# Geohydrological Assessment of De Aar's Groundwater Resources

Report Prepared for

## Emthanjeni Municipality

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October 2007

SRK Consulting
*Engineers and Scientists*

# Geohydrological Assessment of De Aar's Groundwater Resources

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# Abstract

De Aar's current water requirement of 2.2 million m$^3$ per annum is pumped from ten wellfields that are located up to 35km from the town. However, only 1.6 million m$^3$ of groundwater was abstracted during 2006. In the past, De Aar has suffered from severe water shortages which resulted in the Department of Water Affair and Forestry (DWAF) conducting two extensive geohydrological investigations in the mid 1970's and late 1980's aimed at securing sufficient groundwater resources to meet the town's water requirements up until 2020.

Since 2004, the Emthanjeni Municipality have been capturing the monthly volumes abstracted from individual production boreholes, as well as waterlevel information from specific monitoring holes equipped with data-loggers, into a groundwater monitoring and management software package, *AquiMon.* The DWAF's Kimberley regional office provided the Municipality with funding to appoint a hydrogeological consultant to evaluate this monitoring information, to assess the production status of various wellfields and the aquifer systems being exploited by De Aar. In January 2007, SRK Consulting was appointed by the Municipality to conduct this geohydrological study.

The current configuration of fifty-one production boreholes are capable of delivering 260 L/s and have a combined sustainable yield of an estimated 2.7 million m$^3$/annum. This is significantly less than the estimated long-term sustainable yield of the Groundwater Management Units (GMU's) which they tap of ~4.8 Mm$^3$/a. Currently, the volumes of groundwater being abstracted from most of the Municipal wellfields is within the prescribed sustainable yield limits, with the exception of the Vaalbank and Cyfferkuil Wellfields that are being overexploited. The salinity of the groundwater in the various GMU's is highly variable, but is almost always hard to very hard. The best quality groundwater is abstracted from the Cyfferkuil, Burgerville and Zewefontein GMU's located some 30km to the east of De Aar.

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# Glossary of Terms

**Aquifer**: A geological formation capable of supplying economic volumes of groundwater.

**Aquitard**: A saturated geological unit with a relatively low permeability that retards and, but does not prevent the movement of water; while it may not readily yield water to boreholes and springs, it may act as a storage unit.

**Contamination**: The introduction of any substance into the environment by the action of man.

**Ecosystem**: An organic community of plants, animals and bacteria and the physical and chemical environment they inhabit.

**Fractured-rock Aquifer**: Groundwater occurring within fractures and fissures in otherwise impermeable hard-rock formations.

**Groundwater**: Refers to the water filling the pores and voids in geological formations below the water table.

**Groundwater Flow**: The movement of water through openings and pore spaces in rocks below the water table i.e. in the saturated zone. Groundwater naturally drains from higher lying areas to low lying areas such as rivers, lakes and the oceans. The rate of flow depends on the slope of the water table and the transmissivity of the geological formations.

**Groundwater Recharge**: Refers to the portion of rainfall that actually 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 groundwater available for beneficial use, including by man, aquatic ecosystems and the greater environment.

**Intergranular Aquifer**: Groundwater contained in intergranular interstices of sedimentary and weathered formations.

**Major Aquifer System**: Highly permeable formations, usually with a known or probable presence of 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 both for local supplies and in supplying base flow for rivers.

**Non-Aquifer**: A groundwater body that is essentially impermeable, does not readily transmit water and/or has a water quality that renders it unfit for use.

**Non-Aquifer Systems**: 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 an aquifer under unit hydraulic gradient in unit time (expressed as $m^3/m^2 \cdot d$ 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.

**Recharge**: The addition of water to the zone of saturation, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.

**Saline Water**: Water that is generally considered unsuitable for human consumption or for irrigation because of its 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

**Small Industrial Users:** Means water users who qualify as work creating enterprises that do not use more than twenty cubic metres per day and identified in the Standard Industrial Classification of All Economic Activities (5th edition), published by the Central Statistics Service, 1993, as amended and supplemented, under the following categories:

1: food processing

2: prospecting, mining and quarrying

3: manufacturing

4: construction

**Specific Yield**: Ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity from that mass.

**Unconfined Aquifer**: An aquifer with no confining layer between the water table and the ground surface where the water table is free to fluctuate.

**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*.

**Watertable**: 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.

# List of Abbreviations

| | |
|---|---|
| DEADP | Department of Environmental Affairs and Development Planning |
| DWAF | Department of Water Affairs and Forestry |
| EC | Electrical Conductivity (Salinity of water) |
| CMB method | Chloride Mass Balance method |
| CRD method | Cumulative Rainfall Departure method |
| EIA | Environmental Impact Assessment |
| GA | General Authorisation |
| GEP | Groundwater Exploitation Potential |
| GMU | Groundwater Management Unit |
| GRP | Groundwater Resource Potential |
| Ma | Million annums |
| m.amsl | Metres above mean sea level |
| MAP | Mean Annual Precipitation |
| m.bgl | Metres below ground level |
| mS/m | Milli-siemens per metre |
| $m^3/a$ | Cubic metres per annum |
| $Mm^3/a$ | Million cubic metres per annum |
| $m^3/m$ | Cubic metres per month |
| NGDB | National Groundwater Database |
| NWA | National Water Act (Act No. 36 of 1998) |
| OWB | Overberg Water Board |
| SAR | South African Railways |
| SPI | Standard Precipitation Index |
| SRK | SRK Consulting (SA) PTY LTD |

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SRK Report 374624

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**Geohydrological Assessment of the Groundwater Resources of De Aar**

# 1 Introduction

De Aar's current water requirement of 2.2 million m$^3$ per annum is met by some fifty production boreholes distributed across ten wellfields that are located up to 35km from town. In the past the De Aar has suffered from numerous water shortages which resulted in the Department of Water Affair and Forestry (DWAF) conducting two extensive geohydrological investigations in the mid 1970's and late 1980's with the aim of securing sufficient groundwater resources to meet the towns water requirements until 2020.

Since 2004, the Municipality have been capturing the monthly volumes abstracted from individual production boreholes, as well as waterlevel information from specific monitoring holes, into a groundwater monitoring and management software package, *AquiMon*. The DWAF's Kimberley regional office provided the Municipality with the funds to appoint a hydrogeological consultant to evaluate this monitoring information, to assess the production status of various wellfields and aquifer systems being exploited by De Aar. In January 2007, SRK Consulting was appointed by Mr. F.D. Taljaard of the Emthanjeni Municipality to conduct this geohydrological study.

# 2 Background and Brief

## 2.1 Background Information

### 2.1.1 Location of Study Area

De Aar is located in the Northern Cape Province along the N10 road route between Hanover (60km away) and Britstown (50km away). The town falls in the 'Lower Orange' Catchment Management Area (WMA 14) and is located on the drainage divide between the D62C and D62D Quaternary Catchments. De Aar lies some 270 km southwest of Bloemfontein and 400km inland from Port Elizabeth (see inset map in **Figure 5**).

### 2.1.2 Rainfall

Monthly rainfall information was obtained from the SA Weather Service for De Aar (Station No. 0169880/1, **Plate 1**) and Rooiwal (Station No. 0170639/7) for the period January 1950 to August 2007. The locations of these stations are indicated in **Figure 4**. The Mean Annual Precipitation (MAP) for the De Aar and Rooiwal stations is 323mm and 355mm, respectively. The MAP at Rooiwal is 32mm higher than at De Aar, which is to be expected, given that rainfall generally increases from west to east across the country. The cumulative departure of the annual rainfall from MAP for these two stations are presented in **Figure 2**, which indicates that the De Aar region experienced a 'rainfall deficit' over the period 1954 to 1973. The high rainfalls of 1974 to 1976 basically removed the accumulated rainfall deficit. However, the rainfall has remained in a 'deficit' ever since, with the exception of the wet period between 1988 and 1989.

The 24-month Standard Precipitation Index (McKee et al, 1993) or SPI has been calculated for the De Aar and Rooiwal rainfall stations (**Figure 3**) since 1950. The SPI provides a statistical indicator of cycles between 'very wet' (> +1.5) and 'very dry' (< -1.5) periods. The similarity in the rainfall patterns between these two stations is also clearly evident, as well as two 'very wet' periods; (i) the most pronounced extending from 1974 to 1978 and (ii) a less pronounced period in 1989. Note that for a large portion of the time the SPI index remains between 0 and -1.5, indicating the dominance of moderately dry conditions.

The DWAF erected a cumulative rainfall recorder and sampler near the weather station at De Aar on 30 March 2005 (**Plate 2**). The data is downloaded and archived by the DWAF's regional office in Kimberley. Rainfall samples have been collected and analysed for chloride content. This information was not received on time for inclusion in this report.

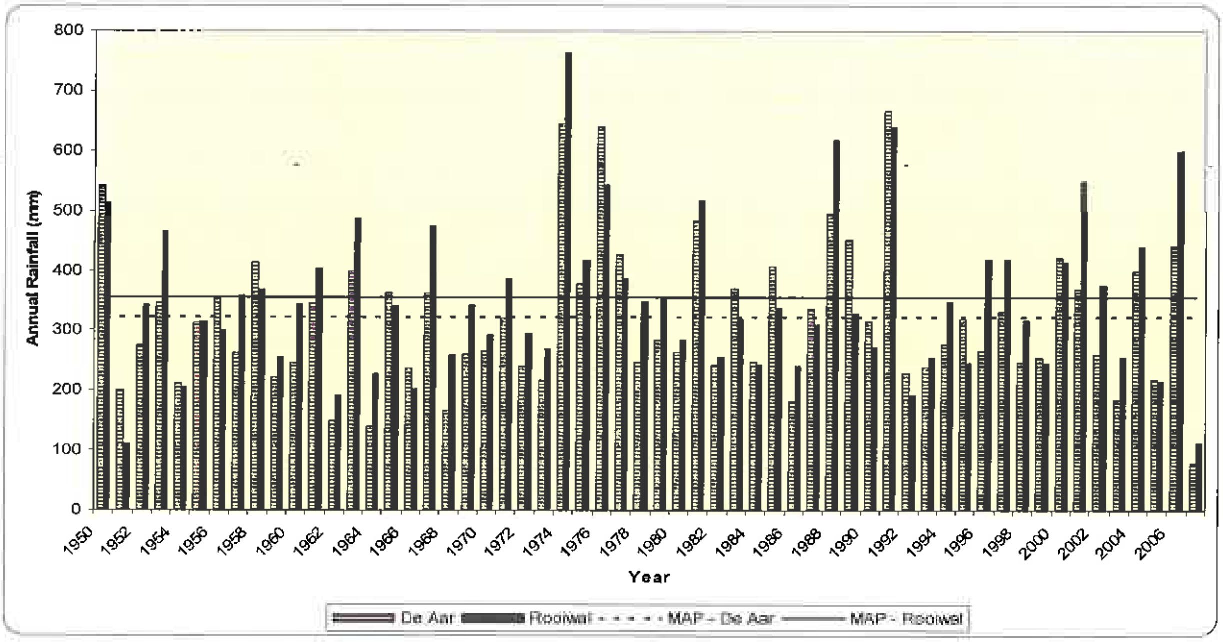



**Figure 1: Annual Rainfall measured at De Aar and Rooiwal for the period 1950 to 2007**

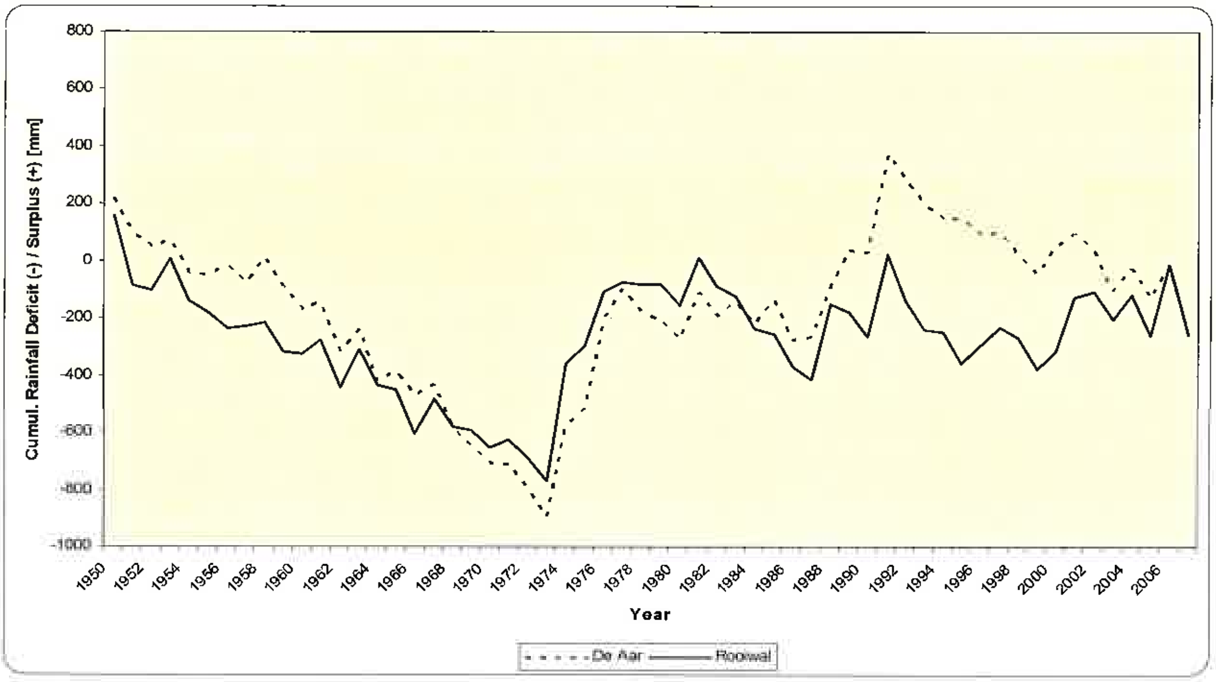



**Figure 2: Cumulative Annual Rainfall Deficit / Surplus from the MAP for De Aar and Rooiwal**

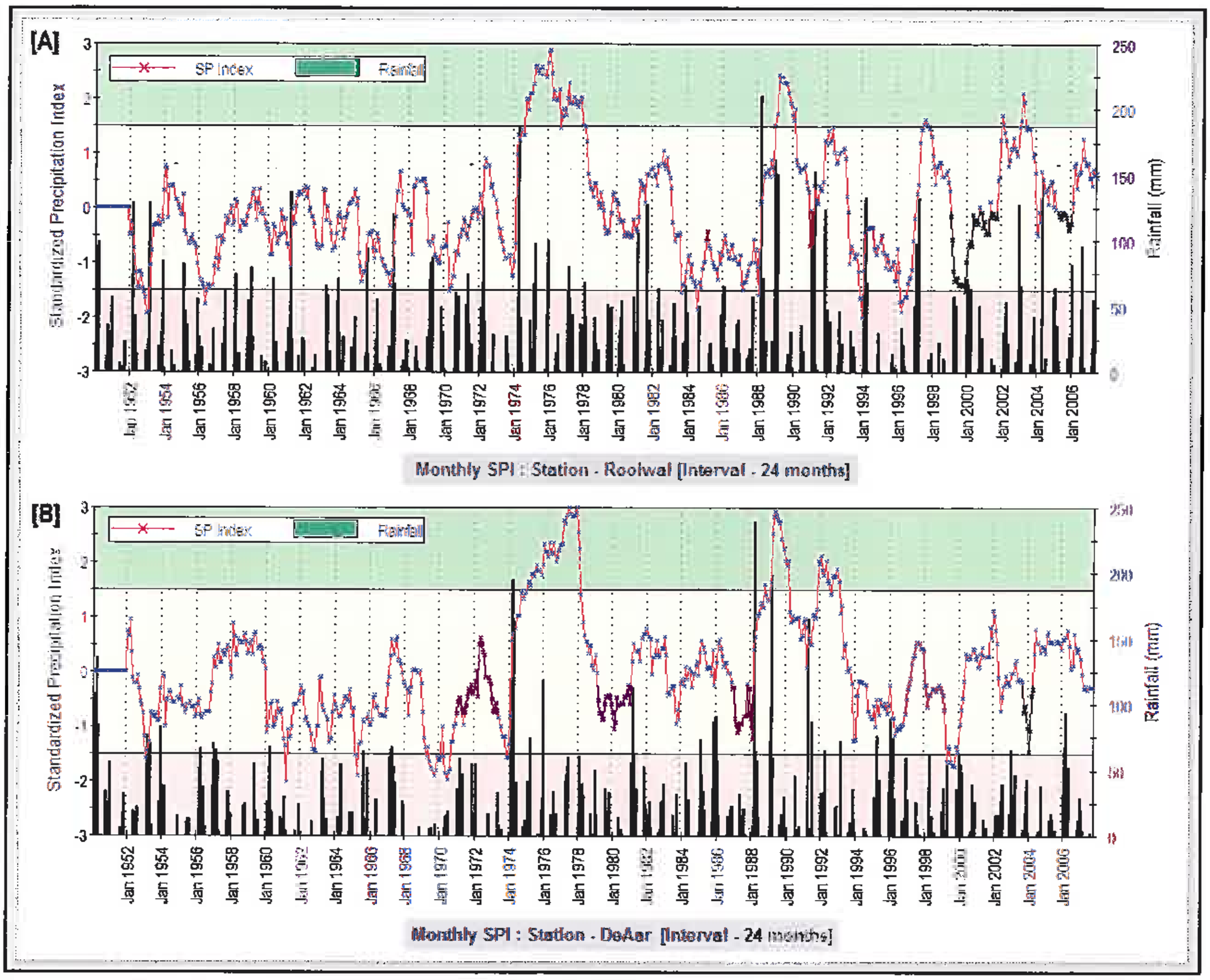



**Figure 3: Spatial Precipitation Index for [A] Rooiwal and [B] De Aar Weather Stations**

**Plate 1: Weather Station at De Aar (photo F. Fourie, DWAF)**

Plate 2: DWAF Bulk rainfall recorder and sampler at De Aar (photo F. Fourie, DWAF)

### 2.1.3 Geology

Bluish grey mudstone and greyish green sandstone of the Middleton Formation of the Adelaide Subgroup (Beaufort Group) outcrop in the eastern parts of the study area, whilst dark grey to black shale of the underlying Tierberg Formation (Ecca Group) outcrop to the west and north of De Aar (**Figure 4**). Sand and clay rich alluvial deposits occur along the major river courses, where at places thicknesses of up to 16m are attained. At such localities, a 2 to 4m thick, coarse-grained sand and gravel unit is commonly present at the base of alluvium.

The Ecca and Beaufort Group sediments have been intruded by numerous Karoo dolerite dykes and sills. Dykes are more abundant in the Middleton Formation to the south and east of De Aar. A number of prominent dolerite ring-dyke and sill complexes are present in the study area (**Figure 4**), e.g. at Zewefontein, Caroluspoort, Vaalbank-Rhenosterpoort and Zwartkoppies.

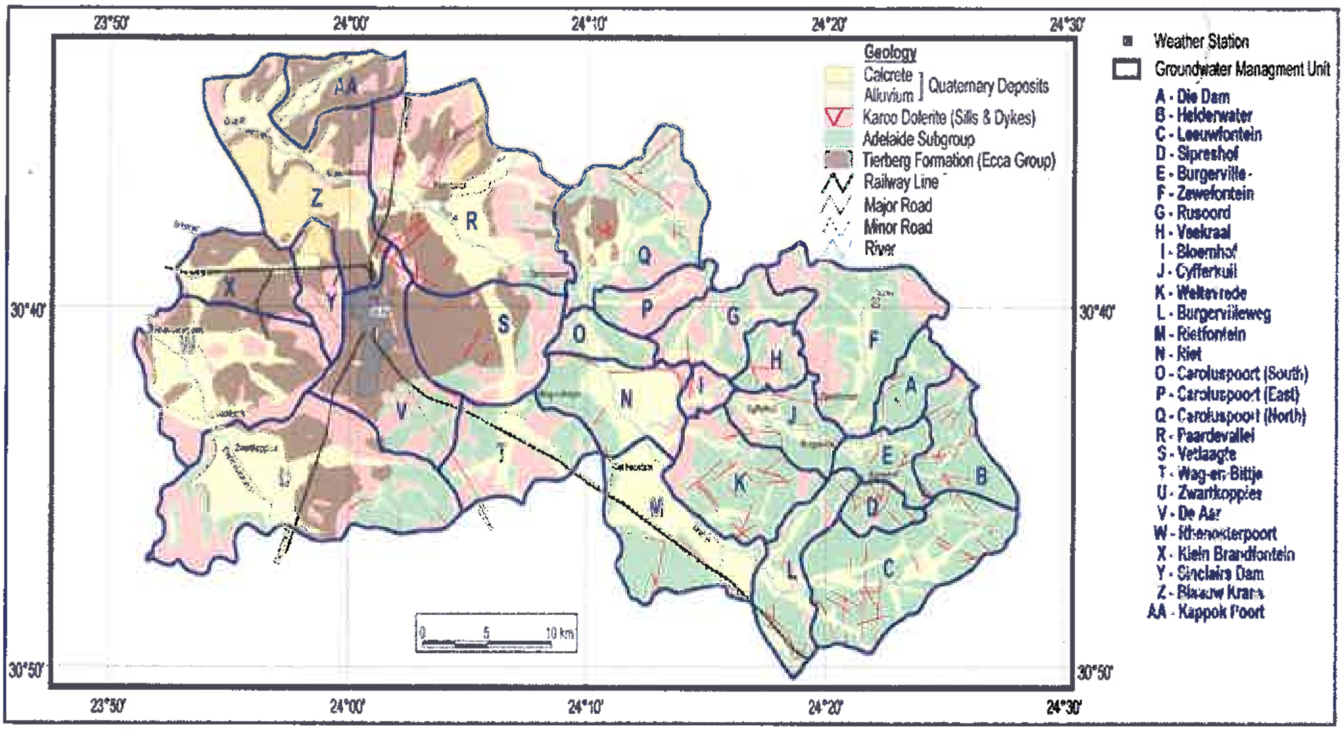



**Figure 4: Groundwater Management Units and Simplified Geology of the De Aar Study Area**

## 2.2 Nature of the brief

In January 2007, Mr. F.D. Taljaard of the Emthanjeni Municipality appointed SRK Consulting to carry out the following geohydrological work (P/11/47):

- Evaluate the waterlevel behaviour in 51 production and 48 monitoring boreholes in the De Aar area in relation to abstraction and rainfall.
- Evaluate the behaviour of each of the 5 wellfields in which these boreholes are located in relation to abstraction and rainfall.
- Asses the 'safe-yield' of the boreholes and make recommendations.
- Capture groundwater chemistry and assess variations with regard to abstraction and recharge.
- Compile a report with recommendations regarding management issues and pumping schedules.

It was also required that the latest version of the *Aquimon* groundwater monitoring and management software and associated database be installed on a computer at the Municipal offices in De Aar.

# 3 Work Program and Results

The project work comprised the following main tasks:

- Desktop study of all relevant geohydrological reports, maps and archived information (i.e. DWAF's National Groundwater Archive and water quality database etc.

- Acquiring, verifying and populating the *AquiMon* database and groundwater management system. Data evaluation and setting of maximum monthly abstraction volumes per production borehole and 'early-warning' or trigger waterlevels for each monitoring borehole. Assign all production and monitoring boreholes to a GMU.

- Establish spatial database and GIS analysis aimed at (i) defining Groundwater Management Units or GMU's, and (ii) to estimate groundwater recharge from rainfall per GMU.

- Report writing.

## 3.1 AquiMon Database and Management System

A large portion of the project time was spent assimilating, compiling, verifying and uploading relevant hydrological information into the *AquiMon* database and setting the relevant trigger waterlevels and maximum monthly abstraction volumes in the management system, which included the following information / tasks:

- Critical information related to the physical (i.e. depth of hole, GPS coordinates, depth of pump-intake etc.) and management attributes (i.e. trigger waterlevels, maximum sustainable monthly abstraction volumes etc.) associated with each production and monitoring borehole.
- Assigning each production and monitoring borehole to a specific GMU.
- Waterlevel information archived in DWAF's National Groundwater Archive (NGA) and data-logger information supplied by their Kimberley office. The data-loggers provide 'high resolution' intra-daily waterlevel information.
- Monthly abstraction volumes for each production borehole up until July 2007, as supplied by Mr. Taljaard of the Emthanjeni Municipality.
- Groundwater chemistry contained in the DWAF national water chemistry database.

The DWAF's NGA contains information from a large number of boreholes and springs that occur in the De Aar area. In March 2006, the DWAF's Kimberley office removed the OTT Type-X recorders from 48 boreholes in the De Aar area and placed 29 OTT Mini-Orpheus data-loggers in a select number of these holes (F. Fourie, email comm; July 2007).

## 3.2 Municipal Water Consumption

De Aar's water requirements are met from ten wellfields comprising of 51 boreholes located up to 30km from the town. The annual water consumption for the period 1970 to 2006 is presented in **Table 1**. The town's current water requirements are estimated at ~2.2 $Mm^3/a$, although only 1.6 Mm3 was abstracted in 2006.

Kock (2002) estimated that during the periods 1998/99 and 1999/00 the total water reticulation system losses were as high as ~556,000 (22%) and ~475,000 (20%) $m^3/a$ for a water consumption of 2,520,570 and 2,331,065 $m^3/a$, respectively.

**Table 1: Summary of De Aar's Annual Water Consumption between 1970 and 2006**

| Year | Water Consumption ($x 10^6 m^3/a$) | Source / Comment |
|---|---|---|
| 1970 | 1.622 | |
| 1971 | 1.865 | |
| 1972 | 1.945 | |
| 1973 | 1.785 | |
| 1974 | 2.049 | |
| 1975 | 2.261 | |
| 1976 | 2.181 | |
| 1977 | 2.438 | |
| 1978 | 2.502 | Abstraction commences from South-Western Scheme |
| 1979 | 2.944 | |
| 1980 | 2.695 | |
| 1981 | 2.821 | Abstraction commences from South-Eastern Scheme |
| 1982 | 2.973 | |
| 1983 | 2.967 | |
| 1984 | 3.154 | |
| 1985 | 3.030 | |
| 1986 | 3.409 | |
| 1987 | 2.920 | |
| 1988 | 2.440 | |
| 1989 | 2.347 | |
| 1990 | 2.440 | Woodford, (1993). |
| 1991-96 | ? | Missing Data |
| 1997 | 2.265 | Kock, Table 3.7 – Groundwater Abstraction, (2002). |
| 1998 | 2.425 | Kock, Table 3.7 – Groundwater Abstraction, (2002). |
| 1999 | 2.583 | Kock, Table 3.7 & Appendix B, (2002). |
| 2000 | 2.251 | Kock, Appendix B – Water Use, (2002). |
| 2001 | 2.353 | Kock, Appendix B – Water Use, (2002). |
| 2002 | 2.143 | Kock, Appendix B – Water Use, (2002). |
| 2003 | 2.141 | Kock, Appendix B – Water Use, (2002). |
| 2004 | 1.017 | Kock, Appendix B – Water Use, (2002). |
| 2005 | 2.040 | AquiMon |
| 2006 | 1.614 | AquiMon |

Notes:
- 1975 to 1988 water use includes SA Railways (SAR) use obtained from Caroluspoort.
- Prior to 1978, De Aar obtained its water from the Cyfferkuil, Burgerville and Zewefontein areas, whilst the SAR obtained water from Caroluspoort.
- Prior to 1999 the records reflect groundwater abstraction from the various wellfields.

## 3.3 Development of De Aar's Groundwater Resources

De Aar derives it name from a farm that was originally owned by one of the pioneers, Jan Gabriel, to settle in the area in 1839. The farm owed its name to a freshwater spring that daylighted alongside an E-W trending dolerite dyke that outcropped on the property. The spring served as a watering point for thousands of sheep. Shortly after the Anglo-Boer War the land was surveyed and a town was laid out by the two Vriedlander brothers who owned the property. In 1904 it was proclaimed a Municipality and is today regarded as the second largest railway hub in southern Africa.

Between 1902 and 1936, De Aar's growth was stinted by the lack of reliable water supply. This situation forced the Cape Government Railways to source water from springs on the farm Caroluspoort, some 14km to the east of De Aar. In 1927, the Town Council opted to purchase the small village of Burgerville (**Figure 5**), located ~34km SE of De Aar, in order to access its fresh groundwater supplies mainly fed by springs. In 1954, the groundwater yield from this area, known as the Burgerville / Zewefontein Scheme, was increased by the drilling and commissioning of three new production boreholes.

Detailed hydrogeological investigations were carried out by the Geological Survey over the period 1971 to 1975, resulting in the establishment of numerous potential production boreholes in the so-called 'Northern', 'South-Eastern' and 'South-Western' areas (Von Hoyer, 1975; Smit, 1975). In September 1978, eight production boreholes in the South-Western Scheme were commissioned, with an additional four boreholes being added in February 1979. A single production borehole was commissioned in the South-Eastern Scheme in 1981, followed by a further seven holes after 1985.

In order to meet the expected rise in water demand, the DWAF embarked on further groundwater investigations during 1987 to 1989. The aim was to establish additional production boreholes in the South-Eastern and Burgerville areas, to re-drill and pump-test selected boreholes originally drilled during the 1971/75 investigation in the Northern and Brandfontein Areas, and to investigate the groundwater potential of the Houtkraal and Hennopskraal farms in the so-called 'Far-Northern Area'.

The local authorities in the towns of De Aar, Britstown and Hanover were combined in accordance with the Municipal Demarcation Act (Act 27) of 1998 to form the Emthanjeni Municipality (Kock, 2002). De Aar currently obtains its water from various wellfields located to the west, east and north of the town. These wellfields have been historically subdivided into five broad geographic areas or schemes (**Figure 5**), namely the so-called:

1. South-Western (A),
2. South-Eastern (B),
3. Northern (E),
4. Caroluspoort (D), and
5. Burgerville / Zewefontein (C) Schemes.

Vegter (1990) subdivided these geographic areas into groundwater units (**Figure 5**) and provided estimates of the exploitation potential of each unit (**Table 2**). These estimates are based upon a detailed assessment of the groundwater conditions and assured yield of groundwater unit XXI-B or

South-Western Scheme. In 1991, Haasbroek (in Woodford, 1993) estimated that De Aar's total groundwater supplies were capable of delivering between 2.1 to 2.5 million m$^3$ per annum.

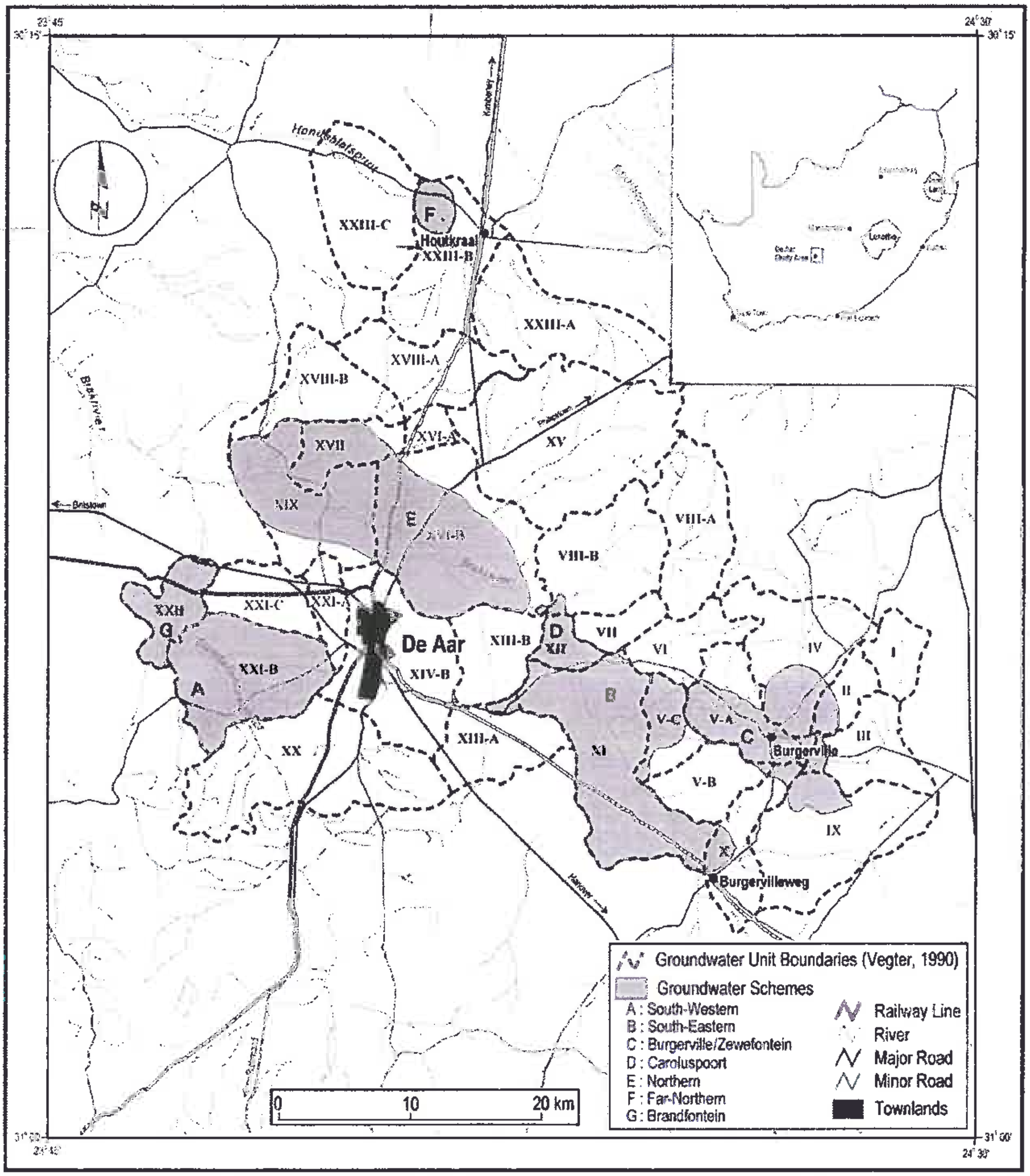



**Figure 5: Groundwater Abstraction Schemes of De Aar (after Woodford, 1993)**

**Table 2: Estimates of supplies available for Urban Use from GMU's in the De Aar Area**

| Groundwater Unit | Area ($km^2$) | Steady Yield ($x10^6$ $m^3/a$) | | Farm Use | Urban Use | Undeveloped Potential |
|---|---|---|---|---|---|---|
| | | Min$^A$ | Max$^B$ | ($x10^6$ $m^3/a$) | ($x10^6$ $m^3/a$) | ($x10^6$ $m^3/a$) |
| I | 21.8 | 0.157 | 0.187 | 0.002 | - | 0.185 |
| II | 18.0 | 0.130 | 0.155 | 0.002 | - | 0.153 |
| III | 46.4 | 0.334 | 0.399 | 0.095+ | 0.150 | 0.154 |
| IV | 63.3 | 0.519 | 0.601 | 0.056 | 0.340 | 0.204 |
| V$_A$ | 48.9 | 0.352 | 0.421 | 0.005 | 0.350 | 0.069 |
| V$_B$ | 41.0 | 0.282 | - | - | - | - |
| VI | 39.0 | 0.282 | 0.337 | 0.044 | - | 0.293 |
| VII | 17.7 | 0.127 | 0.152 | 0.002 | - | 0.150 |
| VIII$_B$ | 72.3 | 0.593 | 0.687 | 0.007 | 0.280 | 0.400 |
| IX | 92.1 | 0.663 | 0.792 | 0.079+ | 0.050 | 0.663 |
| X | 37.7 | 0.271 | 0.324 | 0.004 | 0.150 | 0.175 |
| XI | 122.5 | 1.005 | 1.164 | 0.362+ | 0.600 | 0.202 |
| XII | 14.8 | 0.121 | 0.141 | 0.001 | 0.120 | 0.000 |
| XIII$_B$ | 47.2 | 0.340 | 0.406 | 0.005 | 0.060 | 0.341 |
| XIV$_A$ | 39.9 | 0.287 | 0.343 | 0.004 | - | 0.339 |
| XIV$_B$ | 117.6 | - | - | - | | - |
| XV | 151.0 | - | - | - | - | - |
| XVI$_A$ | 13.1 | - | - | - | - | - |
| XVI$_B$ | 123.7 | 1.014 | 1.175 | 0.362 | 0.280 | 0.538 |
| XVII | 29.6 | 0.213 | 0.255 | 0.153 | 0.060 | - |
| XVIII$_A$ | 56.3 | - | - | - | - | 0.000 |
| XVIII$_B$ | 32.9 | 0.237 | 0.283 | 0.083 | 0.060 | 0.145 |
| XIX | 78.3 | 0.642 | 0.744 | 0.048 | 0.530 | 0.171 |
| XX | 126.9 | 1.041 | 1.206 | 0.013 | 0.300 | 0.893 |
| XXI$_A$ | 22.2 | - | - | - | - | - |
| XXI$_B$ | 81.7 | 0.670 | 0.776 | 0.133 | 0.440 | 0.213 |
| XXI$_C$ | 40.2 | - | - | - | - | - |
| XXII | 30.3 | 0.248 | 0.288 | 0.133 | 0.120 | 0.000 |
| XXIII$_A$ | 80.0 | - | - | - | - | - |
| XXIII$_B$ | 85.0 | 0.615 | 0.712 | 0.238+ | 0.370 | 0.101 |
| XXIII$_C$ | 60.0 | - | - | - | - | - |

Notes: (after Vegter, 1992)
A- recharge rate based on rainfall >= 15mm
B- recharge rate based on rainfall >= 10mm

## 3.4 Definition of Groundwater Management Units

Vegter's (1990) groundwater units (**Figure 5**) were captured in a GIS, as well as a detailed geological map of the area to the east of De Aar encompassing the South-Eastern, Caroluspoort and Burgerville / Zewefontein Schemes (Woodford, unpublished data). This information was overlain in a GIS upon the 1/50,000-scale topocadastral mapsheets and used, in conjunction with the results of the exploration drilling, to redefine and refine certain of Vegter's GMU's. The geographic extents of these GMU's are shown in **Figure 4**, whilst the size of each unit is presented in **Table 3.**

## 3.5 Groundwater Resource Assessment

### 3.5.1 Groundwater Recharge from Rivers during Flood Events

In 1989, the DWAF specifically established two monitoring stations to assess the impact of river flow during flood events on the underlying composite alluvial - bedrock aquifer system, as follows:

(a) Boreholes G39221 – 224, G39035 – 039, G39041 and a rudimentary gauging-station (D6N0579) on the Brak River in the Caroluspoort-South GMU (**Figure 30, Figure 6**); and
(b) Boreholes G39224 - 231 and a gauging-station (D6N0580) on Elandsfontein River (**Figure 7**) in the Rhenosterpoort GMU.

The aim of establishing these monitoring networks was to assess the extent to which groundwater in the alluvial deposits underlying and bordering on the major river systems are being recharged by infrequent flood flow. Quantitative assessment is not possible due to a lack of accurate river flow records in these areas. Waterlevel responses in monitoring holes close to these rivers do not necessarily indicate recharge by infiltration of floodwater through the streambed, but rather appears to the combined result of:

- recharge by rainfall on the higher-lying adjoining hardrock terrain;
- the reduction / cessation of pumping from the Municipal production boreholes; and
- infiltration of the floodwater through the streambed (Vegter, 1993).

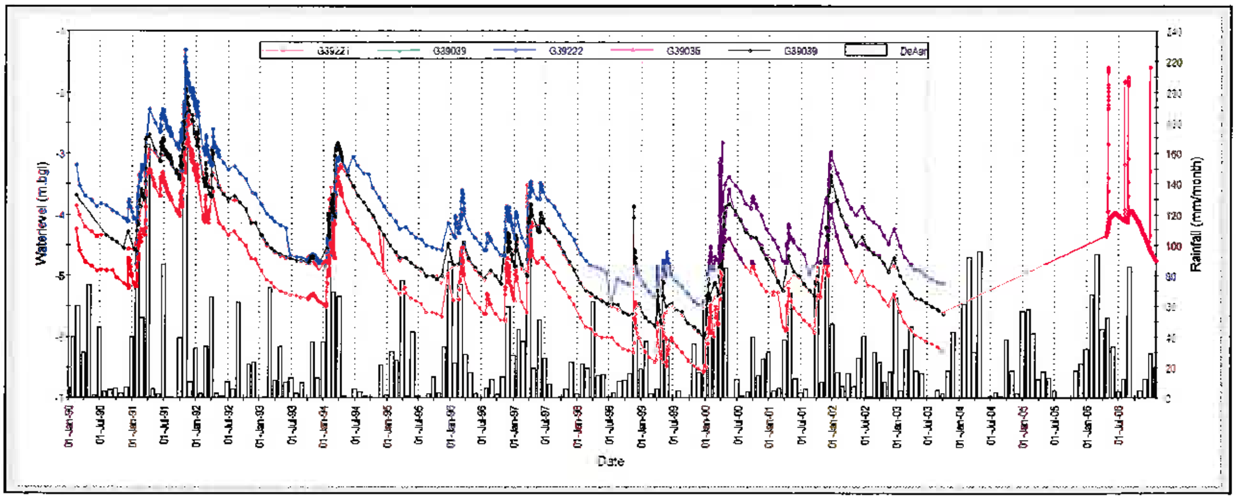



**Figure 6: Monthly Rainfall versus waterlevel fluctuations in monitoring holes at the Brak River Monitoring Station**

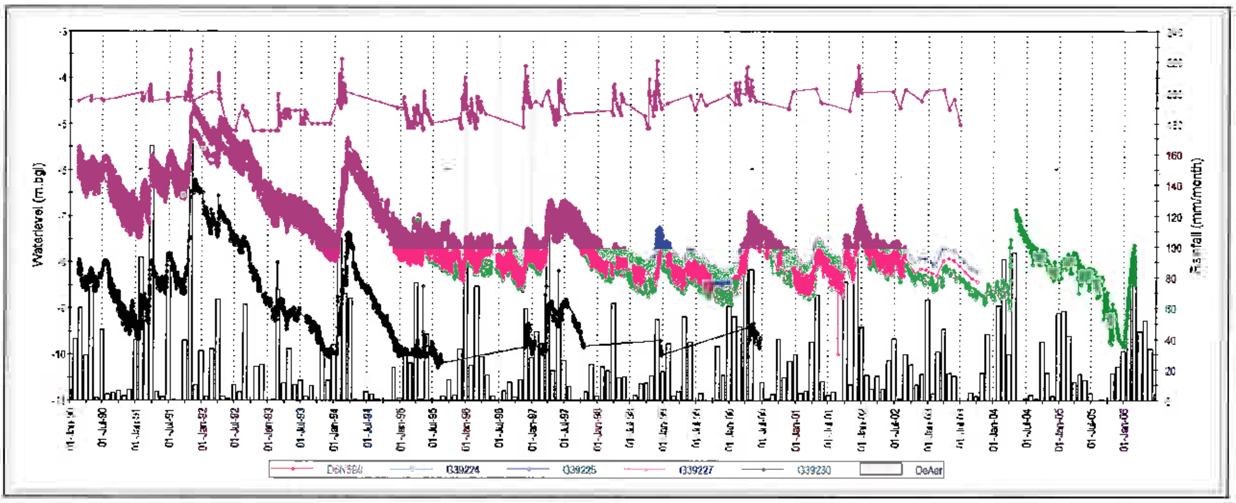



**Figure 7: Monthly Rainfall versus waterlevel fluctuations in monitoring boreholes and river-stage (D6N580) in the Elandsfontein River**

### 3.5.2 Potential Recharge from Rainfall

#### GIS Estimate

A GIS raster-modelling technique was used to estimate the volumes of rainfall recharge per groundwater management unit. A subset of the national Mean Annual Precipitation grid (Schultze, 1997) covering the study area was 'corrected' using the mean annual rainfall values derived from the De Aar and Rooiwal rainfall stations (**Section 2.1.2**).

The mean annual potential recharge (MAPR) was then estimated using a modified Maxey-Eakin technique (Maxey and Eakin, 1949; Davisson and Rose, 2000), which defines a simple relationship between groundwater recharge and mean annual precipitation. The following polynomial equation was used to define recharge volumes per GMU:

$Re = 0.0001 \times MAP^2$ .............. Equation 1

Where Re – depth of mean annual potential recharge in millimetres (after evapotranspiration losses), and

MAP – mean annual rainfall in millimetres.

A GIS raster-modelling process was used to determine the Re for the study area using **Equation 1**, where Schultze's (1997) raster dataset of Mean Annual Precipitation (MAP) was used as input. The Re values were then adjusted for variations in outcrop geology and terrain slope. The MAPR during periods of drought was determined using Schultze's % Coefficient of Variation of MAP raster dataset. The results are summarised in **Table 3** over page, where GMU's that are currently being exploited by Municipal production holes are highlighted.

**Table 3: GIS estimates of Mean Annual Recharge per Groundwater Management Unit**

| Groundwater Management Unit | Area ($km^2$) | Adjusted Mean Annual Precipitation (mm/a) | Recharge Factor (%) | Mean Annual Recharge ($m^3/a$) | |
|---|---|---|---|---|---|
| | | | | Normal | Drought |
| **Blauuw Krans** | **101.290** | **319** | **3.0** | **959,680** | **618,534** |
| Bloemhof | 9.187 | 336 | 3.1 | 96,685 | 62,908 |
| **Burgerville** | **23.024** | **345** | **3.1** | **249,212** | **161,809** |
| **Burgervilleweg** | **43.098** | **338** | **3.0** | **441,060** | **286,347** |
| **Caroluspoort - North** | **84.915** | **339** | **3.0** | **869,304** | **565,171** |
| **Caroluspoort - South** | **17.854** | **342** | **3.0** | **185,192** | **120,800** |
| Caroluspoort East | 22.272 | 336 | 3.1 | 234,584 | 152,660 |
| **Cyfferkuil** | **32.228** | **352** | **3.1** | **354,982** | **231,457** |
| De Aar | 73.624 | 330 | 3.0 | 725,915 | 470,641 |
| Helderwater | 35.709 | 352 | 3.2 | 405,167 | 263,407 |
| **Kappok Poort** | **34.674** | **312** | **2.8** | **299,774** | **192,682** |
| Klein Brandfontein | 39.087 | 311 | 2.7 | 328,433 | 211,029 |
| Die Dam | 21.177 | 348 | 3.2 | 236,375 | 153,590 |
| Leeuwfountain | 90.084 | 344 | 3.1 | 963,991 | 626,123 |
| **Paardevallei** | **148.104** | **329** | **3.0** | **1,441,189** | **933,657** |
| **Rhenosterpoort** | **96.512** | **310** | **2.7** | **810,755** | **520,027** |
| **Riet** | **51.522** | **338** | **3.0** | **514,972** | **334,975** |
| **Rietfontein** | **68.668** | **335** | **2.9** | **666,229** | **432,114** |
| Rusoord | 41.485 | 339 | 3.1 | 435,935 | 283,366 |
| Sinclairs Dam | 23.141 | 333 | 3.1 | 240,993 | 156,657 |
| Sipreshof | 14.631 | 345 | 3.2 | 160,572 | 104,368 |
| Veekraal | 18.269 | 347 | 3.2 | 202,132 | 131,791 |
| Vetlaagte | 71.744 | 336 | 3.0 | 721,660 | 469,115 |
| Wag-en-Bittje | 54.939 | 333 | 3.0 | 555,225 | 359,435 |
| Weltrede | 59.343 | 335 | 3.1 | 615,178 | 399,970 |
| **Zewefontein** | **83.503** | **357** | **3.2** | **964,578** | **628,253** |
| **Zwartkoppies** | **146.464** | **323** | **2.9** | **1,360,337** | **874,860** |
| TOTAL (Average) | 1,505.550 | (336) | 3.0 | 15,040,107 | 9,745,746 |

NOTE:
Schultze's (1997) MAP grid was adjusted using the MAP from rainfall stations at De Aar and Rooiwal (Zewefontein Catchment) using monthly rainfall records for 1950 to 2006.

## Chloride Mass Balance Method

The Chloride-Mass-Balance or CMB method provides estimates of average rates of rainfall recharge assuming that the concentration of chloride in groundwater is only derived from incremental inputs from rainfall. Crucial to the successful application of the method is accurate concentrations of chloride in rainfall. Unfortunately, the DWAF were unable to supply the rainfall chloride concentrations for De Aar in time for inclusion in this report.

Average estimates of chloride in rainfall were obtained for each GMU using DWAF's (2007) national GRAII 1x1km$^2$ raster dataset for South Africa. This dataset provides an average rainfall chloride concentration for the study area of 0.89 mg/L (**Table 4**). **Table 5** indicates the variability of chloride concentrations in rainfall at Bloemfontein (Bean, 2003). The weighted-average concentration of chloride for this dataset is 1.70 mg/L. Average potential rainfall-recharge factor for each GMU was estimated using these two sources of rainfall chloride concentration and the average or median chloride concentrations in groundwater (**Table 4**).

The rainfall-recharge factors provided by the CMB method in Cyfferkuil, Burgerville and Zewefontein GMU's are considered to be realistic for recharge to the fractured-rock aquifers in the study area. These rates vary between 1.6 and 2.8% of MAP if the GRA-II rainfall chloride concentrations are used and 3.2 to 6.8% if the average chloride concentration in rainfall at Bloemfontein is used. The calculated recharge factors for the remaining GMU's are thought to be to low and are probably influenced by the accumulation of salts in the groundwater by evapotranspiration within a 'closed' system. The GRA-II derived average recharge rates (**Table 4**) are also considered to be unrealistically high for this type of terrain.

**Table 4: Estimates of rainfall recharge factors for De Aar's Wellfields**

| Groundwater Management Unit / Wellfield | Chloride Concentration in Groundwater (mg/l) | | | | | | Average Chloride Conc. in Rain (mg/l) | % Recharge Factor [GRAII] |
|---|---|---|---|---|---|---|---|---|
| | Number Samples [Waterpoints] | Min | Max | Mean | Standard Deviation | Median | | |
| SW - Rhenosterpoort | 19 [4] | 123.1 | 789.4 | 311.9 | 150.2 | **260.8** | 0.94 | 0.4 {0.7} [7.4] |
| SW - Vaalbank | 15 [5] | 96.0 | 503.3 | **286.3** | 134.9 | **230.0** | 0.94 | 0.4 {0.7} [7.4] |
| SW - Zwartkoppies | 14 [3] | 65.0 | 463.8 | **213.0** | 118.7 | 203.0 | 0.83 | 0.4 {0.8} [7.1] |
| North - Paardevallei | 26 [4] | 36.0 | 619.7 | 293.9 | 158.9 | **341.3** | 0.92 | 0.3 {0.5} [8.2] |
| Caroluspoort - North | 19 [6] | 38.0 | 1307.0 | 243.2 | 299.8 | **156.0** | 0.88 | 0.6 {1.1} [9.2] |
| Caroluspoort - South | 41 [11] | 23.0 | 2123.0 | 810.2 | 584.3 | **696.0** | 0.90 | 0.1 {0.2} [8.7] |
| SE - Riet | 17 [5] | 171.0 | 1561.0 | 689.1 | 464.9 | **457.8** | 0.90 | 0.2 {0.4} [8.7] |
| Cyfferkuil | 28 [10] | 22.2 | 129.1 | 66.8 | 31.2 | **53.4** | 0.86 | 1.6 {3.2} [8.9] |
| Burgerville | 18 [5] | 9.8 | 86.7 | **43.0** | 18.4 | 42.2 | 0.85 | 2.0 {4.0} [8.3] |
| Zewefontein | 40 [4] | 18.7 | 56.6 | **29.2** | 10.0 | 24.9 | 0.83 | 2.8 {6.8} [9.2] |

NOTES:

- [7.0] – Recharge factor obtained from DWAF's National GRAII 1x1km$^2$ Raster Dataset.
- {0.5} – Recharge factor estimated using the weighted average chloride concentration of 1.7 mg/l for rainfall at Bloemfontein (Table 5)
- Chloride concentration in rainfall from DWAF's National GRAII 1x1km$^2$ Raster Dataset.
- **Bold-faced**: Mean or Median chloride concentration in groundwater used to calculate recharge factor.
- Caroluspoort –North: Borehole G18882 and G18884 excluded.
- South-West Zwartkoppies Wellfield – exclude production borehole G27703.

### 3.5.3 Groundwater Exploitation Potential

The GMU's defined as part of this study lie either within the D62C or D62D Quaternary catchments, which fall into 'Groundwater Abstraction Zone A' as defined in the revised (Government Gazette 26187, No. 399, 20 March 2004) General Authorisation (GA) of Section 39 of the National Water Act #36 (1998), where only Schedule 1 use is allowed.

The DWAF's GRAII Project 2 (2007) produced a national raster dataset of the so-called '*Average Groundwater Resource Potential*' or AGEP, which was summarised per GMU (**Table 6**). The AGEP values lie midway between the estimated recharge volumes for normal and drought periods (**Table 3**), and are generally accepted as reasonable estimates of the long-term sustainable yield of the GMU's in the study area.

**Table 5: Rainfall chloride concentrations measured at Bloemfontein for the period 2002-2003.**

| Month | Bloemfontein | |
|---|---|---|
| | Rainfall (mm) | Chloride (mg/l) |
| February | 36.1 | 0.80 |
| March | 51.0 | 0.53 |
| April | 40.4 | 1.23 |
| May | 31.0 | 0.49 |
| June | 6.0 | 0.58 |
| July | 0.0 | 0.00 |
| August | 99.0 | 0.49 |
| September | 10.0 | 3.12 |
| October | 35.5 | 10.22 |
| November | 20.0 | 10.37 |
| December | 98.1 | 0.24 |
| January | 50.0 | 0.22 |
| Total rainfall (mm) | 477.1 | 1.7 |
| Weighted average - All data | - | - |
| *Source Bean (2003)* | | |

**Table 6: Average Groundwater Resource Potential per GMU**

| Groundwater Management Unit | AGEP ($m^3/a$) | Groundwater Management Unit | AGEP ($m^3/a$) |
|---|---|---|---|
| **Blauuw Krans** | **788,519** | Paardevallei | 1,142,260 |
| Bloemhof | 80,983 | **Rhenosterpoort** | **665,770** |
| **Burgerville** | **225,371** | **Riet** | **413,323** |
| Burgervilleweg | 386,160 | **Rietfontein** | **611,869** |
| **Caroluspoort - North** | **628,041** | Rusoord | 289,260 |
| **Caroluspoort - South** | **128,731** | Sinclair Dam | 152,207 |
| Caroluspoort - East | 159,255 | Sipreshof | 122,076 |
| **Cyfferkuil** | **279,725** | Veekraal | 147,788 |
| De Aar | 537,112 | Vetlaagte | 493,565 |
| Helderwater | 319,513 | Wag-en-Bittje | 480,044 |
| **Kappok Poort** | **261,577** | Weltrede | 539,885 |
| Klein Brandfontein | 297,844 | **Zewefontein** | **656,587** |
| Die Dam | 197,200 | **Zwartkoppies** | **1,045,533** |
| Leeuwfountain | 883,979 | | |
| TOTAL | | | 11,934,176 |

## 3.6 Groundwater Monitoring, Abstraction and Resource Assessment per GMU

De Aar is currently pumping ~2.3 $Mm^3$ of groundwater per annum from approximately 51 production boreholes located up to 36km from the town. The monthly groundwater abstraction is read from the water-meters attached to each production borehole and is archived at the Municipal offices. This information is meant to be captured into *AquiMon* by a Municipal official, but lack of adequate computer skills, inadequate training and 'accidental loss' of the database, which had not been backed-up, have hampered these efforts. The DWAF have equipped some 26 boreholes in the De Aar area with digital waterlevel data-loggers. This information is downloaded from the loggers by a Municipal official and forwarded to the DWAF's regional office in Kimberley. This information is also meant to be captured into *AquiMon* by the Municipality, but for reasons mentioned above, this is not happening. Currently, manual 'hand' waterlevels measurements using a dipmeter are not being taken in any of the other holes previously monitored by the DWAF.

The DWAF's regional office in Kimberley is monitoring groundwater chemistry at three sites on a bi-annual basis, namely at borehole CT37 in the De Aar GMU (**Figure 35**), borehole ZN54 in the Zewefontein GMU (**Figure 42**) and the Populierbos spring in the Burgerville GMU.

### 3.6.1 Zwartkoppies and Rhenosterpoort GMU's

The production boreholes tapping the Zwartkoppies and Rhenosterpoort groundwater management units are collectively referred to as the '*South-Western*' Scheme. Smit (1975) recommended 11 production boreholes located on the farms Rhenosterpoort, Vaalbank and Zwartkopjes. In 1990, Vegter subdivided the South-Western Scheme into two groundwater units, namely XX and XXI-B (**Figure 5**). The geographic extent of Vegter's units have been retained for this study, but they have been renamed to the Rhenosterpoort and Zwartkoppies GMU's (**Figure 4**), respectively. The Rhenosterpoort GMU has been further subdivided into two separate wellfields, referred to as the (1) Rhenosterpoort and (2) Vaalbank Wellfields (**Figure 8**).

#### Groundwater Abstraction and Waterlevel Monitoring

Eight production boreholes on the farms Rhenosterpoort and Vaalbank were commissioned in September 1978, followed by an additional four holes on the farm Zwartkoppies in February 1980. These production boreholes are currently all still in operation. The technical specifications for each production borehole are summarised in **Table 7**. The status of the waterlevel monitoring network in the South-Western Scheme is as follows:

- Rhenosterpoort Wellfield:
  - Only borehole G27720 is currently fitted with a digital waterlevel data-logger.
  - The autographic waterlevel recorders on boreholes G27716 and G27707D were removed by the DWAF towards the end of 2003.
- Vaalbank Wellfield:
  - Digital waterlevel data-loggers are fitted to the following holes: G27709, G23205, G23204C and G39224.

- The autographic waterlevel recorders on boreholes G39225 to G39231 were removed by the DWAF towards the end of 2003. These holes used to form part of a specialised monitoring network aimed at assessing recharge to the alluvial – bedrock aquifer during flood events in the Elandsfontein River.

- Zwartkoppies Wellfield:
  - Digital waterlevel data-loggers are currently fitted in monitoring boreholes G27708 and G27708C.

**Table 7: South-Western Scheme - Operational Production Boreholes and Recommended Management Specifications**

| Borehole Number | Vegter's Groundwater Unit | Depth (m) | Pump-Intake (m) | Pump-Rate (L/s) | Maximum Monthly Abstraction ($m^3$) | Maximum Permissible Waterlevel (m) below collar |
|---|---|---|---|---|---|---|
| **Rhenosterpoort Wellfield** | | | | **24.5** | **26,000** | |
| G27707 | XXIB | 29.0 | 23.0# | 6.0 [10] | 6,600 (5,000) | 8.0 |
| G27719I | XXIB | 42.4 | 27.5# | 7.0 [10] | 7,800 (5,800) | 10.0 |
| G27704 | XXIB | 45.7 | 18.0 | 8.0 [9] | 7,800 (5,800) | 8.5 |
| G23206A | XXIB | 22.8 | 15.0 | 3.5 [10] | 3,800 (3,400) | 8.0 |
| **Vaalbank Wellfield** | | | | **16.0** | **11,400** | |
| G27715G | XXIB | 15.5 | 16.0 | 3.5 [7] | 2,800 (3,400) | 10.0 |
| G23205B | XXIB | 21.6 | 15.0 | 5.0 [6] | 3,100 (5,000) | 9.8 |
| G23205F | XXIB | 22.8 | 18.0 | 4.0 [7] | 2,900 (4,500) | 10.0 |
| G23204D | XXIB | 22.9 | 16.0 | 3.5 [7] | 2,600 (3,400) | 9.0 |
| **Zwartkoppies Wellfield** | | | | **19.0** | **21,300** | |
| G23203A | XX | 22.8 | 16.0 | 4.0 [11] | 4,840 (5,000) | 10.0 |
| G27702G | XX | 26.4 | 16.0 | 4.5 [10] | 4,840 (5,000) | 9.0 |
| G27703 | XX | 22.8 | 12.0 | 6.0 [10] | 6,780 (7,000) | 8.0 |
| G23202 | XX | 19.8 | 12.0 | 4.5 [10] | 4,840 (5,000) | 8.0 |

Notes:
# - Recommended by Smit (1975).
(5,000) – Previously recommended maximum monthly abstraction.
[9] – Pumping schedule in hours per day.
**Maximum Permissible Drawdown** – waterlevel prior to switch-on of pump (i.e. rest-waterlevel) after a rest period of approximately 8 hours. The maximum permissible drawdown indicates (i) the depth below which pump-inlets should be installed, and (ii) the depth at which a float-operated switching device should be installed to safeguard the pump from running dry.
G27715G - drilled 24.4m deep, reduced depth is as a result of a pump getting stuck at the bottom of the hole.
G23206A – in use but not recommended by Smit (1975)

The waterlevels in the central portion (G27716, G23204C and G27720 in the Vaalbank Wellfield) of the Rhenosterpoort GMU are currently some 4m lower than those in the Rhenosterpoort Wellfield (G27716 and G27720, **Figure 9**), although all waterlevels were at a similar level after the floods of 1974. This phenomenon is due to over-pumping from the Vaalbank Wellfield, where the yield capacity of the aquifer is significantly lower than in the Rhenosterpoort Wellfield due to differences in the physical characteristics of the alluvial-bedrock aquifer and the fact that the latter wellfield is located in the discharge zone of the GMU.

The production boreholes in the Zwartkoppies GMU (**Figure 8**) are clustered in a relatively small area in the discharge (outlet) zone of this GMU. The waterlevels have varied between 3.5 to 6 m.bgl (**Figure 10**), but reached an all time low of over 8m.bgl in 1987 due to overexploitation, coupled with very dry conditions. Currently the waterlevels in the aquifer are at acceptable levels (~5m.bgl).

