AN EXPLANATION OF THE 1:250 000 HYDROGEOLOGICAL MAP SERIES, MAP SHEET 2428 MODIMOLLE

By

W.H. Du Toit & C.J. Sonnekus

June 2025

FOREWORD

Groundwater in South Africa is under-utilised, although some local over-exploitation does occur. Groundwater schemes can be implemented quickly and cheaply and are effective in conjunctive use and dispersed scenarios. With increasing pressure on scarce surface water resources, and with the priority of supplying potable water to disadvantaged rural and urban communities, groundwater will play an increasing important role in South Africa's economic and social prosperity.

A major obstacle to the realisation of this prosperity is that insufficient information about groundwater is reaching the planners, decision makers, users, and other affected parties. To rectify this situation, groundwater information locked away in expert's minds and computer databases, is being made available on maps. The second step in this program at the regional level is, the upgrading of the original "General Hydrogeological Maps" at the scale of 1: 500 000 to 4 x 1:250 000 scale hydrogeological maps i.e. Modimolle, Polokwane, Lephalale, and Thabazimbi.

The main purpose of these Hydrogeological Maps, of which the accompanying map sheet is an example, is to display, in an easily understood format, what is known about basic hydrogeological properties. These General Maps represent the synthesis of the most up-to-date data and geohydrologists' knowledge. Thus, these maps are also very useful in identifying areas where additional data should be collected and further investigations need to be conducted.

Groundwater maps – the best available information for the best possible planning, development, and management of a strategic resource – will ultimately benefit all South Africans.

BY MASWUMA ZACHARIA
DIRECTOR: NATIONAL HYDROLOGICAL SERVICES (2025)
DEPARTMENT OF WATER AND SANITATION
PRETORIA

Cover page: The Kranskop Inselberg made up of reddish weathering sandstone and subordinate conglomerates of the Schilpadkop Formation, is a well-known landmark along the N1 just past the Kranskop Toll Plaza (Photograph: WH du Toit).

PREFACE

Except for air, water can, with little doubt, be defined as Man's most precious resource. It is said that to deny Man food, his body can sustain life for weeks but refuse him water and death is likely to come within a few days. The availability of water to even the remotest area is vital to maintain this indispensable condition for human existence.

An estimated 3% of fresh water available on Earth occurs on the surface while 97% occurs underground (Johnson Division, 1975). Owing to the lack of perennial streams in the arid to semi-arid areas, two- thirds of South Africa's surface area is largely dependent on groundwater. To tap and develop this vast amount of underground stored water, a keen knowledge of a region's environment, and above all, its diversified geology, is of the utmost importance to comprehend how and where groundwater occurs.

The Modimolle Hydrogeological Map and the accompanying explanatory brochure introduce the current state of the groundwater knowledge and the basic geohydrological characteristics of the map area. It needs to be explained that within the map's confines, dissimilar and divergent conditions occur, which, to various degrees, may impact on groundwater. Under these circumstances, groundwater occurrence can be varied. Groundwater occurrence is therefore referred to in this brochure.

The primary aim of the General Hydrogeological Map is to produce a synoptic overview of the geohydrological character of an area. The main map therefore features borehole yield, aquifer type, groundwater quality, and groundwater use, which are superimposed against a slightly subdued surface lithological background. The brochure discusses these topics in more detail, as well as issues such as geological controls on groundwater yield and quality, borehole siting methods, groundwater management, groundwater levels, suggestions for future studies, etc. It is hoped that both the groundwater scientist and the interested layman will find the product useful. The map and brochure will hopefully also be informative to planners and developers, especially in the light of the Reconstruction and Development Programme, and it will play a constructive role in general groundwater education, groundwater awareness building and groundwater protection.

Groundwater has always been an important source of water supply to many people and localities in the map area. Water consumers, in many areas, are solely reliant on groundwater for domestic and stock watering purposes. There is a change in focus to utilise groundwater for irrigational purposes due to the high yields intercepted in the underlying aquifers. It is hoped that this map and brochure will serve as a basis for future specialised groundwater maps and groundwater studies as suggested in the brochure.

BACKGROUND TO THE PROJECT

The Southern African Development Community (SADC) is a regional grouping of 16 sovereign countries, comprising Angola, Botswana, Comoros, Eswatini, Democratic Republic of Congo (DRC), Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia, and Zimbabwe. As articulated in the amended Treaty of 1992, SADC's main objective is to foster co-operation and mutual benefit by all Member Countries from the resources in the region, (Revised Sub-Grand Manual 2022).

To counter meteorological changes experienced in the region that influence water supply, the SADC- GMI (Southern African Development Community Groundwater Management Institute) was established as a Centre of Excellence in groundwater. The mandate is to build capacity in the region through targeted training and funding of groundwater related projects. To fulfil this mandate, the SADC-GMI started awarding sub-grants to Member Countries in 2017 for the implementation of groundwater related pilot projects using a grant from the World Bank through the SADC Secretariat.

After the successful completion of one of these projects, (The Sustainable Groundwater Management in SADC Member Countries, Phase 1 project), the SADC-GMI implemented phase 2 of the same project under the strategic guidance of the SADC Secretariat. Phase 2 entails the updating of the Polokwane 2326 hydrogeological map sheet and brochure. VSA Rebotile Metsi Consulting was appointed 15 January 2024 as consultant for the project on a lump-sum contract format. The Prime Partner for SADC-GMI on this project is the Department of Water and Sanitation (DWS), Republic South Africa (RSA). The function of DWS is to monitor, assist, guide, and to assess progress, deliverables, and invoices on behalf of SADC-GMI. This is done through engagement on monthly DWS internal progress meetings as well as monthly SADC-GMI Sub-Grant Project Management Progress Meetings.

ACKNOWLEDGEMENTS

W.H. du Toit, VSA Rebotile Metsi Consulting (Mapping team)
C.J. Sonnekus, VSA Rebotile Metsi Consulting (Mapping team)
Dr ZA. Botes, VSA Rebotile Metsi Consulting (Mapping team)
A.J.I. du Toit, VSA Rebotile Metsi Consulting (GIS team)
B. Saunders, VSA Rebotile Metsi Consulting Graphic (Designer)
A.M. Cronje, VSA Rebotile Metsi Consulting, Admin, (Data capture team)

Project Management team

L.Z. Maswuma, DWS (Director: National Hydrological Services, (NHS)
Dr L. Lalumbe, DWS (Scientist Manager: Directorate: NHS, Geohydrological Information Services, project Manager)
F. Ramusiya, DWS (Scientist Manager: Directorate: NHS, Geohydrological Monitoring and Assessment)
O.V. de Beer, DWS (Scientist Production: Directorate: NHS, Geohydrological Information Services)
T. Chetty, DWS (Scientist Production: Directorate: Spatial Information (SI), Geographic Information & Archiving)

SADC-GMI

J. Sauramba (Executive Director)
T. Dlamini (Communication and documentation)
B. Gwangwawa (ESS Compliance oversight)
S. Luvela (Logistical Coordinator)
K. Mulenga (Infrastructure Consultant)
M. Ntsekhe (Subgrant Compliance oversight)
T. Poo (Finance)

DWS: National Office

Q. Boshomane
F. Fourie
D. Jacobs
A. Kuiper
L. Mathume
K. Majola
S. Mndaweni
Dr P. Mokoena-Fuku
M.C. Pule
H.M. Visagie

DATA AND REPORTS

DWS (Pretoria) National groundwater and water quality databases
DWS (Pretoria) Geohydrological Reports
Council for Geoscience (Pretoria) Geological information
Municipalities for the map area
VSA Rebotile Metsi Consulting

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ABBREVIATIONS AND ACRONYMS

Abbreviation	Description
CMAs	Catchment Management Agencies (plural) single is CMA
CWS	Catchment Water Strategy
DWS	Department of Water and Sanitation
DWA	Department of Water Affairs
DWAF	Department of Water Affairs & Forestry
e.g.	Stands for the Latin phrase exempli gratia, meaning “for example.”
ELU	Existing Lawful Water Use
Et al.	An abbreviation for the Latin phrase et alia, which means "and others".
GIS	Geographic Information System
GMI	Groundwater Management Institute
GRIP	Groundwater Resource Information Project (DWS project early 2000)
GRU	Groundwater Resource Units
GW	Groundwater
GRDM	Groundwater Resource Directed Measures
i.e.	Stands for id est. which is Latin for “that is.”
IGS	Institute for Groundwater Studies
LGS	Lebowa Granite Suite
LSI	Langelier Saturation Index
MC	Management Class
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
mbgl	Meters Below Ground Level
magl	Meters Above Ground Level
mamsl	Meter Above Mean Sea Level
MCWAP	Mokolo Crocodile Water Augmentation Project
ND	Not detected (used in chemistry analysis)
NGA	National Groundwater Archive
NGDB	National Groundwater Database
NHS	National Hydrological Services
NWRS	National Water Resource Strategy
NWA	National Water Act of 1998
NWS	National Water Strategy
PSZ	Palala Shear Zone
RDM	Resource Directed Measures
RGS	Rashoop Granophyre Suite
RLS	Rustenburg Layered Suite
RQOs	Resource Quality Objectives
SADC	South African Development Community
SADC-GMI	South African Development Community Groundwater Management Institute
SANS	South African National Standards
SAR	Sodium Absorption Rate
SDC	Source Directed Controls
SWD	Surface Water Dam
SW	Surface Water
TDS	Total Dissolved Solids
TOR	Terms of Reference
TWQR	Target Water Quality Range
UNESCO	United Nations Educational, Scientific and Cultural Organisation

Abbreviation	Description
Viz.	Stands for videlicet which is Latin for “namely’’, ‘’which is’’ or ‘’as follows’’
WARMS	The Water use Authorization & Registration Management System
WMA	Water Management Area
WMS	Water Management System
WRC	Water Research Commission
WRCS	Water Resource Classification System
WUAs	Water User Associations (plural), single WUA
WULA	Water Use License Application
e-WULAAS	Electronic Water Use License Application and Authorisation System

SYMBOLS AND UNITS

Symbol or unit	Description
a	Annum
Ha	Hectare
HARMEAN	Harmonic mean
km	Kilometer
km^2	Square kilometer
ℓ/s	Liters per second
m	Meter
M	Million
Mm^3	Million cubic meters
meq	Milli-equivalents
mm	Millimeter
mm^2	Square millimeter
mm/a	Millimeters per Annum
m^3	Cubic meter
m^3	Cubic meter
m^3/annum	Cubic meters per annum
m^3/d	Cubic meters per day
mg/ℓ	Milligram per Liter
mS/m	milliSiemens per meter
pH	Logarithm of the hydrogen ion concentration in moles per liter
s	Seconds

1. INTRODUCTION

1.1 General:

The **Modimolle Hydrogeological Map, sheet 2428,** scale 1:250 000, is a reconnaissance map and it is part of an upgrade of the first general synthesis of groundwater resources within this area i.e. the 1:500 000 Polokwane Hydrogeological Map. The latter comprises 4 x 1:250 000 geological maps namely Nylstroom (Modimolle), Pietersburg (Polokwane), Thabazimbi, and Ellisras (Lephalale).

The **objective** of the map and accompanying explanation brochure is to provide the public, the professional community, and planners with a general reference for planning, development, and management of groundwater. It is also to serve as an education tool to promote groundwater as an interesting and scientific subject.

Deliverables: 1:250 000 Hydrogeological map and explanation brochure; Methodology to create these maps and brochures.

Groundwater occurrences are very heterogeneous in South Africa while the mapping standards, legend, etc. demand a high degree of conformity. Not all the important aspects of groundwater could be depicted on the map as conditions can vary dramatically from region to region. The explanatory brochure addresses some of the issues while the map portrays general hydrogeological conditions. The 1:250 000 scale might be regarded by some as relatively small. The map and brochure can thus not replace detailed site investigations needed, when for example, boreholes must be sited or when site specific conditions must be determined. It can, however, to some extent, assist in identifying potential target areas for follow-up detailed ground investigations. Despite this, **site-specific detailed investigations** will always be recommended to determine local conditions. The map and accompanying explanation brochure will however provide general information and guidelines as to which detailed investigations are required and what expected hydrogeological conditions are likely to occur.

The **main features** shown on the map are borehole median yield, aquifer type, groundwater quality, groundwater use and lithology. This brochure provides supplementary information for these topics and discusses other aspects of groundwater on an elementary level. Additional topics include recharge, storage, movement, the location of groundwater using geophysical methods, subterranean water control areas (this function is now part of the function of the Catchment Management Agencies, (CMA). management, pollution, utilization, and suggestions for future groundwater related projects or groundwater exploration.

A new **National Water Act (Act 36 of 1998)** was proclaimed in October 1998, (See section 9.1, page 203). A brief discussion is included under management with the focus on the implication for water users and their obligations. The National Water Act is important as it provides a framework to protect water resources against over exploitation; to ensure water for social and economic development; and to ensure the availability of water for future generations.

Sustainability, equity, and efficiency are the **principles** of the National Water Act that provide the framework to guide the protection, use, development, conservation, management, and control of water resources.

2. MAP COMPILATION

2.1 Data sources:

Data sources for the compilation of the map include:

- The National Groundwater Archive (NGA) under the custody of the Department of Water Affairs (DWA), now the Department of Water and Sanitation (DWS),
- Water Management System (WMS), Department of Water and Sanitation (DWS),
- Borehole data and pumping tests executed during GRIP Project,
- Available Geohydrological reports from DWS,
- Consultant reports compiled for WULAs allocations,
- Existing information from various consultancies stationed in the Limpopo Province,
- Groundwater database of the consultancy,
- Reports and information from some of the municipalities.

Table 1: Number of borehole records extracted and evaluated from the NGA and WMS.

RECORDS EVALUATED					
NGA and GRIP		WMS and GRIP			
Total Number of Borehole Yields	Total Number of Water Levels	Number of points after removal of duplicates	Number of time series data	Number of analyses used for evaluation-(tables)	Number of analyses used for Piper and Durov
9471 and 6221 with zero yields	3396	8476	3896	3963 out of a total of 4580	2390

2.2 Main map: Modimolle hydrogeological map scale 1: 250 000

The map sheet covers an area of approximately 22 333km². As one of four hydrogeological maps sheets, it represents a 31% portion of the upgrade of the first general synthesis of the groundwater resources of the area i.e. the 1:500 000 Polokwane Hydrogeological map that covered a total area of approximately 71 130km² (Botswana excluded).

The 1: 500 000 Polokwane map sheet is bordered by latitudes 23º and 25º south and longitudes 26º and 30º east whereas the Modimolle Hydrogeological map is bordered by latitudes 24º and 25º and longitudes 26º and 30º.

The methodology followed for the 1: 500 000 Polokwane Hydrogeological map series for the delineation of the aquifer units was to use the lithostratigraphy as depicted on the relevant 1: 250 000 geological map sheets namely, Ellisras 2326, Pietersburg 2328, Thabazimbi 2426 and Nylstroom 2428. Lithostratigraphy was used to sub-divide the map sheet area into hydrogeologically relevant lithological units (referenced as aquifer units), which possess some degree of lithological homogeneity and similarities in rock properties. However, lithological homogeneity and similarities in rock properties were not the only consideration. Where geological formations were large enough, they were regarded as separate units, despite lithological homogeneity and similarities in rock properties with adjacent formations or lithologies.

For the Modimolle 1: 250 000 Hydrogeological map sheet, a similar approach was followed, but due to the smaller scale and a larger number of available data points with information, it was possible to use the geological units as aquifer units even if these exhibited similar hydrogeological characteristics.

The Aquifer Units are displayed as grey ornament on the map. A symbol/code in black representing the approximate age of the Formation, (first letter of the Erathem for example: 'M' for Mokolian or 'V' for Vaalian). Erathem was used up to the end of Namibian where after System was used. Hereafter the code/symbol is completed by the adding of two and/or three letters (author's choice) and displayed in black. The choice of the code/symbol to be used was also influenced by codes/symbols allocated to adjacent map sheets as these maps will form a unit.

It was found that the adjacent geological maps do not always match/line up, in terms of polygons, colour, or codes/symbols. This is due to the mapping being executed by many different authors and at different completion dates. This is especially true for the Thabazimbi (1973) and Ellisras (1996) geological map sheets. With the geohydrological map sheets however, the methodology followed was as such to avoid incompatible codes/symbols and polygons thus enabling a smooth fit when these maps are joined. These lithological units were then grouped together based on the expected groundwater occurrence namely, **Intergranular (a), Fractured (b), Karst (c), and Intergranular and Fractured (d).**

The borehole yield data available on the National Groundwater Archive represents data from different populations which are non-uniformly distributed in space and which are heavily skewed in a positive direction. Because of this, the median yield was recommended as a suitable measure of centrality rather than the average. The median was also found to be a reasonable discriminator between hydrogeological regions and was easy to compute and interpret as a "typical" yield of a region. To provide sufficient resolution of the data to permit visual portrayal in a distinguishable manner, the borehole yield data is classified according to six groupings for each of the four classes of mode of groundwater occurrence. The six borehole-yield-groupings have been selected in such a way as to provide physical meaning to the value of the borehole both in terms of the concomitant abstraction equipment and as a provider of water for a particular end water user.

The mapping and initial delineation of groundwater-occurrence-boundaries, based on borehole yield data and the hydrogeological classification, was achieved by superimposing the available individual borehole yields, colour-coded according to the borehole yield range, over the lithological base map and determining the median yield of the different lithologies. Refining of the groundwater occurrence boundaries and the identification of regional patterns and trends was done through visual inspection; experience and knowledge of the area; information contained in geohydrological reports as well as the geology and related structures. Where supported by sufficient evidence and reason based on experience, the aquifer characteristics of geohydrologically well-defined areas were extrapolated into areas of data scarcity.

If major existing and/or licensed groundwater abstraction points equal or higher than 100 000m^3/annum occurs anywhere on the map it is shown as a filled red circle of various sizes that correspond to the estimated/reported annual volume of abstraction. Springs, thermal springs, artesian conditions, automatic water level recorders and monitoring points are shown in pink (filled circle), orange (empty circle), pink (empty circle), purple (open triangle), and purple (triangle with a dot) respectively.

Extensive use was made of the Geographic Information System (GIS), which allowed for cartographic compilation, data display, and manipulation.

2.2.1 : Inset maps:

The following inset maps have been included on the Modimolle Hydrogeological map sheet 2428:

One hydrogeological cross-section, based on limited geological information and the author's own interpretation of the available information. The cross-sections display the third dimension and regional hydrogeological relationships discussed on the map. The static water level is included to show its relationship with surface topography.

Distribution of borehole data: scale 1: 1 000 000 represents available groundwater source information distribution. The yellow colour represents no data points, light pink represents one data point, light blue 2-10 data points, violet 11-20 data points and the purple represent more than 20 data points.

Elevation above sea level: scale 1: 1 000 000, contour intervals relevant to the map at 200m. The elevation in the map area varies between 400-2000mamsl.

Mean annual precipitation: scale 1: 1 000 000, contour intervals at 100 to 200mm/a. The rainfall in the area varies from approximately 300 to just over a 1000mm/a.

Groundwater quality map: scale 1:1 250 000 representing contoured electrical conductivity data, (a measure of salinity), the position of sampling points and the indication of problematic chemical species, Nitrate (concentration >10mg/l) and Fluoride (concentration >1.5mg/l). The EC intervals as well as the Nitrate and Fluoride values shown are based on the prescribed guidelines for human and livestock water consumption.

2.2.2 : Brochure:

The purpose of the explanatory brochure is to give information on the methodology followed in compiling the map, to highlight important groundwater topics, and to discuss groundwater occurrences in more detail as that could be depicted on the map. The objective is also to include relevant aspects for the aquifer units from the most recent research and/or findings from available groundwater reports. Groundwater occurrence is very heterogeneous in South Africa while the mapping standards, legend, etc. demands a high degree of conformity.

Aspects of groundwater that are important, which could not be shown on the map, will vary dramatically from area to area and the brochure provides opportunities to reflect this variability. Included in the brochure are frequency diagrams on borehole yields per aquifer and trilinear Piper and Durov diagrams giving information on groundwater chemistry for the various aquifer units appearing on the map. These should be considered as guideline values, especially for the groundwater resource units with low volumes of data available, as the accuracy of the findings is a function of available data and the quality of the data.

3. HYDROGEOLOGICAL CLASSIFICATION

The international UNESCO classification for hydrogeological maps (UNESCO 1983) was adapted to suit South African hydrogeological conditions and groundwater occurrences. The UNESCO classification distinguishes the occurrence of groundwater only according to the primary or secondary nature of interstices. Table 2 depicts the adapted hydrogeological classification used for the Modimolle map sheet according to the origin and nature of the saturated interstices combined with subdivisions based on existing known blow yields (after Orpen, 1994).

Four modes of groundwater occurrences based on the dominant porosity type are depicted on the 1:500 000 (original) and 1:250 000 (upgraded) hydrogeological map series

- Intergranular (a),
- Fractured (b),
- Karst (c),
- Intergranular-and-Fractured (d)

Where two modes of groundwater occurrences occur at the same site such as along the 'Nylrivier' Nyl River, it is depicted as two-layered (a/d) i.e. the upper aquifer being intergranular (a) and the bottom aquifer intergranular and fractured (d). Depending on the specifics it is portrayed in the colours of the occurrence.

The definition of the productivity ranges has been left by the UNESCO authors for the local map authors to define. Considering local conditions and equipment options for production boreholes, six sub- divisions were defined. On the Modimolle map sheet and in Table 2 of the brochure, the classes are represented by colours and the yield subdivisions by the tone of the respective colour. The subsurface lithology is presented by lithologic ornaments and chronostratigraphy by alphabetical symbols. Production ranges are defined as follows:

- Very high borehole yields, generally greater than >10ℓ/s. Can be used for large scale urban and rural water supply, industry, or large-scale irrigation, (477 boreholes on map).
- High borehole yields, generally greater than 5ℓ/s to 10ℓ/s. Can be used for urban and rural water supply, industry, or large-scale irrigation, (560 boreholes on map).
- Moderate borehole yields generally, 2ℓ/s to 5ℓ/s. It can be used for urban and rural water supply to small towns, industry, or small-scale irrigation, (1082 boreholes on map).
- Low borehole yields generally, 0.5ℓ/s to 2ℓ/s. Can be used for domestic and livestock watering supply to rural settlements, hospitals and health centres or small-scale irrigation at community vegetable gardens, (1831 boreholes on map).
- Very low borehole yields generally, 0.1ℓ/s to 0.5ℓ/s. Can be used for domestic supply to single homesteads, schools, police stations, clinics, small rural villages (250 persons) or livestock watering. Boreholes in this group are mostly equipped with hand, submersible or wind pumps, (1331 boreholes on map).
- Un-economical boreholes with yields generally, < 0.1ℓ/s. Non-reticulated water supply for isolated households or for monitoring in certain cases. Suitability depends on factors such as construction, objective of monitoring, location, and geological setting, (2061 boreholes on map).

Table 2: Hydrogeological Classification of groundwater occurrence and borehole yields in the map area. (After Orpen, 1994).

CLASS A				CLASS B				CLASS C				CLASS D			
INTERGRANULAR				HARD, CONSOLIDATED ROCK MATERIAL											
A water saturated zone, generally unconsolidated but occasionally semi-consolidated. Groundwater is stored and transmitted through intergranular interstices in porous and permeable medium.				Fissured and fractured bedrock resulting from decompression and/or tectonic forces. Groundwater flow predominantly through fractures, faults, joints, and fissures (acting as conduits), and micro-fissures in the bedrock, Rock matrix provides storage.											
				Where the principal water strike is in a fracture or in contact between two different rock types, interporosity groundwater flow can occur within the rock matrix (double-porosity matrix). Groundwater is stored and transmitted in fractures, fissures and/or joints.				In the case of carbonate rocks groundwater is stored and transmitted through incipient fissures and fractures enhanced through chemical dissolution. Some groundwater storage can also be expected in in-situ weathered residuum. Frequently extensive in area				Fractured zone overlain by varying thicknesses of weathered saturated material. Storage and flow in both. Also able to pass vertically with relative ease between the two portions. Fractures act as conduits during abstraction, vertical recharge from intergranular zone. This situation also allows for circumstances where the intergranular portion serves primarily a storage function, the water being transmitted mainly through the fractured portion. This is a common feature of many South African Intergranular & Fractured Aquifers. Occurs when the often-substantial quantities of water stored in the intergranular voids of weathered rock can only be economically abstracted via fractures penetrated by boreholes drilled into the underlying fractured aquifer.			
Group	Typical borehole yield		Colour code	Group	Typical borehole yield		Colour code	Group	Typical borehole yield		Colour code	Group	Typical borehole yield		Colour code
	Range	ℓ/s			Range	ℓ/s			Range	ℓ/s			Range	ℓ/s	
a1	Un-economical	0.0-0.1		b1	Un-economical	0.0-0.1		c1	Un-economical	0.0-0.1		d1	Un-economical	0.0-0.1	
a2	Very low	0.1-0.5		b2	Very low	0.1-0.5		c2	Very low	0.1-0.5		d2	Very low	0.1-0.5	
a3	Low	0.5-2		b3	Low	0.5-2		c3	Low	0.5-2		d3	Low	0.5-2	
a4	Moderate	2-5		b4	Moderate	2-5		c4	Moderate	2-5		d4	Moderate	2-5	
a5	High	5-10		b5	High	5 -10		c5	High	5-10		d5	High	5-1	
a6	Very high	>10		b6	Very high	>10		c6	Very high	>10		d6	Very high	>10	
Alluvial deposits of limited extent along river terraces consisting of transported material such as sand and gravel. Weathered crystalline rock with the principal water strike in the weathered intergranular zone.				Sedimentary rocks of arenaceous origin. Acid volcanic rocks and other igneous rocks with very limited overlying residual weathered products.				Carbonate rocks including dolomite, limestone of marine origin.				Sedimentary. Igneous and Metamorphic rocks with significant thicknesses of overlying saturated residual weathering.			
INTERGRANULAR				FRACTURED				KARST				INTERGRANULAR AND FRACTURED			

4. PHYSICAL ENVIRONMENT

4.1 General

The 1:250 000 Modimolle hydrogeological map sheet which is bounded by latitudes 24°S and 25°S and longitude 28°E and 30°E, covers an area of approximately 22 334km².

The map area covers sections of four District Municipalities with various Local Municipalities or sections thereof falling within the Districts:

- Waterberg District, (consisting of Bela Bela, Modimolle-Mookgopong, Mogalakwena, and a small section of the Lephalale Local Municipality),
- Capricorn District, (consisting of Lepelle-Nkumpi and Polokwane Local Municipalities),
- Greater Sekhukhune District with the Fetakgomo/Tubatse; Ephraim Mogale; Elias Motsoaledi; Makhuduthamaga Local Municipalities.

Many formal, informal, rural settlements and towns are found within the map area. Table 10, page 16 to Table 12 gives basic information regarding the Regional Water Schemes and the villages supplied by these.

4.2 Terrain Morphology

The mapping area was divided by Kruger (1983) into nine terrain morphological units (Kruger, 1983) see Figure 1, viz.:

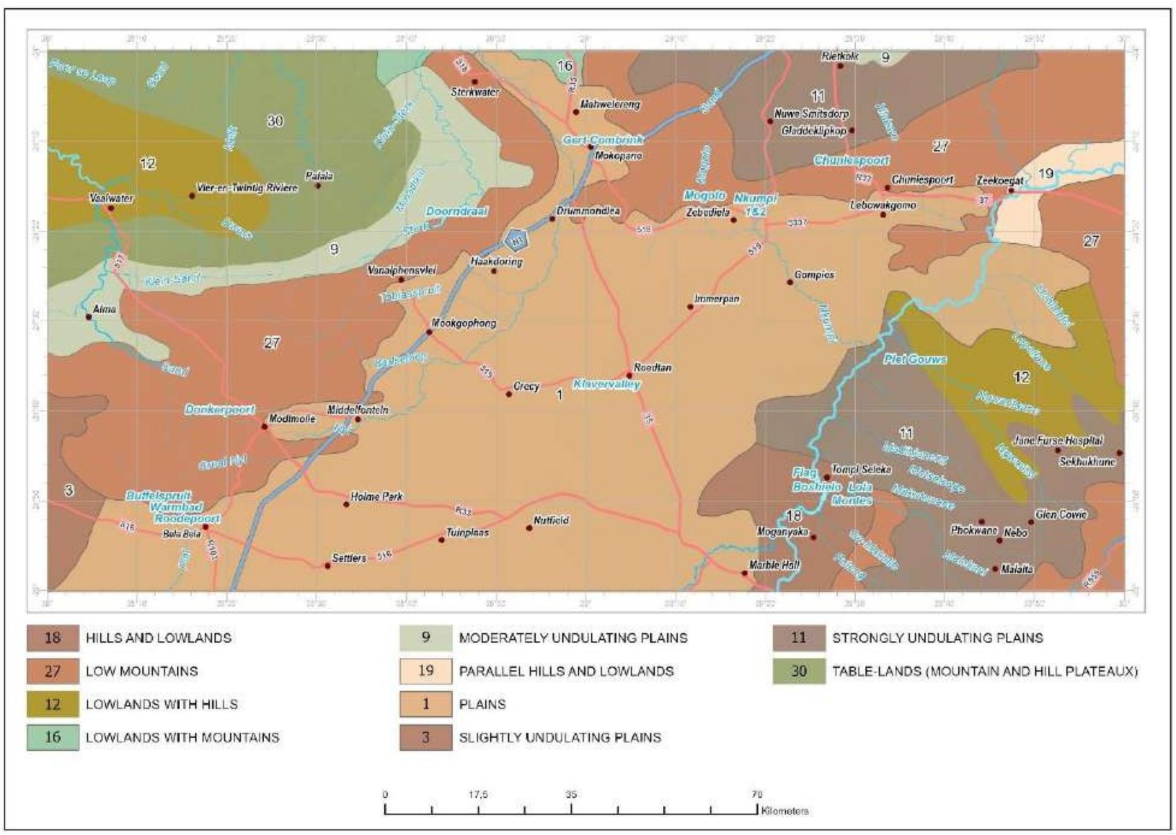


Figure 1: Terrain Morphology (Kruger, 1983)

Table 3: Detailed explanation for Figure 1, Terrain Morphology

BROAD DIVISION	MAP SYMBOL	DESCRIPTION	DRAINAGE DENSITY* (km/km²)	% OF AREA WITH SLOPES <5%
Plains with low relief	1	Plains	low - medium 0 - 2	> 80%
	3	Slightly undulating plains		
Plains with moderate relief	9	Moderately undulating plains	low - medium 0 - 2	
	11	Slightly undulating plains		
Lowlands, hills and mountains with moderate to high relief	12	Lowlands with hills	low - medium 0 - 2	50 - 80%
	13	Lowlands with parallel hills		
	16	Lowlands with mountains		
Open hills, lowlands and mountains with moderate and high relief	18	Hills and lowlands	medium 0.5 - 2	20 - 50%
	19	Parallel hills and lowlands		
Closed hills and mountains with moderate and high relief	23	Hills	medium 0.5 - 2	< 20%
	27	Low mountains		
	29	High mountains		
Tablelands with moderate to high relief	30	Tablelands (mountain and hill plateau)	medium 0.5 - 2	< 80%

* *Total length of drainage channels per km²*

4.3 Climate

The climate is generally hot and dry in the plains becoming more moist and cooler in the higher mountainous and plateau areas. The area receives 90% of its annual rainfall between October and March, generally in the form of convection thunderstorms. Rainfall occurrence over the parts of this area is very erratic and unreliable resulting in long dry periods. The Coefficient of Variation of annual precipitation is between 20-35% over most of the area. Refer to Table 4, page 9, *(data obtained from A Level 1 River Ecoregional Classification System),* Kleynhans et al., (2005).

Table 4: Limpopo Ecoregions and Coefficient of Variation

Ecoregion (ER)	Winter (July)		Summer (February)		Coefficient of Variation (% of annual precipitation)
	Mean daily Minimum Temperature	Mean daily Maximum Temperature	Mean daily Minimum Temperature	Mean daily Maximum Temperature	
North west section (Waterberg plateau ER)	2 to 6°C	16 to 24°C	12 to 20°C	24 to 32°C	20 to 35%
Central-west section (Western Bankenveld ER)	0 to 6°C	14 to 24°C	12 to 20°C	24 to 32°C	20 to 35%
Central-south to east section (Bushveld Basin ER)	0 to 6°C	14 to 24°C	22 to 32°C	12 to 20°C	25 to 35%
North-eastern section (Northern Plateau)	2 to 5°C	18 to 24°C	14 to 20°C	24 to 30°C	25 to 35%
North-east section (Eastern Bankenveld)	0 to 8°C	12 to 24°C	8 to 20°C	18 to 30°C	20 to 34%

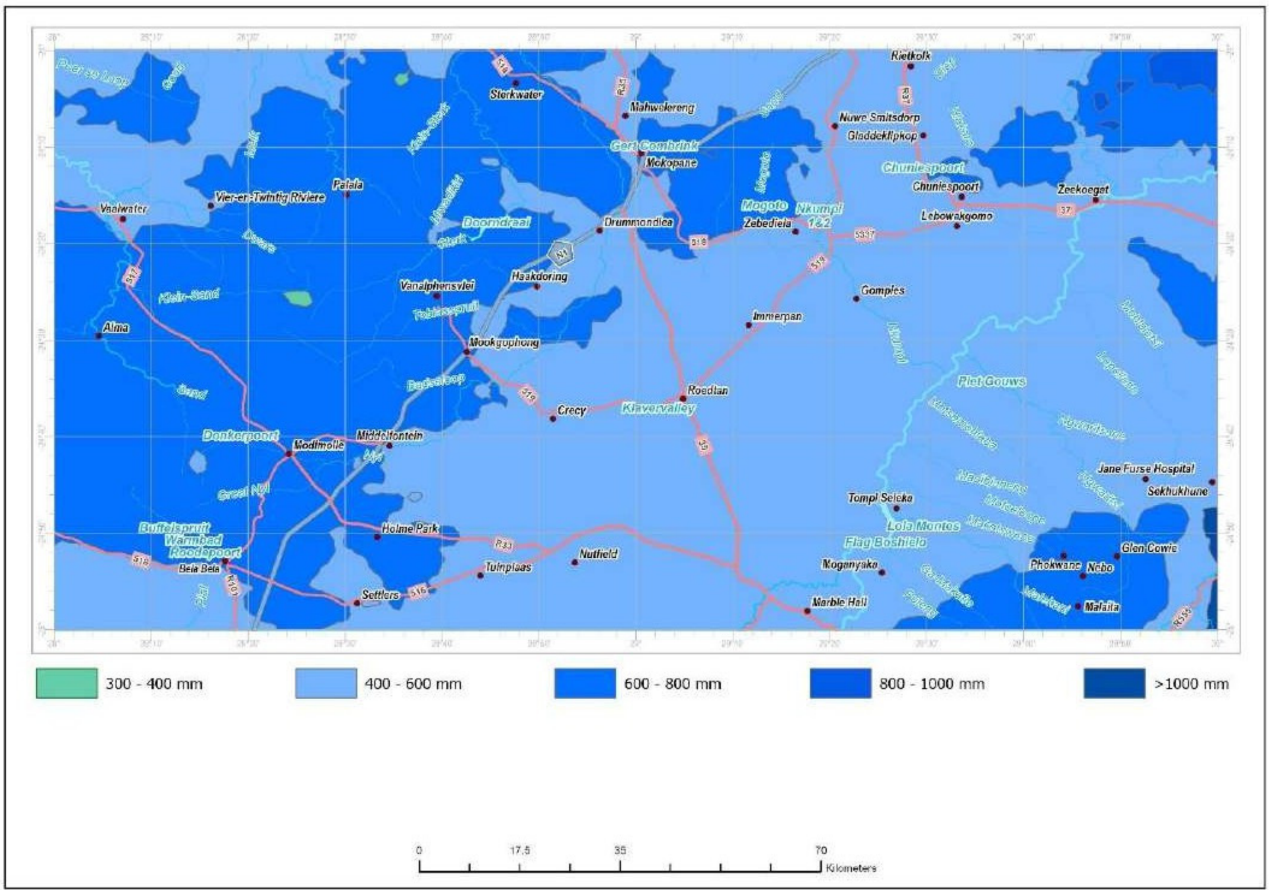


Figure 2: Mean Annual Precipitation

The Mean Annual Precipitation (MAP) (Figure 2), varies from between 400 and 600mm/a in the Springbok Flats area to between 600 and 800mm/a in the area underlain by rocks of the Waterberg Group to between 800 and a 1 000mm/a along the mountainous area in the north-eastern section of the map area. Rainfall occurrence over the largest part of this area is very erratic and unreliable resulting in long dry periods.

