 000	7 years[b]
Lead as Pb (health)	mg/L	< 20	20-50	3 months
Manganese as Mn (aesthetic)	mg/L	< 100	100-1000	7 years
Mercury as Hg (health)	mg/L	< 1	1-5	3 months
Nickel as Ni (health)	mg/L	< 150	150- 350	1 year
Selenium as Se (health)	mg/L	< 20	20-50	1 year
Vanadium as V (health)	mg/L	< 200	200- 500	1 year
Chemical requirements — organic determinand				
Dissolved organic carbon as C (aesthetic/health)	mg/L	< 10	10-20	3 months[e]
Total trihalomethanes (health)	mg/L	< 200	200-300	10 years[f]
Phenols (aesthetic/health)	mg/L	< 10	10-70	No limi[b]

[a] The limits for the consumption of class II water are based on the consumption of 2 L water per day by a person of mass 70 kg over

[b] The limits given are based on aesthetic aspects.

[c] No primary health effect- low pH values can result in structural problems in the distribution system.

[d] These values can indicate process efficiency and risks associated with pathogens.

[e] When dissolved organic carbon is deemed of natural origin, the consumption period can be extended.

[f] This is a suggested value because trihalomethanes have not been proven to have any effect on human health.

7.3 GROUNDWATER WATER QUALITY

7.3.1 Inorganic Water Quality

Groundwater samples were taken after the cessation of the aquifer test pumping to determine the inorganic groundwater quality of the individual boreholes and the borehole fields as a whole. The results of the inorganic sampling of the aquifer test pumped boreholes can be viewed in Table 11 on page 109.

<u>Victoria West Groundwater Quality:</u>

The description of the inorganic water qualities of the aquifer test pumped boreholes are as follows for the town of Victoria West (refer to Table 11 on page 109):

- The groundwater of borehole VBH01 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to a high Electrical Conductivity (EC = 0.104 mS/m, SANS241-1:2011 = < 170 mS/m), total dissolved solids concentrations (TDS = 1302 mg/L, DWAF, Second Edition, 1998 = 1000 – 2400 mg/L), sodium concentrations (Na = 204 mg/L, SANS241-1:2011 = < 200 mg/L) and total hardness concentrations (T. Hard = 610.30 mg/L, DWAF, Second Edition, 1998 = 300 – 600 mg/L).

- The groundwater of borehole VBH12 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to Arsenic concentrations (As = 0.095 mg/L, SANS241-1:2011 = < 0.01 mg/L). The borehole will be resampled to verify the arsenic (As) concentration. The report will be updated accordingly when the laboratory results is received.
- The groundwater of borehole VBH12 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to Arsenic concentrations (As = 0.104 mg/L, SANS241-1:2011 = < 0.01 mg/L). The report will be updated accordingly when the laboratory results is received.

Loxton Groundwater Quality:

The description of the inorganic water qualities of the aquifer test pumped boreholes are as follows for the town of Loxton (refer to Table 11 on page 109):

- The groundwater of borehole LBH01 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to a high electrical conductivity (EC = 175 mS/m, SANS241-1:2011 = < 170 mS/m), total dissolved solids concentrations (TDS = 1225 mg/L, DWAF, Second Edition, 1998 = 1000 – 2400 mg/L), calcium concentrations (Ca = 202.4 mg/L, SANS241:2006 = 150 – 300 mg/L), sulphate concentrations (SO_4 = 584.50 mg/L, SANS241-1:2011 = < 500 mg/L) and total hardness concentrations (T. Hard = 584.3 mg/L, DWAF, Second Edition, 1998 = 300 – 600 mg/L).
- The groundwater of borehole LBH02 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to high electrical conductivity concentrations (EC = 624 mS/m, SANS241-1:2011 = < 170 mS/m), total dissolved solids concentrations (TDS = 4368 mg/L, DWAF, Second Edition, 1998 = 1000 – 2400 mg/L), sodium concentrations (Na = 952.90 mg/L, SANS241-1:2011 = < 200 mg/L), calcium concentrations (Ca = 227.20 mg/L, SANS241:2006 = 150 – 300 mg/L), magnesium concentrations (Mg = 220.60 mg/L, SANS241:2006 = 70 – 100 mg/L), chloride concentrations (Cl = 1109.40 mg/L, SANS241-1:2011 = < 300 mg/L), sulphate concentrations (SO_4 = 1323 mg/L, SANS241-1:2011 = < 500 mg/L) and total hardness concentrations (T. Hard = 1472.5 mg/L, DWAF, Second Edition, 1998 = 300 – 600 mg/L).

Richmond Groundwater Quality:

The description of the inorganic water qualities of the aquifer test pumped boreholes are as follows for the town of Richmond (refer to Table 11 on page 109):

- The groundwater of borehole RBH01 is classified as "Class 1 – recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.

- The groundwater of borehole RBH02 is classified as “Class 1 – recommended standard limit” (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.
- The groundwater of borehole RBH03 is classified as “Class 1 – recommended standard limit” (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.
- The groundwater of borehole RBH04 is classified as “Class 1 – recommended standard limit” (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.
- The groundwater of borehole RBH05 is classified as “Class 1 – recommended standard limit” (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.
- The groundwater of borehole RBH06 is classified as “Class 1 – recommended standard limit” (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.

Merriman Groundwater Quality:

The description of the inorganic water qualities of the aquifer test pumped boreholes are as follows for the town of Merriman (refer to Table 11 on page 109):

- The groundwater of borehole MBH02 is classified as “ARS – above recommended standard limit” (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to a high electrical conductivity (EC = 321 mS/m, SANS241-1:2011 = < 170 mS/m), total dissolved solids concentrations (TDS = 2247 mg/L, DWAF, Second Edition, 1998 = 1000 – 2400 mg/L), sodium concentrations (Na = 382 mg/L, SANS241-1:2011 = < 200 mg/L), calcium concentrations (Ca = 197.20 mg/L, SANS241:2006 = 150 – 300 mg/L), chloride concentrations (Cl = 971.70 mg/L, SANS241-1:2011 = < 300 mg/L) and total hardness concentrations (T. Hard = 594.02 mg/L, DWAF, Second Edition, 1998 = 300 – 600 mg/L).

Table 11. Inorganic groundwater quality class of the aquifer tested boreholes of Graaff-Reinet (according to the SANS241-1:20011 and SANS241:2006 standards).