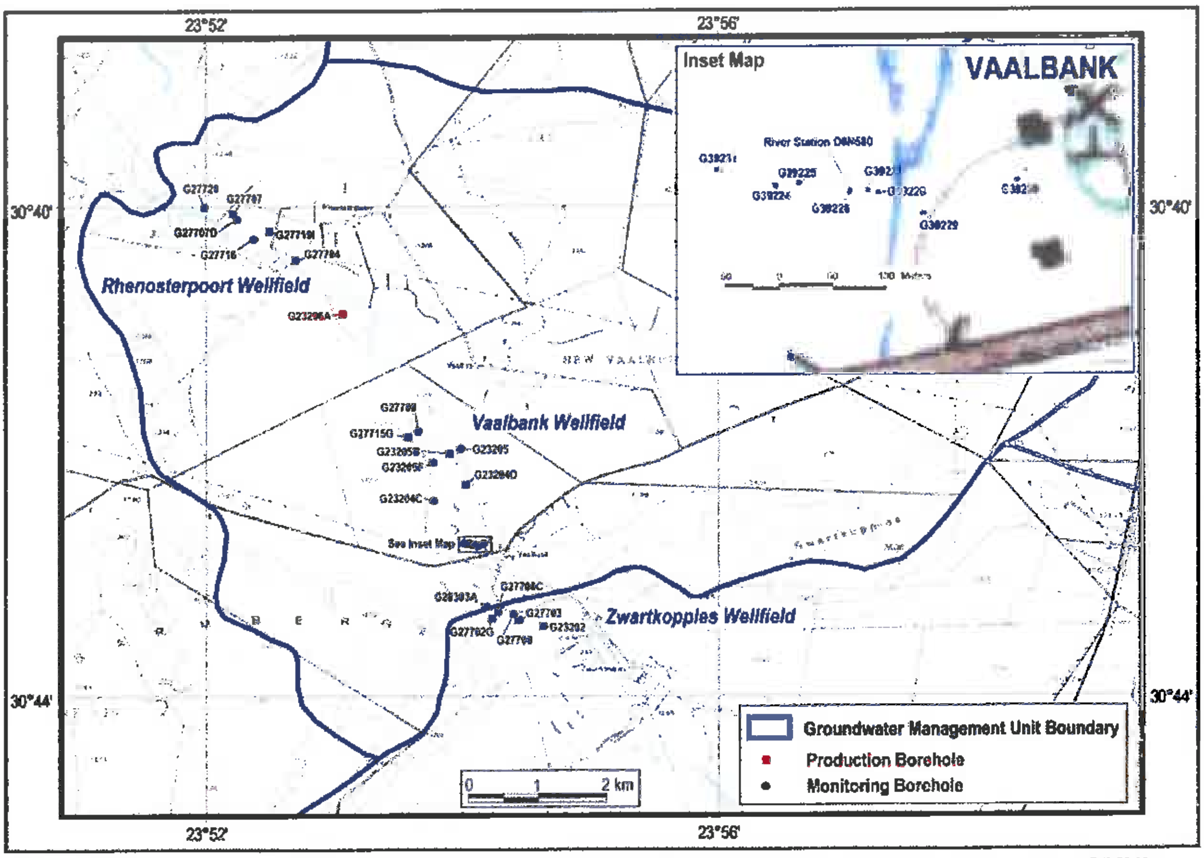



**Figure 8: Production and Monitoring Boreholes in the Rhenosterpoort and Zwartkoppies GMU's**

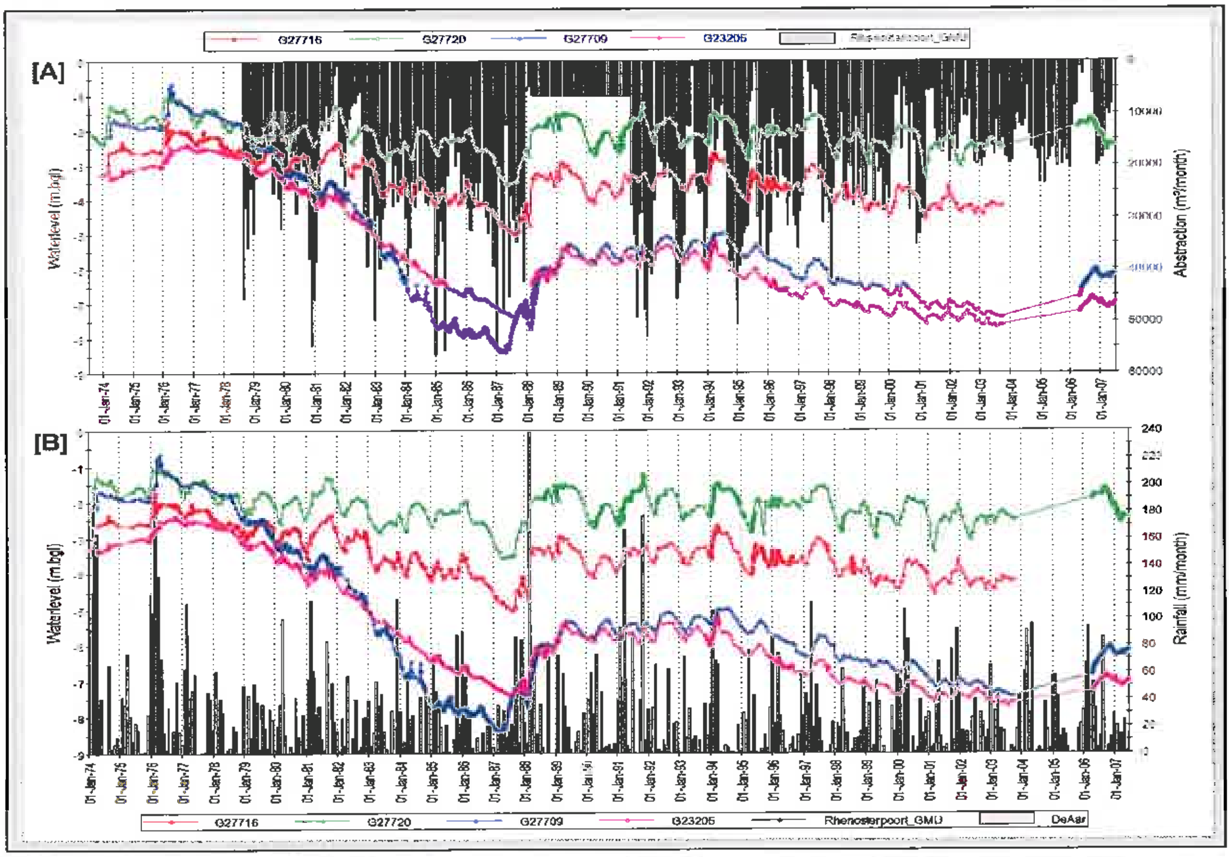



**Figure 9: Rhenosterpoort GMU - Waterlevels versus [A] Abstraction and [B] Monthly Rainfall**

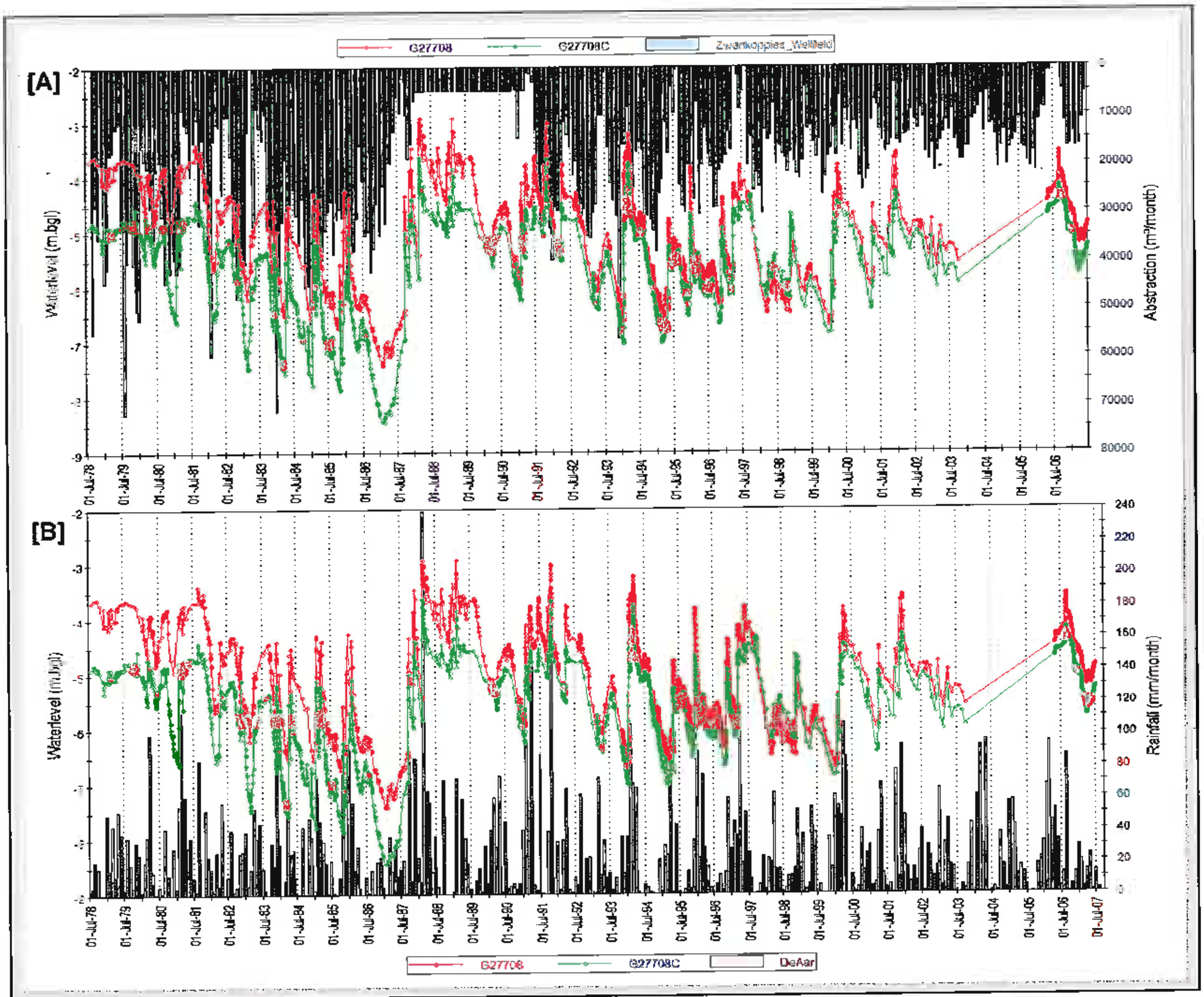



**Figure 10: Zwartkoppies GMU - Waterlevels versus [A] Abstraction and [B] Monthly Rainfall**

Smit (1975) estimated the 'safe yield' of the entire South-Western Scheme (i.e. Rhenosterpoort and Zwartkoppies GMU's) at ~550,000 $m^3$/a. Vegter (1990) estimated the 'minimum steady yield' of the Zwartkoppies and Rhenosterpoort GMU at ~1,041,000 and ~677,000 $m^3$/a, respectively, assuming a recharge rate of 6.6 mm/a or ~2.1% of MAP (**Table 2**). He postulated that between 80 to 90% of the total rainfall recharge to the South-Western Scheme occurred in the higher-lying hard rock areas of the GMU, and that the remainder infiltrated through the bed of the Elandsfontein stream during infrequent flood events. Furthermore, he found that the actual volumes of rainwater recharged during periods of high rainfall were severely restricted by the limited storage capacity ('live' storage) of the fractured-rock aquifers and rapid discharge of water from the catchment by runoff.

Application of the Cumulative Rainfall Departure or CRD Method (Bredenkamp et al, 1995) to monthly rainfall data for De Aar versus wellfield abstraction and waterlevel fluctuations in boreholes G27720 (Rhenosterpoort Wellfield, **Figure 12**), G23205 (Vaalbank Wellfield, **Figure 11**) and G27708 (Zwartkoppies Wellfield, **Figure 13**) indicated a rainfall-recharge factor of between 1.2 and 1.5%, which is somewhat lower than that used to estimate recharge using the Maxey-Eakin Method (**Table 3**). An average recharge factor of 1.2 and 1.5% of MAP is accepted for the Zwartkoppies and Rhenosterpoort GMU's, respectively. The waterlevel variations in borehole G23205 before January 1988 could not be simulated using the CRD method, most likely due to inaccurate abstraction records prior to this date. Storativity values of 0.005 to 0.009 and rainfall threshold values of 15 to 30 mm/month produced the best CRD fits.

**The long-term sustainable yield of the Rhenosterpoort GMU is estimated at 448,800 m³/a** (37,400 m³/month) by down-scaling the recharge volumes in **Table 3** to take into account the revised recharge factor of 1.5% of MAP. Similarly, **the sustainable yield of the Zwartkoppies GMU is estimated at ~567,600 m³/a** (47,300 m³/month) using a recharge factor of 1.2% of MAP. In this GMU, the current configuration of production boreholes can only harvest ~45% of the total recharge, which means that the sustainable yield of the Zwartkoppies Wellfield is ~255,600 m³/a (21,300 m³/month). These revised estimates of the long-term sustainable yield of the GMU's were compared to the annual volumes abstracted since 1978 (**Table 8**), where it can be seen that the set abstraction limits have not been exceeded since 1997. The maximum monthly abstraction volumes from each production borehole have been adjusted to account for the revised yields of the wellfields and are presented in **Table 7**. Production from the Vaalbank Wellfield has been down-scaled by ~25%, whilst that from the Rhenosterpoort Wellfield has been increased by a similar amount, to create a better 'balance' of waterlevel drawdown between the two wellfields.

**Table 8: Annual Groundwater Abstraction from the South-Western Scheme**

| Date | Annual Groundwater Abstraction (m³) | | | |
|---|---|---|---|---|
| | Rhenosterpoort GMU | Zwartkoppies GMU | Total | Comment |
| 1978 | 273,858 | 139,916 | 413,774 | Sep to Dec 1978 |
| 1979 | **675,418** | **415,647** | 1,091,065 | |
| 1980 | **646,992** | **729,664** | 1,376,656 | |
| 1981 | **468,418** | **279,343** | 747,761 | |
| 1982 | **668,813** | **333,596** | 1,002,409 | |
| 1983 | **671,994** | **287,316** | 959,310 | |
| 1984 | **605,816** | **444,336** | 1,050,152 | |
| 1985 | **668,432** | **441,485** | 1,109,917 | |
| 1986 | **576,801** | **408,758** | 985,559 | |
| 1987 | **674,369** | 207,208 | 881,577 | |
| 1988 | 78,106 | 60,416 | 138,522 | Missing Data |
| 1989 | 81,086 | 58,416 | 139,502 | Missing Data |
| 1990 | 81,096 | 58,152 | 139,248 | Missing Data |
| 1991 | 391,931 | 173,901 | 565,832 | Missing Data |
| 1992 | **550,995** | **292,347** | 843,342 | |
| 1993 | **495,692** | **306,323** | 802,015 | |
| 1994 | **473,443** | **274,946** | 748,389 | |
| 1995 | **501,977** | 235,695 | 737,672 | |
| 1996 | **530,934** | **266,140** | 797,074 | |
| 1997 | 354,570 | 147,870 | 502,440 | |
| 1998 | 414,876 | 219,412 | 634,288 | |
| 1999 | 404,436 | 213,713 | 618,149 | |
| 2000 | 293,410 | 175,366 | 468,776 | |
| 2001 | 294,553 | 178,951 | 473,504 | |
| 2002 | 282,510 | 164,539 | 447,049 | |
| 2003 | 330,767 | 190,726 | 521,493 | |
| 2004 | 283,834 | 148,580 | 432,414 | |
| 2005 | 346,579 | 201,225 | 547,804 | |
| 2006 | 149,249 | 86,368 | 235,617 | |
| 2007 | 143,805 | 80,439 | 224,244 | Jan to Jun 2007 |
| Sus Q. | **448,800** | **255,600** | **704,400** | |
| Bold-font – volume in excess of long-term sustainable yield (Sus Q.) of GMU (m³/a). | | | | |

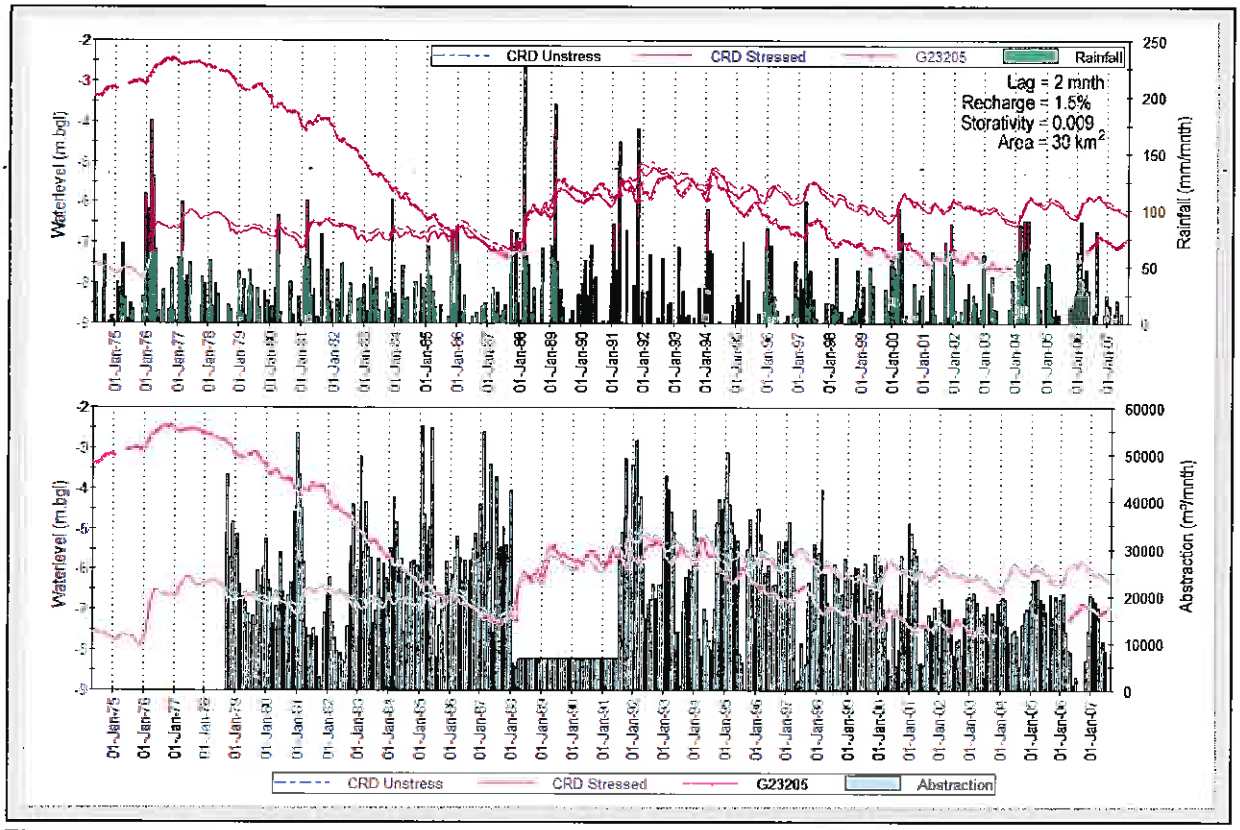



**Figure 11**: **CRD Analysis – Monitoring Borehole G23205 (Vaalbank Wellfield)**

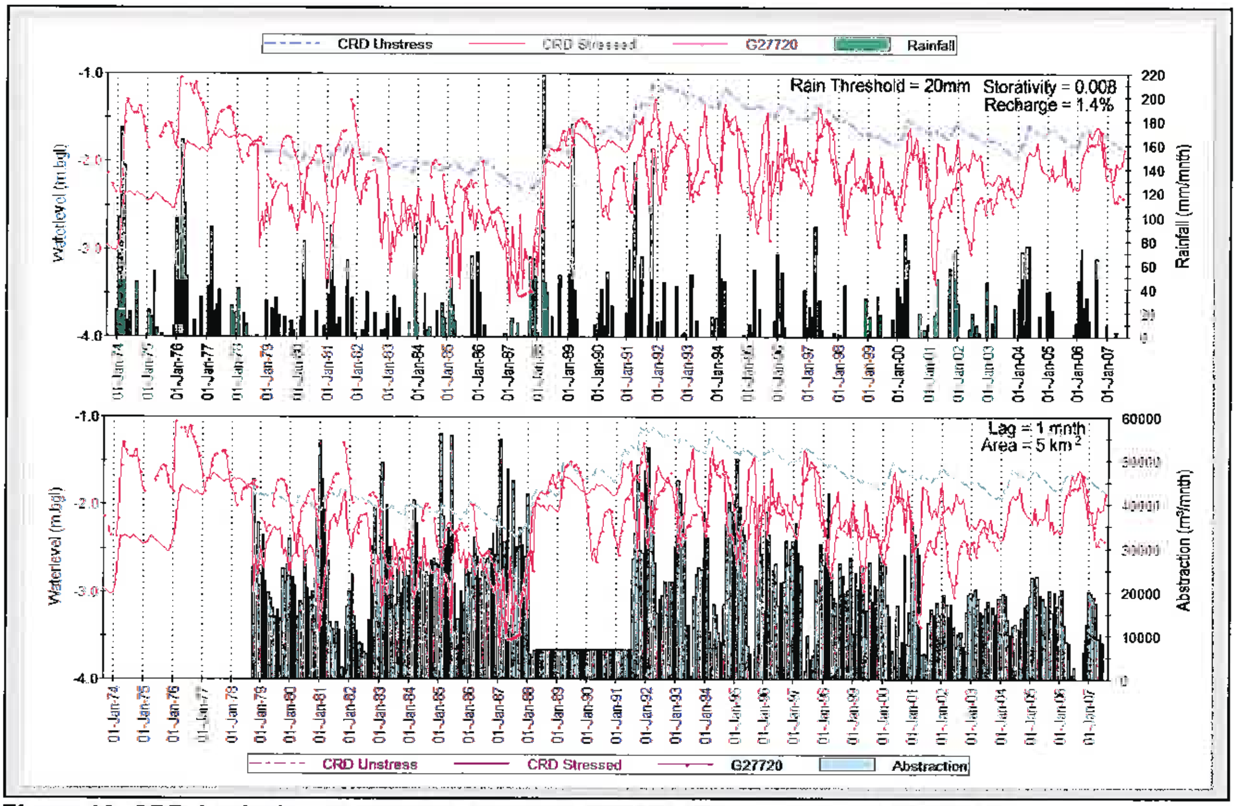



**Figure 12**: **CRD Analysis – Monitoring Borehole G27720 (Rhenosterpoort Wellfield)**

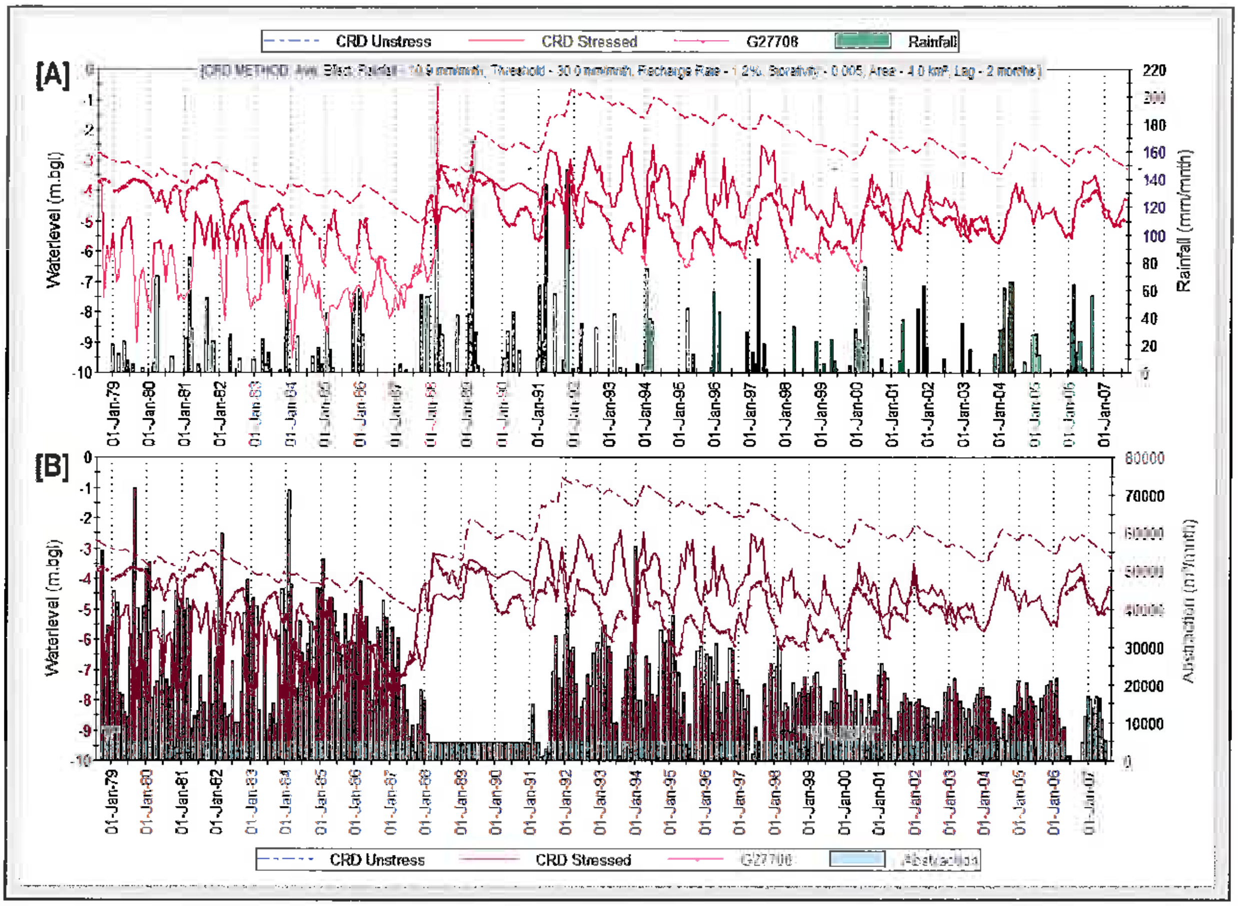



**Figure 13: CRD Analysis – Monitoring Borehole G27708 (Zwartkoppies Wellfield)**

## Groundwater Quality

The historical groundwater chemistry information for the production and monitoring boreholes in these GMU's were imported into *AquiMon* from the DWAF's national water quality database. The available groundwater chemistry for each production borehole is graphically presented on Piper diagrams in **Appendix 3**.

The groundwater from the Rhenosterpoort GMU (**Table 9**) and Zwartkoppies GMU (**Table 10**) is slightly saline. Significant amounts of nitrate are also present in the groundwater. Piper plots showing the groundwater chemistry of the Rhenosterpoort and Zwartkoppies GMU's are presented in **Figure 14** and **Figure 15**, respectively. The salinity of the groundwater typically increases along the flow path, mainly as a result of the accumulation of sodium chloride. The chemistry of the groundwater in production boreholes located in the discharge zones of the GMU's, i.e. G27707 and G2770G in Rhenosterpoort and Zwartkoppies GMU's, respectively, show a more Ca-Mg-$HCO_3$ character that is due to inter-mixing of groundwater in the alluvium with water recharged on the nearby dolerite ring-dykes that form the elevated boundary of these units.

**Table 9: Summary Statistics of Groundwater from production holes in the Rhenosterpoort GMU**

| Chemical Parameter | No. Recs | Minimum | Maximum | Mean | Standard Deviation | Median | Lower Quartile | Upper Quartile | 90th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| Lab. pH | 34 | 7.4 | 8.6 | 8.0 | 0.3 | 7.9 | 7.8 | 8.2 | 8.4 |
| EC (mS/m) | 34 | 85.0 | 375.7 | 194.0 | 65.6 | 178.0 | 137.0 | 245.5 | 274.2 |
| Sodium (mg/l) | 33 | 83.0 | 450.0 | 238.9 | 103.6 | 211.4 | 153.0 | 320.1 | 369.1 |
| Calcium (mg/l) | 34 | 18.0 | 157.6 | 66.8 | 34.6 | 63.5 | 39.1 | 84.8 | 118.9 |
| Magnesium (mg/l) | 33 | 24.0 | 210.0 | 77.2 | 39.8 | 65.0 | 51.2 | 99.8 | 125.7 |
| Chloride (mg/l) | 34 | 96.0 | 789.4 | 300.6 | 144.2 | 248.0 | 204.0 | 421.4 | 482.3 |
| Potassium (mg/l) | 27 | 0.80 | 5.25 | 2.13 | 1.20 | 1.80 | 1.30 | 2.40 | 3.83 |
| Silica (mg/l) | 27 | 1.24 | 25.90 | 20.87 | 4.30 | 21.55 | 20.09 | 22.70 | 23.89 |
| Sulphate (mg/l) | 33 | 48.0 | 727.1 | 244.8 | 133.6 | 203.4 | 168.0 | 320.2 | 387.2 |
| TAL (mg/l) | 33 | 170.9 | 431.9 | 321.1 | 62.5 | 330.0 | 295.0 | 368.4 | 395.5 |
| Fluoride (mg/l) | 32 | 0.2 | 1.8 | 0.8 | 0.4 | 0.7 | 0.5 | 1.1 | 1.3 |
| Nitrate (mg/l) | 30 | 0.02 | 5.49 | 2.46 | 1.56 | 2.18 | 1.24 | 3.55 | 4.69 |
| Ammonia (mg/l) | 25 | 0.00 | 0.13 | 0.03 | 0.03 | 0.02 | 0.02 | 0.03 | 0.09 |
| Orthophosphate | 25 | 0.006 | 0.060 | 0.030 | 0.020 | 0.025 | 0.011 | 0.052 | 0.054 |

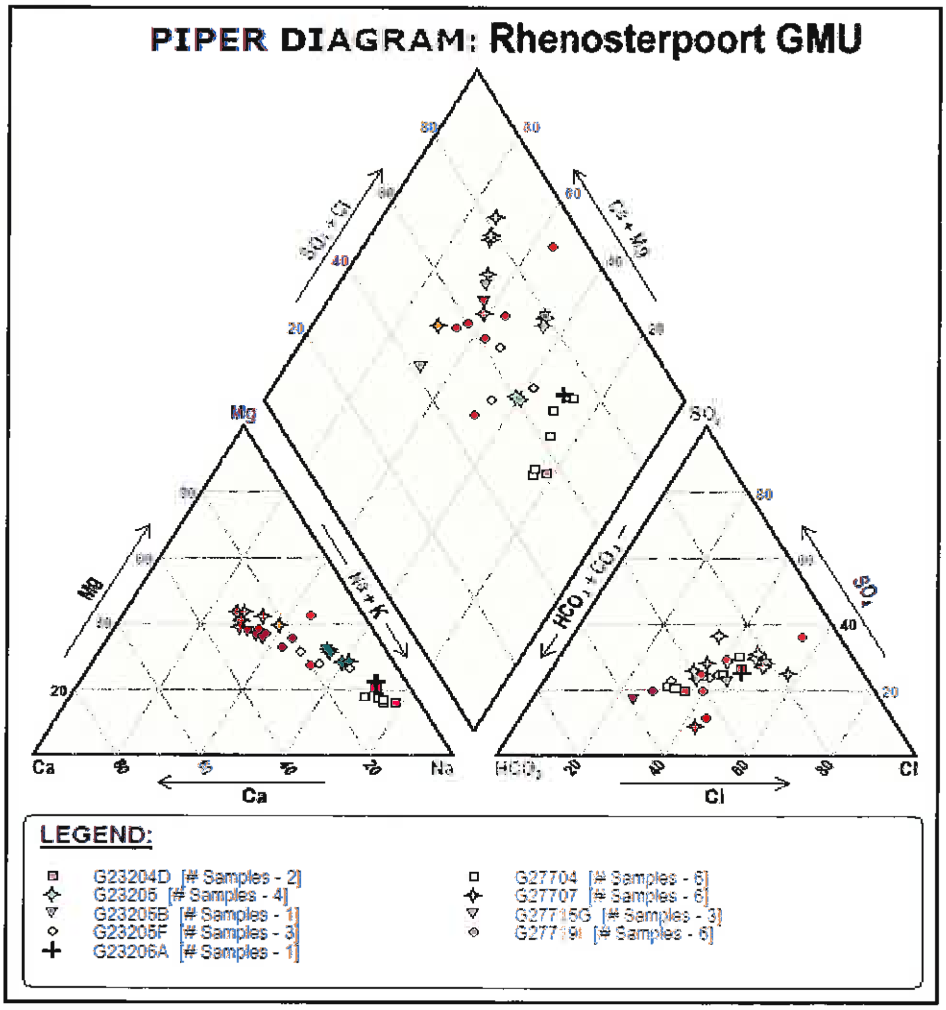



**Figure 14: Piper Plot indicating Macro-Chemistry of Groundwater from Production Boreholes of the Rhenosterpoort GMU**

**Table 10: Summary Statistics of Groundwater from production holes in the Zwartkoppies GMU**

| Chemical Parameter | No. Recs | Minimum | Maximum | Mean | Median | Std Deviation | Lower Quartile | Upper Quartile | 90th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| Lab. pH | 19 | 7.4 | 8.6 | 8.0 | 7.9 | 0.3 | 7.7 | 8.3 | 8.4 |
| EC (mS/m) | 19 | 75.0 | 267.0 | 166.3 | 150.0 | 54.1 | 142.6 | 202.6 | 240.6 |
| Sodium (mg/l) | 19 | 90.0 | 462.8 | 271.7 | 286.0 | 109.2 | 193.8 | 335.6 | 399.3 |
| Calcium (mg/l) | 19 | 23.8 | 90.0 | 54.4 | 55.0 | 15.6 | 44.0 | 60.0 | 73.6 |
| Magnesium (mg/l) | 19 | 7.0 | 70.0 | 44.0 | 46.0 | 16.6 | 35.4 | 55.0 | 61.2 |
| Chloride (mg/l) | 19 | 65.0 | 463.8 | 225.2 | 213.0 | 111.0 | 142.0 | 283.5 | 381.6 |
| Potassium (mg/l) | 12 | 0.40 | 1.20 | 0.78 | 0.78 | 0.25 | 0.59 | 0.89 | 1.13 |
| Silica (mg/l) | 12 | 20.00 | 23.70 | 21.51 | 21.51 | 0.98 | 20.75 | 21.92 | 22.65 |
| Sulphate (mg/l) | 19 | 102.0 | 284.2 | 185.9 | 173.0 | 59.2 | 127.5 | 225.5 | 278.7 |
| TAL (mg/l) | 19 | 214.0 | 444.0 | 373.6 | 385.6 | 61.7 | 342.5 | 420.4 | 438.4 |
| Fluoride (mg/l) | 19 | 0.10 | 1.07 | 0.62 | 0.70 | 0.27 | 0.45 | 0.81 | 0.88 |
| Nitrate (mg/l) | 11 | 0.19 | 30.27 | 4.36 | 1.37 | 8.26 | 1.25 | 2.66 | 4.24 |
| Ammonia (mg/l) | 12 | 0.010 | 0.090 | 0.025 | 0.020 | 0.021 | 0.015 | 0.020 | 0.038 |

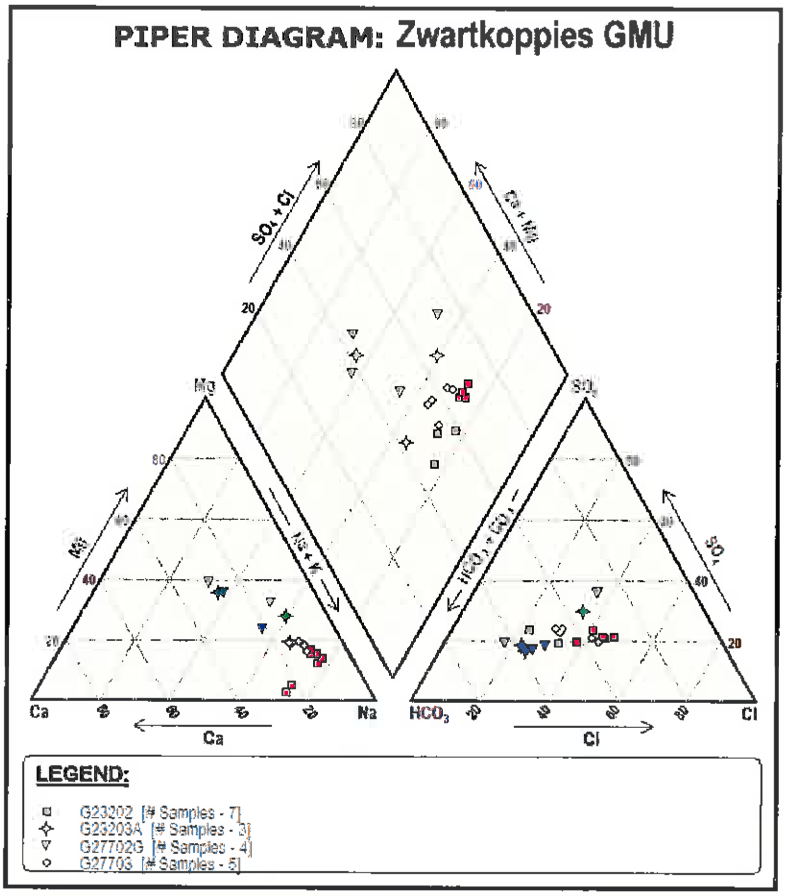



**Figure 15: Piper Plot indicating Macro-Chemistry of Groundwater in Production Boreholes of the Zwartkoppies GMU**

Woodford (unpublished data, 1989) measured the 'bulk' EC of groundwater abstracted from the South-Western Scheme at the inflow to the main distribution reservoir in De Aar over the period January 1988 to October 1989 (**Figure 16**), during which time 1,110 mm of rain fell in the district. The EC of the groundwater increased rapidly during February 1988 following an initial heavy rainfall of 239mm. This increase in salinity is probably due to the dissolution and rapid transport of salts accumulated in the vadose zone down into the shallow aquifer system by this initial pulse of infiltrating rainwater. The aquifer was subsequently recharged by relatively fresh water that resulted in the EC declining from 215 to 149 mS/m by the end of May 1988. The EC of the groundwater then gradually rose as the river flow slowly decreased and eventually stopped flowing in April 1989. Fluctuations in the major ion concentrations of groundwater pumped from G23202 since August 1973 are indicated in **Figure 17**. The salinity of the groundwater has apparently increased over time, due mainly to an increase in sodium and chloride content, especially following the floods of 1988/89.

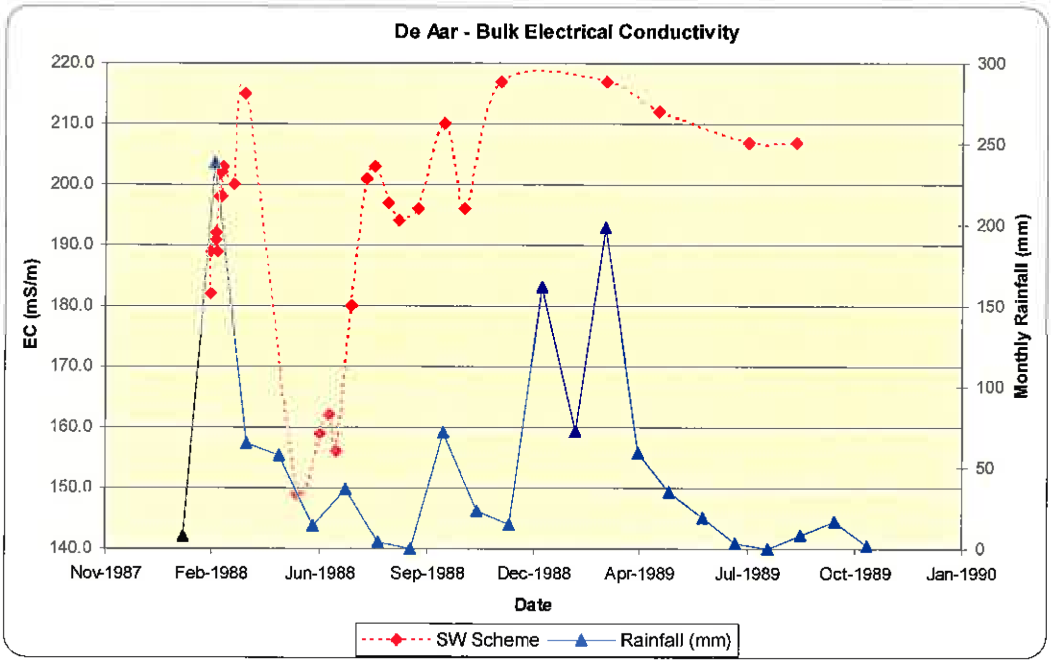



**Figure 16: EC variations of groundwater abstracted from the South-Western Scheme over period February 1988 to August 1989**

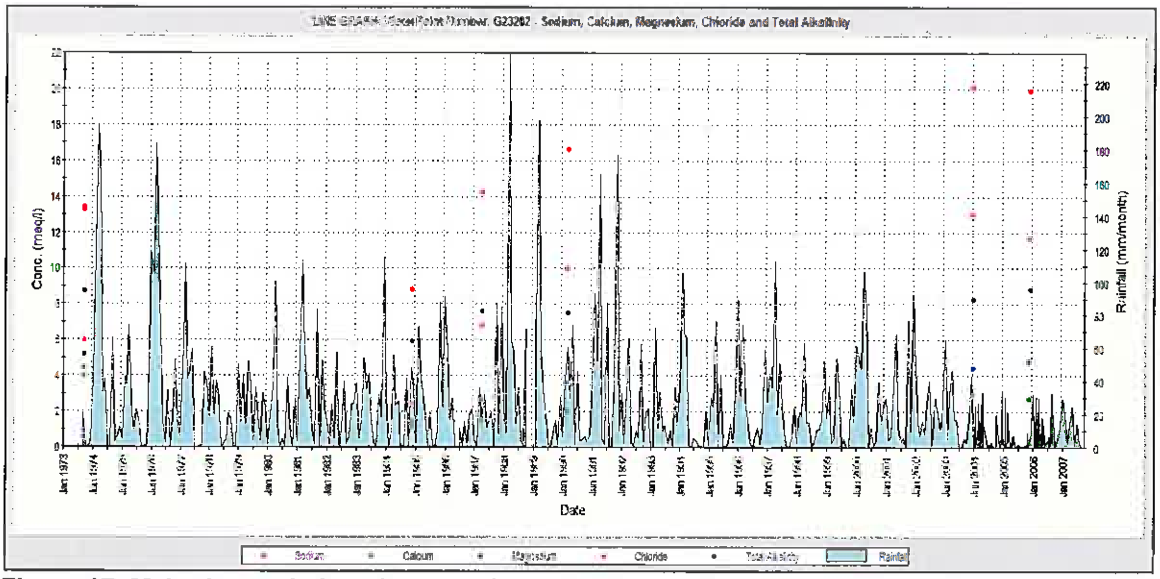



**Figure 17: Major ion variations in groundwater in G23202 (Zwartkoppies GMU)**

**Plate 3: Production Borehole G23205F ('Suidwes' No. 7) in the South-Western Scheme, with cement platform to avoid damage to the hole and pump equipment during flooding (photo F. Fourie)**

### 3.6.2 Paardevallei GMU

Vegter (1990) defined a large groundwater unit, XVI-B (**Figure 5**), in which all the production boreholes of the so-called 'Northern Scheme' are located. The geographic extent (148 $km^2$) of this unit has been retained and it will hereafter be referred to as the Paardevallei GMU. Groundwater is currently being exploited from four production boreholes in the unit (**Figure 18**). The recommended operational and management specifications are presented in **Table 11**. Monitoring boreholes G28420B and G29645 are equipped with waterlevel data-loggers that were installed by the DWAF's regional office in Kimberley. The autographic waterlevel monitoring recorder on borehole G29661 was removed from the hole by the DWAF towards the end of 2003.

**Table 11: Paardevallei GMU - Operational Production Boreholes and Recommended Management Specifications**

| Borehole Number | Vegter's Groundwater Unit | Depth (m) | Pump-Intake (m) | Pump-Capacity (L/s) | Maximum Monthly Abstraction ($m^3$) | Maximum Permissible Drawdown (m) below collar |
|---|---|---|---|---|---|---|
| G29644 | XVIB | 40.0# | 30.0# | 5.0* | 2,900* | 20* |
| G29617 | XVIB | 22.0# | 18.0 | 8.0 | 7,900* | 12 |
| G39145 | XVIB | 45.7 | 15.0 | 8.0 | 7,100* | 13* |
| G28420 | XVIB | 22.0# | 18.0 | 7.0 | 5,000* | 12 |
| **Total** | | | | **28.0** | **22,900** | |

Notes:

# - Recommended by Smit (1975). * - Recommended by Vegter (1990).

**Maximum Permissible Drawdown** – waterlevel prior to switch-on of pump after a rest period of approximately 8 hours. The maximum permissible drawdown indicates (i) the depth below which pump-inlets should be installed, and (ii) the depth at which a float-operated switching device should be installed to safeguard the pump from running dry.

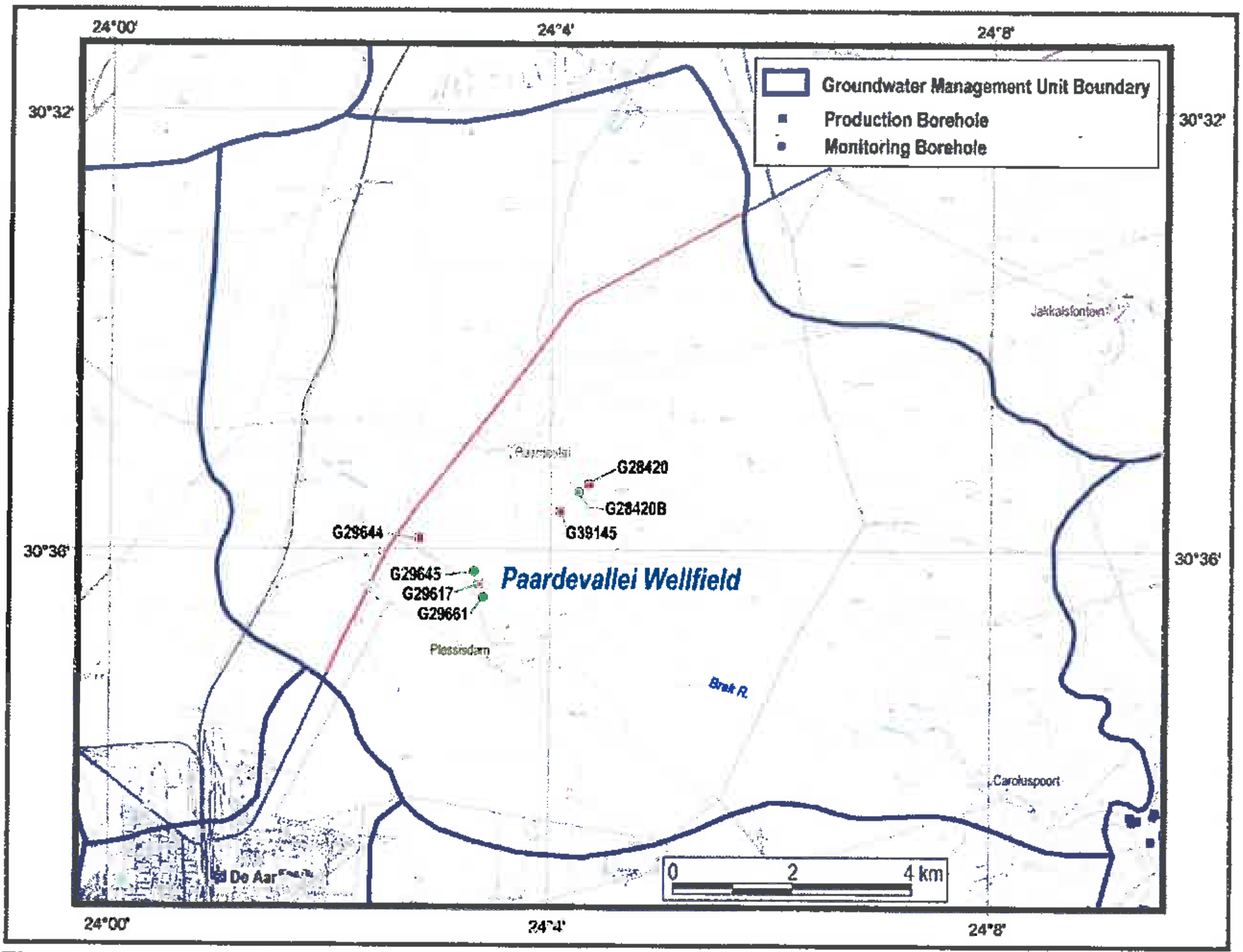



**Figure 18**: Production and Monitoring Boreholes in the Paardevallei GMU

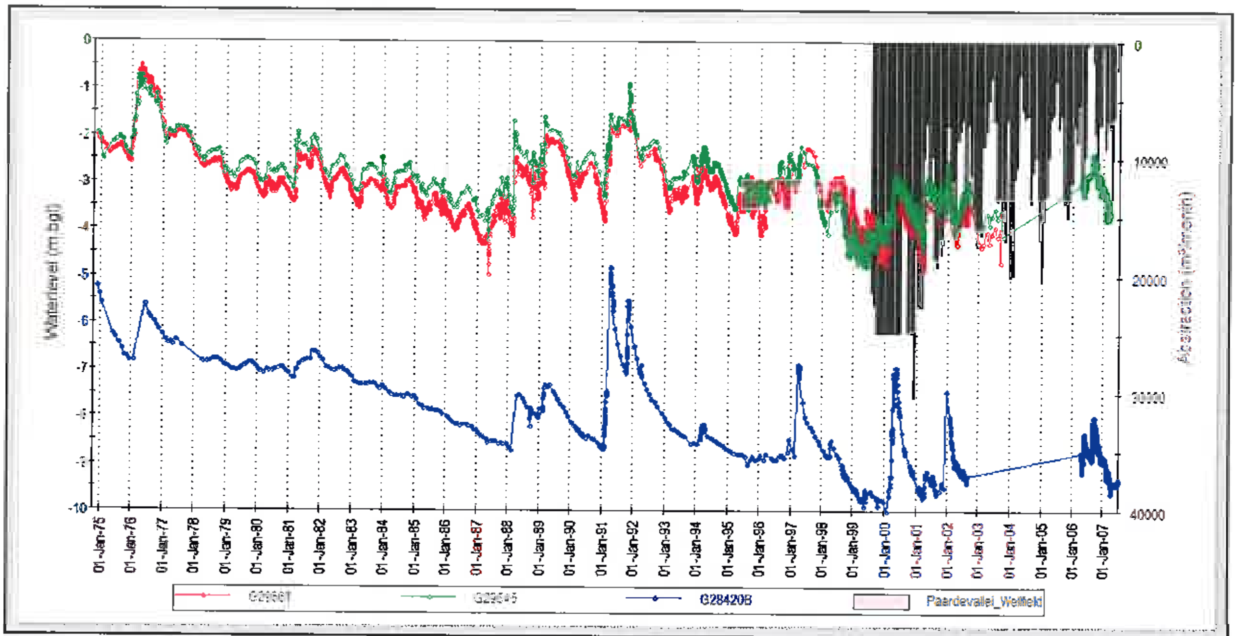



**Figure 19**: Abstraction from the Paardevallei Wellfield versus waterlevel fluctuations in boreholes G29645, G28420B and G29661

Vegter (1992) estimated the 'minimum steady yield' of the GMU at 1,014 $Mm^3$/annum based upon an average recharge rate of 6.6 mm/a or ~2% of MAP (**Table 2**). He estimated that an additional 362,000 $m^3$/a of groundwater is being abstracted from the unit by farmers for irrigation and stock-watering purposes. The 'Average Groundwater Exploitation Potential' of this GMU is ~1,142 $Mm^3$/a (**Table 6**), assuming a CMB derived recharge rate of 8.2% (**Table 4**).

A GIS-based recharge estimate of 1.441 $Mm^3$/a is obtained for periods of normal rainfall assuming an average recharge factor of 3% of MAP (329mm), declining to 934,000 $m^3$/a during droughts (**Table 3**). CRD analyses of monthly rainfall versus waterlevel fluctuations in G28420B (**Figure 20**), G29661 (**Figure 21**) and G29645 (**Figure 22**) produced a 'best-fit' average recharge factor of 1.5%, and storativity values of between 0.003 and 0.004. Note the significant deviation between the CRD levels and the actual waterlevels between January 1992 and late 1999 (**Figure 22**), due to a lack of Municipal abstraction records during this period. A recharge factor of 1.5% of MAP is therefore accepted and the **long-term average sustainable yield of the Unit is set at ~721,000 $m^3$/a** (i.e. half of the GIS-based recharge estimate for normal rainfall conditions). The volume of groundwater available for abstraction from the Municipal production holes is therefore ~359,000 $m^3$/a, if Vegter's estimates of abstraction from privately-owned boreholes are taken into account and assuming that this pumping has remained constant over time. The actual volumes of groundwater abstracted annually since 1999 (**Table 12**) are significantly below the potential yield of the system. Vegter (1990) indicated that additional production holes would be required, both up and downstream of the current boreholes, to fully realise the potential of this GMU. Vegter's recommended monthly abstraction volumes per production borehole are left unaltered (**Table 11**).

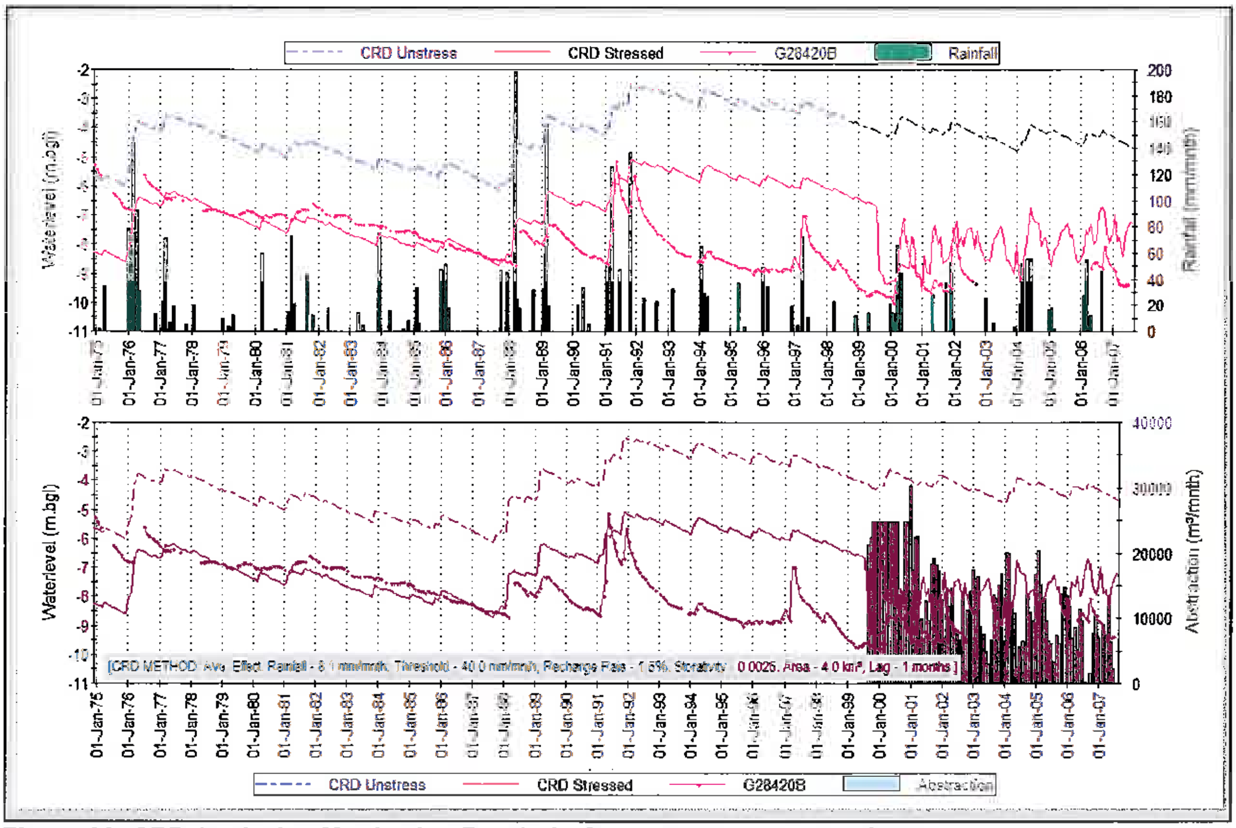



**Figure 20: CRD Analysis - Monitoring Borehole G28420B (Paardevallei GMU)**

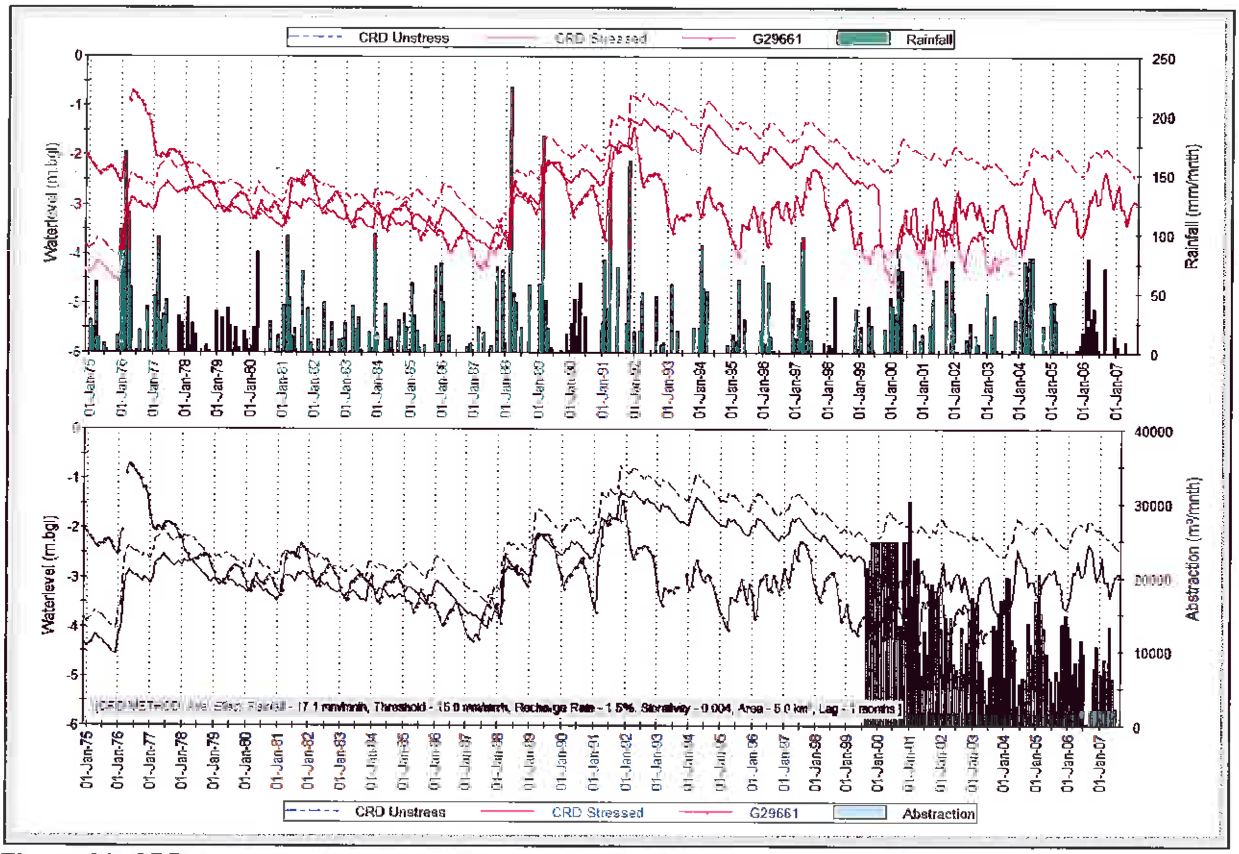



**Figure 21: CRD Analysis - Monitoring Borehole G29661 (Paardevallei GMU)**

**Table 12: Paardevallei GMU - Annual Volumes of Groundwater Abstracted from August 1999 to June 2007**

| Year | Volume Groundwater Abstracted ($m^3$) | Comments |
|---|---|---|
| 1999 | 118,028 | August -December |
| 2000 | 280,499 | |
| 2001 | 187,437 | |
| 2002 | 133,746 | |
| 2003 | 128,844 | |
| 2004 | 134,721 | |
| 2005 | 129,998 | |
| 2006 | 81,326 | |
| 2007 | 38,764 | January - June |
| Total | 1,233,363 | |
| Average | 153,796 | 2000-2006 |

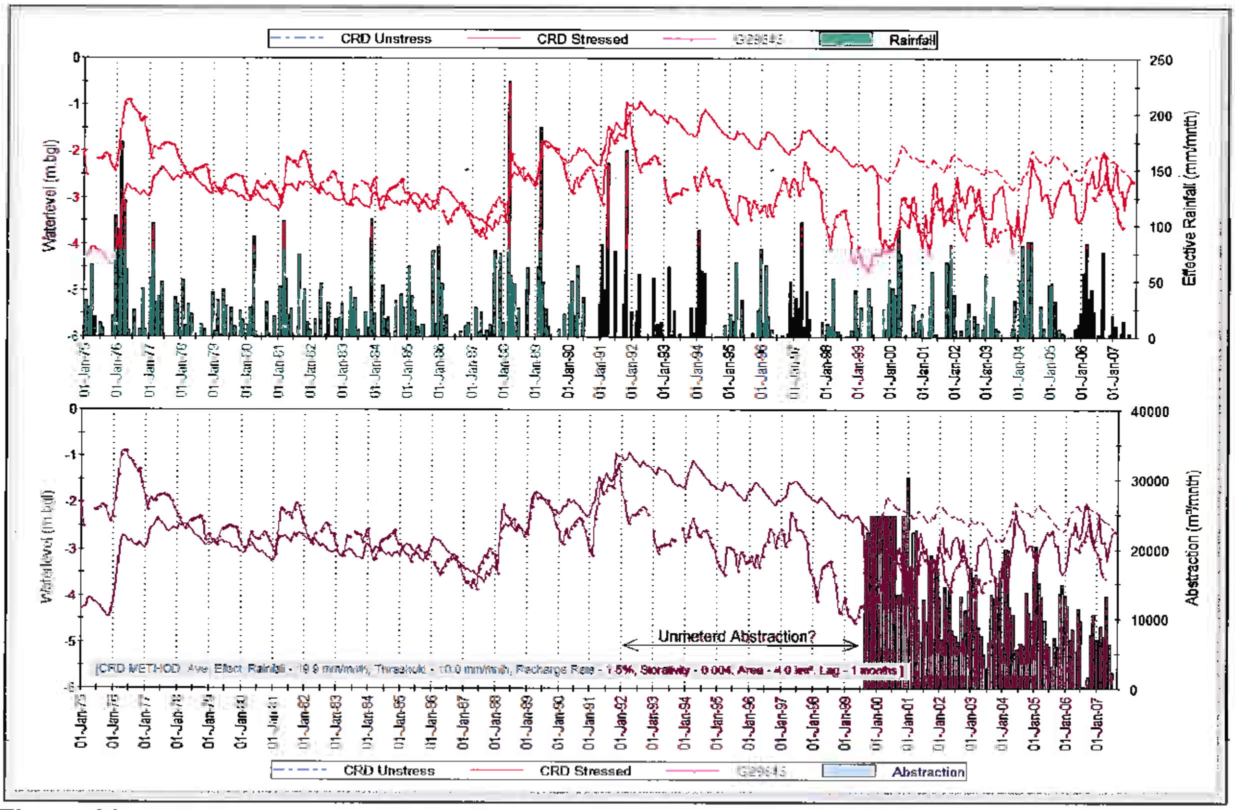



**Figure 22: CRD Analysis - Monitoring Borehole G29645 (Paardevallei GMU)**

## Groundwater Quality

The groundwater quality is acceptable for domestic consumption, although the water is brackish and very hard (**Table 13**). The nitrate levels in the groundwater also tend to be slightly elevated. The fluoride levels in water samples collected from G29644 before 1998 exceed the DWAF's (1996) 1.5 mg/L threshold for safe human consumption. The chemistry of the groundwater samples collected from this hole after 1998, are drastically different from those analysed in 2003 and 2005 (**Figure 23**, **Appendix 3**), and may in fact be due to sampling of the incorrect hole in recent times. The available groundwater chemistry for individual production boreholes are graphically presented on Piper diagrams in **Appendix 3.**

**Table 13: Summary Statistics of Groundwater from Production Holes in the Paardevallei GMU**

| Chemical Parameter | No. Rec. | Minimum | Maximum | Mean | Median | Std Deviation | Lower Quartile | Upper Quartile | 90th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| Lab. pH | 26 | 7.4 | 8.5 | 7.8 | 7.7 | 0.3 | 7.7 | 8.1 | 8.2 |
| EC (mS/m) | 26 | 92.4 | 329.8 | 173.6 | 171.5 | 59.0 | 129.3 | 210.2 | 224.0 |
| Sodium (mg/l) | 26 | 46.0 | 394.0 | 185.3 | 142.5 | 108.4 | 100.5 | 277.9 | 367.3 |
| Calcium (mg/l) | 26 | 7.8 | 196.0 | 91.2 | 77.5 | 56.1 | 57.7 | 135.6 | 166.0 |
| Magnesium (mg/l) | 26 | 3.9 | 134.0 | 66.2 | 67.0 | 35.7 | 51.2 | 92.4 | 102.5 |
| Chloride (mg/l) | 26 | 36.0 | 619.7 | 293.9 | 341.3 | 158.9 | 152.0 | 401.9 | 455.5 |
| Potassium (mg/l) | 24 | 0.70 | 4.60 | 2.23 | 1.19 | 1.47 | 1.00 | 3.83 | 4.25 |
| Silica (mg/l) | 24 | 8.72 | 26.87 | 17.64 | 15.94 | 5.84 | 15.06 | 24.40 | 24.66 |
| Sulphate (mg/l) | 26 | 45.6 | 435.3 | 186.6 | 143.5 | 108.1 | 105.5 | 261.8 | 314.5 |
| Tot. Alkalinity (mg/l) | 26 | 135.7 | 381.3 | 259.8 | 275.0 | 68.9 | 201.5 | 312.3 | 337.0 |
| Fluoride (mg/l) | 26 | 0.20 | 5.89 | 1.56 | 0.76 | 1.76 | 0.66 | 0.95 | 5.15 |
| Nitrate (mg/l) | 25 | 0.020 | 12.730 | 3.826 | 2.480 | 3.193 | 1.930 | 6.280 | 7.495 |
| Ammonia (mg/l) | 17 | 0.015 | 0.140 | 0.048 | 0.020 | 0.041 | 0.020 | 0.060 | 0.122 |

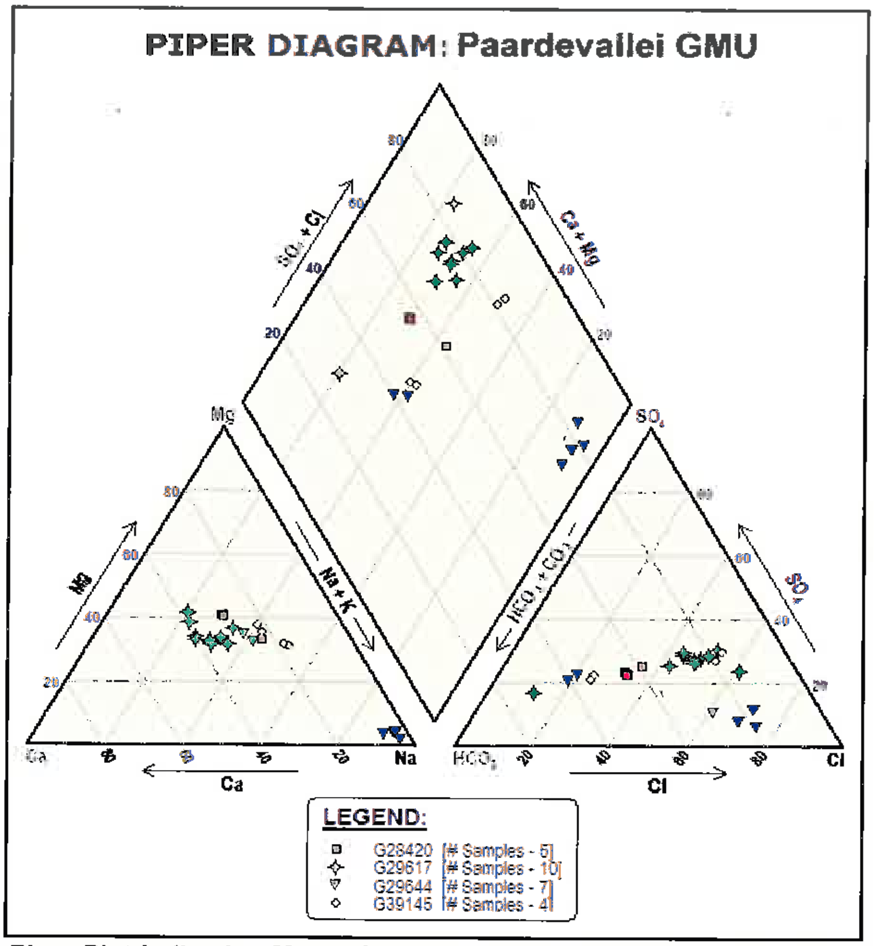



**Figure 23: Piper Plot indicating Macro-Chemistry of Groundwater in Production Boreholes of the Paardevallei GMU**

### 3.6.3 Blaauw Krans GMU

The Blaauw Krans GMU covers an area of some 100 km$^2$ and is referred to by Vegter (1992) as groundwater unit XIX (**Figure 5**). The unit also forms part of De Aar's so-called 'Northern Scheme', although the Municipality have not, as yet, incorporated any of the proposed production holes into their water supply system.