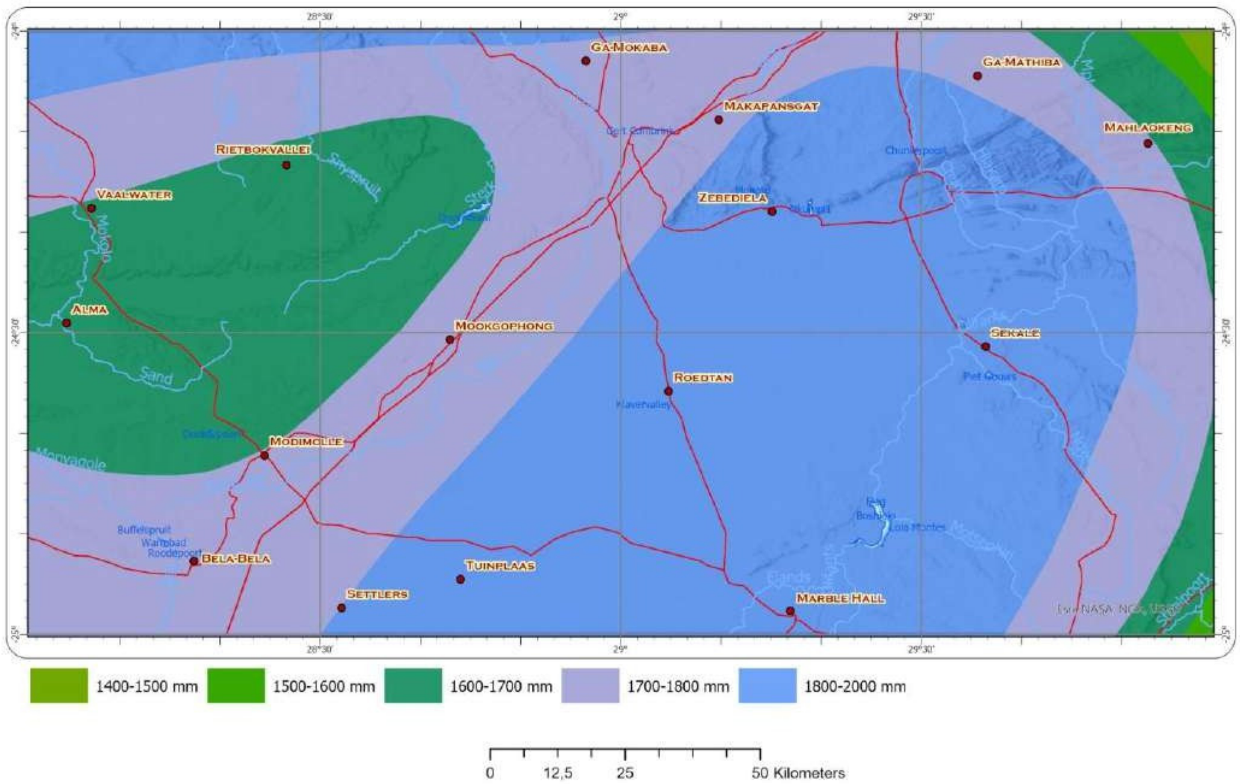


Figure 3: Mean annual evaporation

The mean annual evaporation, (Figure 3) is lowest (1400mm/a) to the east (northeastern and southeastern) sections of the map area. It is between 1500 and 1600mm/a in the area underlain by rocks of the Waterberg Group and the highest (1700 to 2000mm/a) in the Springbok Flats area.

4.4 Surface Hydrology

The area can be divided into **two main drainage regions** i.e. the Limpopo system (A) (Nyl River that later becomes the Mogalakwena River) which drains the north-western part of the map area, and the Olifants system (B). Rivers of the Limpopo and Olifants Systems flow mainly northward and eastward respectively. Figure 4 shows the location of the two main surface water drainage basins as well as the major dams.

The **major dams** together with their storage capacities are depicted in Table 5. Only the Olifants River can be considered as perennial, although it is not unusual for this river to stop flowing in exceptionally dry years. Mode and irregular frequency of precipitation combined with high evaporation rates results in droughts and periodical flows in most of the smaller rivers and streams. Interaction between surface and groundwater in river systems is seasonal with rivers either gaining or losing water from and to groundwater. This interaction is dependent on factors such as the water level of the river, depth of erosion channel and type of riverbed material, structural geology, riparian vegetation, abstraction points near the river and the static water level in the vicinity of the river.

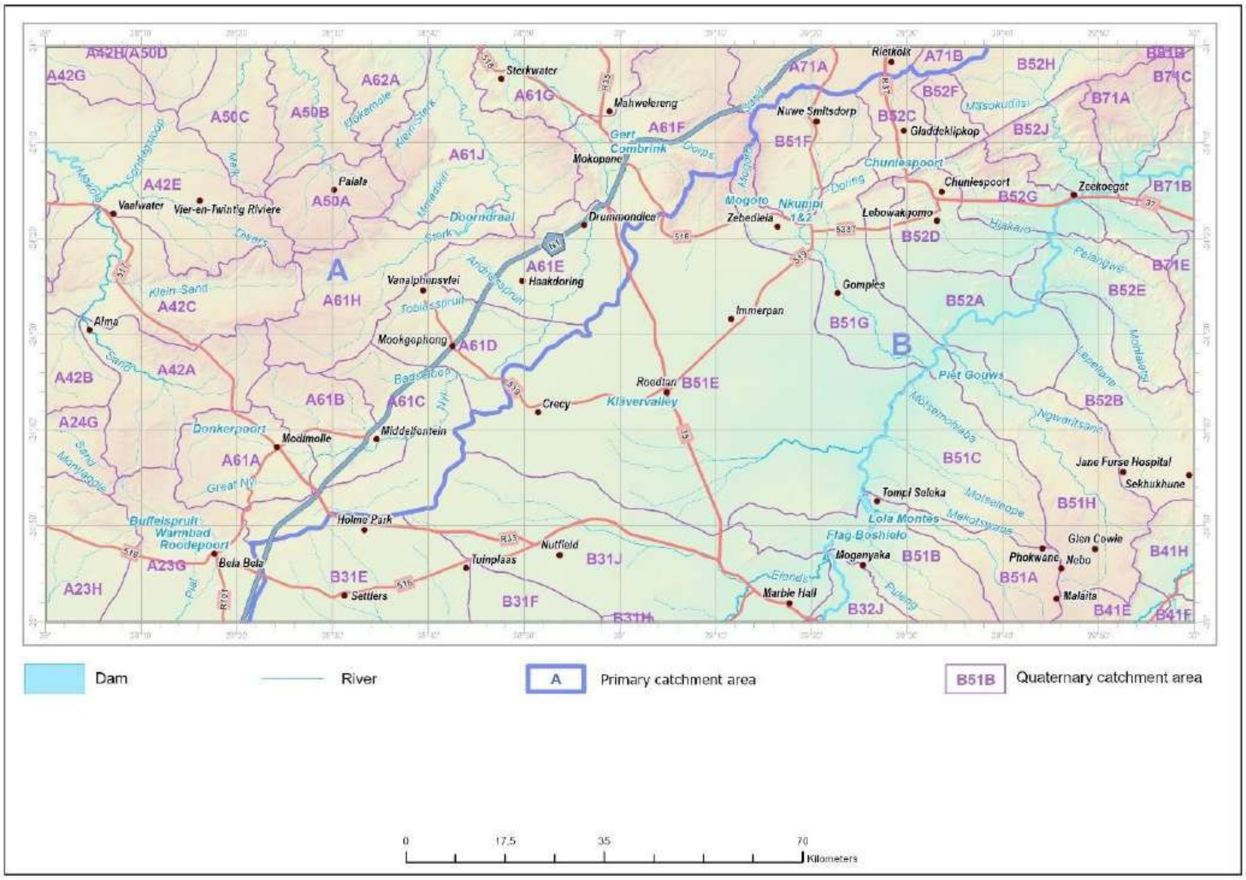


Figure 4: Drainage regions and major dams (HRU, 1981)

Table 5: Major dams, drainage basin, supplying river and storage capacity (HRU, 1981)

DAM NAME	DRAINAGE BASIN	RIVER	STORAGE CAPACITY (Mm³)
Gert Combrink	A6	Dorps	Unknown
Mokolo	A4	Mokolo	157
Mogoto	B5	Mogoto	2.4
Doorndraai	A6	Sterk	40
Onder Gompies (Nkumpi)	B5	Nkumbi	9.1
Donkerpoort	A6	Klein Nyl	2,38
Warmbad	A2	Buffelspruit	1
Flag Bashilo	B5	Olifants	100

Table 6: Surface Hydrology, table showing the upper tributaries of the Mokolo, Lephalala and Mogalakwena that flow into the Limpopo River.

Outermost tributaries	Early Tributaries	Early to later Tributaries	Arises (Ecoregion)	Later Tributaries	Main Tributaries	Main River System	Comment
		Monyagole	Western Bakenveld	Sondags	Sand	**Crocodile flowing into the Limpopo eventually**	The upper reaches of the Sand River arise in the Western Bakenveld Ecoregion before flowing into the Bushveld Basin Ecoregion. The upper reaches of the Pienaars River arises within the map area before flowing into the Thabazimbi map area
Kareespruit with the Droëloopspruit flowing into it	Rietspruit alias Marietsa	Marietsane		Moretele	Pienaars River		
		no name non perennial	Western Bakenveld	Sand	**Mokolo**	**Limpopo**	The upper Tributaries of the Mokolo River arise in the **Western Bankenveld Ecoregion** in the south before flowing through the Waterberg Ecoregion continuing outside the map area where it eventually joins the Limpopo River. The Western Bankenveld Ecoregion has a complex topography that varies from lowlands, hills and mountains to closed hills and mountains with the relief varying from moderate to high. **Waterberg Ecoregion:** The Waterberg is predominantly a tableland with moderate to high relief. The sandstones on the tableland are almost flat lying and are important escarpment shapers. Perennial rivers such as the Mogalakwena and Lephalala have their sources in the Waterberg. Altitude (mamsl) (Modifying) 700 -900 (limited), 900-1700 and MAP (mm/a) (modifying) is between 300 to 600.
		no name non perennial					
		no name non perennial					
		unknown non perennial		Klein Sand			
		Sandspruit		Grootspruit			
		no name nonperennial					
			Waterberg	Brakspruit			
				Klein Vaalwaterspruit			
		Jim Se Loop		Dwars			
		no name non perennial					
		Heuningspruit					
		Sondagsloop					
		no name non perennial					
				Poer se Loop			
				Tambotie			
		Goud	Waterberg	Boklandspruit	**Lephalale**		
		no name non perennial		Melk			
				Rietbokvleispruit			
				Snyspruit			
				no name non perennial			
				no name non perennial			

Table 7: Surface Hydrology, table showing the upper tributaries of the Mogalakwena and Sand that flows into the Limpopo River.

Early to later Tributaries	Arises (Ecoregion)	Later Tributaries	Main Tributaries	Main River System	Comment
	Waterberg	Mokamole	Mogalakwena	Limpopo	The upper Tributaries of the Mogalakwena River arise in the Waterberg Ecoregion in the west and the Western Bankenveld Ecoregion in the east and south. The **Western Bankenveld Ecoregion** has a complex topography that varies from lowlands, hills and mountains to closed hills and mountains with the relief varying from moderate to high. **Waterberg Ecoregion:** The Waterberg is predominantly a tableland with moderate to high relief. The sandstones on the tableland are almost flat lying and are important escarpment shapers. Perennial rivers such as the Mogalakwena and Lephalale have their sources in the Waterberg. Altitude (mamsl) (Modifying) 700 -900 (limited), 900-1700 and MAP (mm/a) (modifying) is between 300 to 600.
Klein Sterk	Waterberg and Western Bankenveld	Sterk			
Mmadikiri					
no name non perennial					
Mmadikiri					
no name non perennial					
no name non perennial					
Andriespruit	Western Bankenveld	Nyl			
Tobiasspruit					
Badseloop					
Middelfonteinspruit					The upper Tributaries of the Nyl River that flow into the Mogalakwena River arise in the Western Bankenveld Ecoregion in the west before flowing into the Bushveld Basin. Tributaries of the Mogalakwena River near Mokopane arise in the west within the Eastern Bankenveld Ecoregion before flowing into the Bushveld Basin. The upper Tributaries of the Sand River arise in the Northern Plateau flowing more or less north-east. The Sand River continuous northerly into the Limpopo Plain Ecoregion before joining the Limpopo River.
Olifantspruit					
Little Nyl					
Great Nyl					
		Dorps			
		Rooisloot			
		Grootsandsloot			
		no name non perennial			
		no name non perennial			
		Bloed	Sand		
		Diep			

Table 8: Surface Hydrology, table showing the main and upper tributaries of the Olifants River System page 1.

Early to later Tributaries	Arises (Ecoregion)	Later Tributaries	Main Tributaries	Main River System	Comment
	Northern Plateau		Hlakaro	**Olifants**	The upper Tributaries of the Nkumpi River that flow into the Olifants River arises in the north within the Northern Plateau Ecoregion and in the west within the Eastern Bankenveld Ecoregion flowing into the Bushveld Basin Ecoregion where it joins the Olifants River. The Mphogodima and associated Tributaries arise predominantly in the Northern Plateau before flowing into the Eastern Bankenveld where it joins the Olifants River. The Hlakaro and Chunies Rivers arises in the Northern Plateau and flows more or less south-easterly into the Olifants River. The Grass Valley and Elands Rivers with their associated Tributaries flows eastwards and arises in the Bushveld Basin Ecoregion. The Elands River and its Tributaries arise in the Bushveld Basin but is not all indicated on the list as it falls outside the map area,
			Chunies		
		Thlabasane	Mphogodima		
		Masokuditsi			
		no name non perennial			
		no name non perennial			
	Eastern Bankenveld	no name non perennial			
no name non perennial	Bushveld Basin	Gotwane	Elands		
no name non perennial					
no name non perennial					
no name non perennial					
no name non perennial					
no name non perennial					
			Moses		
		no name non perennial	Grasvalley		
		no name non perennial			
		no name non perennial			
		no name non perennial			
	Northern Plateau	no name non perennial	Nkumpi		
		Mogoto			
		Doring			

Table 9: Surface Hydrology, table showing the main and upper tributaries of the Olifants River System page 2.

Arises (Ecoregion)	Later Tributaries	Main Tributaries	Main River System	Comment
Bushveld Basin	Mphofotse	Ngwaritsi	**Olifants**	The Ngwaritsi and associated Tributaries arise in the Bushveld Basin and flowing more or less north-westerly into the Olifants River. The Pelangwe, Mohlaletsi, Lepellane, Motsemohlaba, Madibjaneng, Motseleope, Motsemohlaba, Motsephiri, Puleng also flow north-westerly into the Olifants River and arises in the Bushveld Basin. The Monametsi flows north-westerly into the Olifants River but arises in the Eastern Bankenveld Ecoregion. The Tongwane and associated Tributaries arise in the Eastern Bankenveld Ecoregion but flows southerly into the Olifants River.
	Ngwaritsane			
		Motsemohlaba		
		Madibjaneng		
		Motseleope		
		Makotswane		
	Gemsbokspruit	Motsephiri		
	Malekani			
	Ga-Makatle	Puleng		
		Lepellane		
		Mohaletsi		
		Pelangwe		
Eastern Bankenveld		Monametsi		
		no name non perennial		
	no name non perennial	Tongwane		
	Paardevlei			

Table 10: Water schemes in the Capricorn District, Lepelle-Nkumpi and Polokwane Local Municipalities.

Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
Bergnek GWS	CPBERG	Bergnek	Rural	Ground water
Boyne RWS		Mankgaile	Rural	Combination (Conjunctive Use)
Chuene Maja RWS	CPC/M	Chuene, Dichueneng, Ga-Maja, Ga-Mathiba, Ga-Mathiba Ext, Ga-Phiri, Ga-Thaba, Klipspruit, Kopermyn, Leshikishiki, Maratapelo, Marulaneng, Matobole, Mmakata, Motowabogobe, Mphogodiba	Rural	Combination (Conjunctive Use)
Molepo RWS	CPMOL	Bethel, Ga-Lekgothoane, Ga-Mogano, Ga-Molalemane, Ga-Molepo, Ga-Ramphere, Ga- Sebati, Lekgadimane, Lithupaneng, Makatiane, Makubung, Mamatsha, Maripathekong, Marobo, Sebyeng, Sekgweng	Rural	Combination (Conjunctive Use)
Polokwane LM Farms Supply	PlkFS	Farms Polokwane LM	Rural and farming	Combination (Conjunctive Use)
Polokwane WSA	LMPLK			
Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
Ashmole Dale WS	CLNASH	Ashmole Dale	Rural	Groundwater
Groothoek RWS	CLNGRH	Bolahlakgomo, Droogte, Ga-Mmamogwasa, Ga-Molapo, Ga-Rakgwatha, Hwelereng, Lebowakgomo Township, Ledwaba, Lekhuswaneng, Madisa Di Toro, Madisaleolo, Magatle, Makuswaneng, Makweng, Mapatjakeng, Mathibela, Matome, MEC Complex, Mmakotse, Mogoto, Moletlane, Motantanyana, Phishoana, Rafiri, Sekgophokgophong, Zebediela Estate, Sepanapudi	Rural and Urban	Combination (Conjunctive Use)
Mafefe Individual GWS	CLNMAFEF	Betle, Ditabongong, Dublin, Ga-Madiba, Ga-Mampa, Ga-Moila, Gemini, Kapa, Magope, Malakabaneng, Mankele, Manthlane, Mantukulu, Maredi, Maredi Ext 1, Mashushu, Matsoong, Mosola, Motsane, Motsane Ext 1, Motsane Ext 2, Mphape, Ngwaname, Pitsaneng, Potlaneng, Ramonwane, Sekgwarapeng, Setaseng, Shadibeng	Rural	Combination (Conjunctive Use)
Mankweng	CPMAN	Ga-Magowa, Ga-Makanye, Ga-Ramogale, Ga-Thoka, Makgwareng, Mankweng A,	Rural and	Combination (Conjunctive Use)

Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
RWS		Mankweng B, Mankweng C, Mankweng D, Mankweng Unit E, Mankweng Unit F, Mankweng Unit G, Moshate, Phomolong, Tsatsaneng, University of the North	Urban	
Mathabatha Individual GWS	CLNMAT	Ga-Makgoba, Ga-Mathabatha, Grootfontein, Madikeleng, Mahlaokeng, Makopeng, Maseseleng, Mmashadi, Success	Rural	Combination (Conjunctive Use)
Moletje South GWS	CPMS/NC8	Boetse, Diana, Ga-Kgasha, Ga-Madiba, Ga-Mangou, Ga-Matlapa, Glen Roy, Jupiter, Mandela Park, Manyapye, Mapateng, Matlaleng, Maune, Mohlonong, Monotwane 1, Monotwane 2, Naledi, Ngopane, Sebora, Sefahlane, Segoahleng, Sepanapudi, Utjane, Venus, Waterplaats, Chebeng, Doornspruit, Doornspruit Ext, Ga-Mapangula, Ga- Mapangula Ext, Lefahla, Makweya, Newlands, Pax College, Sengatane, Setotolwane High School, Vaalkop 1, Vaalkop 2	Rural and Urban	Combination (Conjunctive Use)
Mphahlele RWS	CLNMPHAHL	Boomplaas, Hlahla, Hwelesaneng, Lebowakgomo, Lekurung, Lekurung, Lesetsi, Letlhokwaneng, Mabokotswane, Magwaneng, Malemang, Masite, Matinkane, Middelkop, Molapo Matebele, Mooiplaas, Naauwpoort, Naauwpoort A, Naauwpoort Ext 1, Patoga, Phosiri, Phutimolle, Rapotela, Schildpadnek A, Seleteng, Serobaneng, Serobaneng, Shotalale, Shotalale Ext, Staanplaas, Tswaing	Rural, Farming and Urban	Combination (Conjunctive Use)
Specon RWS	CLNSPEC	Byldrift, Byldrift Ext, Dithabaneng, Kgaphamadi, Lenting, Leswaneng, Makurung, Malekapane, Maralaleng, Marulaneng, Morotse, Motsereng, Phaswana, Rooibosbult, Seswikaneng, Thamagane	Rural	Combination (Conjunctive Use)

Table 11: Water schemes in the Waterberg District, Bela Bela, Modimolle-Mookgopong, Mogalakwena Local Municipality

Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
Mabaleng RWS	MOD03	Mabaleng, Mabaleng Squatter	Rural and Urban	Combination (Conjunctive Use)
Mabatlane RWS	MOD02	Mabatlane, Mabatlane Squatter	Rural and Urban	Ground water
Makapans Valley Supply	NWO/1	Makapans Valley, Makapans Valley Scattered	Rural	Ground water
Mapela RWS	NW3	Danisane, Ditlotswane, Fothane, Ga-Chokoe, Ga-Magongoa, Ga-Mokaba, Ga- Molekane, Ga-Pila Sterkwater, Ga-Tshaba, Hans, Kgobudi, Kwakwalata, Lelaka, Leleso, Mamala Parakis, Mabuela, Mabusela Sandsloot, Machikiri, Magope, Malokongskop, Masahleng, Masenya, Masoge, Matlou, Matopa, Mesopotania, Millenium Park, Mmahlogo, Mmalepeteke, Mohlotlo Ga-Puka, Mohlotlo Ga- Sekhaolelo, Phafola, Ramorulane, Rooiwal, Seema, Sekgoboko, Sekuruwe, Skimming, Sterkwater Mountain View, Tshamahansi, Witrivier,	Rural	Ground water
Mogalakwena LM Farms Supply	MogFS	Farms Mogalakwena LM	Rural and farming	Ground water
Mokopane RWS	NW4	Madiba, Madiba East, Mahwelereng, Maribashoek / Oorlogsfontein Plots, Maruteng, Masehlaneng, Masodi, Mokopane, Moshate, Mountain View, Mzumbana, Sekgakgapeng	Urban - Former Township	Combination (Conjunctive Use)
Weenen Supply	NWO/4	Weenen	Rural	Ground water, Dolomite aquifer
Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
Modimolle LM Farms Supply	MdmFS	Farms Modimolle LM	Rural and Urban	Groundwater

Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
Modimolle Urban RWS	MOD01	Diflymacheng, Kokanja Retiremeint Village and Resort, Modimolle, Phagameng	Working Towns and Service Centres -Mines, Prisons etc.	Groundwater
Military Base Supply	MOOK0/2	Military base	Working Towns and Service Centres -Mines, Prisons etc.	Groundwater
Mookgophong LM Farms Supply	MooFS	Farms Mookgohpong LM	Rural and farming	Groundwater
Mookgophong RWS	MOOK01	Mookgophong, Mookgophong Naboomspruit, Mookgophong Phomolong, Phomolong Squatter	Urban - Former Township	Combination (Conjunctive Use)
Rietbokvalley Supply	MOOK0/4	Rietbokvalley	Rural	Groundwater
Roedtan Thusang Supply	MOOK0/1	Roedtan, Thusang	Urban - Former Township	Groundwater
Zoetfontein Supply	MOOK0/3	Soetfontein	Working Towns and Service Centres - Mines, Prisons etc.	Groundwater
Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
Bela-Bela LM Farms Supply	BelFS	Farms Bela-Bela LM	Rural	Groundwater
BelaBela RWS	BEL01	Bele-Bela, Bela-Bela Plots, Bela-Bela Warmbaths, Bospoort Plots	Rural and Urban	Combination (Conjunctive Use)

Table 12: Water schemes in the Greater Sekhukhune District, Fetakgomo/Tubatse; Ephraim Mogale; Elias Motsoaledi; Makhuduthamaga Local Municipalities

Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
De Hoop Nebo Plateau Lepellane WS	NSD05	Dinotsi, Ga-Baneng, Ga-Machacha, Ga-Maila Segolo, Ga-Mmela, Ga-Oria, Ga-Phahla, Ga-Radingwana, Manoge, Masehleng, Mashabela Ext4, Mashilavele, Mphanama, Phageng, Shenyaneng	Rural	Groundwater
De Hoop Nebo Plateau Malekana WS	NSD01	Ga-Maepa, Ga-Malekana, Ga-Masha, Ga-Mphana, Ga-Rantho, Ga-Ratau, Hlalanekahle, Kotollo, Maphopha, Maseven	Rural	Groundwater
De Hoop Nebo Plateau Mampuru WS	NSD08	Dithamaga, Eastern Chrome Mine Residence, Ga-Phasha, Kalkfontein, Legotong, Mampuru, Mampuru Ext, Mapodile, Mapodile LCH, Stoking, Tokakgomo A, Tokakgomo Ext, Tsakane	Rural	Combination (Conjunctive Use)
De Hoop Nebo Plateau Middle Ngwaritsi WS	NSD02	Botshabelo, Ga-Malaka, Ga-Malaka B, Ga-Malaka Ext, Lekorokorwaneng, Manotou, Mantlhenyane, Matlakatle, Matlakatle B, Matlakatle C, Ntwane, Patantswane, Patantswane B, Setebong, Thoto, Tikathon	Rural	Groundwater
De Hoop Nebo Plateau Monsterlus WS	NSD10	Ga-Madiba, Jerusalem, Monsterlus Town, Thabaleboto North	Rural	Combination (Conjunctive Use)
De Hoop Nebo Plateau Ngwaritsi WS	NSD04	Diphagane, Ga-Maloa, Ga-Marishane, Ga-Mashabela, Ga-Phahla, Ga-Tisane, Kanaan A, Kanaan B, Kapaneng, Lobethal, Magolapong, Mampe, Maseshegwane, Mogorwane, Mohwelere, Molebeledi, Phushulang, Phusulang, Polaseng	Rural	Combination (Conjunctive Use)
De Hoop Nebo Plateau Nkadimeng WS	NSD06	Disesane, Ga-Magolego, Ga-Maila Mapitsane, Ga-Mohlala, Ga-Mokadi, Madibaneng, Malegale, Manganeng, Mangineng, Marulaneng, Maseleseleng, Masite, Mathibeng, Modiketsi, Molapong, Ramphelane, Sebetole, Sebitsane, Tsatane, Tsatane Ext 1	Rural	Combination (Conjunctive Use)
De Hoop Nebo Plateau Schoonoord WS	NSD07	Ga-Mogashoa Manamane, Ga-Mogashoa Senkgapudi, Ga-Ratau, Makgeru, Schoonoord, Tsopaneng	Rural	Groundwater

Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
De Hoop Nebo Plateau Sephaku WS	NSD11	Motsephiri, Nkosini, Sephaku, Thabaleboto South, Vlakfontein	Rural	Groundwater
De Hoop Nebo Plateau Carbonatites Spitskop WS	NSD09	Eenzaam, Eenzaam LCH, Ga-Phetla, Hlogotlou, Klipspruit (Kgaphamadi), Klipspruit farm, Kotupu (Kopjeng), Lehlakong, Magukubjane, Mare, Maserumule Park, Nebo, Ngwaritsi, Sebetha, Syferfontein, Takataka, Talane, Talane Extension, Thamaga (Morulane)	Rural	Combination (Conjunctive Use)
De Hoop Nebo Plateau De Hoop Dam WS	NSD14	Buffelshoek, buffelshoek, Kalkfontein	Rural	Groundwater
De Hoop Nebo Plateau Jane Furse Glen Cowie WS	NSD03	Ga-Molepane, Ga-Moloi, Glen Cowie, Glen Cowie Ext 1, Glen Cowie Ext 2, Hlahlane, Jane Furse, Jane Furse LCH, Mahlomola, Mochadi, Mokwete, Riverside, Sekwati, Tlame	Rural and Urban	Combination (Conjunctive Use)
Elias Motsoaledi Lukau WS	NSH	Aquaville, Groblersdal, Hlopha, Legolaneng, Lukau, Makaepea, Masakaneng, Mogaung, Motetema, Ngwalemong, Sterkfontein, Tafelkop	Rural	Combination (Conjunctive Use)
Fetakgomo LM Farms Supply	FetFS	Farms Fetakgomo LM	Rural and farming	Combination (Conjunctive Use)
Flag Boshielo RWS Eastern2 WS	NSA02	Dihlabeng, Frischgewaagd, Hwafeng, Kgaruthuthu, Malaeneng, Maololo, Mathapisa, Mmatsekele, Mohloding, Thabeng, Zoetvelden, Brooklyn, Goodhope, Greenside, Klip, Mabintwane, Mathukhuthela, Mogodi, Mohlarekoma, Motseleope, Phokwane	Rural	Combination (Conjunctive Use)
Flag Boshielo RWS Eastern3 WS	NSA03	Brooklyn, Goodhope, Greenside, Klip, Mabintwane, Mangoanyane, Mathukhuthela, Mogodi, Mohlarekoma, Motseleope, Phokwane	Rural	Combination (Conjunctive Use)

Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
Flag Boshielo RWS Flag Boshilo Central WS	NSA01	Arabie LCH, Dikgalaopeng, Ditholong, Ga-Makgatle, Ga-Mampana, Ga-Masha, Ga- Mashehlaneng, Ga-Mmela, Ga-Reagopola, Goru, Kome, Krokodilheuvel, Leeufontein, Letebejane, Mabitsi A, Mabitsi B, Makgatla A, Makgatla B, Makhutsho, Makhutso, Malope, Mamphokgo North, Mamphokgo South, Manapsane, Manotelwaneng, Maraganeng, Masanteng, Mmakgwabe, Mmotwaneng, Moeding, Mogaladi, Mogaladi Ext 3, Mogalatsana, Moganyaka North, Moganyaka South, Mohlalaotwane, Mohlotshi, Mooihoek, Moomane North, Moomane South, Moswanyaneng, Ngwalemong A, Ngwalemong B, Phetwane, Pitsaneng, Puleng A, Puleng B, Sehuswane, Semahlakole, Sephoto, Serageng, Seriteng, Setlaboswane, Thabanapitsi, Tompi Seleka Agri College, Tsimanyane, Vaalbank	Rural	Combination (Conjunctive Use)
Flag Boshielo RWS West WS	NSA04	Kgwaripe, Kgwaripe Ext, Khureng, Klipheuvel, Maletane, Mehlareng, Doornpoort, Elandskraal, Elandskraal x1 LCH, Hinlopen, Van der Merwes Kraal, Weltevrede.	Rural	Combination (Conjunctive Use)
Kwandebele Renosterkop Marble Hall WS	SMOT01	Doornlaagte, Driefontein, Keerom, Kwamatabane, Leeukuil, Makeepsvley, Spitspunt, Toitskraal, Toitskraal S/H, Uitvlugt, Witfontein S/H, Zamenkomst	Rural	Combination (Conjunctive Use)
Laaste Hoop RWS	CPLH	Laaste Hoop Ward 7, Laaste Hoop Ward 7A, Maboi, Manthorwane, Manthorwane Extension, Mogole, Quayle	Rural	Combination (Conjunctive Use)
Lebalelo Central WS	NSR02	Dipururung, Dithabaneng, Dithwaiing, Ditobeleng, Ga-Kgwete, Ga-Maapea, Ga-Makgopa, Ga-Makgopa Ext 1, Ga-Masete, Ga-Masete Ext 1, Ga-Mashabela, Ga-Mashishi, Ga-Selala, Lekgwareng, Madikane, Magabaneng, Magakala, Magakala Ext1, Makgake, Mantsakane, Mantsakane Ext 1, Manyaka, Matadi, Matsakane, Modimolle, Mohlope, Morapaneng, Mosego, Ntswaneng, Plaseng, Seuwe, Swale, Tidintitsane, Twickenham	Rural	Groundwater
Lebalelo North WS	NSR03	Botshabelo, Dithabaneng, Dithabaneng Ext, Dithamaga Marobajin, Ga-Makofane, Ga- Mampa, Ga-Motene, Ga-Phasha, Ga-Podile, Habeng, Ledingwe, Legabeng, Lekgwareng, Malokela, Masehwaneng, Mashegeng, Modubeng, Moshira, Motloulela, Pidima, Radimpshe, Ramallane, Ramallane Ext, Sebepe, Sehunyane, Sehwiting, Sekitlong, Sekopung, Sekopung Ext 1, Sentlhane, Sentlhane Ext, Senyatho, Seokodibeng, Seokodibeng, Shakung, Tsidintsi, Tswereng	Rural	Groundwater

Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
Leolo Local Sources WS	NSL05	Emkhondweni, Ga-Kobe, Ga-Mokgoadi, Ga-Sekele, Geluksfontein Location A, Hoepakrantz, Ka-Mabule, Leolo, Magolego, Mohlake, Sekele, Sekotini, Sopeyana	Rural	Groundwater
Makhuduthamaga LM Farms Supply	MktFS	Farms Makhudutamaga LM	Rural and farming	Combination (Conjunctive Use)
Marble Hall WS	SMAR	Marble Hall	Urban	Combination (Conjunctive Use)
Olifantspoort South Group 2 WS	NSOP02	Ga-Maesela, Ga-Maesela, Ga-Masha, Ga-Matlala, Ga-Nchabeleng, Ga-Nchabeleng Ext, Ga- Nkwana, Ga-Nkwana Ext, Ga-Nkwana LCH, Ga-Seroka, Lepellane, Lepellane Ext, Lerajana, Mabokotswane, Maesela-Mahlabaphooko, Mahluakgomo, Makopa, Makurwaneng, Mapulaneng, Mashabela, Mashabela, Mashabela Ext1, Mashabela Ext2, Mashabela Ext3, Masweneng, Matlala, Mohlaletsi, Mohlaletsi Ext (Rita), Mohlaletsi Ext (Sekateng), Mooiplaas, Pelangwe, Sekhukhune Agic College, Sesesehu, Thabanayaseso, Thobehlale, Tswereng	Rural, Farming and Urban	Combination (Conjunctive Use)
Olifantspoort South Group 3 WS	NSOP03	Atok Platinamyn, Atok Platinamyn Residensieel, BB-Kloof, Forong, Ga-Manotwane, Ga- Mokgotho, Ga-Selepe, Jaglust, Lekgwareng, Mahlabeng, Mahlabeng Ext 1, Malogeng, Maropeng, Masilabela, Matomanye, Mmabulela, Mmabulela Ext 2, Mmabulela Ext 3, Mmabulela Ext 4, Mmasikwe, Moeijelijk, Mogabane, Monametsana, Monametsi, Mosotsi, Mphaaneng, Paschaskraal, Paschaskraal Ext 1, Petsa, Rostok, Rostok Ext 1, Shubushubu, Tshibeng, Tsibeng B, Ucar Chrome	Rural, Farming and Urban	Groundwater

Water Scheme Name	Water Scheme number	Settlements or settlements	Settlement type	Water sources
Olifants-Sand RWS	CPOS	Blood River, Blood River Extension, Kgohlwane, Mabotsa, Makgove, Mokgokong, Montinti Park, New Pietersburg, New Pietersburg, Perskebult, Perskebult Ext 1, Perskebult Ext 2, Polokwane, Polokwane - Dalmada S/H, Polokwane - Doornbult S/H, Polokwane - Elmadal S/H, Polokwane - Ivydale Agricultural Holdings, Polokwane - Leeukuil S/H, Polokwane - Mooifontein S/H, Polokwane - Myngenoegen S/H, Polokwane - Palmietfontein S/H A, Polokwane - Palmietfontein S/H B, Polokwane - Palmietfontein S/H C, Polokwane - Roodepoort S/H, Polokwane - SDA3, Polokwane - Tweefontein S/H, Seshego, Thokgwaneng, Toska Mashinini, Zone 6	Rural, Farming and Urban	Combination (Conjunctive Use)
Piet Gouws Masemola WS	NSP01	Apel Cross, Apel Cross Low Cost Housing, Ga-Masemola, Mahlolwaneng, Thabampshe, Veeplaats Agri. College	Rural, Farming and Urban	Combination (Conjunctive Use)
Piet Gouws Veeplaas WS	NSP02	Kgwaripe, Mmotwaneng, Nkotokwane, Phelindaba, Tswaing, Vlakplaas A, Vlakplaas B	Rural, Farming and Urban	Combination (Conjunctive Use)

5. GEOLOGY

5.1 Regional geology

The geology occurring on the Nylstroom Hydrogeological map sheet area, almost spans the length of the South African geological history and contains many of the major stratigraphic groups in the country. A simplified geological map, (Figure 5) was compiled from the 1: 250 000 Nylstroom published geological map sheet and explanatory notes on the back of the map sheet (Council for Geoscience).