	Site Name	Date	Quality Class	pH	EC mS/m	TDS mg/L	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Cl mg/L	SO_4 mg/L	SO_4 (Ae) mg/L	F mg/L	NO_3-N mg/L	T.ALK mg/L	Fe mg/L	Fe (Ae) mg/L	Mn mg/L	Mn (Ae) mg/L	T. Hard mg/L	As mg/L	Ionbal %
1.)	**VBH01**	20131102	"ARS"	7.49	186.00	1302	204.00	108.00	83.00	1.30	233.90	247.80	247.80	0.20	0.50	460	0.033	0.033	0.008	0.008	610.30	0.006	0.71
2.)	**VBH11**	20131004	"ARS"	7.72	90.50	634	139.60	36.50	7.80	0.50	128.90	16.66	16.66	0.74	0.11	249	0.062	0.062	0.088	0.088	123.23	0.095	-2.62
3.)	**VBH12**	20131009	"ARS"	7.65	96.30	674	146.30	41.50	8.70	0.70	148.00	14.70	14.70	0.76	0.10	248	0.077	0.077	0.097	0.097	139.42	0.104	-1.70
4.)	**LBH01**	20131014	"ARS"	7.75	175.00	1225	157.10	202.40	19.10	2.60	128.01	584.50	584.50	0.26	3.36	166	0.053	0.053	0.016	0.016	584.31	0.006	-2.06
5.)	**LBH02**	20131016	"ARS"	7.39	624.00	4368	952.90	227.20	220.60	2.30	1109.40	1323.00	1323.00	0.12	1.35	516	0.050	0.050	0.055	0.055	1472.46	0.006	1.23
6.)	**RBH01**	20131030	"Class 1"	7.35	87.40	612	67.00	74.00	35.00	2.72	63.80	67.80	67.80	0.86	0.67	325	0.031	0.031	0.004	0.004	328.50	0.006	-1.01
7.)	**RBH02**	20131026	"Class 1"	7.40	83.90	587	67.00	73.00	33.00	3.59	59.70	72.30	72.30	1.05	1.07	316	0.030	0.030	0.006	0.006	317.80	0.006	-1.16
8.)	**RBH03**	20131028	"Class 1"	7.28	99.20	694	79.50	70.00	35.00	3.60	74.20	83.50	83.50	1.22	1.38	329	0.053	0.053	0.010	0.010	318.50	0.006	-3.18
9.)	**RBH04**	20131020	"Class 1"	7.28	79.50	557	75.20	64.40	23.10	2.40	53.40	62.50	62.50	0.94	0.96	298	0.090	0.090	0.052	0.052	255.71	0.006	-2.53
10.)	**RBH05**	20131015	"Class 1"	7.30	82.60	578	59.40	69.00	27.80	3.80	51.94	58.00	58.00	0.75	2.76	283	0.042	0.042	0.007	0.007	286.48	0.006	-0.93
11.)	**RBH06**	20131013	"Class 1"	7.24	99.30	695	74.50	71.10	36.90	4.20	60.90	71.90	71.90	1.08	3.87	358	0.043	0.043	0.020	0.020	329.04	0.006	-3.76
12.)	**MBH02**	20131008	"ARS"	6.96	321.00	2247	382.90	197.20	24.80	1.70	971.70	37.47	37.47	0.02	0.50	81.8	0.154	0.154	0.025	0.025	594.68	0.006	-2.19

Quality of Domestic Water Supplies, DWA&F, Second Edition 1998

- Class 0 - **Ideal water quality** - Suitable for lifetime use.
- Class 1 - **Good water quality** - Suitable for use, rare instances of negative effects.
- Class 2 - **Marginal water quality** - Conditionally acceptable. Negative effects may occur in some sensitive groups
- Class 3 - **Poor water quality** - Unsuitable for use without treatment. Chronic effects may occur.
- Class 4 - **Dangerous water quality** - Totally unsuitable for use. Acute effects may occur.

SABS South Africa National Standard: Drinking Water, SANS 241-2:2011 Edition 1

- Class 1 - **Recommended standard limit** - Suitable for lifetime use.
- ARS - **Above recommended standard limit** - Unsuitable for lifetime human consumption.

SABS South Africa National Standard: Drinking Water, SANS 241:2006 Edition 6.1

- Class 1 - **Recommended operational limit** - Suitable for lifetime use.
- Class 2 - **Maximum allowable limit** - Suitable for limited duration use only.
- AMA - **Above maximum allowable limit** - Unsuitable for human consumption.

*** (Ae) - Aesthetic standards.**

*** (OP) - Operatinal standards.**

ıth Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, First Edition 1993 & Second Edition 1!

- NR - **Target water quality range** - No risk.
- IR - **Good water quality** - Insignificant risk. Suitable for use, rare instances of negative effects.
- LR - **Marginal water quality** - Allowable low risk. Negative effects may occur in some sensitive groups
- HR - **Poor water quality** - Unsuitable for use without treatment. Chronic effects may occur.

7.3.2 Bacteriological Water Quality of the Graaff-Reinet

The results of the bacteriological sampling of the aquifer tested boreholes are given in Table 12 on page 111. Water bacteriological quality samples were also taken at existing production boreholes. Microbiological parameter descriptions are given below:

- **Total Coliform bacteria:** The total coliform group includes bacteria of faecal origin and several other bacterial groups.
  - Effect and possible implications of failure – Health: Total coliforms are indicative of the general hygienic quality of water and are primarily used in the evaluation of the operational efficiency of water treatment processes. They also indicate microbial growth in the distribution system or post-treatment contamination of drinking water. As the total coliform group includes bacteria of faecal origin and indicates the possible presence of bacterial pathogens such as Salmonella spp., Shigella spp., Vibrio cholerae, pathogenic E. coli, etc, high total coliform counts can be responsible for diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever.
- **Faecal Coliforms:** Faecal coliform bacteria are found in water wherever the water is contaminated with faecal waste of human or animal origin. Faecal coliforms are primarily used to indicate the presence of bacterial pathogens such as Salmonella spp., Shigella spp., Vibrio cholera, Campylobacter jejuni, Campylobacter coli, Yersinia enterocolitica and pathogenic E. coli. These organisms can be transmitted via the faecal/oral route by contaminated or poorly treated water and may cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever.
  - Effect and possible implications of failure – Health: The risks of being infected correlates with the level of contamination of the water and the amount of contaminated water consumed. Higher concentrations of faecal coliforms in water will indicate a higher risk of contracting waterborne disease, even if small amounts of water are consumed. Any bacteriological failure with regards to faecal coliforms can therefore be considered a direct indication of risk to health.
- **E.Coli:** Escherichia coli (E.coli) are used as an indicator of faecal pollution by warm blooded animals (often interpreted as human faecal pollution). The presence of faecal pollution by warm blooded animals may indicate the presence of pathogens responsible for infectious disease such as gastroenteritis, cholera, dysentery and typhoid fever after ingestion of contaminated water.
  - Effect and possible implications of failure – Health: The risks of being infected correlates with the level of contamination of the water and the amount of contaminated water consumed. Higher concentrations of E.coli in water will indicate a higher risk of contracting waterborne disease, even if small amounts of water are consumed. Any bacteriological failure with regards to E.coli can therefore be considered a direct indication of risk to health.