The DWAF have installed digital waterlevel loggers in three monitoring boreholes in the unit, namely G29632D, G29642C and G29648E (**Figure 24**). The OTT autographic waterlevel recorders on monitoring holes G29637D and G29652B were removed by the DWAF towards the end of 2003 and 1999, respectively.

Vegter (1990) recommended that 10 existing production boreholes capable of delivering 525,000 m$^3$/a be developed to boost the Municipalities water supplies. Vegter (1992) estimated that the 'minimum steady yield' of this GMU is 642,000 m$^3$/a (**Table 2**), assuming a recharge factor of 2.1% of MAP. **The DWAF's GRAII (2007) 'Average Groundwater Exploitation Potential' of 788,519 m$^3$/a (Table 6) is accepted as the long-term sustainable yield of this GMU.**

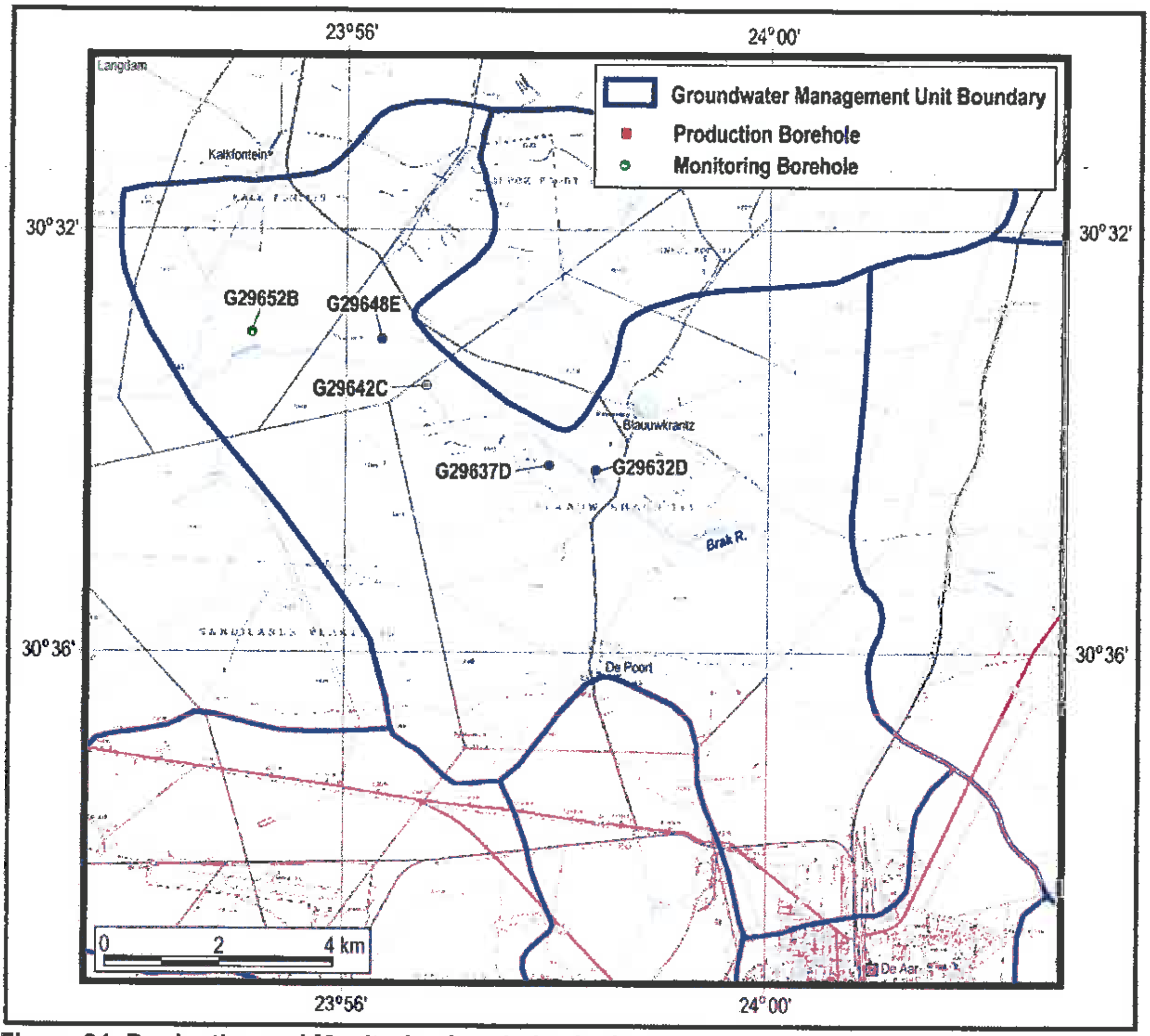



**Figure 24**: Production and Monitoring boreholes in the Blaauw Krans GMU

### 3.6.4 Caroluspoort-North GMU

Prior to 1948, the Cape Government Railways obtained water for their locomotives from springs emanating at the 'poort' or outlet to the Caroluspoort-North GMU (**Figure 4**). The South African Railways (SAR) developed 6 high-yielding large-diameter wells in the alluvium in 1954 and later a number of boreholes were also drilled in this area. The SAR sold this property to the De Aar Municipality in February 1989.

In 1992, Vegter subdivided the Caroluspoort wellfield in two groundwater units, namely VIII-B and XII (**Figure 5**). The Caroluspoort-North GMU basically conforms to the boundary of Vegter's VIII-B unit, except along its outlet in the extreme south. At this location, Vegter's boundary between the VIII-B and the XII units extends between wells G18881 and G18882 (**Figure 25**). The boundary between the Caroluspoort-North (VIII-B) and Caroluspoort-South GMU (XII) is shifted to just south of wells G18890 and G18886 (**Figure 25**).

The Municipality is currently abstracting groundwater from six large-diameter wells located in the Caroluspoort-North Wellfield. In the past, wells Put4, G18881, G1886 and G18890 were pumped to supply the SAR. Monitoring boreholes BG10 (D6N0508 installed 1966), BG1 (D6N0500 installed 1960) and BG32 (D6N0507 installed 1966) were fitted with autographic recorders, that were replaced by digital data-loggers in 2003.

**Table 14: Carolusport-North GMU – Summary of Operational Production Boreholes and Management Recommendations**

| Well Number | Vegter's Groundwater Unit | Depth (m) | Pump-Intake (m) | Pump-Capacity (L/s) [hrs/day] | Maximum Monthly Abstraction ($m^3$) | Maximum Permissible Drawdown (m) below collar |
|---|---|---|---|---|---|---|
| G6778 | VIII-B | 15.0 | 13.0 | 4.0 [10] | 4,200* | 8.0 |
| G6779 | VIII-B | 15.0 | 13.0 | 5.0 [9] | 5,000* | 8.0 |
| PUT5 | VIII-B | 15.0 | 13.0 | 4.0 [10] | 4,200* | 8.0 |
| G18880 | VIII-B | 16.0 | 14.0 | 4.0 [15] | 6,600* | 8.0 |
| G18882 | VIII-B | 15.0 | 15.0 | 3.0 [9] | 3,000 | 8.0 |
| G18884 | XII | 15.0 | 12.0 | 5.0 [9] | 5,000* | 8.0 |
| **Total** | | | | **25.0** | **28,000** | |

Notes:

# - Recommended by Smit (1975). * - Recommended by Vegter (1990).

**Maximum Permissible Drawdown** – waterlevel prior to switch-on of pump after a rest period of approximately 8 hours. The maximum permissible drawdown indicates (i) the depth below which pump-inlets should be installed, and (ii) the depth at which a float-operated switching device should be installed to safeguard the pump from running dry.

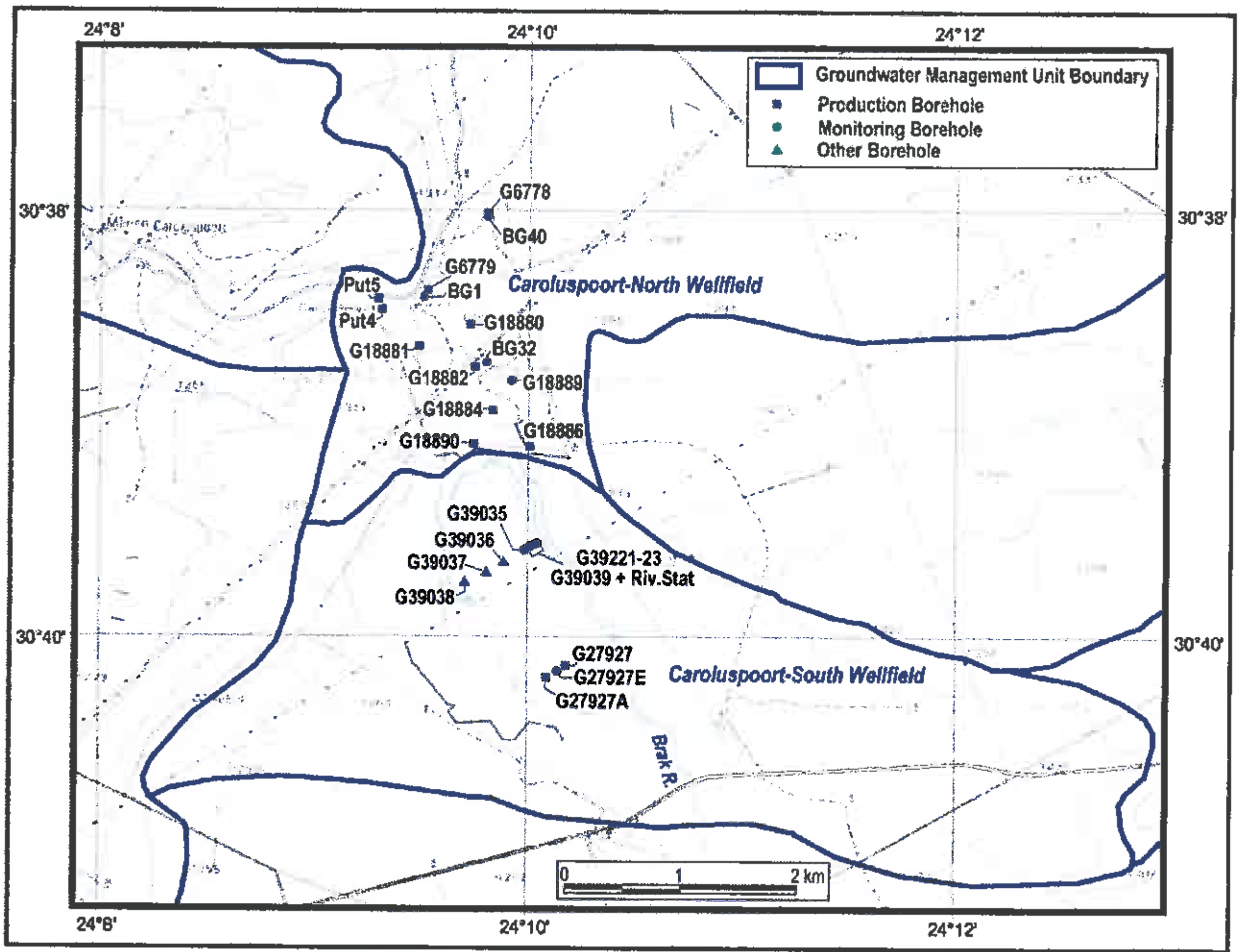



**Figure 25: Production and Monitoring Boreholes in the Carolusport-South and -North GMU's**

Vegter (1961) estimated the 'safe yield' of the SAR's Caroluspoort wellfield at 1,365 $m^3$/day or 500,000 $m^3$/a. Later, Dziembowski (1971) revised this estimate to 700,000 $m^3$ per annum based on monitoring information collected over the period 1960 to 1971. Vegter (1975) downscaled the safe yield of the wellfield to 585,000 $m^3$/a. In 1992, Vegter estimated the 'minimum steady' yield' of the VIII-B groundwater unit at 593,000 $m^3$ per annum (**Table 2**) assuming a recharge factor of 1.9% of MAP. The average recharge to the Caroluspoort-North GMU during years of normal rainfall is estimated at 860,000 $m^3$/a using a GIS-based technique and assuming an average recharge factor of 3%. Groundwater recharge from rainfall declines to 565,000 $m^3$/a during periods of drought (**Table 3**). CRD analysis (Bredenkamp et al, 1995) of monthly rainfall data from De Aar versus waterlevel fluctuations in monitoring boreholes BG1 (**Figure 26**) and BG32 (**Figure 27**) indicate 'best-fit' rainfall-recharge factors of 1.2% to 1.4%, respectively, using a rainfall threshold value of 20 mm/month. CRD estimates of aquifer storativity varied between 0.007 and 0.009. A recharge factor of 1.1% of MAP was obtained using the CMB method (**Table 4**). The DWAF's GRAII (2007) national dataset indicates an excessively high recharge factor of 9.2%, although the 'Average Groundwater Exploitation Potential' of 612,000 $m^3$ per annum (**Table 6**) is acceptable. **The long-term sustainable yield of Caroluspoort-North GMU is taken as 558,000 $m^3$/a** assuming an average recharge factor of 1.3% of MAP. The volumes of groundwater abstracted from the Caroluspoort-North Wellfield should, however, not exceed 336,000 $m^3$/annum or 28,000 $m^3$/month. The annual volumes of groundwater abstracted from the Caroluspoort-North Wellfield are presented in **Table 15**, where it is evident that, in the past, almost double the current recommended volumes were abstracted by the SAR. The Municipality have only exceeded this volume on two occasions (1994 and 1999) since purchasing the property in 1989. Unfortunately, no abstraction records are available for the period 1970 to 1981.

**Table 15: Caroluspoort-North GMU – Annual Volumes Abstracted from 1959 to June 2007**

| Year | Volume Abstracted ($m^3$) | Year | Volume Abstracted ($m^3$) |
|---|---|---|---|
| 1959 | 23,617 | 1989 | 0 |
| 1960 | 296,305 | 1990 | 11,519 |
| 1961 | 275,417 | 1991 | 240,279 |
| 1962 | 303,184 | 1992 | 231,683 |
| 1963 | 319,684 | 1993 | 234,592 |
| 1964 | **487,904** | 1994 | **338,852** |
| 1965 | **601,896** | 1995 | 326,511 |
| 1966 | **619,013** | 1996 | 316,367 |
| 1967 | **773,890** | 1997 | 310,633 |
| 1968 | **799,007** | 1998 | 279,242 |
| 1969 | **632,877** | 1999 | **349,241** |
| 1970-1981 | ? | 2000 | 283,791 |
| 1982 | **713,099** | 2001 | 239,682 |
| 1983 | **719,217** | 2002 | 235,663 |
| 1984 | **638,666** | 2003 | 299,073 |
| 1985 | **570,203** | 2004 | 290,251 |
| 1986 | **568,301** | 2005 | 285,738 |
| 1987 | **581,429** | 2006 | 311,693 |
| 1988 | **345,646** | 2007 June | 140,842 |
| **Bold** – exceed maximum recommended volume of 300,000$m^3$/a. | | | |

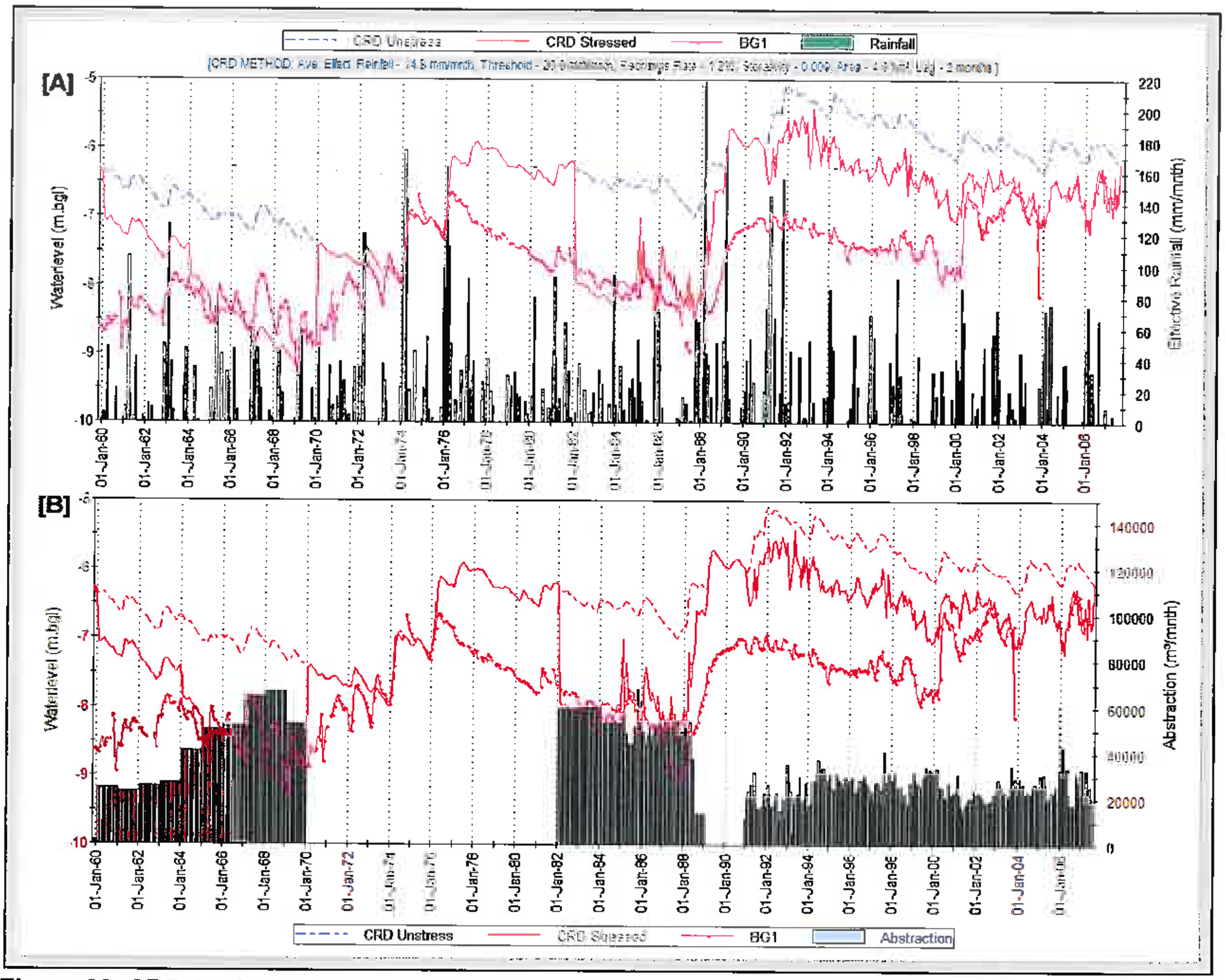



**Figure 26**: CRD Analysis - Monitoring Borehole BG1 (Caroluspoort-North GMU)

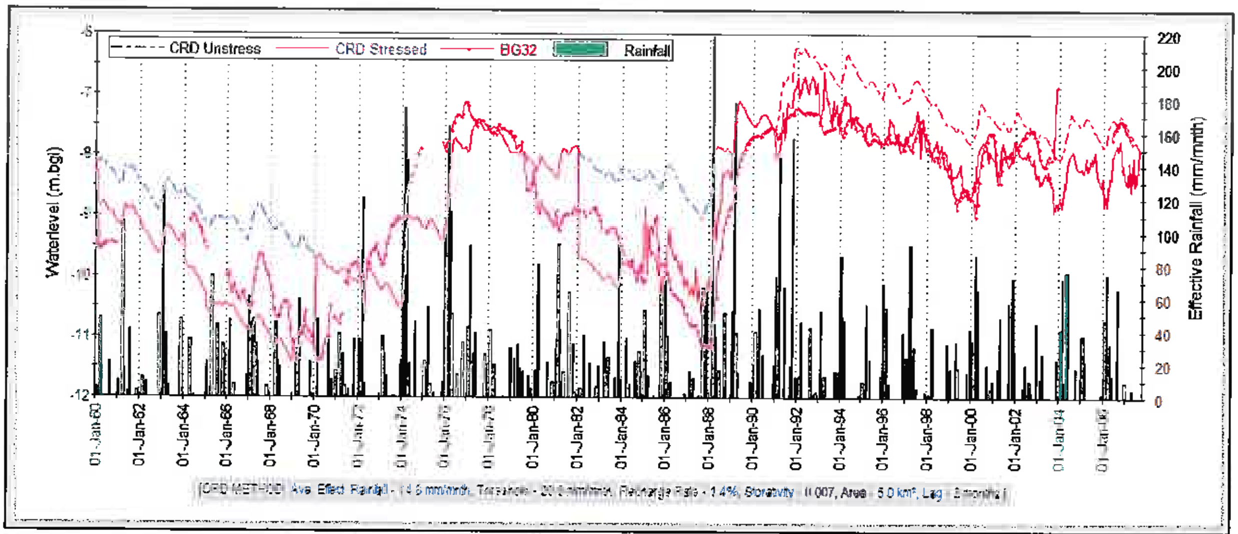



**Figure 27**: CRD Analysis - Monitoring Borehole BG32 (Caroluspoort-North GMU)

### Groundwater Quality

The groundwater in this GMU is generally slightly saline and very hard (**Table 16**), but it is fit for domestic consumption. The groundwater is characterised as calcium-magnesium-chloride-bicarbonate type (**Figure 28**), which indicates an inter-mixing of locally recharged rainwater from the surrounding hardrock terrain with more saline groundwater contained in the alluvium.

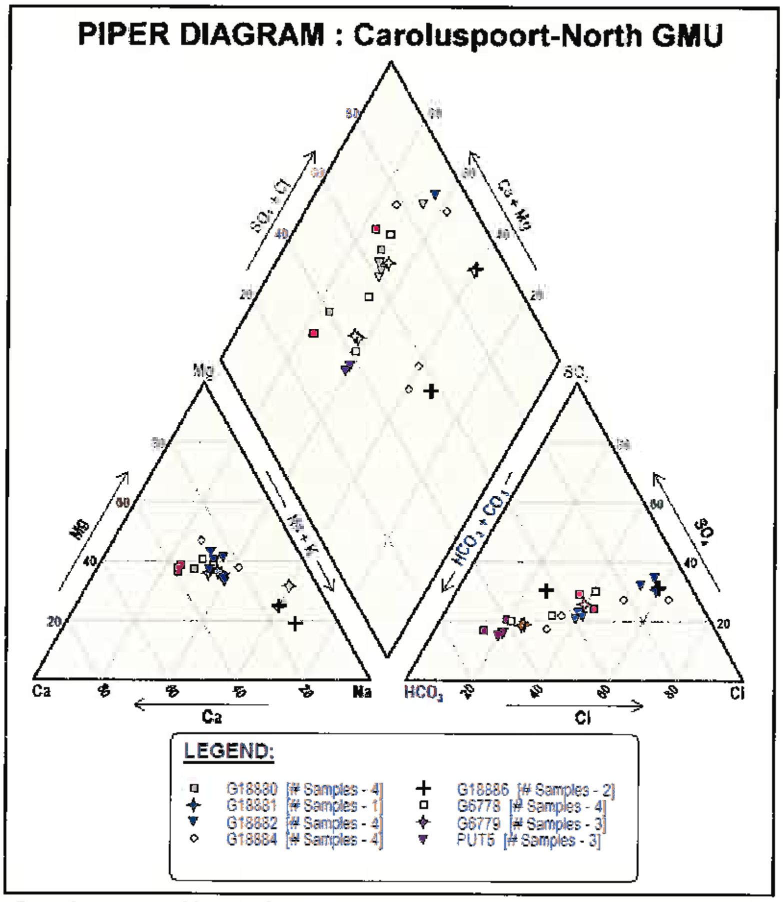



**Figure 28**: Caroluspoort-North GMU - Piper Plot indicating Chemistry of Groundwater from Production Wells

**Table 16**: Caroluspoort-North - Summary Statistics of Groundwater from Production Holes

| Chemical Parameter | No. Rec. | Minimum | Maximum | Mean | Median | Std Deviation | Lower Quartile | Upper Quartile | 90th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| Lab. pH | 29 | 7.4 | 8.4 | 7.9 | 7.9 | 0.4 | 7.5 | 8.3 | 8.4 |
| EC (mS/m) | 26 | 85.8 | 550.0 | 208.8 | 162.0 | 125.7 | 111.5 | 282.5 | 379.5 |
| Sodium (mg/l) | 25 | 50.3 | 889.0 | 203.2 | 119.0 | 183.9 | 102.2 | 272.4 | 379.0 |
| Calcium (mg/l) | 25 | 44.5 | 271.0 | 96.3 | 84.5 | 46.9 | 61.9 | 110.4 | 140.6 |
| Magnesium (mg/l) | 25 | 44.6 | 262.0 | 94.3 | 73.0 | 61.9 | 51.0 | 93.8 | 184.6 |
| Chloride (mg/l) | 29 | 38.0 | 1307.0 | 317.4 | 215.0 | 314.5 | 94.7 | 274.0 | 818.5 |
| Potassium (mg/l) | 24 | 0.15 | 2.70 | 0.80 | 0.61 | 0.59 | 0.45 | 0.95 | 1.61 |
| Silica (mg/l) | 25 | 21.50 | 2.87 | 23.65 | 23.44 | 1.39 | 22.59 | 24.69 | 25.27 |
| Sulphate (mg/l) | 25 | 77.0 | 961.0 | 281.5 | 175.5 | 237.1 | 118.1 | 313.0 | 623.2 |
| Tot. Alkalinity (mg/l) | 29 | 162.8 | 456.0 | 304.5 | 305.0 | 73.7 | 264.0 | 352.9 | 379.2 |
| Fluoride (mg/l) | 26 | 0.10 | 1.26 | 0.72 | 0.72 | 0.26 | 0.58 | 0.90 | 1.00 |
| Nitrate (mg/l) | 25 | 0.05 | 2.57 | 0.92 | 0.51 | 0.78 | 0.40 | 1.37 | 2.33 |
| Ammonia (mg/l) | 17 | 0.015 | 0.040 | 0.019 | 0.020 | 0.006 | 0.015 | 0.020 | 0.020 |

### 3.6.5 Caroluspoort-South GMU

The Caroluspoort-South GMU has an areal extent of only $18km^2$ (**Figure 4**, **Table 3**) and is basically the same of Vegter's (1992) XII groundwater unit (**Figure 1**). The Brak River flows through the centre of the GMU and it lies directly upstream of the Caroluspoort-North unit. Two production boreholes, G27927 and G27927A (**Figure 25**), tap the composite alluvial-bedrock aquifer in this GMU. Borehole G27927A was last pumped in May 2003. This wellfield was commissioned in 1985 as part of the 'South-Eastern Scheme'. Monitoring borehole G27927E is equipped with a digital waterlevel data-logger. Waterlevels in G27927E fluctuated between 2 to 3 m.bgl prior to the start of pumping from this wellfield and declined to between 6 and 7m below surface towards the end of 1998 due to over-pumping (**Figure 29**).

**Table 17: Caroluspoort-South GMU – Summary of Operational Production Boreholes and Management Recommendations**

| Well Number | Vegter's Groundwater Unit | Depth (m) | Pump-Intake (m) | Pump-Capacity (L/s) | Maximum Monthly Abstraction ($m^3$) | Maximum Permissible Drawdown (m) below collar |
|---|---|---|---|---|---|---|
| G27927A | XII | 19.2 | 16.0 | 6.0 | 4,000* | 7.0* |
| G27927 | XII | 22.1 | 19.0 | 6.0 | 3,000* | 7.0* |
| **Total** | | | | **12.0** | **7,000** | |

Notes:
# - Recommended by Smit (1975). * - Recommended by Vegter (1990).
Vegter 1990 – recommended pumping rates of 11.1 and 8.3 L/s for G27927 and G27927A, respectively.
**Maximum Permissible Drawdown** – waterlevel prior to switch-on of pump after a rest period of approximately 8 hours. The maximum permissible drawdown indicates (i) the depth below which pump-inlets should be installed, and (ii) the depth at which a float-operated switching device should be installed to safeguard the pump from running dry.

In 1989, the DWAF drilled a profile of eight monitoring holes, G39221-223 and G39035-039 (**Figure 25**), perpendicular to the banks of the Brak River (**Plate 4**). Autographic waterlevel recorders were installed on boreholes G39221-223, G39035 and G39039, as well as a stilling-well to measure the depth of river flow during flood events (Riv. Station D6N079). A hydrogeological profile of the site is presented in **Figure 30**, showing the nature of the alluvial-bedrock aquifer. The salinity of the groundwater is relatively low (<350 mS/m) in the vicinity of the main tributary of the Brak River and increases dramatically towards the east (>700 mS/m). This is attributed to the system being recharged by relatively lower salinity river water (120 mS/m) during periods of flooding. Unfortunately, the stilling-well continually silted up and no useful records of river flow were obtained. DWAF removed all the waterlevel recorders towards the end of 2003 and placed a digital waterlevel data-logger in G39035. Waterlevel fluctuations in these monitoring holes clearly show that the aquifer system only receives significant recharge during months when the rainfall exceeds 40mm (**Figure 31**). Note that the sharp 'spikes' in the waterlevels recorded in G39035 since 2003 reflect periods when the Brak River was in flood.

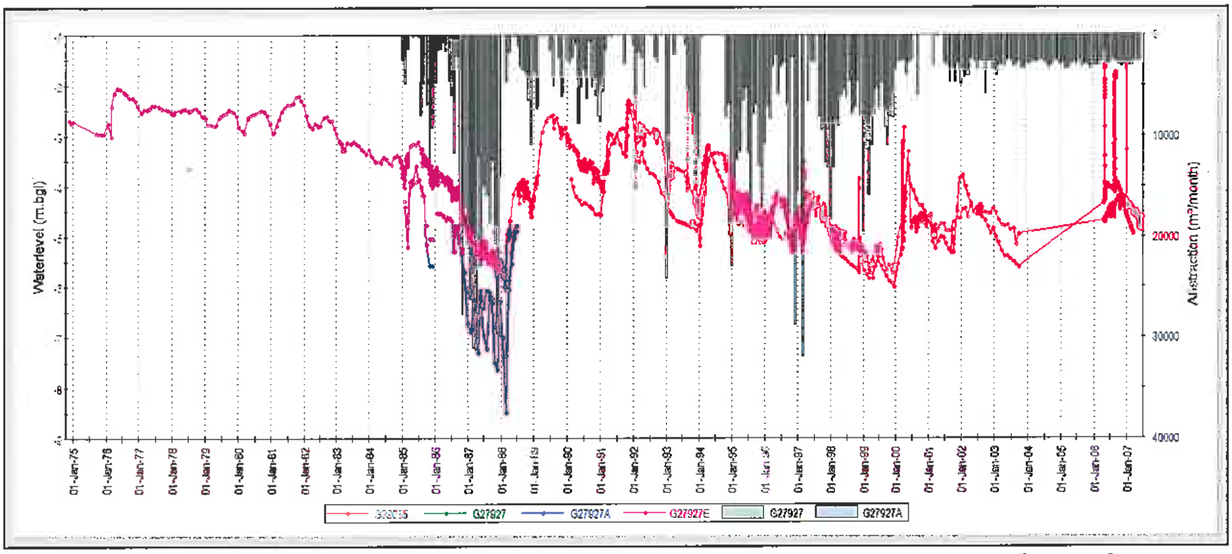



**Figure 29**: Caroluspoort-South GMU – Waterlevel fluctuations versus groundwater abstraction

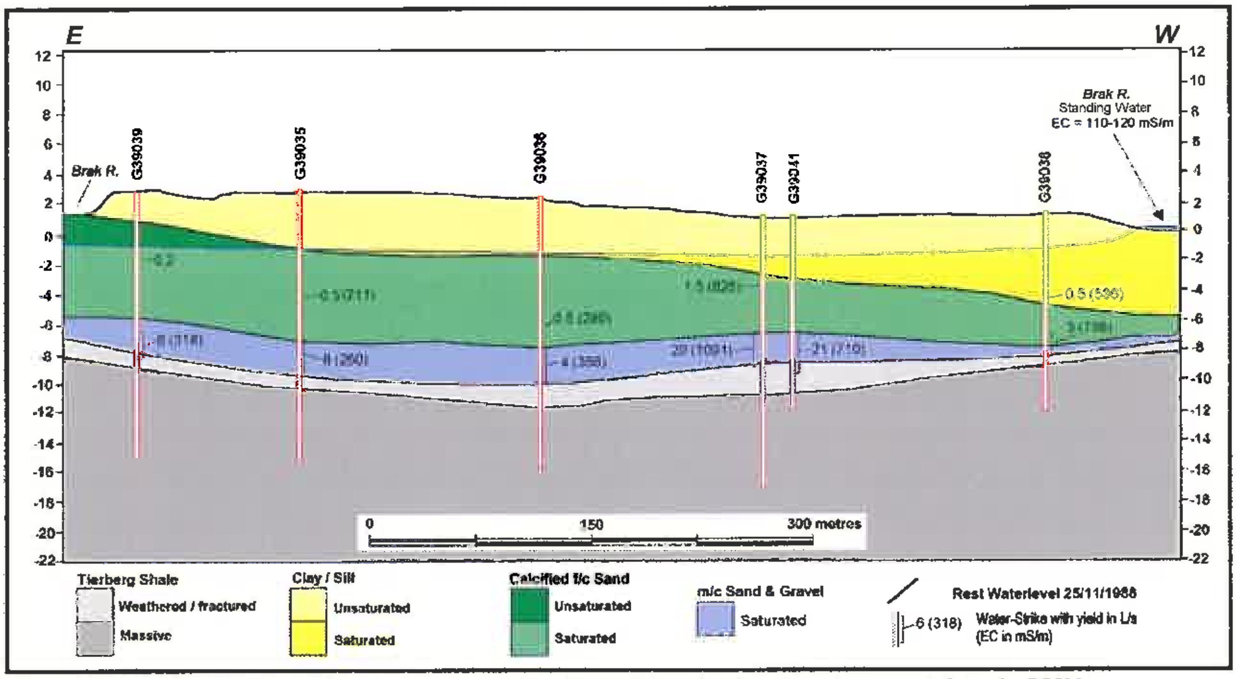



**Figure 30**: Hydrogeological-Profile across the Brak River in the Caroluspoort South GMU

**Plate 4: Caroluspoort - South Wellfield: view to north-east showing monitoring boreholes drilled perpendicular to the Brak River (photo F.Fourie)**

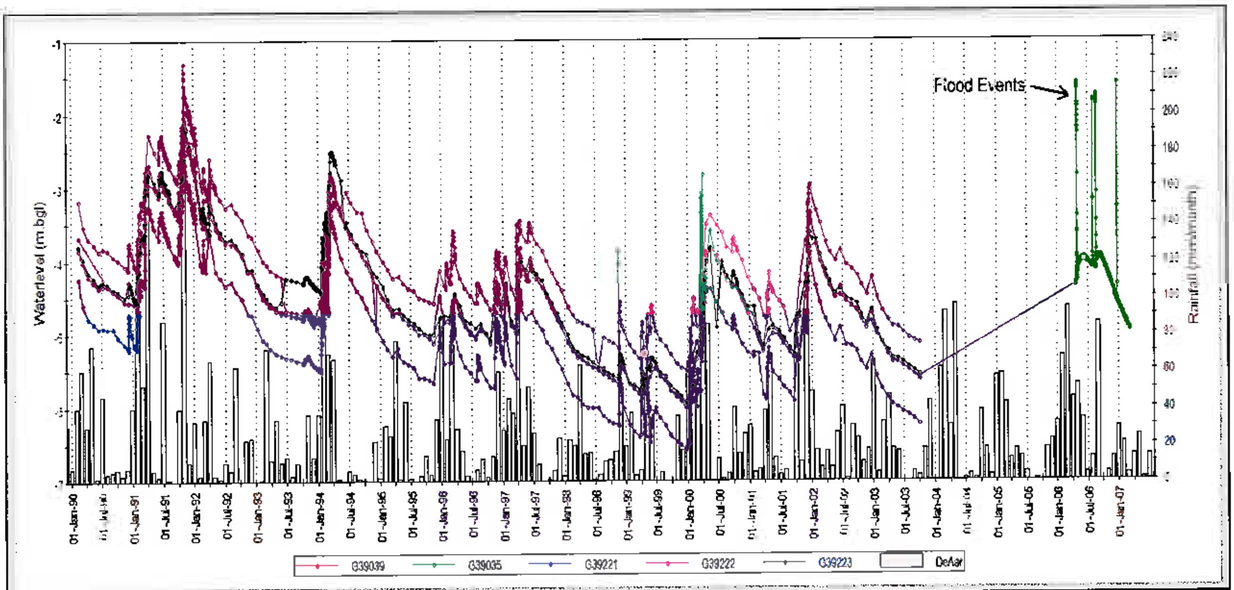



**Figure 31: Waterlevel fluctuations in the alluvial-bedrock aquifer underlying the Brak River**

Vegter (1992) estimated the 'minimum steady yield' of the groundwater unit at 121,000 $m^3/a$ assuming an average recharge factor of 1.9% of MAP. In **Section 3.5.2**, the recharge to the GMU is estimated at ~185,000 $m^3/a$ during periods of normal rainfall (MAP 342mm) and assuming a recharge factor 3%. The recharge is estimated to decline to 121,000 $m^3/a$ during droughts **(Table 3)**.

The DWAF's GRAII '*Average Groundwater Exploitation Potential*' dataset for this GMU is 129,000 $m^3/a$ (**Table 6**). CRD analysis of monthly rainfall at De Aar versus abstraction from the GMU and waterlevel fluctuations in G39035 (**Figure 32**) and G29727E (**Figure 33**) provides a 'best-fit' recharge factor of 1.3% and an aquifer storativity of between 0.004 and 0.007. The CMB method indicates a maximum rainfall-recharge factor of 1.1% using an average rainfall chloride concentration of 1.7 mg/l (**Table 4**). An average recharge factor of 1.5% is, howeve, regarded as more realistic and therefore the mean recharge, adjusted for this lower recharge factor, of **~93,000 $m^3/a$ is accepted as the long-term sustainable yield of the GMU**. The sustainable yield of the wellfield is maintained at 7,000 $m^3$/month or 84,000 $m^3/a$ (**Table 17**).

**Table 18: Caroluspoort-South GMU - Annual Groundwater Abstraction between 1985 and June 2007**

| Year | Volume Abstracted ($m^3$) | Year | Volume Abstracted ($m^3$) |
|---|---|---|---|
| 1985 | 53,125 | 1997 | **102,452** |
| 1986 | **103,984** | 1998 | **98,786** |
| 1987 | **256,535** | 1999 | **119,550** |
| 1988 | 63,179 | 2000 | 26,307 |
| 1989 | 25,778 | 2001 | 24,478 |
| 1990 | 51,330 | 2002 | 42,183 |
| 1991 | 18,658 | 2003 | 37,037 |
| 1992 | 29,997 | 2004 | 33,205 |
| 1993 | **92,282** | 2005 | 35,706 |
| 1994 | 27,390 | 2006 | 33,277 |
| 1995 | **152,743** | 2007 June | 17,332 |
| 1996 | **100,944** | | |
| **Bold** – exceed max. recommended volume of 84,000 $m^3/a$. | | | |

## Groundwater Quality

The groundwater in this GMU is generally brackish and very hard (**Table 19**), with a sodium-magnesium-chloride character (**Figure 34**). Piper plots indicating groundwater chemistry of each borehole in the GMU are presented in **Appendix 3**. The sodium, chloride, and in some cases magnesium, concentrations of the groundwater exceeds the DWAF's recommended limits for domestic consumption.

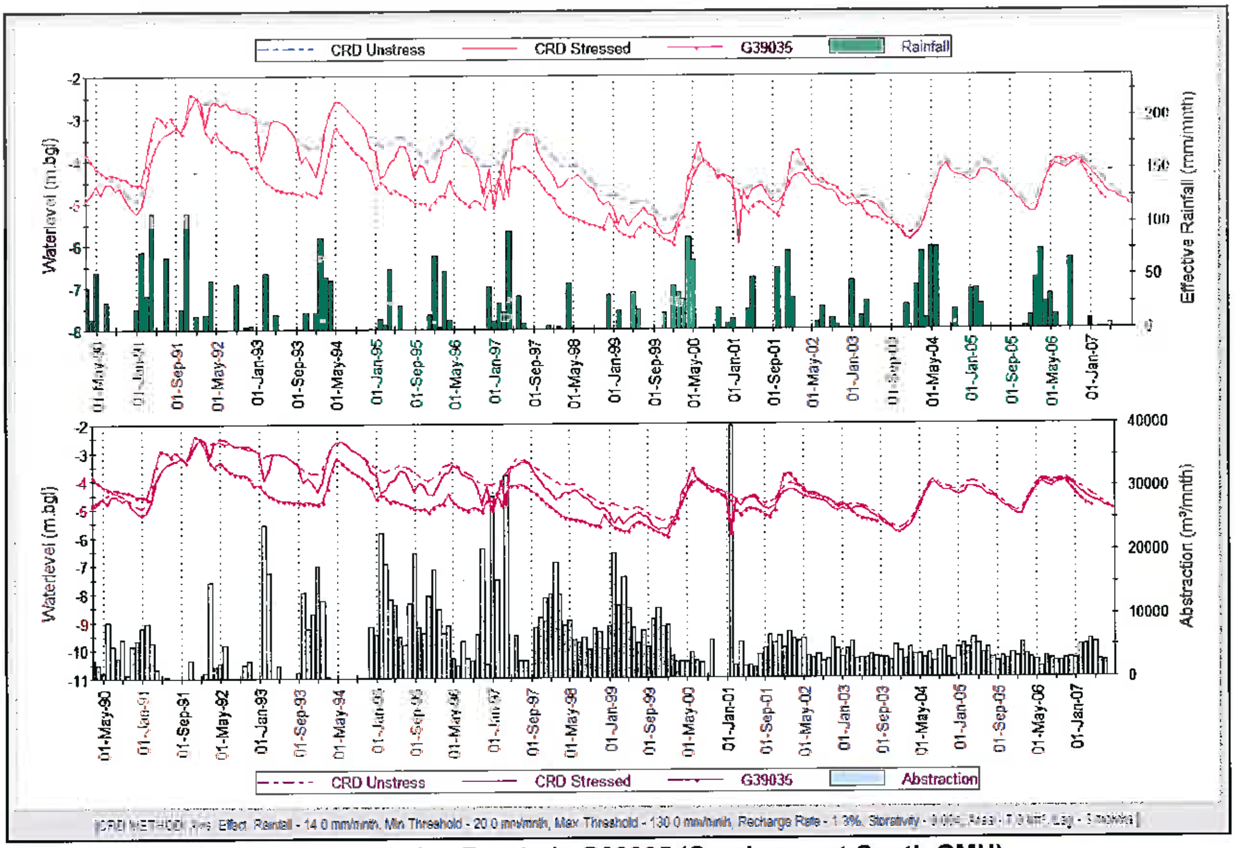



**Figure 32: CRD Analysis - Monitoring Borehole G39035 (Caroluspoort-South GMU)**

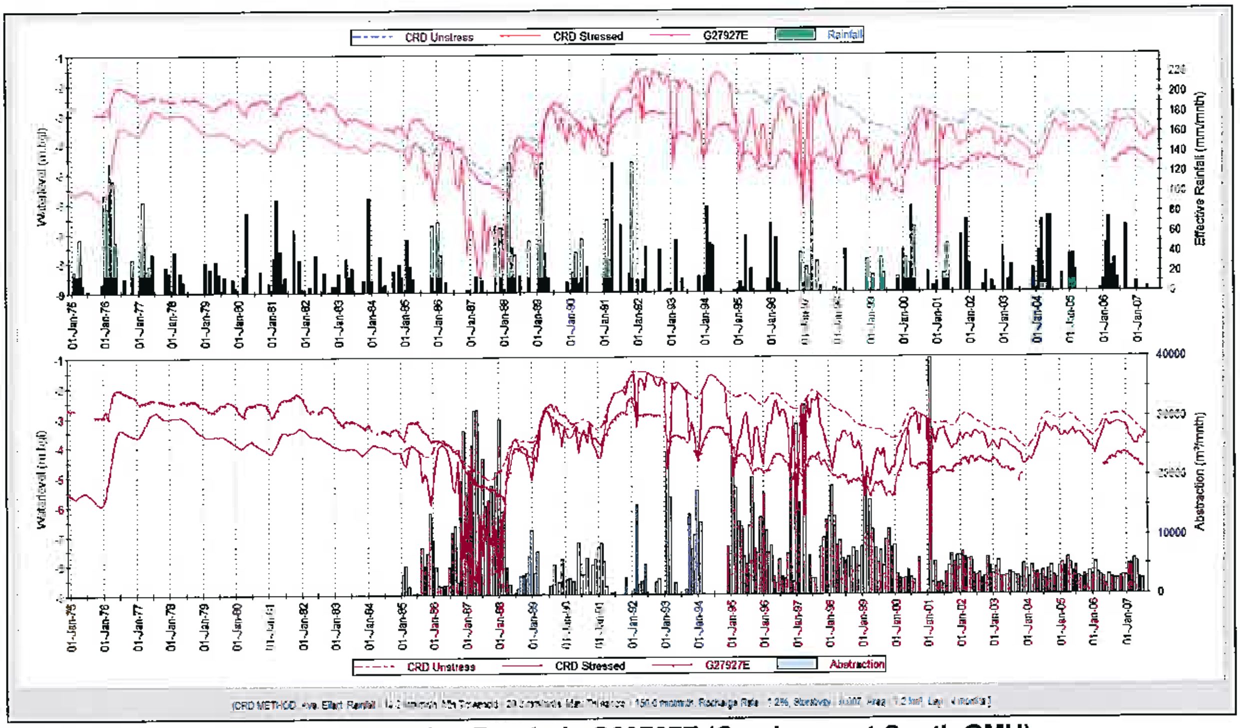



**Figure 33: CRD Analysis - Monitoring Borehole G29727E (Caroluspoort-South GMU)**

**Table 19: Caroluspoort-South GMU - Summary Statistics of Groundwater Chemistry**

| Chemical Parameter | No. Rec. | Minimum | Maximum | Mean | Median | Std Deviation | Lower Quartile | Upper Quartile | 90th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| Lab. pH | 31 | 7.0 | 8.9 | 7.8 | 7.8 | 0.3 | 7.6 | 8.0 | 8.2 |
| EC (mS/m) | 32 | 84.6 | 1018.1 | 427.5 | 363.5 | 232.2 | 268.1 | 488.6 | 778.9 |
| Sodium (mg/l) | 32 | 106.9 | 1605.0 | 578.1 | 470.5 | 414.2 | 332.0 | 639.8 | 1398.9 |
| Calcium (mg/l) | 32 | 10.0 | 213.7 | 92.9 | 96.0 | 50.0 | 53.3 | 117.3 | 159.8 |
| Magnesium (mg/l) | 32 | 21.0 | 495.0 | 179.2 | 144.0 | 126.2 | 97.8 | 238.0 | 379.1 |
| Chloride (mg/l) | 32 | 23.0 | 2123.0 | 966.4 | 957.3 | 567.1 | 548.3 | 1368.0 | 1559.6 |
| Potassium (mg/l) | 29 | 0.40 | 15.80 | 4.01 | 2.86 | 3.76 | 1.00 | 5.20 | 8.50 |
| Silica (mg/l) | 26 | 1.33 | 24.90 | 16.22 | 18.85 | 6.85 | 12.08 | 21.15 | 22.05 |
| Sulphate (mg/l) | 32 | 76.0 | 2222.0 | 569.4 | 356.0 | 577.2 | 180.4 | 631.0 | 1538.9 |
| Tot. Alkalinity (mg/l) | 32 | 147.0 | 601.0 | 311.2 | 280.0 | 125.9 | 250.8 | 388.6 | 488.0 |
| Fluoride (mg/l) | 32 | 0.4 | 1.7 | 0.9 | 0.8 | 0.3 | 0.7 | 1.0 | 1.4 |
| Nitrate (mg/l) | 27 | 0.010 | 7.900 | 1.416 | 0.480 | 2.128 | 0.075 | 1.470 | 5.220 |
| Ammonia (mg/l) | 20 | 0.010 | 0.090 | 0.047 | 0.040 | 0.025 | 0.030 | 0.055 | 0.090 |

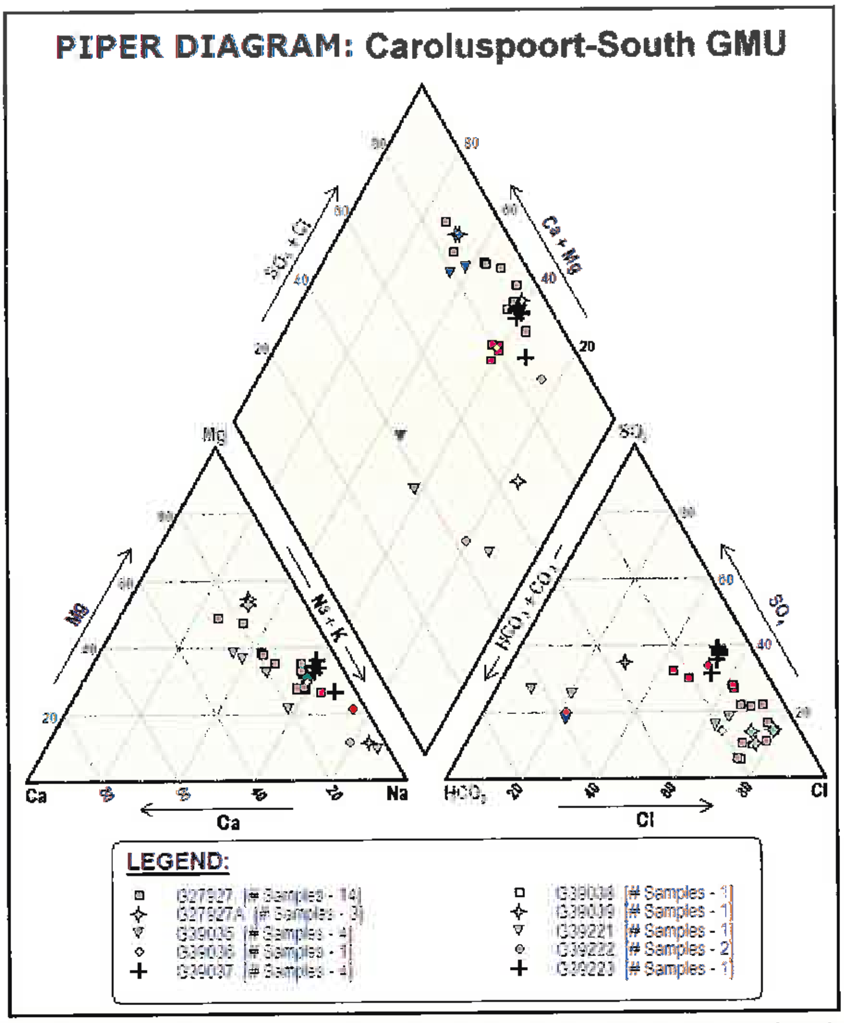



**Figure 34: Piper Plot indicating groundwater chemistry of the Caroluspoort-South GMU**

### 3.6.6 Riet and Rietfontein GMU's

The Riet and Rietfontein Groundwater Management Unit cover an area of 52 and 69 km$^2$, respectively (**Figure 4**), and together are almost similar in geographic extent to Vegter's (1990) XI groundwater unit (**Figure 1**). The Riet, Rietfontein and Caroluspoort-South GMUs make up the Municipality's 'South-Eastern Scheme'. Currently, the Riet and Rietfontein Wellfields are comprised of 5 and 6 production boreholes, respectively (**Figure 35, Table 20**). Initially, only production borehole G27917E was commissioned in 1981, followed by G27918C, G28301, G28304 and G28313B in 1985, and the remainder of the boreholes were brought into production towards the end of 1998.

**Table 20: Riet and Rietfontein GMU - Summary of Operational Production Boreholes and Management Recommendations**

| Borehole Number | Vegter's Groundwater Unit | Depth (m) | Pump-Intake (m) | Pump-Rate (L/s) | Maximum Monthly Abstraction (m$^3$) | Maximum Permissible Waterlevel (m) below collar |
|---|---|---|---|---|---|---|
| **Riet Wellfield** | | | | | | |
| G29717E | XI | 36.0 | 25.0 | 12.0 | 9,000 (10,000) | 13.0# |
| G38517 | XI | 36.0 | 24.0 | 3.0 | 2,000 (2,500) | 13.0# |
| G38455 | XI | 30.0 | 18.0 | 3.5 | 2,000 (3,000) | 12.0# |
| G38473 | XI | 24.0 | 17.0 | 4.0 | 2,000 (2,000) | 12.0# |
| G38468 | XI | 48.0 | 35.0 | 3.0 | 2,000 (2,000) | 18.0# |
| TOTAL | | | | **25.5** | **17,000 (19,500)** | |
| **Rietfontein Wellfield** | | | | | | |
| G27918C | XI | 24.4 | 22.0 | 15.0 | 12,500 (13,000) | 11.0# |
| G28301 | XI | 24.4 | 16.0 | 6.0 | 3,300 (3,300) | 8.0# |
| G28304 | XI | 25.0 | 20.0 | 6.0 | 3,300 (3,300) | 10.0# |
| G28307 | XI | 22.0 | 14.0 | 4.5 | 5,000 (5,000) | 7.5# |
| G28313B | XI | 21.4 | 16.0 | 3.0 | 3,000 (3,000) | 9.5# |
| G38507 | XI | 42.0 | 30.0 | 10.0 | 6,000 (6,000) | 17.0# |
| TOTAL | | | | **44.5** | **33,100 (33,600)** | |

Notes:
* - Recommended by Vegter(1990). # - Recommended by Woodford (1993).
(5,000) – Monthly abstraction volumes listed in Water Services Development Plan.
Borehole G38271 has replaced production borehole G27927E.
**Maximum Permissible Drawdown** – waterlevel prior to switch-on of pump (i.e. rest-waterlevel) after a rest period of approximately 8 hours. The maximum permissible drawdown indicates (i) the depth below which pump-inlets should be installed, and (ii) the depth at which a float-operated switching device should be installed to safeguard the pump from running dry.
G27715G - drilled 24.4m deep, reduced depth is as a result of a pump getting stuck at the bottom of the hole.
G23206A – in use but not recommended by Smit (1975)

The current waterlevel monitoring system in the Riet and Rietfontein GMU's is inadequate for proper assessment of the performance of the wellfields and timeous detection of over-exploitation of the aquifer systems. In the Rietfontein GMU, waterlevels are currently being monitored in boreholes G28302K and G28304F using digital data-loggers. Only borehole G29717 in the Riet GMU is being monitored using a digital data-logger (**Figure 35**). The waterlevel and abstraction information for these holes are graphically presented in **Figure 36** (see plots per borehole in **Appendix 3**).

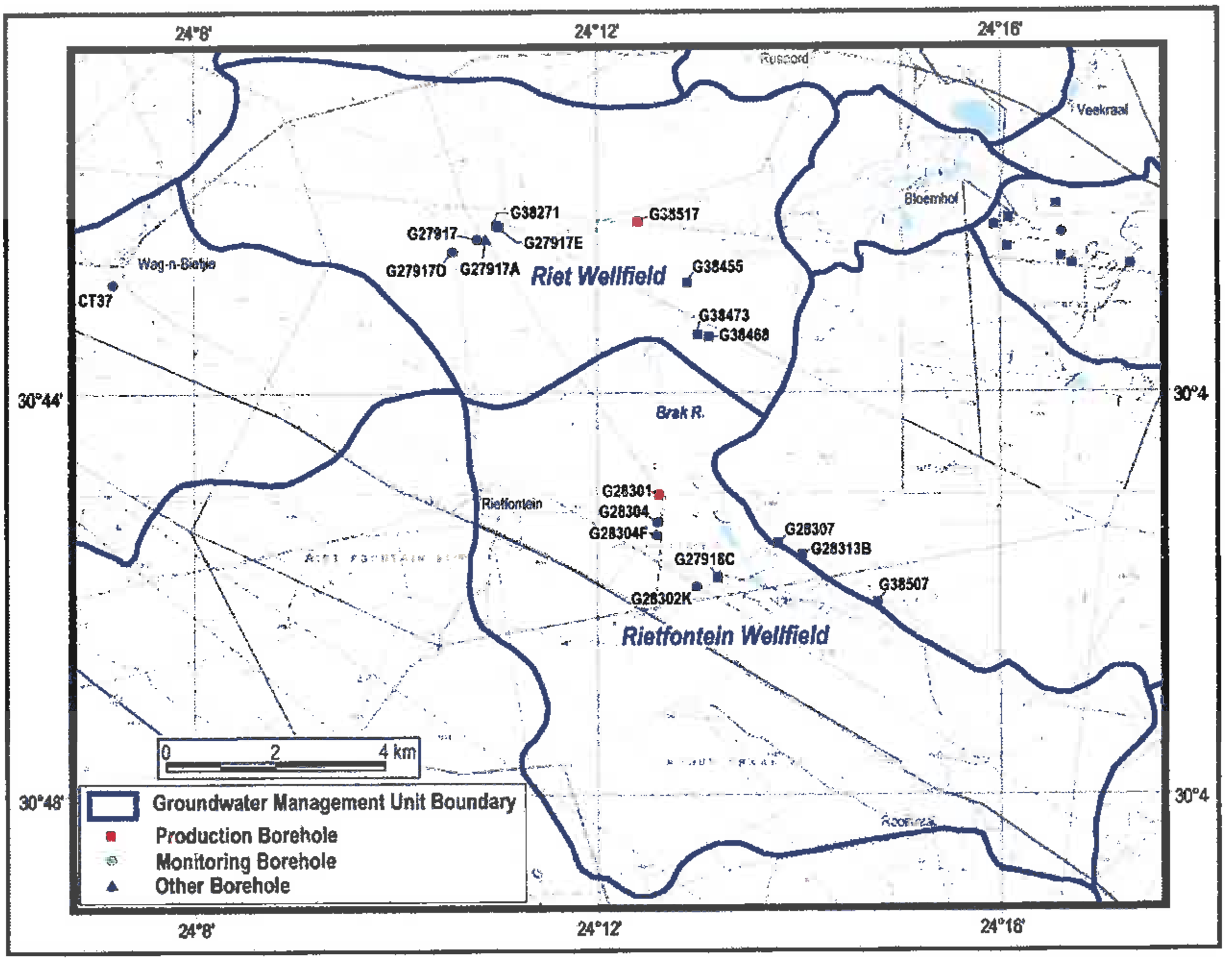



**Figure 35: Production and Monitoring boreholes in the Riet and Rietfontein GMU's**

Smit (1975) estimated the combined 'safe-yield' of the Riet and Rietfontein GMU's at 1.2 x $10^6$ $m^3$/a based on the analyses of pumping-test information. Vegter (1992) estimated the 'minimum steady yield' of the Riet and Rietfontein GMU's at 1.005 x$10^6$ $m^3$/a (**Table 2**), assuming a recharge factor of 2% of MAP. He estimated that 362,000 $m^3$ of groundwater was being abstracted annually from privately-owned boreholes in the unit. Recharge to the Riet and Rietfontein GMU's is estimated using a GIS technique at ~515,000 and 666,000 $m^3$/a, respectively, assuming a recharge factor of 3% (**Table 3**). During periods of drought the combined recharge to both GMU's could to decline to 767,000 $m^3$/a. The DWAF's GRAII (2007) 'Average Groundwater Exploitation Potential' or AGEP for the Riet and Rietfontein GMU's is ~413,000 and 612,000 $m^3$/a (**Table 6**). Cumulative Rainfall Departure or CRD analysis (Bredenkamp et al, 1995) of monthly rainfall at De Aar versus abstraction from the GMU's and waterlevel fluctuations in boreholes G27917 (Riet GMU, **Figure 37**), G28302K (**Figure 38**) and G28304F (Rietfontein GMU, **Figure 38**) provide a 'best-fit' recharge factor of between 1.2 to 1.4% and storativity values of 0.002 to 0.004. **The AGRP of the Riet and Rietfontein GMU's of 1.025 x$10^6$ $m^3$ is accepted as the long-term sustainable yield of these units**, whilst the combined capacity of the current wellfields is estimated at 50,100 $m^3$/month (**Table 20**) or 601,200 $m^3$/a. The annual volumes of groundwater abstracted from the Riet and Rietfontein GMU's are presented in **Table 21**. Groundwater abstraction from both GMU's has remained below the sustainable yields of the respective GMUs since 1990, with the exception of the Riet GMU in 2001.