The major stratigraphic units formed the basis for the delineation of the hydrogeological aquifer units that were chosen according to geohydrological similarities. The boundaries of the hydrological aquifer units are in most cases similar to the geological boundaries. The major stratigraphic groups are as follows:

- The Basement Complex
- Granite intrusives
- Transvaal Supergroup
- Bushveld Complex
- Waterberg Group
- Karoo Supergroup
- Quaternary

The Basement Complex
Portions of the Basement Complex cutting across the map boundary, occurs in the northern portion of the map and consists essentially of gneiss, banded gneiss, granite gneiss with infolded xenoliths of mafic to ultra-mafic material, and migmatite associated with leucocratic granite [Goudplaats gneiss (Zgo)], migmatite gneiss [Hout River Gneiss (Rho)], and Pietersburg Greenstone Belt (Zpg) [Pietersburg Group)]. The Pietersburg Greenstone Belt (Zpg) occurs within the gneiss (Zgo and Rho) as a southwest striking belt of steeply folded material ranging from ultra-mafic to mafic lavas, acidic lavas, arenaceous sediments and chemical sediments such as banded iron formation and chert. The sequence was subjected to low-grade (green schist facies) metamorphism.

Granite intrusives
The Basement Complex has been intruded by numerous younger granites such as Lunsklip (Rl-Vl), Uitloop (Ru-Vu), Geyser (Rge), and Turfloop Granites (Vt-Rt). Other intrusives include the Unnamed Granite (Vz) of Vaalian to Randian age

Transvaal Supergroup
The Transvaal Supergroup occurs as steeply dipping strata striking approximately east-west across the map sheet and folded about the Bushveld Complex. The Sequence consists of a basal quartzite, shale, and basalt layer [Wolkberg Group (Vwo)] followed by a period of chemical sediment deposition consisting of a lower banded iron formation and chert layer [Black Reef Formation (Vbr)] followed by a thick sequence of dolomite with interlayered chert [Chuniespoort Group represented in the map area by the Penge Formation (Vpe) and the Malmani Subgroup (Vma)]. Chemical deposition of the Chuniespoort Group was followed by cyclic episodes of quartzite and shale deposition [Pretoria Group consisting in the map area of Undifferentiated Pretoria Group (Vpg), Timeball Hill Formation (Vti) and Lakenvalei Formation (Vla)]. A capping of acidic lava [Rooiberg Group (Vrg)] and Glentig Formation (Vgl) marks the end of Transvaal deposition and the beginning of the intrusion of the Bushveld Complex.

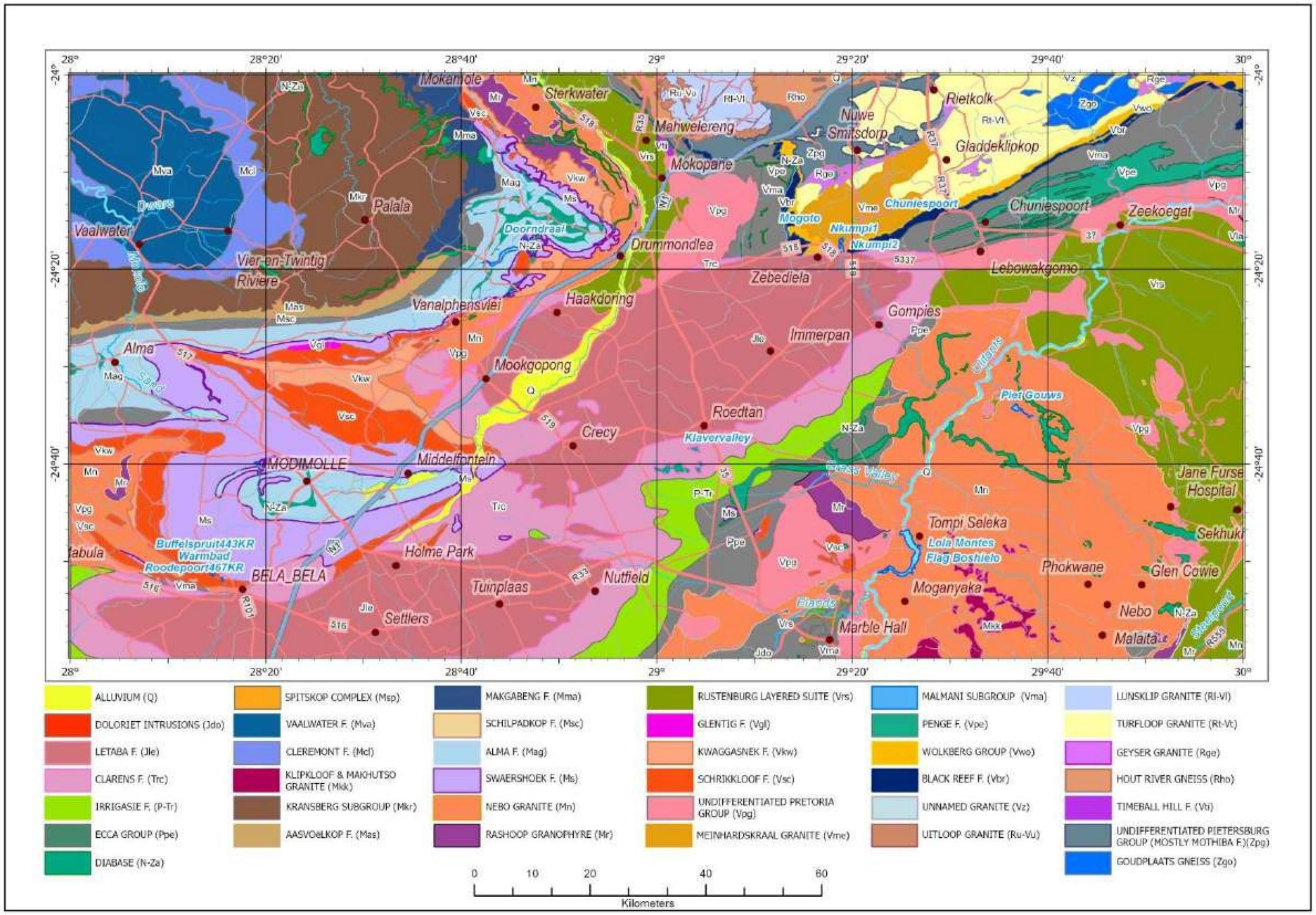


Figure 5: Simplified regional geology of the map area

Bushveld Complex

The emplacement of the complex was preceded by the intrusion of diabase sills that is largely confined to the Transvaal basin. The Bushveld Igneous Complex (BIC) is the largest layered igneous intrusion within the Earth's crust (Wikipedia, the free Encyclopedia). It has been tilted and eroded forming the outcrops around what appears to be the edge of a great geological basin: the Transvaal Basin. It is approximately two billion years old and is divided into four limbs: northern, eastern, southern, and western. It comprises the mafic and ultramafic phase of the Rustenburg Layered suite (RLS) and the felsic phase of the Rashoop Granophyre Suite (RGS) and the Lebowa Granite Suite (LGS). The genetic relationship between the granites (LGS) and granophyres (RGS) and their relation to the underlying layered mafic-ultramafic intrusion (RLS) is not fully understood, (Earth-Science Reviews, Volume 250, id.104703, 2024). The RGS is generally more closely aligned with the pre-Bushveld Rooiberg Group, (Walraven, 1987a). Research suggests that the RGS was formed by melting of felsic volcanic rocks of the Rooiberg Group during the emplacement of the RLS, (Kinnaird, 2002). The granite intruded and formed a sill-like intrusive body over most of the complex. It has an estimated thickness of some 2.5km (MacCaskie, 1983).

Within the map sheet the eastern limb of The Bushveld Complex underly the eastern part and consists of a lower layered ultra-mafic unit, a middle massive gabbro unit, and an upper-layered mafic unit [Rustenburg Layered Suite (Vrs and Vmo)] capped by a red granite and granophyre unit [Nebo Granite (Mn) and the Rashoop Granophyre Suite (Mr)]. Intrusive into the Nebo Granite (Mn) is the Spitskop Complex (Msp) consisting predominantly of alkaline rocks with a wide range of composition.

Waterberg Supergroup

The Bushveld Complex intrusion was followed by the deposition of the Soutpansberg (Msp) and Waterberg (Mw) Supergroups. The Waterberg Supergroup includes the Koedoesrand Formation (Mko).

The Waterberg Group was deposited in the basin formed by sagging of the cooling Bushveld Complex intrusion. The Waterberg Supergroup is preserved in two main basins, namely the Cullinan-Middelburg basin and the Waterberg Basin in which the Nylstroom, Matlabas and Kransberg Subgroups are preserved, (Jansen, Tankard *et al*, 1982). Sedimentary studies show that the source rocks were from the Transvaal Supergroup and Bushveld Complex and transported by an active river system. Locally material could be transported and deposited by wind action during arid periods, (Tankard *et al*, 1982).

Rocks of the Waterberg Supergroup were deposited in a fault-bounded basin in the northern part of the Kaapvaal craton. In the south the basin is bounded by the Polokwane-Murchison lineament and in the north the Palala shear zone, (Callaghan, 1987). This is the main basin and referred to as the Waterberg Basin.

The Waterberg basin consists of two overlapping basins. In the deep basin on the south the Swaershoek and Alma beds were laid down, (northern portion of the Thabazimbi and Nylstroom map sheets). The Langkloof beds (Aasvoëlkop Formation) form the base of the succession in the younger, larger but shallower basin and are transgressive over older formations from south of the Matlabas River into Botswana. The entire succession is predominantly arenaceous, but the Langkloof and Vaalwater beds are in part argillaceous. In the Swaershoek and Alma beds, rapid changes in lithology and thickness and locally very coarse clastics, are due to erosion in the source areas, which were rejuvenated by contemporaneous block-faulting.

Diabase dykes and sills

Diabase dykes and sills (N-Za) are pervasive throughout the whole region. Most dykes are generally related to two main igneous events. The older dykes are thought to be of Bushveld Complex age, and the younger dykes are generally of late and post Karoo age. The latter dykes were the feeder conduits to the Karoo basalt suggesting that the basalt outpouring probably covered the whole map sheet area prior to Gondwana break-up and their later removal by erosion.

Karoo Supergroup

The topography underlain by Karoo age rocks within the map area is characterized by extensive flat country known as the Springbok Flats. The deposition of Karoo strata into the Springbok Flats intracratonic basin was controlled by changes in paleo-environments with the maximum depth in the south. Structurally the Springbok Flats Karoo Basin comprises two elongated basins i.e. Roedtan Basin (north) and Settlers-Tuinplaats Basin (south). These two basins are bordered by pre-Karoo aged tectonic features i.e. Thabazimbi-Murchison lineament (northern boundary of the Roedtan Basin) and the Droogekloof Fault Zone (northern boundary of the Settlers-Tuinplaats Basin.

The Karoo-Supergroup represents the final major episode of deposition before the break-up of Gondwanaland. It is divided into a few geographical areas of which one occurs on the map sheet namely the Springbok flats. Deposition in the Springbok flats is believed to have occurred within a shallow inland depression, shallower in the north and deeper to the south.

The Supergroup consists of lower diamictite of probable glacial origin [Dwyka)] overlain by shale (at places carbonaceous), mudstone, and sandstone horizons [Ecca Group (Ppe)], Permian- Triassic (P-Tri) Formations consisting of the Irrigasie (P-Tri), and Clarens [Triassic (Trc)] Formations and overlain by a thick sequence of basalt [Letaba Formation (Jle)].

Recent literature indicates that stratigraphically the Springbok Flats Karoo Basin was subdivided into seven distinctive lithostratigraphic units. From the youngest to the oldest the Letaba Formation represents the final stage in the succession that ended the deposition of sedimentary rocks with the outpouring of amygdaloidal basaltic lavas. Underlying the volcanic rock is sedimentary rock of aeolian (wind-blown deposits) of the Clarens Formation. The lower lithostratigraphic units represent siltstone, sandstone and basal calcrete conglomerate, fluvial deposits, cyclothems deposits that influenced the formation of coal deposits (periods of deposition controlled by transgression and regression of water) coarser deltaic deposits and the lower Dwyka Formation formed by glacial derived deposits, (L. Nel 2012).

Quaternary

The youngest strata are thin sequences of Quaternary to Tertiary Aeolian Kalahari sand (not shown on map) and alluvial sand (Q) along the major drainages in the area.

5.2 Structural geology

In the basement complex, the main structural features are largely controlled by Murchison direction with a dominant north-easterly to east-north-easterly trend. The Pietersburg belt of greenstones and clastic sediments has been subjected to intensive deformation with steeply dipping foliations. Deformation and to a certain extent deposition of the Transvaal Succession is also controlled by the Murchison direction in other words by the westward extension of the Murchison and Pietersburg belt zones of crustal weakness under the north-eastern rim of the Transvaal Basin. The banded ironstone and dolomite around the Malips and Mhalapitsi Rivers are intensely folded and in places also the Wolkberg Group especially near the eastern boundary of the map. The sinuous strikes of the Transvaal rocks between Buttonkop and Zebediela delineate anticlinal or domal and synclinal structures. A synclinal structure pitching to the south-west is developed on the south-western extension of the Pietersburg Belt.

In the Stavoren and Moos River Fragments, complex structures were formed during the intrusion of pre-granitic Bushveld rocks, namely two-fold systems with local overturning and drag folds and faults which are partly tear faults in the Moos River Fragment, and thrusts in the Stavoren

Fragment. Folding in the Moos River Fragment probably occurred at considerable depth under high load pressures and thrusting in the Stavoren Fragment at higher levels. Faults in the Wolkberg Group and several large post-Bushveld faults (partly tear faults), for instance the Wonderkop, Sekhukhune, and Steelpoort faults, display a dominant northeast trend. The Ysterberg fault, a tear fault, may have been reactivated during different periods.

Prominent structures are displayed in the Waterberg Group in the Alma trough, namely the Swaershoekberge anticlinorium and Nylstroom syncline, with accompanying anticlynal structures (Loubad and Zwartkloof anticlynals). Their origin and original non-linear pattern are attributed to late-magmatic Bushveld activity during their embryonic stage.

Subsequent folding, flexing, and faulting during Waterberg and post-Waterberg times transformed the embryonic structures into their present shape and locally their limbs were tilted to vertical or over-turned. The Droogekloof overthrust fault developed along the Swartkloof anticline. Block faulting took place in early Waterberg times and gentle folding after deposition of the Alma Formation. To the north, the succession in the late-Waterberg Basin was hardly affected, with the exception of the area north of the Swaershoek Mountains, where beds of the Schilpadkop Formation are tilted to the vertical, and of the Sandriviersberg Formation by 30 degrees. Post- Waterberg tensional faults and fractures are frequently intruded by diabasic dykes.

The Karoo Basin in the Northern Springbok Flats consists of two very shallow elongate basins or syclinical flexures and a broad flat anticlinical flexure with general north-easterly directions. These structures are intersected by several sinuous normal faults averaging the same strike. A large post-Karoo fault-system with a downthrough up to 300m to the south bounds the basin on the north (Zebediela fault).

Figure 6 represents one of the products of the Groundwater Resource Information Project (GRIP). The map displays dykes, faults, and lineaments derived from remote sensing techniques using a combination of various research earth science satellite imagery. The map, (Figure 6) is included in the brochure but the interpreted structural features could not be displayed as an additional layer on the 1:250 000 Hydrogeological map sheet. This is as it would clutter the map considerably with the information already depicted. The dykes, faults, and lineaments that are included on the hydrogeological map sheet are the same as those depicted on the 1:250 000 Nylstroom 2428 geological map.

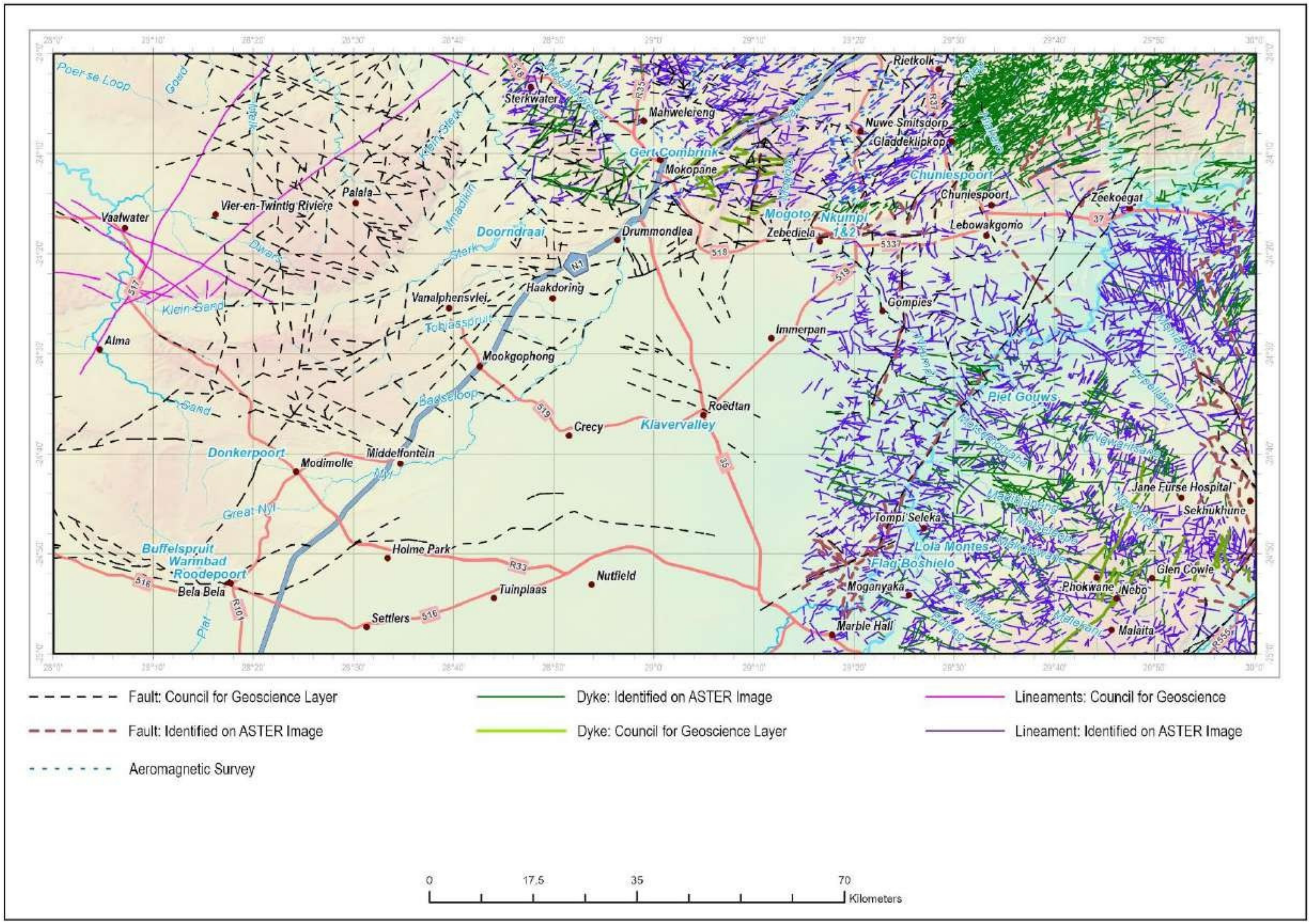


Figure 6: Inferred and observed geological lineaments.

6. GENERAL: HYDROCHEMISTRY AND AQUIFER UNITS

The chemical composition of groundwater is the result of interaction between rainwater, soils and various rock types. Most of this interaction takes place in the unsaturated zone and later in the saturated zone along the groundwater flow path, where physical and geochemical properties of the rock types influence the type and character of the groundwater quality.

To characterise and compare the chemical composition of groundwater in the various rock formations, complete chemical analysis of 4580 groundwater samples, taken during the period from 1968 to 2008, was utilized.

The chemical data was predominantly obtained from WMS, NGA and from the database of the consultancy. The first combined data worksheet consisted of data for the area covered by the 1:500 000 Polokwane map sheet. The total data points for the larger area numbered 41 942 data points. After removing duplicates and calculating the harmonic mean for time series data the number of data points decreased to 13 320 data points.

Duplicates were first removed from the combined total list before the data points occurring on the Nylstroom map sheet was separated. Therefore, the total number of duplicates removed for the Nylstroom area is not known as it is part of the statistics for the larger area. The time series data were however counted for each borehole point. For the Nylstroom map sheet 8 476 samples were available after the removal of duplicates. The number of data points after the calculation of the harmonic mean for time series data was 4580 thus 3896 samples represent time series data. Of these data, 3963 analyses were used for the evaluation of chemistry with the results summarized in various tables. Of these only 2390 analyses could be used for the Piper and Durov diagrams.

The reason for the large number of duplicates was that in the past data was captured by many entities and at few occasions the various groundwater databases were combined with the DWS database and vice versa. The coordinates of the available analysis points were used to divide the data within the relevant Aquifer Units.

The accuracy of the chemical analysis was checked by the plausibility of the Electrical Conductivity (EC) and Electro Neutrality (E.N). The calculations are as follows: EC is [∑anions (meq/L) =∑cations (meq/L)] =EC/100(µS/cm) and for the E.N. it was calculated as follows, [∑cations (meq/L) +∑anions (meq/L)] / [∑cations (meq/L) -∑anions (meq/L)]*100%, (≤10%). This was mainly for the samples that were plotted on the trilinear Piper and Durov diagrams as the major cations and anions are used. Samples that failed the (EN) and (EC) evaluation were predominantly due to incomplete data for the major anions and cations. For the summary tables listing statistical information such as the maximum and minimum concentration for parameters, some of the analysis was used even if the plausibility checks were not acceptable.

The Brochure for the 1: 500 000 Polokwane hydrogeological map sheet used a basic method of general characterisation of water composition known as the Kurlov method (Kurlov, 1928). It is based on the relative concentrations of (meq/l) of major cations and anions. The data was used to create a stiff diagram that was described in terms of the dominant cations and anions

For the 1: 250 000 Modimolle map sheet, the limitations of the stiff diagram used as a single interpretation method were re-evaluated. Stiff diagrams are more suited to spatial comparisons by plotting each analysis on a map to identify trends and to identify water types on individual analysis. Spatial analysis based on stiff diagrams plotted on the map sheet area was not done but can be considered as a methodology for the 1:250 000 hydrogeological map series.

For the chemical evaluation of each aquifer unit, as described in this explanatory brochure for the map sheet, the methodology is as follows:

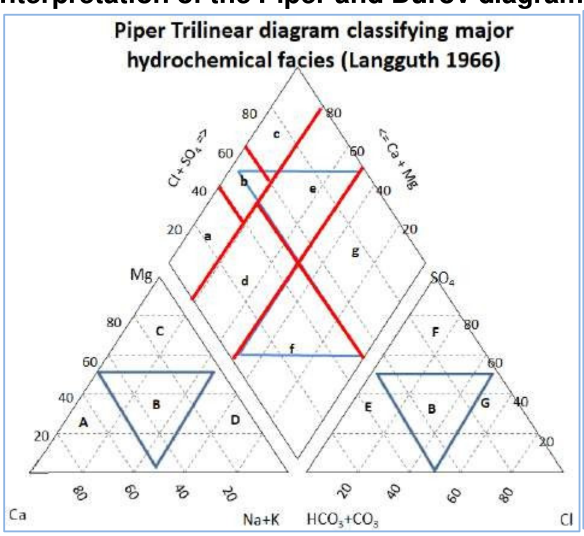
- A summary table within the general section of the document that lists the major cations, anions, and physical properties as presentations falling within the ideal, good, and moderate water ranges (DWS guideline document, Class 0-2). The last range is called unacceptable and represents the DWS guideline Class 3 & 4.
- A summary table within the section of each aquifer unit that constitutes a list of the combined samples in each aquifer. Information in the table includes, but is not limited to the number of analyses, maximum, minimum, percentiles (10%, 50% & 90%), and statistics on variation.
- The use of Piper and Durov diagrams for the evaluation of the water chemistry for each unit. It was used to identify water types and hydrochemical processes.

For both the Piper and Durov diagrams, the major ions are displayed as percentages of milli-equivalents in two ternary (trilinear) graphs, one for cations and one for anions (each parameter plot on one of the three axis). For the piper, the plot point for the major cations (Ca^{2}, Mg^{2}, Na^{+} + K^{+}) and anions (HCO_3^{-}, SO_4^{2-}, Cl^{-}) for each sample, in their respective triangular fields are projected along lines parallel to the triangular grid axes, ensuring a unique location in the central diamond field where a single plot point is created. This single point represents the composition of the cations and anions for each water analysis.

A similar procedure is followed for the Durov diagram, but the plot points are extended into a central square field along lines parallel to the proportional axes of the triangular grid. This ensures a unique location (single plot point) in the square for each sample. This single point represents both the anions and cations (thus 6 values are presented as one point).

- The assertion is that most natural waters contain cations and anions in chemical equilibrium. It is assumed that the most abundant cations are two "alkaline earths" that is calcium (Ca^{2}) and magnesium (Mg^{2}) and one "Alkali" that is sodium (Na^{+}). For the plot, sodium and potassium (K^{+}) are combined on one axis. The most common anions are, one "weak acid" namely, bicarbonate
- (HCO_3^{-}) and two "strong acids" namely, sulphate (SO_4^{2-}) and chloride (Cl^{-}).

Interpretation of the Piper and Durov diagrams:



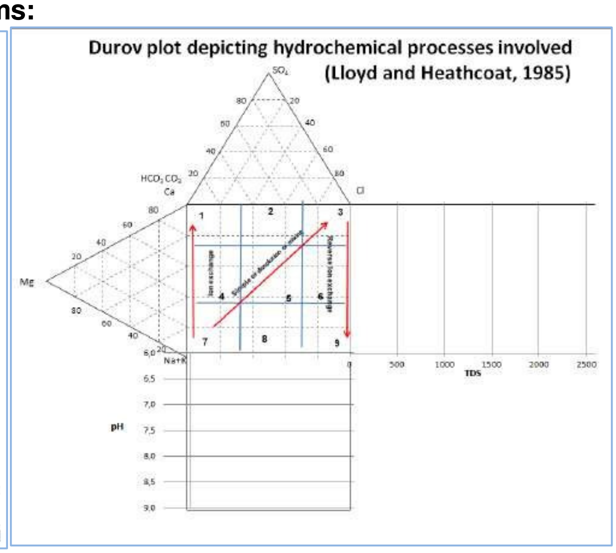


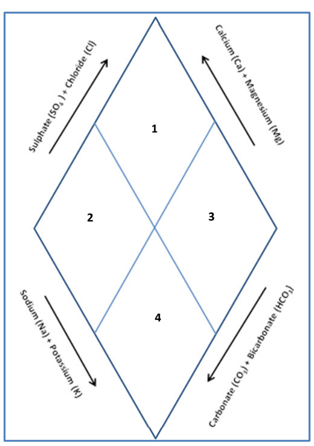
Table 13: Classification of water based on Piper diagram (Langguth, 1966), Water types.

Diamond shape diagram	Triangles	
Normal earth alkaline water with prevailing bicarbonate	A	Calcium type
Normal earth alkaline water with prevailing bicarbonate and sulphate or chloride	B	No Dominant type
Normal earth alkaline water with prevailing sulphate or chloride	C	Magnesium type
Earth alkaline water with increased portions of alkalis with prevailing bicarbonate	D	Sodium type
Earth alkaline water with increased portions of alkalis with prevailing sulphate and chloride	E	Bicarbonate type
Alkaline water with prevailing bicarbonate	F	Sulphate type
Alkaline water with prevailing sulphate or chloride	G	Chloride type

Table 14: Classification of water types based on Durov diagram (Lloyd and Heathcote, 1985).

Section	Water Types
1	HCO_3^- and Ca^{2+} dominant frequently indicates recharging waters in limestone, sandstone and many other aquifers
2	The water is dominated by Ca^{2+} and HCO_3^-, which typically suggests fresh, recharging groundwater, but if $Mg^{2+}$is also present in significant amounts, it suggests ion exchange processes might be occurring. However, those samples in which Na^+ is significant and $Ca^{2+}/Mg^{2+} < 1$ an important ion exchange is presumed.
3	HCO_3^- and Na^+ are dominant, normally indicates ion exchanged water, although the generation of CO_2 at depth can produce HCO_3^- where Na^+ is dominant under certain circumstances.
4	SO_4^{2-} dominates, or anion discriminate and Ca^{2+} dominant, Ca^{2+} and SO_4^{2-} dominant, frequently indicates recharge water in lava and gypsiferous deposits, otherwise mixed water exhibiting simple dissolution may be indicated.
5	No dominant anion or cation, indicates water exhibiting simple dissolution or mixing, plots along the dissolution or mixing line.
6	SO_4^{2-} dominates, or anion discriminate and Na^+ dominant, is a water type that is not frequently encountered and indicate probable mixing or uncommon dissolution influences.
7	Cl^- and Na^+ dominant is frequently encountered unless cement pollution is present. Otherwise, the water may result from reverse ion exchange of Na-Cl waters.
8	Cl^- dominant anion and Na^+ dominant cation, indicate that the ground waters be related to reverse ion exchange of Na-Cl waters
9	Cl^- and Na^+ dominant is frequently indicated end-point down gradient waters through dissolution.

Interpretation: Piper diamond shaped diagram



Section	Hydrochemical facies, general interpretation of chemical dominance
1	Strong acids exceed weak acids, Alkaline earths exceed alkalines.
2	Weak acids exceed strong acids, Alkaline earths exceed alkalines.
3	Strong acids exceed weak acids, Alkaline exceed alkaline earths.
4	Weak acids exceed strong acids, Alkaline exceed alkaline earths.

The samples within division 1 & 2- represent the dominance of alkaline earths over alkalies namely, (Ca^2 + Mg^2) > (Na^+ + K^+) and division 3 & 4 represents the dominance of alkalies over alkaline earths namely, (Na^+ + K^+) > (Ca^2 + Mg^2).

The samples within division 2 & 4 represent the dominance of weak acidic anions over strong acidic anions namely, (CO_3^{2-} + HCO_3^-) > (SO_4^{2-} + Cl^-) and division 1 and 3 represent the dominance of strong acidic anions over weak acidic anions namely, (SO_4^{2-} + Cl^-) > (CO_3^{2-} + HCO_3^-).

Water quality in terms of Electrical Conductivity (EC)

The general water quality in terms of EC in each of the units is described as:

- Ideal (EC < 70mS/m),
- Good (EC ≥ 70 < 150mS/m),
- Moderate (EC ≥ 150 < 370mS/m),
- Unacceptable (EC ≥ 370mS/m).

6.1 Aquifer Hydrochemistry

Data obtained from the National Water Quality Database (WMS), NGA, and the groundwater data bank of the consultancy were utilised for hydrochemical data analysis and interpretation. The data points were plotted and sorted for each aquifer unit.

Data is presented in various tables of which Table 15 to Table 26 are within Section 6 namely, General: Hydrochemistry and Aquifer Units.

Table 15 & Table 16 represent the identification of the water types for each unit by using the Piper Diagram and the classification as proposed by Langguth 1966. More than one water type was identified for most of the units. This is as many of the units have a large areal extent and interact with various other units in a lateral and vertical direction. The water types were identified but no attempt was made to link the different water types to a geolocation for further assessment. For instance, it is known that within the Letaba Formation the Calcium and Magnesium Bicarbonate water is related to the adjacent dolomite in the northern section of the unit.

Table 17 & Table 18 summarize statistics for the major cations and anions within each aquifer unit. In the summary table the median value (50^{th} percentile) is presented. This table will give an indication of the median concentration in mg/l for each of the major cations and anions within the aquifer but does not show the percentages of samples that fall within the acceptable or unacceptable range. Table 19 & Table 20 summarize the values of the 90^{th} percentile for the major anions and cations.

Table 21 & Table 22 summarize statistics for the major anions and Table 23 & Table 24 for the major cations within each aquifer unit. The data presented entails the percentages of each parameter that fall within the acceptable (ideal, good, marginal) and unacceptable limits for domestic use. These statistics are very useful in terms of problematic constituents that can be expected in each of the units during the planning phase of groundwater development projects. The water quality ranges used to divide the data for each parameter is according to the DWS guideline namely, Class 0, Class 1 and Class 2; the final range represents the classes 3 & 4 referred to in the table as the unacceptable limit range.

Table 25 & Table 26 represent the physical properties namely, Electrical Conductivity and Ph as well as the anion Fluoride. The same methodology was followed as in Table 21 & Table 24.

For each of the aquifer units another summary table is included within the description for each unit. This gives statistics on concentrations for various parameters such as minimum, maximum, 10, 50 and 90th percentiles. It also includes the corrosiveness of the water and the suitability for irrigation in terms of the Sodium adsorption ratio (SAR) that can be used for desktop studies.

In total 5 aquifer units did not have any chemistry data available for analysis. They are Dolerite Jurassic (Jdo); Aasvoëlkop Formation (Mas); Glentig Formation (Vgl); Lakenvalei Formation (Vla) and the (Unnamed Granite (Vaalian rocks) (Vz). Another 8 units have only between 1 to 10 analyses available that may result in a less accurate evaluation of the characterization of the unit in regard to chemistry.

A: Normal earth alkaline water with prevailing Bicarbonate

- **Calcium Magnesium Bicarbonate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anion HCO_3^-. The units dominated by this water type are predominantly within the dolomites or the aquifers are connected to the dolomites. The units are Penge Formation (Vpe-53.8%), Black Reef Formation (Vbr-61%) and Wolkberg Group (Vwo-80%). This water type was also identified in another 12 units ranging from 1.1% to as high as 30%.

- **Calcium Bicarbonate water**

This water type is dominated by the cation Ca^{2+} and the anion HCO_3^-. The unit dominated by this water type is predominantly within the dolomites or the aquifers are connected to limestone within the dolomites. This water type was identified in 10 units ranging from 1.9% to as high as 31.3%.

- **Magnesium Bicarbonate water**

This water type is dominated by the cation Mg^{2+} and the anion HCO_3^-. Aquifer units that have a large percentage of water falling within this type are the Schilpadkop Formation (Msc-100%); Malmani Subgroup (Vma-66.6%); Rustenburg Layered Suite (Vrs-27.1%) and the Hout River Gneiss (Rho-80%). The Malmani Subgroup consists of dolomite. This water type was also identified in another 7 units ranging from 1.6% to as high as 14.3%.

B: Normal earth alkaline water with prevailing Bicarbonate and Sulphate or Chloride

The water type may represent a transition from fresh recharge water rich in (Ca-HCO_3), towards more evolved groundwater influenced by additional mineral dissolution and ion exchange over time. This water type can be linked to carbonate (limestone, dolomite, and marble) and evaporite rocks [Gypsum ($CaSO_4 2H_2O$); Anhydrite ($CaSO_4$) → Contribute Ca^{2+} and SO_4^{2-}] and [Halite (NaCl) → Introduces Cl^-], thus shifting water chemistry from a bicarbonate dominance toward chloride influence. It may also be linked to some siliciclastic formations and mixed sediments; [Alluvial and glacial deposits with mixed lithology → Provide a combination of Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, and Cl^-] and [Sandstones and conglomerates with carbonate cements → Release Ca^{2+} and HCO_3^- into solution].

- **Calcium Magnesium Bicarbonate Sulphate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anions HCO_3^- and SO_4^{2-}. No units were identified with this water type as the dominant type.

- **Calcium Magnesium Bicarbonate Chloride water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anions HCO_3^- and Cl^-. The aquifer unit Kransberg Subgroup (Mkr -25%) is partly dominated by this type of water. Another 2 units were identified with this water type but not as the dominant type, it constituted 0.2% and 20.7% respectively.

- **Calcium Bicarbonate Chloride water**

This water type is dominated by the cation Ca^{2+} and the anions HCO_3^- and Cl^-. Although this water type was identified within some of the units none are dominated, the Makgabeng Formation (Mma -33.3%) has one borehole out of three that comprise of this water type. It was also identified in another unit where it constitutes 5%, (Goudplaats Gneiss, Zgo)

- **Magnesium Bicarbonate Chloride water**

This water type is dominated by the cations Mg^{2+} and the anions HCO_3^- and Cl^- . Although this water type was identified within 7 of the units it never exceeds 10%.

C: Normal earth alkaline water with prevailing Sulphate or Chloride

This water type indicates groundwater that has evolved beyond the early recharge stage (Ca- HCO_3 type) and has undergone additional mineral dissolution, cation exchange, or mixing with older water. If gypsum or halite is present, bicarbonate dominance may shift to sulphate or chloride. If sandstone and clays are present with evaporites as the binding chemical cementation, the water type can mitigate over time by slow dissolution of gypsum or halite from pore spaces.