The bacteriological water qualities of the aquifer tested boreholes are as follows (refer to Table 12 on page 111):

- The bacteriological water qualities of boreholes VBH01, VBH11, VBH12, LBH01, LBH02, RBH01, RBH02, RBH03, RBH04, RBH05, RBH06 and MBH02 are classified as "ARS" waters. According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due mostly to elevated plate counts. Boreholes LBH02, RBH01 and RBH04 also indicates elevated counts of total coliform as well E.Coli counts in boreholes RBH01 and RBH04.

Bacterial contamination may fluctuate enormously with time. It is therefore recommended that the groundwater abstracted from the production boreholes be chlorinated to remove all potential harmful bacteria before utilisation.

Table 12. Bacteriological groundwater quality class of the aquifer tested boreholes of Graaff-Reinet (according to DWAF, Quality of Domestic Water Supply, Volume 1: Assessment Guide. WRC Report No.: TT101/98, 1998 and the SANS241-1:20011 and SANS241:2006 standards).

	Site Name	Date	Quality Class	Total Plate Count per ml	Total Coliform Count / 100 ml	E.Coli Count / 100 ml (Escherichia Coliform)
1.)	**VBH01**	20131102	"ARS"	> 1000	7.00	0.00
2.)	**VBH11**	20131004	"ARS"	> 1000	0.00	0.00
3.)	**VBH12**	20131009	"ARS"	> 1000	0.00	0.00
4.)	**LBH01**	20131014	"ARS"	> 1000	7.00	0.00
5.)	**LBH02**	20131016	"ARS"	> 1000	12.00	0.00
6.)	**RBH01**	20131030	"ARS"	> 1000	186.00	2.00
7.)	**RBH02**	20131026	"ARS"	> 1000	1.00	0.00
8.)	**RBH03**	20131028	"ARS"	> 1000	7.00	0.00
9.)	**RBH04**	20131020	"ARS"	> 1000	1300.00	12.00
10.)	**RBH05**	20131015	"ARS"	> 1000	7.00	0.00
11.)	**RBH06**	20131013	"ARS"	> 1000	0.00	0.00
12.)	**MBH02**	20131008	"ARS"	> 1000	0.00	0.00

SABS South Africa National Standard: Drinking Water, SANS 241-2:2011 Edition 1

Class 1	- **Recommended standard limit** - Suitable for lifetime use.
ARS	- **Above recommended standard limit** - Unsuitable for lifetime human consumption.

* TNTC - To Numerous To Count

8 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the information supplied in this report:

BACKGROUND INFORMATION

Catchment

The study area is located in north western part of the Northern Cape Province. The quaternary sub-catchment for the towns is as follows:

- Victoria West is located in quaternary sub-catchment D61E;
- Loxton is located in quaternary sub-catchment D55D;
- Richmond is located in quaternary sub-catchment D61A;
- Hutchinson West is located in quaternary sub-catchment D61E; and
- Merriman is located in quaternary sub-catchment D61A.

The area as a whole is located in DWA Water Management Area 14.

Climate

The study area has hot summers and cool winters, and a predominantly summer rainfall. The air temperatures range from an average maximum of 30 to 32 ^{o}C in January to an average minimum of 0 to 2 ^{o}C in July, meaning conditions with mildly hot summers and cold to very cold winters (South African Atlas of Agrohydrology and –Climatology, 1997).

The mean annual rainfall for the study area is on average 279.15 mm/a, which occurs mainly as thunderstorms but soft rains also do occur (Rainfall Station Gauge No.: 0139 658, Loxton (238.5 mm/a) & Rainfall Station Gauge No.: 0142 805, Richmond (319.8 mm/a), Surface Water Resources of South Africa, 1990).

General Aquifer Information of the Graaff-Reinet District

The groundwater component of river flow (base flow) is negligible in the study area. The groundwater depth in the study area is approximately < 10 mbgl according to the DWA Groundwater Resources Map. The mean annual recharge of the area is between 10 - 15 mm/a. Therefore the study area has an estimated recharge percentage at 4.8% of MAP.

In general the recommended drilling depths below water level are 30 – 50 meters for the study area. Fractures restricted principally to a zone directly below groundwater level that consist of compacted sedimentary rocks intruded by Jurassic Jura age intrusive dolerite sills and to a lesser extent dykes structure. Storage coefficient in order of magnitude for the study area is < 0.001 for the sedimentary rocks. The qualitative indication of spatial distribution of storage media based on drilling success rate for the area is between > 60%. (Groundwater Resources of South Africa Maps, DWA, 1995).

RESULTS OF THE FIELD GEOPHYSICAL SURVEY AND BOREHOLE SITING

A geophysical field survey was conducted at the towns of Victoria West, Loxton, Richmond, Hutchinson and Merriman. The survey included eight (8) magnetic traverse lines. A total of seventeen (16) borehole positions were sited by means of geophysical traverses and geological observations. The geophysical traverse data sheets can be viewed in Appendix B.

Victoria West Geophysical Survey Results

The description of the geophysical traverses of the magnetic field survey as well as the sited drilling positions for Victoria West is as follows:

- Traverse line VW-TV01: The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 30 m. One drilling target was sited on the geological structure, namely VWP1 (East: 23.07302and South: -31.41948, WGS84).
- Traverse line VW-TV02: The traverse was conducted from south to north. A potential geological (dolerite dyke) structure was observed at station 22 m. One drilling target was sited on the geological structure, namely VWP21 (East: 23.07793 and South: -31.41948, WGS84).
- Traverse line VW-TV03: The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 12 m. One drilling target was sited on the geological structure, namely VWP31 (East: 23.06834 and South: -31.40636, WGS84).
- Traverse line VW-TV04: The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 13 m.