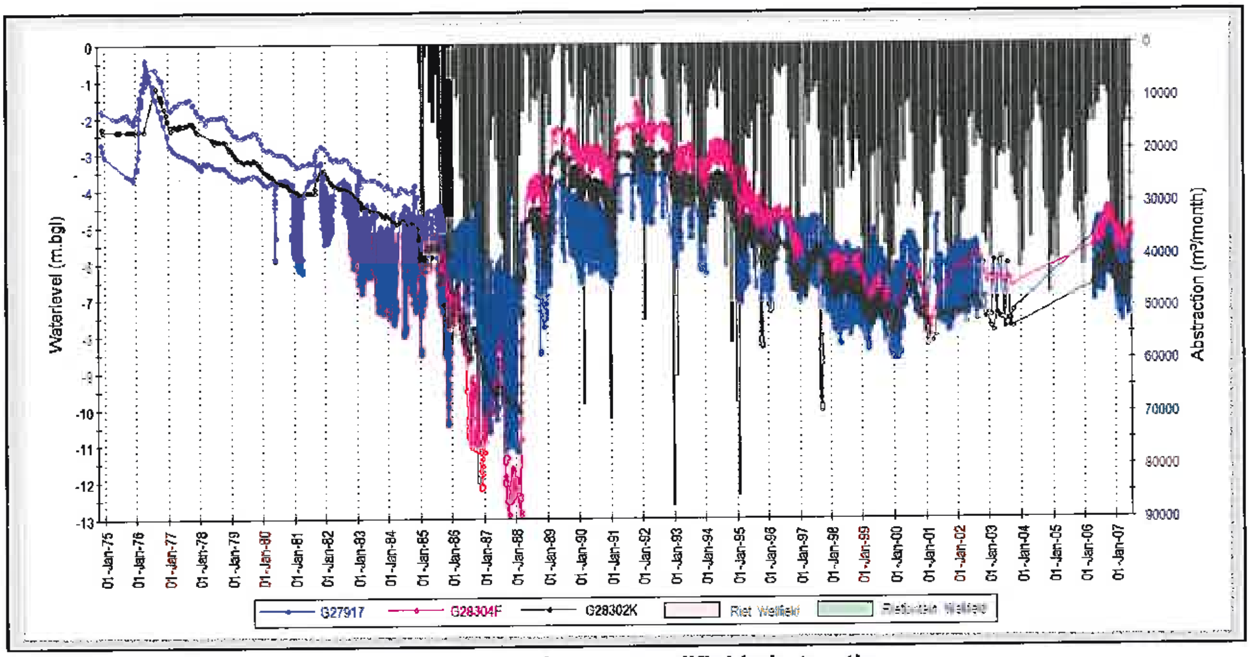



**Figure 36: Riet - Rietfontein GMU - waterlevel versus wellfield abstraction**

**Table 21: Annual Abstraction from the Riet and Rietfontein GMU's**

| Year | Annual Abstraction ($m^3$) | | |
|---|---|---|---|
| | **Riet GMU** | **Rietfontein GMU** | **TOTAL** |
| 1981 | 64,475 | - | 64,475 |
| 1982 | 96,709 | - | 96,709 |
| 1983 | **254,534** | - | 254,53 |
| 1984 | **233,479** | - | 233,479 |
| 1985 | 96,287 | 230,592 | 326,879 |
| 1986 | 130,010 | **408,186** | 538,196 |
| 1987 | **236,150** | **402,126** | **638,276** |
| 1988 | ? | 253,407 | 253,407 |
| 1989 | ? | 84,000 | 84,000 |
| 1990 | ? | 243,965 | 243,965 |
| 1991 | 30,796 | 93,420 | 124,216 |
| 1992 | 41,740 | 116,126 | 157,866 |
| 1993 | 132,800 | 218,608 | 351,408 |
| 1994 | 66,994 | 183,288 | 250,282 |
| 1995 | 158,872 | 271,041 | 429,913 |
| 1996 | 79,711 | 129,981 | 209,692 |
| 1997 | 103,321 | 142,452 | 245,773 |
| 1998 | 151,290 | 151,204 | 302,494 |
| 1999 | 201,154 | 256,674 | 457,828 |
| 2000 | 120,045 | 171,160 | 291,205 |
| 2001 | **221,822** | 220,509 | 442,331 |
| 2002 | 126,983 | 218,522 | 345,505 |
| 2003 | 117,716 | 194,486 | 312,202 |
| 2004 | 120,334 | 210,370 | 330,704 |
| 2005 | 134,007 | 229,444 | 363,451 |
| 2006 | 90,769 | 135,312 | 226,081 |
| June 2007 | 79,327 | 125,178 | 204,505 |

NOTES:
* - Groundwater abstracted only from borehole G27917E in the Riet GMU
1985-1998- Groundwater abstracted from boreholes G27917E, G27918C, G28303, G28304 and G28301.
**Bold** – exceeds annual sustainable yield of 204,000 and 397,200 $m^3$ for the Riet and Rietfontein Wellfields

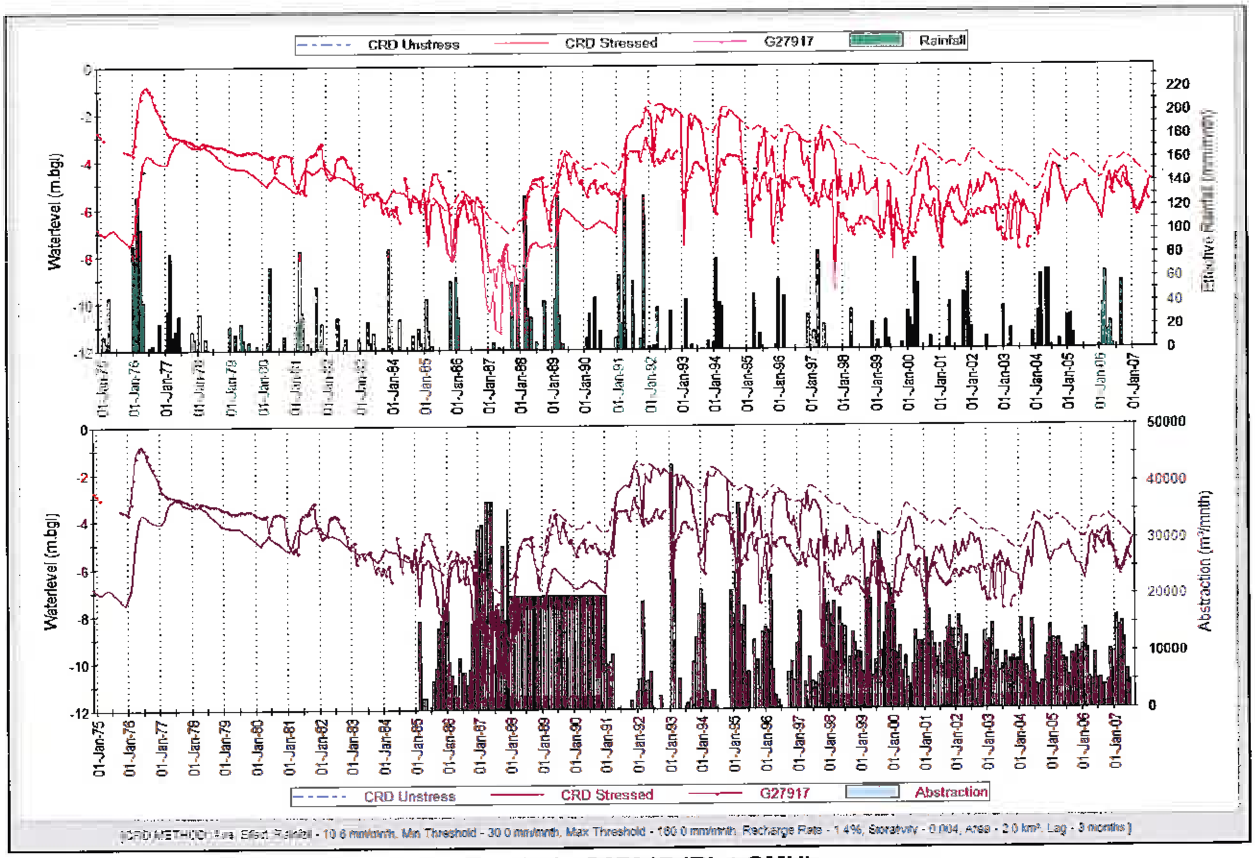



**Figure 37**: CRD Analysis - Monitoring Borehole G27917 (Riet GMU)

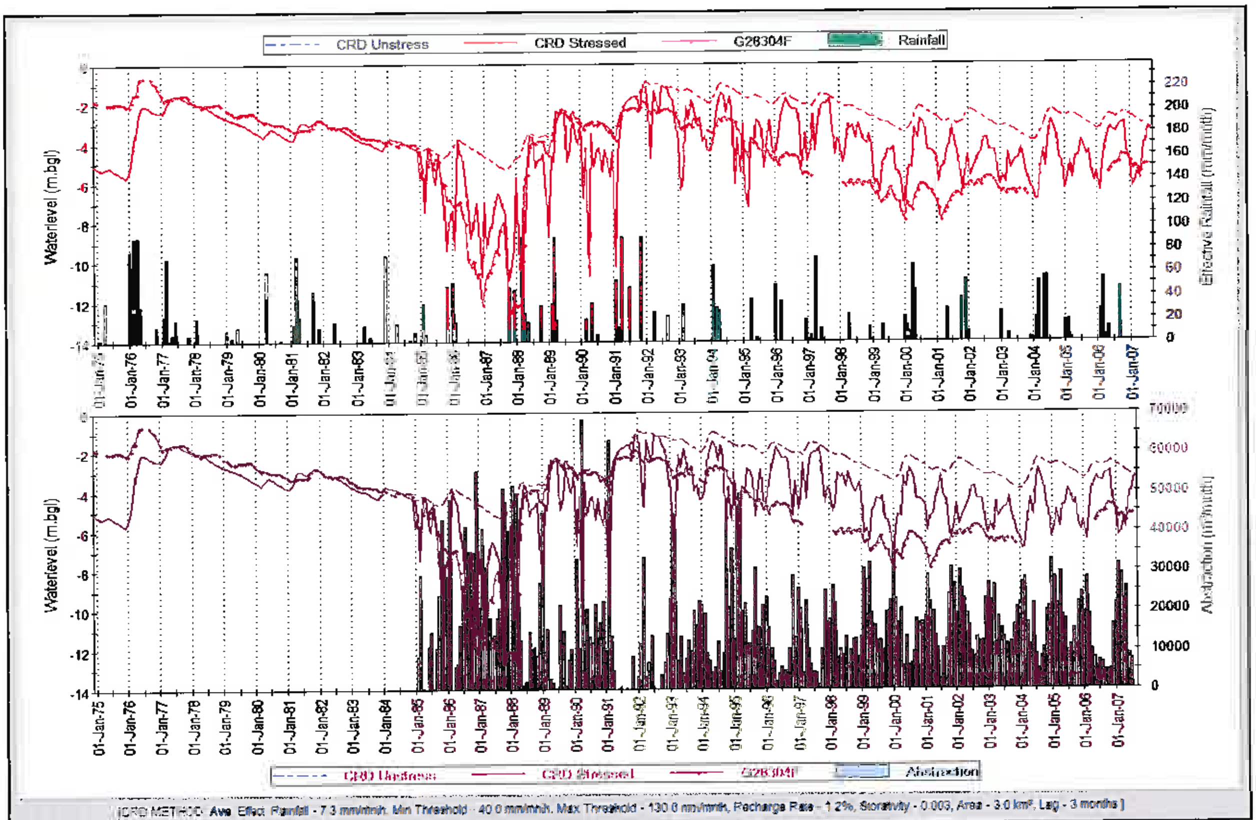



**Figure 38**: CRD Analysis - Monitoring Borehole G28304F (Rietfontein GMU)

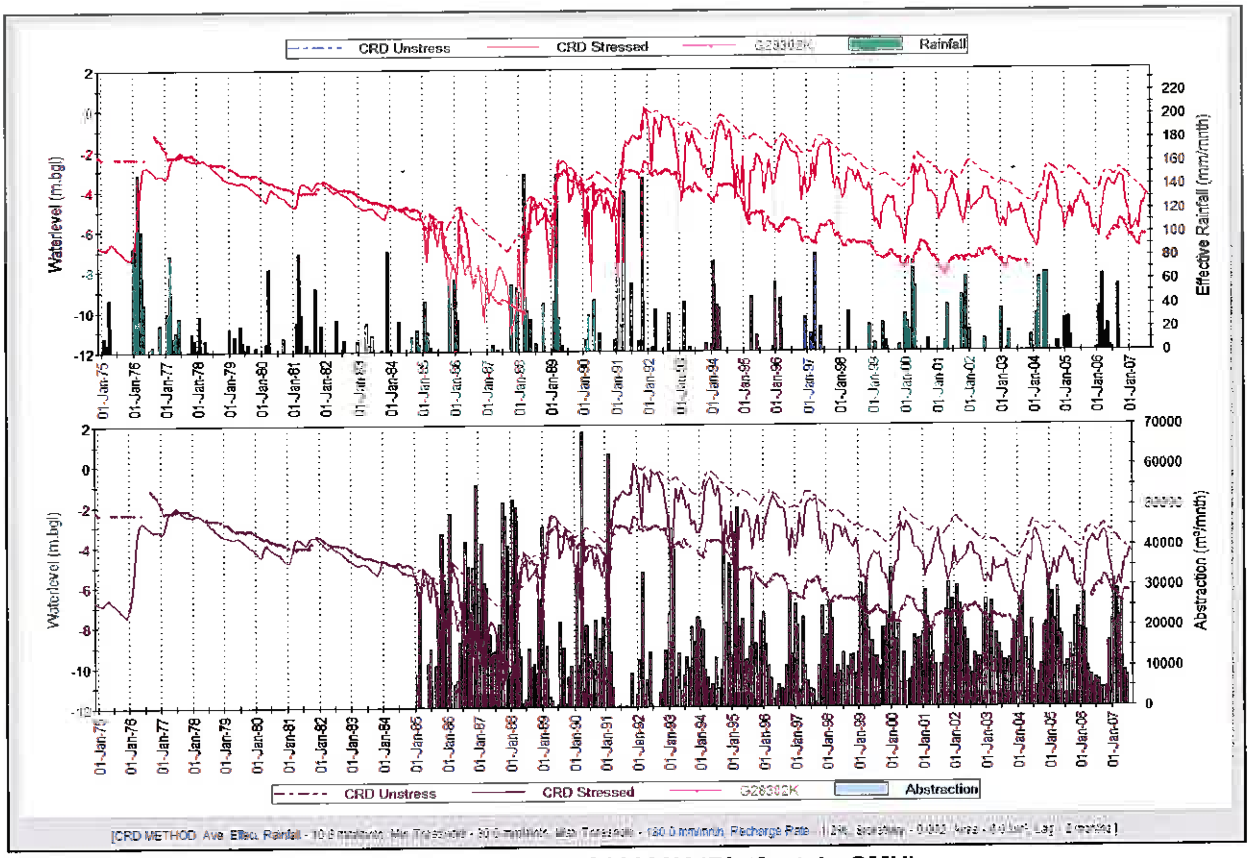



**Figure 39: CRD Analysis - Monitoring Borehole G28302K (Rietfontein GMU)**

## Groundwater Quality

The macro-chemistry of groundwater from the Riet and Rietfontein GMU's is summarised in **Table 22,** where it is clear that the salinity of the groundwater in the Riet GMU is almost double that of the Rietfontein GMU. The nitrate concentrations are elevated in the groundwater from both GMU's, especially in the Rietfontein GMU which is in the order of 12 mg/l. The groundwater from the Riet and Rietfontein GMU's are classed as calcium-magnesium-chloride (**Figure 40**) and calcium-magnesium-bicarbonate (**Figure 41**) types, respectively. The groundwater from both groundwater units is very hard.

**Table 22: Riet and Rietfontein GMUs - Summary Statistics of Groundwater Chemistry**

| Chemical Parameter | No. Rec. | Minimum | Maximum | Mean | Median | Std Deviation | Lower Quartile | Upper Quartile | 90th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| **Riet GMU** | | | | | | | | | |
| Lab. pH | 32 | 5.7 | 8.3 | 7.7 | 7.8 | 0.5 | 7.6 | 8.0 | 8.2 |
| EC (mS/m) | 32 | 82.0 | 760.0 | 310.4 | 246.0 | 177.4 | 165.3 | 394.7 | 576.8 |
| Sodium (mg/l) | 32 | 6.3 | 1232.0 | 313.8 | 214.5 | 276.7 | 127.9 | 474.5 | 547.2 |
| Calcium (mg/l) | 32 | 16.7 | 358.2 | 162.7 | 112.6 | 106.9 | 82.9 | 271.8 | 325.0 |
| Magnesium (mg/l) | 32 | 36.0 | 278.0 | 132.6 | 115.1 | 70.9 | 70.4 | 180.8 | 236.0 |
| Chloride (mg/l) | 31 | 2.5 | 1561.0 | 540.6 | 409.5 | 428.7 | 201.8 | 727.0 | 1177.5 |
| Potassium (mg/l) | 30 | 1.28 | 24.90 | 6.16 | 4.33 | 5.80 | 2.41 | 7.42 | 10.28 |
| Silica (mg/l) | 29 | 4.47 | 18.50 | 13.58 | 14.20 | 3.42 | 12.50 | 16.40 | 17.65 |
| Sulphate (mg/l) | 32 | 3.0 | 1454.0 | 518.9 | 400.0 | 368.1 | 220.7 | 779.0 | 1039.2 |
| Tot. Alkalinity (mg/l) | 32 | 162.0 | 540.7 | 300.9 | 297.9 | 81.8 | 252.8 | 321.7 | 375.7 |
| Fluoride (mg/l) | 32 | 0.4 | 2.4 | 1.0 | 1.0 | 0.4 | 0.7 | 1.1 | 1.3 |
| Nitrate (mg/l) | 31 | 0.130 | 9.200 | 3.121 | 3.185 | 1.861 | 1.490 | 3.530 | 5.600 |
| Ammonia (mg/l) | 25 | 0.015 | 0.110 | 0.044 | 0.040 | 0.025 | 0.020 | 0.060 | 0.066 |
| **Rietfontein GMU** | | | | | | | | | |
| Lab. pH | 42 | 6.8 | 8.6 | 7.7 | 7.8 | 0.5 | 7.5 | 8.0 | 8.3 |
| EC (mS/m) | 40 | 52.1 | 435.2 | 125.0 | 91.3 | 78.7 | 79.4 | 134.1 | 249.1 |
| Sodium (mg/l) | 42 | 14.0 | 449.0 | 82.5 | 51.9 | 88.8 | 39.9 | 82.5 | 233.2 |
| Calcium (mg/l) | 42 | 24.0 | 233.0 | 88.5 | 79.3 | 35.9 | 70.1 | 100.4 | 119.5 |
| Magnesium (mg/l) | 42 | 18.4 | 188.0 | 58.0 | 50.6 | 30.0 | 43.0 | 58.8 | 96.3 |
| Chloride (mg/l) | 42 | 34.4 | 911.0 | 163.2 | 90.0 | 178.6 | 60.5 | 189.5 | 359.8 |
| Potassium (mg/l) | 37 | 2.00 | 94.00 | 6.41 | 3.00 | 14.94 | 2.97 | 4.00 | 6.16 |
| Silica (mg/l) | 25 | 2.40 | 18.50 | 14.02 | 16.05 | 4.61 | 13.51 | 16.82 | 18.02 |
| Sulphate (mg/l) | 42 | 33.0 | 671.0 | 118.0 | 68.0 | 124.7 | 43.1 | 122.6 | 238.3 |
| Tot. Alkalinity (mg/l) | 42 | 116.0 | 347.2 | 261.8 | 272.5 | 57.5 | 217.8 | 297.3 | 330.0 |
| Fluoride (mg/l) | 42 | 0.4 | 1.2 | 0.8 | 0.8 | 0.2 | 0.6 | 0.9 | 1.0 |
| Nitrate (mg/l) | 40 | 0.060 | 23.000 | 11.834 | 12.180 | 6.100 | 6.898 | 16.475 | 19.840 |
| Ammonia (mg/l) | 21 | 0.015 | 0.190 | 0.043 | 0.020 | 0.045 | 0.020 | 0.040 | 0.080 |

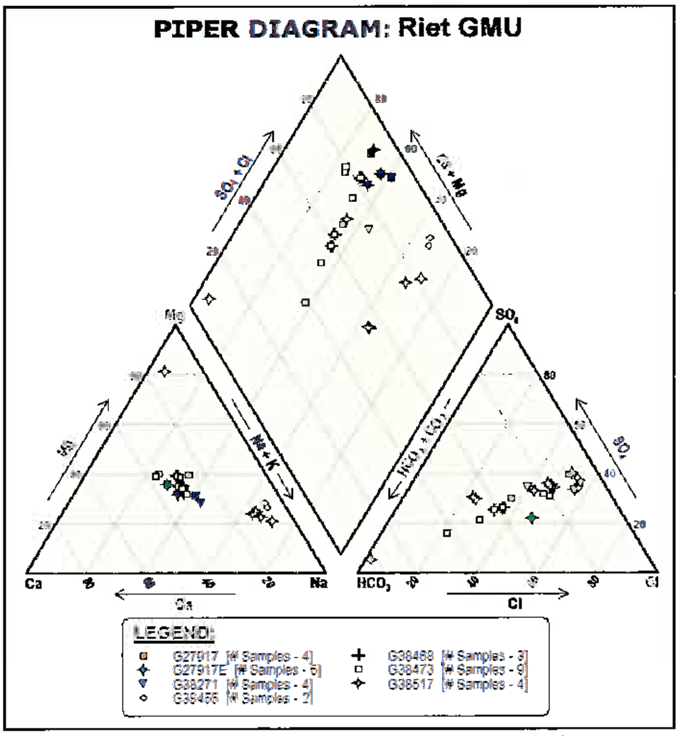



**Figure 40: Piper Plot indicating groundwater chemistry of the Riet GMU**

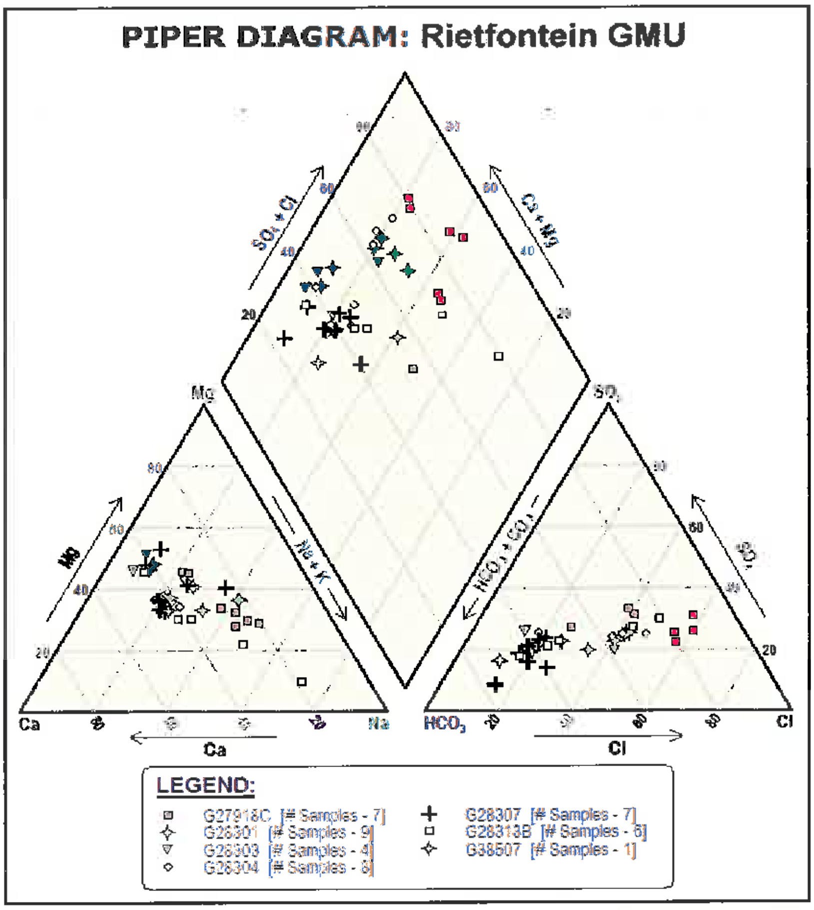



**Figure 41: Piper Plot indicating groundwater chemistry of the Rietfontein GMU**

### 3.6.7 Cyfferkuil GMU

The Cyfferkuil GMU covers an area of some 32 km$^2$ and corresponds with the southern part of Vegter's (1990) V-A groundwater unit (**Figure 5**), whilst the Veekraal GMU conforms to the northern part of this unit (**Figure 4**). The Cyfferkuil Wellfield forms part of the so-called 'Burgerville–Zewefontein Scheme'. Currently, the Cyfferkuil Wellfield is comprised of four production boreholes on the farm Cyfferkuil and three holes near Burgerville (**Table 23, Figure 42**). Borehole CF31 is low-yielding and should be replaced by borehole G39025 (Woodford, 1993). Borehole G38535 was pumped during 2003 to 2004. This hole is not suitable for production purposes. Borehole G38537 should be brought into production. Boreholes CF36 and CF39 were pumped prior to 1988 at part of the Municipal wellfield. Two monitoring boreholes, G39023 and G39028, are equipped with digital waterlevel data-loggers.

Waterlevel fluctuations in the Cyfferkuil GMU since 1989 are presented in **Figure 43**, where it can be seen that localised over-exploitation of the aquifer system occurred in the vicinity of G29023 during 1995/96 and 1999. The waterlevel information for each monitoring borehole is presented graphically in **Appendix 2**.

**Table 23: Cyfferkuil GMU - Summary of Operational Boreholes and Management Recommendations**

| Borehole Number | Vegter's Groundwater Unit | Depth (m) | Pump-Intake (m) | Pump-Rate (L/s) | Maximum Monthly Abstraction ($m^3$) | Maximum Permissible Waterlevel (m) below collar |
|---|---|---|---|---|---|---|
| CF31 | V-A | 82.0 | 32.0 | (~~3.0~~) | (~~3,000~~) | ? |
| CF34 | V-A | 46.0 | 32.0 | 4.0 | 3,000 | ? |
| CF35 | V-A | 46.0 | 36.0 | 4.0 | 2,500 | ? |
| G39024# | V-A | 36.0 | 30.0 | 10.0 | 6,000 | 18.0* |
| G39025# | V-A | 72.0 | 20.0 | 4.0 | 3,000 | 13.0# |
| G38537# | V-A | 66.0 | 24.0 | 3.0 | 2,000 | 10.0# |
| ZN5 | V-A | 50.4 | ? | 3.0 | 1,250 | ? |
| G23229 | V-A | 47.6 | ? | 3.0 | 1,900 | ? |
| G23232 | V-A | 72.5 | ? | 4.0 | 2,500 | ? |
| TOTAL | | | | **35.0** | **21,150** | |

Notes:

* - Recommended by Vegter(1990). # - Recommended by Woodford (1993).

**Maximum Permissible Drawdown** – waterlevel prior to switch-on of pump (i.e. rest-waterlevel) after a rest period of approximately 8 hours. The maximum permissible drawdown indicates (i) the depth below which pump-inlets should be installed, and (ii) the depth at which a float-operated switching device should be installed to safeguard the pump from running dry.

Vegter (1992) estimated the 'minimum steady yield' of groundwater unit V-A at 352,000 $m^3/a$ (**Table 2**), assuming a recharge factor of 1.6% of MAP. This equates to ~232,000 $m^3$/annum if his 'steady yield' is adjusted to the actual size of the Cyfferkuil GMU. Recharge to the GMU under normal rainfall conditions (MAP of ~352mm) is estimated at 355,000 $m^3/a$ (**Table 3**), assuming a recharge factor of 3.1% of MAP. During periods of drought the average annual recharge is likely to decline to 232,000 $m^3$. The DWAF GRAII 'Average Groundwater Exploitation Potential' for this GMU is about 280,000 $m^3/a$ (**Table 6**). The Chloride Mass Balance or CMB method indicates a rainfall-recharge factor of 1.6% and 3.2% assuming an average rainfall chloride concentration of 0.86 and 1.7 mg/l, respectively. The lower CMB derived recharge factor is the same as that obtained by Vegter (1992) and is accepted as being the most realistic for this GMU. CRD analyses of monthly rainfall from Rooiwal in the Zewefontein GMU versus abstraction and waterlevel fluctuations in boreholes G39023 (**Figure 44**) and G39028 (**Figure 45**) provides 'best-fit' recharge factors of 1.3 and 1.5%, respectively, and an average aquifer storativity value of 0.002. **The long-term sustainable yield of the GMU is therefore taken as 260,000 $m^3/a$,** of which 254,000 $m^3/a$ can be harvested by the current production holes (i.e. the groundwater resources of this GMU are fully developed).

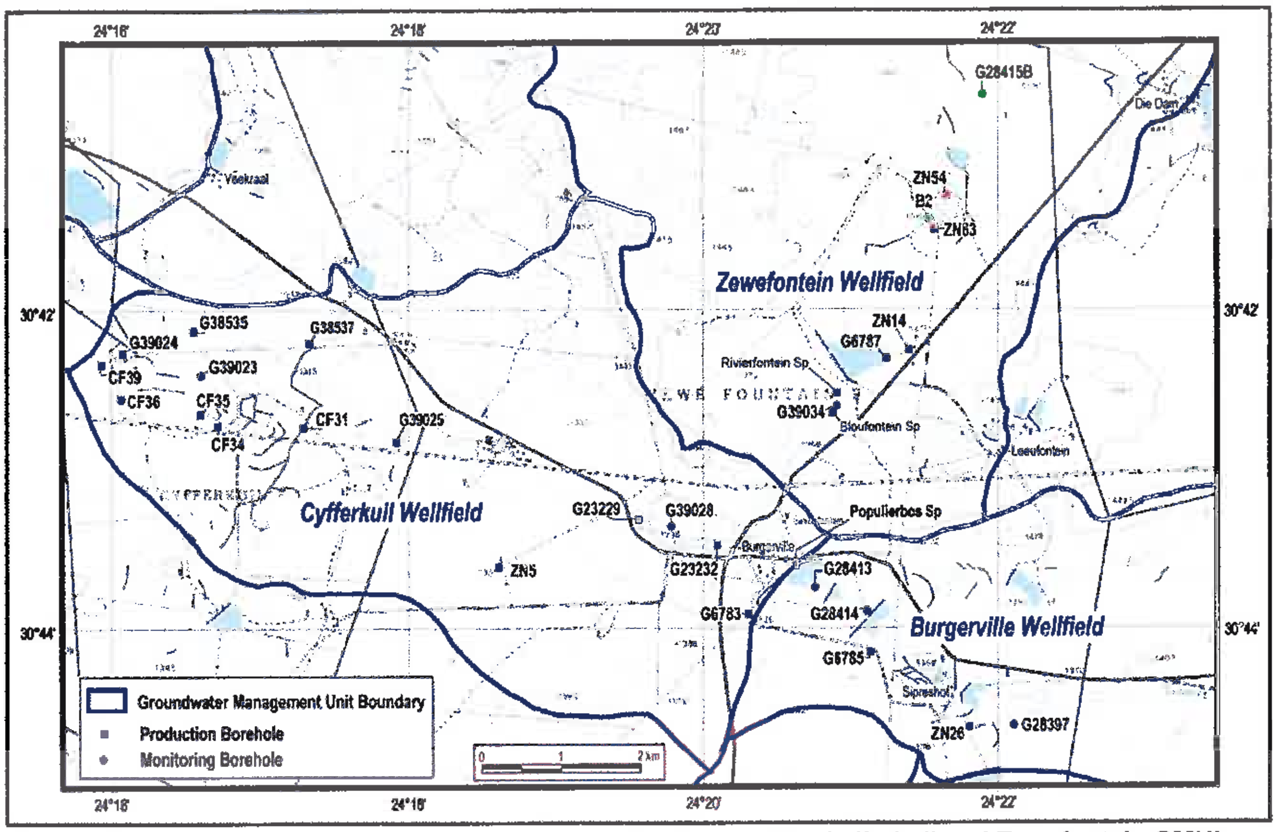



**Figure 42: Production and Monitoring boreholes in the Burgerville, Cyfferkuil and Zewefontein GMU's**

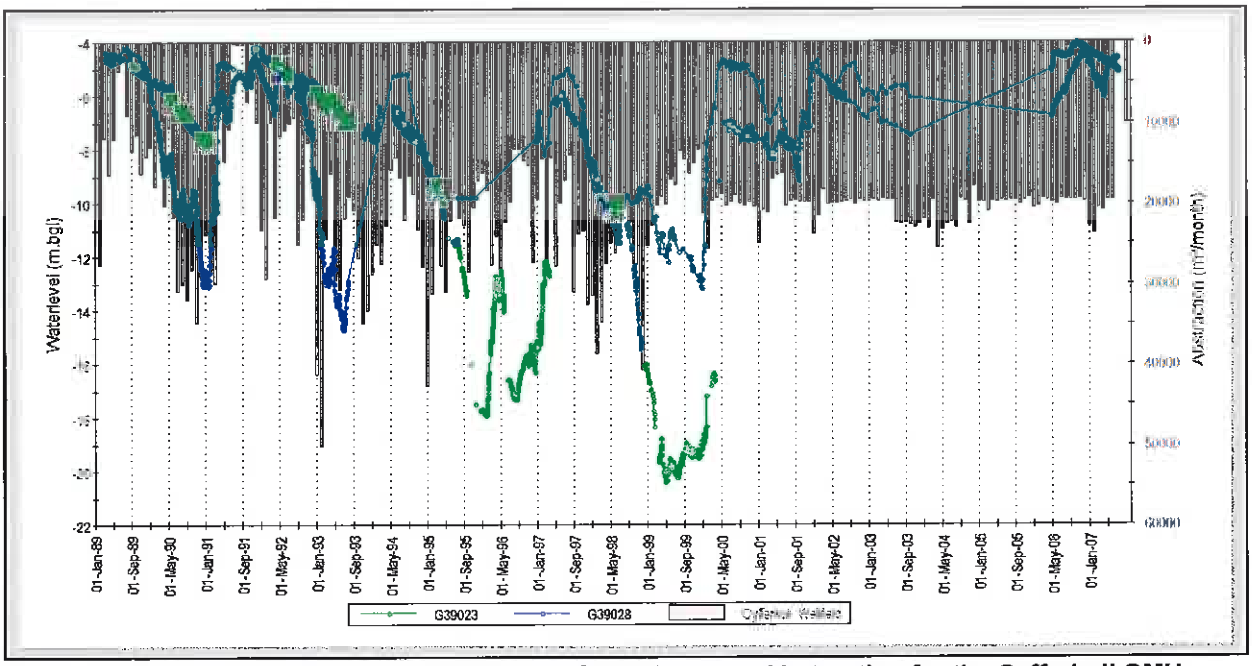



**Figure 43: Waterlevel variations in G39023 and G39028 versus Abstraction for the Cyfferkuil GMU**

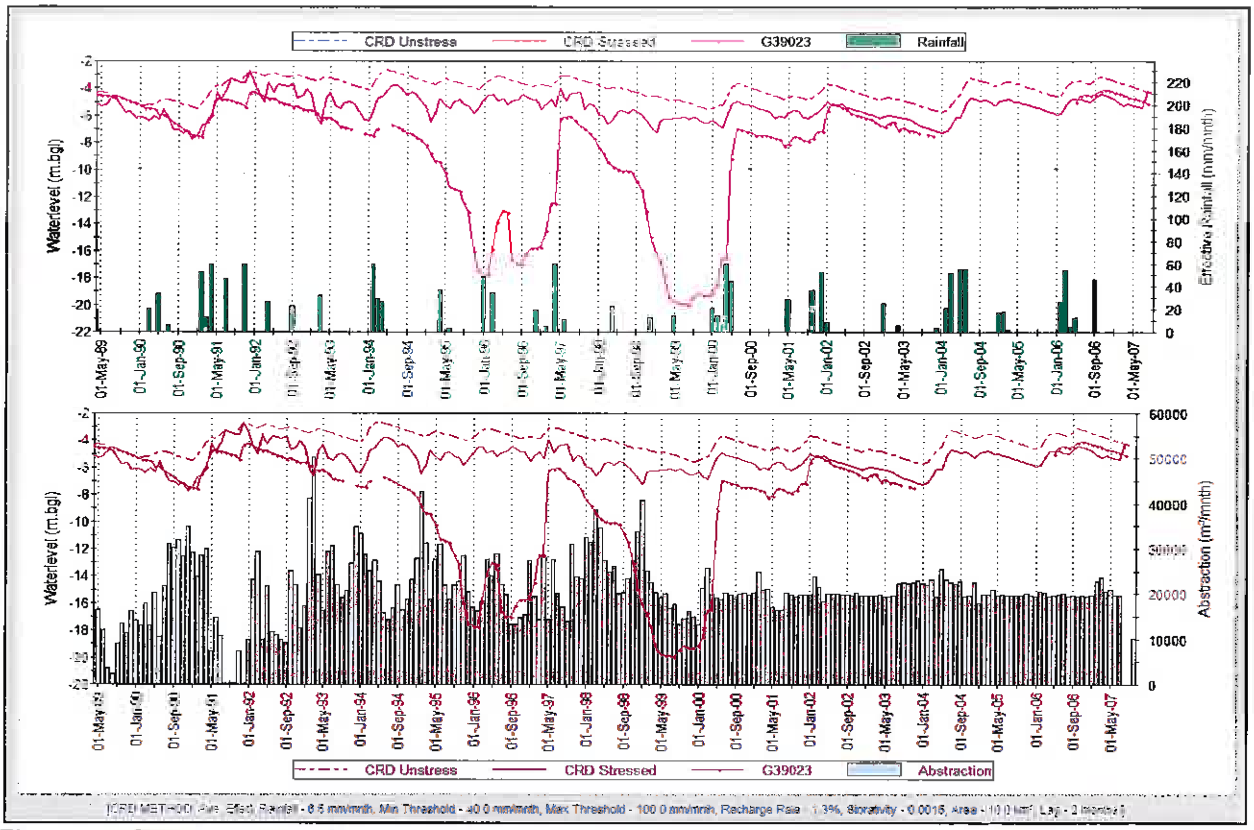



**Figure 44**: CRD Analysis – Monitoring Borehole G39023 (GMU Cyfferkuil)

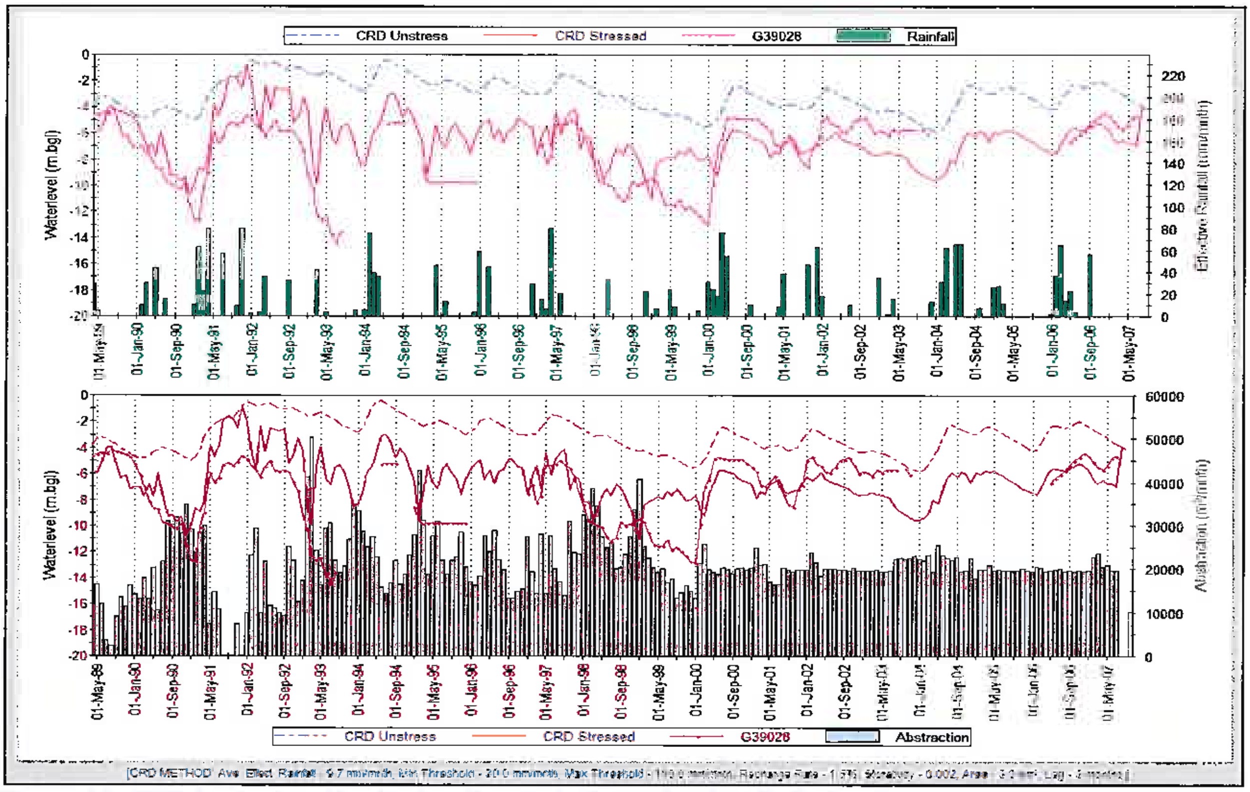



**Figure 45**: CRD Analysis – Monitoring Borehole G39028 (GMU Cyfferkuil)

The annual volumes of groundwater abstracted from the GMU since 1964 are presented in **Table 24**, which indicates that this GMU has in the past been heavily over-exploited due to the good quality of the water, as well as the relatively low cost of purchasing the water from the landowner at Cyfferkuil. The GMU has been over exploited since 2000 and abstraction should be immediately scaled back to within the estimated sustainable yield of the wellfield.

**Table 24: Cyfferkuil GMU - Annual Volumes of Groundwater Abstracted**

| Year | Annual Abstraction ($m^3$) | Year | Annual Abstraction ($m^3$) |
|---|---|---|---|
| 1964 | 16,832 | 1986 | **293,963** |
| 1965 | 189,580 | 1987 | 119,193 |
| 1966 | 148,064 | 1988 | 98,154 |
| 1967 | 163,601 | 1989 | 150,832 |
| 1968 | **258,191** | 1990 | **281,845** |
| 1969 | **255,432** | 1991 | 133,533 |
| 1970 | **233,503** | 1992 | 202,911 |
| 1971 | 135,127 | 1993 | **349,138** |
| 1972 | 223,978 | 1994 | **259,715** |
| 1973 | **273,374** | 1995 | **303,290** |
| 1974 | 126,892 | 1996 | **241,585** |
| 1975 | 230,711 | 1997 | **266,126** |
| 1976 | 127,002 | 1998 | **349,476** |
| 1977 | 215,170 | 1999 | 214,906 |
| 1978 | **274,836** | 2000 | **244,565** |
| 1979 | **397,324** | 2001 | **235,839** |
| 1980 | **262,913** | 2002 | **242,550** |
| 1981 | 206,151 | 2003 | **253,161** |
| 1982 | **289,729** | 2004 | **260,739** |
| 1983 | 148,868 | 2005 | **237,849** |
| 1984 | 172,213 | 2006 | **236,981** |
| 1985 | **275,333** | June 2007 | 127,245 |

Note: **Bold** – exceeds safe yield of GMU of 230,000 $m^3$/a.

## Groundwater Quality

The groundwater is fresh and in terms of its macro-chemical constituents suitable for direct human consumption (**Table 25**), although the water is hard (average $CaCO_3$ hardness is 308 mg/L).

**Table 25: Cyfferkuil GMU - Statistics Summary of Groundwater Chemistry**

| Chemical Parameter | No. Records | Minimum | Maximum | Mean | Median | Std Deviation | Lower Quartile | Upper Quartile | 90th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| Lab. pH | 28 | 7.5 | 8.8 | 8.2 | 8.3 | 0.3 | 7.9 | 8.4 | 8.5 |
| EC (mS/m) | 28 | 60.0 | 134.1 | 101.5 | 101.9 | 16.3 | 93.4 | 108.9 | 122.5 |
| Sodium (mg/l) | 28 | 32.3 | 184.9 | 108.0 | 111.5 | 28.5 | 101.1 | 120.5 | 133.3 |
| Calcium (mg/l) | 28 | 32.0 | 65.0 | 49.2 | 50.0 | 7.9 | 45.4 | 54.5 | 58.6 |
| Magnesium (mg/l) | 28 | 28.6 | 62.0 | 44.9 | 45.3 | 7.5 | 39.5 | 50.4 | 52.0 |
| Chloride (mg/l) | 28 | 22.2 | 129.1 | 66.8 | 53.4 | 31.2 | 45.1 | 84.3 | 119.5 |
| Potassium (mg/l) | 28 | 1.3 | 13.5 | 2.8 | 2.1 | 2.5 | 1.8 | 2.4 | 3.6 |
| Silica (mg/l) | 28 | 9.5 | 16.6 | 13.8 | 14.1 | 1.5 | 13.0 | 14.7 | 15.3 |
| Sulphate (mg/l) | 28 | 33.8 | 184.5 | 114.2 | 114.9 | 41.1 | 89.0 | 144.7 | 167.5 |
| Tot. Alkalinity (mg/l) | 28 | 201.3 | 405.5 | 318.6 | 324.8 | 54.5 | 288.8 | 358.6 | 384.3 |
| Fluoride (mg/l) | 27 | 0.493 | 1.562 | 0.939 | 0.908 | 0.190 | 0.855 | 0.980 | 1.152 |
| Nitrate (mg/l) | 28 | 0.070 | 6.070 | 1.653 | 1.584 | 1.257 | 0.696 | 2.175 | 3.011 |
| Ammonia (mg/l) | 24 | 0.010 | 0.210 | 0.044 | 0.020 | 0.045 | 0.015 | 0.051 | 0.097 |

The groundwater has a sodium-magnesium-bicarbonate character (**Figure 46**). The available groundwater chemistry per borehole is graphically presented on Piper diagrams in **Appendix 3**.

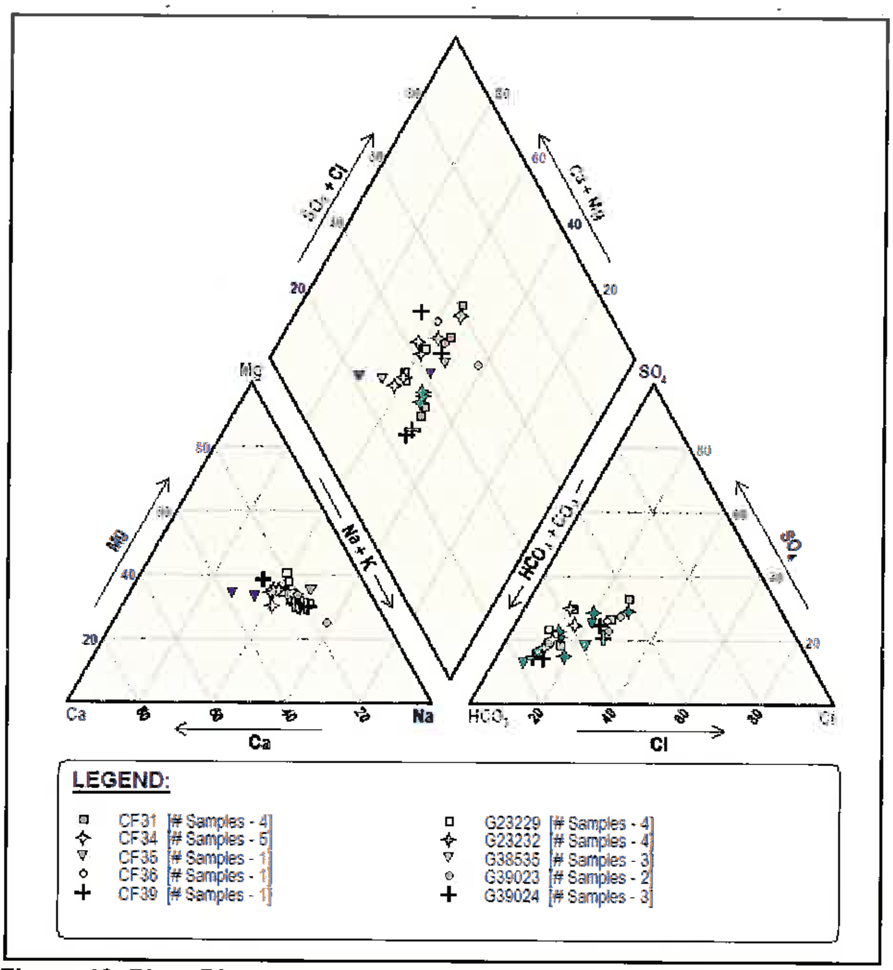



**Figure 46: Piper Diagram of Groundwater from the Cyfferkuil GMU**

### 3.6.8 Zewefontein GMU

The Zewefontein Groundwater Management Unit (**Figure 4**) covers an area of 86 km$^2$ and has the same geographic extent as Vegter's (1990) IV groundwater unit (**Figure 5**). Four Municipal production boreholes are located in the southernmost discharge zone or 'outlet' of the GMU (**Figure 42**). The available technical information for these boreholes are summarised in **Table 26**. Three monitoring boreholes, B2, G39034 and G28415B, have been equipped by the DWAF with digital waterlevel data-loggers. Monitoring borehole G39034 was specifically drilled alongside the eye of 'Bloufontein' spring and downstream of 'Riverfontein' spring. In July 1990 the combined yield of these two springs was measured at 8.6 L/s (Vegter, 1990). The waterlevel fluctuations in the monitoring holes and monthly groundwater abstraction from the wellfield are presented in **Figure 47**, whilst the waterlevel time-series plots for each borehole are contained in **Appendix 2**. The Mean Annual Precipitation of the GMU is 357mm (Rooiwal weather station, **Section 3.1.1**)

**Table 26: Zewefontein GMU - Summary of Operation Production Boreholes and Management Recommendations**

| Borehole Number | Vegter's Groundwater Unit | Depth (m) | Pump-Intake (m) | Pump-Rate (L/s) | Maximum Monthly Abstraction ($m^3$) | Maximum Permissible Waterlevel (m) below collar |
|---|---|---|---|---|---|---|
| G6797 | IV | 26.0 | 23.0 | 3.0 | 2,500 | ? |
| ZN14 | IV | - | - | 4.0 | 3,200 | ? |
| ZN54 | IV | 24.0 | - | 6.0 | 11,000 | ? |
| ZN63 | IV | - | - | 5.0 | 11,000 | ? |
| TOTAL | | | | 18.0 | 27,700 | |

Notes:

**Maximum Permissible Drawdown** – waterlevel prior to switch-on of pump (i.e. rest-waterlevel) after a rest period of approximately 8 hours. The maximum permissible drawdown indicates (i) the depth below which pump-inlets should be installed, and (ii) the depth at which a float-operated switching device should be installed to safeguard the pump from running dry.

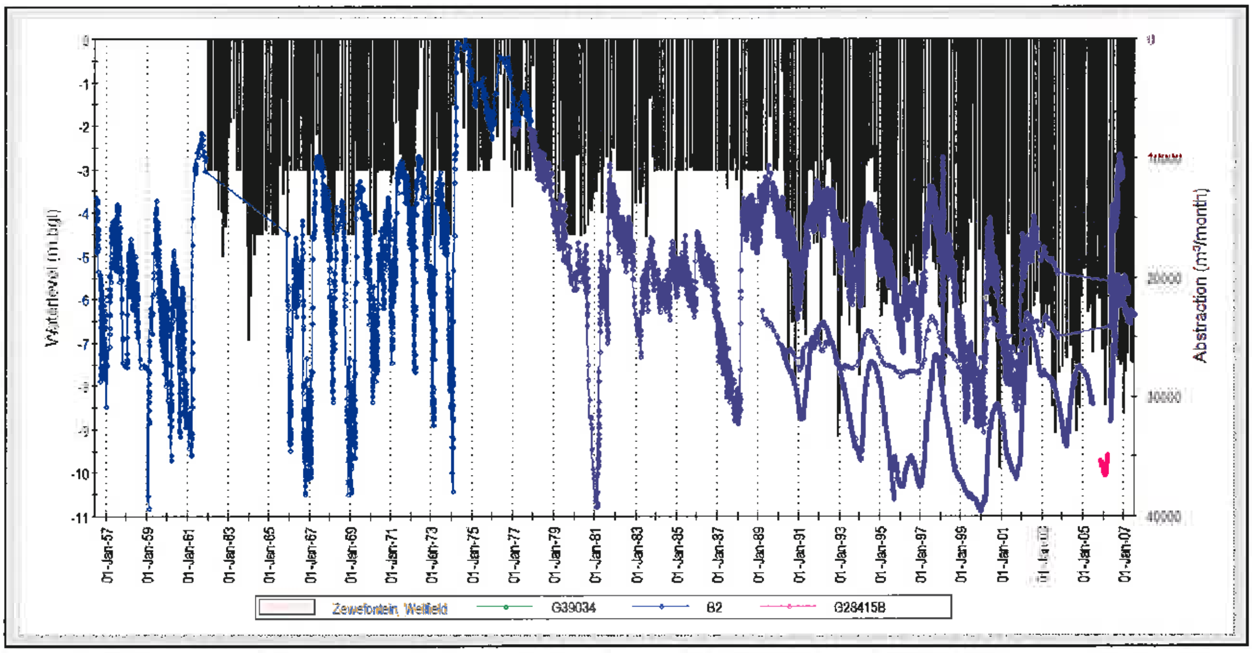
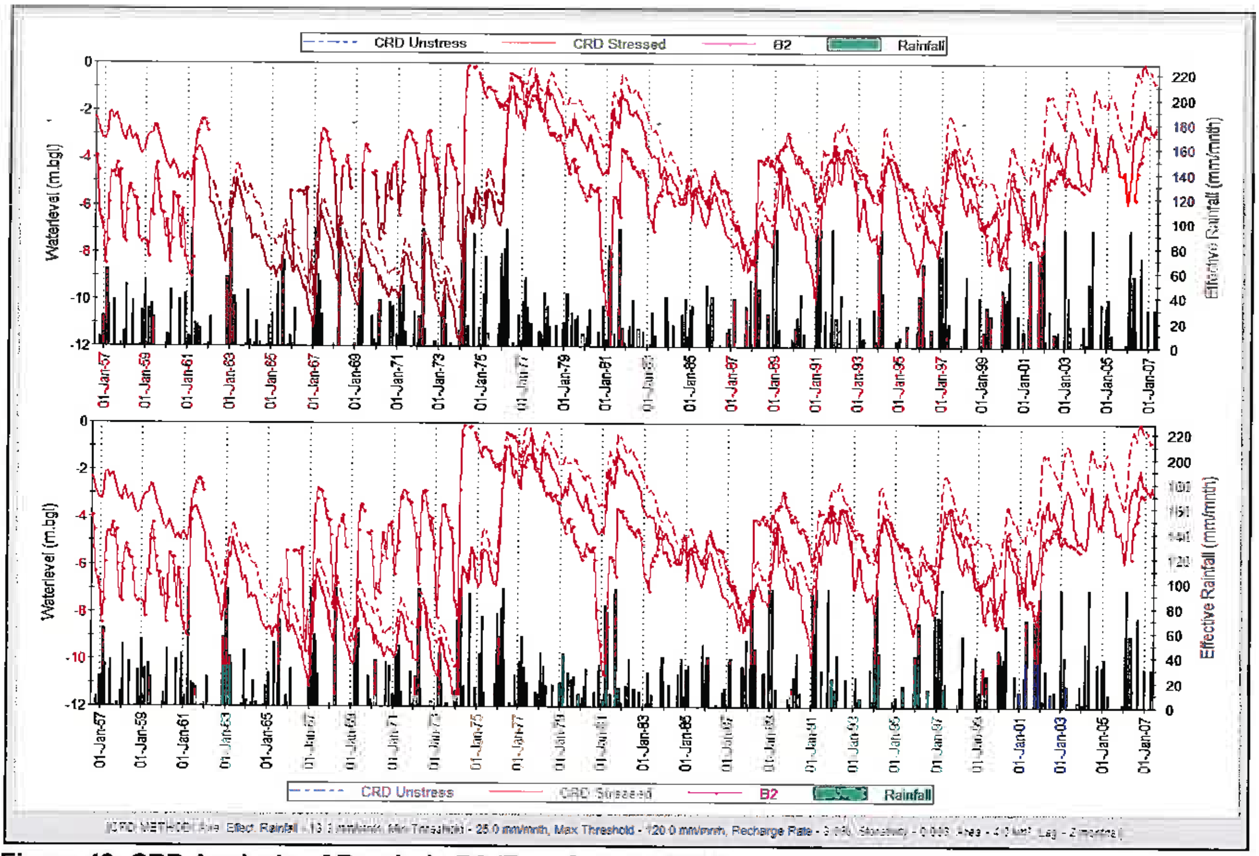
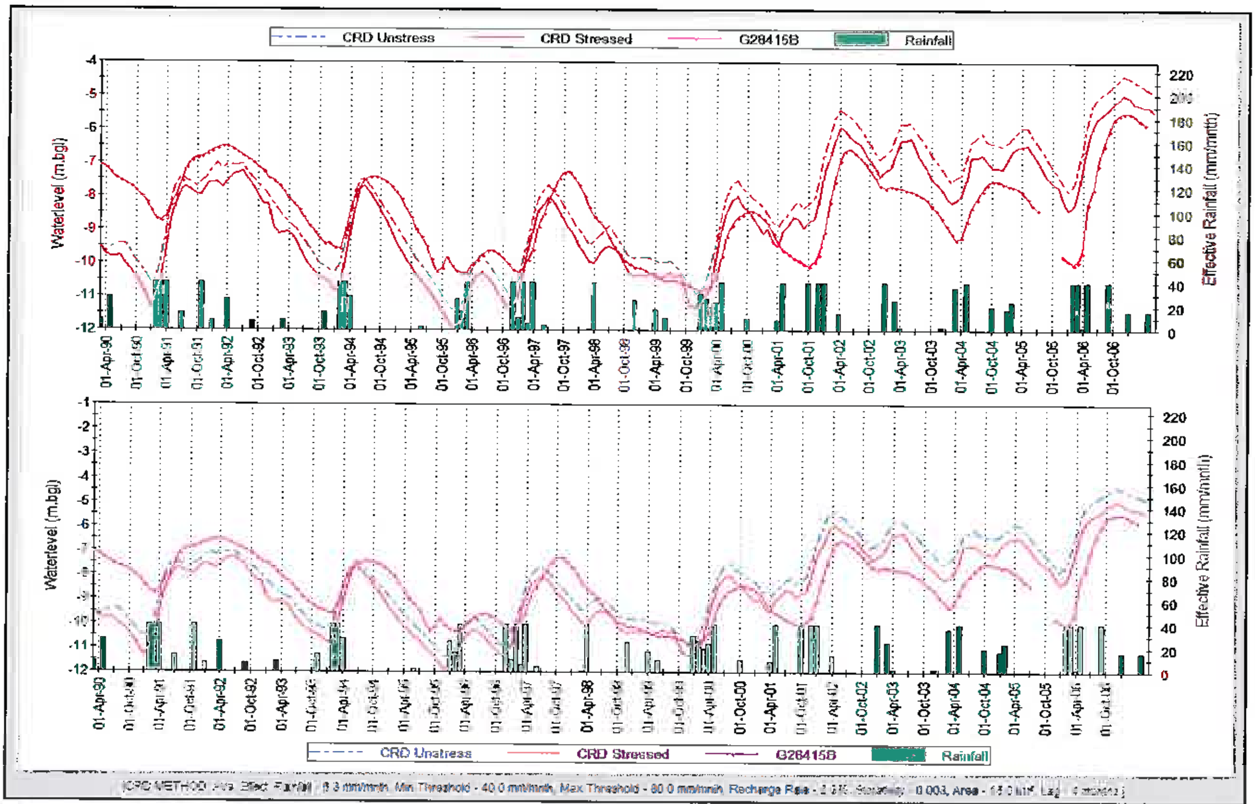



**Figure 47: Waterlevel fluctuations in monitoring holes B2, G39024 and G28415B versus abstraction from the Zewefontein GMU**

Smit (1975) estimated the 'safe-yield' of the Burgerville and Zewefontein Area at 600,000 $m^3/a$. Vegter (1992) derived a 'minimum 'steady-yield' for groundwater unit IV of 519,000 $m^3/a$ (**Table 2**), assuming a recharge factor of ~2% of MAP. Mean annual recharge to the GMU was estimated at 964,578 $m^3$, assuming a recharge factor of 3.2% of MAP (**Table 3**). During droughts the recharge from rainfall is expected to decline to ~628,300 $m^3/a$. The CMB method indicated a recharge factor of 2.8% of MAP (**Table 4**), assuming a rainfall chloride concentration of 0.83 mg/l. The DWAF's GRAII 'Average Groundwater Exploitation Potential' or AGEP for the Zewefontein GMU is ~657,000 $m^3$/annum (**Table 6**). CRD analysis of monthly rainfall data from Rooiwal (**Section 2.1.2**) versus waterlevel time-series data from monitoring holes B2 (**Figure 48**), G28415B (**Figure 49**) and G39034 (**Figure 50**) produced 'best-fit' recharge factors ranging from 2.5 to 3.0% of MAP, and average storativity values of between 0.003 and 0.006. The CRD analysis indicates a minimum threshold rainfall of between 25 and 40 mm/month. **The mean average recharge of 844,000 $m^3/a$ is accepted as the long-term sustainable yield of the GMU,** assuming an average recharge factor of 2.8% of MAP.