- **Calcium Magnesium Sulphate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anion SO_4^{2-}. The sulphate water is usually associated with groundwater encountered in lavas and gypsum deposits.
The water type was not identified in any of the aquifer units due to the dominance of HCO_3 and Cl^-

- **Calcium Magnesium Chloride water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anion Cl^-. This water type was identified within the Irrigasie Formation (P-Tr-47.4%) and the Penge Formation (Vpe- 30.8%), as a significant percentage of the water but not the dominant type. The cation content is variable. Where Ca^{2+} and Mg^{2+} are dominant, water is related to reverse ion exchange (replacement of Na^+ with Ca^{2+} and Mg^{2+}). It was also identified in another 6 units but as a minor water type, (0.2% to 10%).

- **Magnesium Chloride water**

This water type is dominated by the cation Mg^{2+} and the anion Cl^-. This water type was identified within 4 aquifer units but not as the dominant type. The type is indicative of reverse ion exchange.

- **Calcium Chloride water**

This water type is dominated by the cation Ca^{2+} and the anion Cl^-. This water type was identified within 3 aquifer units but not as the dominant type.

D: Earth alkaline water with increasing portions of alkalis with prevailing Bicarbonate

This water type represents a transitional stage between calcium-magnesium-bicarbonate (Ca-Mg-HCO_3) and sodium-bicarbonate (Na-HCO_3) or mixed-alkali-bicarbonate (Na-K-HCO_3) water types. It suggests progressive water evolution due to mineral dissolution, cation exchange, and prolonged groundwater interaction with rocks. Rock types associated with the evolution of this water type includes siliciclastic rocks and clay-rich sediments that will be the source of Na^+ and K^+, it includes Feldspar-bearing rocks (granite, gneiss, arkosic sandstone) where the weathering of alkali feldspars (e.g., orthoclase, plagioclase) releases Na^+ and K^+. This increases Na^+ and K^+ concentrations, shifting the water type toward an alkali dominance. Clay minerals such as illite, montmorillonite, kaolinite participate in cation exchange reactions, replacing Ca^{2+} and Mg^{2+} with Na^+ and K^+. Volcanic Rocks such as basalt, rhyolite and trachyte are another potential source of alkalis and silica where weathering of volcanic glass and feldspar minerals releases Na^+ and K^+, thus increasing the alkali contribution.

- **Mixed Calcium Magnesium Bicarbonate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentration with the dominant anion HCO_3^-. In 29 of the aquifer units this type was identified. The following units are either dominated by this type, or a large percentage of the samples fall within it. The units are Tertiary Quaternary Alluvial Deposits (Q-29.9%), Clarens Formation (Trc-20.6%), Vaalwater Formation (Mva-46%), Cleremont Formation (Mcl-42.1%); Makgabeng Formation (Mma -33.3%), Alma Formation (Mag-45.5%), Swaershoek Formation (Ms-40%), Rashoop Granophyre Suite (Mr-50%), Letaba Formation (Jle-44.5%); Diabase (N-Za-40.8%), Spitskop Complex (Msp-28.5%), Nebo Granite (Mn-49.2%), Pretoria Group (Vpg-22.7%), Meinhardskraal Granite (Vme-100%), Lunsklip Granite (Ri-Vi-58.4%), Turfloop Granite (Rt-Vt-52.7%), Geyser Granite (Rge-44.5%), Goudplaats Gneiss (Zgo-68%) and the Mothiba Formation (Pietersburg Greenstone Belt) (Zpg- 50%).

E: Earth alkaline water with increasing portions of alkalis with prevailing Sulphate and Chloride

This water type represents a transition from calcium-magnesium dominance to increasing sodium and potassium proportions, with sulphate (SO_4^{2-}) and chloride (Cl^-) prevailing. The evolution of this water type can relate to a combination of evaporite dissolution, cation exchange, and prolonged groundwater residence time. The hydrochemical process and evaporite dissolution is a primary source of SO_4^{2-} and Cl^-. With the dissolution of gypsum, anhydrite, halite, and sylvite Ca^{2+}, Na^+, K^+, SO_4^{2-}, and Cl^- are released. This is a major driver of sulphate-chloride dominance in groundwater.

The hydrochemical process in which cation exchange dominates relates the abundance of clay minerals such as illite, montmorillonite, smectite and kaolinite. Over time Ca^{2+} and Mg^{2+} is replaced with Na^+ and K^+ and will lead to a progressive shift from Ca-Mg-SO_4-Cl water to Na-K- SO_4-Cl water.

Other processes such as silicate weathering will release Na^+ and K^+, thus enhancing the alkali proportions in the groundwater. This relates to the weathering of feldspar that contributes to the gradual enrichment of Na^+ and K^+ over time. This process occurs more in deep groundwater or areas with prolonged rock-water interaction.

- **Mixed Calcium Magnesium Sulphate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentrations and the anion SO_4^{2-}. None of the units were identified with this type of water.

- **Mixed Calcium Magnesium Chloride water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentrations and the anion Cl^-. In 13 of the aquifer units this type was identified. The following units are either dominated by this type, or a large percentage of the samples fall within it. The units are Tertiary Quaternary Alluvial Deposits (Q-22.4%), Clarens Formation (Trc-22.9%), Makgabeng Formation (Mma-33.3%), Rashoop Granophyre Suite (Mr-50%), Letaba Formation (Jle-23.8%), Ecca Formation (Ppe-25.5%), Rustenburg Layered Suite (Vrs-24%), and the Turfloop Granite (Rt-Vt-22.8%).

- **Mixed Calcium Magnesium Bicarbonate Chloride water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentrations and the anions HCO_3^- and Cl^-. Although this water type was identified within 7 of the units it is never the dominant water type, it constitutes between 2.5% to 28% of the water types.

- **Mixed Calcium Magnesium Chloride Sulphate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentrations and the anions Cl^- and SO_4^{2-}. Although this water type was identified within 5 of the units it only occurs as a large percentage in the Nebo Granite (Mn-18.2%).

F: Alkaline water with prevailing Bicarbonate

This water type is typically characterized by high Na^+ and K^+ concentrations with HCO_3^- as the dominant anion. It results from long-term rock-water interactions, cation exchange, and silicate weathering, with minimal influence from evaporite dissolution.

Associated rock types with this water type is feldspar-rich rocks such as igneous and metamorphic rocks (granites and gneisses); volcanic rocks (basalt, andesite, rhyolite, trachyte and tuff); carbonate rocks, (that may only be the original source of HCO_3^-), quartz-rich sandstones, (contain feldspars and clay minerals that release Na^+ and K^+ upon weathering) and clay-rich sediments, (shale, mudstone, and alluvial deposits that contain clay minerals, (montmorillonite, illite, kaolinite), which exchange Ca^{2+} and Mg^{2+} for Na^+ and K^+ (cation exchange), thus shifting the groundwater chemistry to a Na-HCO_3 type.

- **Sodium Bicarbonate water**

This water type is dominated by the cation Na^+ and the anion HCO_3^-. This type of water is generally related to the movement of groundwater from intensive recharge areas and normally indicates a cation exchange process. The water type was identified in 20 units, only the ones that are dominated or where it occurs in a large percentage are listed. The units are Vaalwater Formation (Mva-21.6%), Schrikkloof Formation (Vsc-37.4%); Kwaggasnek Formation (Vkw- 62.5%), Spitskop Complex (Msp-42.9%), Klipkloof Granite (Mkk-27.3%), Lunsklip Granite (Ri-Vi- 25%), Turfloop Granite (Rt-Vt-21%), Geyser Granite (Rge-44.5%),

G: Alkaline water with prevailing Sulphate or Chloride

- **Sodium Sulphate water**

This water type is dominated by the cation Na^+ and the anion SO_4^{2-}. The sulphate water is usually associated with groundwater encountered in lavas and gypsum deposits. This water type was identified within 3 aquifer units but as low percentages, (0.6% to 12.5%).

- **Sodium Chloride water**

This water type is dominated by the cation Na^+ and the anion Cl^-. Within 20 units this water type was identified. The units that have a large percentage of water within this type are the Quaternary Alluvial Deposits (Q-25.3%), Clarens Formation (Trc-22.4%), Irrigasie Formation (P-Tr-43.9%), Kransberg Subgroup (Mkr-25%), Ecca Formation (Ppe-70.5%), Diabase (N-Za-22.2%), Uitloop Granite (Ru-Vu-100%).

- **Sodium Chloride Sulphate water**

This water type is dominated by the cation Na^+ and the anions Cl^- and SO_4^{2-}. This water type was identified within 2 aquifer units but not as the dominant type, (9% to 13.1%).

Other problem chemical species, which occur in the area covered by the map sheet, include Nitrate and Fluoride (Figure 7, page 54). Nitrate and nitrite concentrations reported as N greater than 10mg/l can cause Methemoglobinemia (blue baby syndrome) in children younger than two years. Fluoride concentrations greater than 1.5mg/l can cause brown staining and the crumbling of teeth and bone structure.

Table 15: Interpretation of the hydrochemical facies, water type, first page

Aquifer Unit	samples used	Calcium Magnesium Bicarbonate	Calcium Bicarbonate	Magnesium Bicarbonate	Calcium Magnesium Bicarbonate Sulphate	Calcium Magnesium Bicarbonate Chloride	Calcium Bicarbonate Chloride	Magnesium Bicarbonate Chloride	Calcium Magnesium Sulphate	Calcium Magnesium Chloride	Magnesium-Chloride	Calcium-Chloride	Mixed Calcium Magnesium Bicarbonate	Mixed Calcium Magnesium Sulphate	Mixed Calcium Magnesium Chloride	Mixed Calcium Magnesium Bicarbonate Chloride	Mixed Calcium Magnesium Chloride-Sulphate	Sodium Bicarbonate water	Sodium Sulphate water	Sodium Chloride water	Sodium Chloride Sulphate
Category A: Intergranular aquifers																					
Q	**67**			7.5				1.5			10.4		29.9		22.4			3.0		25.3	
Category B: Fractured aquifers																					
Jdo	**0**	No samples available or no samples passed the plausibility tests (EN and EC)																			
Trc	**170**	7.1	2.9	2.4								6.5	20.6		22.9			14.6	0.6	22.4	
P-Tr	**57**							1.7		47.4			7.0							43.9	
Mkr	**12**	8.3	8.3			25.0							16.7				16.7			25.0	
Mva	**37**	10.8						2.7					46.0		10.8			21.6		8.1	
Mcl	**19**		21.1										42.1		10.5		10.5	15.8			
Mas	**0**	No samples available or no samples passed the plausibility tests (EN and EC)																			
Mma	**3**						33.3						33.3		33.3						
Msc	**1**			100.0																	
Mag	**22**	18.2								4.5			45.5				4.5	18.2		9.1	
Ms	**25**		8.0							4.0			40.0			28.0		8.0		12.0	
Vgl	**0**	No samples available or no samples passed the plausibility tests (EN and EC)																			
Vsc	**25**		31.3										12.5			6.3		37.4		12.5	
Vkw													12.5					62.5	12.5	12.5	
Mr	**2**												50.0		50.0						
Vla	**0**	No samples available or no samples passed the plausibility tests (EN and EC)																			
Vti	**0**	No samples available or no samples passed the plausibility tests (EN and EC)																			
Vpe	**13**	53.8								30.8			15.4								
Vbr	**18**	61.0		11.1				5.6				5.6	16.7								
Vwo	**5**	80.0	20.0																		
Category C: Karst aquifers																					
Vma	**99**	13.1	15.2	66.6									5.1								
Note: Dominant type highlighted																					

Table 16: Interpretation of the hydrochemical facies, water type, second page

Symbol and number of samples		A: Normal earth alkaline water with prevailing Bicarbonate			B: Normal earth alkaline water with prevailing Bicarbonate and Sulphate or Chloride				C: Normal earth alkaline water with prevailing Sulphate or Chloride				D: Earth alkaline water with increasing portions of alkalis with prevailing Bicarbonate	E: Earth alkaline water with increasing portions of alkalis with prevailing Sulphate and Chloride				F: Alkaline water with prevailing Bicarbonate	G: Alkaline water with prevailing Sulphate or Chloride		
Aquifer Unit	samples used	Calcium Magnesium Bicarbonate	Calcium Bicarbonate	Magnesium Bicarbonate	Calcium Magnesium Bicarbonate Sulphate	Calcium Magnesium Bicarbonate Chloride	Calcium Bicarbonate Chloride	Magnesium Bicarbonate Chloride	Calcium Magnesium Sulphate	Calcium Magnesium Chloride	Magnesium-Chloride	Calcium-Chloride	Mixed Calcium Magnesium Bicarbonate	Mixed Calcium Magnesium Sulphate	Mixed Calcium Magnesium Chloride	Mixed Calcium Magnesium Bicarbonate Chloride	Mixed Calcium Magnesium Chloride-Sulphate	Sodium Bicarbonate water	Sodium Sulphate water	Sodium Chloride water	Sodium Chloride Sulphate
Category D: Intergranular and Fractured aquifers																					
Jle	321		1.9	1.6				1.6		6.3	4.1		44.5		23.8	2.5		7.2		6.5	
Ppe	51									2.0					25.5			2.0		70.5	
N-Za	27	11.1	3.7										40.8		11.1	7.4		3.7		22.2	
Msp	14		14.3	14.3									28.5					42.9			
Mkk	10												18.2		9.1	18.2	18.2	27.3			9.0
Mn	534	1.1				0.2				0.2			49.2					19.9	3.2	13.1	13.1
Vrs	648	6.7		27.1		20.7		1.2			2.9	0.5	3.8		24.0			2.7		10.3	
Vpg	170	18.8		9.4							3.6		22.7		12.3	13.7		4.3		15.2	
Vme	6												100.0								
Vz	0	No samples available or no samples passed the plausibility tests (EN and EC)																			
Ru-Vu	3																			100.0	
Rl-Vl	12												58.4				8.3	25.0		8.3	
Rt-Vt	59												52.7		22.8			21.0		3.5	
Rge	9			11.0									44.5					44.5			
Rho	25			80.0									4.0					12.0		4.0	
Zgo	19						5.0						68.0			11.0				16.0	
Zpg	10	30.0						10.0		10.0			50.0								
Note: Dominant type highlighted																					

Table 17: Hydrochemistry of the Modimolle Map Area, 50th percentile (median) first page

Symbol	Total number of samples				50th Percentile (median) and comparison to SANS 241:2015 maximum acceptable limits										
Aquifer Unit	**After manipulation**	**Missing major anions or cations**	**E.N. ? ±10% & EC ? 20%**	**Used for Piper and Durov**	**pH ideal 6 to 9**	**EC** mS/m	**NO_3** mg/l	**F** mg/l	**TAL as (CaCO3)** mg/l	**Na** mg/l	**Mg** mg/l	**SO_4** mg/l	**Cl** mg/l	**K** mg/l	**Ca** mg/l
						370	**20**	**1.5**		**400**	**100**	**600**	**600**	**100**	**300**
Category A: Intergranular aquifers															
Q	**127**	60	52.8%	67	7.85	105.10	1.04	0.60	234.70	63.70	34.90	27.90	99.67	2.59	53.57
Category B: Fractured aquifers															
Jdo	**0**	No data available													
Trc	**242**	72	70.2%	170	7.77	75.20	2.06	0.35	175.90	63.38	14.77	8.24	77.21	3.83	45.85
P-Tr	**105**	48	54.3%	57	7.80	143.50	2.83	0.70	314.00	191.14	45.20	35.50	219.60	7.01	70.30
Mkr	**23**	11	52.2%	12	6.97	4.90	0.76	0.17	17.77	5.86	2.33	4.00	5.00	0.66	3.25
Mva	**42**	5	88.1%	37	8.10	55.60	0.68	0.27	211.65	42.95	15.65	9.54	25.43	1.37	30.06
Mcl	**31**	0	35.5%	19	7.41	15.10	1.06	0.15	51.05	7.64	3.17	4.00	6.67	0.86	7.92
Mas	**0**	No data available													
Mma	**5**	2	60.0%	3	7.64	43.30	15.30	0.30	177.20	44.50	11.98	12.10	27.30	1.80	44.80
Msc	**1**	0	100.0%	1	7.90	85.60	5.65	0.05	425.70	30.00	74.00	2.00	57.00		62.00
Mag	**41**	19	53.7%	22	7.30	36.84	0.44	0.28	131.80	25.89	11.00	6.68	11.37	1.22	26.75
Ms	**52**	27	48.1%	25	7.33	9.85	0.64	0.18	49.80	7.05	3.29	2.00	5.40	0.92	12.17
Vgl	**0**	No data available													
Vsc	**26**	0	57.7%	16	7.67	32.20	0.12	1.01	124.87	22.74	5.85	7.92	21.85	7.03	30.14
Vkw	**12**	0	50.0%	8	7.71	29	0.43	4.07	113.25	25.55	3.25	6.8	10.4	2.38	25.8
Mr	**2**	0	100.0%	2	7.62	86.49	6.35	0.83	208.08	81.07	25.42	5.02	130.65	1.89	59.63
Vla	**0**	No data available													
Vti	**2**	2	0.0%	0	7.70	65.90		0.04		27.65	79.20	47.25	64.95	2.92	46.80
Vpe	**17**	4	76.5%	13	8.01	67.09	3.45	0.26	295.85	21.90	40.97	11.07	23.45	2.65	65.76
Vbr	**22**	4	81.8%	18	8.16	30.96	0.27	0.15	124.95	5.91	11.95	6.01	6.60	2.04	24.05
Vwo	**8**	3	62.5%	5	8.05	35.07	1.58	0.17	185.46	5.40	23.23	3.77	12.04	2.68	38.47
Manipulation of samples: removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC															

Table 18: Hydrochemistry of the Modimolle Map Area, 50th percentile (median) second page

Symbol	Total number of samples				50th Percentile (median) and comparison to SANS 241:2015 maximum acceptable limits										
Aquifer Unit	**after manipulation**	**missing major anions or cations**	**E.N. ? ±10% & EC ? 20%**	**Used for piper and Durov**	**pH ideal 6 to 9**	**EC** mS/m	**NO_3** mg/l	**F** mg/l	**TAL as (CaCO3)** mg/l	**Na** mg/l	**Mg** mg/l	**SO_4** mg/l	**Cl** mg/l	**K** mg/l	**Ca** mg/l
						370	**20**	**1.5**		**400**	**100**	**600**	**600**	**100**	**300**
Category C: Karst aquifers															
Vma	**122**	23	81.1%	99	8.00	63.25	1.85	0.21	320.79	9.00	48.11	6.34	12.96	1.75	53.78
Category D: Intergranular and Fractured aquifers															
Jle	**998**	677	32.2%	321	7.80	86.30	19.29	0.25	258.26	48.50	41.00	22.00	40.07	2.91	73.47
Ppe	**66**	15	77.3%	51	7.94	258.95	2.91	3.49	317.10	354.05	71.15	106.12	536.10	13.90	62.05
N-Za	**30**	3	90.0%	27	7.97	104.44	5.00	1.34	311.80	97.39	27.45	26.17	93.29	4.33	42.70
Msp	**17**	3	82.4%	14	8.07	71.10	1.44	0.38	309.62	46.20	22.11	14.13	10.06	7.30	51.16
Mkk	**10**	0	100%	10	7.64	32.05	0.36	3.68	125.50	27.81	2.58	2.29	9.96	3.17	24.72
Mn	**668**	134	79.9%	534	7.80	43.60	2.89	1.29	120.95	42.52	5.92	8.60	32.97	3.36	29.10
Vrs	**909**	24	43.2%	546	8.08	119.76	14.53	0.27	353.00	65.70	77.76	50.63	100.20	1.71	69.35
Vpg	**194**	24	87.6%	170	7.80	90.15	1.98	0.53	289.01	53.10	38.05	19.09	57.56	2.44	59.27
Vme	**6**	0	100%	6	7.96	60.40	0.53	0.50	289.00	43.05	23.10	14.10	10.95	1.62	49.10
Vz	**0**	No data available													
Ru-Vu	**3**	0	100%	3	8.02	171.00	0.05	6.89	66.20	252.50	1.70	188.40	327.60	2.60	95.70
Rl-Vl	**13**	1	92.3%	12	8.25	35.80	1.25	2.13	104.70	23.50	10.15	7.40	10.50	0.83	16.70
Rt-Vt	**86**	27	68.6%	59	7.96	76.00	5.76	0.65	254.50	57.27	28.67	21.20	47.36	2.71	55.65
Rge	**13**	4	69.2%	9	8.21	62.60	4.21	0.67	227.87	54.51	22.08	13.19	33.80	2.02	40.03
Rho	**28**	3	89.3%	25	8.14	83.55	1.66	0.33	445.13	28.08	51.50	8.49	20.96	4.47	30.31
Zgo	**28**	9	67.9%	19	7.92	98.06	8.97	0.51	262.90	88.10	40.90	27.36	83.13	2.85	57.90
Zpg	**14**	4	71.4%	10	8.05	58.00	1.93	0.20	156.25	21.50	31.41	9.05	12.70	1.49	29.50
Manipulation of samples: removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC															

Table 19: Hydrochemistry of the Modimolle Map Area, 90th percentile (median); first page

Symbol	Total number of samples	90th Percentile (median) and comparison to SANS 241:2015 maximum acceptable limits													
Aquifer Unit	After manipulation	pH ideal 6 to 9	EC mS/m	NO_3 mg/l	F mg/l	TAL as (CaCO3) mg/l	Na mg/l	Mg mg/l	SO_4 mg/l	Cl mg/l	K mg/l	Ca mg/l	Fe mg/l	Mn mg/l	Zn mg/l
			370	20	1.5		400	200	600	600	100	300	2	1	10
Category A: Intergranular aquifers															
Q	**126**	8.25	269.06	14.34	4.14	429.94	308.65	135.00	170.69	603.19	6.86	150.93	0.06	0.50	0.21
Category B: Fractured aquifers															
Jdo	**0**	No data available													
Trc	**242**	8.21	156.09	13.10	2.80	403.65	184.00	68.98	70.75	310.44	8.66	105.39	0.05	0.05	2.32
P-Tr	**105**	8.41	430.84	23.55	3.09	426.20	399.00	165.60	123.58	1210.28	18.55	228.90	0.06	0.36	1.09
Mkr	**23**	7.91	129.42	4.32	0.33	366.66	109.09	56.18	20.40	223.72	5.00	47.01	0.40	0.05	3.32
Mva	**38**	8.39	89.49	5.08	0.50	349.48	89.01	57.52	27.13	96.44	5.73	53.36	0.05	0.05	0.06
Mcl	**31**	7.95	43.18	4.44	0.43	160.70	24.08	14.51	12.63	26.62	1.47	34.11	0.05	0.07	0.67
Mas	**0**	No data available													
Mma	**5**	8.07	117.48	17.79	2.18	219.18	92.06	59.64	82.86	168.08	12.99	70.29	0.05	0.05	0.03
Msc	**1**	7.90	85.60	5.65	0.05	425.70	30.00	74.00	2.00	57.00		62.00			
Mag	**41**	8.00	112.70	3.30	1.48	400.00	65.27	58.90	39.55	72.30	3.55	89.99	0.05	0.25	0.14
Ms	**52**	7.90	41.85	13.94	1.21	153.50	35.62	22.43	10.20	48.00	6.08	43.60	0.11	0.31	1.25
Vgl	**0**	No data available													
Vsc	**26**	7.95	170.31	21.79	5.29	291.35	191.95	45.92	54.30	284.16	14.43	85.82	0.01	0.16	0.10
Vkw	**12**	7.90	69.48	16.01	6.16	200.08	77.00	22.69	14.99	40.08	4.27	46.50	0.01		0.01
Mr	**2**	7.70	131.14	6.86	1.05	287.22	123.81	42.84	5.88	230.13	2.86	87.29	0.12	0.02	0.97
Vla	**0**	No data available													
Vti	**2**	7.76	67.26		0.04		28.97	82.88	50.65	69.87	3.06	53.68			
Vpe	**13**	8.27	123.69	18.42	0.45	339.99	31.74	77.50	36.91	184.79	3.53	111.71	0.08	0.05	0.09
Vbr	**22**	8.51	67.22	9.32	0.35	273.54	29.98	39.52	14.63	36.19	4.30	61.92	0.02	0.02	0.33
Vwo	**8**	8.63	66.62	7.48	0.37	256.09	17.83	42.68	18.20	27.91	4.66	49.70	0.07	0.04	0.42
Category C: Karst aquifers															
Vma	**96**	8.40	100.87	7.71	0.71	429.77	48.54	81.14	21.51	70.81	3.64	85.71	0.05	0.08	0.76
Manipulation of samples: removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC															

Table 20: Hydrochemistry of the Modimolle Map Area, 90th percentile (median); second page

Symbol	Total number of samples	90th Percentile (median) and comparison to SANS 241:2015 maximum acceptable limits													
Aquifer Unit	After manipulation	pH ideal 6 to 9	EC	NO_3	F	TAL as (CaCO3)	Na	Mg	SO_4	Cl	K	Ca	Fe	Mn	Zn
			mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
			370	20	1.5		400	200	600	600	100	300	2	1	10
Category D: Intergranular and Fractured aquifers															
Jle	**998**	8.26	201.48	40.65	0.58	363.62	116.95	105.60	108.63	328.80	8.86	137.95	0.05	0.06	0.30
Ppe	**66**	8.38	551.01	27.74	13.77	545.42	899.80	166.75	445.24	1450.85	36.75	214.36	0.07	0.26	0.43
N-Za	**30**	8.36	180.88	10.37	4.41	420.90	286.78	80.06	83.82	312.04	13.47	90.71	0.05	0.65	2.29
Msp	**17**	8.38	99.86	10.27	0.96	495.75	110.76	58.16	34.76	31.36	10.99	86.27	0.04	1.09	0.07
Mkk	**10**	8.41	47.09	2.31	4.87	155.12	46.77	5.16	22.48	40.07	5.86	45.18	0.28	0.05	0.85
Mn	**565**	8.34	147.68	23.73	4.40	320.68	172.75	41.17	75.69	236.91	11.77	79.43	0.10	0.28	1.99
Vrs	**909**	8.46	276.30	44.99	1.13	508.00	251.37	158.13	198.00	538.33	6.48	144.59	0.05	0.10	0.85
Vpg	**148**	8.29	380.52	19.09	4.16	424.78	424.07	116.53	102.84	876.25	21.55	148.07	0.08	0.19	1.24
Vme	**6**	8.52	63.70	1.62	0.88	310.20	55.45	27.41	22.70	17.35	3.35	56.20	0.02	6.82	0.04
Vz	**0**	No data available													
Ru-Vu	**3**	8.40	177.40	0.21	7.17	134.76	279.30	4.58	283.84	393.76	3.22	97.78			
Rl-Vl	**12**	8.58	50.72	6.81	2.93	168.88	62.97	14.84	60.68	21.23	2.51	34.44			
Rt-Vt	**85**	8.47	137.19	26.18	3.19	370.59	168.14	52.05	65.03	153.15	6.18	90.86	0.05	0.50	0.68
Rge	**13**	8.42	76.88	22.72	3.80	280.23	82.08	34.74	32.13	61.35	4.08	66.70	0.76	0.12	6.80
Rho	**28**	8.46	107.85	7.55	1.19	545.10	76.04	87.97	30.13	74.37	8.57	79.93	0.05	0.01	0.97
Zgo	**28**	8.44	121.60	45.89	1.02	424.39	153.16	50.85	72.81	120.42	6.88	93.62	0.36	0.37	3.42
Zpg	**14**	8.47	79.68	6.44	1.92	271.21	34.94	47.47	34.79	52.75	2.62	72.01	0.05	0.05	0.15
Manipulation of samples: removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC															

Table 21: Summarized Major Anions: Chloride, Nitrate and Sulphate concentration ranges within aquifer units, first page

Aniones		Chloride Cl (mg/l)				Nitrate NO2 + NO3 as N (mg/l)				Sulphate SO4 (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable
Limit Ranges		100	200	600	>600	6	10	20	>20	200	400	600	>600
Category A: Intergranular aquifers													
Q	126	50.0%	13.9%	25.4%	10.7%	74.2%	11.7%	5%	9.2%	95.1%	1.6%	0.8%	2.4%
Category B: Fractured aquifers													
Jdo	0												
Trc	242	62.0%	16.5%	18.6%	2.9%	71.5%	12.0%	12.4%	4.1%	98.8%	0.4%	0.4%	0.4%
P-Tr	105	16.2%	29.5%	39.0%	15.2%	64.7%	6.9%	15.7%	12.7%	92.4%	4.8%	2.9%	
Mkr	23	81.8%	4.5%	13.6%		90.5%			9.5%	100%			
Mva	42	89%	5.3%	5.3%		92.1%	5.3%	2.6%		100%			
Mcl	31	100%				93.3%	3.3%		3.3%	100%			
Mas	0												
Mma	5	60%	40%			20%		80%		100%			
Msc	1	100%				100%				100%			
Mag	41	92.7%	2.4%	2.4%	2.4%	92.3%		2.6%	5.1%	100%			
Ms	52	92.2%	2.0%	5.9%		83%	4.3%	8.5%	4.3%	100%			
Vgl	0												
Vsc	26	84.6%	3.8%	3.8%	7.7%	72.0%	8.0%	8.0%	12.0%	96.2%	3.8%		
Vkw	12	91.7%	8.3%			83.3%		8.3%	8.3%	100.0%			
Mr	2	50%		50%		50%	50%			100%			
Vla	0												
Vti	2	100%								100%			
Vpe	13	69.2%	23.1%	7.7%		61.5%	7.7%	23.1%	7.7%	100.0%			
Vbr	22	100.0%				82%	9.1%	9.1%		100%			
Vwo	8	100%				87.5%		12.5%		100%			
Category C: Karst aquifers													
Vma	96	94.7%	4.3%		1.1%	81.9%	12.8%	5.3%		98.9%		1.1%	
Note: 0% removed to make the table more readable													

Table 22: Summarized Major Anions: Chloride, Nitrate and Sulphate concentration ranges within aquifer units, second page

Aniones		Chloride Cl (mg/l)				Nitrate NO2 + NO3 as N (mg/l)				Sulphate SO4 (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable
Limit Ranges		100	200	600	>600	6	10	20	>20	200	400	600	>600
Category D: Intergranular and Fractured aquifers													
Jle	998	73.1%	10.4%	11.7%	4.7%	21.7%	8.7%	22.1%	48%	95.1%	3.4%	1.3%	0.1%
Ppe	66	1.5%	7.6%	45.5%	45.5%	58%	7.6%	15.2%	20%	80.3%	7.6%	3.0%	9.1%
N-Za	30	50.0%	30%	20.0%		63%	20.0%	13.3%	3%	97%	3%		
Msp	17	100%				70.6%	11.8%	17.6%		100%			
Mkk	10	100%				100%				100%			
Mn	565	77.7%	9.7%	10.3%	2.3%	63%	9.4%	14.0%	13.3%	98.6%	1.4%		
Vrs	909	50.0%	20.1%	21.4%	8.5%	27.3%	10.5%	25.0%	37.2%	90.4%	7.0%	1.8%	0.8%
Vpg	148	58.8%	12.2%	18.2%	10.8%	72.1%	9.5%	10.2%	8%	96.6%	1.4%	1.4%	0.7%
Vme	6	100.0%				100.0%				100%			
Vz	0												
Ru-Vu	3	33%				100%				67%	33%		
Rl-Vl	12	91.7%	8.3%			75%	25%			100%			
Rt-Vt	85	75.3%	20%	4.7%		51.8%	15.7%	13.3%	19.3%	100%			
Rge	13	100.0%				54.5%	27.3%		18.2%	100%			
Rho	28	96.4%	3.6%			85.2%	7.4%	7.4%		100%			
Zgo	28	60.7%	35.7%	3.6%		28.6%	32.1%	14.3%	25%	100%			
Zpg	14	92.9%	7.1%			85.7%	7.1%		7.1%	100%			
Note: 0% removed to make the table more readable													

Table 23: Summarized Major Cations: Calcium, Potassium, Magnesium and Sodium concentration ranges within aquifer units, first page

Cations		Calcium Ca (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Sodium Na (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable
Limit Ranges		80	150	300	>300	25	50	100	>100	30	70	100	>100	100	200	400	>400
Category A: Intergranular aquifers																	
Q	126	64.8%	24.6%	7.4%	3.3%	100%				46.7%	25.4%	11.5%	16.4%	65.8%	16.2%	12.8%	5.1%
Category B: Fractured aquifers																	
Jdo	0																
Trc	242	80.2%	17.4%	1.7%	0.8%	99.5%		0.5%		63.6%	26.9%	4.1%	5.4%	62.8%	28.5%	7.4%	1.2%
P-Tr	105	57.4%	22.8%	15.8%	4.0%	96.3%	2.4%	1.2%		37.6%	34.7%	11.9%	15.8%	15.8%	40.6%	33.7%	9.9%
Mkr	23	95.5%	4.5%			100%				81.8%	13.6%	4.5%		90.0%		10.0%	
Mva	42	97.3%	2.7%			100%				73.0%	21.6%	2.7%	2.7%	89.5%	7.9%	2.6%	
Mcl	31	100%				100%				100%				100%			
Mas	0																
Mma	5	100.0%				100%				60.0%	40.0%			100%			
Msc	1	100.0%										100%		100%			
Mag	41	87.9%	12.1%			100%				66.7%	27.3%	3.0%	3.0%	92.5%	5.0%	2.5%	
Ms	52	93.2%	2.3%	4.5%		100%				93.2%	4.5%		2.3%	97.7%	2.3%		
Vgl	0																
Vsc	26	84.6%	15.4%			100.0%				96.2%	3.8%			80.8%	7.7%	7.7%	3.8%
Vkw	12	91.7%	8.3%			100.0%				100.0%				91.7%	8.3%		
Mr	2	50%	50%			100%				50%	50%			50%	50%		
Vla	0																
Vti	2	100%				100%						100%		100%			
Vpe	13	61.5%	38.5%			100%				7.7%	61.5%	30.8%		100.0%			
Vbr	22	100.0%				100%				86.4%	13.6%			100%			
Vwo	8	100%				100%				57.1%	42.9%			100%			
Category C: Karst aquifers																	
Vma	96	85.1%	14.9%			100.0%				17.0%	71.3%	7.4%	4.3%	97.8%	1.1%		1.1%
Note: 0% removed to make the table more readable																	

Table 24: Summarized Major Cations: Calcium, Potassium, Magnesium and Sodium concentration ranges within aquifer units, second page

Cations		Calcium Ca (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Sodium Na (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable
Limit Ranges		80	150	300	>300	25	50	100	>100	30	70	100	>100	100	200	400	>400
Category D: Intergranular and Fractured aquifers																	
Jle	998	59.3%	32.0%	7.3%	1.3%	99.6%	0.4%			27.1%	54.2%	7.9%	10.8%	85.9%	12.7%	1.2%	0.2%
Ppe	66	59.1%	22.7%	16.7%	1.5%	73.4%	25.0%	1.6%		30.3%	19.7%	10.6%	39.4%	4.5%	7.6%	42.4%	45.5%
N-Za	30	80.0%	20.0%			100.0%				50.0%	33.3%	13.3%	3.3%	53.3%	20.0%	26.7%	
Msp	17	76.5%	23.5%			100%				76.5%	11.8%	11.8%		82.4%	17.6%		
Mkk	10	100%				100%				100%				100%			
Mn	565	90.1%	8.1%	1.6%	0.2%	97.7%	2.0%	0.4%		84.6%	10.8%	2.3%	2.3%	78.3%	14.2%	5.3%	2.1%
Vrs	909	59.7%	31.3%	8.4%	0.7%	99.3%	0.7%			42.5%	24.3%	28.1%	5.1%	66.6%	19.5%	11.9%	2.0%
Vpg	148	73.6%	16.2%	7.4%	2.7%	94.3%	5.0%	0.7%		37.8%	39.2%	8.8%	14.2%	66.7%	10.6%	11.3%	11.3%
Vme	6	100%				100%				100.0%				100%			
Vz	0																
Ru-Vu	3	33%	67%			100%				100%					33%	67%	
Rl-Vl	12	100%				100%				100.0%				91.7%	8.3%		
Rt-Vt	85	87.3%	7.6%	5.1%		100%				52.5%	46.3%	1.3%		78.5%	15.2%	6.3%	
Rge	13	100%				100%				80.0%	20.0%			100%			
Rho	28	89.3%	10.7%			96.6%	3.4%			21.4%	32.1%	46.4%		92.9%	7.1%		
Zgo	28	77.8%	22.2%			100%				33.3%	63.0%	3.7%		66.7%	33.3%		
Zpg	14	100%				100%				38.5%	61.5%			100%			

Note: 0% removed to make the table more readable

Table 25: Summarized Electrical Conductivity, pH, and Fluoride concentration ranges within aquifer units, first page

Physical properties & F		Conductivity (mS/m)				pH (pH units)				Flouride F (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable
Limits Ranges		70	150	370	>370	4.0 -5.9	6.0-9.0	9.1 - 10.0	>10 & <4	0.7	1	1.5	>1.5
Category A: Intergranular aquifers													
Q	126	31.7%	38.2%	22.8%	7.3%		99.2%		0.8%	54.1%	11.5%	14.8%	19.7%
Category B: Fractured aquifers													
Jdo	0												
Trc	242	47.5%	39.7%	11.2%	1.7%	1.2%	98.8%			72.3%	6.6%	4.5%	16.5%
P-Tr	105	7.6%	45.7%	35.2%	11.4%		99%	1%		50.5%	10.5%	12.4%	26.7%
Mkr	23	83%	9%	9%		22%	78%			100%			
Mva	42	68.4%	28.9%	2.6%		2.6%	97%			97.4%	2.6%		
Mcl	31	97%	3.3%				100%			90.3%	3.2%	3.2%	3.2%
Mas	0												
Mma	5	60.0%	40.0%				100%			80%			20%
Msc	1		100%				100%			100%			
Mag	41	75.6%	19.5%	4.9%		2.4%	97.6%			72.5%	2.5%	15%	10%
Ms	52	94.2%	1.9%	3.8%		7.7%	90.4%		1.9%	82.4%	3.9%	5.9%	7.8%
Vgl	0												
Vsc	26	69.2%	19.2%	11.5%		3.8%	96.2%			42.3%	7.7%	11.5%	38.5%
Vkw	12	91.7%	8.3%				100.0%			33.3%			66.7%
Mr	0	50%	50%				100%			50%		50%	
Vla	0												
Vti	2	100%					100%			100%			
Vpe	13	53.8%	46.2%				100%			100%			
Vbr	22	90.9%	9.1%				100%			100%			
Vwo	8	87.5%	12.5%				100%			87.5%	12.5%		
Category C: Karst aquifers													
Vma	96	61.7%	37.2%	1.1%			98.9%	1.1%		90.0%	1.1%	7%	2.2%
Note: 0% removed to make the table more readable													

Table 26: Summarized Electrical Conductivity, pH, and Fluoride concentration ranges within aquifer units, second page

Physical requirements		Conductivity (mS/m)				pH (pH units)				Flouride F (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un- accept able	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un- acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un- acceptable
Limits Ranges		70	150	370	>370	4.0 -5.9	6.0-9.0	9.1 - 10.0	>10 & <4	0.7	1	1.5	>1.5
Category D: Intergranular and Fractured aquifers													
Jle	998	25.6%	58.1%	14.6%	1.7%		99.3%	0.7%		92.1%	4.1%	2.4%	1.4%
Ppe	66	1.5%	9%	56.1%	33.3%		100%			3.0%	6%	8%	83.3%
N-Za	30	30%	50.0%	20.0%			100%			33.3%	10.0%	10%	47%
Msp	17	47.1%	52.9%				100%			88.2%			11.8%
Mkk	10	100.0%					100%			10.0%	20.0%		70.0%
Mn	565	68.1%	21.9%	9.2%	0.7%	0.4%	99.6%			34.3%	8.0%	12.3%	45.5%
Vrs	909	12.9%	51.2%	32.8%	3.0%		100%			79.9%	8.1%	7.4%	4.7%
Vpg	148	40.5%	32.4%	16.9%	10.1%		100.0%			59.9%	5.4%	9.5%	25.2%
Vme	6	100.0%					100%			83.3%		16.7%	
Vz	0												
Ru-Vu	3	33%		67%			100%						100%
Rl-Vl	12	91.7%	8.3%				100%			8.3%	8.3%	16.7%	66.7%
Rt-Vt	85	42.2%	49.4%	8.4%			100%			51.2%	7.3%	12.2%	29.3%
Rge	13	69.2%	30.8%				100%			53.8%		23.1%	23.1%
Rho	28	46.4%	53.6%				100%			78.6%	7.1%	7.1%	7.1%
Zgo	28	14.3%	78.6%	7.1%			100%			81.5%	7.4%	3.7%	7.4%
Zpg	14	78.6%	21.4%				100%			69.2%	7.7%	7.7%	15.4%
Note: 0% removed to make the table more readable													

6.2 Aquifer Units

The lithostratigraphy of the hydrogeological map sheet is based on the existing 1:250 000 geological map sheet 2428 Nylstroom, that was used to sub-divide the map sheet area into hydrogeological relevant lithological units (referenced as aquifer units), which possess some degree of lithological homogeneity and similarities in rock properties. However, lithological homogeneity and similarities in rock properties were not the only consideration. Where geological formations were large enough, they were regarded as separate units, despite lithological homogeneity and similarities in rock properties with adjacent formations or lithologies.