Loxton Geophysical Survey Results

The description of the geophysical traverses of the magnetic field survey as well as the sited drilling positions for Loxton is as follows:

- Traverse line L-TV01: The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 30 m. One drilling target was sited on the geological structure, namely LP1 (East: 22.33423 and South: -31.48564, WGS84).
- Traverse line L-TV02: The traverse was conducted from south to north. A potential geological (dolerite dyke) structure was observed at station 44 m. One drilling target was sited on the geological structure, namely LP2 (East: 22.33525 and South: -31.48257, WGS84).
- Traverse line L-TV03: The traverse was conducted from south west to north east. A potential geological (dolerite dyke) structure was observed at station 10 m. One drilling target was sited on the geological structure, namely LP3 (East: 22.33525 and South: -31.47982, WGS84).
- Traverse line L-TV04: The traverse was conducted from west to east. A potential geological (dolerite dyke) structure was observed at station 55 m. One drilling target was sited on the geological structure, namely LP4 (East: 22.33838 and South: -31.47674, WGS84).

Hutchinson Geophysical Survey Results

The four (4) drilling targets for Hutchinson were sited on municipal property. The drilling target information is as follows:

- Drilling target HP1 (East: 23.18805 and South: - -31.49499, WGS84). The drilling target was site according to geological observations and interpretations.
- Drilling target HP2 (East: 23.18805 and South: - -31.49499, WGS84). The drilling target was site according to geological observations and interpretations.
- Drilling target HP3 (East: 23.18805 and South: - -31.49499, WGS84). The drilling target was site according to geological observations and interpretations.
- Drilling target HP4 (East: 23.18805 and South: - -31.49499, WGS84). The drilling target was site according to geological observations and interpretations.

Merriman Geophysical Survey Results

The two (2) drilling targets for Merriman were sited on municipal property. The drilling target information is as follows:

- Drilling target MP1 (East: 23.62016 and South: -31.21021, WGS84). The drilling target was site according to geological observations and interpretations.
- Drilling target MP2 (East: 23.61754 and South: -31.21202, WGS84). The drilling target was site according to geological observations and interpretations.

GEOLOGY OF THE STUDY AREA

The lithostratigraphy of the study area consists of the Karoo Supergroup Geology as well as Surficial or Quaternary Deposits and Karoo Dolerite Intrusives of the Jurassic Jura. The lithostratigraphy of the study area is as follows:

- **Beaufort Group:**
- Adelaide Subgroup;
  - Teekloof Formation: The Teekloof Formation is sub-divided by the Oukloof and Hoedemaker Members. The sedimentary rocks of the Teekloof Formation consist of green, red and purple mudstone, shales, sandstone and subordinate sandstone, (Geological Survey Map, 3224 Graaff-Reinet, 1:250 000 Series); and
- **Late Tertiary Surficial or Quaternary Deposits:** Unconsolidated alluvium and colluvium deposits (Geological Survey Map, 3122, Victoria West, 1:250 000 Series).
- **Dolerite Intrusives (Jurassic Jura Age):** The dolerites of the area consist of sills and dyke structures (Geological Survey Map, 3122, Victoria West, 1:250 000 Series).

GEOLOGICAL LOGS AND BOREHOLE CONSTRUCTION OF THE NEWLY DRILLED BOREHOLES

As mentioned earlier sixteen (16) boreholes were percussion drilled during the course of the project. The geology of the study area consists of the sedimentary rocks of the Karoo Supergroup and more specifically the Beaufort Group, which contains sedimentary rocks such sandstones, shales and mudstones. The whole sedimentary sequence has been intruded by magmatic features such as dolerite dykes and sills.

Victoria West: Geological / Hydrogeological Logging

The results of the percussion drilling and geological / hydrogeological logging are as follows for Victoria West:

- Drilling Target VWP1 (Borehole Number: VBH08) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of dark grey dolerite (dyke structure). The groundwater strikes were encountered at the depths 26 mbgl and 49 mbgl. The blow yield of the borehole was estimated at 2 900 L/h. The borehole was not recommended for aquifer test pumping due to low yield.
- Drilling Target VWP2 (Borehole Number: VBH09) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl. The geology consisted of light grey shales. A groundwater strike was encountered at the depth of 24 mbgl. The blow yield of the borehole was estimated at 400 L/h. The borehole was not recommended for aquifer test pumping due to low yield.
- Drilling Target VWP3 (Borehole Number: VBH10) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of light grey shales. The groundwater strikes were encountered at the depths 28 mbgl and 44 mbgl. The blow yield of the borehole was estimated at 3 200 L/h. The borehole was not recommended for aquifer test pumping due to low yield.
- Drilling Target VWP5 (Borehole Number: VBH11) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of light grey shales and dolerite bits at the end of borehole area. The groundwater strikes were encountered at the depths 42 mbgl and 68 mbgl. The blow yield of the borehole was estimated at 15 000 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.
- Drilling Target VWP6 (Borehole Number: VBH12) was exploited by percussion drilling. The borehole was drilled to a depth of 90 mbgl and equipped with a sanitary seal. The geology consisted of light grey shales and dark grey dolerite. The groundwater strikes were encountered at the depths 32 mbgl and 78 mbgl. The blow yield of the borehole was estimated at 18 000 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.
- Drilling Target VWP7 (Borehole Number: VBH13) was exploited by percussion drilling. The borehole was drilled to a depth of 60 mbgl. The geology consisted of light grey shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.

<u>Loxton: Geological / Hydrogeological Logging</u>

The results of the percussion drilling and geological / hydrogeological logging are as follows for Loxton:

- Drilling Target LP1 (Borehole Number: LBH01) was exploited by percussion drilling. The borehole was drilled to a depth of 90 mbgl and equipped with a sanitary seal. The geology consisted of light grey and purple shales. The groundwater strikes were encountered at the depths 54 mbgl and 57 mbgl. The blow yield of the borehole was estimated at 6 000 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.
- Drilling Target LP2 (Borehole Number: LBH02) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of light grey and black carbonaceous shales. The groundwater strikes

were encountered at the depths 36 mbgl and 54 mbgl. The blow yield of the borehole was estimated at 5 400 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.