**<u>Figure 48</u>: CRD Analysis of Borehole B2 (Zewefontein GMU)**




**<u>Figure 49</u>: CRD Analysis Monitoring Borehole G28415B (Zewefontein GMU)**

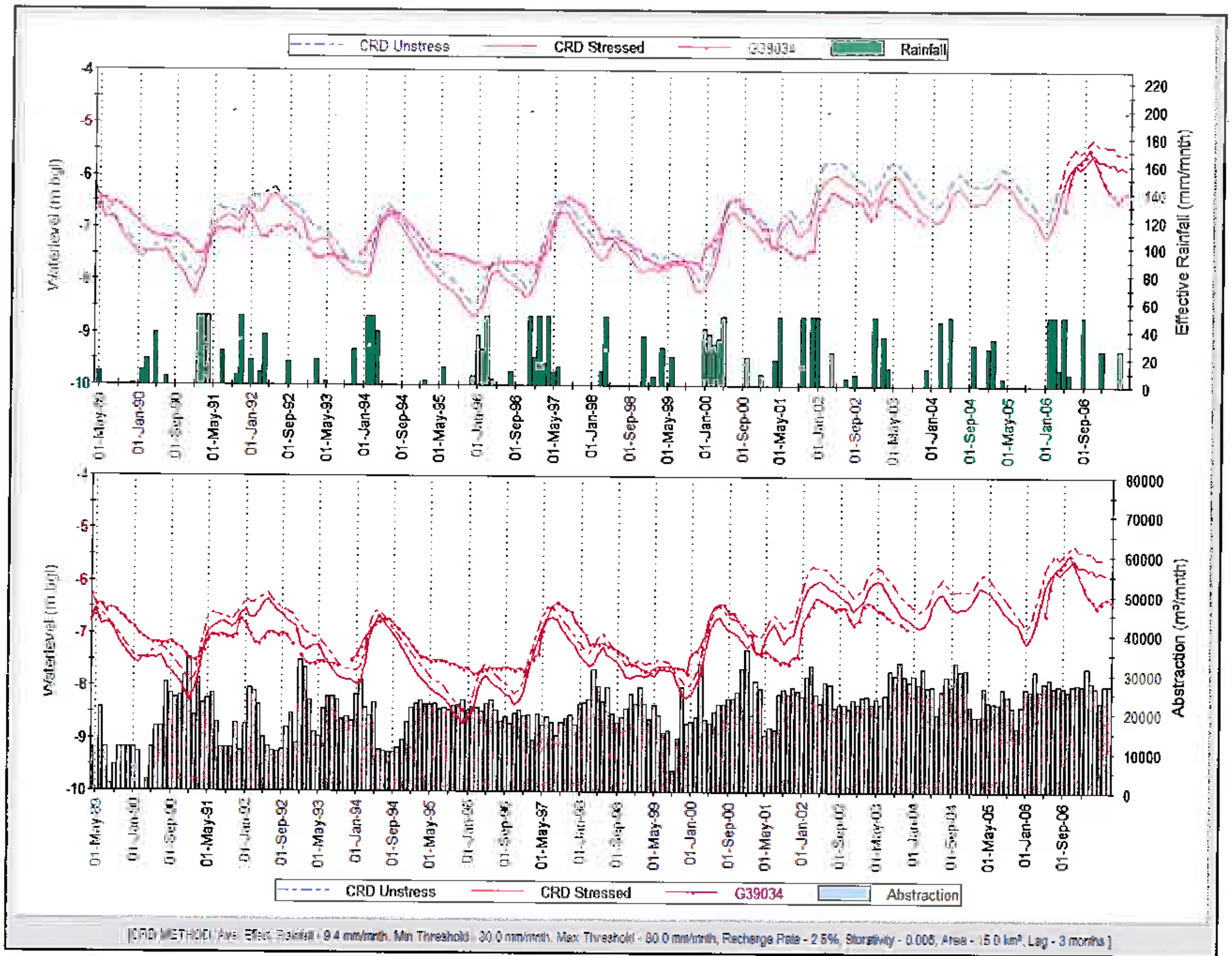



**Figure 50**: **CRD Analysis of Monitoring Borehole G39034 (Zewefontein GMU)**

The Municipal production boreholes are clustered at the downstream outlet to the Zewefontein GMU and unlikely to be able to 'harvest' more than 40% of the annual average recharge from rainfall. The sustainable yield of the current wellfield is therefore set at 338,000 $m^3$/annum. Furthermore, production boreholes ZN54 and ZN63 are in hydraulically connected and are therefore likely to interfere with one another during pumping. A similar situation exists between boreholes ZN14 and G6787. The annual groundwater abstraction from the Municipal production holes since 1962 is presented in **Table 27**, indicating that the annual sustainable yield of the wellfield has never been exceeded.

## Groundwater Quality

The groundwater abstracted from the wellfield has a low salinity and is fit for direct human consumption (**Table 28**), but the water is hard ($CaCO_3$ hardness 282 mg/L). The groundwater has a calcium-magnesium-bicarbonate character (**Figure 51**), typical of direct recharge of rainwater and dynamic throughflow in fractured-rock aquifers. he groundwater chemistry information per production borehole is presented on Piper diagrams in **Appendix3**.

**Table 27: Zewefontein GMU - Annual Volumes of Groundwater Abstracted**

| Year | Annual Abstraction ($m^3$) | Year | Annual Abstraction ($m^3$) |
|---|---|---|---|
| 1962 | 153,444 | 1985 | 141,470 |
| 1963 | 134,598 | 1986 | 130,920 |
| 1964 | 211,245 | 1987 | 121,620 |
| 1965 | 161,111 | 1988 | 124,594 |
| 1966 | 133,280 | 1989 | 116,607 |
| 1967 | 124,340 | 1990 | 219,868 |
| 1968 | 169,086 | 1991 | 212,794 |
| 1969 | 144,751 | 1992 | 210,397 |
| 1970 | 143,933 | 1993 | 254,415 |
| 1971 | 124,362 | 1994 | 193,858 |
| 1972 | 125,110 | 1995 | 261,505 |
| 1973 | 154,877 | 1996 | 242,161 |
| 1974 | 56,582 | 1997 | 213,485 |
| 1975 | 126,008 | 1998 | 277,013 |
| 1976 | 73,910 | 1999 | 218,744 |
| 1977 | 116,382 | 2000 | 291,971 |
| 1978 | 112,048 | 2001 | 271,984 |
| 1979 | 172,500 | 2002 | 296,699 |
| 1980 | 169,220 | 2003 | 321,206 |
| 1981 | 131,419 | 2004 | 329,587 |
| 1982 | 140,443 | 2005 | 268,947 |
| 1983 | 137,730 | 2006 | 325,158 |
| 1984 | 109,150 | June 2007 | 162,732 |

Note:
**Bold** – Exceeds sustainable wellfield yield of 338,000 $m^3/a$

**Table 28: Zewefontein GMU - Statistical Summary of Groundwater Chemistry**

| Chemical Parameter | No. Rec. | Minimum | Maximum | Mean | Median | Std Deviation | Lower Quartile | Upper Quartile | 90th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| Lab. pH | 41 | 6.6 | 8.6 | 8.1 | 8.1 | 0.3 | 8.0 | 8.3 | 8.4 |
| EC (mS/m) | 40 | 68.7 | 99.6 | 77.8 | 76.6 | 5.9 | 73.3 | 80.0 | 84.4 |
| Sodium (mg/l) | 40 | 49.8 | 76.2 | 64.1 | 62.9 | 6.7 | 58.7 | 69.1 | 73.5 |
| Calcium (mg/l) | 40 | 37.1 | 73.6 | 55.6 | 56.3 | 5.3 | 55.0 | 57.8 | 59.6 |
| Magnesium (mg/l) | 40 | 27.7 | 42.7 | 34.8 | 34.4 | 2.8 | 33.4 | 36.2 | 38.1 |
| Chloride (mg/l) | 40 | 18.7 | 56.6 | 29.2 | 24.9 | 10.0 | 23.0 | 28.1 | 46.0 |
| Potassium (mg/l) | 40 | 0.84 | 2.43 | 1.20 | 1.08 | 0.35 | 0.98 | 1.27 | 1.71 |
| Silica (mg/l) | 40 | 13.47 | 17.92 | 15.88 | 15.79 | 0.93 | 15.18 | 16.35 | 17.12 |
| Sulphate (mg/l) | 40 | 29.2 | 94.2 | 44.5 | 38.0 | 13.8 | 35.1 | 48.7 | 65.3 |
| Tot. Alkalinity (mg/l) | 40 | 213.5 | 372.4 | 320.0 | 327.7 | 34.8 | 312.9 | 338.8 | 353.7 |
| Fluoride (mg/l) | 39 | 0.4 | 0.8 | 0.5 | 0.5 | 0.1 | 0.5 | 0.6 | 0.7 |
| Nitrate (mg/l) | 40 | 1.38 | 6.75 | 3.08 | 2.97 | 0.94 | 2.69 | 3.36 | 3.85 |
| Ammonia (mg/l) | 39 | 0.02 | 0.12 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.05 |

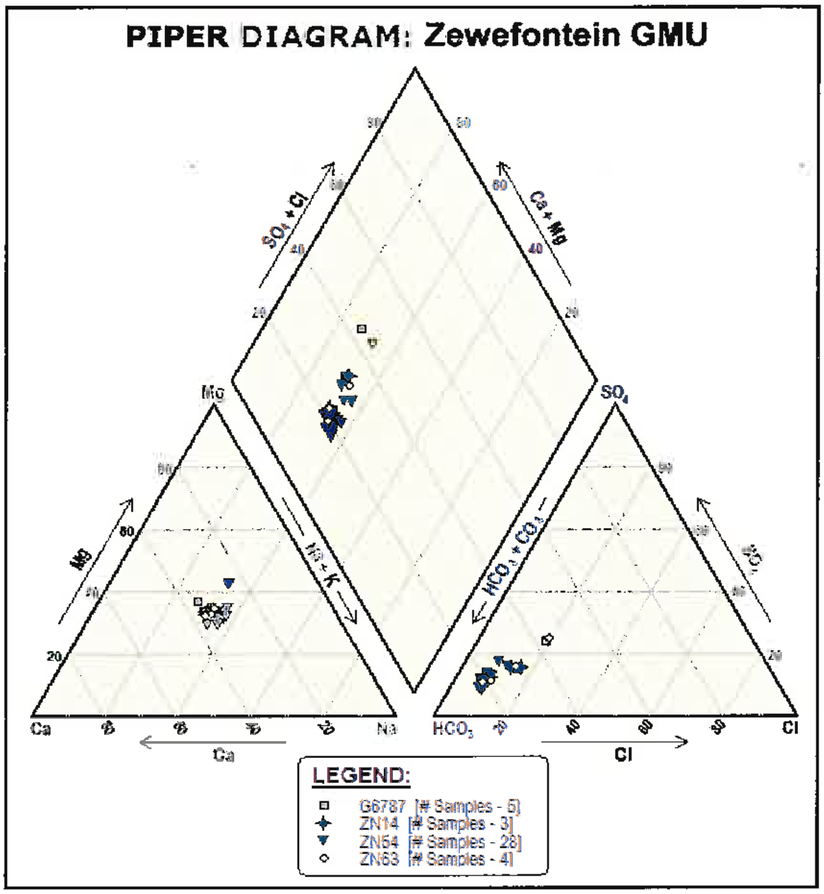



**Figure 51: Piper Diagram of Groundwater from Production Boreholes in the Zewefontein GMU**

### 3.6.9 Burgerville GMU

The Burgerville GMU extends over an area of 43 km$^2$ (**Figure 4**) and overlaps with two of Vegter's (1990) proposed groundwater units, namely III and V-A (**Figure 1**). Three production borehole are currently being utilised in this GMU, namely G6783, G6785 and ZN26 (**Table 1**, **Figure 42**). Borehole ZN26 on the farm Sipreshof was drilled in 1962. The De Aar Municipality utilised ZN26 from 1962 up until January 1985. In 1987, the Municipality tested the hole at 6.7 L/s for 72 hours and re-commenced pumping in early 1988.

**Table 29: Burgerville GMU - Summary of Operational Production Boreholes and Management Recommendations**

| Borehole Number | Vegter's Groundwater Unit | Depth (m) | Pump-Intake (m) | Pump-Rate (L/s) | Maximum Monthly Abstraction (m$^3$) | Maximum Permissible Waterlevel (m) below collar |
|---|---|---|---|---|---|---|
| G6783 | V-A | 55.0 | - | 3.5 | 1,900 | ? |
| G6785 | V-A | 42.0 | - | 3.5 | 1,900 | ? |
| ZN26 | III | 30.0 | - | 6.0 | 5,000 | ? |
| **TOTAL** | | | | **13.0** | **8,800** | |

Notes:

**Maximum Permissible Drawdown** – waterlevel prior to switch-on of pump (i.e. rest-waterlevel) after a rest period of approximately 8 hours. The maximum permissible drawdown indicates (i) the depth below which pump-inlets should be installed, and (ii) the depth at which a float-operated switching device should be installed to safeguard the pump from running dry.

The 'Populierbos' spring flows strongly after heavy rainfalls and this water is piped to De Aar, along with the flow from the Rivierfontein and Bloufontein springs in the adjoining Zewefontein GMU. Unfortunately the Municipality are currently not monitoring these flow rates. The DWAF have installed digital waterlevel data-loggers in boreholes G28414 and G28397 (**Figure 42**), whilst the autographic recorder on G28413 was removed towards the end of 2003. **Figure 52** shows waterlevel variations in boreholes G28397 and G28414 versus volumes of groundwater abstracted from the Burgerville Wellfield. The unit has been overexploited in the past, especially during droughts, i.e. 1979 to 1981, 1994 to 1995 etc. The waterlevels in the wellfield have recovered dramatically since 2002, indicating that current pumping-rates are in line with the sustainable yield of the wellfield.

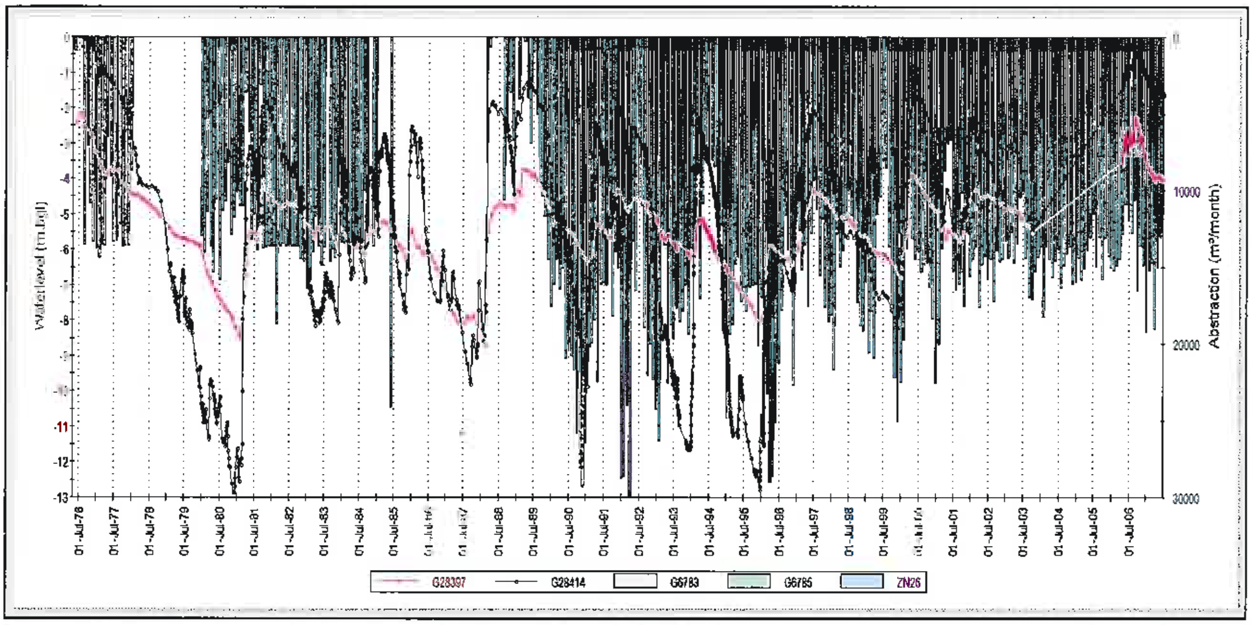



**Figure 52: Waterlevel fluctuations in G28397 and G28414 versus volumes abstracted from G6783, G6785 and ZN26**

Recharge to the GMU is estimated at 249,000 $m^3$/annum during periods of normal rainfall (MAP 338 mm, **Table 3**), assuming a rainfall-recharge factor of 3.1%. The CMB method indicates recharge factors of 2 and 4% using rainfall chloride concentrations of 0.85 and 1.7 mg/l, respectively (**Table 5**). The DWAF's GRAII (2007) dataset indicates an 'Average Groundwater Exploitation Potential' in the order of ~225,000 $m^3$/annum (**Table 6**). CRD analysis of monthly rainfall data from Rooiwal versus waterlevel fluctuations in borehole G28414 (**Figure 53**) and G28397 (**Figure 54**) produces a 'best-fit' rainfall-recharge factor of 2.8% and an aquifer storativity value of 0.004 and 0.007, respectively. A minimum threshold rainfall of 10 to 15mm/month is required before significant recharge occurs. **The long-term sustainable yield of the GMU is therefore taken as ~250,000 $m^3$/a**, whilst the yield of the current wellfield is ~180,000 $m^3$/annum. The wellfield was over-exploited for a decade spanning 1990 to 2000 (**Table 30**). Since 2002, the pumping has been reduced to within the sustainable yield of the wellfield and this has resulted in the waterlevels almost recovering to the post 1976 flood levels (**Figure 52**).

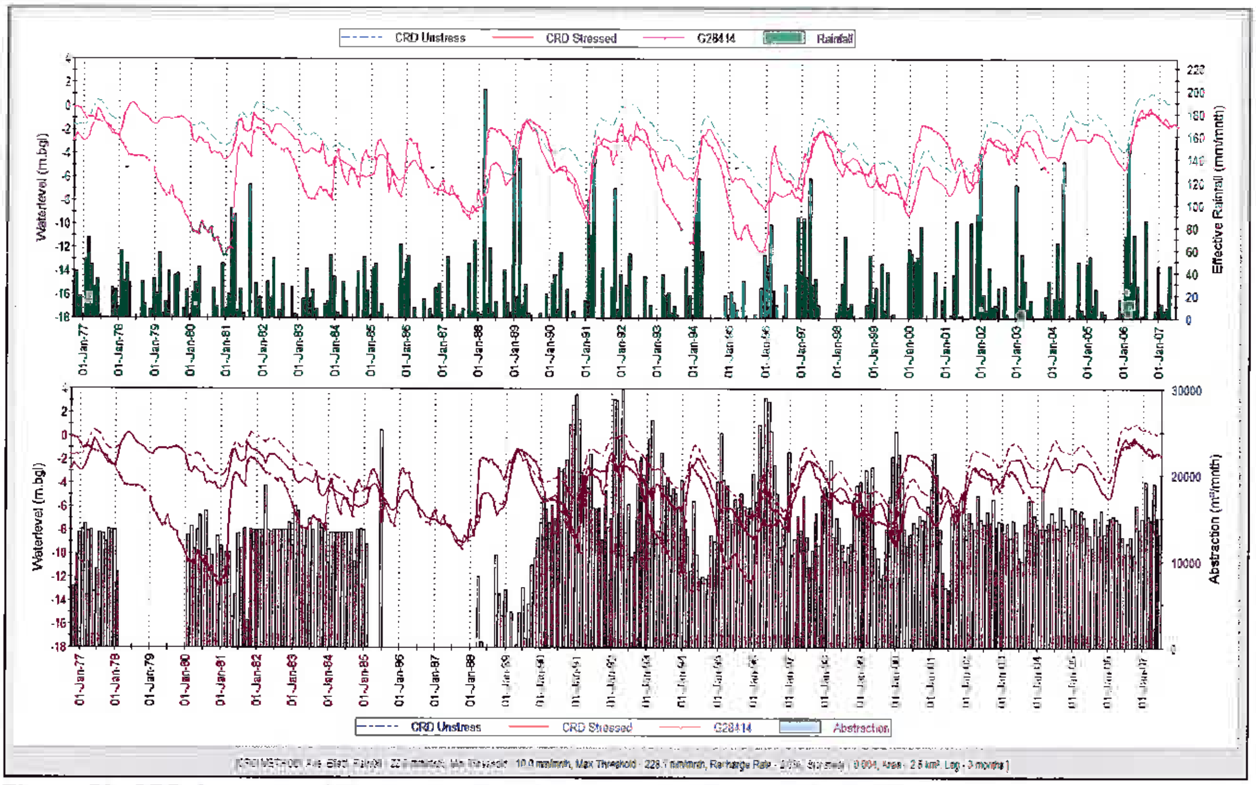



**Figure 53**: CRD Analysis of Monitoring Borehole G28414 (Burgerville GMU)

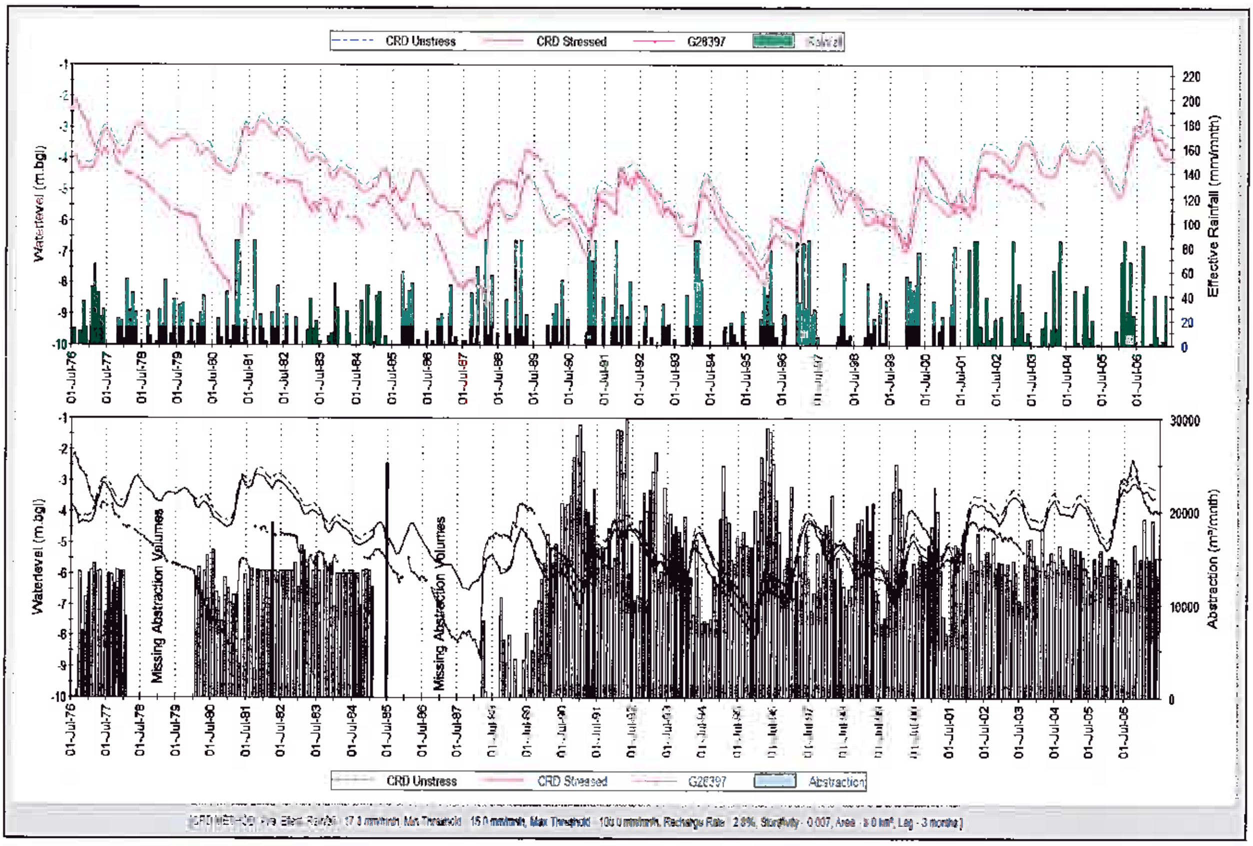



**Figure 54**: CRD Analysis of Monitoring Borehole G28397 (Burgerville GMU)

**Table 30: Burgerville Wellfield - Annual Volumes of Groundwater Abstraction**

| Year | Annual Abstraction ($m^3$) | Year | Annual Abstraction ($m^3$) |
|---|---|---|---|
| 1962 | 172,906 | 1985 | 37,129 |
| 1963 | 146,902 | 1986 | ? |
| 1964 | 161,279 | 1987 | ? |
| 1965 | 146,677 | 1988 | 36,036 |
| 1966 | **196,356** | 1989 | 68,381 |
| 1967 | 150,397 | 1990 | **246,700** |
| 1968 | 163,659 | 1991 | **215,458** |
| 1969 | 161,120 | 1992 | **246,085** |
| 1970 | 18,690 | 1993 | **227,356** |
| 1971 | 166,769 | 1994 | 140,522 |
| 1972 | 149,694 | 1995 | **212,205** |
| 1973 | 150,954 | 1996 | **250,786** |
| 1974 | 93,946 | 1997 | 166,445 |
| 1975 | 161,956 | 1998 | **182,439** |
| 1976 | 73,015 | 1999 | **192,244** |
| 1977 | 150,747 | 2000 | **188,791** |
| 1978 | 8,754 | 2001 | 166,775 |
| 1979 | ? | 2002 | **180,882** |
| 1980 | 148,686 | 2003 | 167,074 |
| 1981 | 124,716 | 2004 | 179,521 |
| 1982 | 167,622 | 2005 | 170,841 |
| 1983 | 152,794 | 2006 | 163,932 |
| 1984 | 157,916 | June 2007 | 96,314 |

**Bold** - Abstraction exceed sustainable yield of the Wellfield, i.e. 180,000 $m^3$/annum.

Note: Abstraction data prior to 1990 appears to be incomplete when compared to waterlevel fluctuations in the unit.

## Groundwater Quality

The groundwater from the Burgerville Wellfield has a low salinity (EC < 90 mS/m) and is fit for direct human consumption (

**Table** 31), but it is very hard (average $CaCO_3$ hardness of 341 mg/l). The groundwater has a calcium-magnesium-bicarbonate character (**Figure 55**). The groundwater chemistry information per production borehole is presented on Piper diagrams in **Appendix3**.

**Table 31: Burgerville GMU - Statistical Summary of Groundwater Chemistry**

| Chemical Parameter | No. Rec. | Minimum | Maximum | Mean | Median | Std Deviation | Lower Quartile | Upper Quartile | 90th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| Lab. pH | 18 | 7.1 | 8.5 | 8.0 | 8.1 | 0.4 | 7.8 | 8.3 | 8.4 |
| EC (mS/m) | 18 | 44.9 | 111.8 | 80.2 | 80.2 | 16.4 | 71.1 | 85.1 | 105.1 |
| Sodium (mg/l) | 18 | 29.1 | 79.0 | 52.0 | 50.4 | 12.6 | 46.5 | 56.0 | 71.3 |
| Calcium (mg/l) | 18 | 36.8 | 97.7 | 73.5 | 78.4 | 15.8 | 67.8 | 80.0 | 91.3 |
| Magnesium (mg/l) | 18 | 19.1 | 58.0 | 37.6 | 35.7 | 9.8 | 31.7 | 42.3 | 52.7 |
| Chloride (mg/l) | 18 | 9.9 | 86.7 | 43.0 | 42.2 | 18.4 | 33.1 | 45.5 | 66.4 |
| Potassium (mg/l) | 16 | 1.25 | 3.10 | 2.57 | 2.70 | 0.50 | 2.55 | 2.88 | 3.05 |
| Silica (mg/l) | 16 | 7.40 | 13.90 | 11.86 | 11.87 | 1.39 | 11.48 | 12.69 | 13.12 |
| Sulphate (mg/l) | 18 | 15.4 | 120.4 | 64.7 | 61.5 | 27.7 | 49.1 | 75.8 | 111.4 |
| Tot. Alkalinity (mg/l) | 18 | 203.9 | 437.0 | 303.6 | 311.1 | 60.8 | 251.8 | 330.1 | 378.1 |
| Fluoride (mg/l) | 18 | 0.9 | 1.1 | 1.0 | 0.9 | 0.1 | 0.9 | 1.0 | 1.0 |
| Nitrate (mg/l) | 16 | 1.180 | 11.100 | 5.440 | 5.862 | 2.752 | 3.666 | 7.453 | 8.127 |
| Ammonia (mg/l) | 15 | 0.010 | 0.200 | 0.037 | 0.020 | 0.047 | 0.018 | 0.025 | 0.071 |

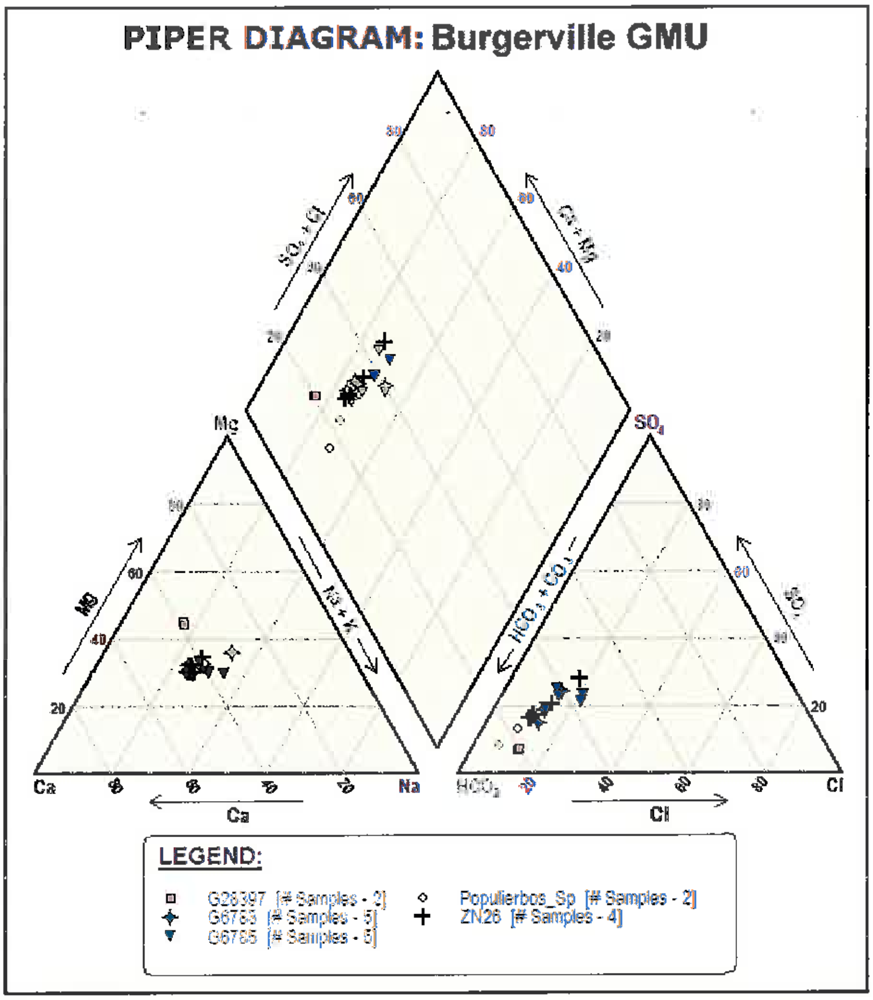



**Figure 55: Piper Diagram of Groundwater from Production Boreholes in the Burgerville GMU**

# 4 Conclusions and Recommendations

Based on the information presented in this documents the following can be concluded:

De Aar's current water requirements are 2.2 $Mm^3$/annum, although only 1.6 $Mm^3$ of groundwater was abstracted in 2006. This water is pumped from 51 production boreholes located in 10 Groundwater Management Units or GMU's, extending up to 35km away from the town. The production holes are capable of delivering 260 L/s, with a combined sustainable yield of 2.7 $Mm^3$/a. This is significantly less than the estimated long-term sustainable yield of the GMU's of 4.8 $Mm^3$ per annum.

The salinity of the groundwater is highly variable, but it is almost always hard to very hard. The best quality groundwater is pumped the Cyfferkuil, Burgerville and Zewefontein GMU's located some 30km to the east of De Aar.

The following specific recommendations are made based upon the findings of this study:

- Ground Abstraction:
  - *Rhenosterpoort & Zwartkoppies GMU's*: These groundwater units are fully developed and no further production boreholes should be considered.

    Boreholes G27707, G27704, G27715G, G23204D, G27702G and G27703 should be pumped 'out-of-phase' from the other production boreholes.
  - *Blaauw Krans GMU*: This unit is currently not being utilised by De Aar and should be considered for development to meet the town's future water requirements.

    The 10 potential production boreholes, estimated to be capable of delivering ~525,000 $m^3$ of water per annum, pump-tested and re-assessed.
  - *Caroluspoort-South GMU*: Borehole G39037 should be brought into production at a rate not exceeding 3,500 $m^3$/a, whilst borehole G29727A should only be maintained as a standby borehole.
  - *Cyfferkuil GMU*: This unit has been over-exploited since 2000 and pumping should immediately be scaled back to within the estimated long-term sustainable yield of the wellfield of 230,000 $m^3$/a.

    Borehole G39025 was drilled as a replacement borehole for CF31 and therefore the pump equipment in CF31 should be re-located to G39025.

    Borehole G38535 was pumped during 2003 to 2004. This borehole should not be utilised for production purposes.

    Borehole G38547 should be commissioned as a production borehole, only after a multi-rate pumping-test has been carried on the hole.
  - *Zewefontein GMU*: This unit has not been developed to its full potential and additional production boreholes should be established further up in the catchment in order to harvest an estimated 'surplus' of 450,000 $m^3$/a of good quality groundwater.

    Productions holes ZN54 and ZN63 should be pumped 'out-of-phase' from one another, as should boreholes G6787 and ZN14.
  - *Burgerville GMU*: The current wellfield is not capable of harvesting all the available groundwater from this unit and it is recommended that an additional 1 to 2 production boreholes be developed in the area between production hole ZN26 and the Hotom farm.

Borehole G38270 on the farm Sipreshof should be pump-tested with the aim of equipping it as a production borehole.

- The monthly groundwater abstraction information in *AquiMon* is, in places, incomplete especially prior to 1999, which hinders meaningful assessment of the groundwater resource potential. Effort should be made to obtain this information from the Municipal and DWAF's archives and capture it in *AquiMon*.

* Groundwater-level Monitoring: Waterlevel monitoring is crucial to ensuring that the various GMU's are optimally utilised and that they are not overexploited. The following early-warning trigger-levels have been set in *AquiMon* and should be closely adhered to:

  - *Zwartkoppies GMU*: Waterlevels in monitoring boreholes G27708 and G27708C should not be allowed to drop below the trigger-levels of 6.5 and 7.0 metres below ground-level (m.bgl), respectively.
  - *Rhenosterpoort GMU*: A digital waterlevel data-logger should be immediately re-installed in borehole G27716. The waterlevel in this hole should not to drop below 5.5 m.bgl.

    The waterlevel in borehole G27720 should not decline below the trigger-level of 3.5 m.bgl.

    Waterlevels in monitoring holes G23204C, G23205 and G27709 should not be allowed to decline below the trigger levels of 9.5, 7.4 and 6.8 m.bgl, respectively.

    Waterlevels in the Vaalbank Wellfield have declined almost to their trigger-levels and this situation should be closely monitored over the next 6 months to decide if an intervention measure is required.
  - *Paardevallei GMU*: Waterlevels in boreholes G28420B and G29465 should not be allowed to drop below the trigger-levels of 9.5 and 4.5 m .bgl, respectively.
  - *Caroluspoort-North GMU*: Waterlevels in boreholes BG1, BG32 and BG40 should not decline below the set trigger-levels of 8.5, 9.5 and 9.0 m.bgl, respectively.
  - *Caroluspoort-South GMU*: The waterlevel in G29727E should not drop below the set trigger-level of 5.5 m.bgl.
  - *Rietfontein GMU*: It is crucial that two additional digital waterlevel data-loggers be immediately installed in boreholes G38459 and G38456.

    The waterlevels in G28302K and G28304F should not be allowed to decline below the trigger-level of 8 m.bgl.
  - *Riet GMU*: It is crucial that three additional digital waterlevel data-loggers be placed in the following holes (or nearest suitable hole); namely G38235, G38509 and G38233.

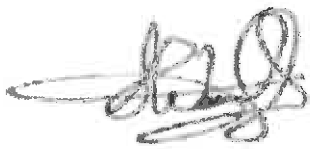
    The waterlevel in G27917 should not be allowed to drop below the trigger-level of 9 m.bgl.

    Borehole G27917 is situated too close to the production hole and it is recommended that the waterlevel data-logger be shifted to a more suitable borehole some 100 to 200m further away from G29717E.
  - *Cyfferkuil GMU*: The waterlevels in G39023 and G39028 should not be allowed to drop below the set trigger-level of 9m.bgl.
  - *Zewefontein GMU*: The waterlevels in B2, G28415B and G39034 should not decline below the trigger-levels of 9.0, 10.0 and 7.5 m.bgl, respectively.
  - *Burgerville GMU*: The waterlevels in G28414 and G28397 should not be allowed to drop below the trigger-levels of 8.0 and 7.0 m.bgl, respectively.

Abstraction from a GMU or wellfield should be immediately reduced if the waterlevels in the above specified monitoring holes decline and remain below the set trigger-levels to avoid declining yields (inefficient pumping) and possible deterioration of the water quality, as well as in the long-term, 'damage' to the aquifer itself (i.e. clogging of water-bearing fractures by precipitation of carbonates).

- Groundwater Quality Monitoring: Groundwater from the following boreholes should be sent to an accredited laboratory for chemical analysis on an annual basis:
  - *Rhenosterpoort GMU*: boreholes G27707, G27704, G23205B, G23204D and G27715G.
  - *Zwartkoppies GMU*: boreholes G23202 and G27702G.
  - *Paardevallei GMU*: boreholes G48420, G39145, G29617 and G29644.

    Establish the cause for the drastic differences in water chemistry in borehole G29644.
  - *Caroluspoort-North GMU*: wells PUT-5, G6778, G6779, G18880, G1882 and G18882.
  - *Caroluspoort-South GMU*: borehole G27927.
  - *Riet GMU*: boreholes G38271, G38455, G38468, G38473 and G38517.
  - *Rietfontein GMU*: boreholes G27918C, G28301, G28304, G28307, G28313B and G38507.
  - *Cyfferkuil GMU*: boreholes CF31, CF34, G39024, G38535, G23229 and G23232.
  - *Zewefontein GMU*: boreholes G6787 and ZN54.
  - *Burgerville GMU*: boreholes G6783, G6785, ZN26 and the 'Populierbos' spring.
  - Groundwater analysis should, as a minimum, include the following physical parameters and chemical constituents: pH, electrical conductivity, total dissolved solids, sodium, calcium, magnesium, chloride, sulphate, total alkalinity, potassium, silica, fluoride, nitrate, ammonia and iron.
  - The water samples should be collected over a single time period, preferably between February and March of each year.
  - Groundwater from individual boreholes should be sent for bacteriological analyses on an annual basis.
- The DWAF should continue to analyse the chloride and sodium content of rainwater collected in their cumulative rainfall gauges located at De Aar and the Riet pump-station. The Oxygen-18 and deuterium content of the rainwater should also be determined.
- The flow rates of the Populierbos and Rivierfontein / Bloufontein springs should be measured on a monthly basis and captured in *AquiMon*.
- The monthly abstraction volumes, water chemistry and waterlevel monitoring data should be compiled and uploaded in the established *AquiMon* monitoring and management computer system by an official of the Emthanjeni Municipality on a monthly basis. The Municipality should have a qualified hydrogeologist assess this information and produce a monitoring and aquifer status report on an annual basis.



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**SRK Consulting**

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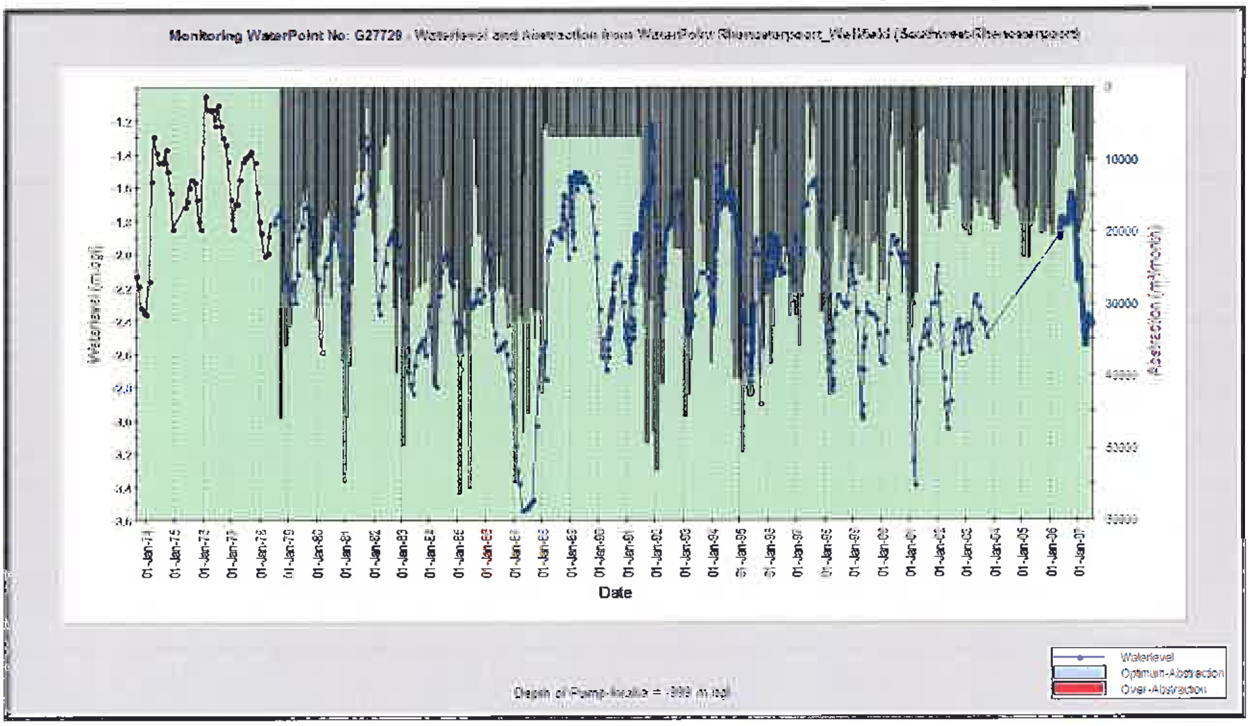
# Appendices

## Appendix 1: Monitoring Boreholes equipped with Digital Data-Loggers

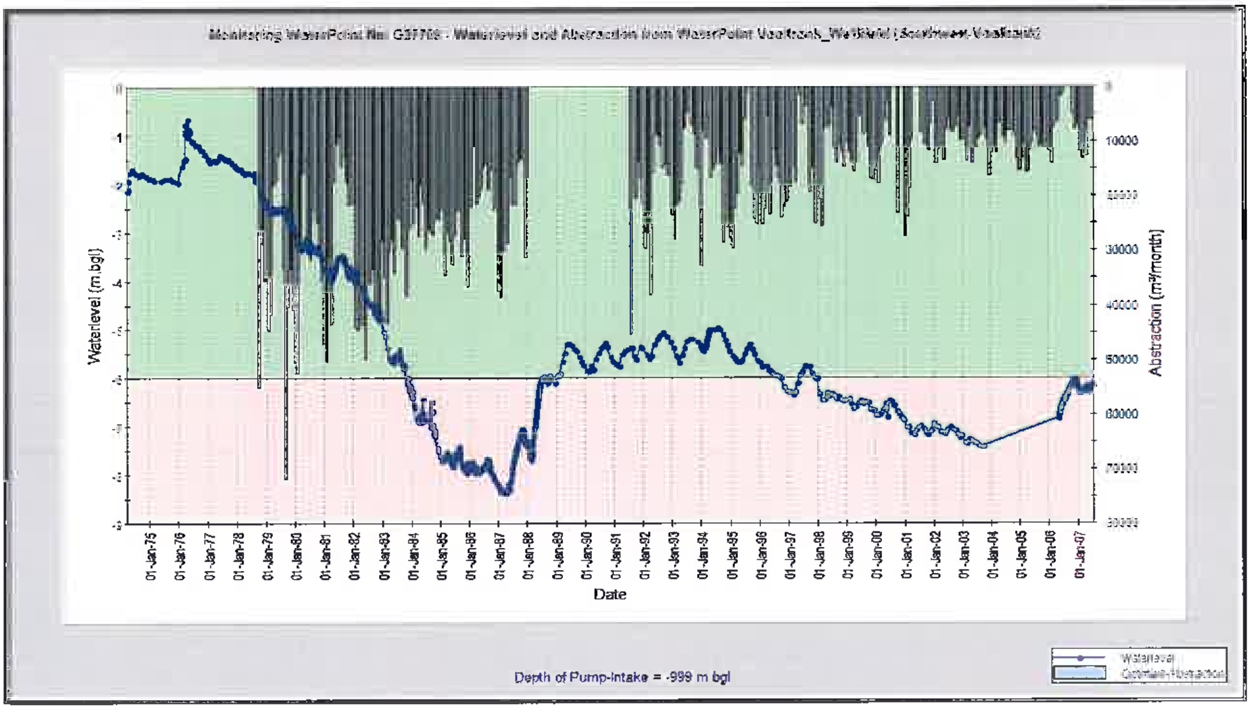
| AquiMon | DWAF NGDB Code | Drainage Number |
|---|---|---|
| G28415B | 3024CB00035 | D6N0061 |
| G39067 | 3024AC00004 | D6N0067 |
| G39186 | 3024AC00005 | D6N0068 |
| G39224 | 3023DB00356 | D6N0069 |
| BG1 | 3024CA00328 | D6N0500 |
| B2 | 3024CB00067 | D6N0501 |
| BG32 | 3024CA00329 | D6N0507 |
| BG40 | 3024CA00330 | D6N0508 |
| G27720 | 3023DB00374 | D6N0517 |
| G27709 | 3023DB00071 | D6N0520 |
| G23205 | 3023DB00080 | D6N0521 |
| G23204C | 3023DB00235 | D6N0522 |
| G29648E | 3023DB00412 | D6N0526 |
| G29642C | 3023DB00426 | D6N0527 |
| G29632D | 3023DB00424 | D6N0529 |
| G28420B | 3024CA00010 | D6N0530 |
| G29645 | 3024CA00319 | D6N0531 |
| G27927E | 3024CA00115 | D6N0537 |
| G27917 | 3024CA00324 | D6N0538 |
| G28304F | 3024CC00007 | D6N0539 |
| G28414 | 3024CB00075 | D6N0545 |
| G28397 | 3024CB00076 | D6N0546 |
| G27708 | 3023DB00124 | D6N0550 |
| G27708C | 3023DB00114 | D6N0551 |
| G39034 | 3024CB00087 | D6N0562 |
| G39028 | 3024CB00088 | D6N0563 |
| G39023 | 3024CB00085 | D6N0564 |

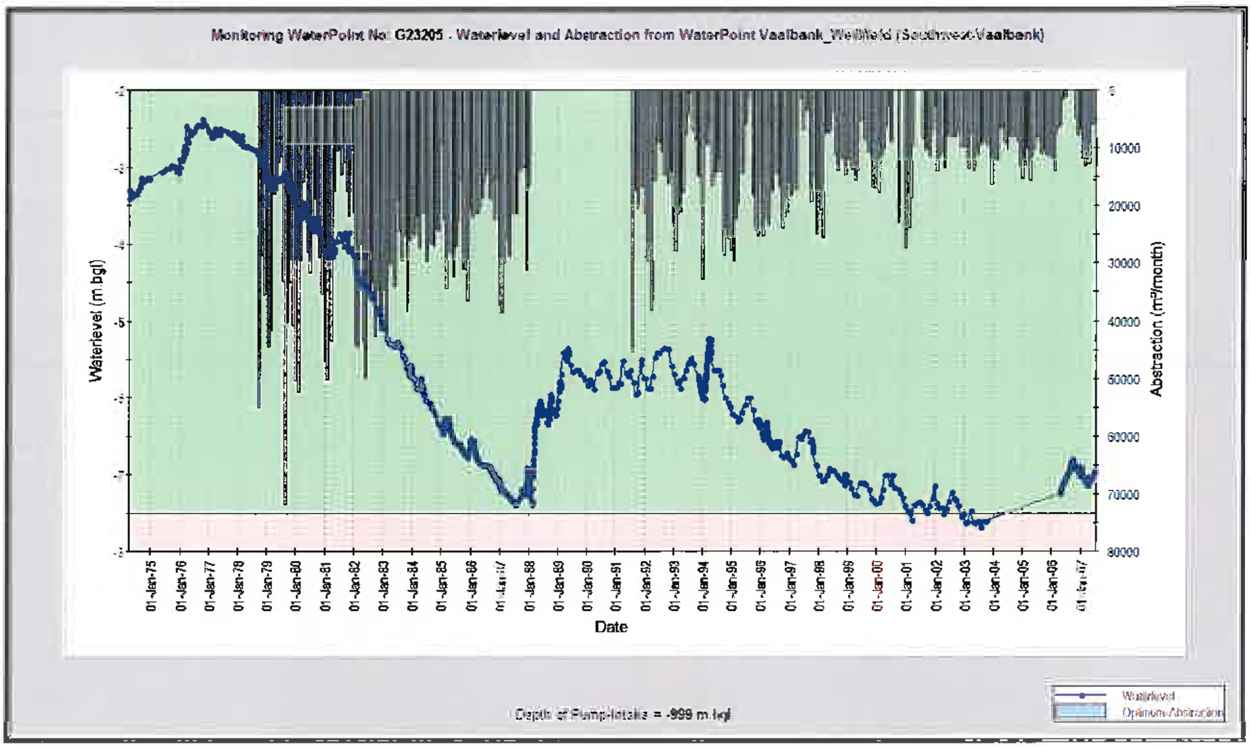
# Appendix 2: Waterlevel Graphs for Monitoring Boreholes equipped with digital data-loggers

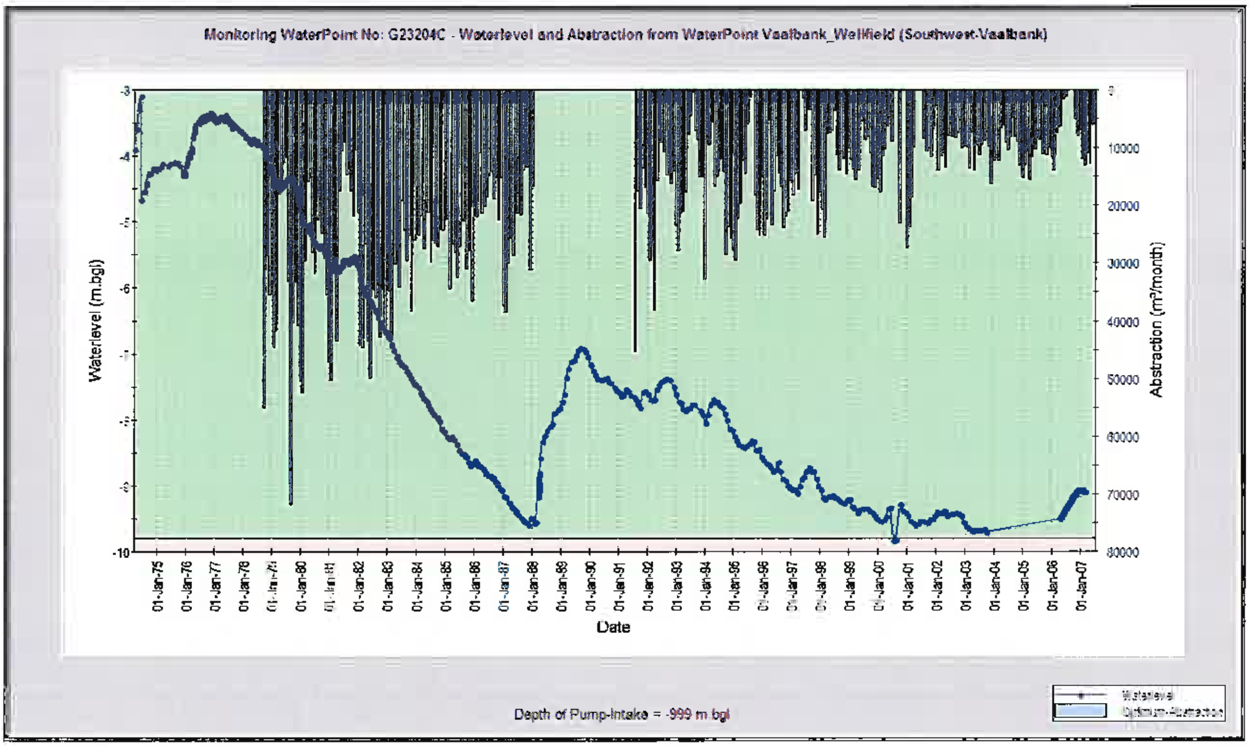
## Rhenosterpoort GMU:

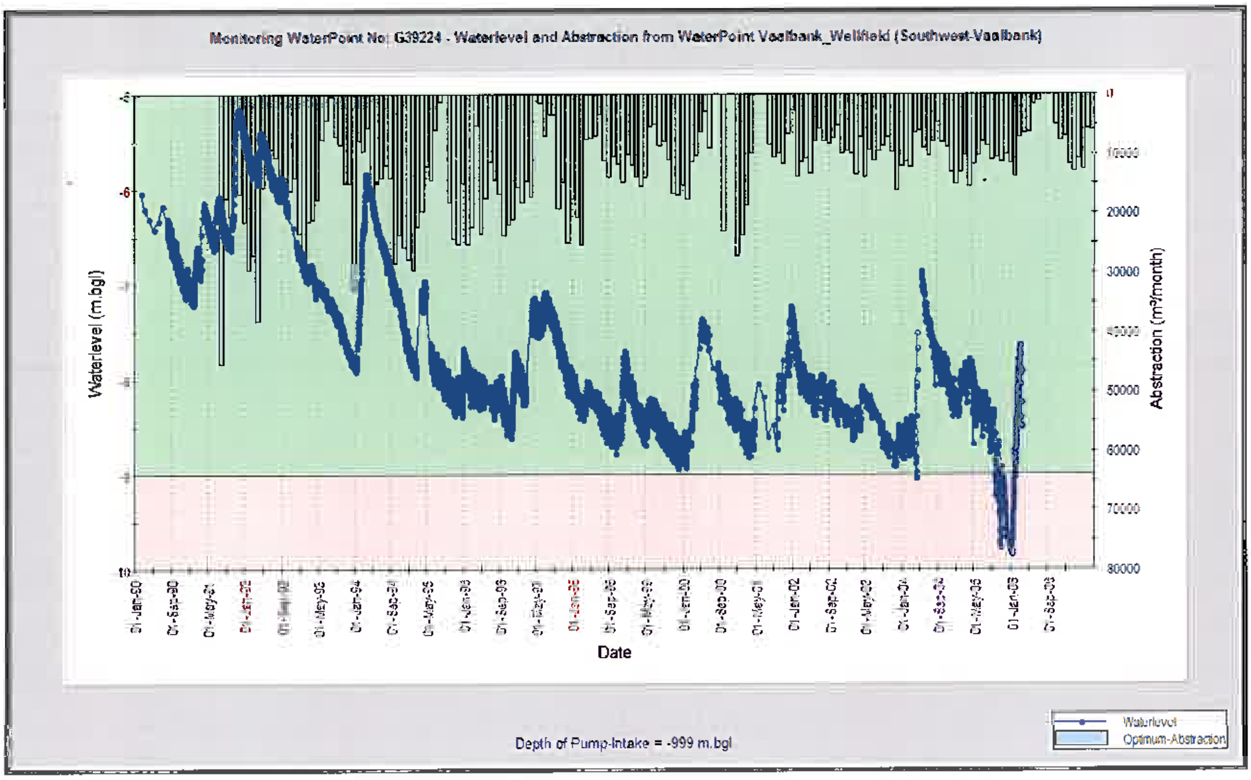



## Swartkoppies GMU:

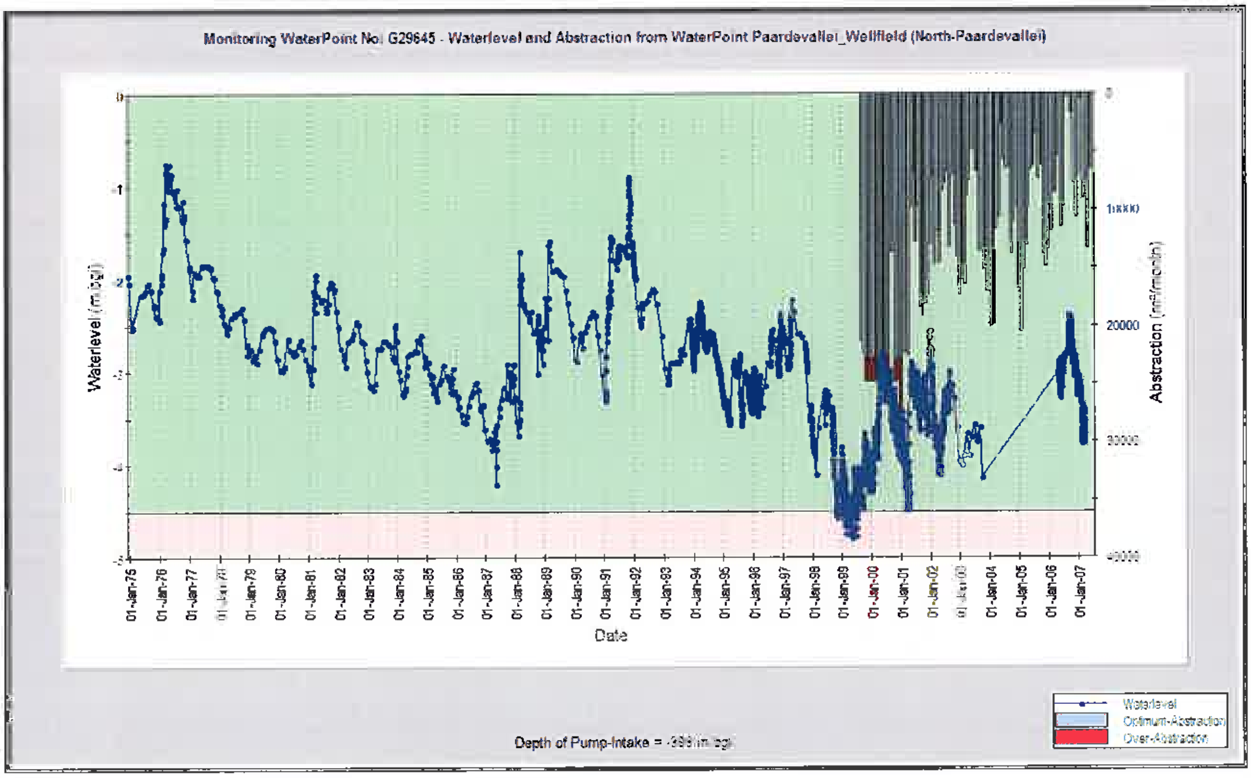


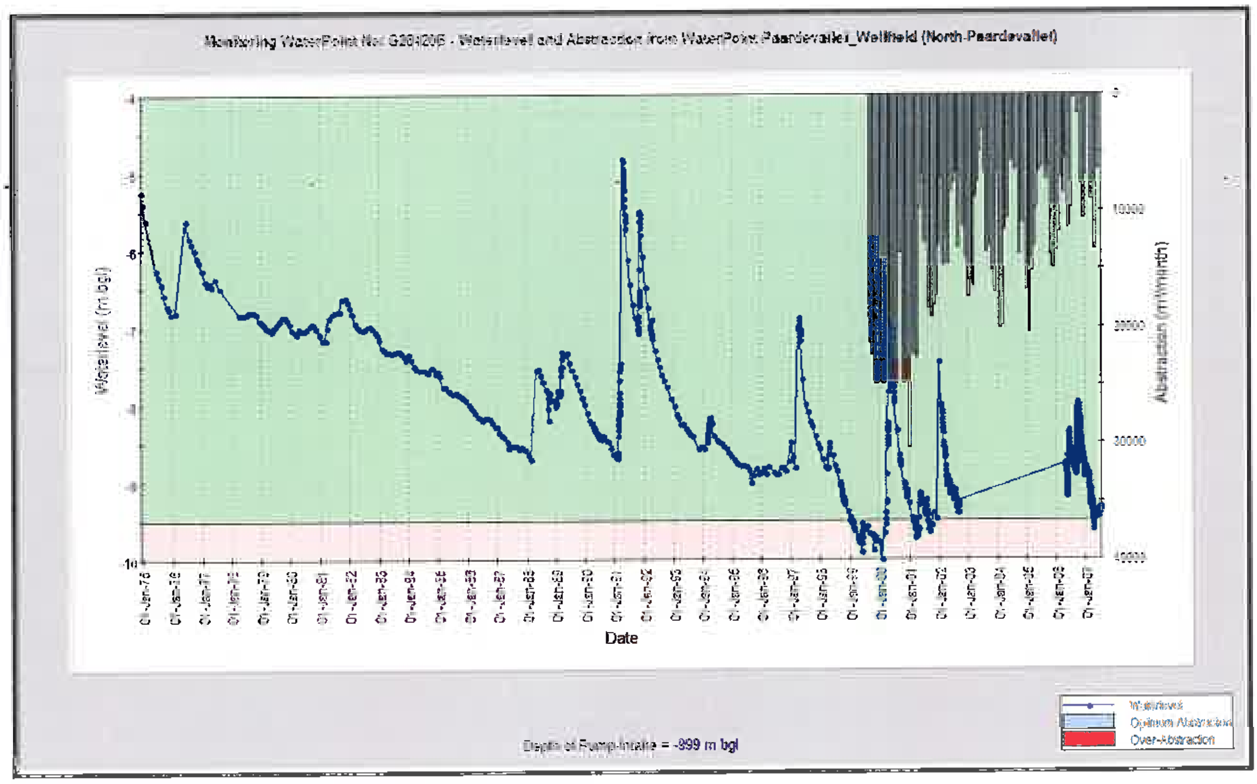

Monitoring WaterPoint No: G23205 - Waterlevel and Abstraction from WaterPoint Vaalbank_Wellfield (Southwest-Vaalbank)
Waterlevel (m.bgl)
Abstraction (m³/month)
10000
20000
30000
40000
50000
60000
70000
80000
Date
Depth of Pump-Intake = -999 m bgl


Monitoring WaterPoint No: G23204C - Waterlevel and Abstraction from WaterPoint Vaalbank_Wellfield (Southwest-Vaalbank)
Waterlevel (m.bgl)
Abstraction (m³/month)
10000
20000
30000
40000
50000
60000
70000
80000
Date
Depth of Pump-Intake = -999 m bgl