The aquifer units are grouped together based on the interpreted groundwater occurrence namely, **Intergranular (a), Fractured (b), Karst (c), and Intergranular and Fractured (d).**

A total of thirty-nine (39) groundwater resource units were identified, characterized, and discussed in terms of areal extent, general geology, and statistics on yield and groundwater quality. Additional aspects covered in some of the units include groundwater targets, proven geophysical methods, and references to findings from previous groundwater reports. The methodology used for the characterization of each unit is consistent throughout the report and is based on the same approach used for the 1:500,000 hydrogeological map series.

The Intergranular aquifer consists of single (1) unit with an aerial extent of 293.5km², representing 1.3% of the map area. The Fractured aquifers comprise of twenty (20) units with an aerial extent of 8927.4km², representing 39.9% of the map area. The Karst aquifer consists of a single (1) unit with an aerial extent of 759.3km², representing 3.4% of the map area. The Intergranular and Fractured aquifers include seventeen (17) units, covering 12 353.6km², that represents 55.3% of the map area.

The total map area covers an area of approximately 22 333.8km². Surface water bodies cover an area of 3.4km² or 0.02% of the map area.

Table 27: Basic information for the aquifer units and areal extent, first page

Unit symbol	Lithostratigraphy	Geochronology	Geological time period	Geological description	Areal extent (km²)	% of map area
Water			Surface water bodies	Water	3.983	0.02%
Category A: Intergranular aquifers						
Q	Alluvium	Tertiary Quaternary	Tertiary Quaternary	Alluvium	293.476	1.31%
				Total for Alluvium aquifers	293.476	1.31%
Category B: Fractured aquifers						
Jdo	Dolerite Jurassic	Intrusion of Karoo age	Jurassic	Dolerite Jurasic, Karoo age intrusions	7.611	0.03%
Trc	Clarens Formation	Karoo Supergroup	Triassic	Fine-grained sandstone, siltstone	1442.566	6.46%
P-Tr	Irrigasie Formation	Karoo Supergroup	Permian to Triassic	Predominantly red mudstone containing one or more sandstone units towards the base	476.318	2.13%
Mkr	Kransberg Subgroup	Waterberg Supergroup	Mokolian	Sandstone, subordinate conglomerate, siltstone and shale, (Undifferentiated Sandriviersberg & Mogalakwena Formations)	1531.375	6.86%
Mva	Vaalwater Formation	Waterberg Supergroup	Mokolian	Fine- to medium-grained, feldspathic sandstone, siltstone, shale	807.120	3.61%
Mcl	Cleremont Formation	Waterberg Supergroup	Mokolian	Very coarse-grained, white sandstone with fine-grained, purple, micaceous sandstone at the base	418.053	1.87%
Mas	Aasvoëlkop Formation	Waterberg Supergroup	Mokolian	Siltstone, mudrock, sandstone	127.972	0.57%
Mma	Makgabeng Formation	Waterberg Supergroup	Mokolian	Fine- to medium- grained cross-bedded sandstone, slightly feldspathic at the base	180.014	0.81%
Msc	Schilpadkop Formation	Waterberg Supergroup	Mokolian	Sandstone, conglomerate	213.833	0.96%
Mag	Alma Formation	Waterberg Supergroup	Mokolian	Felspathic and lithic sandstone, subordinate conglomerate and mudrock	852.358	3.82%
Ms	Swaershoek Formation	Waterberg Supergroup	Mokolian	Medium- to coarse-grained sandstone (pebbly in places), conglomerate, trachytic lava, quartz porphyry	1244.085	5.57%
Vgl	Glentig Formation	Transvaal Supergroup	Vaalian	Red and purple argillaceous rocks, fine- to medium-grained sandstone and altered lava overlain by conglomerate and grey quartz-feldspar porphyry	3.498	0.02%
Vsc	Schrikkloof Formation	Transvaal Supergroup	Vaalian	Fine-grained, flow-banded, porphyritic and spherulitic felsite	577.898	2.59%
Vkw	Kwaggasnek Formation	Transvaal Supergroup	Vaalian	Fine-grained, flow-banded, porphyritic and spherulitic felsite	353.443	1.58%
Mr	Rashoop Granophyre Suite	Bushveld Complex	Mokolian	Quartz-feldspar porphyry, granite granophyre	223.571	1.00%
Vla	Lakenvalei Formation	Transvaal Supergroup	Vaalian	Quartzite, feldspathic quartzite, arkose	0.872	0.004%
Vti	Timeball Hill Formation	Transvaal Supergroup	Vaalian	Mudrock, quartzite, minor diamictite	5.624	0.03%
Vpe	Penge Formation	Transvaal Supergroup	Vaalian	Ironstone,	216.126	0.97%
Vbr	Black Reef Formation	Transvaal Supergroup	Vaalian	Quartzite, subordinate conglomerate and shale	110.858	0.50%
Vwo	Wolkberg Group	Transvaal Supergroup	Vaalian	Shale, quartzite, arkose, sub greywacke, conglomerate, basalt, pyroclastic rock	134.237	0.60%
				Total for Fractured aquifers	8927.432	39.97%
Category C: Karst aquifers						
Vma	Malmani Subgroup	Transvaal Supergroup	Vaalian	Dolomite/limestone (+ chert), shale, subordinate quartzite, conglomerate and diamictite	759.320	3.40%
				Total for Karst aquifers	759.320	3.40%

Table 28: Basic information for the aquifer units and areal extent, second page

Unit symbol	Lithostratigraphy	Geochronology	Geological time period	Geological description	Areal extent (km²)	% of map area
Category D: Intergranular and Fractured aquifers						
Jle	Letaba Formation	Karoo Supergroup	Jurassic	Basalt	3079.155	13.79%
Ppe	Ecca Formation	Karoo Supergroup	Permian	Shale, with sandstone-rich units present towards the basin margins in the south, west and northeast and coal seams in the northeast	486.816	2.18%
N-Za	Diabase	Intrusions pre-Karoo ag	Mokolian	Diabase	431.672	1.93%
Msp	Spitskop Complex	Spitskop Complex	Mokolian	Ijolite, nepheline syenite, pyroxenite, carbonatite, fenite	23.213	0.10%
Mkk	Klipkloof & Makhutso Granite	Bushveld Complex	Mokolian	Klipkloof & Makhutso Granite	75.120	0.34%
Mn	Nebo Granite	Bushveld Complex	Vaalian	Nebo Granite, Coarse-grained granite	3473.500	15.55%
Vrs	Rustenburg Layered Suite	Bushveld Complex	Vaalian	Magnetite gabbro with magnetitite layers	2062.770	9.24%
Vpg	Undifferentiated Pretoria Group	Transvaal Supergroup	Vaalian	Undifferentiated	1070.391	4.79%
Vme	Meinhardskraal Granite	Granite intrusions	Vaalian	Pink to red, fine- to medium-grained biotite granite, minor grey granite and granophyre	210.663	0.94%
Vz	Unnamed Granite, Vaalian	Granite intrusions	Vaalian	Unnamed Leucocratic biotite granite	1.889	0.01%
Ru-Vu	Uitloop Granite	Granite intrusions	Randian	Reddish, fine- to coarse-grained biotite granite	41.466	0.19%
Rl-Vl	Lunsklip Granite	Granite intrusions	Randian to Vaalian	Pink, medium- to coarse-grained, hornblende-biotite granite	139.136	0.62%
Rt-Vt	Turfloop Granite	Granite intrusions	Randian to Vaalian	Grey to pink, medium- to coarse-grained, adamellitic/granodioritic biotite granite	680.619	3.05%
Rge	Geyser Granite	Granite intrusions	Randian	Leucocratic biotite granite	64.382	0.29%
Rho	Hout River Gneiss	Basement Gneisses	Randian	Leucocratic, strongly migmatised biotite gneiss and greyish, weakly migmatised biotite gneiss; minor leucogneiss and dark grey biotite gneiss	141.287	0.63%
Zgo	Goudplaats Gneiss	Basement Gneisses	Swazian	Leucocratic, strongly migmatised biotite gneiss and greyish, weakly migmatised biotite gneiss; minor leucogneiss and dark grey biotite gneiss	110.334	0.49%
Zpg	Pietersburg Greenstone Belt (Pietersburg Group)	Pietersburg Group	Swazian	talc-chlorite & amphibole-chlorite schist, amphibolite, Greenstone Belt, pedominantly Mothiba Formation	261.141	1.17%
				Total for Intergranular and Fractured aquifers	12353.554	55.31%
				Total areal extent of map area	**22333.783**	100.00%

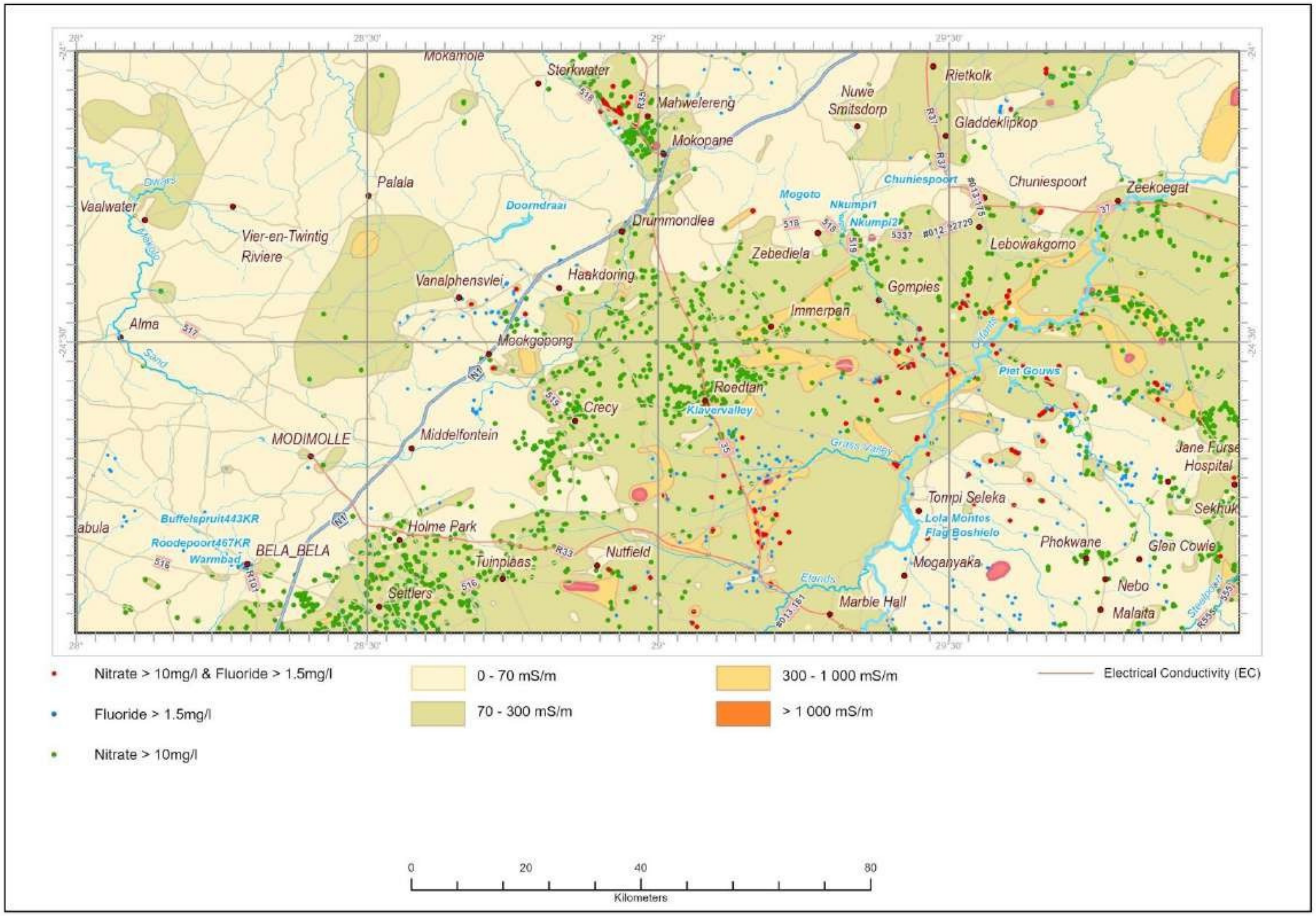


Figure 7: Distribution of electric conductivity (EC) and boreholes with Nitrate and Fluoride values exceeding the acceptable levels for human consumption.

7. HYDROGEOLOGY OF THE VARIOUS GEOLOGICAL GROUPS AND FORMATIONS

In this chapter the hydrogeology of the various geological groups and formations is briefly described in terms of its geographical location, occurrence, general use, and quality. Hydrogeology is supported by a statistical analysis of the borehole data available for each group or formation. For yield data, the results are portrayed as borehole yield frequency diagrams and for hydrochemistry as stiff diagrams. Table 29, page 56 shows the percentage boreholes in each yield range as obtained from the yield frequency diagrams.

Table 29: Summary of borehole yield distributions.

Aquifer Unit	Total number dry boreholes	Total number wet boreholes	Total boreholes with no information	0-0.01 (ℓ/s)	0.1-0.5 (ℓ/s)	0.5-2 (ℓ/s)	2-5 (ℓ/s)	5-10 (ℓ/s)	>10 (ℓ/s)
Category A: Intergranular aquifers									
Q	10	46	48	13.0%	8.7%	19.6%	21.7%	21.7%	15.2%
Category B: Fractured aquifers									
Jdo	No data available								
Trc	149	443	723	8.8%	25.7%	27.8%	14.7%	12.9%	10.2%
P-Tr	61	98	165	15.3%	34.7%	32.7%	10.2%	4.1%	3.1%
Mkr	30	219	75	14.2%	20.1%	44.7%	17.4%	3.2%	0.5%
Mva	182	380	112	17.1%	23.4%	32.4%	20.8%	5.8%	0.5%
Mcl	0	136	23	16.2%	24.3%	27.2%	16.2%	8.8%	7.4%
Mas	9	36	7	11.1%	13.9%	41.7%	19.4%	8.3%	5.6%
Mma	25	54	18	1.9%	29.6%	42.6%	14.8%	9.3%	1.9%
Msc	13	60	6	15.0%	20.0%	43.3%	16.7%	5.0%	
Mag	44	361	199	12.2%	22.2%	38.8%	15.8%	7.8%	3.3%
Ms	71	367	223	13.9%	25.3%	34.3%	19.1%	5.2%	2.2%
Vgl	No data available								
Vsc	61	153	75	12.4%	24.2%	38.6%	19.6%	3.3%	2.0%
Vkw	23	44	55	9.1%	27.3%	40.9%	15.9%	6.8%	
Mr	17	22	12	27.3%	18.2%	31.8%	22.7%		
Vla	No data available								
Vti	2	6	1			16.7%	50.0%	33.3%	
Vpe	13	11	49	9.1%		45.5%	9.1%	9.1%	27.3%
Vbr	9	26	29	19.2%	15.4%	19.2%	11.5%	7.7%	26.9%
Vwo	10	46	48	13.0%	8.7%	19.6%	21.7%	21.7%	15.2%
Category C: Karst aquifers									
Vma	128	206	247	10.2%	17.5%	18.0%	14.6%	11.7%	28.2%
Category D: Intergranular and Fractured aquifers									
Jle	192	907	2294	4.5%	10.3%	23.8%	25.7%	16.1%	19.6%
Ppe	36	137	186	10.2%	30.7%	38.0%	10.9%	4.4%	5.8%
N-Za	35	65	7	13.8%	21.5%	30.8%	21.5%	9.2%	3.1%
Msp	25	34	42		14.7%	20.6%	8.8%	20.6%	35.3%
Mkk	88	19	0	26.3%	26.3%	42.1%	5.3%		
Mn	1239	798	320	20.8%	31.6%	32.1%	9.5%	3.8%	2.3%
Vrs	782	619	831	6.8%	19.2%	31.0%	23.9%	13.1%	6.0%
Vpg	190	234	230	13.2%	17.9%	25.2%	18.4%	15.0%	10.3%
Vme	40	27	46	25.9%	18.5%	33.3%	22.2%		
Vz	No data available								
Ru-Vu	0	10	0	80.0%	20.0%				
Rl-Vl	8	35	0	48.6%	25.7%	22.9%	2.9%		
Rt-Vt	82	133	70	14.3%	27.1%	30.8%	16.5%	6.0%	5.3%
Rge	11	15	10	6.7%	33.3%	26.7%	20.0%	13.3%	
Rho	8	23	31	13.0%	34.8%	30.4%	17.4%	4.3%	
Zgo	15	36	23	2.8%	33.3%	19.4%	19.4%	11.1%	13.9%
ZPG	28	29	16	10.3%	17.2%	34.5%	20.7%	13.8%	3.4%

7.1 CATEGORY A: INTERGRANULAR AQUIFERS

7.1.1 Tertiary-quaternary alluvium deposits (Q)

Groundwater occurs in tertiary-quaternary alluvium deposits of limited lateral extent and thickness along river terraces in the map area like the Nyl, Mogalakwena, and Olifants Rivers. Accumulatively it only covers approximately 1.31% of the total map area (Figure 8). In general, the alluvium consists of a clay/silt layer overlying poorly to well-sorted sand and gravel layers.

Along the Nyl River a major well field supplies Mookgophong with water; the thickness of the alluvium seldom exceeds 20m. Along, and within, the Mogalakwena River in the map boundary just north of Mokopane (Primary aquifer component of the Rooisloot aquifer), the maximum thickness is between 15m to 25m. Further away from the river the thickness of the alluvium decreases quickly and the Rooisloot aquifer character changes to intergranular and fractured.

Along the Olifants River near Elandskraal, 3 shallow boreholes, (depth less than 9m) occur within the river, with recommended abstractions of 518m³/day at each. The thickness of the sand is reported to be between 6m to 8m, but it is not known if underlying fractured bedrock contributes to the yield. In the north-east section of the river near Tswaing, the alluvium was reported to be 21m thick and consisting of very fine to medium grained sand; the blow yield reported on one borehole was only 0.3ℓ/s. This is an indication of low permeability within the alluvium in this area.

The alluvial aquifers in the map area, where it is underlain by weathered and fractured bedrock aquifers, are mostly utilized in conjunction with the underlying bedrock. In such scenarios the alluvium acts as storage, (reported primary porosity is 10% to 30%); while the shallow fractured rock underlying the sand is the conduit. Within the Mogalakwena River especially to the north of the map area shallow wells and porous concrete sumps (caissons) are used to abstract water from the river. This is as the alluvium becomes coarser further down the river to the north due to the inflow of the weathering product of the Nebo Granite. Water levels respond quickly during recharge events, i.e. when the rivers flow. Due to its limited extent laterally and vertically, the aquifers are vulnerable to over-abstraction, especially during periods of drought when rivers are dry or with limited flow that influence the recharge to the aquifers. Borehole yields are generally higher where the alluvium consists of coarse-gravely grained material, a sufficient thickness below the water table and strikes within interconnected underlying fractured zones.

In terms of groundwater quality, 19.7% of the water samples, at least one element exceeds the maximum allowed limits for human consumption. For this unit the anions of concern are Fluoride followed by elevated concentrations of Chloride (10.7%) and Nitrate in 9.2% of the analysis. The cation of concern is Magnesium that exceeds the maximum allowable concentration in 16.4% of the analysis.

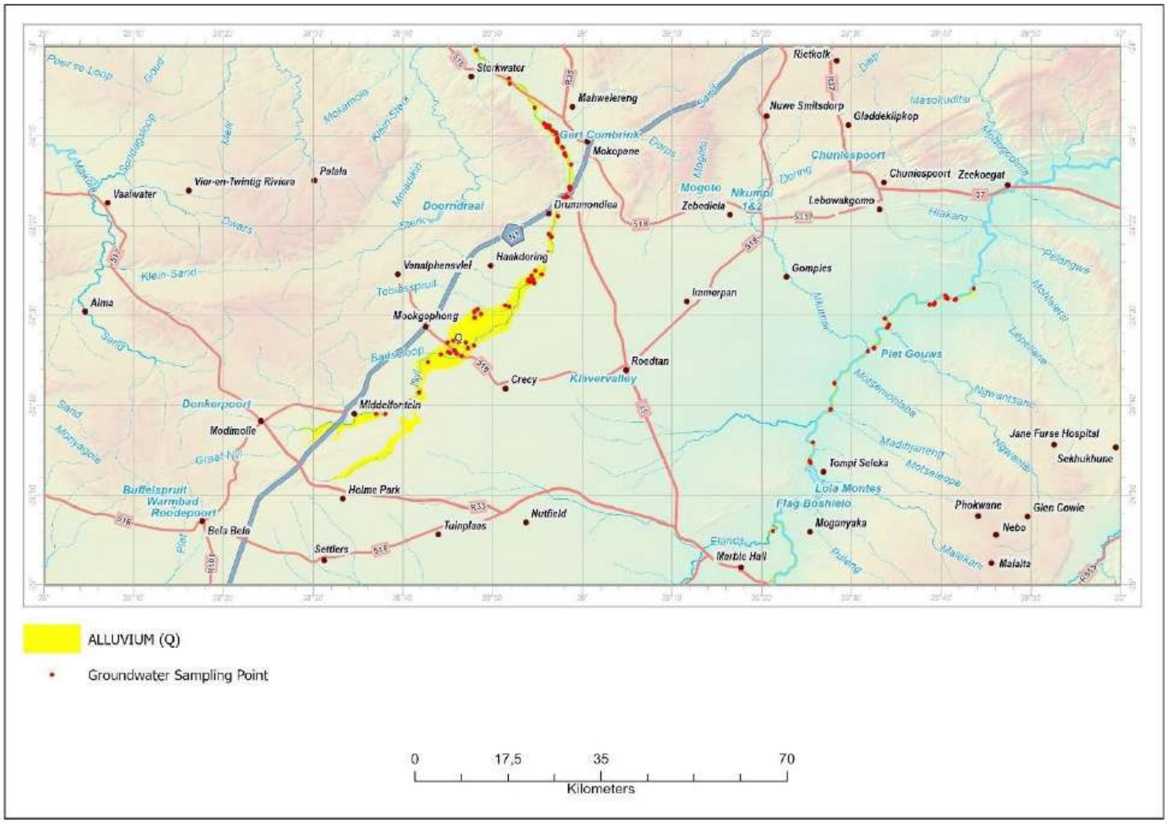


Figure 8: Geographical distribution of the intergranular aquifers (Q) and the associated groundwater sampling points.

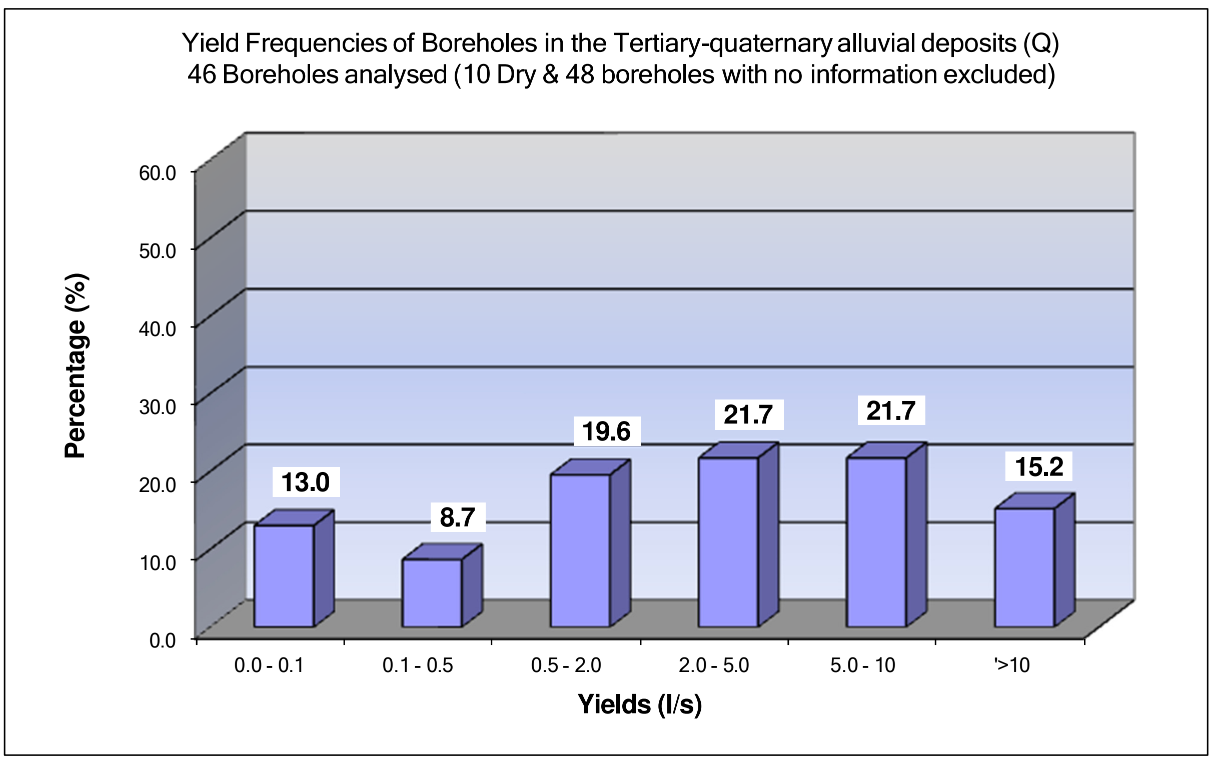


Figure 9: Yield frequency for Tertiary-Quaternary alluvial (Q) aquifers.

Figure 9 is a representative yield frequency diagram of yields within the alluvial aquifers. The diagram shows that 41.3% of the existing boreholes yield between 0.1ℓ/s to 2ℓ/s, with 19.6% yielding between 2ℓ/s to 5ℓ/s and 37% of the boreholes yielding more than 5ℓ/s.

The static water level ranges from surface to 19.35 meters below ground level mbgl, with a median of 3.38mbgl and an average of 5.1mbgl, (based on 51 data records). The maximum depth recorded is 146.8 meters (m), with an average of 53.6m and a median of 48.1m, (51 data records). The maximum installation depth is 84m with an average of 27.9m. From the statistics on the installation depths, it is clear that the statistics include a large number of boreholes that target deeper fractured zones overlain by alluvium.

The maximum recommended daily abstraction on record is 1987.2 cubic meters per day (m^3/day) with an average of 184.4m^3/day. The 90th percentile is 518.4m^3/day and a median abstraction of 86.4m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 41.

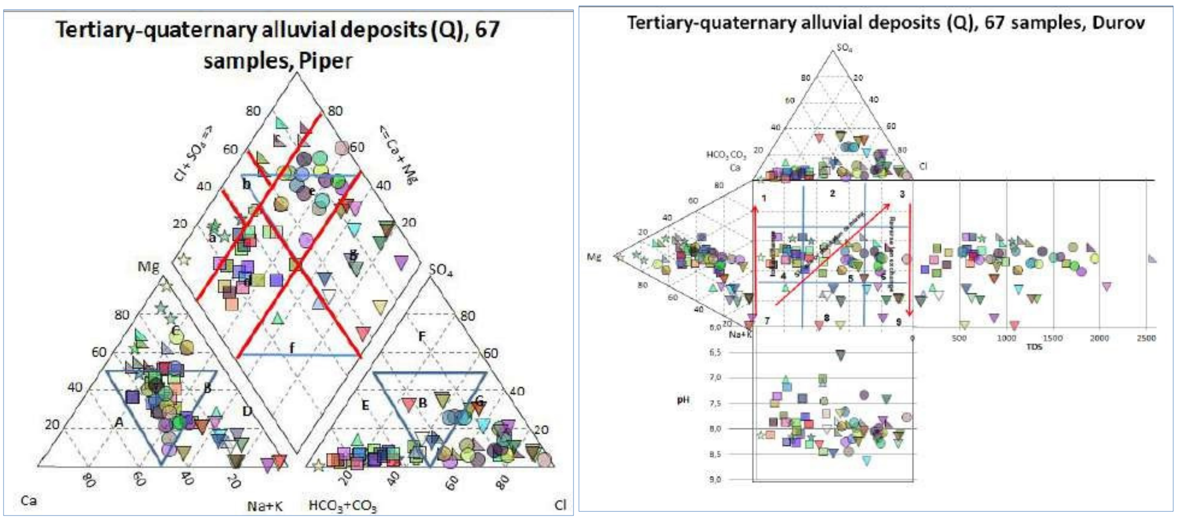


Figure 10: Trilinear diagrams, Piper and Durov for the Tertiary-quaternary alluvial deposits (Q).

The trilinear Piper diagram, (Figure 10) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (71.6%), Weak acidic anions > Strong acidic anions (41%); Alkali >Alkali earths (28.4%); Strong acids > Weak acids (59%).

The type of water within this unit is a function of the geology within the upper catchment area, the time of year (river dry or with water), the depth of the borehole (only within alluvial or deeper fractures) the layering of the deposit (layered permeability-clay/sand) and the timing of the sampling (after longer pumping: water from the underlying fractured zones may dominate).

From the available data and ignoring the above influences groundwater in this unit classify as:

- Mixed Calcium-Magnesium-Bicarbonate type (29.9%);
- Sodium-Chloride type (25.3%);
- Mixed Calcium-Magnesium-Chloride type with increased Sodium (22.4%);
- Magnesium-Chloride type (10.4%);
- Magnesium-Bicarbonate type (7.5%);
- Sodium-Bicarbonate type (3%);
- Magnesium-Bicarbonate-Chloride type with increased Sulphate (1.5%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (38.8%), points plot along the dissolution or mixing line.
- Mixed water exhibiting simple dissolution (25.4%),
- Anion discriminate and Na dominant, probable mixing or uncommon dissolution influences (14.9%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (11.9%),
- Cl and Na dominant is frequently indicative of end-point gradient waters through Dissolution (9%).

High total dissolved solids (TDS) in some of the samples may indicate long residence times in the aquifer, allowing geochemical reactions to reach near-completion. These samples may reflect the influence of the underlying geology, where deeper fractures contribute more significantly to groundwater supply than the overlying alluvium. In other studies, conducted on the Limpopo River, high TDS values were observed in the sand aquifer following intense rainfall events in the immediate vicinity of the river. These elevated TDS levels were contrary to expectations and were attributed to the arid environment, where the heavy rainfall mobilized accumulated salts from the surrounding area into the aquifer.