- Drilling Target LP3 (Borehole Number: LBH03) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl. The geology consisted of light grey and purple shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.
- Drilling Target LP4 (Borehole Number: LBH04) was exploited by percussion drilling. The borehole was drilled to a depth of 90 mbgl. The geology consisted of light grey shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.

Richmond: Geological / Hydrogeological Logging

The results of the percussion drilling and geological / hydrogeological logging are as follows for Richmond:

- Existing municipal production borehole RBH04 re-drilled due to blockages in the original borehole caused by poor borehole construction. The borehole was drilled to a depth of 62 mbgl and equipped with a sanitary seal. The geology consisted of light brown and light grey shales. The groundwater strikes were encountered at the depths 25 mbgl and 28 mbgl. The blow yield of the borehole was estimated at 10 500 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality.

Hutchinson: Geological / Hydrogeological Logging

The results of the percussion drilling and geological / hydrogeological logging are as follows for Hutchinson:

- Drilling Target HP1 (Borehole Number: HBH08) was exploited by percussion drilling. The borehole was drilled to a depth of 60 mbgl. The geology consisted of light grey shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.
- Drilling Target HP3 (Borehole Number: HBH09) was exploited by percussion drilling. The borehole was drilled to a depth of 70 mbgl and equipped with a sanitary seal. The geology consisted of light grey and purple shales. A groundwater strike was encountered at a depth of 48 mbgl. The blow yield of the borehole was estimated at 200 L/h. The borehole was not recommended for aquifer test pumping due to low yield.
- Drilling Target HP4 (Borehole Number: VBH10) was exploited by percussion drilling. The borehole was drilled to a depth of 80 mbgl and equipped with a sanitary seal. The geology consisted of light grey and purple shales. A groundwater strike was encountered at a depth of 65 mbgl. The blow yield of the borehole was estimated at 3 000 L/h. The borehole was not recommended for aquifer test pumping due to low yield.

Merriman: Geological / Hydrogeological Logging

The results of the percussion drilling and geological / hydrogeological logging are as follows for Merriman:

- Drilling Target MP1 (Borehole Number: MBH02) was exploited by percussion drilling. The borehole was drilled to a depth of 70 mbgl and equipped with a sanitary seal. The geology consisted of light grey shales. A groundwater strike was encountered at a depth of 54 mbgl. The blow yield of the borehole was estimated at 3 000 L/h. The borehole was recommended for aquifer test pumping to determine the sustainable abstraction rate as well as the groundwater quality due to low volume water needs of Merriman (26 households).
- Drilling Target MP2 was exploited by percussion drilling. The borehole was drilled to a depth of 70 mbgl. The geology consisted of light grey shales. The borehole was found to be dry and was therefore not recommended for aquifer testing.

GENERAL BOREHOLE INFORMATION

This section contains the general borehole information of the existing municipal boreholes as well as the newly drilled boreholes for the towns of Victoria West, Loxton, Richmond, Hutchinson and Merriman.

Victoria West Borehole Information

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Victoria West. The summary of the general borehole information for Victoria West is as follows:

- The commonage contains seven (7) existing municipal boreholes namely, VBH01, VBH02, VBH03, VBH04, VBH05, VBH06 and VBH07. Three (3) boreholes are currently in use for abstraction purposes. The utilised boreholes include VBH01, VBH02 and VBH07.
- Six (6) new boreholes were drilled namely, VBH08, VBH09, VBH10, VBH11, VBH12 and VBH13.
- The following boreholes have been aquifer test pumped to determine their sustainable yields and groundwater quality namely VBH01, VBH11 and VBH12.
- The descriptions of the current state of the existing borehole equipment can be viewed in Appendix D.

Loxton Borehole Information

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Loxton. The summary of the general borehole information for Loxton is as follows:

- The commonage contains fourteen (14) existing municipal boreholes and a Pit namely, BH-BG, BH-BK01, BH-BK02, BH-BK03, BH-BK04, BH-BK05, BH-BK06, BH-BPB, BH-KG, PIT, BH-SV, BH-WP01, BH-WP02, BH-BSG01 and BH-BSG02. Six (6) boreholes and the Pit are currently in use for abstraction purposes. The utilised boreholes include BH-BG, BH-BK01, BH-BK03, BH-BK05, BH-BPB, PIT and BH-BSG01.
- Four (4) new boreholes were drilled namely, LBH01, LBH02, LBH03 and LBH04.
- The following boreholes have been aquifer test pumped to determine their sustainable yields and groundwater quality namely LBH01 and LBH02.

Richmond Borehole Information

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Richmond. The summary of the general borehole information for Richmond is as follows:

- The commonage contains six (6) existing municipal boreholes namely, RBH01, RBH02, RBH03, RBH04, RBH05 and RBH06. Five (5) boreholes are currently in use for abstraction purposes. The utilised boreholes includes and RBH01, RBH02, RBH03, RBH05 and RBH06.
- Borehole RBH04 has collapsed at 26 mbgl due to poor borehole construction and was re-drilled and constructed properly.
- The following boreholes have been aquifer test pumped to determine their sustainable yields and groundwater quality namely RBH01, RBH02, RBH03, RBH04, RBH05 and RBH06.
- The descriptions of the current state of the existing borehole equipment can be viewed in Appendix D.

Hutchinson Borehole Information

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Hutchinson. The summary of the general borehole information for Hutchinson is as follows:

- The commonage contains six (6) private boreholes utilised for municipal water production purposes namely, HBH01, HBH02, HBH03, HBH04, HBH05 and HBH06. Six (6) private boreholes are currently in use for abstraction purposes. Municipal borehole HBH07 is also utilised for water abstraction purposes.
- Three (3) new boreholes were drilled namely, HBH08, HBH09 and HBH10 but were found to be dry and therefore not recommended for aquifer test pumping.

Merriman Borehole Information

A hydrocensus has been performed for the commonage to catalogue and assess the existing municipal boreholes of Merriman. The summary of the general borehole information for Merriman is as follows:

- The commonage contains one (1) existing municipal borehole namely MBH01. Borehole MBH01 is currently in use for abstraction purposes.
- One (1) new borehole was drilled namely, MBH02. The borehole has been aquifer test pumped to determine their sustainable yields and groundwater quality.