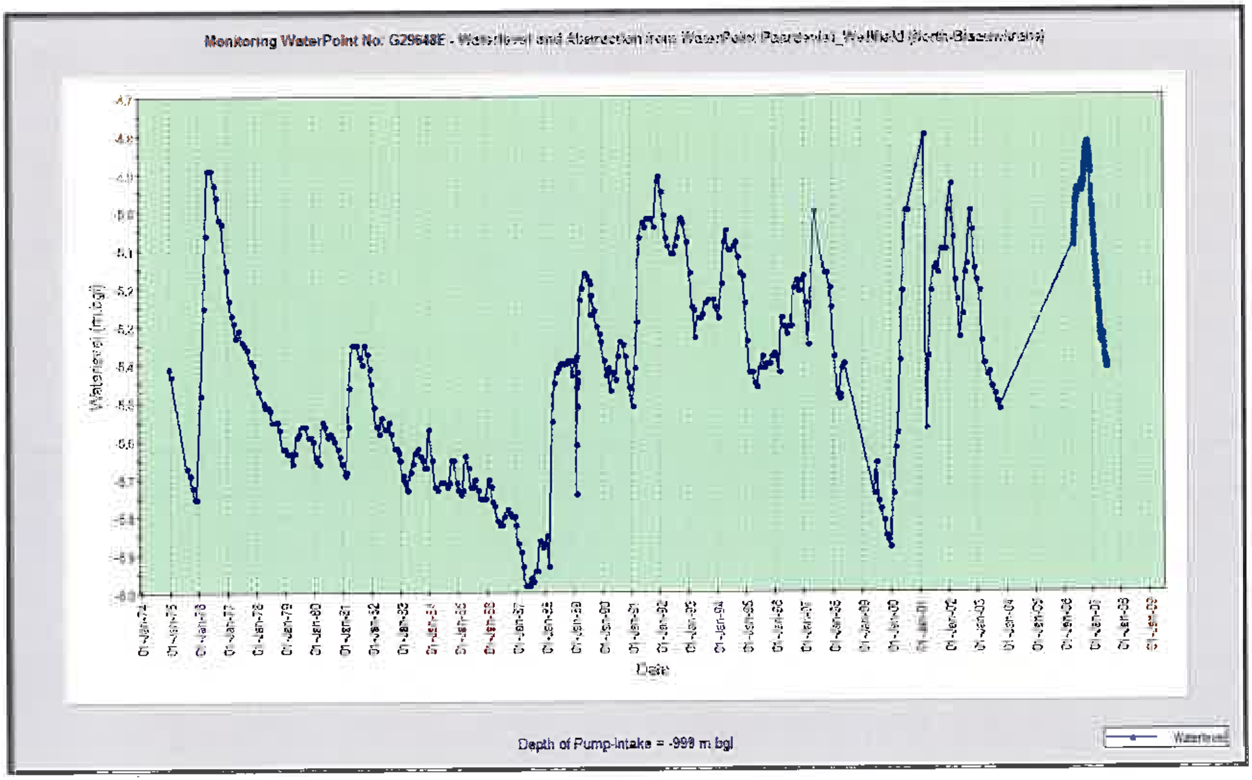


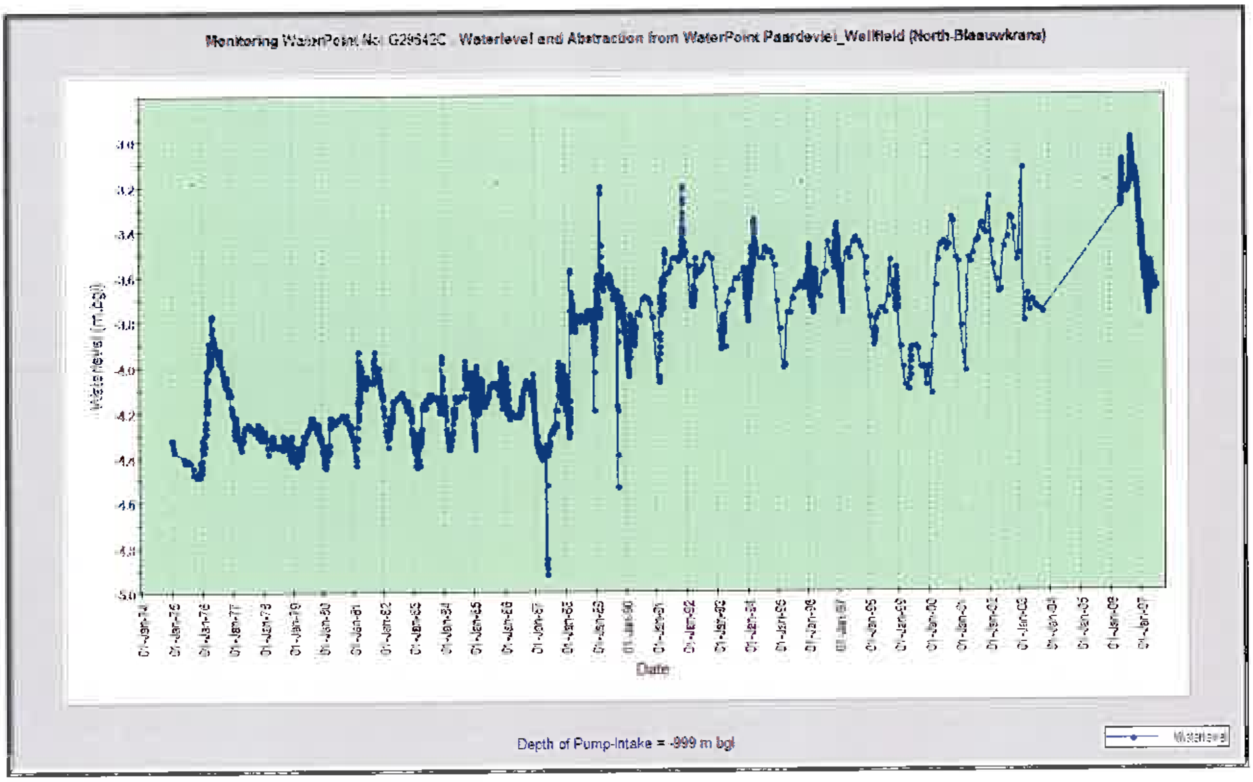

## Paardevallei GMU:

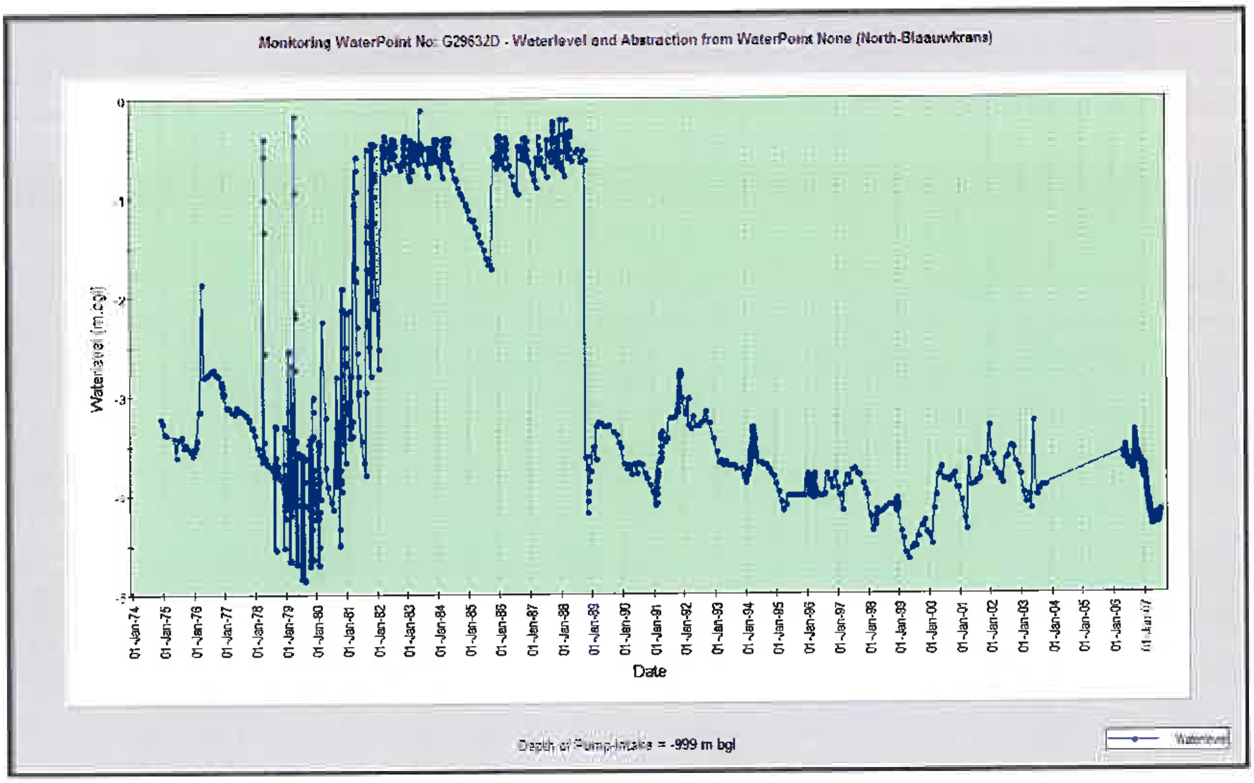




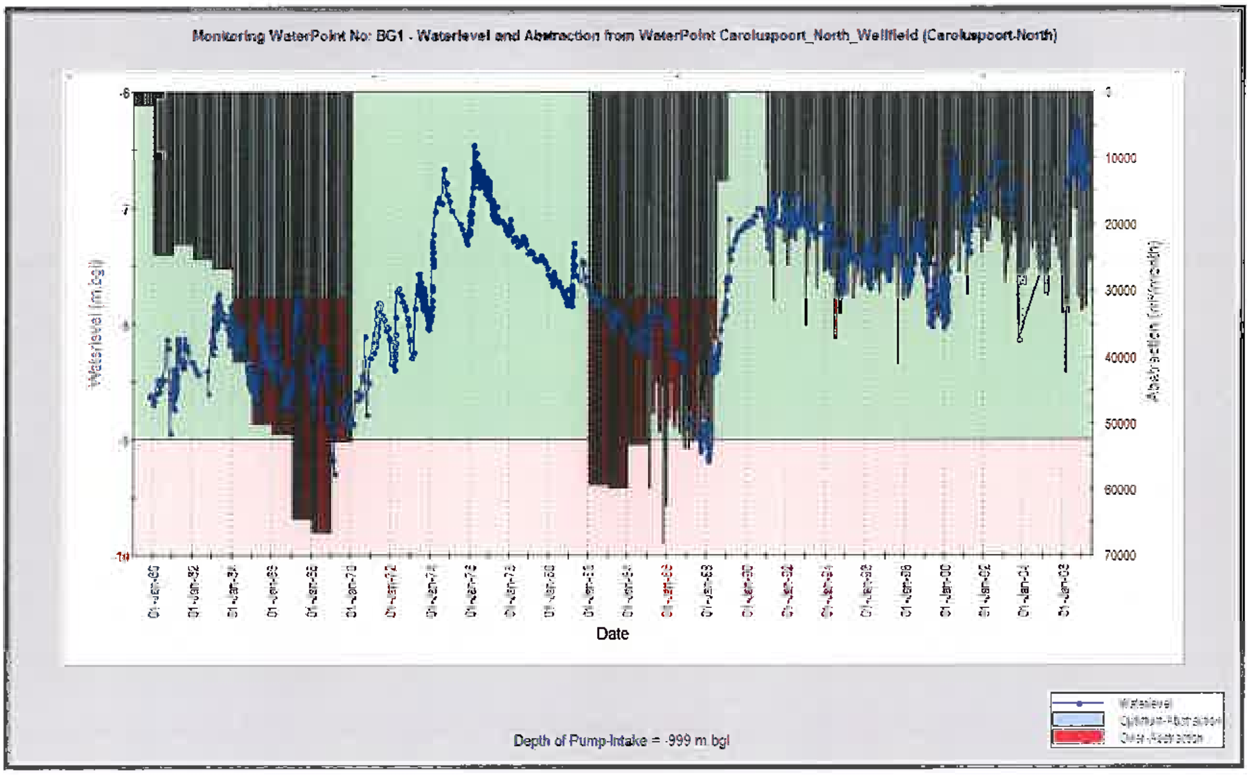

## Blaauw Krans GMU:

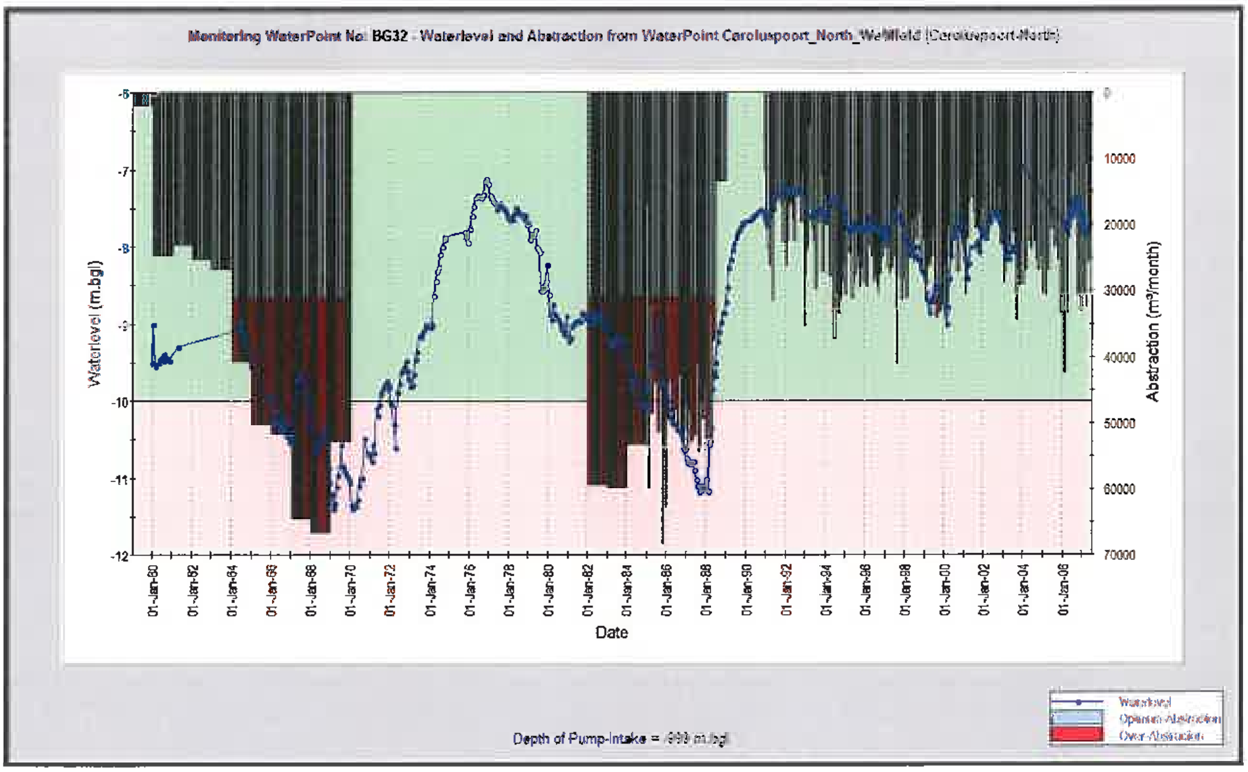


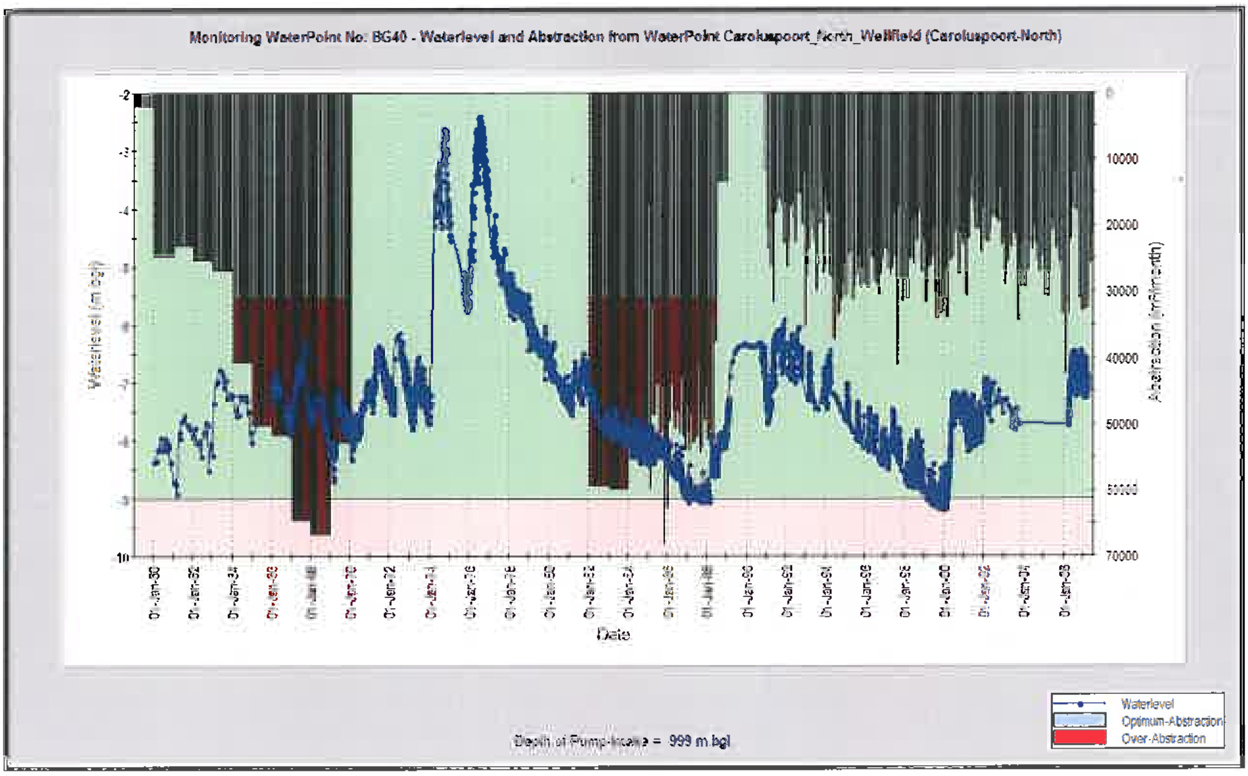

Monitoring WaterPoint No: G29642C - Waterlevel and Abstraction from WaterPoint Paardevlei_Wellfield (North-Blaauwkrans)
Waterlevel (m.bgl)
Date
Depth of Pump-Intake = -999 m bgl
Waterlevel


Monitoring WaterPoint No: G29632D - Waterlevel and Abstraction from WaterPoint None (North-Blaauwkrans)
Waterlevel (m.bgl)
Date
Depth of Pump-Intake = -999 m bgl
Waterlevel

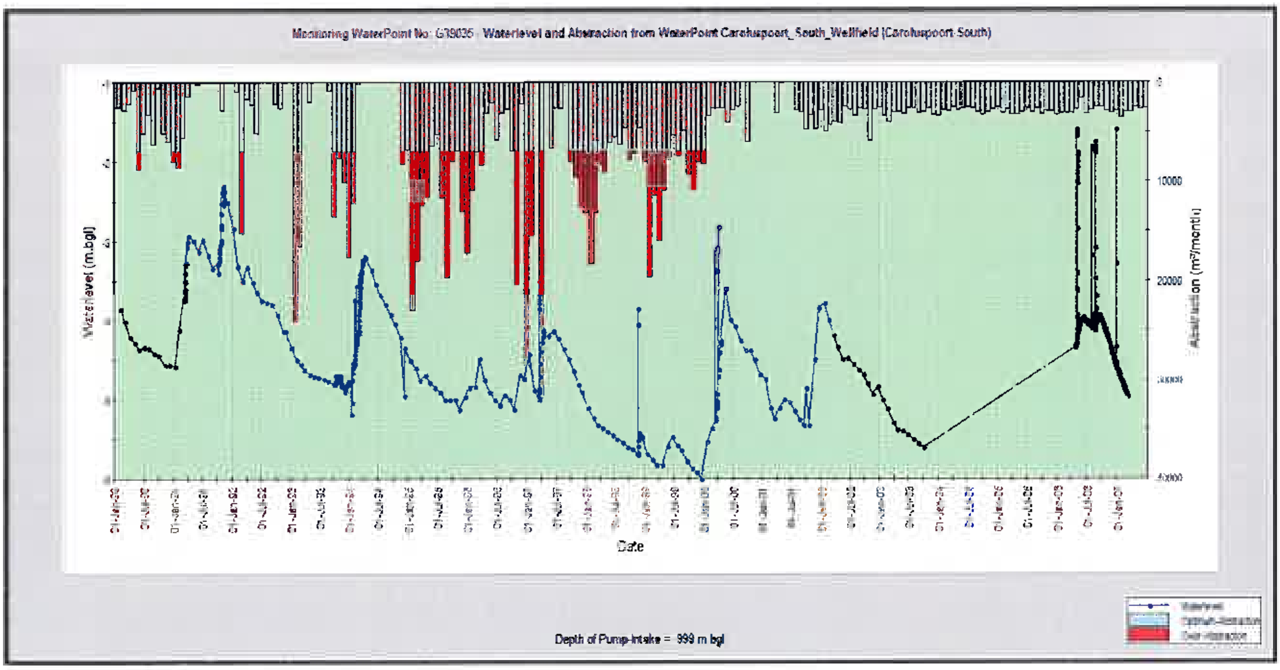
## Caroluspoort-North GMU:

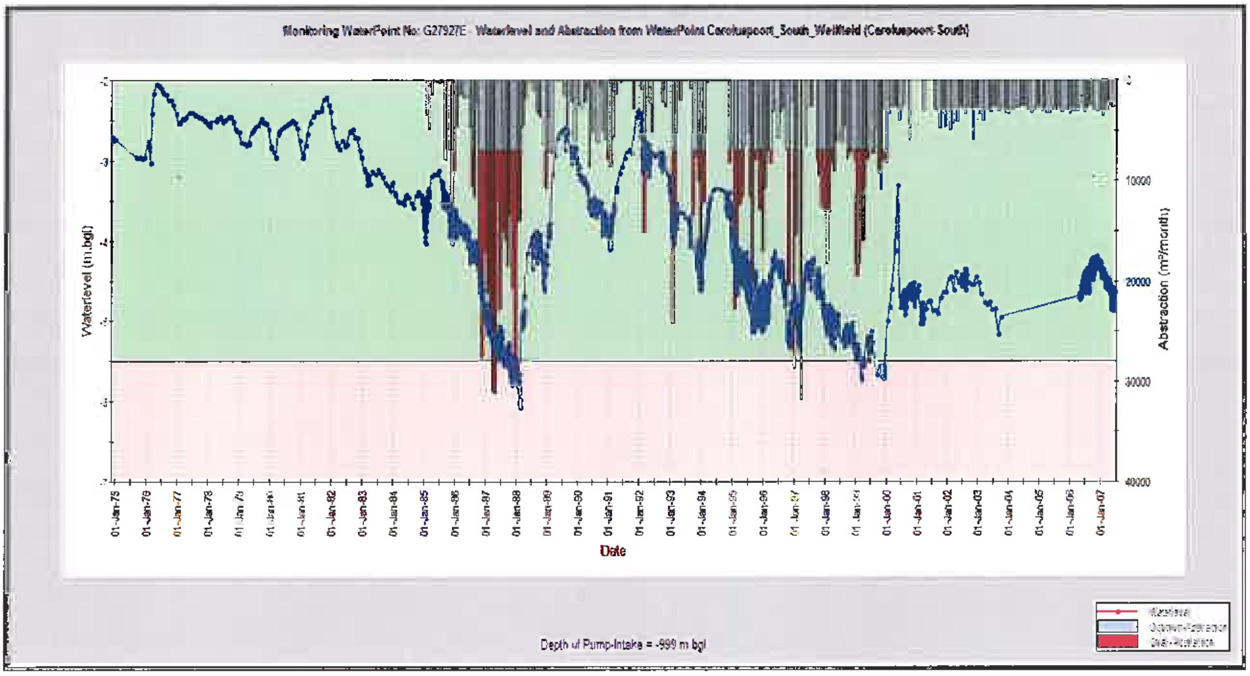


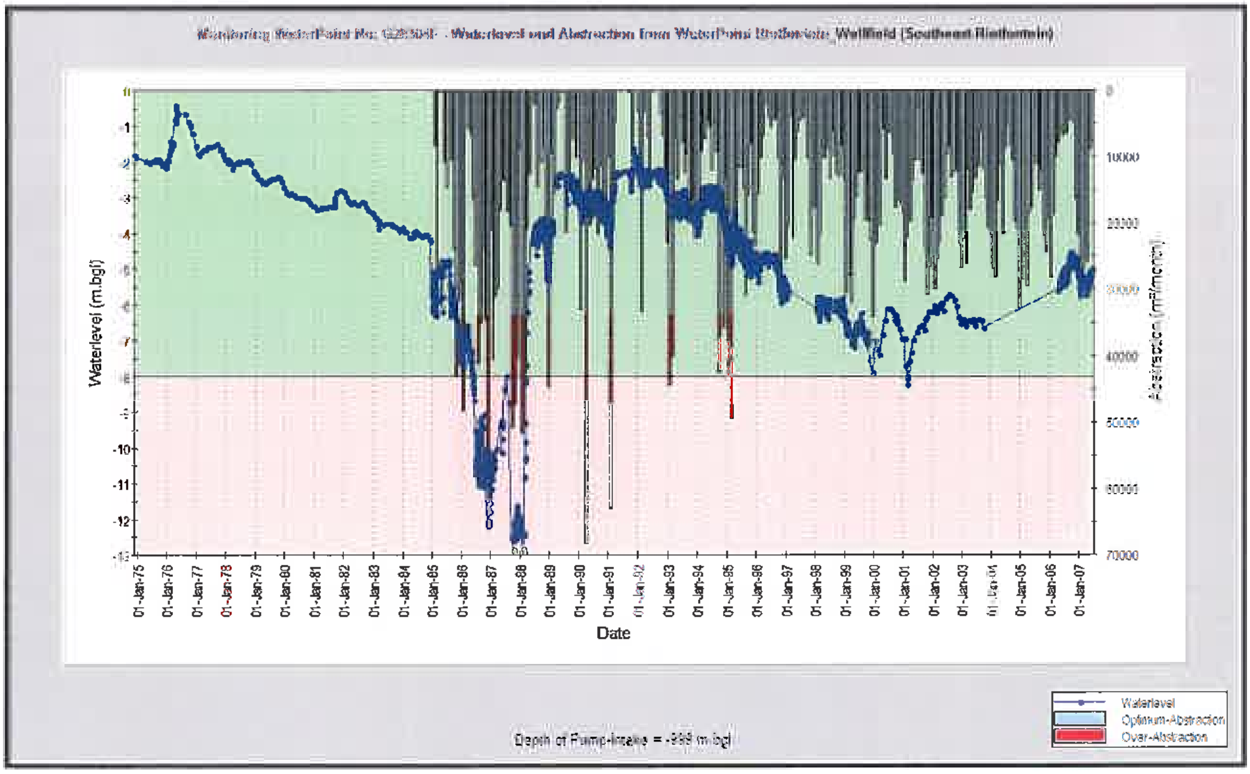


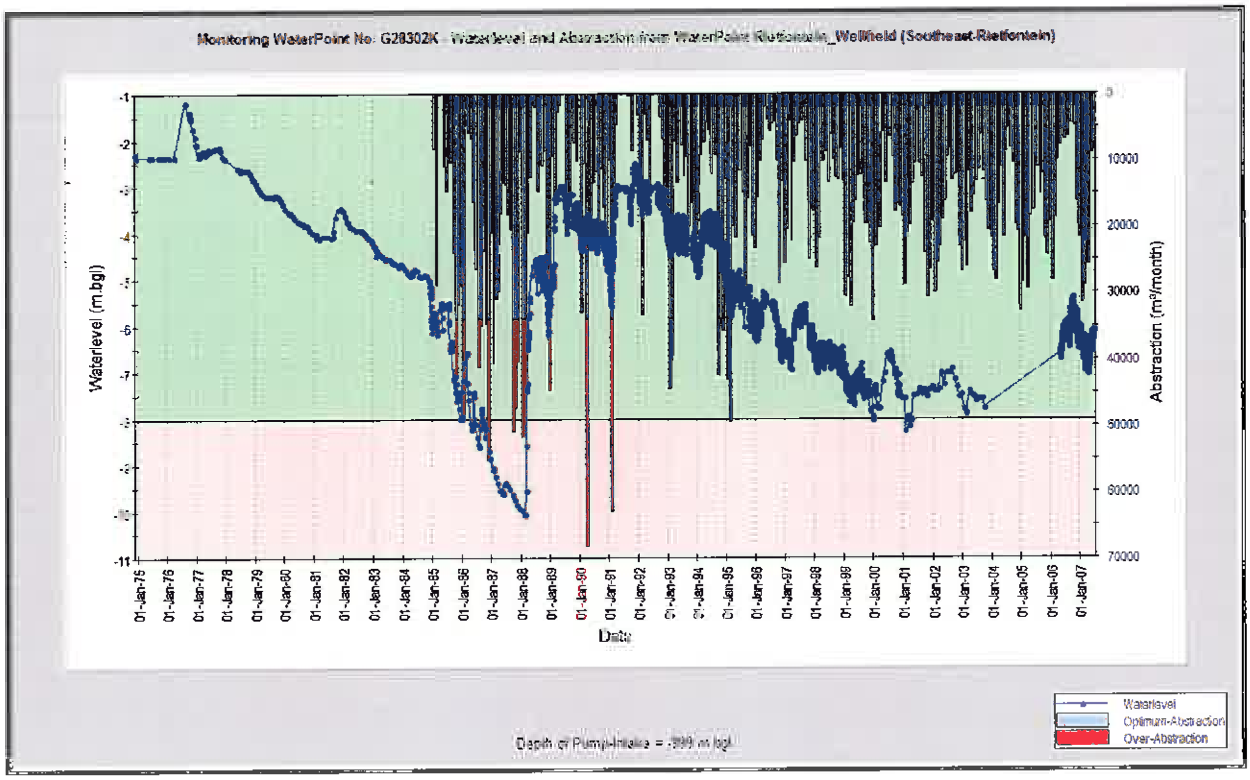

## Caroluspoort-South GMU:



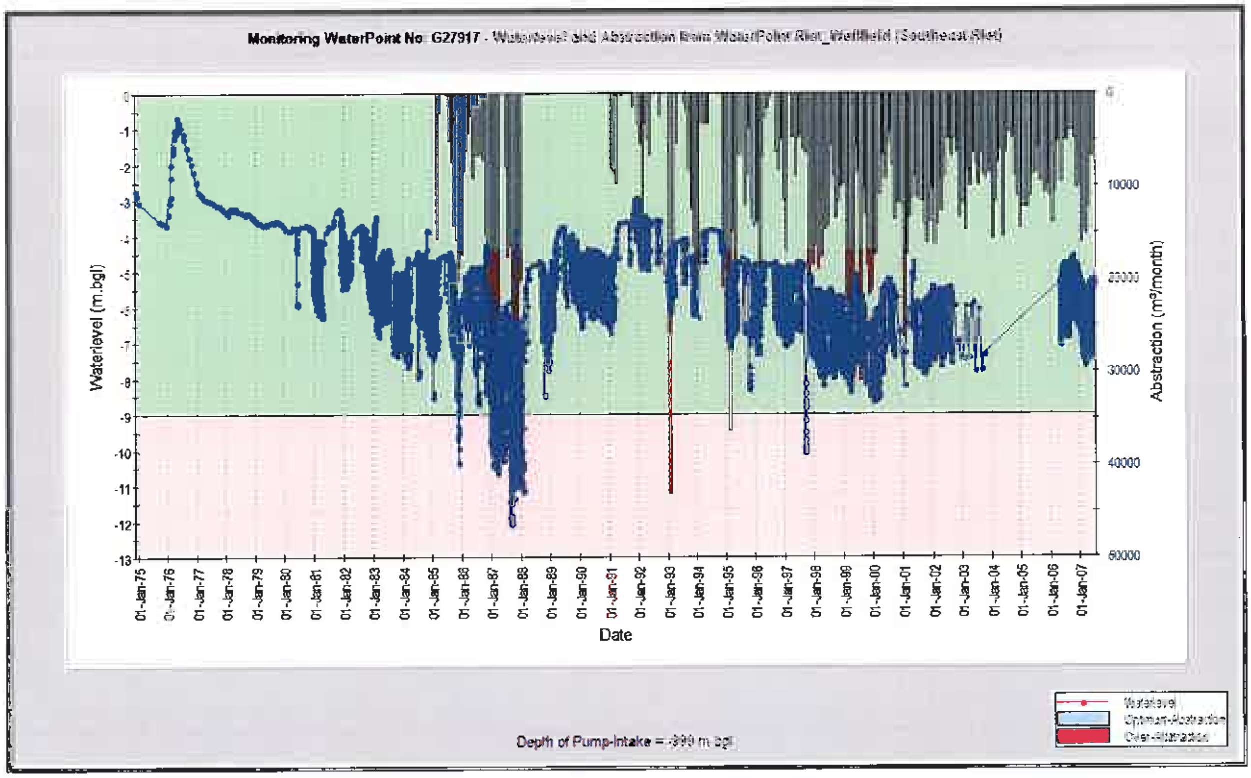



## Rietfontein GMU:

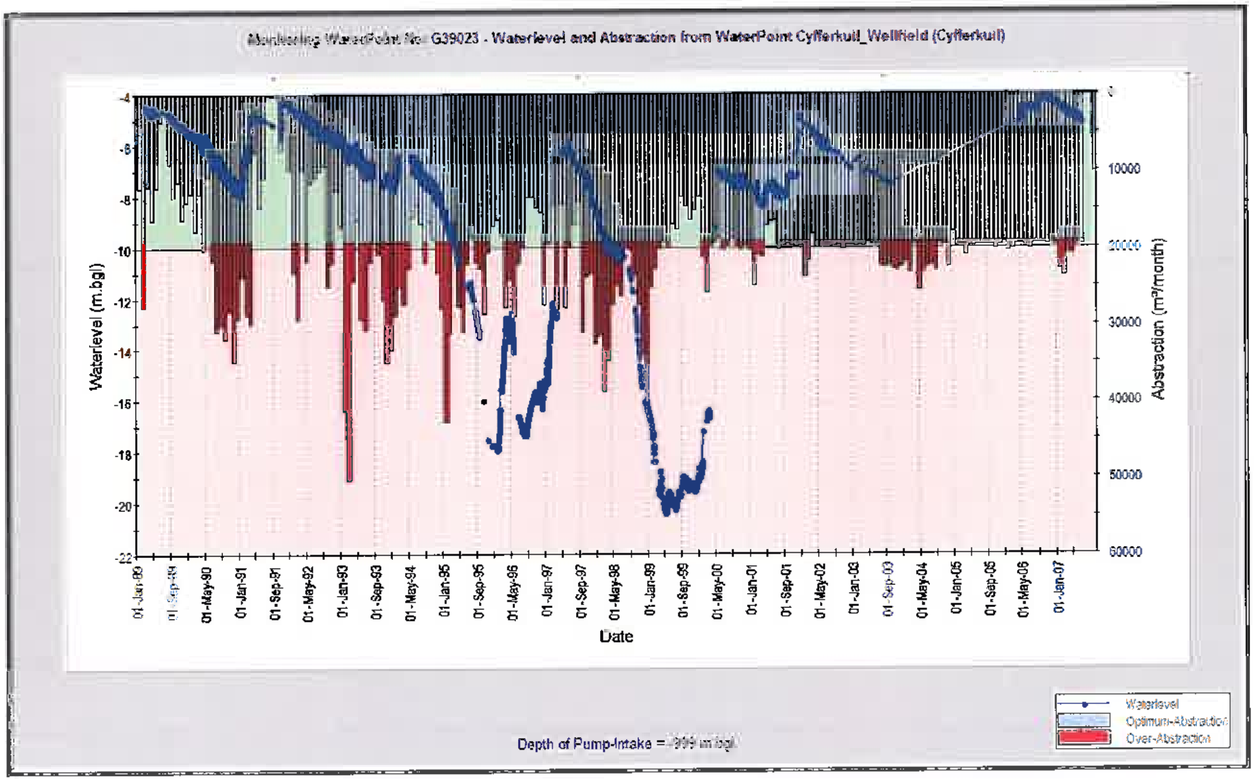


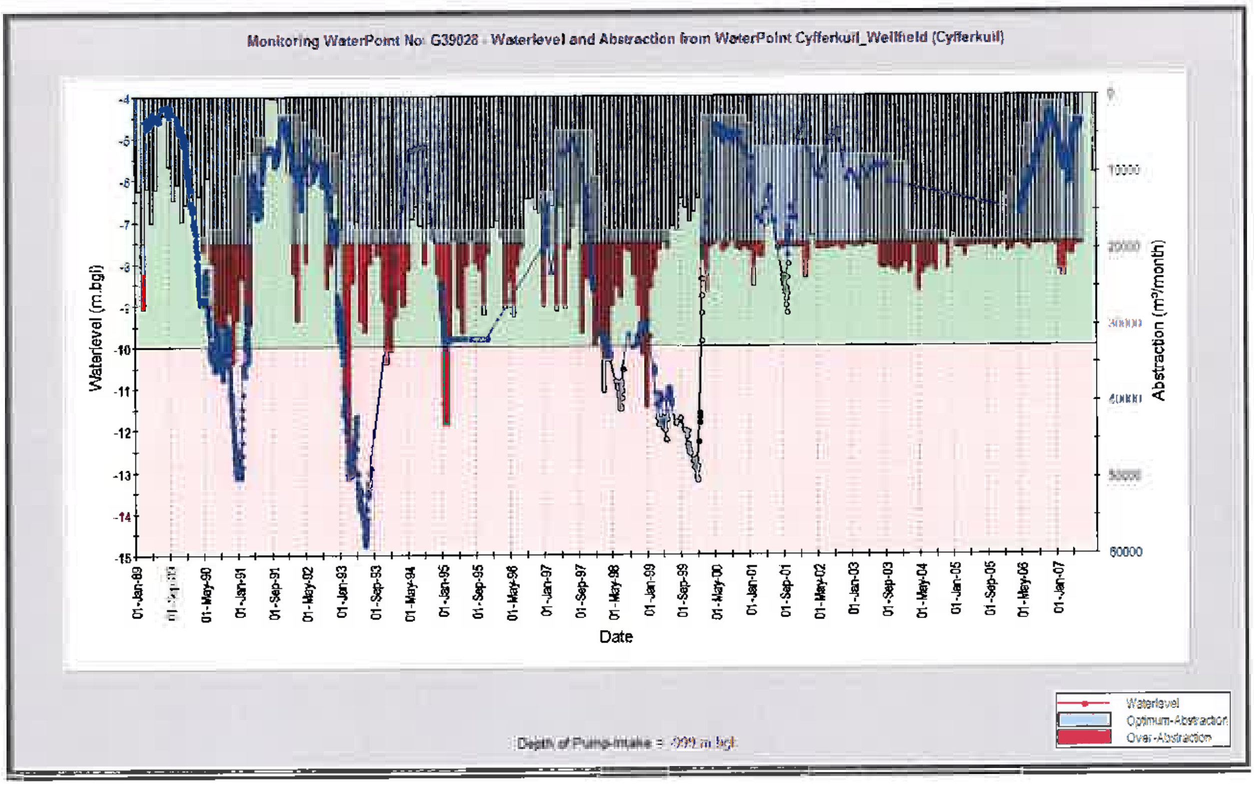

Monitoring WaterPoint No: G28302K
Waterlevel (m.bgl)
Abstraction (m³/month)
Date
Waterlevel
Optimum-Abstraction
Over-Abstraction

## Riet GMU:

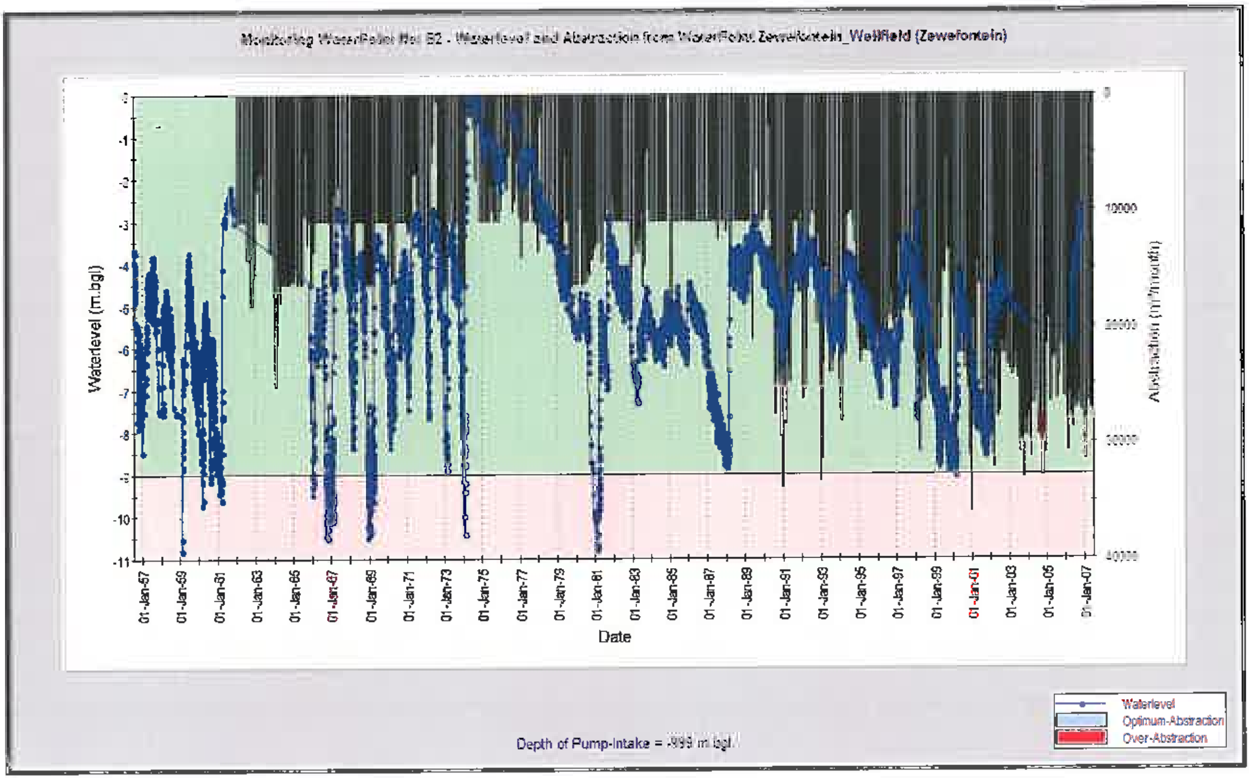

Monitoring WaterPoint No: G27917
Waterlevel (m.bgl)
Abstraction (m³/month)
Date

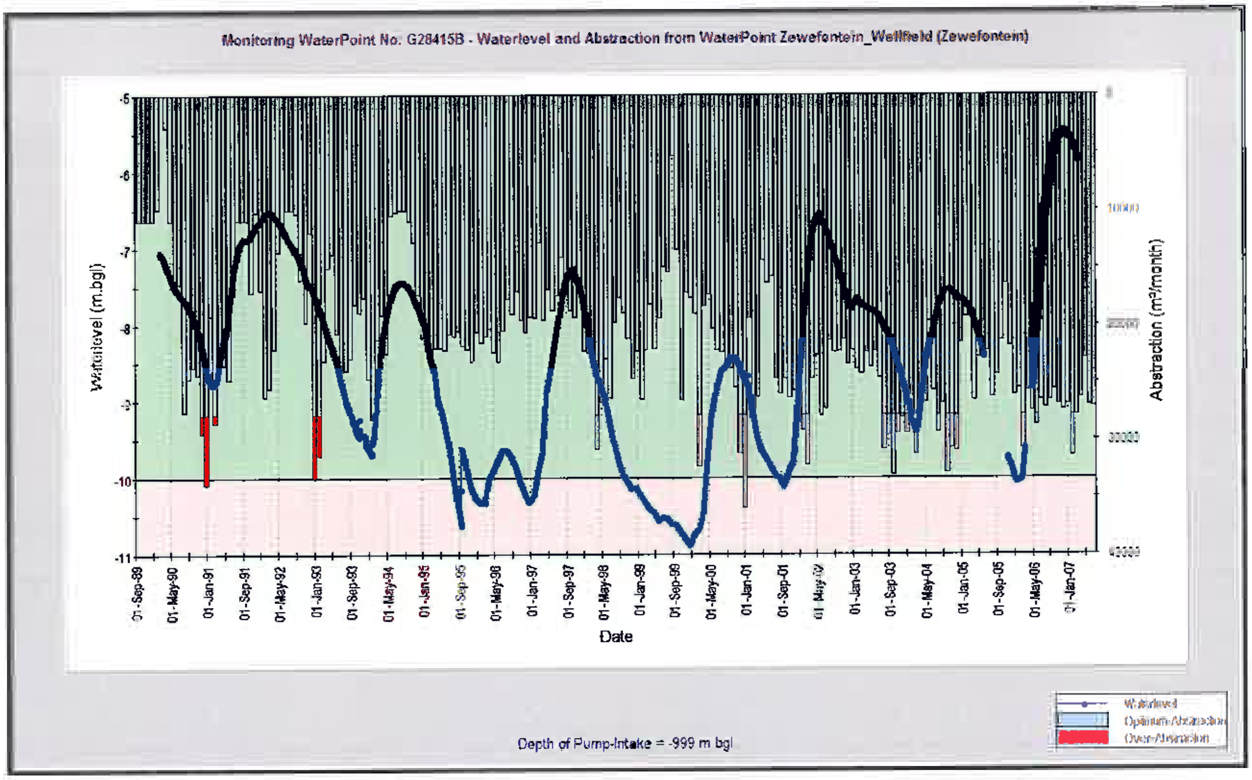
## Cyfferkuil GMU:

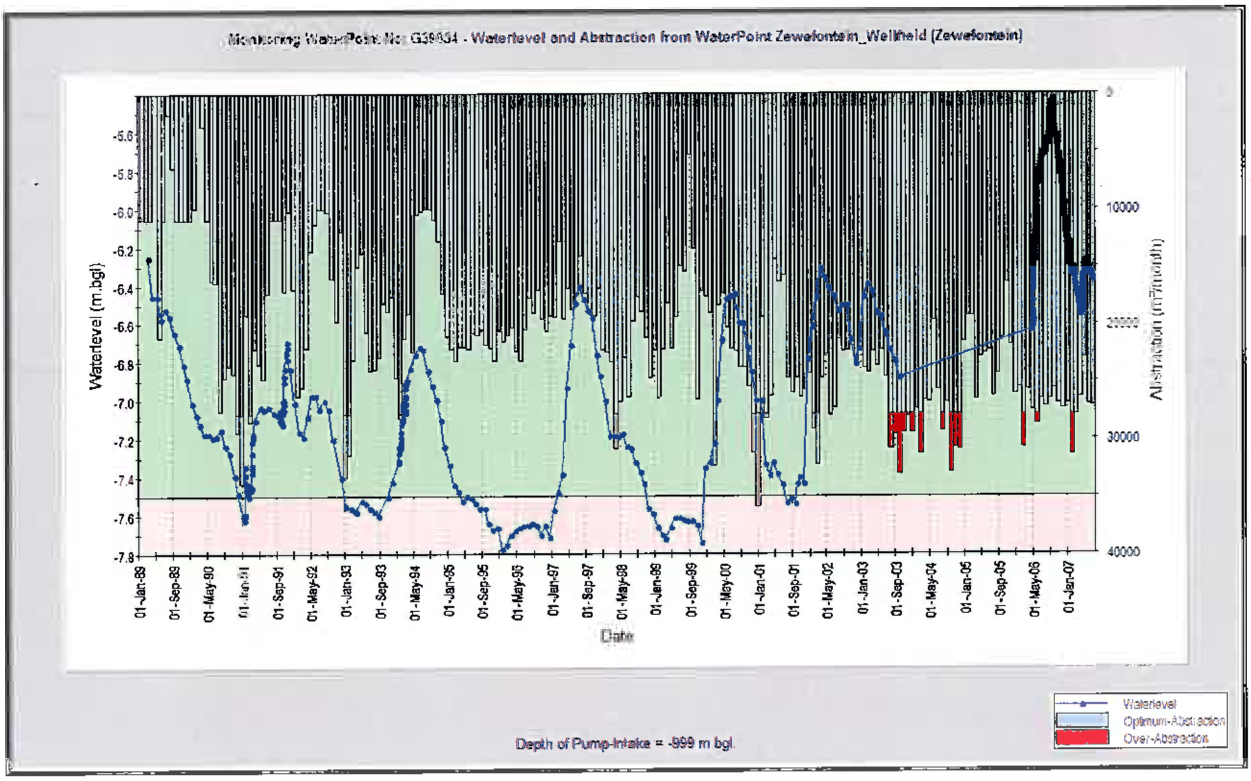


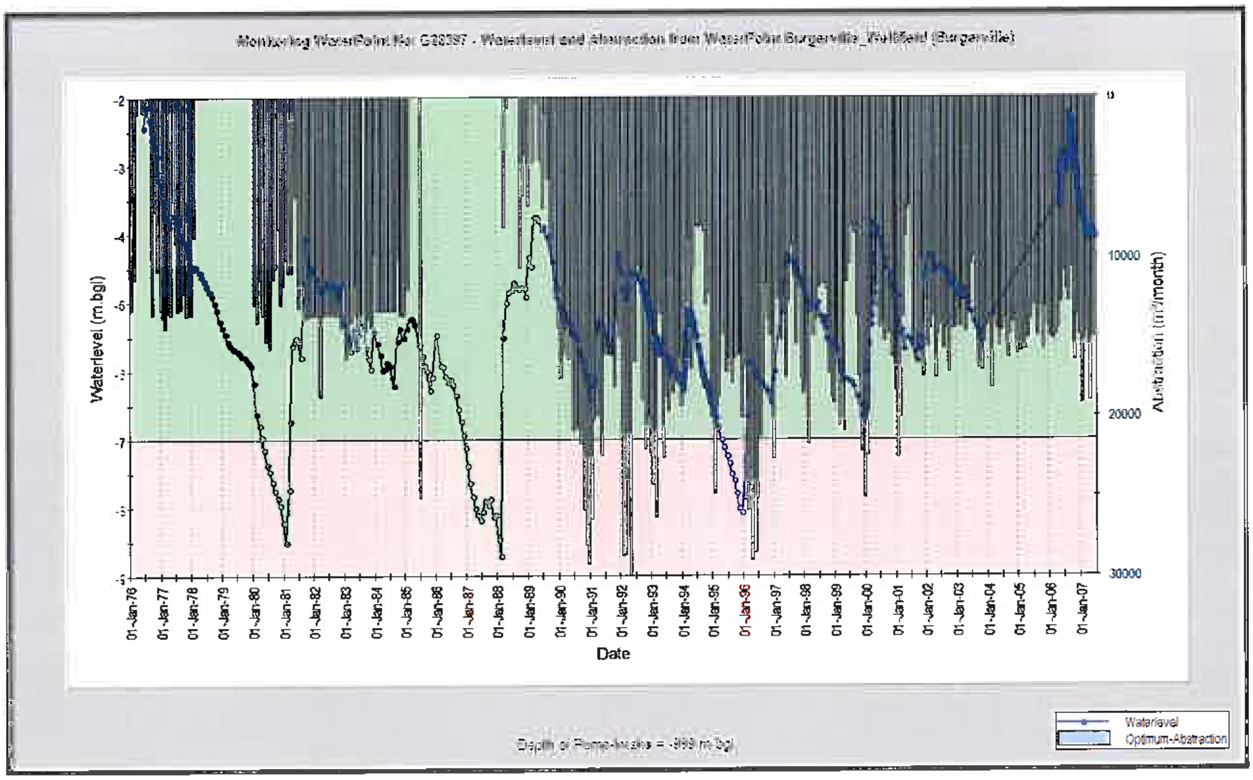
## Zewefontein GMU:

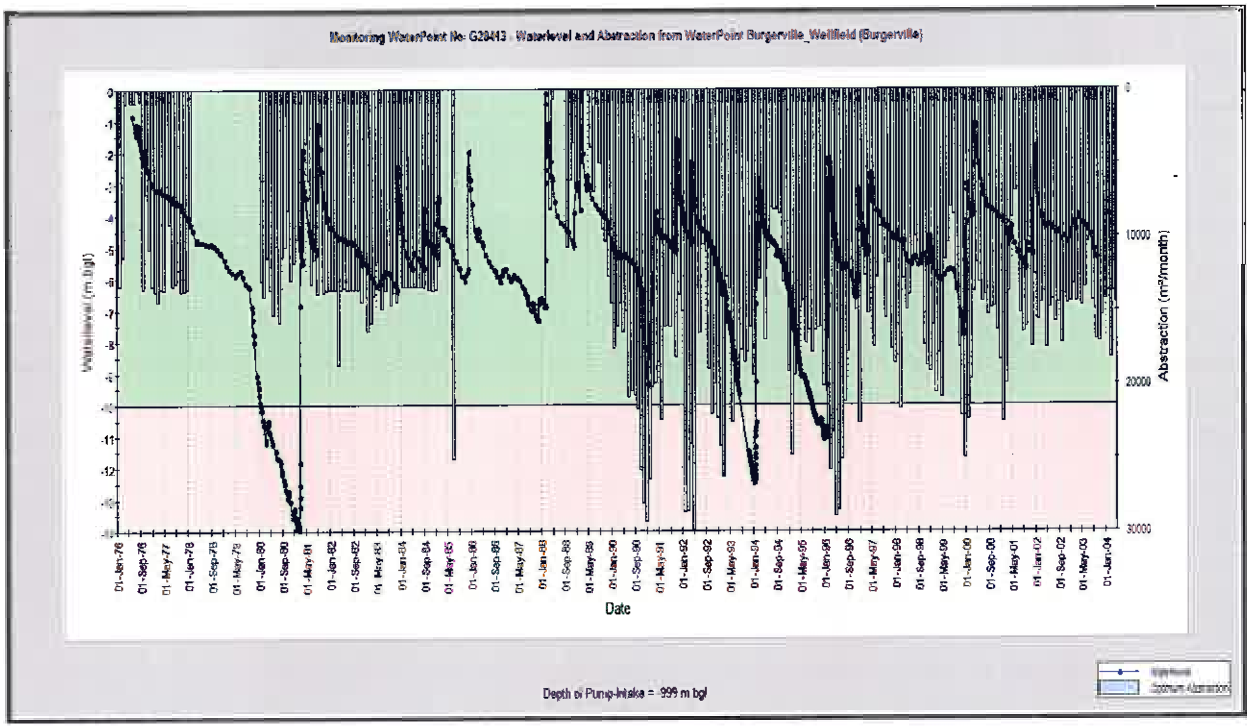


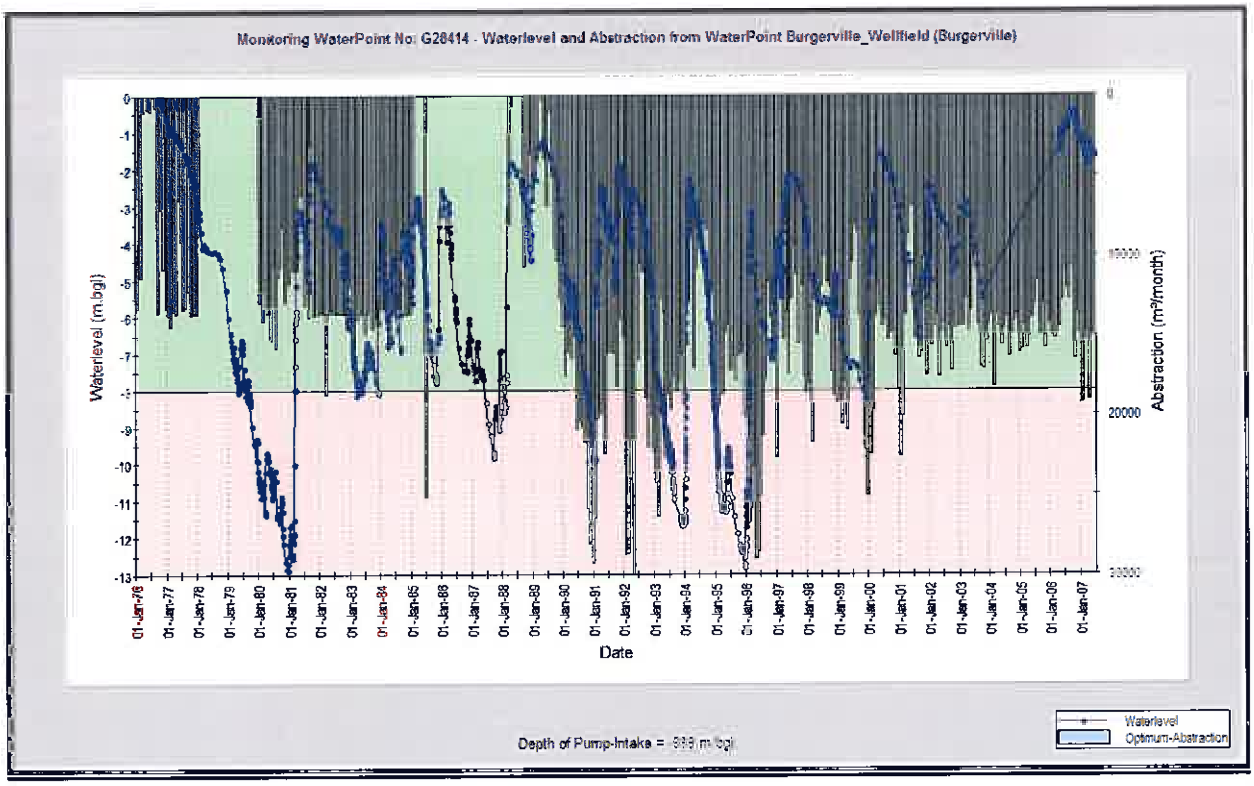






## Burgerville GMU:

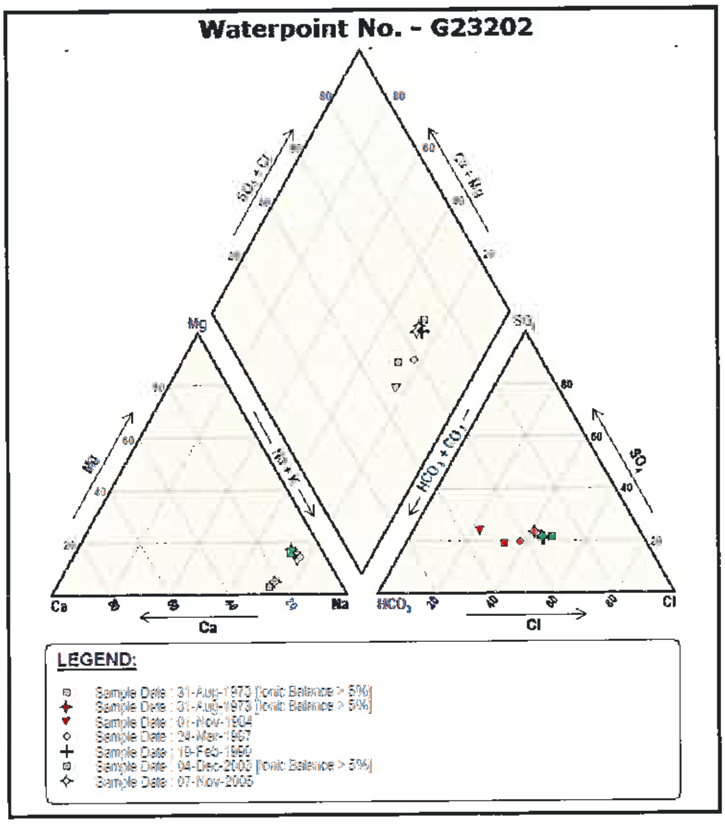


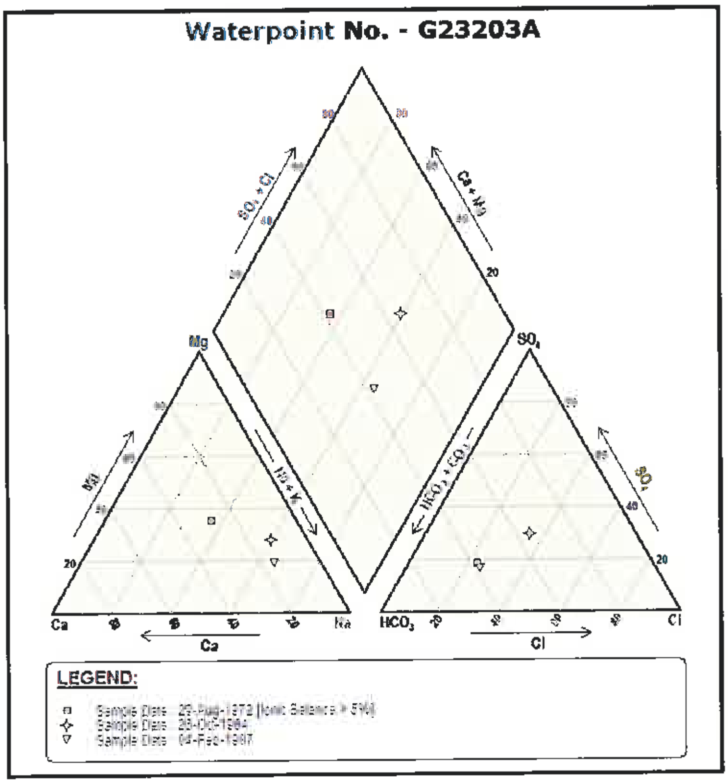

Monitoring WaterPoint No: G28413 - Waterlevel and Abstraction from WaterPoint Burgerville_Wellfield (Burgerville)
Waterlevel (m.bgl)
Abstraction (m³/month)
Date
Depth of Pump-Intake = -999 m bgl

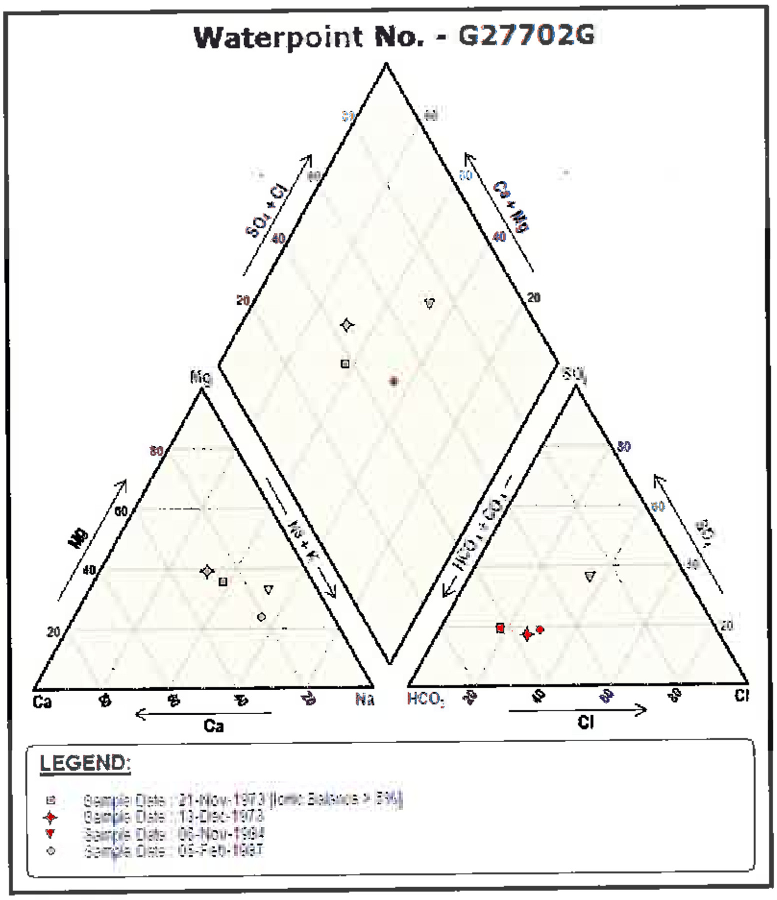

Monitoring WaterPoint No: G28414 - Waterlevel and Abstraction from WaterPoint Burgerville_Wellfield (Burgerville)
Waterlevel (m.bgl)
Abstraction (m³/month)
Date
Depth of Pump-Intake =
Waterlevel
Optimum-Abstraction