Table 30: Chemical statistics for the Tertiary-quaternary alluvial deposits (Q)

Element / Parameter	Statistics Drawn from a population of 127 data points for the Tertiary-quaternary alluvial deposits (Q)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	123	3,55	8,59	7,71	7,77	7,28	7,85	8,25	0,57	7,3%
Electrical Conductivity (mS/m EC)	123	7,90	750,80	60,03	143,19	27,90	105,10	269,06	139,43	97,4%
Total Dissolved Salts (mg/l TDS)	94	62,00	9000,00	480,76	1121,27	255,00	810,50	1740,39	1206,75	107,6%
Calcium (mg/l Ca)	122	1,90	661,70	21,70	75,99	14,37	53,57	150,93	82,42	108,5%
Magnesium (mg/l Mg)	122	0,50	397,40	8,96	59,30	5,10	34,90	135,00	70,84	119,5%
Sodium (mg/l Na)	117	2,00	905,00	32,12	125,24	17,48	63,70	308,65	166,23	132,7%
Potassium (mg/l K)	92	0,21	16,19	1,70	3,39	0,77	2,59	6,86	2,74	80,9%
Chloride (mg/l Cl)	122	4,45	2505,00	33,72	257,56	11,74	99,67	603,19	399,68	155,2%
Sulphate (mg/l SO_4)	123	1,12	762,50	10,12	71,92	3,64	27,90	170,69	129,53	180,1%
Total Alkalinity (mg/l) $CaCO_3$)	107	19,00	786,00	149,59	242,29	99,00	234,70	429,94	127,23	52,5%
Nitrate (mg/l N)	120	0,02	66,55	0,08	5,91	0,02	1,04	14,34	11,93	201,7%
Fluoride (mg/l F)	122	0,05	13,53	0,40	1,48	0,22	0,60	4,14	2,53	170,8%
Silicon as Si	91	1,33	45,50	13,83	23,33	7,15	21,57	39,68	12,56	53,8%
Iron (Fe)	45	0,01	1,50	0,01	0,06	0,01	0,01	0,06	0,22	390,3%
Manganese (Mn)	29	0,01	5,71	0,02	0,35	0,01	0,08	0,50	1,05	301,9%
Ortho Phosphate as Phosphorus as PO4	79	0,01	0,80	0,02	0,11	0,01	0,03	0,20	0,21	196,8%
ZAR	117	0,07	25,02	0,94	3,08	0,58	1,69	7,83	3,95	128,2%
LSI	107	Langelier Saturation Index (LSI)			Slightly Scaling		53,3%	Highly Scaling		0,0%
		Highly corrosive		3,7%	Slightly corrosive		9,3%	Balanced Corrosion		33,6%

Table 30 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality in terms of electric conductivity (EC) is good with values varying between 7.9 and 269mS/m in 90% of the analysis, only 7.3% is above 370mS/m. The Total Dissolved Solids (TDS) is acceptable in 72.3% of the samples, (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions of 127 samples show elevated concentrations of Fluoride (F >1.5mg/l) in 19.7%, Magnesium (Mg > 100mg/l) in 16.4%; Chloride (Cl > 600mg/l) in 10.7%; Nitrate (N >10mg/l) in 9.2%; Sodium (Na > 400mg/l) in 5.1%; Calcium (Ca > 300) in 3.3% and Sulphate (SO_4 > 600mg/l) in 2.4% of the analysis. The pH value is unacceptable in 0.8% (pH >10 & <4).

The Langelier Saturation Index (LSI) indicates that the water is corrosive (13%); slightly scaling (53.3%) and 33.6% balanced. The ZAR index indicates that 70.1% of the water is of a fair quality for irrigation (ZAR < 3).

The abstracted groundwater supplies a large number of people in rural, semi-formal settlements and towns for domestic use. Water is also extracted for livestock watering and irrigation. Overall, the water quality is generally good to moderate.

However, due to the shallow nature of the aquifer, microbiological contamination is a persistent risk. Best practices to mitigate this risk include water treatment methods such as UV disinfection and chlorination. Additional effective methods include: Boiling (suitable for household-scale disinfection), Ozonation (effective for large-scale or municipal systems), Slow sand filtration (removes pathogens through biological and physical processes), Ceramic filtration (suitable for household use, especially in remote areas), Solar disinfection (SODIS) (low-cost method, fill a polyethylene terephthalate (PET) with water and expose to sunlight (6 hours minimum) and Membrane filtration (e.g., ultrafiltration or reverse osmosis), it is highly effective, though more expensive.

7.2 SECONDARY AQUIFERS

Consolidated hard rocks cover virtually all (± 98.7%) of the map area. The rock mass was formed over a period of 3800 million years which almost spans the whole length of the South African geological history. Processes of tectonic deformation (folding, faulting) aided by weathering, dissolution (carbonate rocks) and unloading through erosion generated and/or enhanced fractures, interstices, and solution cavities in the hard rocks of the map area, eventually contributed to the present groundwater environment prevailing in the different groups and formations. Therefore, the aquifer types vary between Karst, fractured, and intergranular & fractured.

7.2.1 CATEGORY B: FRACTURED AQUIFERS

- Dolerite Jurassic (Jdo),
- Clarens Formation (Trc)
- Irrigasie Formation (P-Tri)
- Kransberg Subgroup (Undifferentiated Sandriviersberg & Mogalakwena Formations) (Mkr)
- Vaalwater Formation (Mva)
- Cleremont Formation (Mcl)
- Aasvoëlkop Formation (Mas)
- Makgabeng Formation (Mma)
- Schilpadkop Formation (Msc)
- Alma Formation (Mag)
- Swaershoek Formation (Ms)
- Glentig Formation Vgl)
- Schrikkloof Formation (Vsc) (Rooiberg Group)
- Kwagasnek Formation (Vkw) (Rooiberg Group)
- Rashoop Granophyre Suite (Mr)
- Lakenvalei (Vla)
- Timeball Hill Formation (Vti)
- Penge Formation (Vpe), (Banded ironstone)
- Black Reef Formation (Vbl)
- Wolkberg Group (Vw)

Fractured aquifers which cover approximately 39.97% of the total map area comprise of 20 aquifer units. The geographical distribution of the fractured rock aquifers is shown as Figure 11.

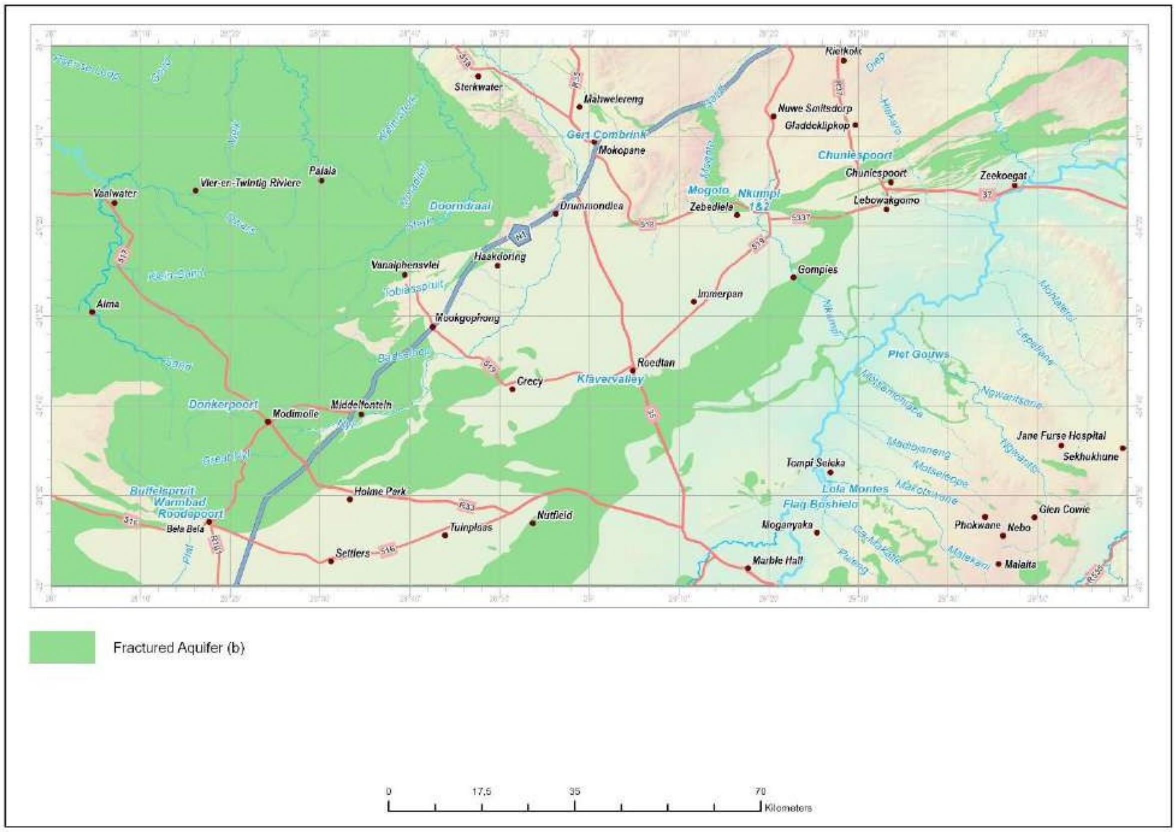


Figure 11: Geographical distribution of the fractured rock aquifers

7.2.1.1 KAROO DOLERITE JURASSIC (Jdo)

Jurassic aged dolerite a basic or intermediate rock occurs as sills along the southern boundary of the map near Marble Hall, (Figure 12) and covers approximately 0.03% of the map area. Large dolerite sills in other parts of the country might be classified as intergranular and weathered but water occurs mostly in fractures in dolerite within the map area hence the classification as a fractured aquifer. Dolerite intrusions in the form of dykes and sills also created secondary fractures and joints in contact with the host rock. These intrusions are limited when comparing them with the main Karoo Basin.

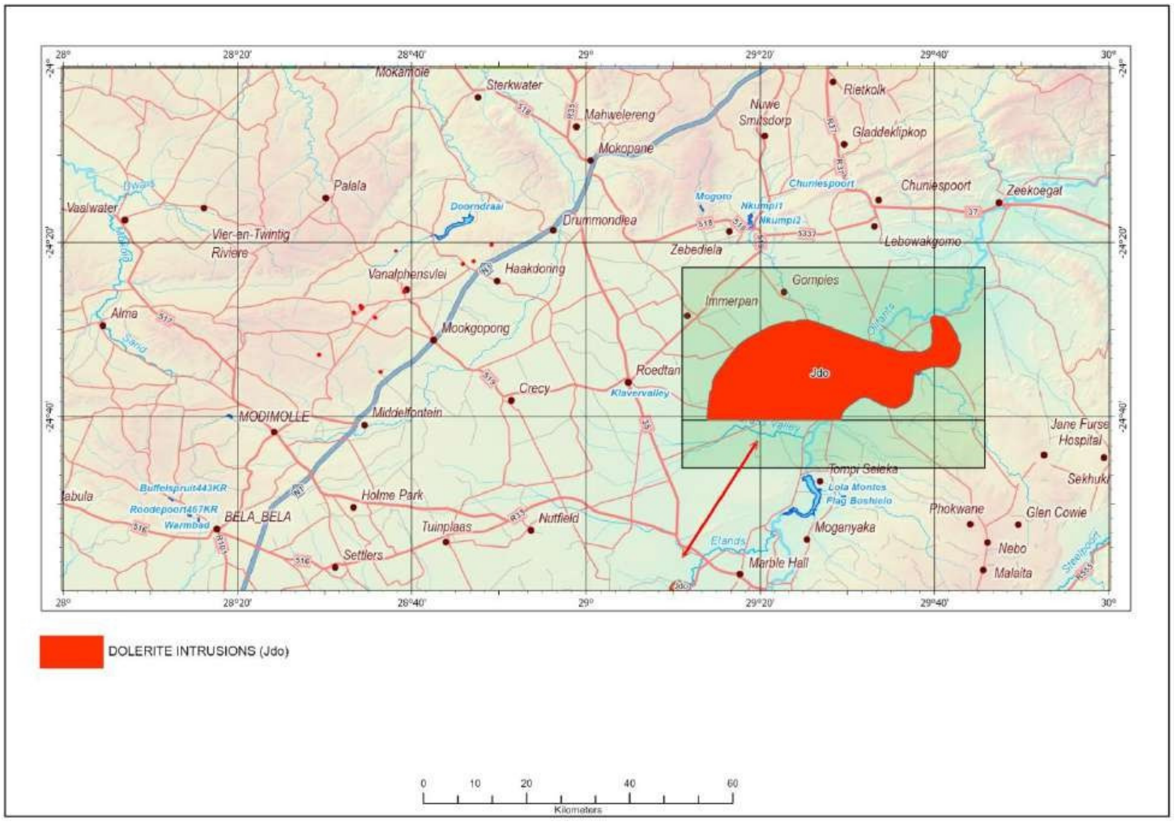


Figure 12: Geographical distribution of the Dolerite (Jdo) and the associated groundwater sampling points.

No borehole records containing yield or water chemistry data were available for this aquifer unit; therefore, it could not be fully characterized. Additionally, boreholes associated with dolerite intrusions in the form of dykes could not be distinguished from the country rocks from the available datasets. As a result, only dolerite intrusions in the form of sills can be used to classify boreholes within this unit.

7.2.1.2 CLARENS FORMATION (Trc)

This Formation occurs on the Springbok Flats where it encircles and underlies the basaltic rocks occupying the central part of the basin, (Figure 13). The Formation consists essentially of fine-grained, aeolian sandstone. Some dolerite dykes and sills have intruded the Formation. It covers approximately 6.46% of the total map area.

The sandstone has a low to very low primary permeability with low storage potential. Statistics reveal that 62.3%, (Figure 14) of successful boreholes yields less than 2ℓ/s. A further 14.7% of boreholes yield between 2ℓ/s and 5ℓ/s and 23% are yielding more than 5ℓ/s. The relative moderate to high yielding boreholes which penetrated the sandstone of the Clarens Formation in the Crecy area are related to fractures in hard re-crystallised layers within the massive sandstone, or locally developed primary permeability (Fayazi, 1994). The contact zone with the overlaying basaltic rock yield water of varying quantity.

Dolerite intrusions in the form of dykes and sills also created secondary fractures and joints in contact with the host rock. These intrusions are limited when comparing them with the number of intrusions within the main Karoo Basin. High yielding boreholes also occur in fault zones although exploratory drilling in the Crecy area revealed that the fault zone has been calcified and brecciated, reducing its groundwater storage potential considerably.

Studies conducted on the equivalent of this sandstone north of Vivo (Verhagen et. al., 2002, Van Wyk, 2002) and in the Kruger National Park (Du Toit, 1998) revealed the sandstone to have a significant primary porosity. In the Vivo study it was specifically found to occur where the sandstone was covered with a thick layer of basalt. No published research of this phenomenon is available for the Springbok Flats area and should be considered in future groundwater studies.

The contact zone between basalt and sandstone yields varying quantities but are usually <0.5ℓ/s. However, higher yielding water strikes is generally intercepted in the sandstone between 40m and 75m below the main basalt/sandstone contact which could be related to the phenomenon described above.

The quality of the water is generally good to moderate. In 16.5% of the water samples, at least one element occurs that exceeds the maximum allowed limits for domestic use. For this unit the anion of concern is Fluoride.

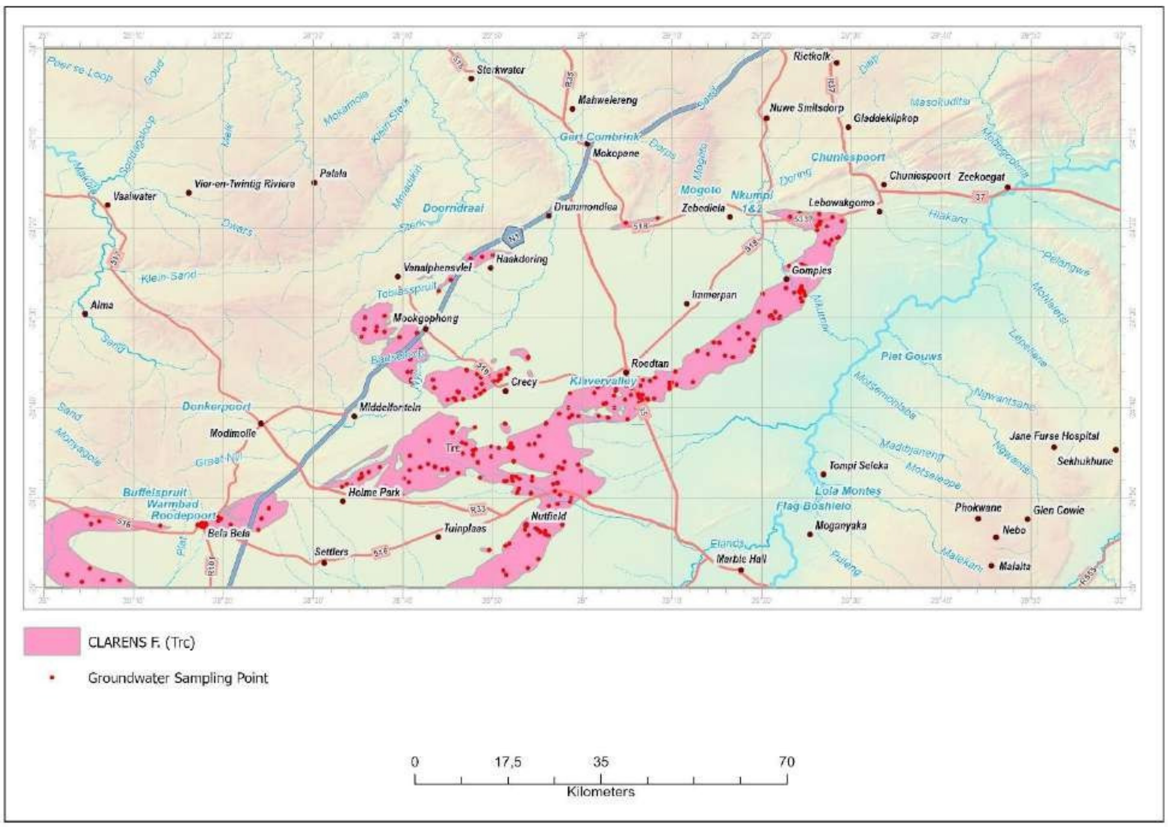


Figure 13: Geographical distribution of the Clarens Formation (Trc) and the associated groundwater sampling points.

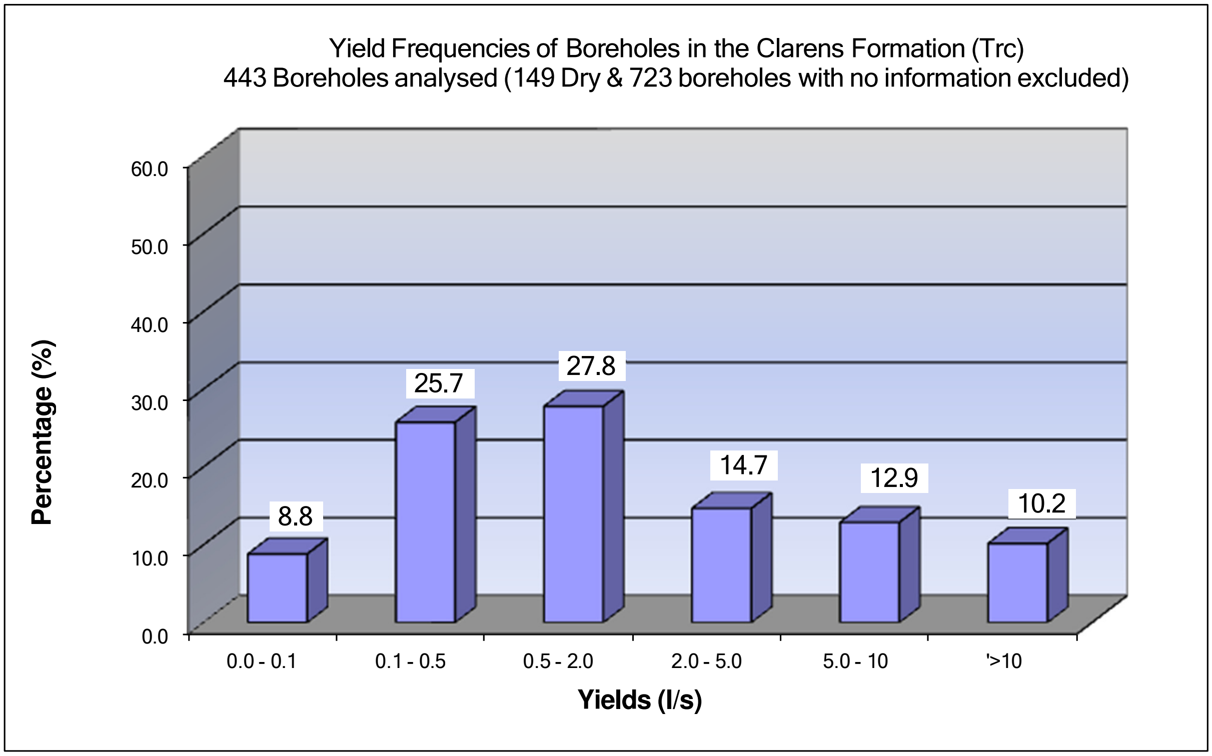


Figure 14: Yield frequency for the fractured aquifers of the Clarens Formation (Trc).

The static water level ranges from 2.2 meters below ground level (mbgl) to 42.69mbgl, the median is 12.27mbgl and the average is 14.04mbgl, (based on 72 data records). The maximum depth recorded is 301m, with an average of 78.2m and median depth of 74.9m, (87 data records). The maximum installation depth reported is 150m and with an average of 45.5m that can be indicative of water strike depths, (58 data records).

The maximum recommended daily abstraction is reported as 777.6 cubic meters per day (m³/day) and the average is 76.5m³/day. The 90th percentile of the daily abstraction is 200.4m³/day and the median is 11.5m³/day. The total number of boreholes subjected to pump testing within this unit on record is 57.

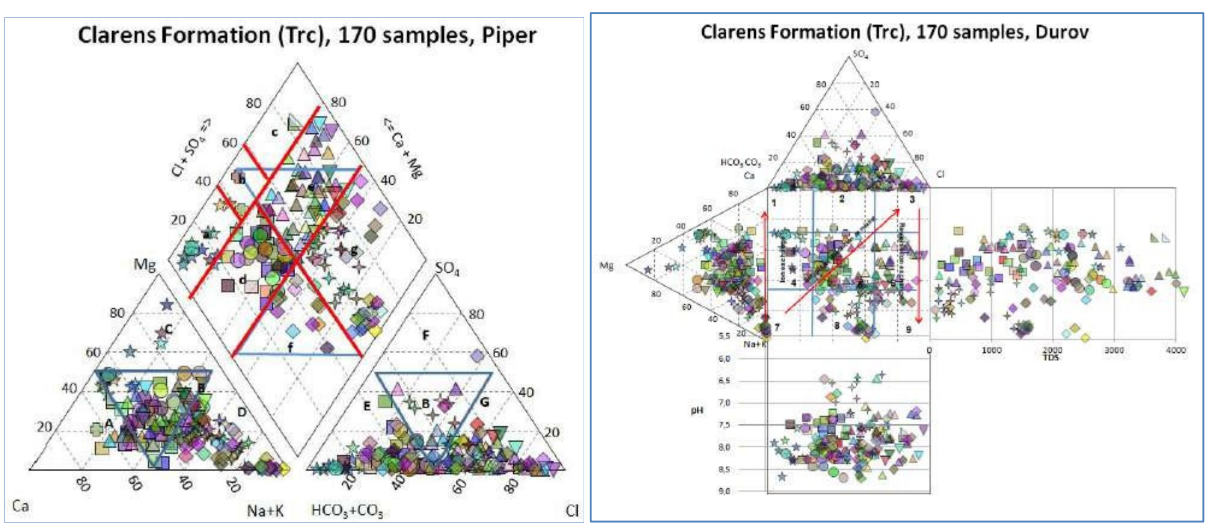


Figure 15: Trilinear diagrams, Piper and Durov for the Clarens Formation (Trc).

The trilinear Piper diagram, (Figure 15) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (62.4%), Weak acidic anions > Strong acidic anions (40.6%); Alkali >Alkali earths (37.6%); Strong acids > Weak acids (59.4%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Chloride type with increased Sodium (22.9%);
- Sodium-Chloride type (22.4%);
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (20.6%);
- Sodium-Bicarbonate type (8.2%);
- Mixed Calcium-Magnesium-Bicarbonate type (7.1%);
- Calcium-Chloride type (6.5%)
- Sodium-Bicarbonate-Chloride type with increased Sulphate (4.1%);
- Calcium-Bicarbonate (2.9%);
- Magnesium-Bicarbonate (2.4%);
- Sodium-Bicarbonate-Chloride type (2.4%);
- Sodium-Sulphate type (0.6%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (39.4%), plot along the dissolution or mixing line.
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (18.8%),
- Anion discriminates and Na dominant, some SO_4 probable mixing or uncommon dissolution influences (18.2%),
- Anion discriminate and Ca dominant indicating mixed water or water exhibiting simple dissolution (12.4%),
- HCO_3 and Ca dominant, indication of recharge in sandstone (5.3%),
- Cl and Na dominant, frequently indicative of end-point gradient waters through Dissolution (3.5%).
- Dominant Ca and HCO_3, ion exchange water, Mg concentration is significant (2.4%).
- The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 31: Chemical statistics for Clarens Formation (Trc)

Element / Parameter	Statistics Drawn from a population of 242 data points for Clarens Formation (Trc)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	242	5,87	8,70	7,62	7,66	6,96	7,77	8,21	0,54	7,0%
Electrical Conductivity (mS/m EC)	242	3,10	1210,00	37,15	92,54	16,53	75,20	156,09	103,47	111,8%
Total Dissolved Salts (mg/l TDS)	184	23,00	3636,00	252,23	629,43	102,90	537,50	1094,50	506,67	80,5%
Calcium (mg/l Ca)	242	0,50	590,00	11,94	54,28	6,26	45,85	105,39	59,22	109,1%
Magnesium (mg/l Mg)	242	0,50	290,40	3,79	29,60	1,30	14,77	68,98	36,65	123,8%
Sodium (mg/l Na)	242	2,30	1780,00	26,76	95,02	10,80	63,38	184,00	139,78	147,1%
Potassium (mg/l K)	185	0,38	64,15	2,84	4,85	1,48	3,83	8,66	5,42	111,7%
Chloride (mg/l Cl)	242	1,50	3740,00	23,63	146,52	9,60	77,21	310,44	304,50	207,8%
Sulphate (mg/l SO_4)	242	0,80	620,00	4,64	27,86	2,00	8,24	70,75	62,97	226,0%
Total Alkalinity (mg/l) $CaCO_3$)	242	9,60	1250,00	90,19	212,74	41,56	175,90	403,65	152,07	71,5%
Nitrate (mg/l N)	242	0,02	36,80	0,12	4,80	0,02	2,06	13,10	6,56	136,6%
Fluoride (mg/l F)	242	0,05	25,40	0,21	1,55	0,07	0,35	2,80	3,61	233,6%
Silicon as Si	183	2,57	48,89	17,75	23,29	10,35	24,98	36,31	10,07	43,2%
Iron (Fe)	24	0,01	0,26	0,01	0,03	0,01	0,01	0,05	0,05	157,8%
Manganese (Mn)	11	0,01	0,21	0,02	0,05	0,01	0,05	0,05	0,06	119,7%
Ortho Phosphate as Phosphorus as PO4	144	0,01	0,80	0,01	0,04	0,01	0,01	0,07	0,13	292,8%
ZAR	242	0,19	30,57	1,22	3,12	0,61	1,98	6,39	3,80	121,8%
LSI	184	Langelier Saturation Index (LSI)			Slightly Scaling		**32,1%**	Highly Scaling		**0,0%**
		Highly corrosive		**9,8%**	Slightly corrosive		**21,2%**	Balanced Corrosion		**37,0%**

Table 31 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality in terms of electric conductivity (EC) is good with values varying between 3.1 and 156.1 mS/m in 90% of the analysis, only 1.7% is above 370mS/m.

The Total Dissolved Solids (TDS) is acceptable in 93.5% of the samples (TDS ≤ 1200mg/l). The evaluation of the major cations and anions for 242 samples shows elevated concentrations of Fluoride (F >1.5mg/l) in 16.5%; Magnesium (Mg > 100mg/l) in 5.4%; Nitrate (N >10mg/l) in 4.1%; Chloride (Cl > 600mg/l) in 2.9%; Sodium (Na > 400mg/l) in 1.2% and Calcium (Ca > 300) in 0.8% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be corrosive (31%) or slightly scaling (32.1%) and 37% balanced. The ZAR index indicates that 67% of the water is of a fair quality for irrigation (ZAR < 3).

The water abstracted is predominantly supplying rural settlements and farms, Roedtan is underlain by Letaba Basalt but the due to the decreasing water table deeper boreholes are drilled that draw water from the underlying sandstone (Clarens Formation). In Bela-Bela large scale groundwater abstraction are related to major fault zones. Water from this unit is also abstracted for livestock watering and irrigation.

7.2.1.3 IRRIGASIE FORMATION (P-Tr)

The unit occurs as two clusters, i.e. one along the 29° longitude close to the southern map boundary and the second cluster along the 28° longitude also close to the southern map boundary. The eastern cluster forms part of the south-eastern rim of the Springbok Flats (Figure 16). The unit consists of a succession of mudstone, siltstone, sandstone, conglomerate, shale, grit, and marl intruded by minor dolerite dykes and sills. It covers approximately 2.13% of the total map area.

The sedimentary rocks of this Formation have low to very low primary permeability with low storage potential. Statistics indicate that 82.7%, (Figure 17) of the successful boreholes yield less than 2ℓ/s. A further 10.2% of the boreholes yield between 2ℓ/s and 5ℓ/s and 7.2% have yields exceeding 5ℓ/s. The high number of successful boreholes, even though many are low yielding signifies that it is not difficult to find water for a single household or for livestock watering.

In terms of water quality, 26.7% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride, followed by the cation Magnesium (15.8%). In addition, elevated Chloride and Nitrate concentrations exceed the maximum allowable limit in 15.2% and 12.7% of the analysis respectively. The quality of the water is generally poor and can vary significantly over short distances.

In general, the groundwater occurrence in the sedimentary rocks is either controlled by lithology such as the contact zones between various sediments or by secondary structures such as fractures or joints locally developed along bedding planes. Groundwater can also be found in extensively developed fractures and joints within the sediments including faulting and associated shear zones. These were created through regional tectonics of the two synclinal flexures and post Karoo tectonic episodes, (Fayazi, 1994). Minor dolerite intrusions occurring as dykes and sills created secondary fractures and joints in contact with the host rock.

Water is abstracted for livestock watering and domestic purposes, and where quality and yield permit, also for irrigation.

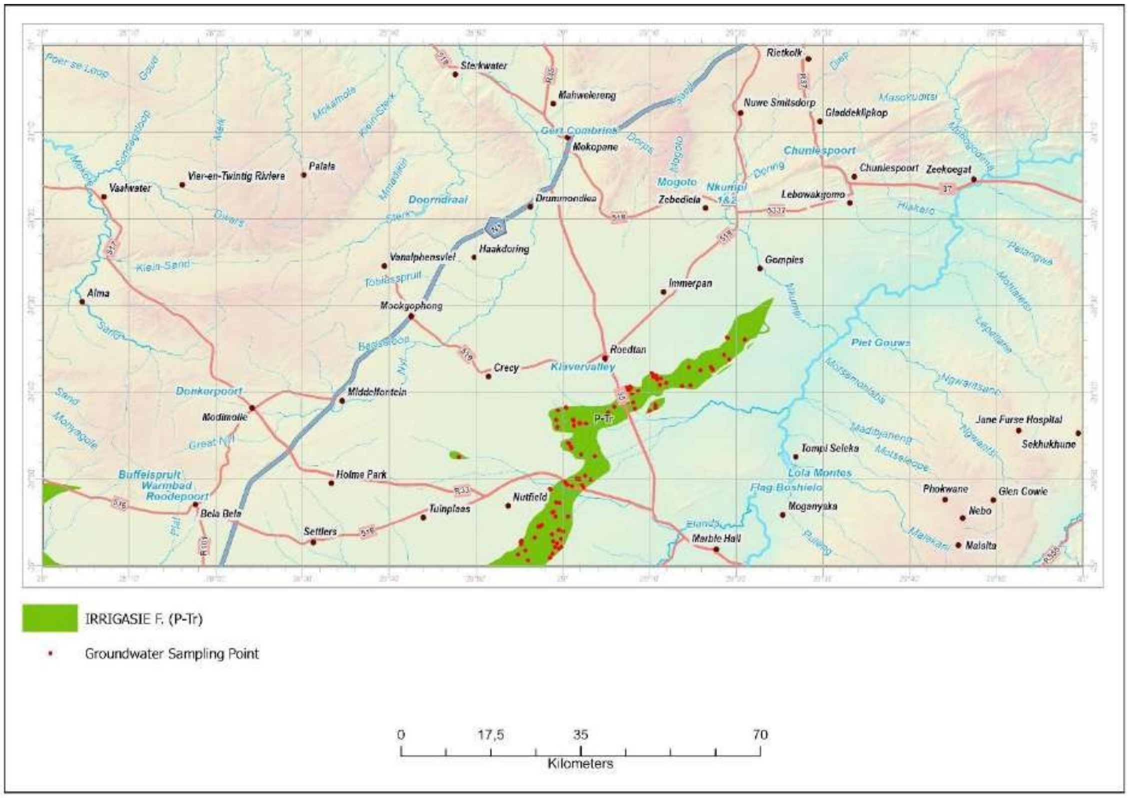


Figure 16: Geographical distribution of the Irrigasie Formation (P-Tr) and the associated groundwater sampling points

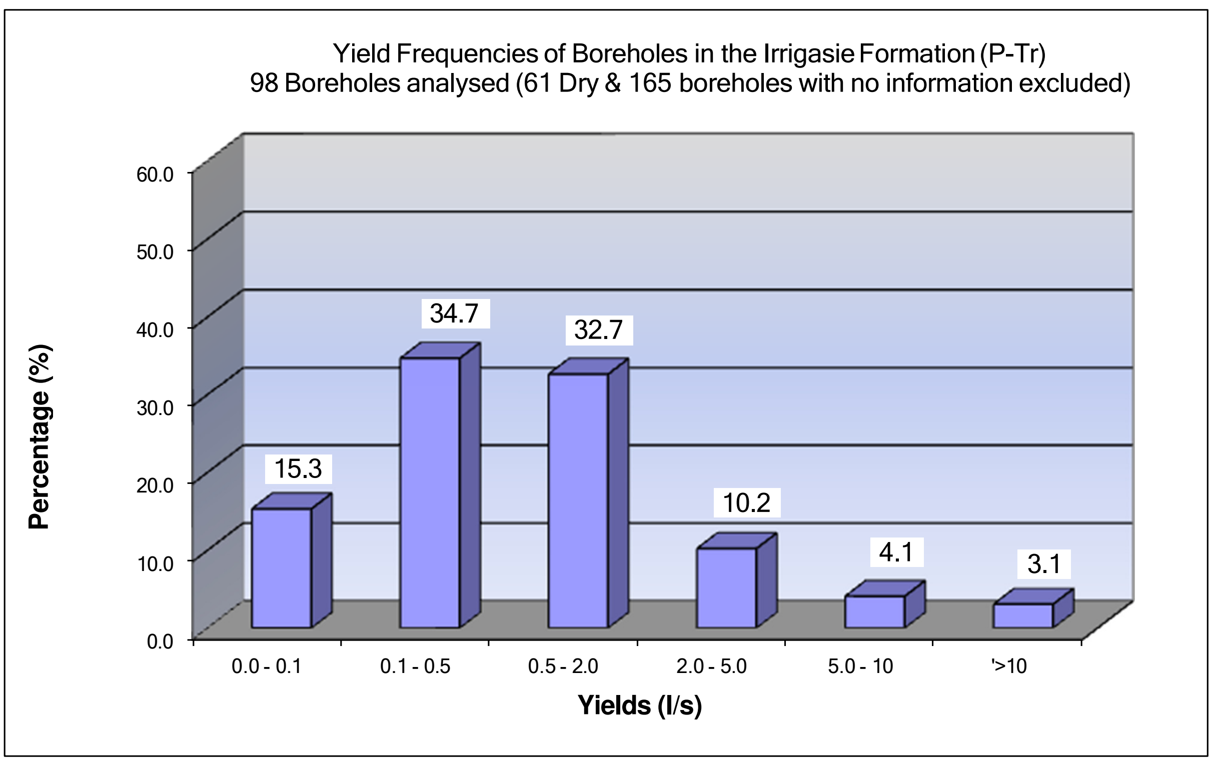


Figure 17: Yield frequency for the fractured aquifers of the Irrigasie Formation (P-Tr).

The static water level ranges from 3.07 meters below ground level (mbgl) to 48.54mbgl, with a median static water level of 21.94mbgl and an average of 21.89mbgl, (based on 26 data records). The maximum depth recorded is 195m, with an average depth of 78m and a median depth of 70.5m, (38 data records). The maximum installation depth is 84m with an average of 53.6m. The installation depth can be indicative of water strike depths, (21 data records).

The maximum recommended daily abstraction on record is 74.3 cubic meters per day (m^3/day) and the average is 17.5m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 21.