ABSTRACTION RECOMMENDATIONS AND MANAGEMENT OPTIONS

The following sustainable yields are recommended for the aquifer test pumped boreholes of Ubuntu Municipality:

Victoria West: Recommended Abstraction Rates

- The recommended sustainable abstraction rate for borehole VBH01 (Victoria West) is calculated at 2.20 L/s (95.0 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole VBH01 is classified as “ARS, above recommended standard” (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to EC (186.0 mS/m), Na (204.0 mg/L) and Total Hardness (610.3 mg/L). Borehole is conditionally recommended for abstraction if water is chlorinated and mixed or treated to a concentration acceptable to the SANS241-1:2011 Standard (EC < 170 mS/m, Na < 200 mg/L & Total Hardness < 300 mg/L). Recommended pump installation depth is 30 mbgl.

- The recommended sustainable abstraction rate for borehole VBH11 (Victoria West) is calculated at 2.10 L/s (91.0 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole VBH11 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to As (Arsenic, As = 0.095 mg/L). Borehole is conditionally recommended for abstraction if water is chlorinated and mixed or treated to a concentration acceptable to the SANS241-1:2011 Standard (As < 0.01 mg/L). Recommended pump installation depth is 75 mbgl.
- The recommended sustainable abstraction rate for borehole VBH12 (Victoria West) is calculated at 1.70 L/s (73 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole VBH12 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to As (Arsenic, As = 0.104 mg/L). Borehole is conditionally recommended for abstraction if water is chlorinated and mixed or treated to a concentration acceptable to the SANS241-1:2011 Standard (As < 0.01 mg/L). Recommended pump installation depth is 85 mbgl.

Loxton: Recommended Abstraction Rates

- The recommended sustainable abstraction rate for borehole LBH01 (Loxton) is calculated at 0.30 L/s (13 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. Borehole LBH01 has a low sustainable yield and a poor water quality. Not recommended for abstraction.
- The recommended sustainable abstraction rate for borehole LBH02 (Loxton) is calculated at 3.60 L/s (156 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole LBH02 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to EC (624.0 mS/m), Na (952.9 mg/L), Ca (227.2), Mg (220.6 mg/L), Cl (1109.4 mg/L), SO4 (1323.0 mg/L) and Total Hardness (1472.4 mg/L). Borehole is conditionally recommended for abstraction if the water abstracted is treated to ensure that the water quality complies with SANS214-1:2011 water quality standards (EC < 170 mS/m, Na < 200 mg/L, Ca < 150, Mg < 100 mg/L, Cl < 300 mg/L, SO4 , 500 mg/L & Total Hardness , 300 mg/L). Treatment options for elevated electrical conductivity values (EC), sodium (Na) and total hardness (T.Hard) concentrations include methods such as reverse osmosis or electro-dialysis, distillation or demineralisation with a mixed bed resin or ion-exchange process. All large scale salt removal processes require high levels of operator and maintenance skills as processes are easily fouled by suspended matter or hard water. The concentrated brine produced may present disposal problems. Treatment options for elevated magnesium (Mg) concentrations include lime softening followed by re-carbonation. Other techniques that can be utilised include ion-exchange resins or precipitation of magnesium at a high pH. Methods to remove magnesium from water also require skilled operation and high maintenance (DWAF, Quality of Domestic Water Supply, Volume 1: Assessment Guide. WRC Report No.: TT101/98, 1998).

Richmond: Recommended Abstraction Rates

- The recommended sustainable abstraction rate for borehole RBH01 (Richmond) is calculated at 5.20 L/s (225 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole RBH01 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 33 mbgl. The estimated duty cycle recommended with the current pump installed is 10-hours a day at 5.80 L/s.
- The recommended sustainable abstraction rate for borehole RBH02 (Richmond) is calculated at 1.80 L/s (78 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole RBH02 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 33 mbgl. The estimated duty cycle recommended with the current pump installed is 16-hours a day at 1.50 L/s.
- The recommended sustainable abstraction rate for borehole RBH03 (Richmond) is calculated at 6.30 L/s (272 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole RBH03 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 35 mbgl. The estimated duty cycle recommended with the current pump installed is 24-hours a day at 2.5 L/s. The current pump is undersized for the borehole safe yield volume.
- The recommended sustainable abstraction rate for borehole RBH04 (Richmond) is calculated at 0.10 L/s (4 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. Low sustainable yield. Not recommended for abstraction with a motorised installation.
- The recommended sustainable abstraction rate for borehole RBH05 (Richmond) is calculated at 2.80 L/s (121 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole RBH05 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 35 mbgl. The estimated duty cycle recommended with the current pump installed is 6-hours a day at 3.90 L/s.
- The recommended sustainable abstraction rate for borehole RBH06 (Richmond) is calculated at 5.0 L/s (216 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole RBH06 is classified as "Class 1" (inorganic water quality), suitable for life time use (SANS 241:2011). Recommended for use if the groundwater abstracted is chlorinated to eliminate all potential harmful bacteriological contaminants. Recommended pump installation depth is 35 mbgl. The estimated duty cycle recommended with the current pump installed is 9-hours a day at 5.70 L/s.

Merriman: Recommended Abstraction Rates

- The recommended sustainable abstraction rate for borehole MBH02 (Merriman) is calculated at 0.4 L/s (17 m^3/d) for a 12-hour duty cycle per day with 12-hours of recovery time. The groundwater of borehole MBH02 is classified as "ARS, above recommended standard" (inorganic water quality). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to EC (321.0 mS/m), Na (382.9 mg/L), Ca (197.2 mg/L) and Cl (971.7 mg/L).). Borehole is conditionally recommended for abstraction if the water abstracted is treated to ensure that the water quality complies with SANS214-1:2011 water quality standards (EC < 170 mS/m, Na < 200 mg/L, Ca < 150, Cl < 300 mg/L, & Total Hardness , 300 mg/L). Treatment options for elevated electrical conductivity values (EC), sodium (Na) and total hardness (T.Hard) concentrations include methods such as reverse osmosis or electro-dialysis, distillation or demineralisation with a mixed bed resin or ion-exchange process. All large scale salt removal processes require high levels of operator and maintenance skills as processes are easily fouled by suspended matter or hard water. The concentrated brine produced may present disposal problems. (DWAF, Quality of Domestic Water Supply, Volume 1: Assessment Guide. WRC Report No.: TT101/98, 1998).