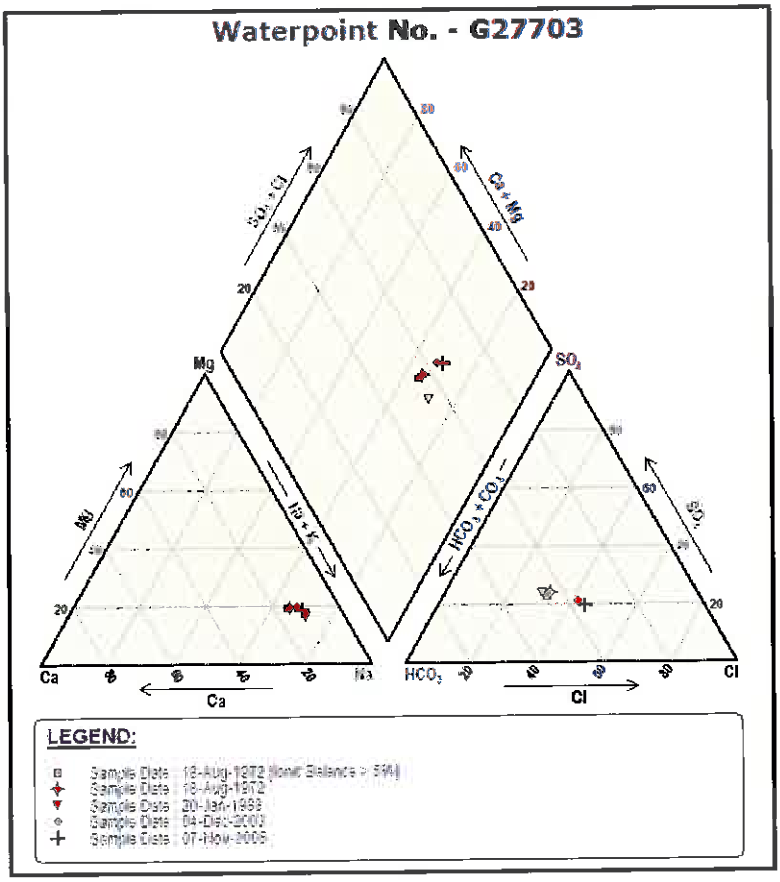
# Appendix 3: Piper Plots of Water Chemistry per Borehole

## Zwartkoppies GMU



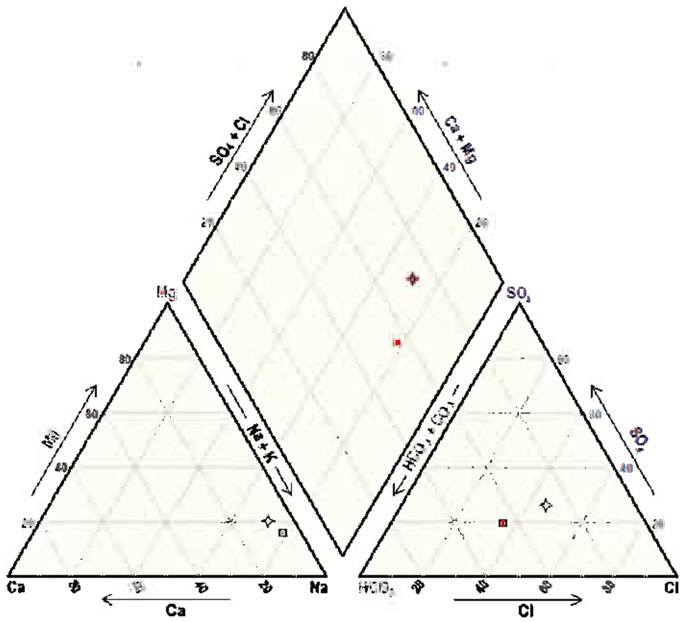




Waterpoint No. - G27702G
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 21-Nov-1973 (Ionic Balance > 5%)
Sample Date : 13-Dec-1973
Sample Date : 06-Nov-1994
Sample Date : 05-Feb-1997


Waterpoint No. - G27703
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 18-Aug-1972 (Ionic Balance > 5%)
Sample Date : 18-Aug-1972
Sample Date : 07-Nov-2006

## Rhenosterpoort GMU

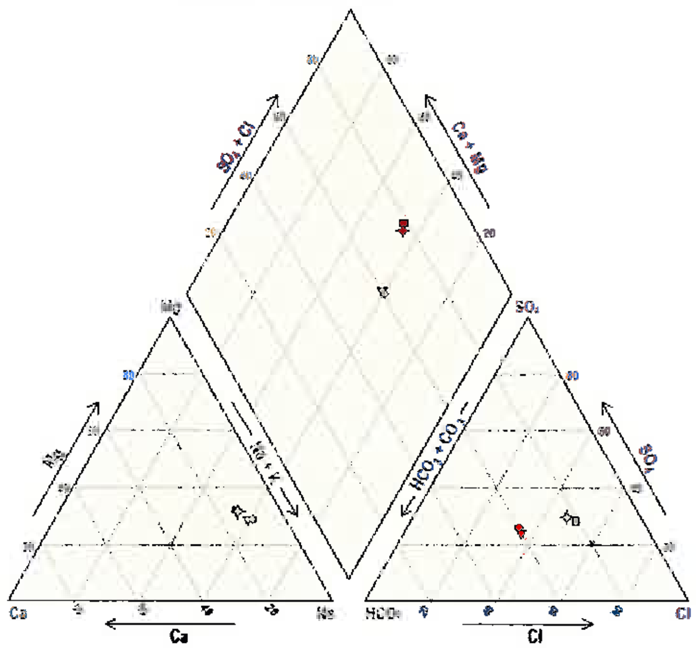
**Waterpoint No. - G23204D**




**LEGEND:**

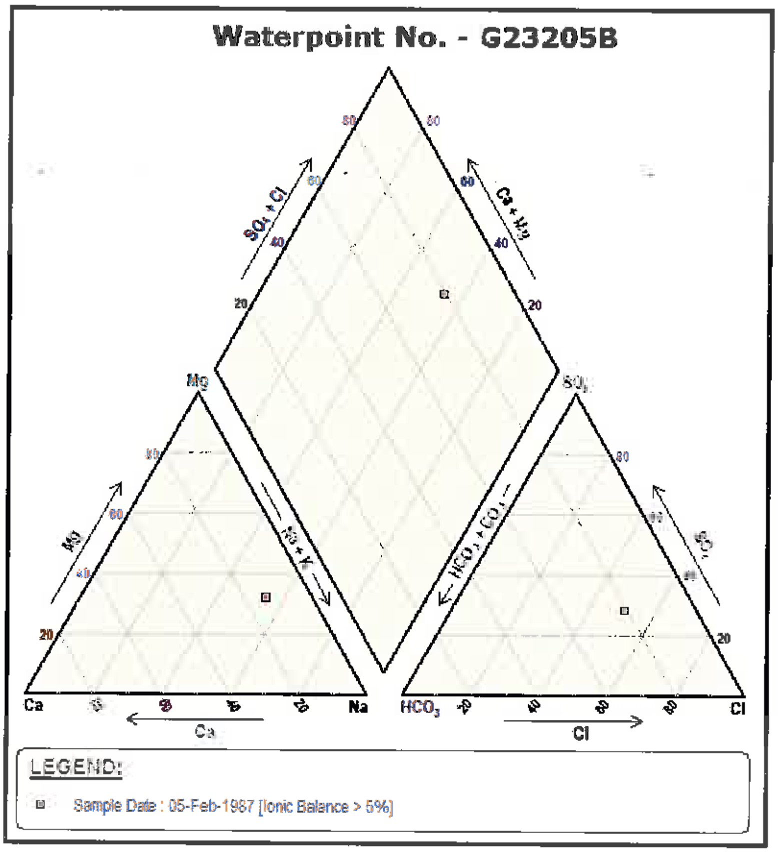
Sample Date : 21-Jul-1972 [Ionic Balance > 5%]
Sample Date : 04-Feb-1987

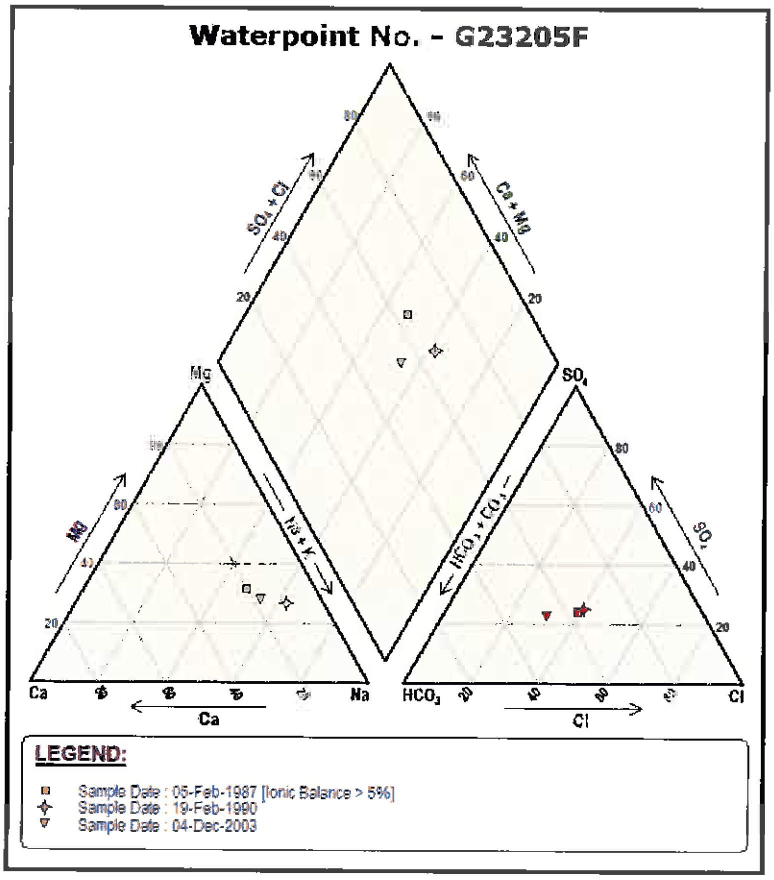
**Waterpoint No. - G23205**

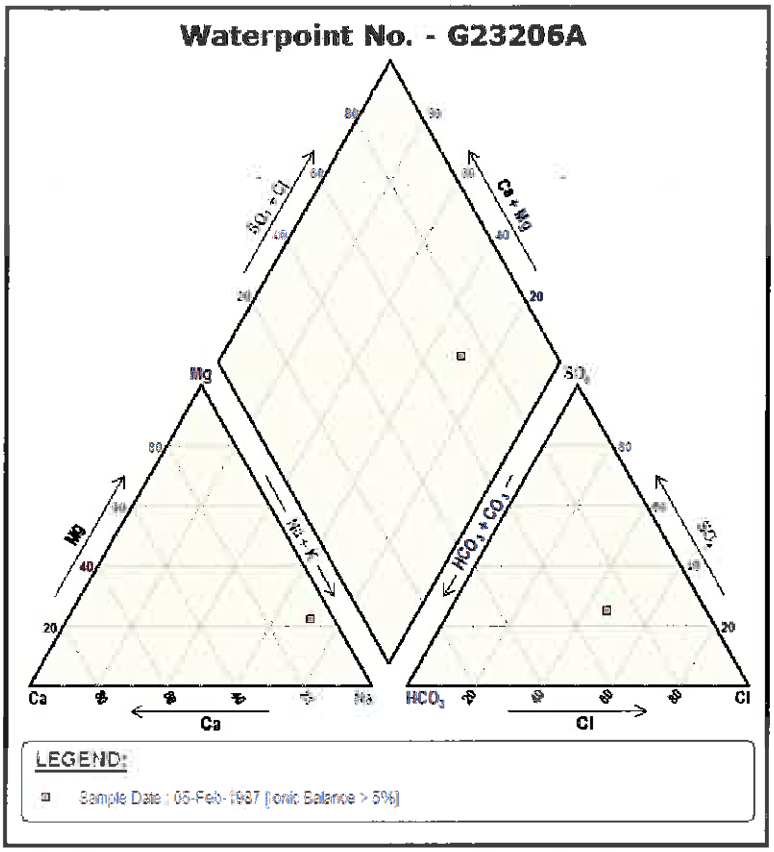


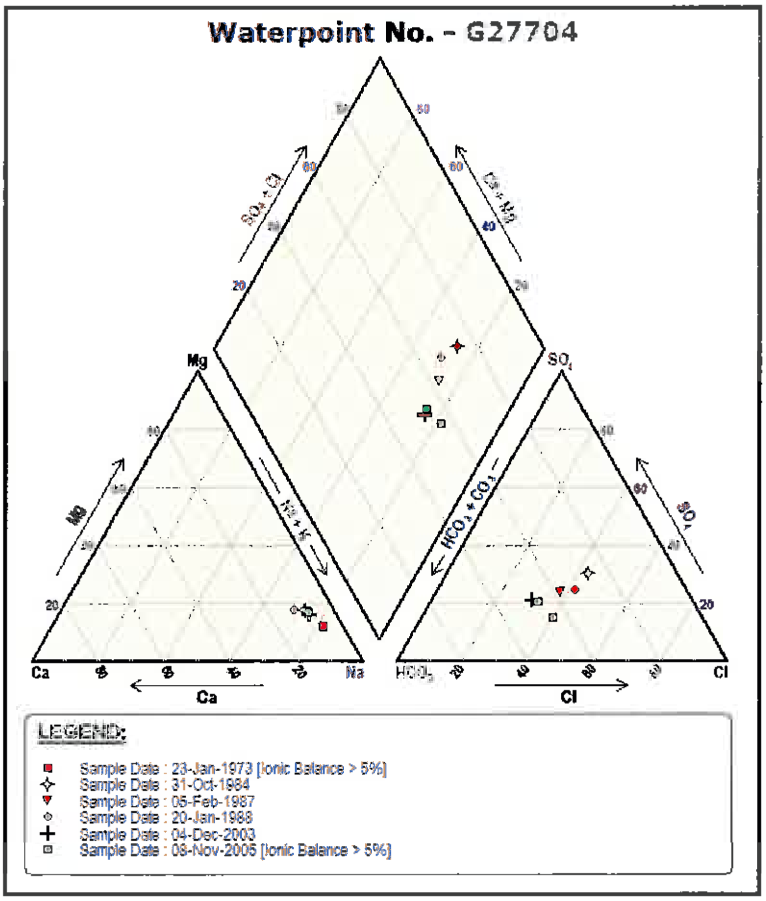

**LEGEND:**

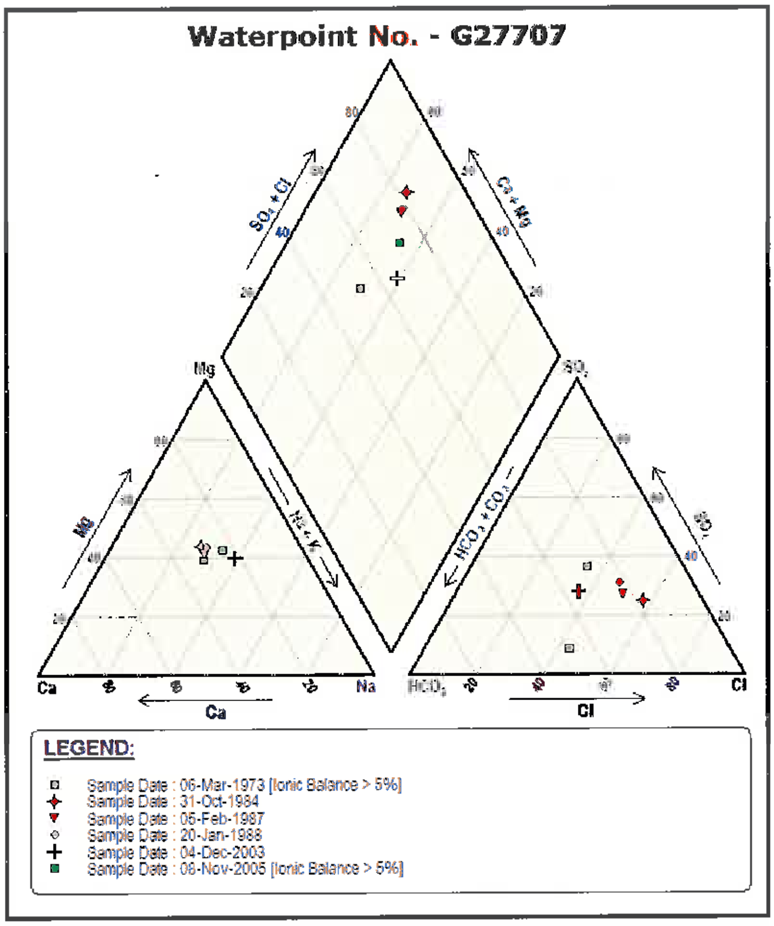
Sample Date : 05-Feb-1987 [Ionic Balance > 5%]
Sample Date : 20-Jan-1988
Sample Date : 04-Dec-2003
Sample Date : 08-Nov-2005

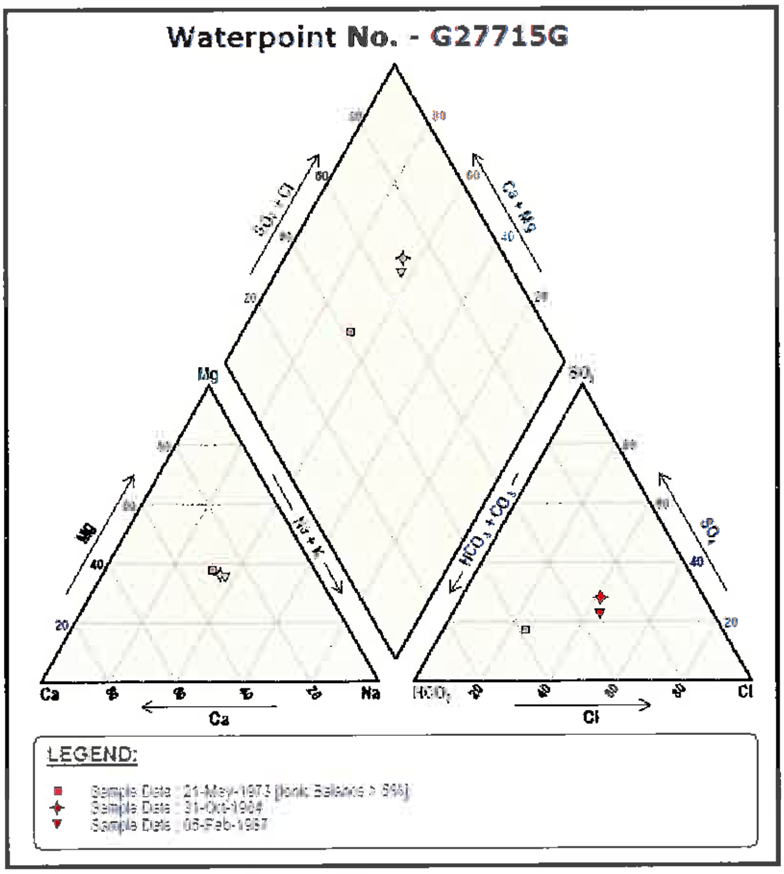

Waterpoint No. - G23205B
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 05-Feb-1987 [Ionic Balance > 5%]

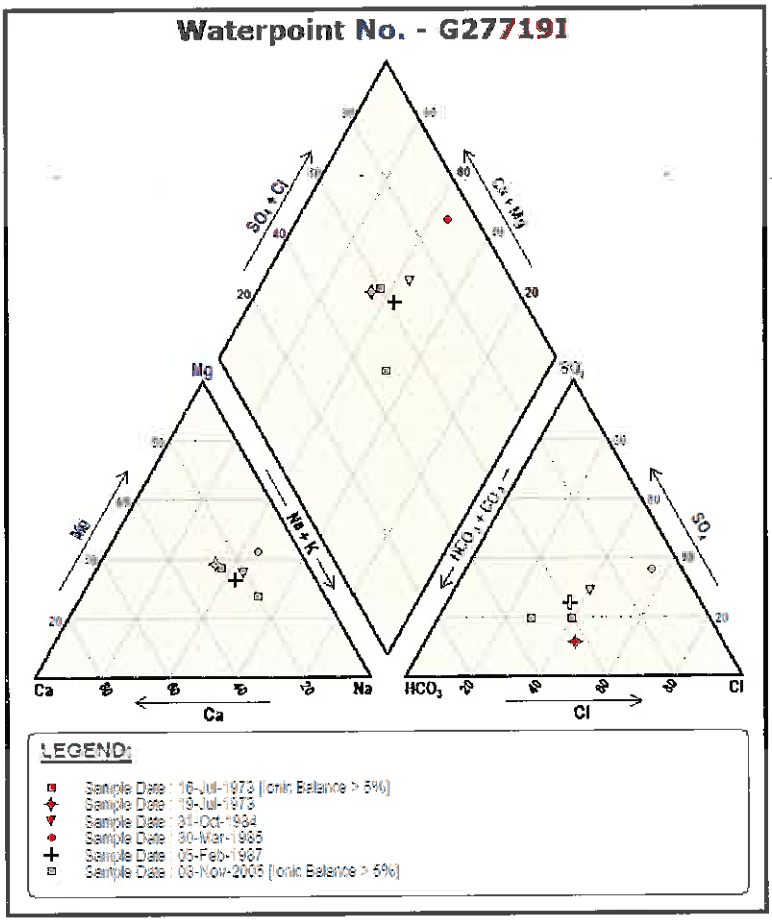

Waterpoint No. - G23205F
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 05-Feb-1987 [Ionic Balance > 5%]
Sample Date : 19-Feb-1990
Sample Date : 04-Dec-2003

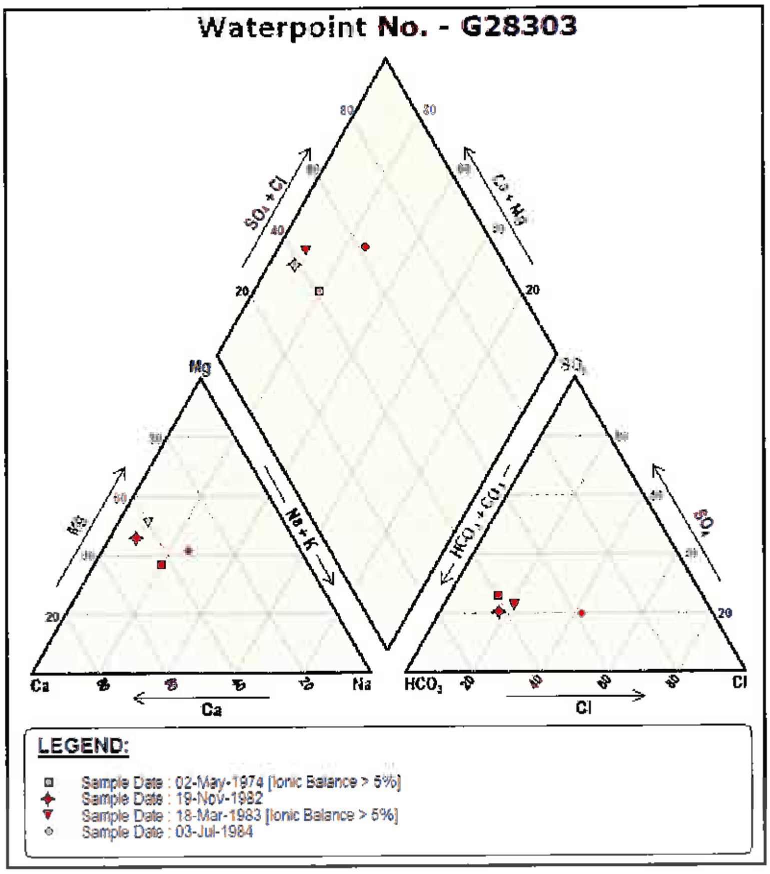

Waterpoint No. - G23206A
Mg
SO4
Ca
Na
HCO3
Cl
SO4 + Cl
Ca + Mg
Na + K
HCO3 + CO3
LEGEND:
Sample Date : 05-Feb-1987 [Ionic Balance > 5%]


Waterpoint No. - G27704
Mg
SO4
Ca
Na
HCO3
Cl
SO4 + Cl
Ca + Mg
Na + K
HCO3 + CO3
LEGEND:
Sample Date : 23-Jan-1973 [Ionic Balance > 5%]
Sample Date : 31-Oct-1984
Sample Date : 05-Feb-1987
Sample Date : 20-Jan-1988
Sample Date : 04-Dec-2003
Sample Date : 08-Nov-2005 [Ionic Balance > 5%]

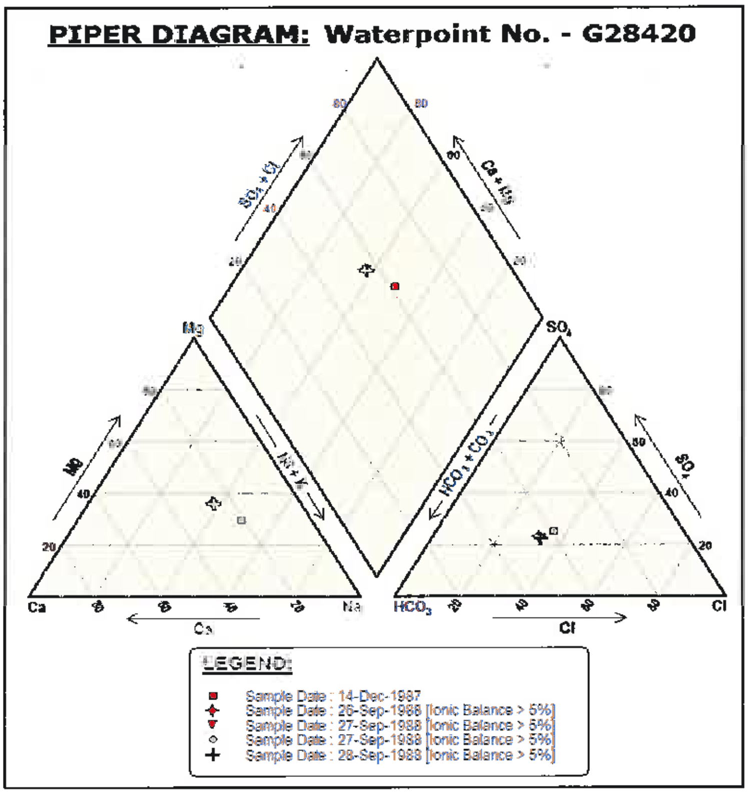

Waterpoint No. - G27707
$SO_4$ + Cl
Ca + Mg
Mg
Na + K
$HCO_3$ + $CO_3$
$SO_4$
Ca
Na
$HCO_3$
Cl
LEGEND:
Sample Date : 06-Mar-1973 [Ionic Balance > 5%]
Sample Date : 31-Oct-1984
Sample Date : 05-Feb-1987
Sample Date : 20-Jan-1988
Sample Date : 04-Dec-2003
Sample Date : 08-Nov-2005 [Ionic Balance > 5%]

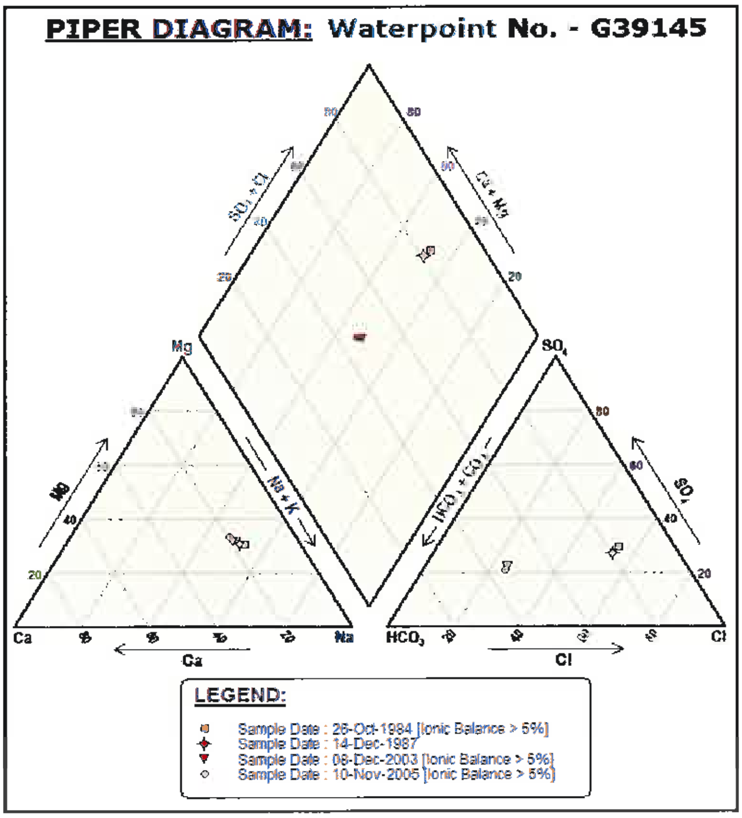

Waterpoint No. - G27715G
$SO_4$ + Cl
Ca + Mg
Mg
Na + K
$HCO_3$ + $CO_3$
$SO_4$
Ca
Na
$HCO_3$
Cl
LEGEND:
Sample Date : 21-May-1973 [Ionic Balance > 5%]
Sample Date : 31-Oct-1984
Sample Date : 05-Feb-1987

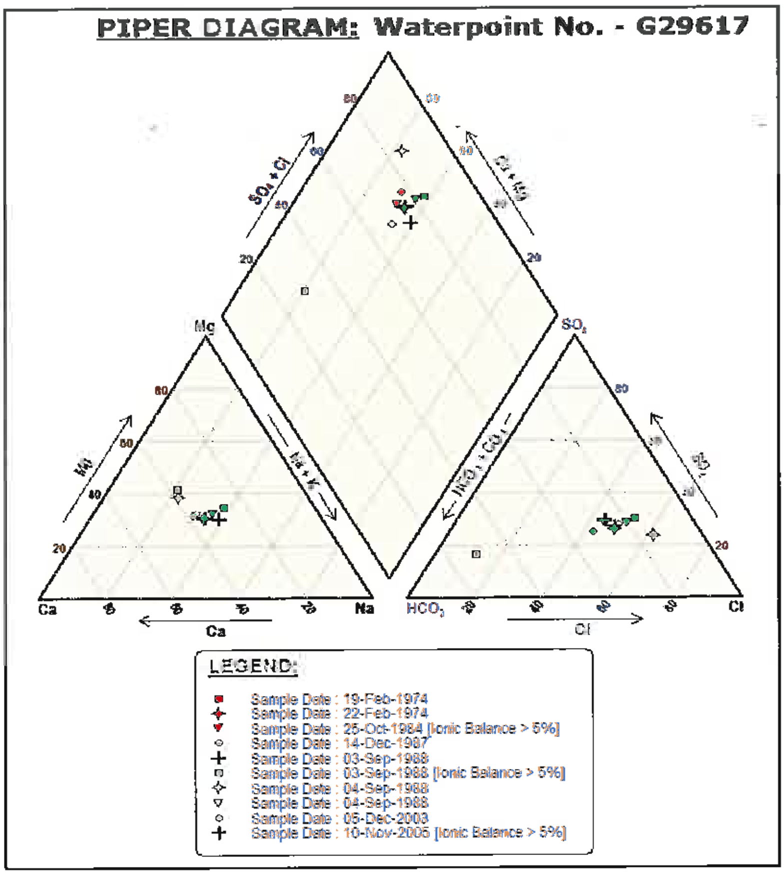

Waterpoint No. - G27719I
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 16-Jul-1973 [Ionic Balance > 5%]
Sample Date : 19-Jul-1973
Sample Date : 31-Oct-1984
Sample Date : 30-Mar-1985
Sample Date : 05-Feb-1987
Sample Date : 03-Nov-2005 [Ionic Balance > 5%]

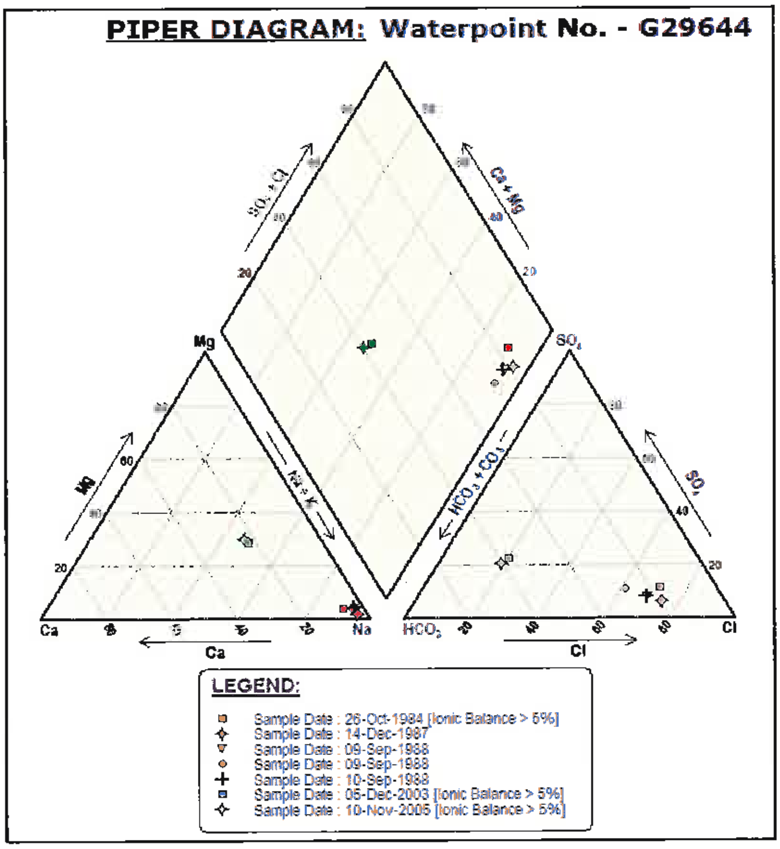

Waterpoint No. - G28303
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 02-May-1974 [Ionic Balance > 5%]
Sample Date : 19-Nov-1982
Sample Date : 18-Mar-1983 [Ionic Balance > 5%]
Sample Date : 03-Jul-1984

## Paardevallei GMU

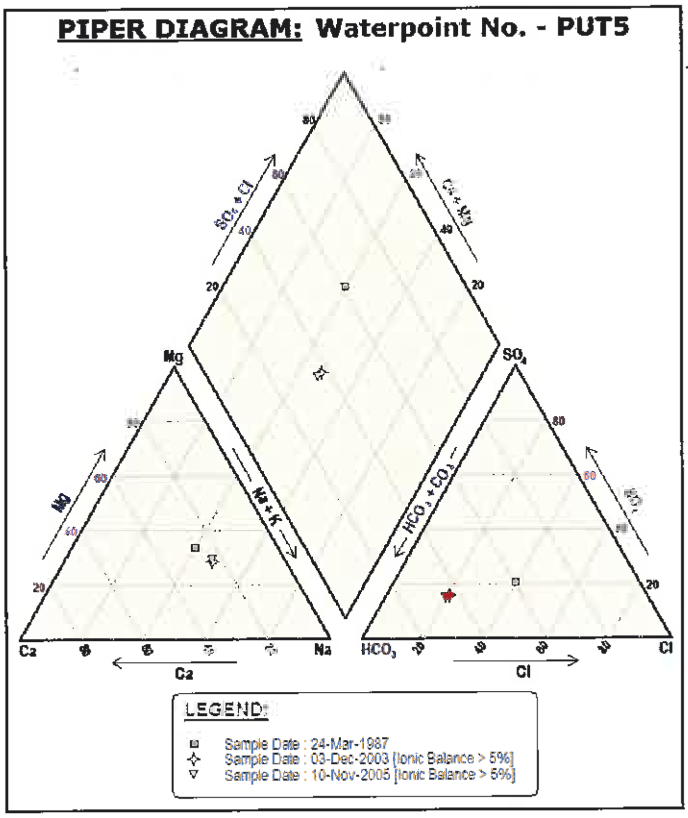


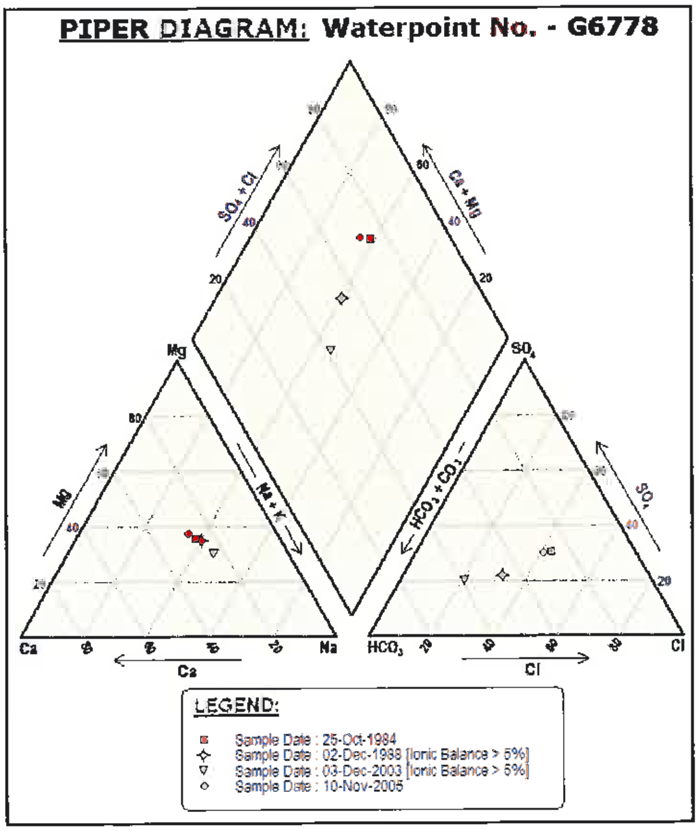



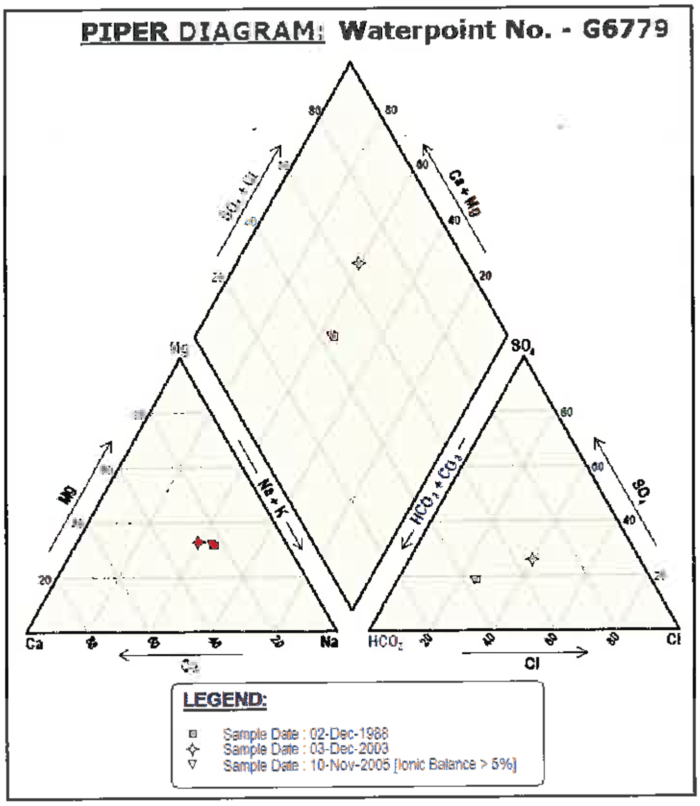

PIPER DIAGRAM: Waterpoint No. - G29617
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 19-Feb-1974
Sample Date : 22-Feb-1974
Sample Date : 25-Oct-1984 [Ionic Balance > 5%]
Sample Date : 14-Dec-1987
Sample Date : 03-Sep-1988
Sample Date : 03-Sep-1988 [Ionic Balance > 5%]
Sample Date : 04-Sep-1988
Sample Date : 04-Sep-1988
Sample Date : 05-Dec-2003
Sample Date : 10-Nov-2006 [Ionic Balance > 5%]

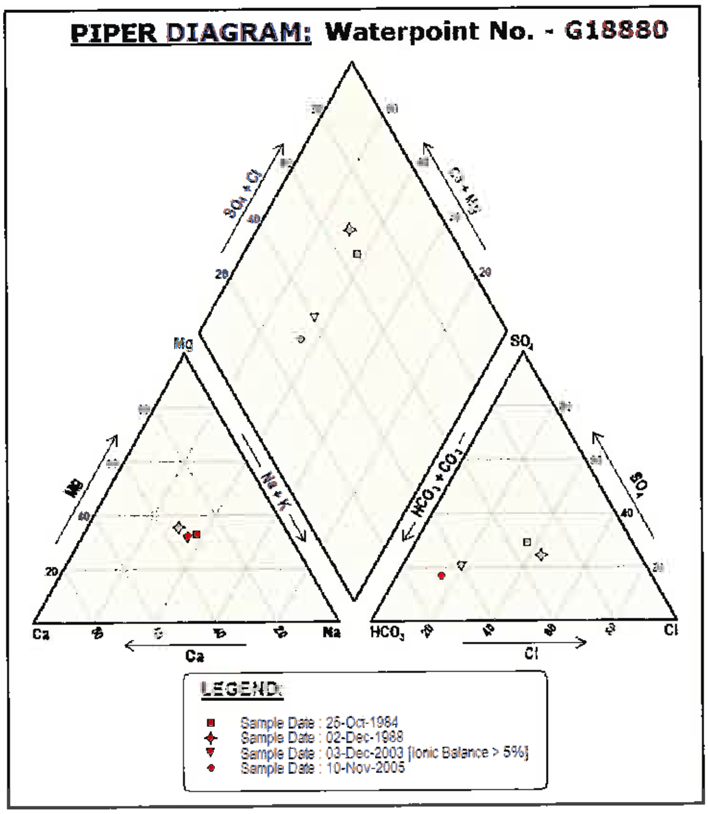

PIPER DIAGRAM: Waterpoint No. - G29644
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 26-Oct-1984 [Ionic Balance > 5%]
Sample Date : 14-Dec-1987
Sample Date : 09-Sep-1988
Sample Date : 09-Sep-1988
Sample Date : 10-Sep-1988
Sample Date : 05-Dec-2003 [Ionic Balance > 5%]
Sample Date : 10-Nov-2006 [Ionic Balance > 5%]

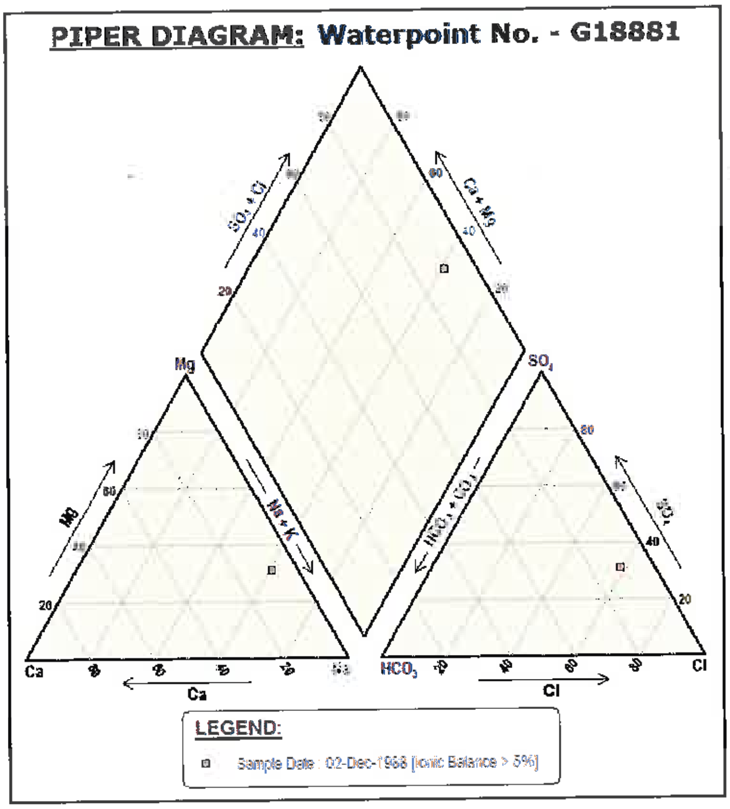
## Caroluspoort-North GMU

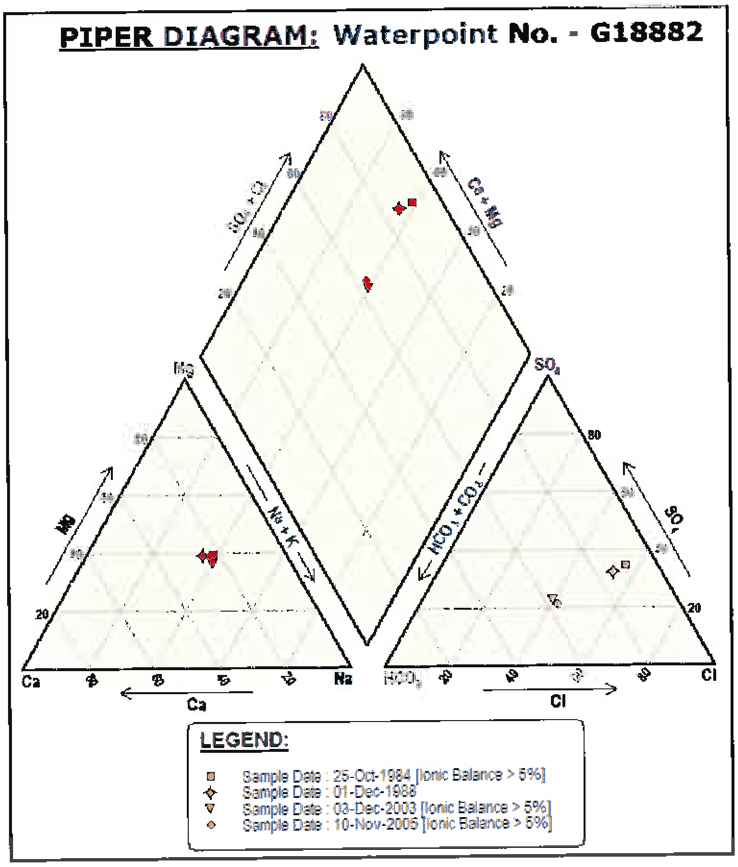


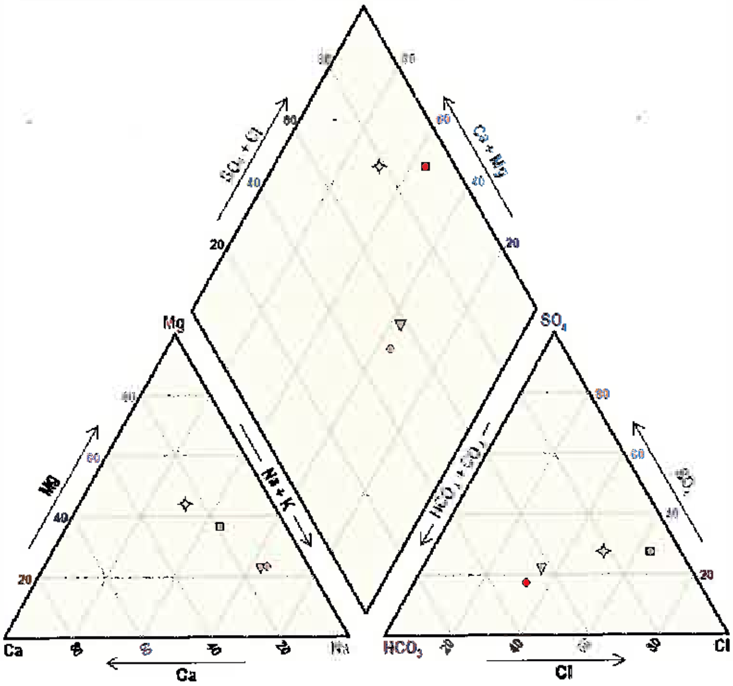

PIPER DIAGRAM: Waterpoint No. - G6779
Mg
SO4 + Cl
Ca + Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 02-Dec-1988
Sample Date : 03-Dec-2003
Sample Date : 10-Nov-2005 [Ionic Balance > 5%]


PIPER DIAGRAM: Waterpoint No. - G18880
Mg
SO4 + Cl
Ca + Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 25-Oct-1984
Sample Date : 02-Dec-1988
Sample Date : 03-Dec-2003 [Ionic Balance > 5%]
Sample Date : 10-Nov-2005


PIPER DIAGRAM: Waterpoint No. - G18881
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 02-Dec-1968 [Ionic Balance > 5%]


PIPER DIAGRAM: Waterpoint No. - G18882
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 25-Oct-1984 [Ionic Balance > 5%]
Sample Date : 01-Dec-1988
Sample Date : 03-Dec-2003 [Ionic Balance > 5%]
Sample Date : 10-Nov-2005 [Ionic Balance > 5%]

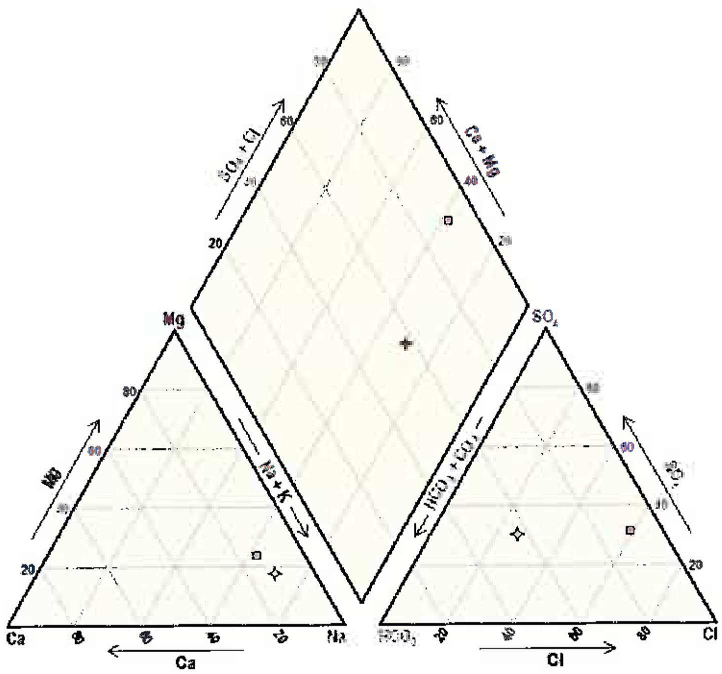
**PIPER DIAGRAM: Waterpoint No. - G18884**




**LEGEND:**

- Sample Date : 25-Oct-1984 [Ionic Balance > 5%]
- Sample Date : 02-Dec-1988 [Ionic Balance > 5%]
- Sample Date : 03-Dec-2003 [Ionic Balance > 5%]
- Sample Date : 10-Nov-2005

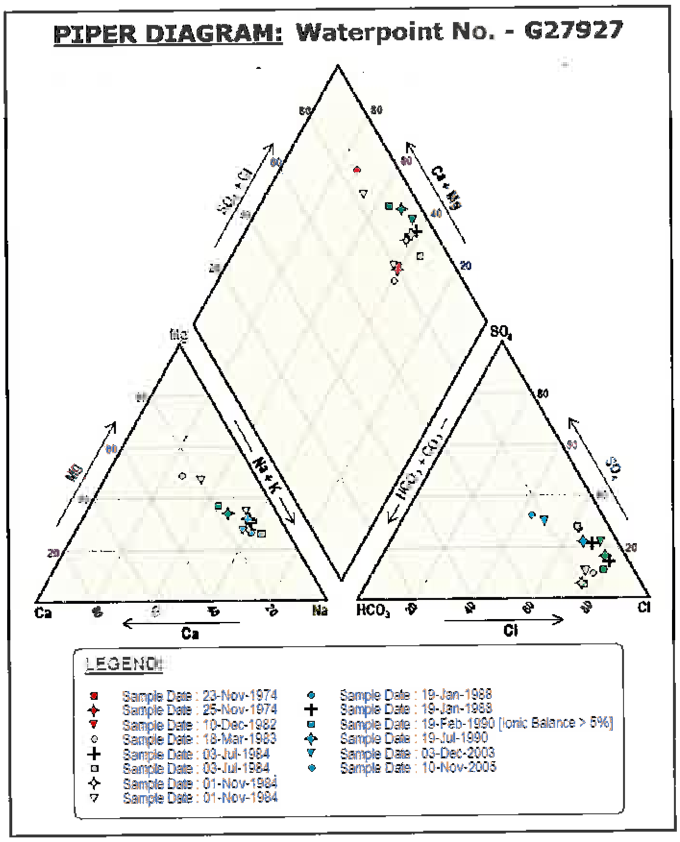
**PIPER DIAGRAM: Waterpoint No. - G18886**

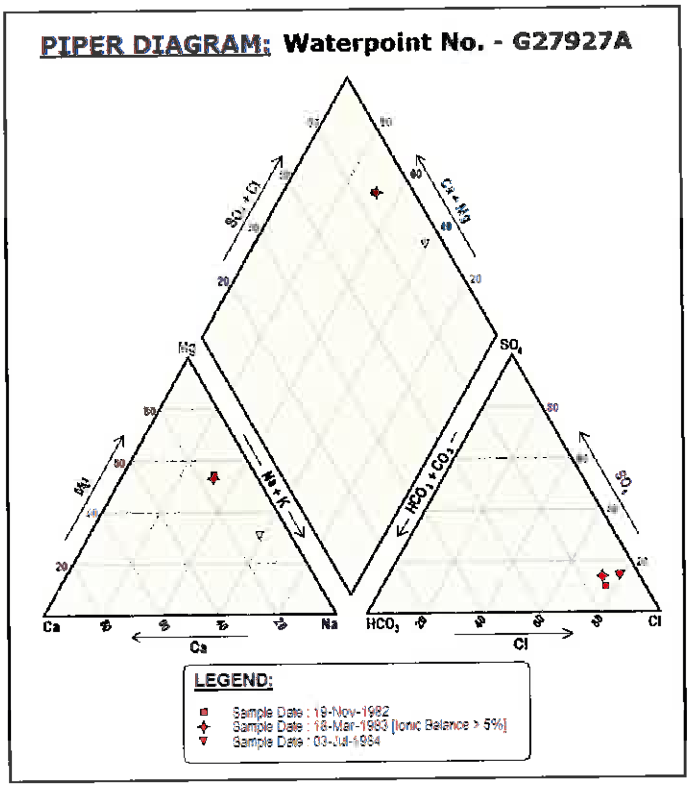


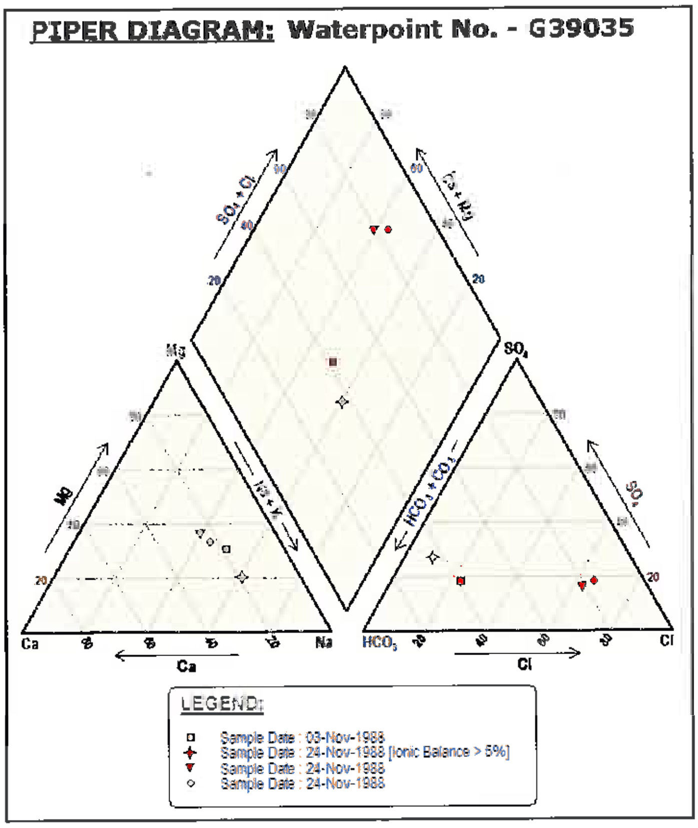

**LEGEND:**

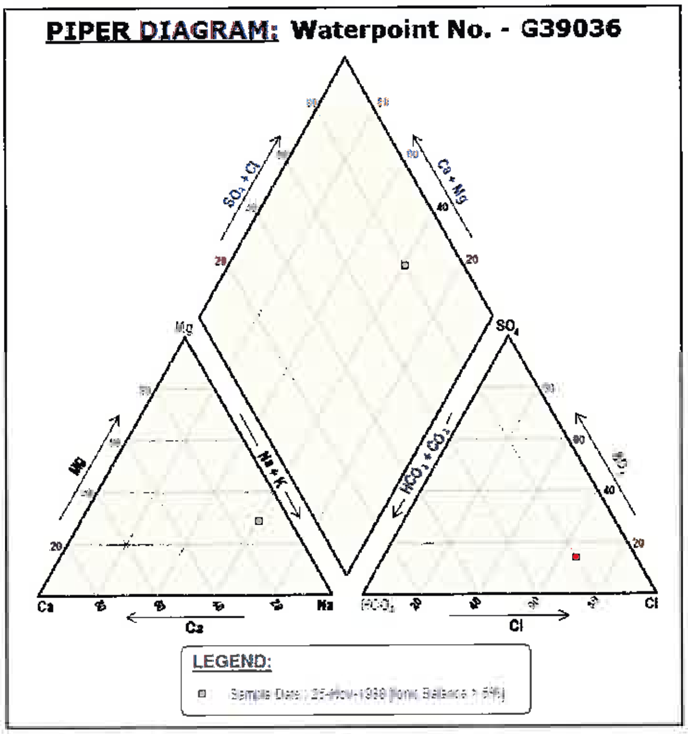
- Sample Date : 25-Oct-1984 [Ionic Balance > 5%]
- Sample Date : 02-Dec-1988

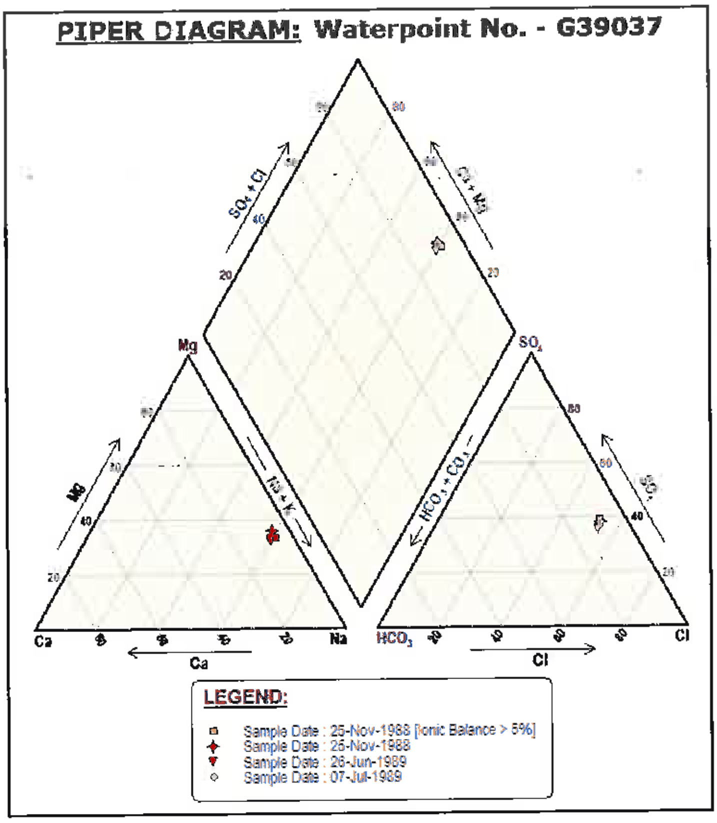
## Caroluspoort-South GMU

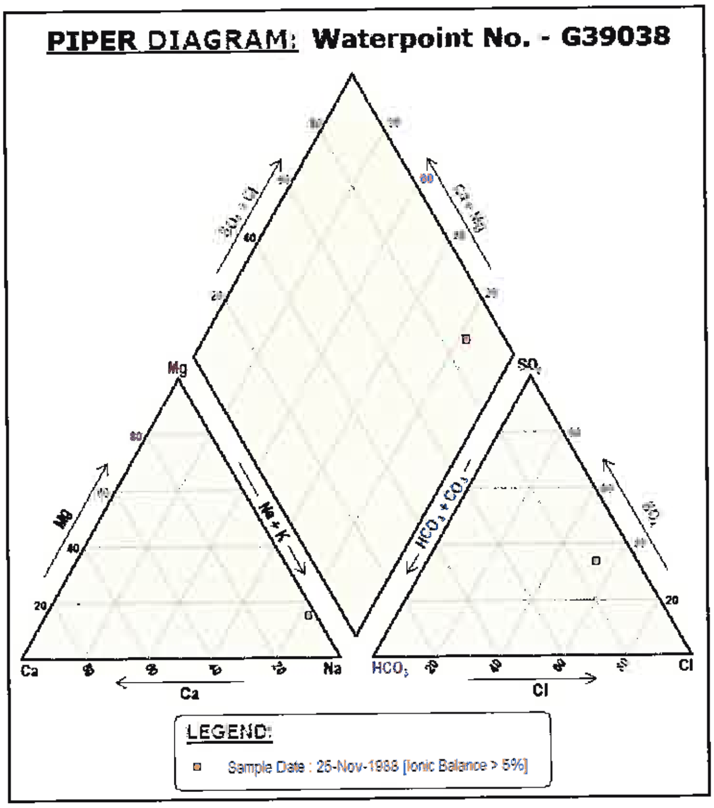


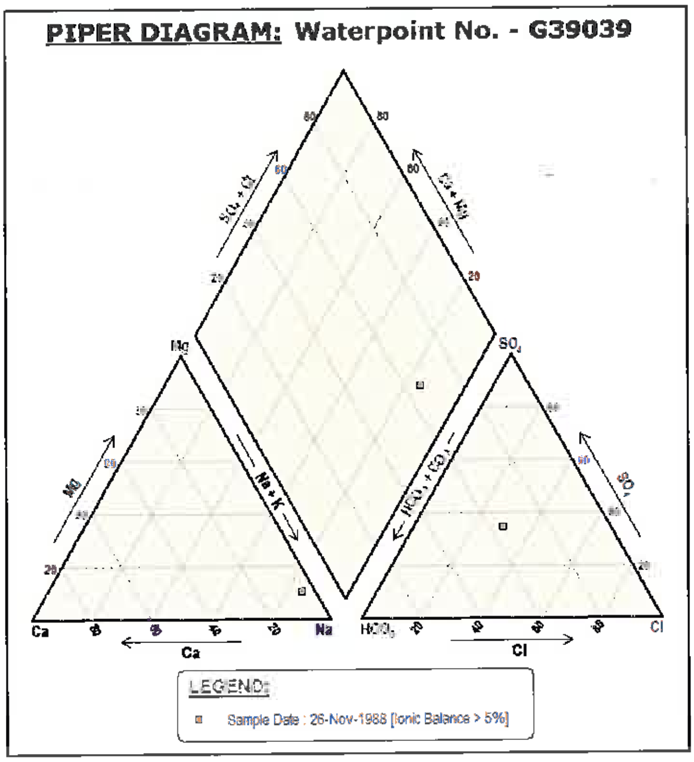




PIPER DIAGRAM: Waterpoint No. - G39035
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 03-Nov-1988
Sample Date : 24-Nov-1988 [Ionic Balance > 5%]
Sample Date : 24-Nov-1988
Sample Date : 24-Nov-1988