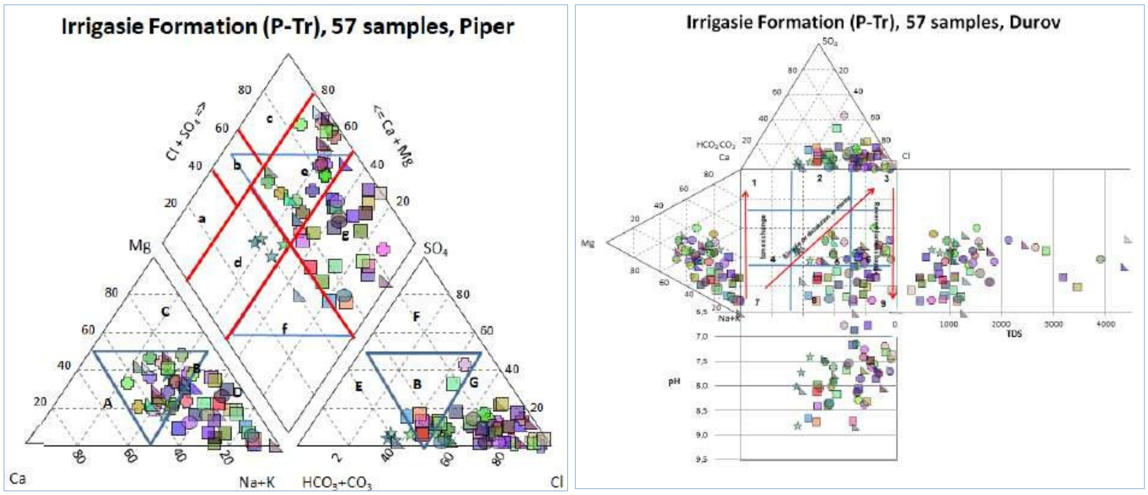


Figure 18: Trilinear diagrams, Piper and Durov for the Irrigasie Formation (P-Tr).

The trilinear Piper diagram, (Figure 18) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (51.9%), Weak acidic anions > Strong acidic anions (9.3%); Alkali >Alkali earths (48.1%); Strong acids > Weak acids (90.7%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Chloride type (47.4%);
- Sodium-Chloride type (43.9%);
- Mixed Calcium-Magnesium-Bicarbonate (7%);
- Sodium-mixed Bicarbonate-Chloride with some Sulphate (1.7%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- Anion discriminate and Na dominant, probable mixing or uncommon dissolution influences (35%),
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (24.6%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (21.1%),
- Cl and Na dominant is frequently indicative of end-point gradient waters through Dissolution (19.3%).
- The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 32: Chemical statistics for the Irrigasie Formation (P-Tr)

Element / Parameter	Statistics Drawn from a population of 105 data points for the Irrigasie Formation (P-Tr)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10^{th} percentile	50^{th} percentile (median)	90^{th} percentile	Standard Deviation	Coefficient of Variation
pH	105	6,60	9,09	7,78	7,81	7,16	7,80	8,41	0,49	6,2%
Electrical Conductivity (mS/m EC	105	15,0	806,0	126,8	201,8	78,1	143,5	430,8	164,6	81,6%
Total Dissolved Salts (mg/l TDS)	85	138,0	5240,0	888,1	1378,1	556,0	1068,0	2937,6	1031,1	74,8%
Calcium (mg/l Ca)	101	4,0	682,0	34,0	99,7	16,2	70,3	228,9	103,3	103,6%
Magnesium (mg/l Mg)	101	0,50	393,40	9,31	68,40	5,50	45,20	165,60	84,13	123,0%
Sodium (mg/l Na)	101	18,8	843,0	148,5	231,6	84,9	191,1	399,0	159,1	68,7%
Potassium (mg/l K)	82	0,50	73,98	4,42	9,54	2,43	7,01	18,55	9,97	104,6%
Chloride (mg/l Cl)	105	20,0	2485,9	148,5	429,2	78,0	219,6	1210,3	538,1	125,4%
Sulphate (mg/l SO_4)	105	1,47	525,80	16,85	65,18	8,36	35,50	123,58	92,50	141,9%
Total Alkalinity (mg/l) $CaCO_3$)	91	5,0	685,6	153,7	298,6	139,0	314,0	426,2	122,1	40,9%
Nitrate (mg/l N)	102	0,02	82,50	0,31	9,03	0,17	2,83	23,55	14,48	160,4%
Fluoride (mg/l F)	105	0,08	12,67	0,47	1,48	0,20	0,70	3,09	2,22	149,5%
Silicon as Si	80	3,26	43,40	16,69	24,48	9,10	25,01	38,91	11,58	47,3%
Iron (Fe)	24	0,01	0,23	0,02	0,05	0,01	0,05	0,06	0,04	96,3%
Manganese (Mn)	23	0,01	1,26	0,03	0,17	0,01	0,05	0,36	0,31	180,2%
Ortho Phosphate as Phosphorus as PO4	60	0,01	0,80	0,02	0,18	0,01	0,02	0,80	0,31	169,4%
ZAR	101	0,61	45,49	3,61	5,92	1,81	4,12	11,51	5,83	98,5%
LSI	71	Langelier Saturation Index (LSI)			Slightly Scaling		**67,6%**	Highly Scaling		**0,0%**
		Highly corrosive		**1,4%**	Slightly corrosive		**5,6%**	Balanced Corrosion		**25,4%**

Table 32 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality in terms of the electric conductivity (EC) is marginally poor with values between 15 and 143.5mS/m in 50% of the analysis; 11.4% is above 370mS/m.

The Total Dissolved Solids (TDS) is acceptable in 60% of the samples (TDS ≤ 1200mg/l). The evaluation of the major cations and anions from 105 samples shows elevated concentrations of Fluoride (F >1.5mg/l) in 26.7%; Magnesium (Mg > 100mg/l) in 15.8%; Chloride (Cl > 600mg/l) in 15.2%; Nitrate (N >10mg/l) in 12.7%; Sodium (Na > 400mg/l) in 9.9% and Calcium (Ca > 300) in 4% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be corrosive but predominantly slightly scaling (67.6%) and 25.4% balanced. The ZAR index indicates that 20.8% of the water is of a fair quality for irrigation (ZAR < 3).

7.2.1.4 KRANSBERG SUBGROUP (Mkr) (UNDIFFERENTIATED SANDRIVIERSBERG & MOGALAKWENA FORMATIONS)

The Waterberg Group has been sub-divided into three sub-groups namely Nylstroom, Matlabas and Kransberg. Although the undifferentiated Sandriviersberg and Mogalakwena Formations of the Kransberg Subgroup are discussed here and covers approximately 6.86% of the area, an over- view of the Waterberg Group is provided.

The Waterberg Group occupies the north-western portion of the map area and consists of two overlapping sedimentary basins. In the deep basin (Alma trough) beds of the Swaershoek, Alma and Sterkrivier Formations were laid down. The Schilpadkop and locally the Makgabeng Formation form the base of the succession in the younger, larger, but shallower basin. The entire succession is predominately arenaceous (consists of sand), but the Aasvoëlkop and Vaalwater Formations are partly arkosic (25% feldspar content). The oldest sub-division (Nylstroom) of which the lower portion is the Swaershoek Formation is of late-Bushveld age and confined to proto basins of which the largest coincides approximately with the Nylstroom syncline (Council for Geoscience).

Trachytic lavas (composed mostly of alkali feldspar) are well developed and quartz porphyry occurs locally in the Swaershoek Formation. The Alma, Schilpadkop and Aasvoëlkop Formations are poorly exposed and mostly only the conglomerate beds are seen. The Alma Formation becomes less felspathic in the east. In the Sterk River area both the Swaershoek and Alma Formations decrease in thickness (Council for Geoscience). The Schilpadkop Formation wedges out to the north-east and the partly argillaceous (clay) Aasvoëlkop Formation grades into the arenaceous Makgabeng Formation. The Sandriviersberg Formation, which occupies the southern Waterberg plateau grades to the east and north into the Makgabeng Formation, which locally contains numerous conglomerate layers (Council for Geoscience).

Sedimentary structures are well developed in the Sandriviersberg and Mogalakwena Formations (cross bedding) and the Vaalwater Formation (cross-bedding, ripple marks, convolute bedding, and lamination).

The undifferentiated Sandriviersberg and Mogalakwena Formations comprise mostly of coarse-grained sandstone, grit, and conglomerate. Groundwater occurs mainly in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has indicated that fractures do occur at these depths and can be considered when developing groundwater as a water source. It is, however, difficult to trace these deeply seated fractures using geophysical methods. Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone generally resulting in the formation of depressions but also produces a more fertile soil that stimulates a dense vegetation growth along the dykes. These can sometimes be traced for many kilometres. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them, (See also chapter 7.2.3.3, page 143).

The permeability and storage capacity of the Kransberg sub-group are generally low. Yields tend to diminish quickly during periods of drought.

Plate 1: Intensely fractured Mogalakwena Formation on the farm Klipfontein 797 LR, which consists of purplish brown, coarse grained sandstone with interbedded conglomerate and boulder conglomerate (Photograph: WH du Toit)

The Waterberg Group as the Kransberg subgroup has been intruded extensively by sills and dykes of predominantly diabasic composition. These diabase intrusions (N-Za) play a major role in the occurrence of groundwater. If dykes and sills are ignored, the groundwater potential of the Waterberg Group is generally low with 79% of the yields less than 2ℓ/s, (Figure 20).

The quality of the water is generally ideal to good with a small number of the analysis within moderate quality. In 9.5% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit the anion of concern is Nitrate.

Plate 2 & Plate 3: Weathering of the sandstone of the Mogalakwena Formation produces extraordinary and beautiful scenery and rock shapes as illustrated in the photographs (Photograph: WH du Toit).

Plate 4: Bushman paintings engraved in sandstone of the Mogalakwena Formation on the farm Waterval 601 LQ south of Lephalale (Ellisras) (Photograph: WH du Toit).

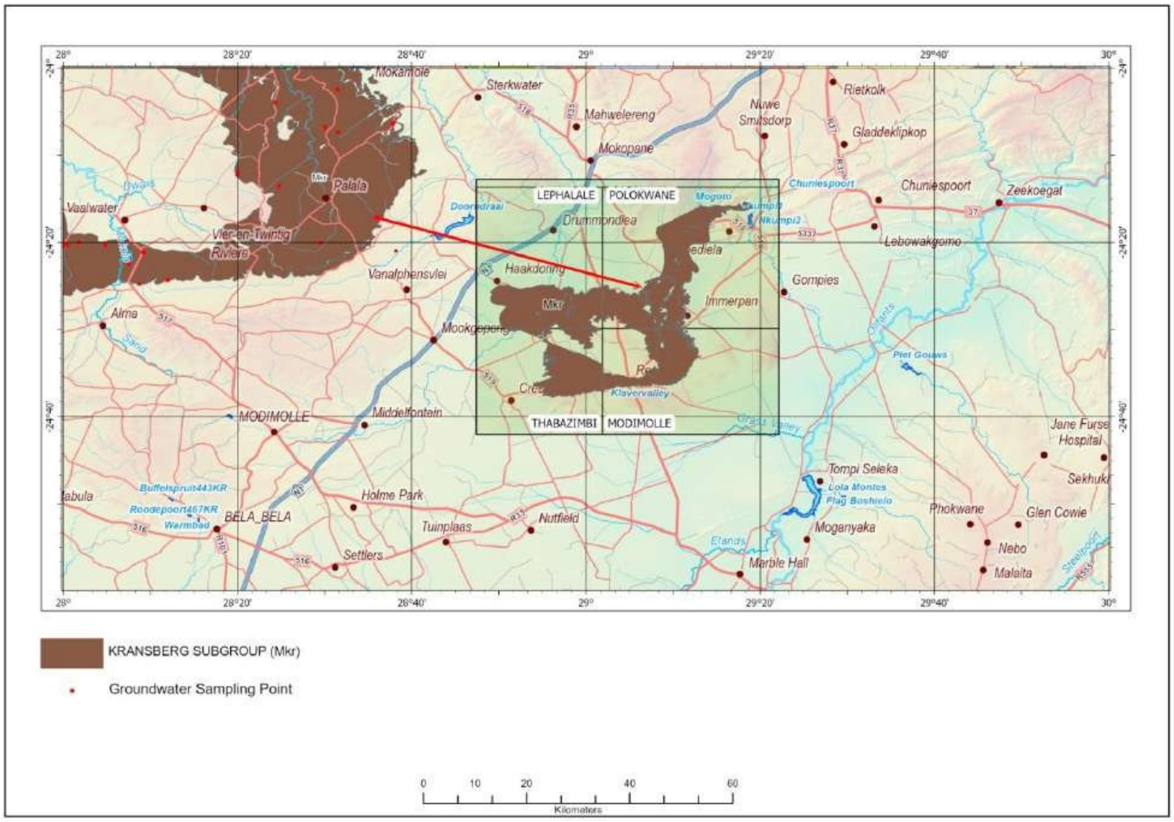


Figure 19: Geographical distribution of the Kransberg Subgroup (Mkr)

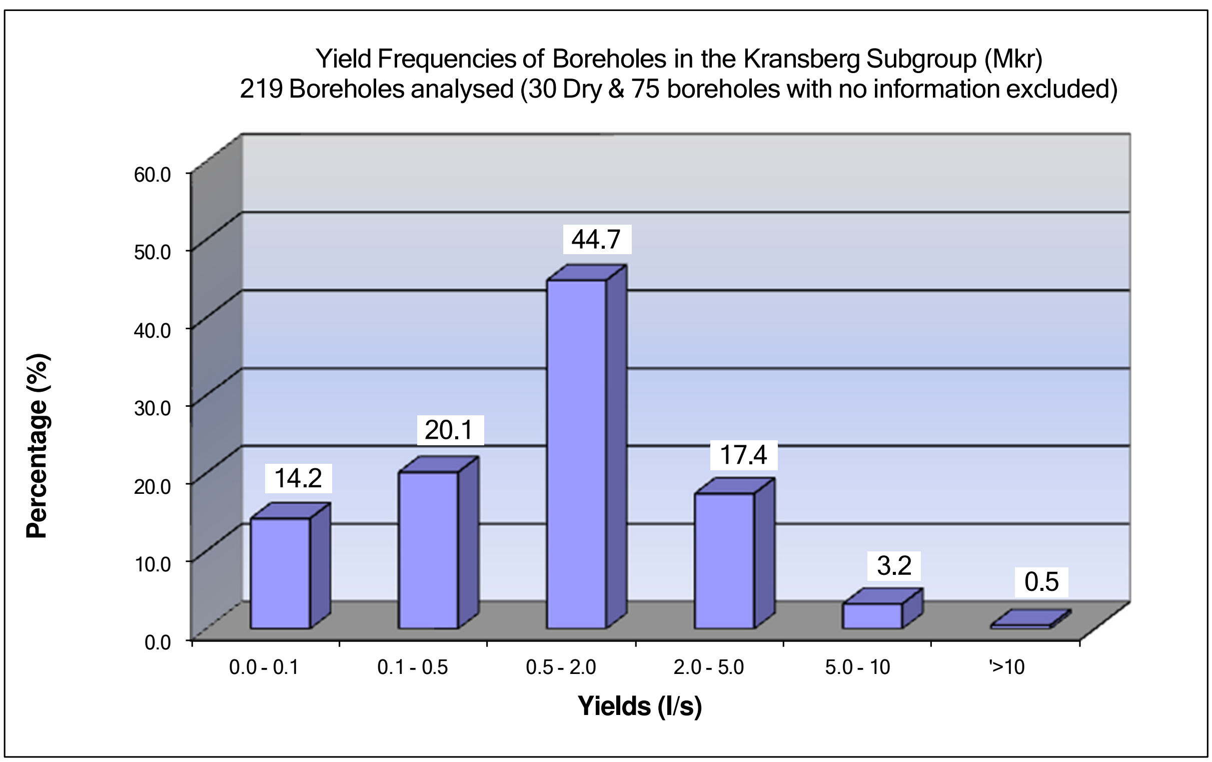


Figure 20: Yield frequency for fractured aquifers of the Kransberg Subgroup (Mkr).

The yield frequency diagram, (Figure 20), indicates that 79% of the successful boreholes yield between 0.1ℓ/s and 2ℓ/s whereas 17.4 % yields between 2ℓ/s and 5ℓ/s and 3.7% of the boreholes have yields exceeding 5ℓ/s.

The static water level ranges from 1.22 meters below ground level (mbgl) to 109.73mbgl, with a median static water level of 15.24mbgl and an average static water level of 18.74mbgl, (based on 118 data records). The maximum depth recorded is 154m, with an average depth of 89.5m and a median depth of 86.2m, (9 data records). The maximum installation depth is 60m, (4 data records) which can be indicative of deep fractures that relate to water strike depths.

The maximum recommended daily abstraction on record is 69.1 cubic meters per day (m³/day) and the average is 36.1m³/day. The median daily abstraction is 28m³/day. The total number of boreholes subjected to pump testing within this unit on record is 4.

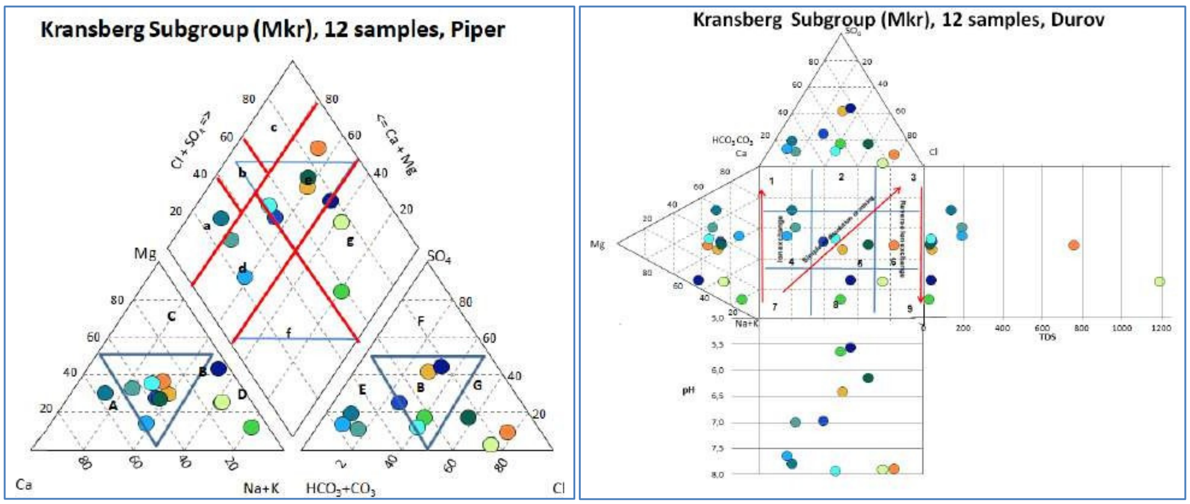


Figure 21: Trilinear diagrams, Piper and Durov for the Kransberg Subgroup (Mkr).

The trilinear Piper diagram, (Figure 21) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (75%), Weak acidic anions > Strong acidic anions (25%); Alkali >Alkali earths (25%); Strong acids > Weak acids (75%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (25%);
- Sodium-Chloride type (25%);
- Mixed Calcium-Magnesium-Chloride-Sulphate type with increasing Sodium (16.7%);
- Mixed Calcium-Magnesium-Bicarbonate type with increasing Sodium (16.7%);
- Calcium-Magnesium Bicarbonate type (8.3%),
- Calcium-Bicarbonate type (8.3%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (64%), plot along the dissolution or mixing line.
- Cl and Na dominant indicative of reverse ion exchange of Na-Cl waters (18%),
- HCO_3 and Ca dominant indicative of recharge in sandstone (9%),
- Cl is the dominant anion and Na the dominant cation, indicative of downgradient end-point dissolution (9%). This corresponds to the high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 33: Chemical statistics for the Kransberg Subgroup (Mkr)

Element / Parameter	Statistics Drawn from a population of 23 data points for the Kransberg Subgroup (Mkr)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	23	5,05	8,17	6,75	6,88	5,66	6,97	7,91	0,92	13,4%
Electrical Conductivity (mS/m EC	23	2,20	187,70	5,43	34,44	2,45	4,90	129,42	58,74	170,5%
Total Dissolved Salts (mg/l TDS)	19	18,22	1243,00	43,64	229,83	22,09	42,00	883,80	397,98	173,2%
Calcium (mg/l Ca)	22	0,50	96,00	2,23	17,91	0,98	3,25	47,01	26,29	146,7%
Magnesium (mg/l Mg)	22	0,50	83,00	1,51	13,57	0,60	2,33	56,18	24,42	180,0%
Sodium (mg/l Na)	20	2,24	253,90	5,12	36,57	2,38	5,86	109,09	76,91	210,3%
Potassium (mg/l K)	21	0,39	15,23	0,82	2,77	0,47	0,66	5,00	4,37	158,0%
Chloride (mg/l Cl)	22	2,50	405,00	5,25	56,41	2,83	5,00	223,72	124,22	220,2%
Sulphate (mg/l SO_4)	21	0,50	43,00	2,24	9,08	1,00	4,00	20,40	11,98	132,0%
Total Alkalinity (mg/l) $CaCO_3$)	20	5,60	369,90	15,32	89,30	6,97	17,77	366,66	126,88	142,1%
Nitrate (mg/l N)	21	0,02	32,56	0,13	3,48	0,05	0,76	4,32	8,37	240,3%
Fluoride (mg/l F)	20	0,07	0,43	0,14	0,19	0,07	0,17	0,33	0,10	56,2%
Silicon as Si	21	3,93	30,14	6,75	9,19	4,37	7,90	15,40	6,72	73,1%
Iron (Fe)	6	0,02	0,75	0,03	0,15	0,02	0,02	0,40	0,29	198,6%
Manganese (Mn)	6	0,01	0,05	0,02	0,03	0,01	0,02	0,05	0,02	64,2%
Ortho Phosphate as Phosphorus as PO4	19	0,01	0,80	0,01	0,06	0,01	0,01	0,04	0,18	303,4%
ZAR	20	0,20	5,93	0,50	1,19	0,30	0,50	2,36	1,68	141,9%
LSI	16	Langelier Saturation Index (LSI)			Slightly Scaling		**12,5%**	Highly Scaling		**0,0%**
		Highly corrosive		**50,0%**	Slightly corrosive		**18,8%**	Balanced Corrosion		**18,8%**

Table 33 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is good in terms of electric conductivity (EC) with values between 2.2 and 187.7mS/m.

The Total Dissolved Solids (TDS) is acceptable in 89.5% of the samples, (TDS ≤ 1200mg/l). This is also evident from the TDS plot on the Durov diagram; 2 samples are problematic. The evaluation of the major cations and anions from 23 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 9.5% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be predominantly corrosive (68.8%), to slightly scaling (12.5%) and 18.8% balanced. The ZAR index indicates that 90% of the water is of a fair quality for irrigation (ZAR < 3).

The water abstracted supply people in rural farms; the water is also abstracted for livestock watering and for irrigation that occur in flat areas or within valleys.

7.2.1.5 VAALWATER FORMATION (Mva)

The Vaalwater Formation comprises fine-grained felspathic sandstone as well as micaceous sandstone, arkose, siltstone, and shale. It forms the roof or top layer of the Kransberg Subgroup (Council of Geoscience) and covers approximately 3.61% of the mapping area. Similar to most of the Formations in the Waterberg Group, it appears on the map as a fractured aquifer and occupies the north-western area of the map sheet, (Figure 22). The Vaalwater Formation has been intruded extensively by sills and dykes of predominantly diabasic composition. These diabase intrusions (N-Za) play a major role in the occurrence of groundwater. If dykes and sills are ignored, the groundwater potential of the Waterberg Group is generally low.

The yield diagram indicates that 72.9% of boreholes are yielding less less than 2ℓ/s, (Figure 23). In terms of groundwater quality at least one element exceeds the maximum allowable limit for domestic use in 2.7% of the water samples. For this unit the cation of concern is Magnesium. Based on Electrical Conductivity (EC), the quality of the water is generally ideal to be good.

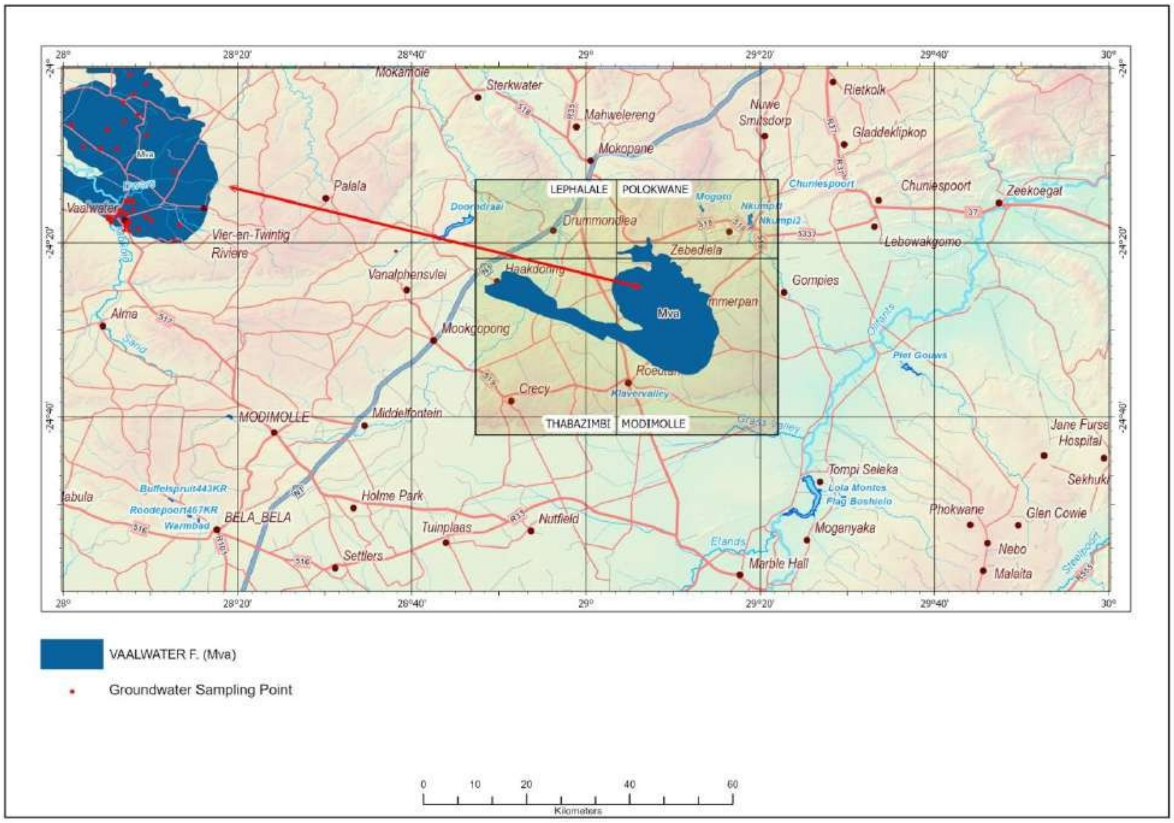


Figure 22: Geographical distribution of the Vaalwater Formation (Mva) and the associated groundwater sampling points.

As in most of the Formations in the Waterberg Group, groundwater occurs mainly in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has indicated that fractures do occur at these depths and can thus be targeted in the search for groundwater sources. It is, however, difficult to trace these deeply seated fractures using geophysical methods.

Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone (generally resulting in the formation of depressions); weathering may lead to fertile soil that stimulates a dense vegetation growth along the dykes. The dense vegetation can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water level, good water strikes can be found, (See also chapter 7.2.3.3, page 143). The permeability and storage capacity of the Vaalwater Formation are generally low. Yields tend to diminish quickly during periods of drought.

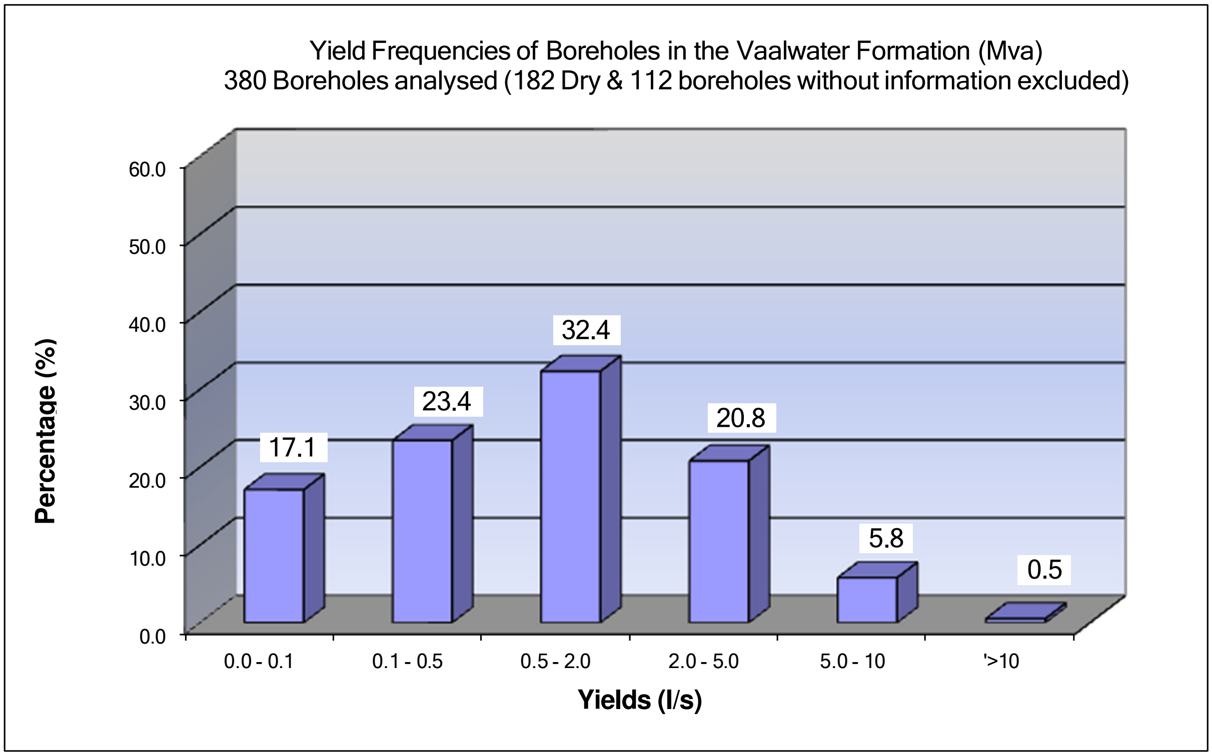
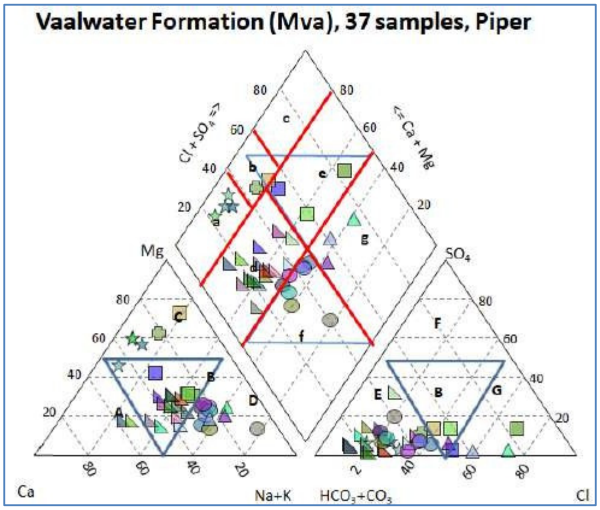


Figure 23: Yield frequency for fractured aquifers of the Vaalwater Formation (Mva).

The analysis of 380 borehole records indicates that 32.4% of the maximum yields are between 0.5ℓ/s to 2ℓ/s, with 40.5% of boreholes yielding less than 0.5ℓ/s and 27.1% of boreholes yielding between 2ℓ/s to 5ℓ/s, (Figure 23).

The static water level ranges from 0.11 meters below ground level, (mbgl) to 114.3mbgl, with a median static water level of 25.9mbgl, and an average static water level of 28.52mbgl, (based on 82 data records). The maximum depth recorded is 248m, with an average depth of 118.6m and a median depth of 105.5m, (28 data records). The maximum installation depth is 120m and the average is 72.9, (14 data records). The installation depth can be an indication of water strike depths.

The maximum recommended daily abstraction on record is 172.8 cubic meters per day (m^3/day), with an average abstraction of 77.1m^3/day. The 90th percentile is 121.8m^3/day and the median daily abstraction is 86.4m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 14.



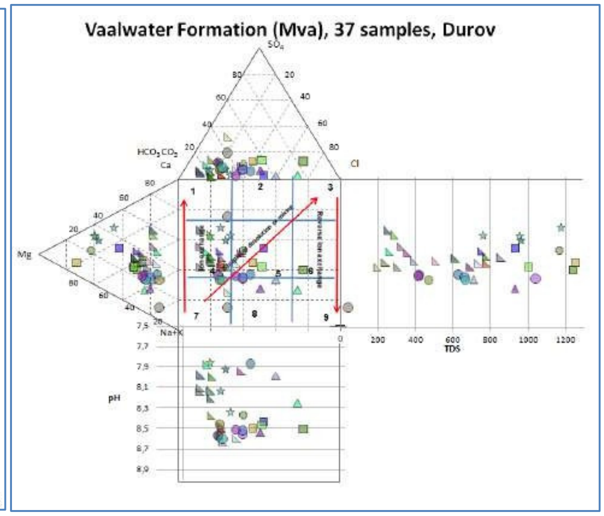


Figure 24: Trilinear diagrams, Piper and Durov for the Vaalwater Formation (Mva).

The trilinear Piper diagram, (Figure 24) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (70.3%), Weak acidic anions > Strong acidic anions (81.1%); Alkali >Alkali earths (29.7%); Strong acids > Weak acids (18.9%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type with increasing Sodium (46%);
- Sodium-Bicarbonate type (21.6%);
- Calcium-Magnesium-Bicarbonate (10.8%);
- Mixed Calcium-Magnesium-Chloride type with increasing Sodium (10.8%);
- Sodium-Chloride type (8.1%);
- Magnesium-Bicarbonate-Chloride (2.7%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- Anion discriminate and Ca dominant indicating mixed water exhibiting simple dissolution (48.6),
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (27%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (16.2%),
- HCO_3 and Ca dominant, indication of recharge in sandstone (2.7%),
- Anion discriminates and Na dominant, probable mixing or uncommon dissolution influences (2.7%),
- Cl and Na dominant are frequently indicative of end-point gradient waters through Dissolution (2.7%).

Table 34: Chemical statistics for the Vaalwater Formation (Mva)

Element / Parameter	Statistics Drawn from a population of 42 data points for the Vaalwater Formation (Mva)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	38	5,50	8,48	7,86	7,91	7,46	8,10	8,39	0,58	7,3%
Electrical Conductivity (mS/m EC)	38	2,50	189,80	30,42	57,45	23,15	55,60	89,49	35,18	61,2%
Total Dissolved Salts (mg/l TDS)	38	26,00	1278,00	247,76	426,42	160,17	420,60	724,80	245,02	57,5%
Calcium (mg/l Ca)	37	0,50	91,70	11,16	33,89	16,84	30,06	53,36	17,59	51,9%
Magnesium (mg/l Mg)	37	0,50	100,20	7,66	25,03	5,43	15,65	57,52	23,28	93,0%
Sodium (mg/l Na)	38	5,00	253,80	27,80	51,32	14,23	42,95	89,01	44,67	87,0%
Potassium (mg/l K)	37	0,74	15,09	1,46	2,66	0,90	1,37	5,73	3,06	115,1%
Chloride (mg/l Cl)	38	1,50	402,80	13,18	51,09	5,55	25,43	96,44	75,56	147,9%
Sulphate (mg/l SO_4)	38	2,00	68,04	6,30	13,38	3,16	9,54	27,13	13,93	104,1%
Total Alkalinity (mg/l) $CaCO_3$)	37	12,40	403,00	127,01	209,05	104,03	211,65	349,48	98,44	47,1%
Nitrate (mg/l N)	38	0,02	13,00	0,12	1,85	0,04	0,68	5,08	2,78	150,3%
Fluoride (mg/l F)	38	0,12	0,95	0,26	0,33	0,16	0,27	0,50	0,17	51,9%
Silicon as Si	37	4,05	29,22	12,04	13,90	9,84	12,83	19,98	4,90	35,2%
Iron (Fe)	9	0,01	0,05	0,01	0,02	0,01	0,01	0,05	0,02	80,3%
Manganese (Mn)	7	0,01	0,05	0,01	0,02	0,01	0,01	0,05	0,02	91,1%
Ortho Phosphate as Phosphorus as PO4	35	0,01	0,80	0,02	0,07	0,01	0,02	0,10	0,17	242,8%
ZAR	37	0,25	5,79	1,07	1,74	0,52	1,57	2,97	1,14	65,2%
LSI	37	Langelier Saturation Index (LSI)			Slightly Scaling		48,6%	Highly Scaling		0,0%
		Highly corrosive		5,4%	Slightly corrosive		2,7%	Balanced Corrosion		43,2%

Table 34 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In terms of the electric conductivity (EC) the overall water quality is good, values vary between 2.5 and 189.8mS/m.