It is also recommended that groundwater monitoring be implemented to manage the groundwater resources in a sustainable and responsible manner and to prevent dewatering of the aquifer as well as to monitor the water quality over a prolonged period. The groundwater resource monitoring for the newly drilled and tested boreholes are as follows:

- The rest or static water levels as well as pump water levels of the newly drilled production boreholes are to be measured at two monthly. The abstraction volumes are also to be measured by means of a flow meter. The decline in groundwater levels are not necessarily due to abstraction but could also be a function of seasonal change such extended drought or dry periods. Therefore should drastic declines in static or pump water levels occur, the abstraction rates will have to be decreased to ensure sustainable utilisation according to seasonal rainfall if necessary.
- The recommended abstraction boreholes must be equipped with conduit pipes to ensure that groundwater level measurements can be taken even when the boreholes are equipped. It further recommended that the abstraction boreholes be equipped with flow meters to measure and record the abstracted flow volumes.
- Monthly rainfall records are to be compiled if unavailable from South African Weather Services to determine recharge to aquifer in relation to groundwater level elevation.
- Groundwater quality is generally fairly stable and chances occur slowly (dictated by groundwater flow paths and velocities) except for bacteriological constituents. For this reason samples are normally taken as grab samples and typically at a reduced frequency compared to surface water samples. Groundwater sampling should at least be undertaken bi-annually to account for seasonality. For the first year monthly sampling should be performed to determine a baseline groundwater quality for the borehole fields (DWA, Water Monitoring Systems, Best Practice Guidelines G3, 2007).
- A monitoring protocol or management plan should be drafted according to DWA, Water Monitoring Systems, Best Practice Guidelines G3, 2007.

GROUNDWATER QUALITY RESULTS

The sampling of the boreholes was conducted after the completion of the aquifer test pumping. The sample was analysed for inorganic as well as bacteriological constituents. The parameters analysed for was specified by DWA under the SANS241-1:2011 Standards.

Hydrochemical Imaging

Piper Diagram Description of the Tested Boreholes of Victoria West:

The piper diagram description of the groundwater of the aquifer tested boreholes is as follows:

- General Water Type Description: The groundwater of Victoria West is of the calcium / magnesium bicarbonate and sodium bicarbonate/chloride type, which is also described as dynamic waters.
- Cation Type Description: The cations of the groundwater of boreholes VBH11 and VBH12 are of sodium / potassium type, while the cations of the groundwater of borehole VBH01 displays no particular dominant cations.
- Anion Type Description: The anions of the groundwater of boreholes VBH11 and VBH12 are of the bicarbonate type, while the anions of the groundwater of borehole VBH01 displays no particular dominant anions.

Piper Diagram Description of the Tested Boreholes of Loxton:

The piper diagram description of the groundwater of the aquifer tested boreholes is as follows:

- General Water Type Description: The groundwater of Loxton is of the calcium / sodium sulphate type, which is also described as old and stagnant waters.
- Cation Type Description: The cations of the groundwater of borehole LBH01 is of the calcium type, while the cations of the groundwater of borehole LBH02 is of the sodium / potassium type:
- Anion Type Description: The anions of the groundwater of borehole LBH01 is of the sulphate type, while the anions of the groundwater of borehole LBH02 displays no particular dominant anions.

Piper Diagram Description of the Tested Boreholes of Richmond:

The piper diagram description of the groundwater of the aquifer tested boreholes is as follows:

- General Water Type Description: The groundwater of Richmond is of the calcium / magnesium type, which is also described as recent waters.
- Cation Type Description: The cations of the groundwater of the aquifer tested boreholes displays borehole no particular dominant anions.
- Anion Type Description: The anions of the groundwater of the aquifer tested boreholes are of the bicarbonate type.

Piper Diagram Description of the Tested Boreholes of Merriman:

The piper diagram description of the groundwater of the aquifer tested boreholes is as follows:

- General Water Type Description: The groundwater of Merriman is of the calcium / sodium sulphate type, which is also described as old and stagnant waters.
- Cation Type Description The cations of the groundwater of borehole MBH02 is of the sodium / potassium type:
- Anion Type Description: The anions of the groundwater of borehole MBH02 is of the chloride type.

Expanded Durov Diagram Description of the Tested Boreholes of Victoria West:

The expanded durov diagram description of the groundwater of the aquifer tested boreholes is as follows:

- **Field 3:** HCO_3^- and Na^+ dominant, often indicates ion exchanged water. The following boreholes are displayed within field 3: VBH11 and VBH12.
- **Field 5:** No dominant anions or cations, indicates water resulting from dissolution or mixing. The following borehole is displayed within field 5: VBH01

Expanded Durov Diagram Description of the Tested Boreholes of Loxton:

The expanded durov diagram description of the groundwater of the aquifer tested boreholes is as follows:

- **Field 4:** SO_4^{2-} (or indiscriminate) and Ca^{2+} dominant, may be a recharge water in lavas or associated gypsum deposits. The following borehole is displayed within field 4: LBH01.
- **Field 6:** SO_4^{2-} (or indiscriminate) Na^+ dominant, is a water type not frequently found and may be due to mixing influences. The following borehole is displayed within field 6: LBH02.

groundwater chemistry of the aquifer tested boreholes of Loxton.

Expanded Durov Diagram Description of the Tested Boreholes of Richmond:

The expanded durov diagram description of the groundwater of the aquifer tested boreholes is as follows:

- **Field 2:** HCO_3^- and Mg^{2+} dominant or HCO_3^- and Ca^{2+} and Mg^{2+} important, indicates water often associated with dolomite or mafic igneous rocks. The following boreholes are displayed within field 2: RBH01, RBH02, RBH03, RBH04, RBH05 and RBH06.

Expanded Durov Diagram Description of the Tested Boreholes of Merriman:

The expanded durov diagram description of the groundwater of the aquifer tested boreholes is as follows:

Field 9: Cl^- and Na^+ dominant, frequently indicates an end point water in a water evolution sequence and are thus old stagnant water. The following boreholes are displayed within field 9: MBH02.

Inorganic Water Quality

Groundwater samples were taken after the cessation of the aquifer test pumping to determine the inorganic groundwater quality of the individual boreholes and the borehole fields as a whole.