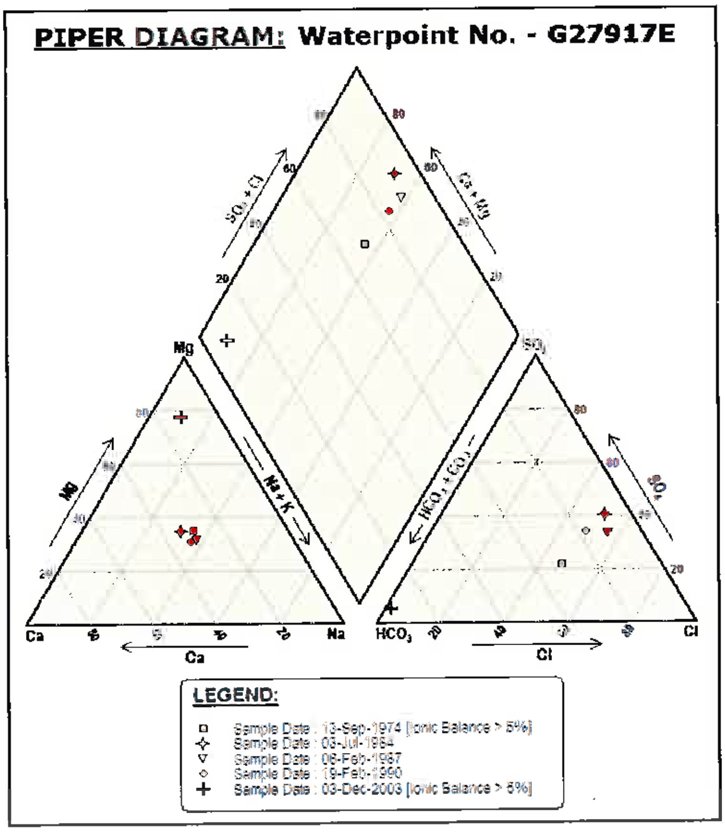

PIPER DIAGRAM: Waterpoint No. - G39036
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:

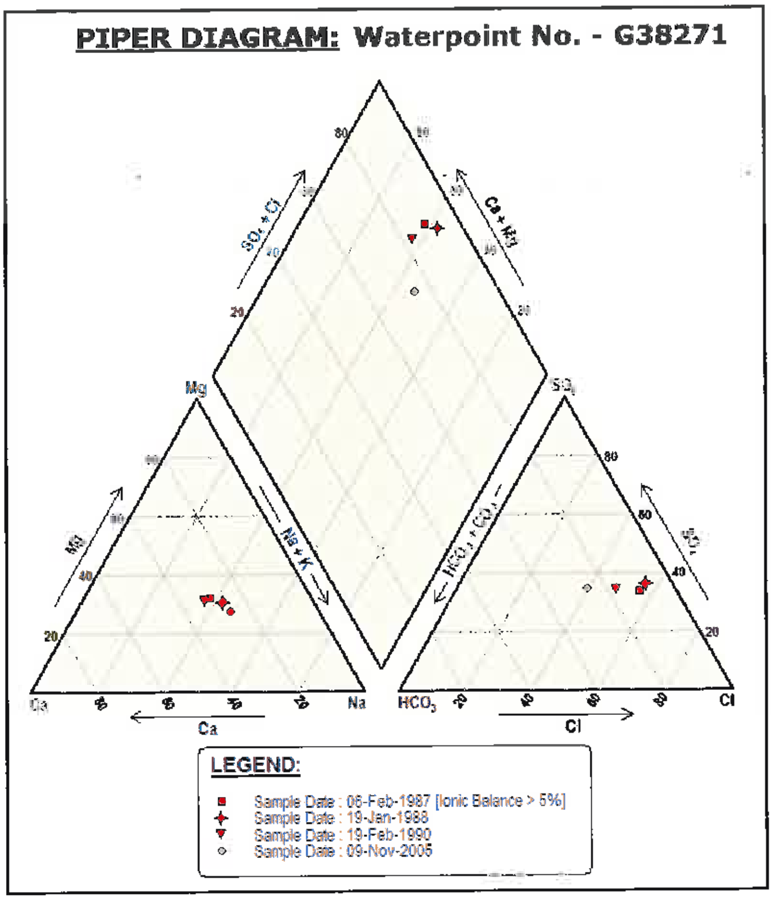

PIPER DIAGRAM: Waterpoint No. - G39037
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 25-Nov-1988 [Ionic Balance > 5%]
Sample Date : 25-Nov-1988
Sample Date : 26-Jun-1989
Sample Date : 07-Jul-1989

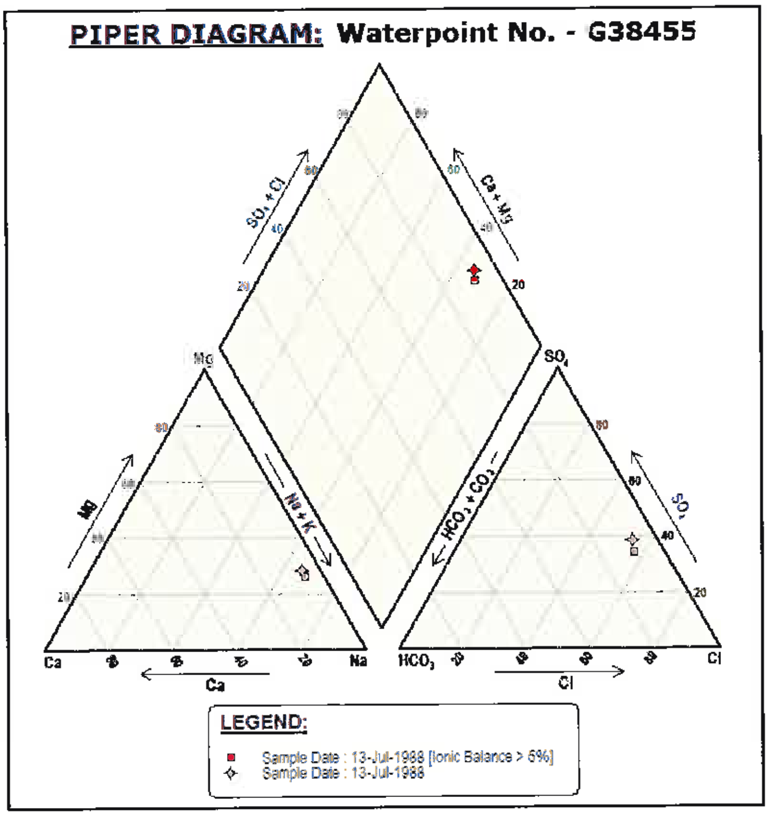

PIPER DIAGRAM: Waterpoint No. - G39038
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 25-Nov-1988 [Ionic Balance > 5%]

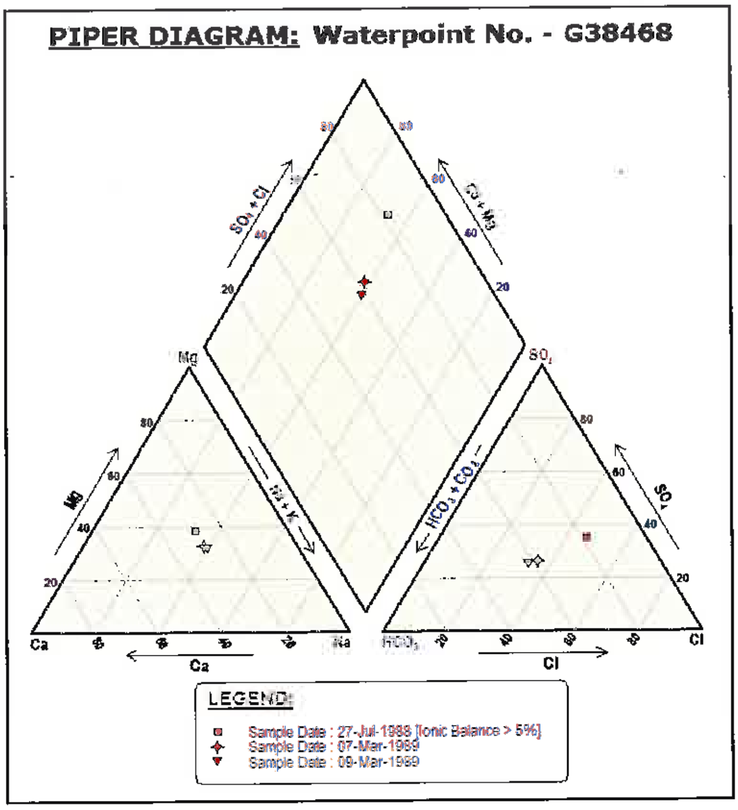

PIPER DIAGRAM: Waterpoint No. - G39039
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
SO4
Ca
Na
HCO3
Cl
Ca
Cl
LEGEND:
Sample Date : 26-Nov-1988 [Ionic Balance > 5%]

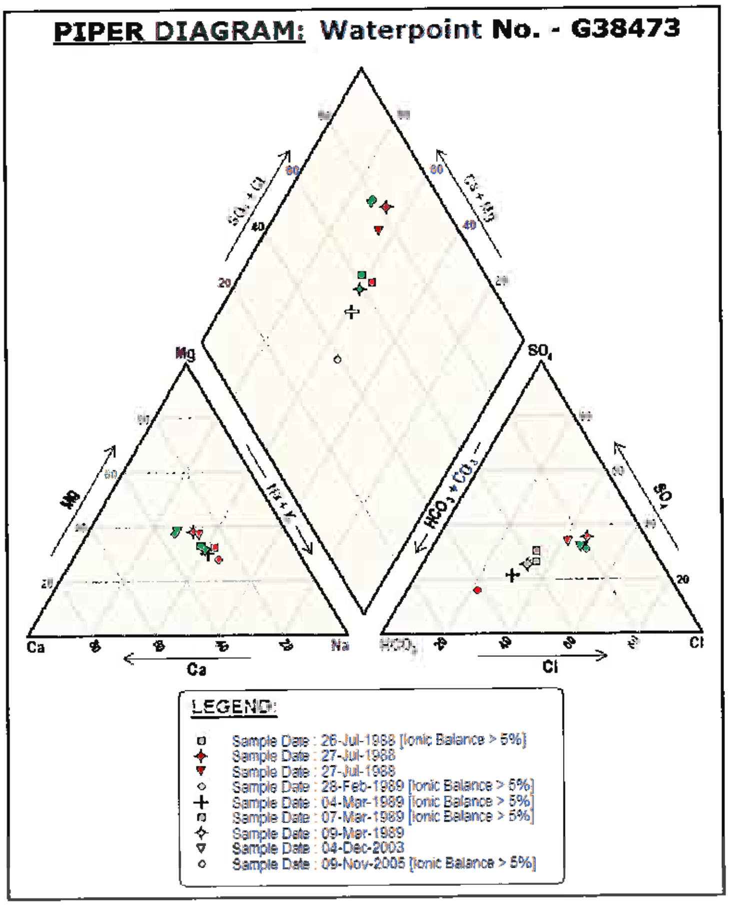
## Riet GMU

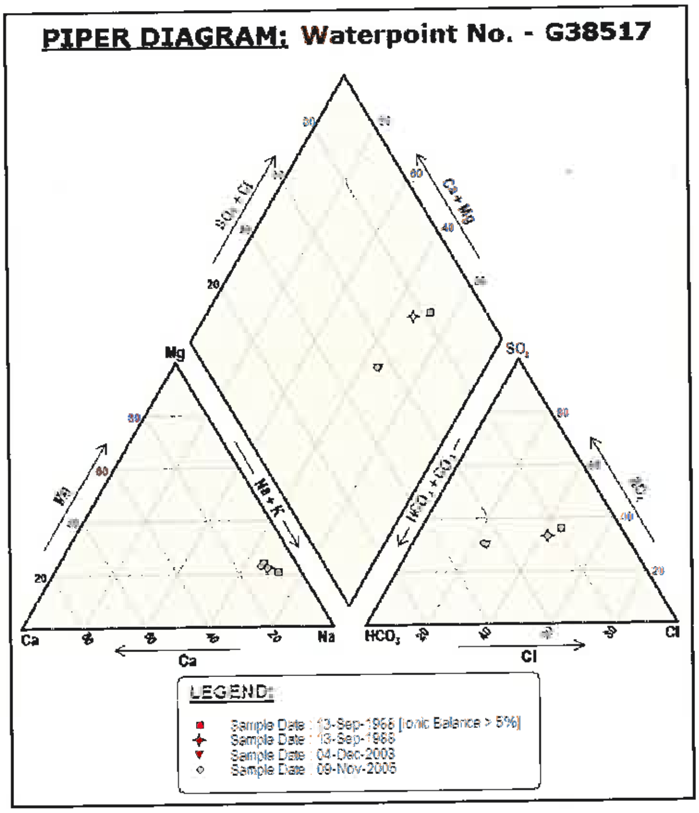

PIPER DIAGRAM: Waterpoint No. - G27917E
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
SO4
Ca
Na
HCO3
Cl
Ca
Cl
LEGEND:
Sample Date : 13-Sep-1974 [Ionic Balance > 5%]
Sample Date : 03-Jul-1984
Sample Date : 06-Feb-1987
Sample Date : 19-Feb-1990
Sample Date : 03-Dec-2003 [Ionic Balance > 5%]


PIPER DIAGRAM: Waterpoint No. - G38271
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 06-Feb-1987 [Ionic Balance > 5%]
Sample Date : 19-Jan-1988
Sample Date : 19-Feb-1990
Sample Date : 09-Nov-2005

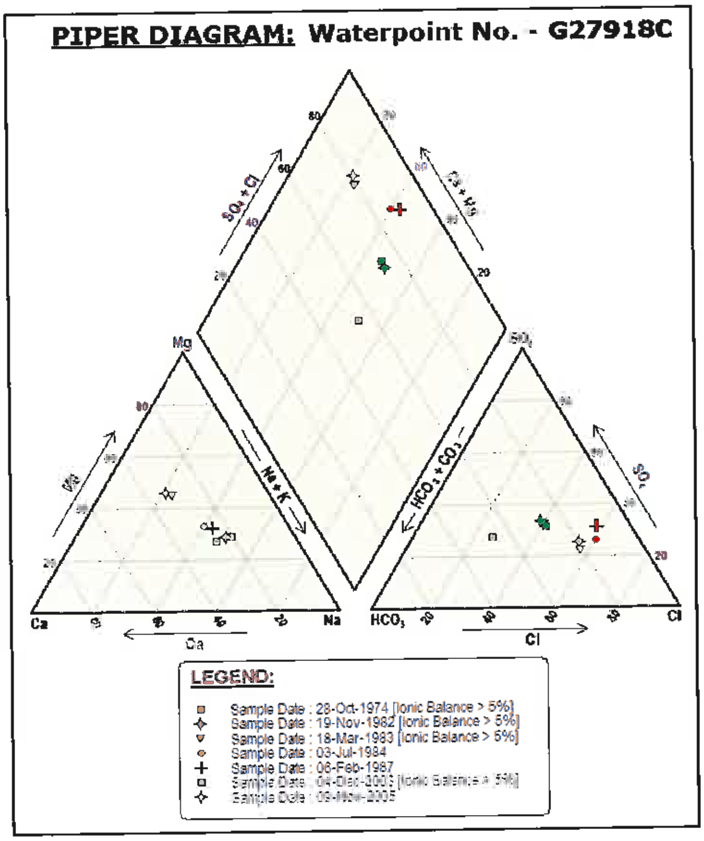

PIPER DIAGRAM: Waterpoint No. - G38455
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 13-Jul-1988 [Ionic Balance > 5%]
Sample Date : 13-Jul-1988

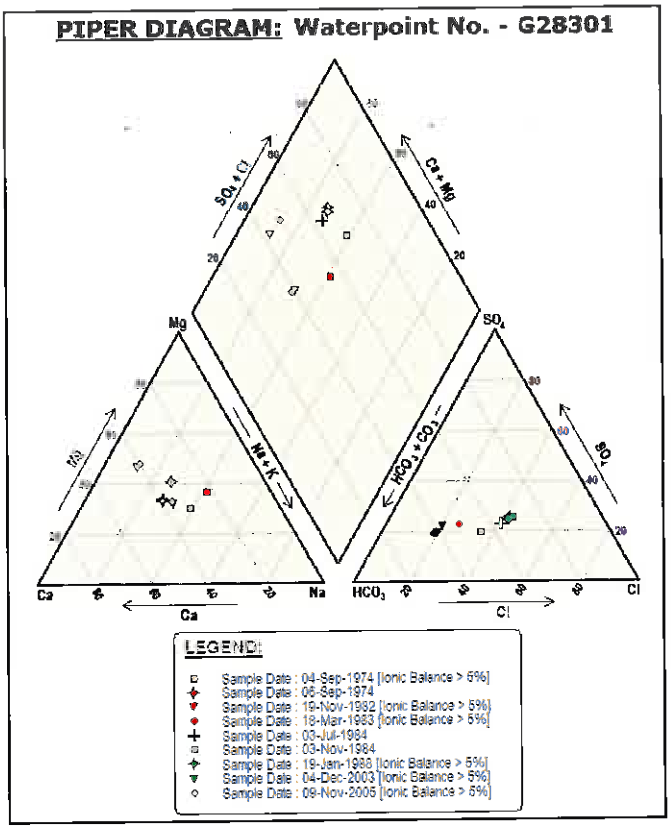

PIPER DIAGRAM: Waterpoint No. - G38468
LEGEND:
Sample Date : 27-Jul-1988 [Ionic Balance > 5%]
Sample Date : 07-Mar-1989
Sample Date : 09-Mar-1989

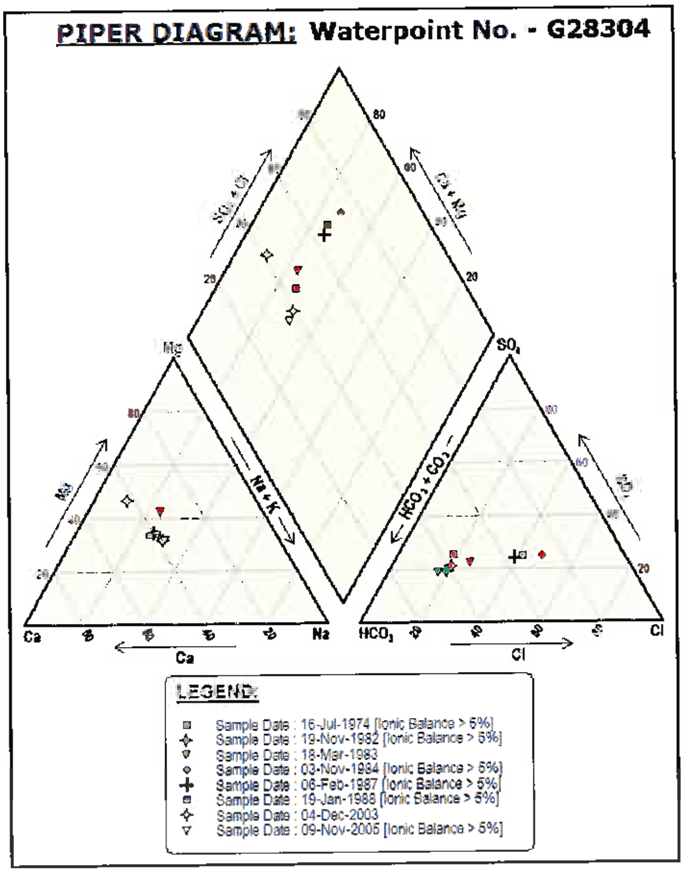

PIPER DIAGRAM: Waterpoint No. - G38473
LEGEND:
Sample Date : 26-Jul-1988 [Ionic Balance > 5%]
Sample Date : 27-Jul-1988
Sample Date : 27-Jul-1988
Sample Date : 28-Feb-1989 [Ionic Balance > 5%]
Sample Date : 04-Mar-1989 [Ionic Balance > 5%]
Sample Date : 07-Mar-1989 [Ionic Balance > 5%]
Sample Date : 09-Mar-1989
Sample Date : 04-Dec-2003
Sample Date : 09-Nov-2005 [Ionic Balance > 5%]

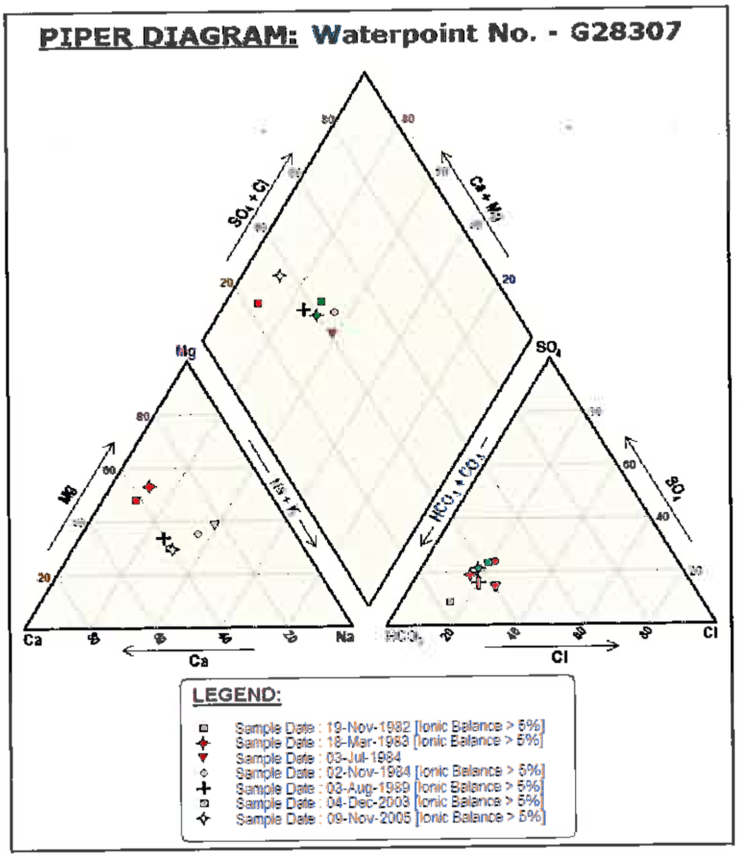


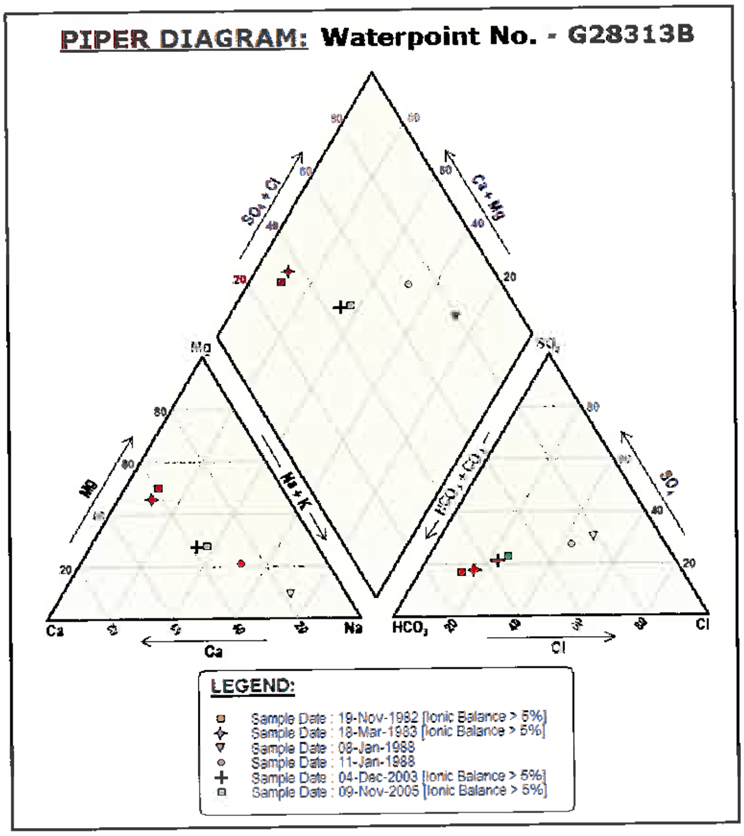

## Rietfontein GMU

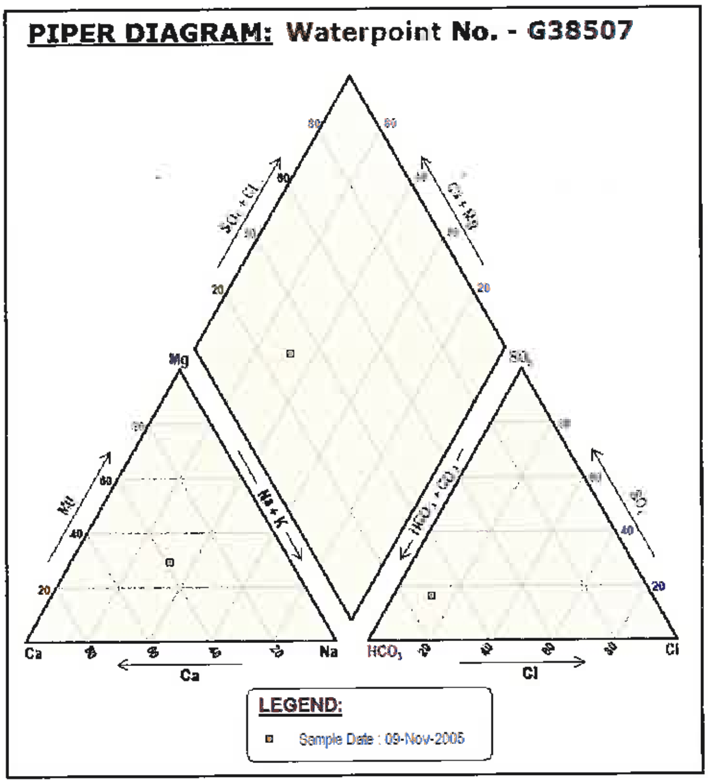



PIPER DIAGRAM: Waterpoint No. - G28301
Mg
Ca
Na
SO4
HCO3
Cl
Ca + Mg
SO4 + Cl
Na + K
HCO3 + CO3
LEGEND:
Sample Date : 04-Sep-1974 [Ionic Balance > 5%]
Sample Date : 06-Sep-1974
Sample Date : 19-Nov-1982 [Ionic Balance > 5%]
Sample Date : 18-Mar-1983 [Ionic Balance > 5%]
Sample Date : 03-Jul-1984
Sample Date : 03-Nov-1984
Sample Date : 19-Jan-1988 [Ionic Balance > 5%]
Sample Date : 04-Dec-2003 [Ionic Balance > 5%]
Sample Date : 09-Nov-2005 [Ionic Balance > 5%]

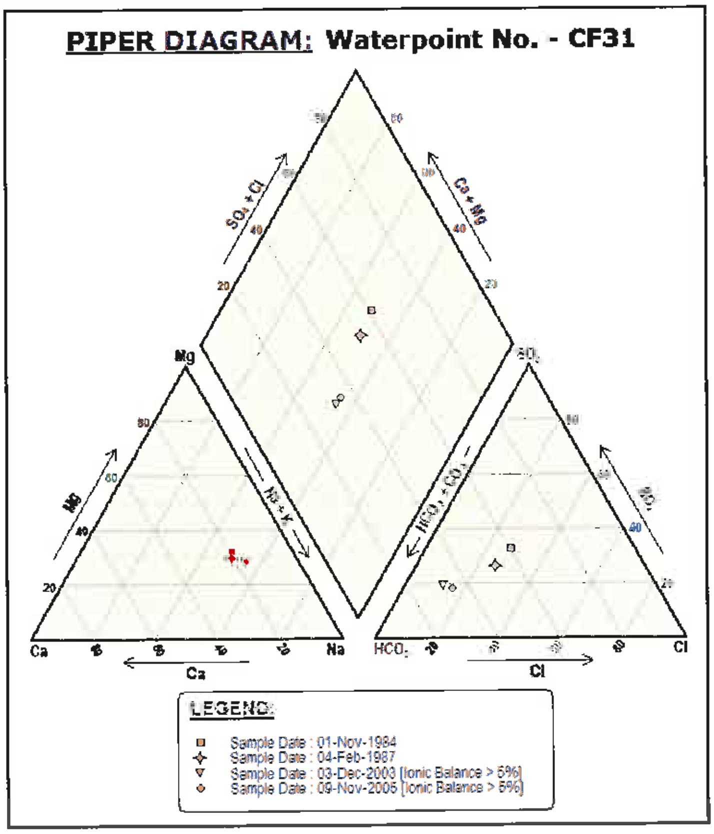

PIPER DIAGRAM: Waterpoint No. - G28304
Mg
Ca
Na
SO4
HCO3
Cl
Na + K
HCO3 + CO3
LEGEND:
Sample Date : 16-Jul-1974 [Ionic Balance > 5%]
Sample Date : 19-Nov-1982 [Ionic Balance > 5%]
Sample Date : 18-Mar-1983
Sample Date : 03-Nov-1984 [Ionic Balance > 5%]
Sample Date : 06-Feb-1987 [Ionic Balance > 5%]
Sample Date : 19-Jan-1988 [Ionic Balance > 5%]
Sample Date : 04-Dec-2003
Sample Date : 09-Nov-2005 [Ionic Balance > 5%]

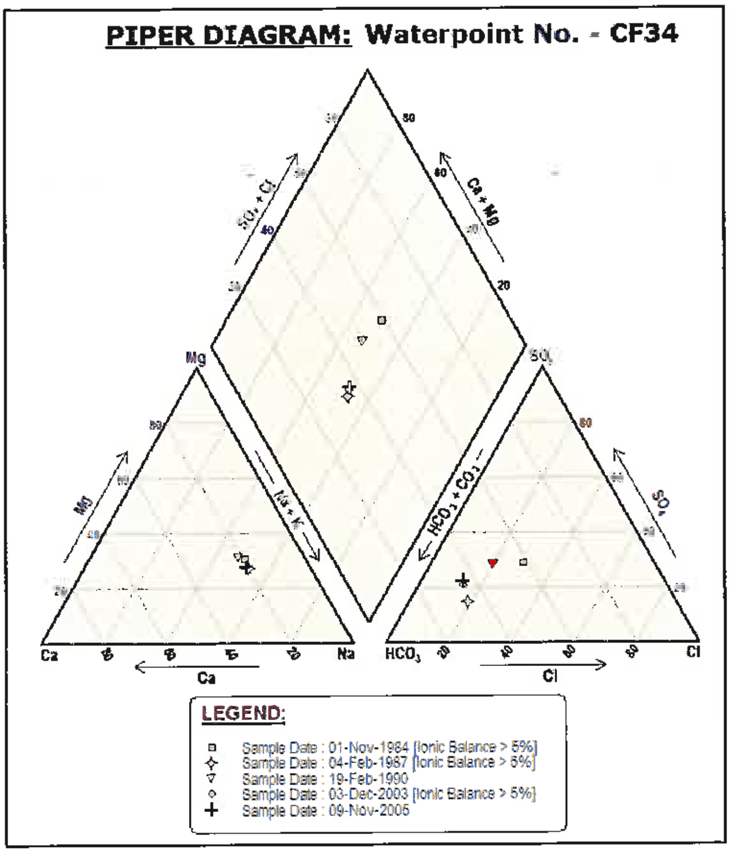

PIPER DIAGRAM: Waterpoint No. - G28307
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 19-Nov-1982 [Ionic Balance > 5%]
Sample Date : 18-Mar-1983 [Ionic Balance > 5%]
Sample Date : 03-Jul-1984
Sample Date : 02-Nov-1984 [Ionic Balance > 5%]
Sample Date : 03-Aug-1989 [Ionic Balance > 5%]
Sample Date : 04-Dec-2003 [Ionic Balance > 5%]
Sample Date : 09-Nov-2005 [Ionic Balance > 5%]

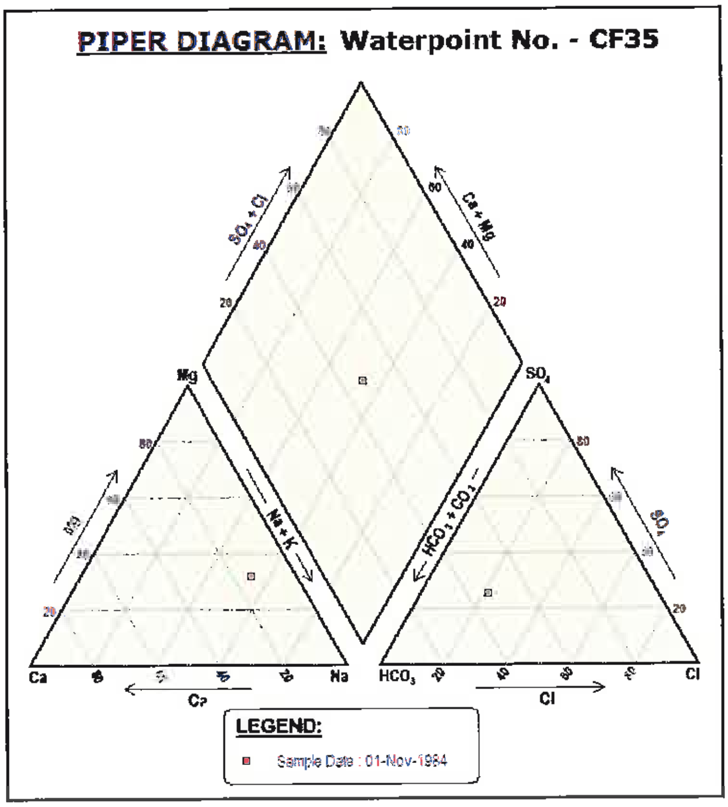

PIPER DIAGRAM: Waterpoint No. - G28313B
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 19-Nov-1982 [Ionic Balance > 5%]
Sample Date : 18-Mar-1983 [Ionic Balance > 5%]
Sample Date : 08-Jan-1988
Sample Date : 11-Jan-1988
Sample Date : 04-Dec-2003 [Ionic Balance > 5%]
Sample Date : 09-Nov-2005 [Ionic Balance > 5%]

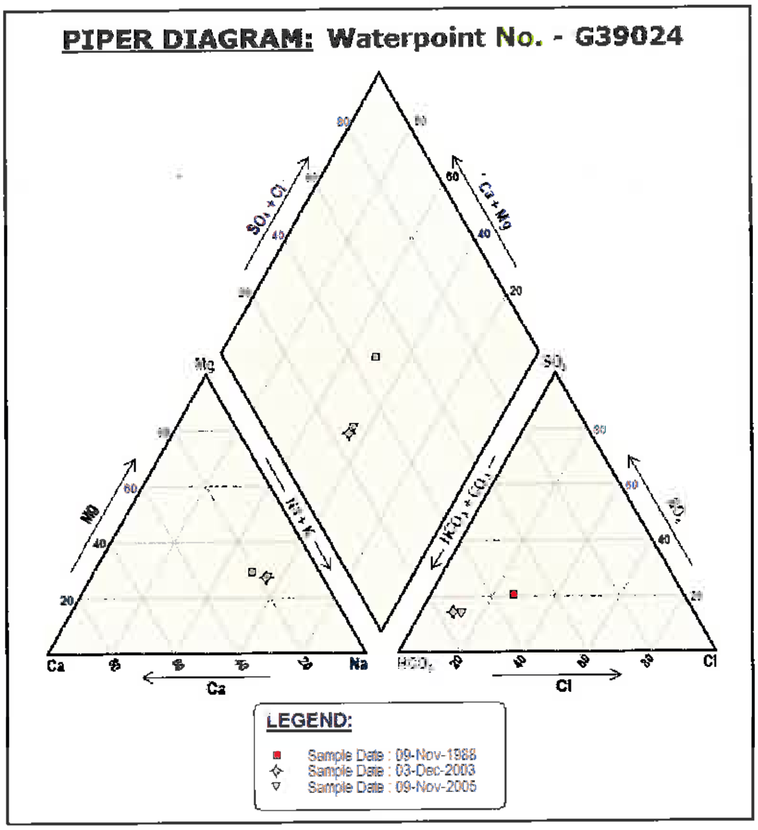


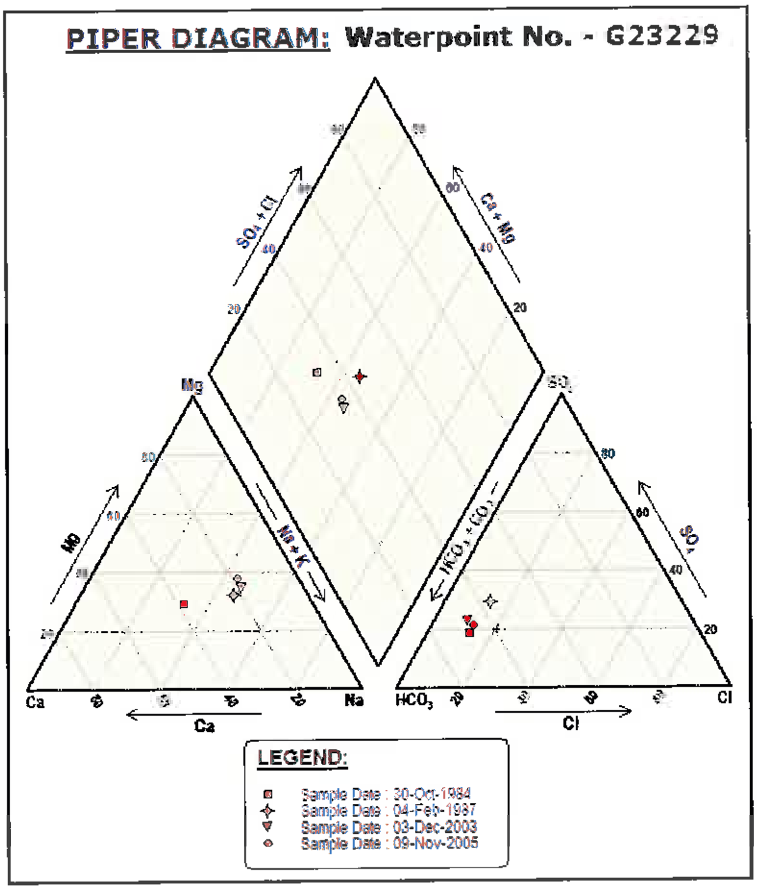

## Cyfferkuil GMU

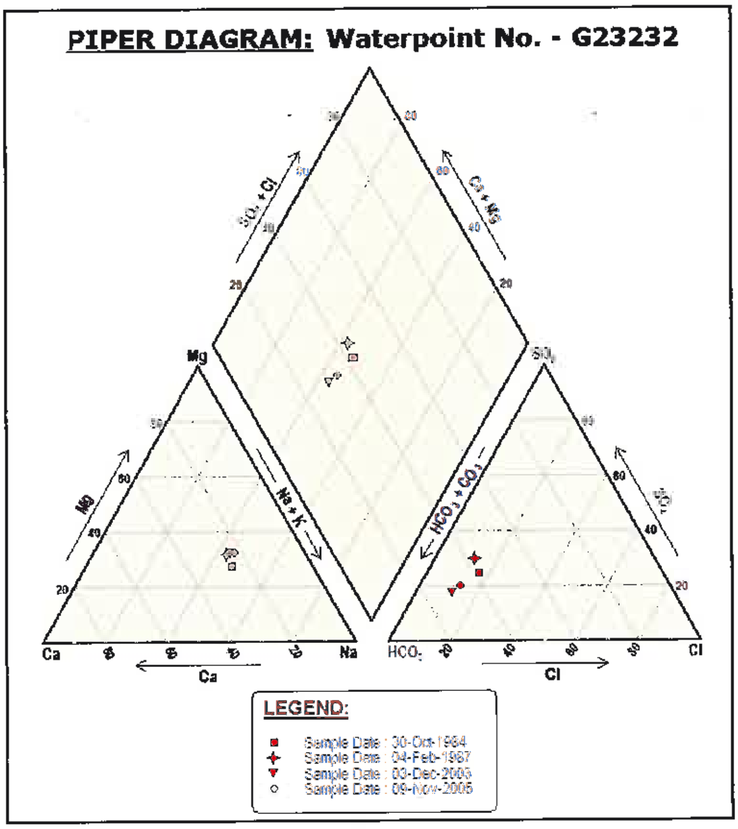


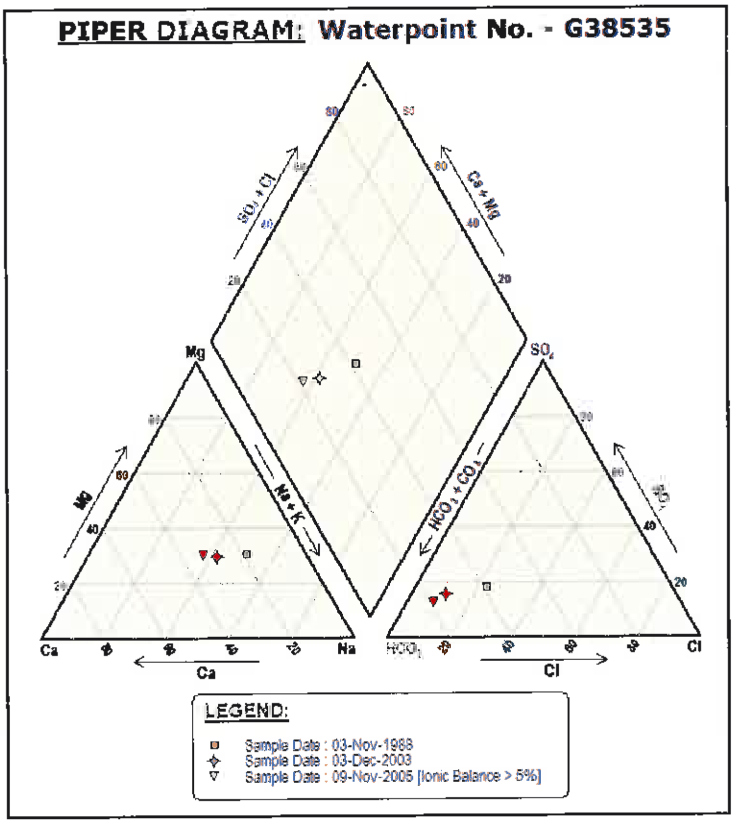

PIPER DIAGRAM: Waterpoint No. - CF34
Mg
SO4
Ca
Na
HCO3
Cl
Ca+Mg
SO4+Cl
Na+K
HCO3+CO3
LEGEND:
Sample Date : 01-Nov-1984 [Ionic Balance > 5%]
Sample Date : 04-Feb-1987 [Ionic Balance > 5%]
Sample Date : 19-Feb-1990
Sample Date : 03-Dec-2003 [Ionic Balance > 5%]
Sample Date : 09-Nov-2005


PIPER DIAGRAM: Waterpoint No. - CF35
Mg
SO4
Ca
Na
HCO3
Cl
Ca+Mg
SO4+Cl
Na+K
HCO3+CO3
LEGEND:
Sample Date : 01-Nov-1984

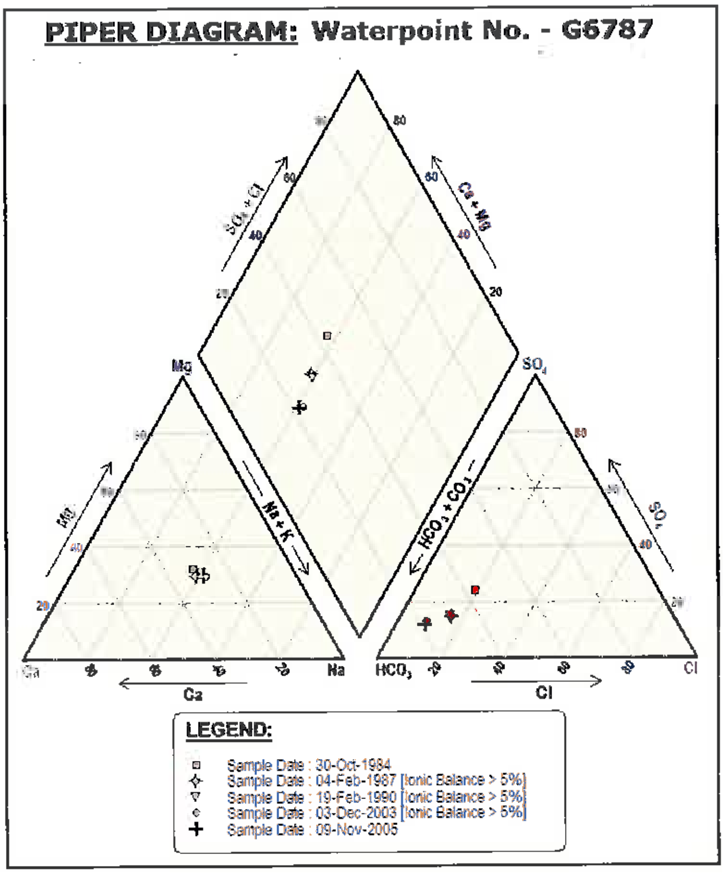

PIPER DIAGRAM: Waterpoint No. - G39024
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 09-Nov-1988
Sample Date : 03-Dec-2003
Sample Date : 09-Nov-2005

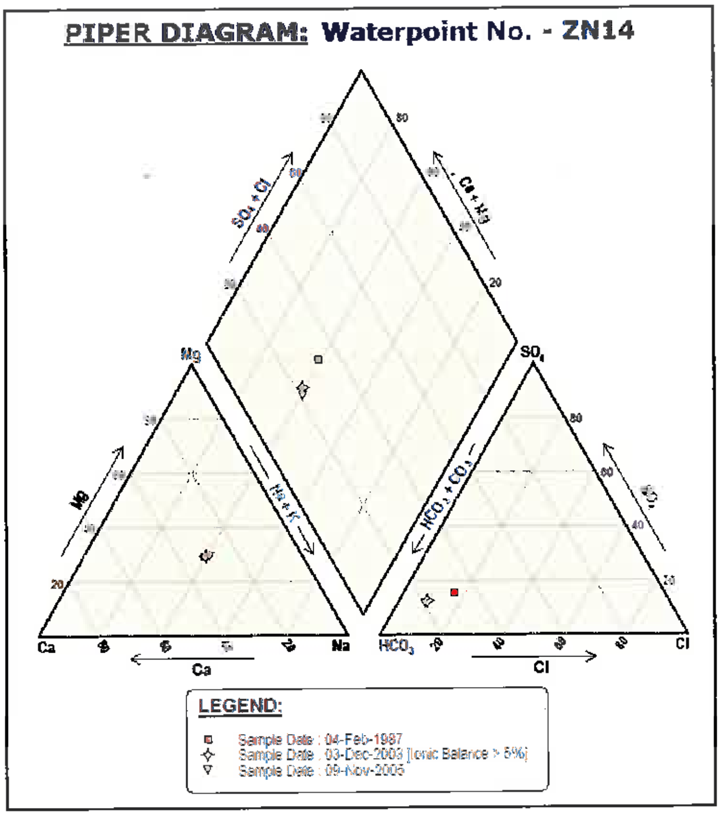

PIPER DIAGRAM: Waterpoint No. - G23229
SO4 + Cl
Ca + Mg
Mg
SO4
Na + K
HCO3 + CO3
Ca
Na
HCO3
Cl
LEGEND:
Sample Date : 30-Oct-1984
Sample Date : 04-Feb-1987
Sample Date : 03-Dec-2003
Sample Date : 09-Nov-2005

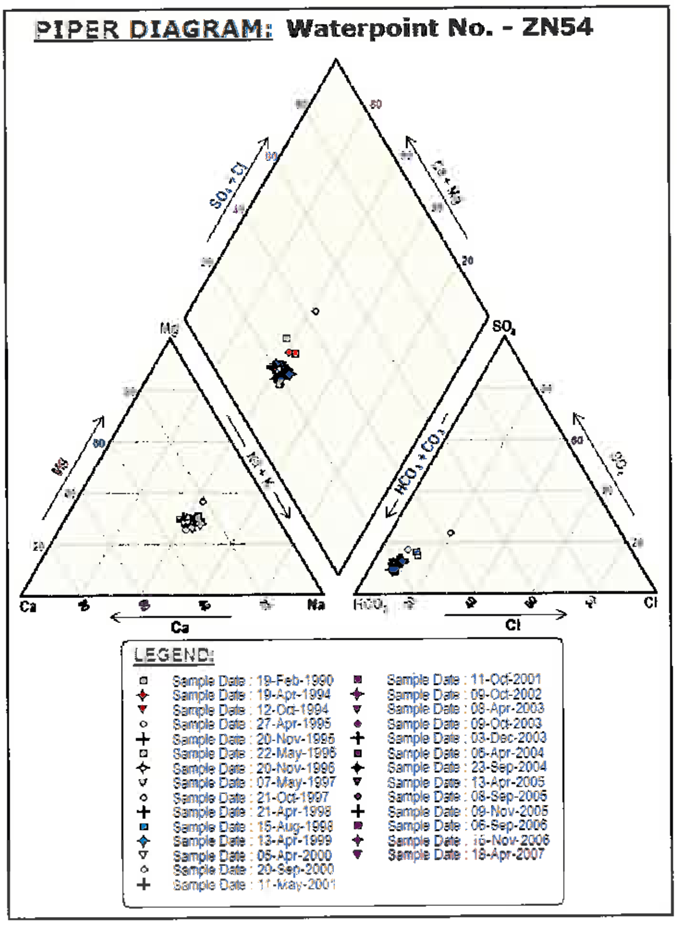

PIPER DIAGRAM: Waterpoint No. - G23232
$SO_4$ + Cl
Ca + Mg
Mg
$SO_4$
Na + K
$HCO_3$ + $CO_3$
Mg
Ca
Na
Ca
$HCO_3$
Cl
Cl
LEGEND:
Sample Date : 30-Oct-1984
Sample Date : 04-Feb-1987
Sample Date : 03-Dec-2003
Sample Date : 09-Nov-2005

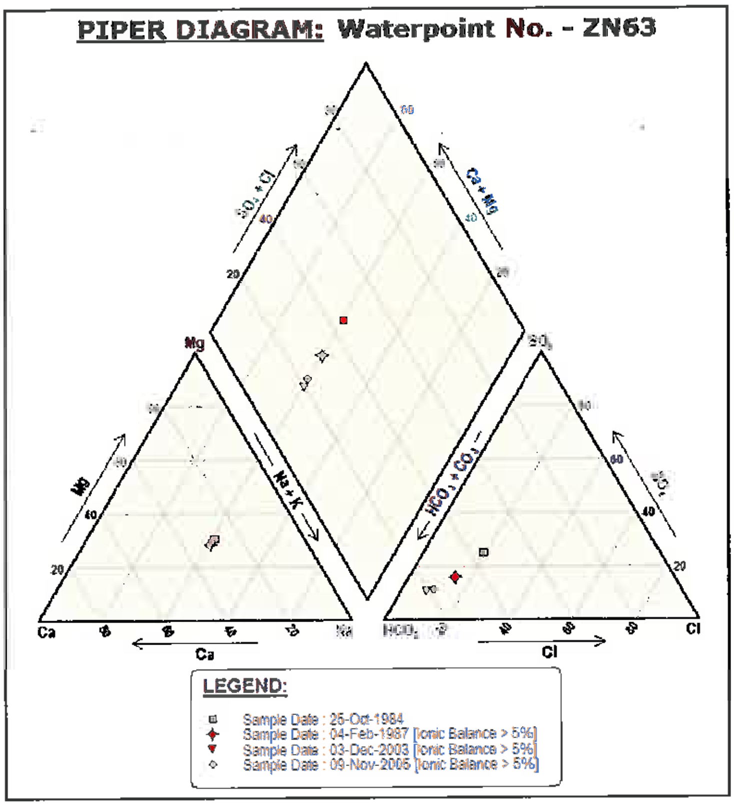

PIPER DIAGRAM: Waterpoint No. - G38535
$SO_4$ + Cl
Ca + Mg
Mg
$SO_4$
Na + K
$HCO_3$ + $CO_3$
Mg
Ca
Na
Ca
$HCO_3$
Cl
Cl
LEGEND:
Sample Date : 03-Nov-1988
Sample Date : 03-Dec-2003
Sample Date : 09-Nov-2005 [Ionic Balance > 5%]

## Zewefontein GMU

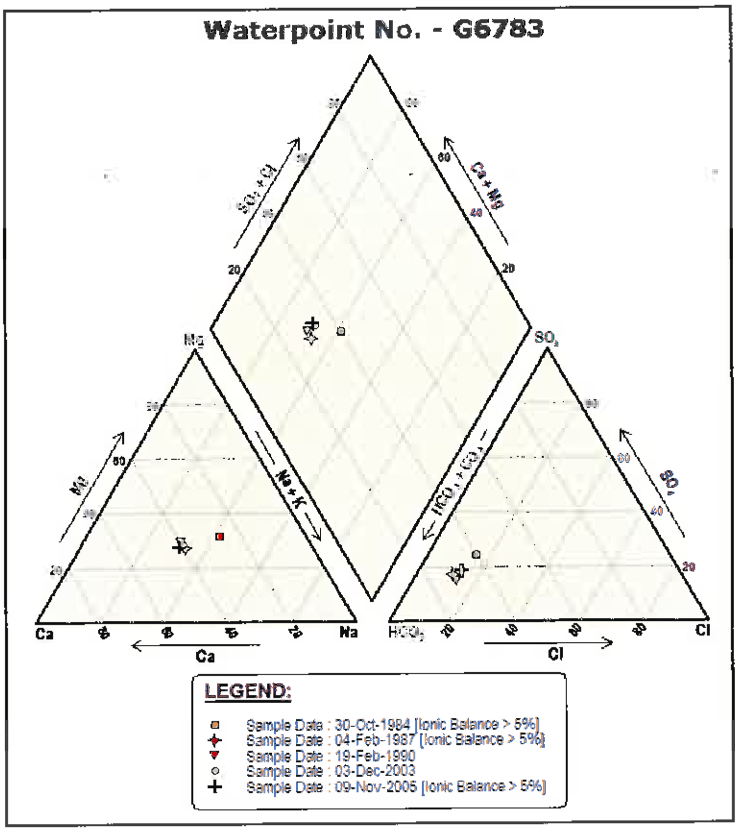


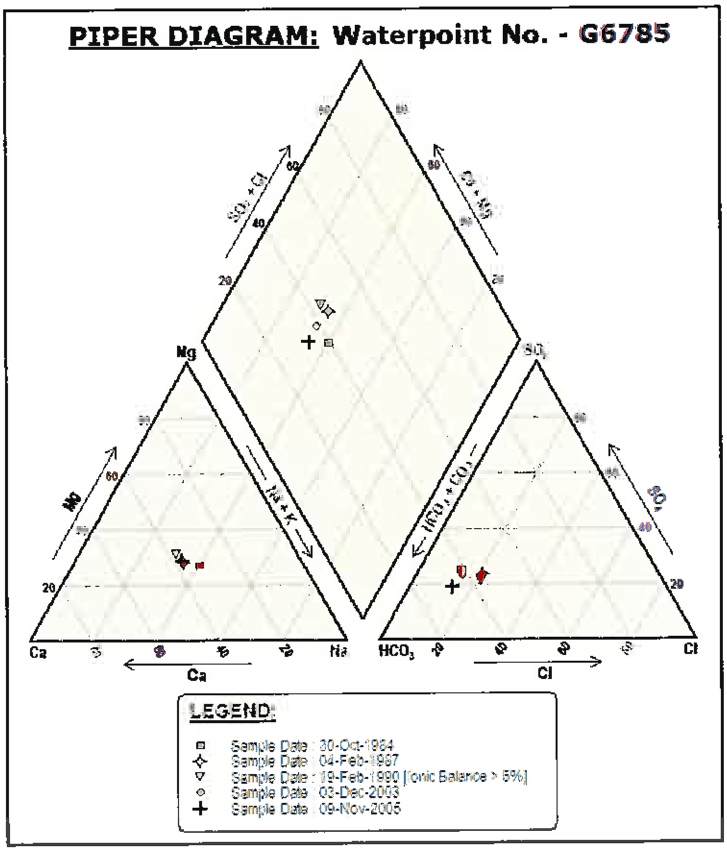

PIPER DIAGRAM: Waterpoint No. - ZN14
$SO_4$ + Cl
Ca + Mg
Mg
$SO_4$
Na + K
$HCO_3$ + $CO_3$
Ca
Na
$HCO_3$
Cl
LEGEND:
Sample Date : 04-Feb-1987
Sample Date : 03-Dec-2003 [Ionic Balance > 5%]
Sample Date : 09-Nov-2005

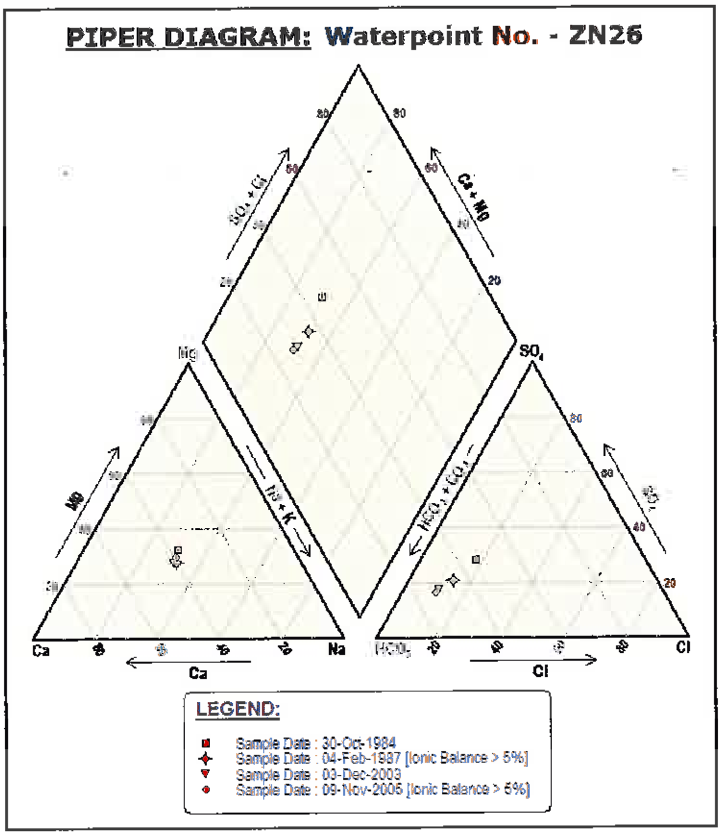

PIPER DIAGRAM: Waterpoint No. - ZN54
$SO_4$ + Cl
Ca + Mg
Mg
$SO_4$
Na + K
$HCO_3$ + $CO_3$
Ca
Na
$HCO_3$
Cl
LEGEND:
Sample Date : 19-Feb-1990
Sample Date : 19-Apr-1994
Sample Date : 12-Oct-1994
Sample Date : 27-Apr-1995
Sample Date : 20-Nov-1995
Sample Date : 22-May-1996
Sample Date : 20-Nov-1996
Sample Date : 07-May-1997
Sample Date : 21-Oct-1997
Sample Date : 21-Apr-1998
Sample Date : 15-Aug-1998
Sample Date : 13-Apr-1999
Sample Date : 05-Apr-2000
Sample Date : 20-Sep-2000
Sample Date : 11-May-2001
Sample Date : 11-Oct-2001
Sample Date : 09-Oct-2002
Sample Date : 08-Apr-2003
Sample Date : 09-Oct-2003
Sample Date : 03-Dec-2003
Sample Date : 06-Apr-2004
Sample Date : 23-Sep-2004
Sample Date : 13-Apr-2005
Sample Date : 08-Sep-2005
Sample Date : 09-Nov-2005
Sample Date : 06-Sep-2006
Sample Date : 16-Nov-2006
Sample Date : 18-Apr-2007

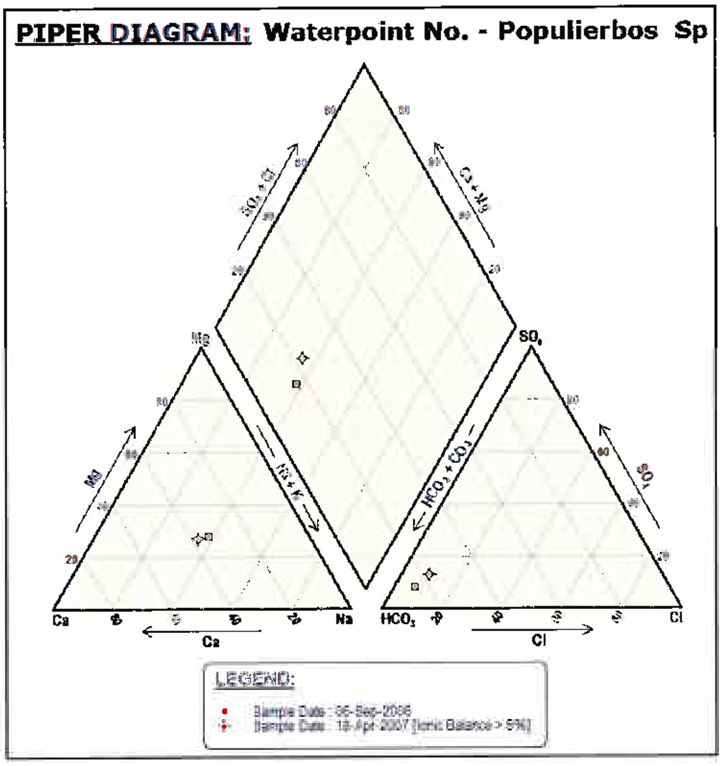



## Burgerville GMU


Waterpoint No. - G6783
Mg
SO4
Ca
Na
HCO3
Cl
Ca
Cl
SO4 + Cl
Ca + Mg
Na + K
HCO3 + CO3
LEGEND:
Sample Date : 30-Oct-1984 [Ionic Balance > 5%]
Sample Date : 04-Feb-1987 [Ionic Balance > 5%]
Sample Date : 19-Feb-1990
Sample Date : 03-Dec-2003
Sample Date : 09-Nov-2005 [Ionic Balance > 5%]


PIPER DIAGRAM: Waterpoint No. - G6785
Mg
SO4
Ca
Na
HCO3
Cl
Ca
Cl
SO4 + Cl
Ca + Mg
Na + K
HCO3 + CO3
LEGEND:
Sample Date : 30-Oct-1984
Sample Date : 04-Feb-1987
Sample Date : 19-Feb-1990 [Ionic Balance > 5%]
Sample Date : 03-Dec-2003
Sample Date : 09-Nov-2005


PIPER DIAGRAM: Waterpoint No. - ZN26
SO4 + Cl
Ca + Mg
Mg
SO4
Mg
Na + K
HCO3 + CO3
SO4
Ca
Na
HCO3
Cl
Ca
Cl
LEGEND:
Sample Date : 30-Oct-1984
Sample Date : 04-Feb-1987 [Ionic Balance > 5%]
Sample Date : 03-Dec-2003
Sample Date : 09-Nov-2006 [Ionic Balance > 5%]


PIPER DIAGRAM: Waterpoint No. - Populierbos Sp
SO4 + Cl
Ca + Mg
Mg
SO4
Mg
Na + K
HCO3 + CO3
SO4
Ca
Na
HCO3
Cl
Ca
Cl
LEGEND:
Sample Date : 06-Sep-2006
Sample Date : 18-Apr-2007 [Ionic Balance > 5%]

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