Victoria West Groundwater Quality:

The description of the inorganic water qualities of the aquifer test pumped boreholes are as follows for the town of Victoria West:

- The groundwater of borehole VBH01 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to a high

Electrical Conductivity (EC = 0.104 mS/m, SANS241-1:2011 = < 170 mS/m), total dissolved solids concentrations (TDS = 1302 mg/L, DWAF, Second Edition, 1998 = 1000 – 2400 mg/L), sodium concentrations (Na = 204 mg/L, SANS241-1:2011 = < 200 mg/L) and total hardness concentrations (T. Hard = 610.30 mg/L, DWAF, Second Edition, 1998 = 300 – 600 mg/L).

- The groundwater of borehole VBH12 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to Arsenic concentrations (As = 0.095 mg/L, SANS241-1:2011 = < 0.01 mg/L). The borehole will be resampled to verify the arsenic (As) concentration. The report will be updated accordingly when the laboratory results is received.
- The groundwater of borehole VBH12 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to Arsenic concentrations (As = 0.104 mg/L, SANS241-1:2011 = < 0.01 mg/L). The report will be updated accordingly when the laboratory results is received.

Loxton Groundwater Quality:

The description of the inorganic water qualities of the aquifer test pumped boreholes are as follows for the town of Loxton:

- The groundwater of borehole LBH01 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to a high electrical conductivity (EC = 175 mS/m, SANS241-1:2011 = < 170 mS/m), total dissolved solids concentrations (TDS = 1225 mg/L, DWAF, Second Edition, 1998 = 1000 – 2400 mg/L), calcium concentrations (Ca = 202.4 mg/L, SANS241:2006 = 150 – 300 mg/L), sulphate concentrations (SO_4 = 584.50 mg/L, SANS241-1:2011 = < 500 mg/L) and total hardness concentrations (T. Hard = 584.3 mg/L, DWAF, Second Edition, 1998 = 300 – 600 mg/L).
- The groundwater of borehole LBH02 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to high electrical conductivity concentrations (EC = 624 mS/m, SANS241-1:2011 = < 170 mS/m), total dissolved solids concentrations (TDS = 4368 mg/L, DWAF, Second Edition, 1998 = 1000 – 2400 mg/L), sodium concentrations (Na = 952.90 mg/L, SANS241-1:2011 = < 200 mg/L), calcium concentrations (Ca = 227.20 mg/L, SANS241:2006 = 150 – 300 mg/L), magnesium concentrations (Mg = 220.60 mg/L, SANS241:2006 = 70 – 100 mg/L), chloride concentrations (Cl = 1109.40 mg/L, SANS241-1:2011 = < 300 mg/L), sulphate concentrations (SO_4 = 1323 mg/L, SANS241-1:2011 = < 500 mg/L) and total hardness concentrations (T. Hard = 1472.5 mg/L, DWAF, Second Edition, 1998 = 300 – 600 mg/L).

Richmond Groundwater Quality:

The description of the inorganic water qualities of the aquifer test pumped boreholes are as follows for the town of Richmond:

- The groundwater of borehole RBH01 is classified as "Class 1 – recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.

- The groundwater of borehole RBH02 is classified as "Class 1 – recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.
- The groundwater of borehole RBH03 is classified as "Class 1 – recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.
- The groundwater of borehole RBH04 is classified as "Class 1 – recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.
- The groundwater of borehole RBH05 is classified as "Class 1 – recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.
- The groundwater of borehole RBH06 is classified as "Class 1 – recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.

Merriman Groundwater Quality:

The description of the inorganic water qualities of the aquifer test pumped boreholes are as follows for the town of Merriman:

- The groundwater of borehole MBH02 is classified as "ARS – above recommended standard limit" (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to a high electrical conductivity (EC = 321 mS/m, SANS241-1:2011 = < 170 mS/m), total dissolved solids concentrations (TDS = 2247 mg/L, DWAF, Second Edition, 1998 = 1000 – 2400 mg/L), sodium concentrations (Na = 382 mg/L, SANS241-1:2011 = < 200 mg/L), calcium concentrations (Ca = 197.20 mg/L, SANS241:2006 = 150 – 300 mg/L), chloride concentrations (Cl = 971.70 mg/L, SANS241-1:2011 = < 300 mg/L) and total hardness concentrations (T. Hard = 594.02 mg/L, DWAF, Second Edition, 1998 = 300 – 600 mg/L).

Bacteriological Water Quality of the Graaff-Reinet

The bacteriological water qualities of the aquifer tested boreholes are as follows:

- The bacteriological water qualities of boreholes VBH01, VBH11, VBH12, LBH01, LBH02, RBH01, RBH02, RBH03, RBH04, RBH05, RBH06 and MBH02 are classified as "ARS" waters. According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due mostly to elevated plate counts. Boreholes LBH02, RBH01 and RBH04 also indicates elevated counts of total coliform as well E.Coli counts in boreholes RBH01 and RBH04.

Bacterial contamination may fluctuate enormously with time. It is therefore recommended that the groundwater abstracted from the production boreholes be chlorinated to remove all potential harmful bacteria before utilisation.

SUMMARY OF ADDITIONAL RECOMMENDATIONS AND THE WAY FORWARD

The summary of additional recommendations and the way forward are as follows:

- It is recommended that additional groundwater exploration be conducted on the dolerite dyke structure on which VBH11 and VBH12 is located to the north east of Victoria

West. It is also recommended that additional groundwater exploration be conducted on the dolerite structure on which VBH07 is located to the south of Victoria West. Treatment of the reservoir water or mixing options for EC (Electrical Conductivity) is also recommended for investigation.

- It is recommended that the feasibility of a water treatment plant for Loxton be investigated as the water of the reservoir is not of a SANS241:2011 quality and is unsuitable for use according to existing water quality data. Potentially sustainable groundwater volume is not the problem if the water bearing structure on, which LBH02 is further developed by groundwater exploration.
- The production boreholes in Richmond are currently utilised 24-hours a day. It is recommended that a 13-hour duty cycle be adhered to with 11-hours of recovery per day. It is also recommended that the undersized pump at production borehole RBH03 be replaced to add additional water volume to the water system. Groundwater monitoring is also recommended at borehole RBH04 that will not be utilised for abstraction due to a low sustainable yield. If the groundwater level of the monitoring borehole reaches 17 mbgl, which is the geometric mean of the critical water level of the borehole field, it is recommended that the duty cycles of the production boreholes be reduced to ensure the sustainable abstraction.
- It is recommended that the groundwater of MBH02 at Merriman be treated on small scale before utilisation by the small community.

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