The Total Dissolved Solids (TDS) is acceptable in 97.4% of the samples (TDS ≤ 1200mg/l). The evaluation of the major cations and anions from 42 samples show elevated concentrations of Magnesium (Mg > 100mg/l) in 2.7% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be corrosive (8.1%) but predominantly it will result in slight scaling (48.6%) with 43.2% balanced. The ZAR index indicates that 91.9% of the water is of a fair quality for irrigation (ZAR < 3).

The water is abstracted for game, livestock watering and domestic purposes for rural farms and for Vaalwater town. Some irrigation occurs within the south-western section of the unit; it is expected that conjunctive use with surface water supply the demand.

7.2.1.6 CLEREMONT FORMATION (Mcl)

The Cleremont Formation underlies the Vaalwater Formation and is also part of the Kransberg Subgroup. It consists of course-grained white sandstone and occurs in the north-western portion of the map sheet, (Figure 25). It covers approximately 1.86% of the map sheet.

The unit extent north-west into the Thabazimbi and Polokwane map sheets and continues into the Lephalale map sheet (north-west corner boundary). The combined larger outcrop when mapped appears to form a ring around the Vaalwater Formation, (see inset map Figure 25).

The sandstone is medium to coarse-grained, well sorted with a high percentage of quarts; locally gritty and whitish in colour. Rare occurrences of sedimentary rock with a light-pink or light-red colour occur and are apparently restricted to the base of the formation, (Callaghan, 1987, Callaghan and Brandl, 1991).

Using the dataset for all adjacent map sheets, statistical analysis indicates that 70.7% of successful boreholes yield less than 2ℓ/s. For comparison the dataset for the Modimolle map sheet specifically indicates that 6**7.7%** of boreholes yield less than 2ℓ/s**.**

Although the chemical data falling within the Modimolle map sheet was sufficient, the characterization of the aquifer unit in terms of water quality was based on information from all four adjacent 1: 250 000 hydrogeological map sheets, namely Polokwane, Lephalale, Thabazimbi and Modimolle.

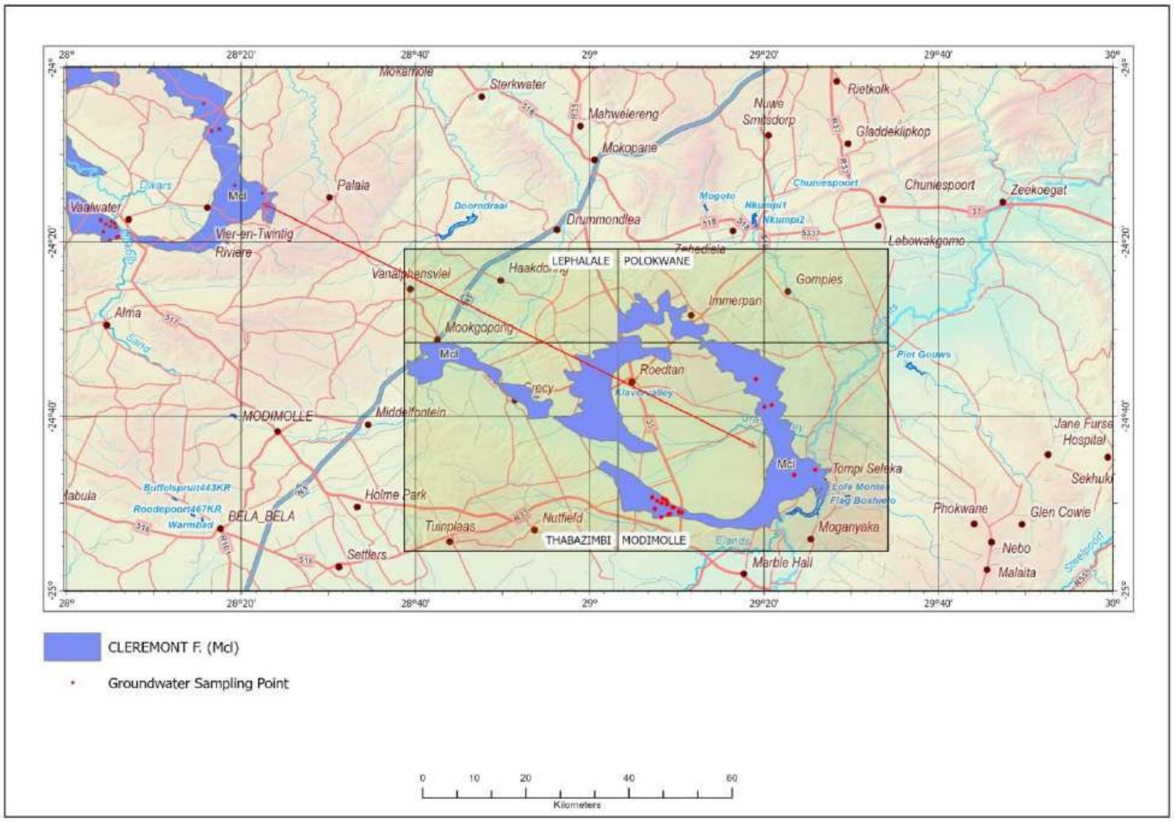


Figure 25: Geographical distribution of the Cleremont Formation and the associated groundwater sampling points

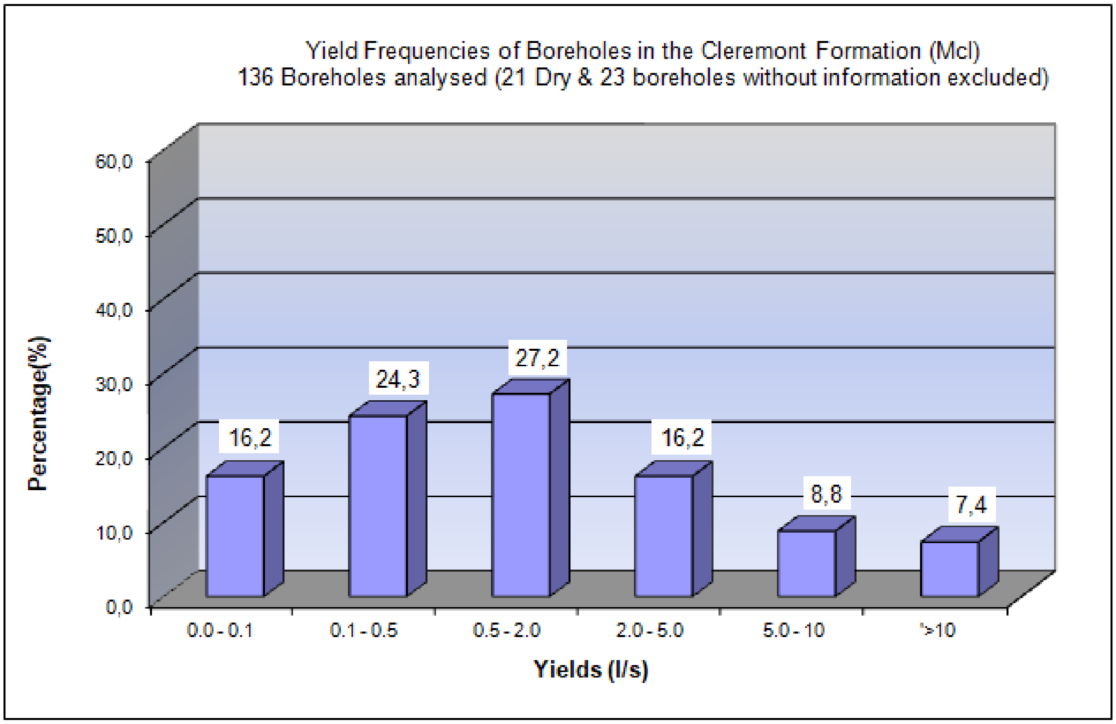


Figure 26: Yield frequency for fractured aquifers of the Cleremont Formation (Mcl), data from the Modimole map sheet.

The yield frequency distribution, (Figure 26) indicates that 27.2% of successful boreholes yield between 0.5ℓ/s to 2ℓ/s, with 40.5% of boreholes yielding less than 0.5ℓ/s and 32.4% of the boreholes are yielding more than 2ℓ/s.

Using the data within the Modimolle map sheet boundary the following was indicated: The static water level ranges from 1.5 meters below ground level, (mbgl) to 120mbgl, with a median static water level of 18.59mbgl and an average static water level of 24.46mbgl, (based on 78 data records). The maximum depth recorded is 250.4m, with an average depth of 110.5m and a median depth of 111.7m, (26 data records). The maximum installation depth is 66m and the average is 14.5m. The installation depth can be indicative of deep fractures that relate to water strike depths.

The maximum recommended daily abstraction on record is 276.5 cubic meters per day (m^3/day) and an average of 125.2m^3/day. The 90th percentile for daily abstraction is 257.4m^3/day and the median is 108m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 12.

Similar in characteristics to the Vaalwater, undifferentiated Sandriviersberg and Mogalakwena Formations, groundwater occurs mainly in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has indicated that fractures do occur at these depths and is thus a target for good supplies. It is, however, difficult to trace these deeply seated fractures using geophysical methods.

Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone (generally resulting in the formation of depression), but it also produces a more fertile soil that stimulates dense vegetation growth along the dykes. These can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them, (See also chapter 7.2.3.3, page 143). The permeability and storage capacity of Cleremont Formation are generally low. Yields tend to diminish quickly during periods of drought.

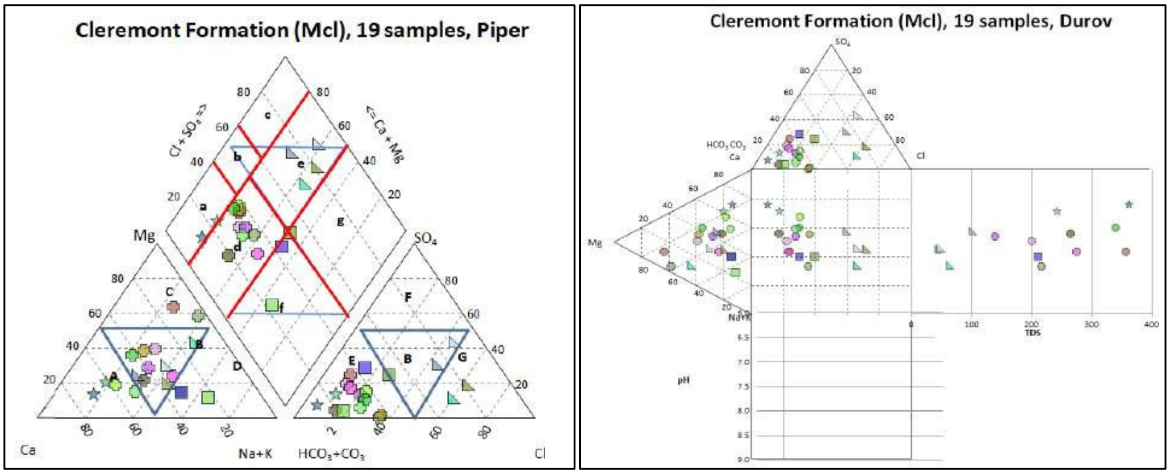


Figure 27: Trilinear diagrams, Piper and Durov for the Cleremont Formation (Mcl).

The groundwater resource unit extent into three adjacent map sheets, namely Polokwane, Lephalale and Thabazimbi. For the chemical data 28 data points falls on the Modimolle map sheet;
2 on the Lephalale map sheet, 1 on the Thabazimbi map sheet and 0 data points on the Polokwane map sheet. The accuracy of the chemical analysis was checked by the plausibility of the Electrical Conductivity (EC) and Electro Neutrality (E.N). Only 19 analyses could be used as 12 analyses were not considered accurate.

The trilinear Piper diagram, (Figure 27) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (84.2%), Weak acidic anions > Strong acidic anions (79%); Alkali >Alkali earths (15.8%); Strong acids > Weak acids (21%).

The second evaluation was on the water type: mixed

- Calcium-Magnesium-Bicarbonate type with increased Sodium (42.1%);
- Calcium-Bicarbonate type (21.1%).
- Sodium-Bicarbonate type (15.8%);
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium and Sulfate (10.5%);
- Mixed Calcium-Magnesium-Chloride type (10.5%);

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (42.9%),
- No dominant anion or cation indicates fresh recent recharged water exhibiting simple dissolution or mixing (28.6%), plots along the dissolution or mixing line,
- HCO_3 and Ca dominant, indication of recharge in sandstone (14.3%),
- HCO_3 and Ca dominant, with prevailing Na, an important ion exchange is presumed (4.8%),
- Anion discriminate and Na dominant, probable mixing or uncommon dissolution influences (4.8%),
- HCO_3 and Na dominant, indication of ion exchanged water (4.8%),

Table 35: Chemical statistics for the Cleremont Formation (Mcl).

Element / Parameter	Statistics Drawn from a population of 31 data points for the Cleremont Formation (Mcl)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	30	6.06	8.36	7.19	7.25	6.08	7.41	7.95	0.67	9.3%
Electrical Conductivity (mS/m EC	30	2.54	95.95	8.95	20.76	3.40	15.10	43.18	20.35	98.1%
Total Dissolved Salts (mg/l TDS)	30	17.2	721.3	64.5	157.1	24.6	115.5	308.3	152.6	97.2%
Calcium (mg/l Ca)	26	0.67	77.70	2.77	14.85	0.82	7.92	34.11	17.81	119.9%
Magnesium (mg/l Mg)	26	0.67	45.16	2.43	6.45	1.09	3.17	14.51	9.34	144.7%
Sodium (mg/l Na)	26	1.50	59.50	5.31	12.09	2.57	7.64	24.08	13.12	108.5%
Potassium (mg/l K)	26	0.35	6.81	0.73	1.10	0.39	0.86	1.47	1.23	111.7%
Chloride (mg/l Cl)	30	2.98	62.00	6.51	11.27	3.48	6.67	26.62	12.46	110.5%
Sulphate (mg/l SO_4)	29	0.09	19.87	1.52	5.69	1.47	4.00	12.63	4.99	87.7%
Total Alkalinity (mg/l) $CaCO_3$)	27	4.0	287.3	15.3	69.7	5.5	51.0	160.7	72.3	103.8%
Nitrate (mg/l N)	30	0.02	29.53	0.20	2.59	0.08	1.06	4.44	5.44	209.6%
Fluoride (mg/l F)	31	0.05	5.15	0.14	0.38	0.09	0.15	0.43	0.92	241.1%
Silicon as Si	26	4.34	32.56	6.98	8.78	4.69	7.94	13.90	5.93	67.6%
Iron (Fe)	11	0.0050	0.0900	0.0104	0.0282	0.0054	0.0205	0.0500	0.03	99.7%
Manganese (Mn)	6	0.0092	0.0820	0.0299	0.0485	0.0296	0.0500	0.0660	0.02	47.7%
Ortho Phosphate as Phosphorus as PO4	29	0.005	0.800	0.017	0.130	0.010	0.019	0.800	0.27	210.2%
ZAR	26	0.21	3.11	0.49	0.68	0.32	0.50	1.11	0.57	82.8%
LSI	26	Langelier Saturation Index (LSI)			Slightly Scaling		**3.8%**	Highly Scaling		**0.0%**
		Highly corrosive		**46.2%**	Slightly corrosive		**38.5%**	Balanced Corrosion		**11.5%**

The data points used for the chemical statistics are from all four maps as the outcrop represents a single groundwater resource unit.

Table 35 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. In terms of the electric conductivity (EC), the overall water quality is ideal; it varies between 2.5 and 95.9mS/m. The Total Dissolved Solids (TDS) is acceptable in 100% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 31 samples show elevated concentrations of Nitrate, (N >20mg/l) in 3.3% and Fluoride (F >1.5mg/l) in 3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be predominantly corrosive (84.7%); slightly scaling (3.8%) and balanced in 11.5% of the analysis. The ZAR index indicates that 96.2% of the water is of a fair quality for irrigation (ZAR < 3).

The water is abstracted for game, livestock watering and domestic purposes for rural farms and for Vaalwater town. Some irrigation occurs within the western section of the unit; it is expected that conjunctive use with surface water supplies the demand. The quality of the water is generally ideal to be good. No elements in the available analysis exceed the maximum allowed limit for human consumption.

7.2.1.7 AASVOËLKOP FORMATION (Mas)

The Aasvoëlkop Formation appears on the map as a fractured aquifer. It is the top layer of the Matlabas Subgroup. It comprises siltstone, mudstone, fine-grained feldspathic sandstone, and conglomerate (Council of Geoscience). It forms a rim around the Kransberg Subgroup on the north-western portion of the map sheet, (Figure 28). It covers approximately 0.57% of the total map area.

Groundwater is found in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone (generally resulting in the formation of depression) but also produces a more fertile soil that stimulates a dense vegetation growth along the dykes. These can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them, (See also chapter 7.2.3.3, page 143). The permeability and storage capacity of the Aasvoëlkop Formation are generally low. Yields tend to diminish quickly during periods of drought.

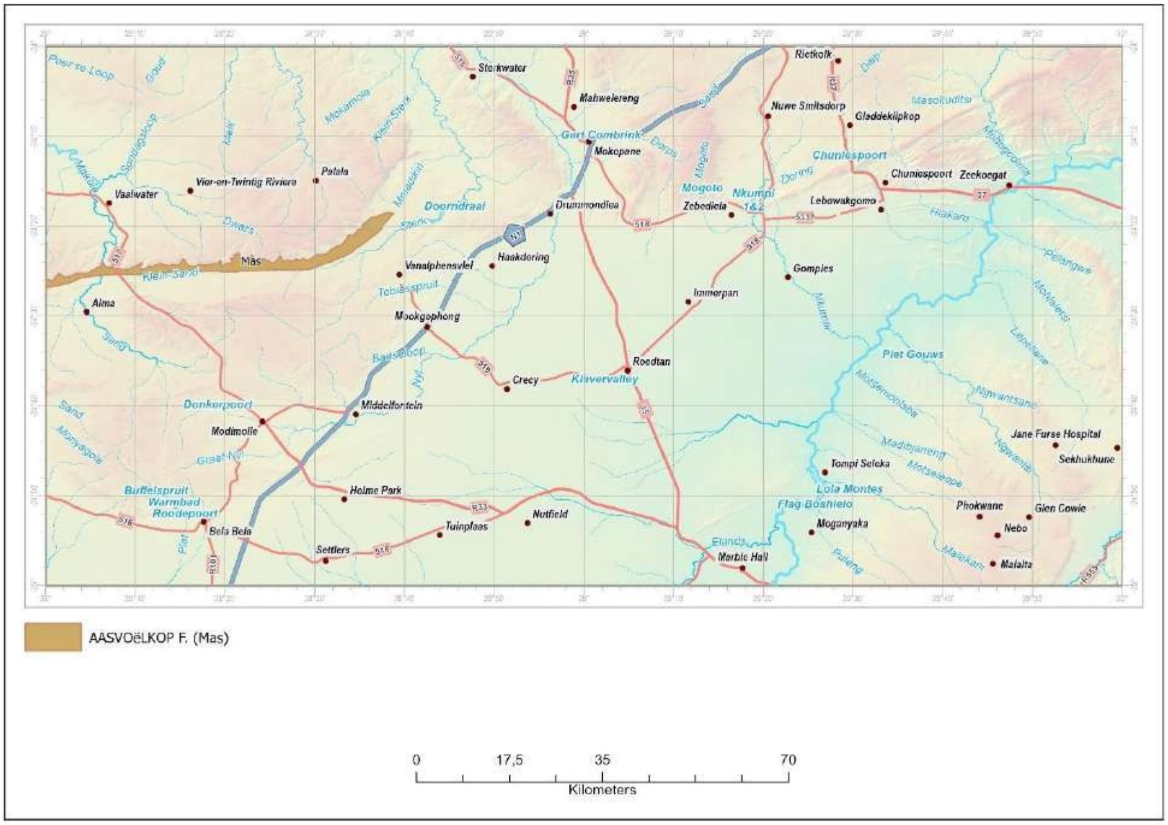


Figure 28: Geographical distribution of the Aasvoëlkop Formation (Mas) and the associated groundwater sampling points.

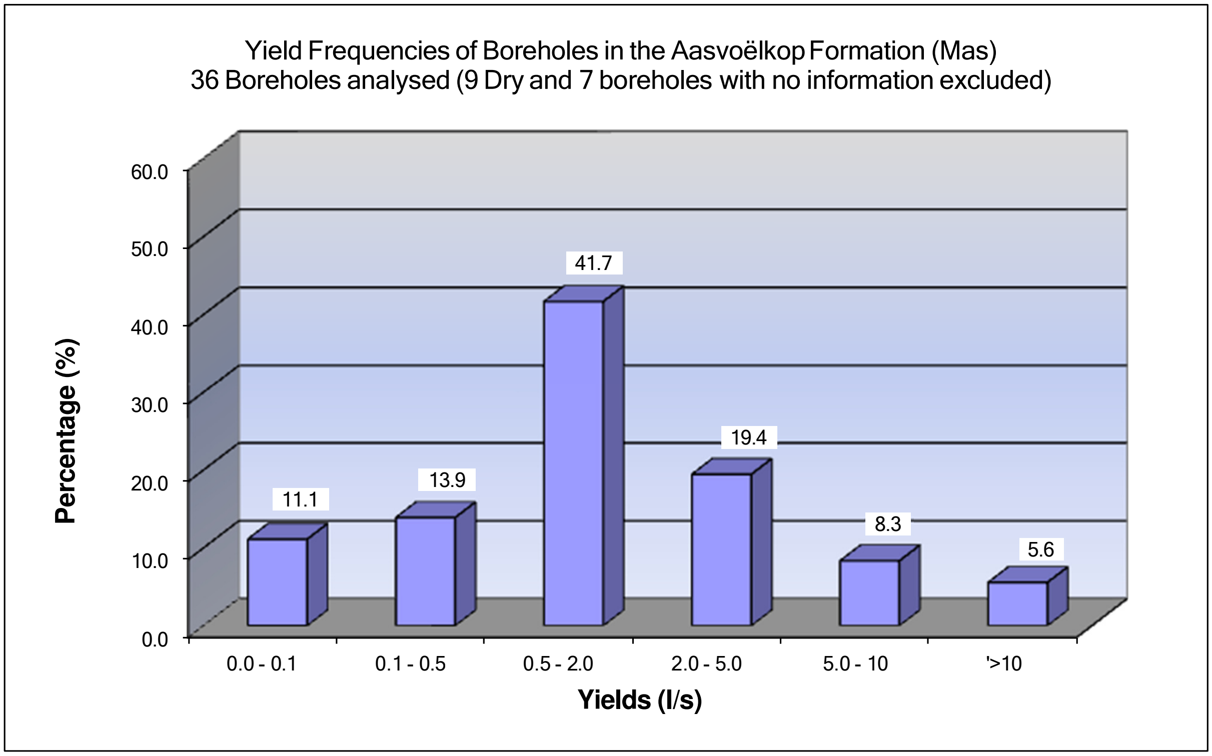


Figure 29: Yield frequency for fractured aquifers of the Aasvoëlkop Formation (Mas).

The yield frequency distribution, (Figure 29) indicates that 25% of the successful boreholes have maximum yields less than 0.5ℓ/s. A further 41.7% of the boreholes yield between 0.5ℓ/s to 2ℓ/s, with 19.4% yielding between 2ℓ/s to 5ℓ/s. Only 5.6% of the boreholes have yields exceeding 10ℓ/s. Only one record on depth is available for this unit, it is 150m.

No data was available for the characterization of water chemistry for this aquifer unit. However, the water-bearing properties of this unit are, in many respects, similar to those of the Waterberg Group. For more information on this groundwater resource unit, the reader is referred to the 1:250 000 hydrogeological map sheets of Thabazimbi and Lephalale.

7.2.1.8 MAKGABENG FORMATION (Mma)

The Makgabeng Formation consists of fine to medium-grained sandstone, sometimes felspathic in places. It covers approximately 0.81% of the map sheet and appears as a rim around the Waterberg Mountains in the north-western section of the map sheet, north of Mookgophong, (Figure 30). It is part of the Nylstroom Subgroup. The partly argillaceous Aasvoëlkop Formation grades into the arenaceous Makgabeng Formation, whereas the Sandriviersberg Formation, which occupies the southern Waterberg plateau, grades to the east and north into the Makgabeng Formation. Locally the Makgabeng Formation contains numerous conglomerate layers, (Council of Geoscience).

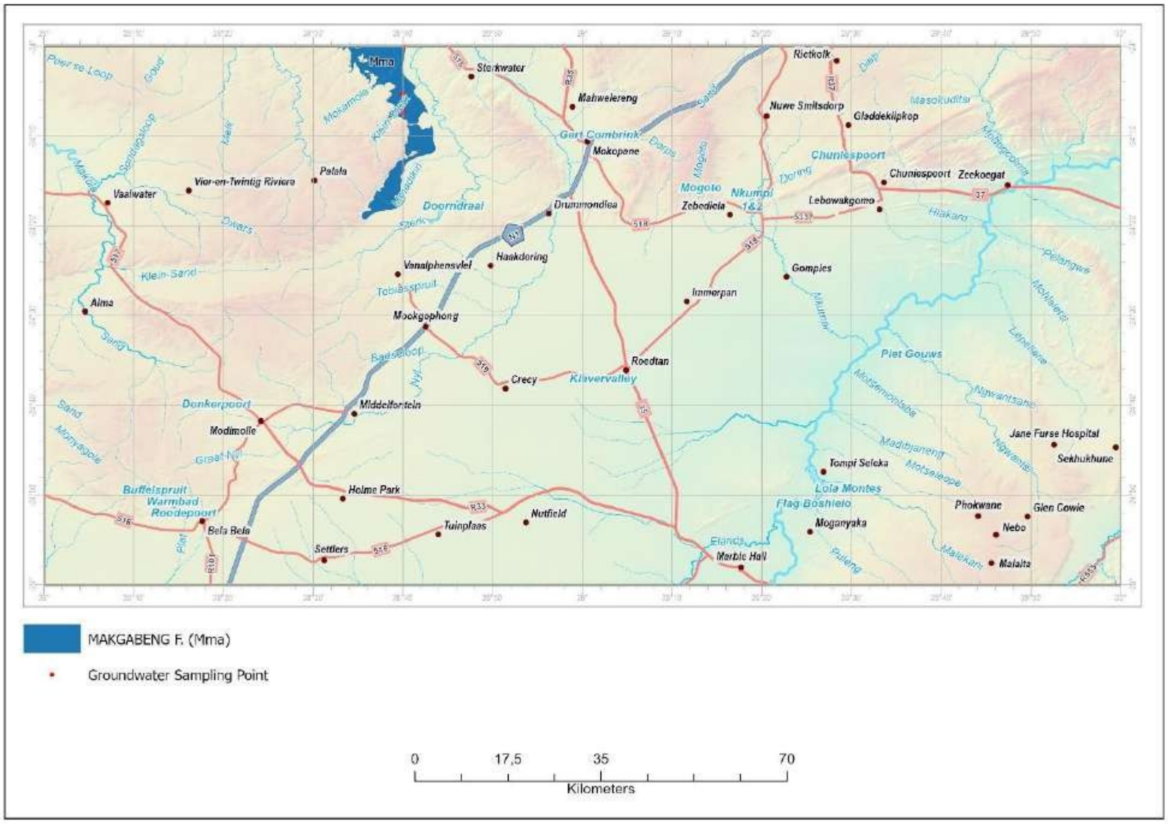


Figure 30: Geographical distribution of the Makgabeng Formation (Mma) and the associated groundwater sampling points

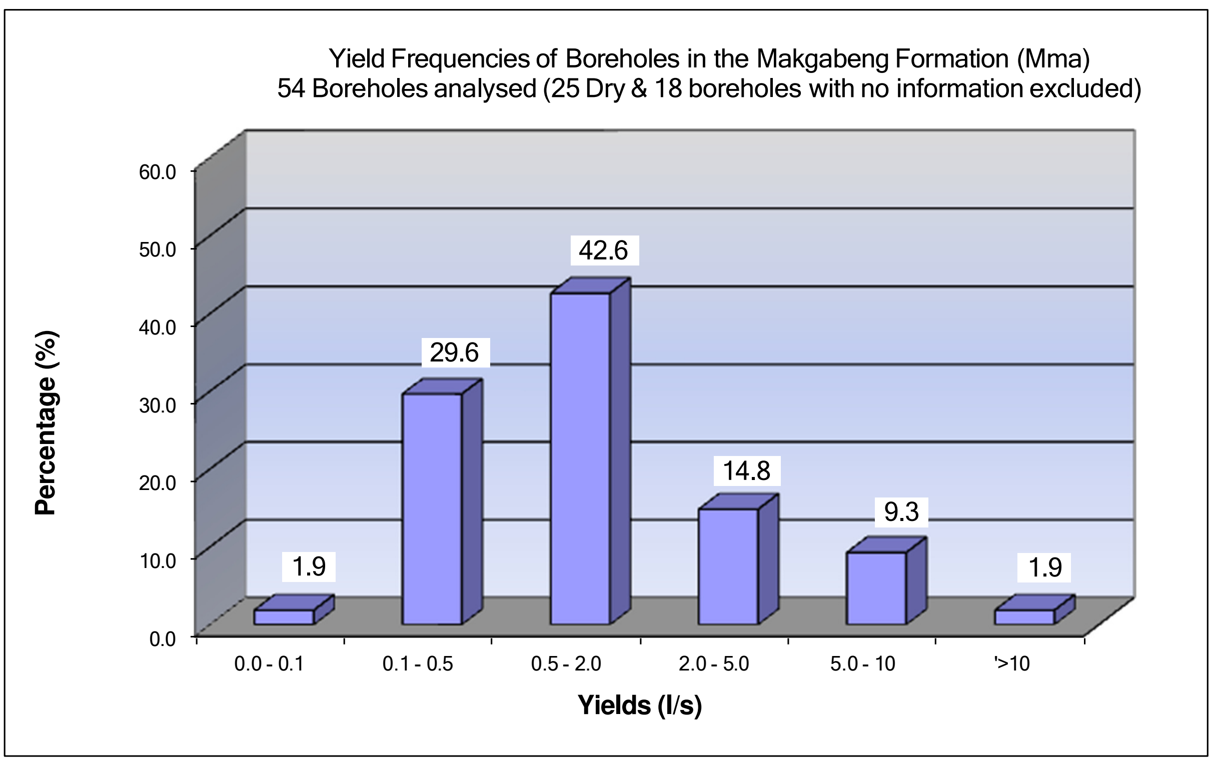


Figure 31: Yield frequency for fractured aquifers of the Makgabeng Formation (Mma).

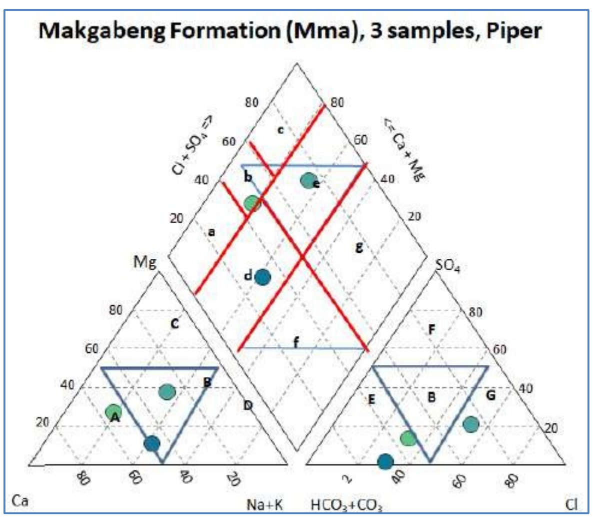
The yield frequency distribution, (Figure 31) indicates that 74.1% of successful boreholes yield less than 2ℓ/s. A further 14.8% of boreholes yield between 2ℓ/s to 5ℓ/s, with 11.1% yielding more than 5ℓ/s.

The static water level ranges from 3.04 meters below ground level, (mbgl) to 80mbgl, with a median static water level of 13.72mbgl and an average static water level of 17.65mbgl, (based on 54 data records). The maximum depth recorded is 100m, with an average depth of 66.2m and a median depth of 70m, (7 data points). The depth of installation is between 27m and 30m using the information from 2 data records.

The maximum recommended daily abstraction on record is 69.1 cubic meters per day (m^3/day) and the average is 47.5m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 2.

Groundwater is found in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has indicated that fractures do occur at these depths and is thus a target for good supplies. It is, however, difficult to trace these deeply seated fractures using geophysical methods.

Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone (generally resulting in the formation of depression) but also produces a more fertile soil that stimulates a dense vegetation growth along the dykes. These can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them, (See also chapter 7.2.3.3, page 143). The permeability and storage capacity of the Makgabeng Formation is generally low. Yields tend to diminish quickly during periods of drought.



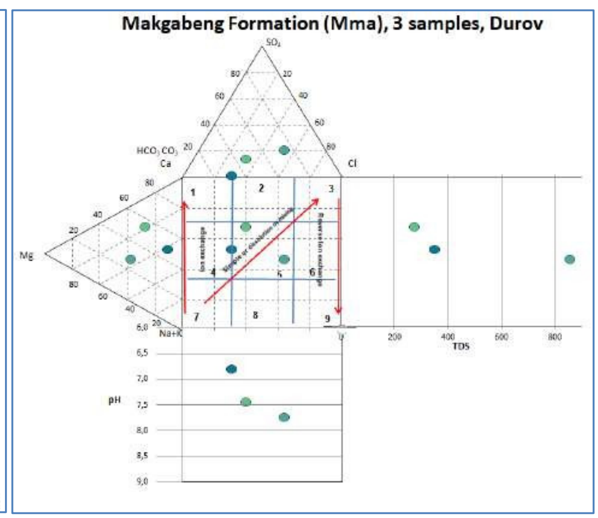


Figure 32: Trilinear diagrams, Piper and Durov for the Makgabeng Formation (Mma).

The trilinear Piper diagram, (Figure 32) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (50%); Alkali >Alkali earths (0%); Strong acids > Weak acids (50%).

The groundwater in this unit classifies as:

- Calcium-Bicarbonate-Chloride type (33.3%);
- Mixed Calcium-Magnesium-Chloride type with increased Sodium (33.3%),
- Mixed Calcium-Sodium-Bicarbonate type (33.3%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. No dominant anion or cation can be attributed to fresh recent recharge water or indicates water exhibiting simple dissolution or mixing (39.1%). It plots along with the dissolution or mixing line.

Table 36: Chemical statistics for the Makgabeng Formation (Mma)

Element / Parameter	Statistics Drawn from a population of 5 data points for the Makgabeng Formation (Mma)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	5	7,29	8,15	7,69	7,71	7,38	7,64	8,07	0,34	4,4%
Electrical Conductivity (mS/m EC	5	40,00	119,00	55,56	71,56	40,12	43,30	117,48	41,61	58,2%
Total Dissolved Salts (mg/l TDS)	5	272,14	860,00	406,93	525,84	280,88	347,23	858,34	304,38	57,9%
Calcium (mg/l Ca)	5	39,29	70,95	50,36	53,57	40,98	44,80	70,29	15,26	28,5%
Magnesium (mg/l Mg)	5	6,30	60,50	13,89	29,80	8,54	11,98	59,64	27,15	91,1%
Sodium (mg/l Na)	5	15,42	93,37	29,95	52,14	16,17	44,50	92,06	37,95	72,8%
Potassium (mg/l K)	5	0,50	13,92	1,17	5,69	0,56	1,80	12,99	6,52	114,6%
Chloride (mg/l Cl)	5	20,00	169,50	34,35	80,81	20,51	27,30	168,08	79,40	98,3%
Sulphate (mg/l SO_4)	5	2,00	88,69	6,96	37,18	4,80	12,10	82,86	40,86	109,9%
Total Alkalinity (mg/l) $CaCO_3$)	3	97,58	229,67	148,18	168,15	113,50	177,20	219,18	66,51	39,6%
Nitrate (mg/l N)	5	0,22	18,98	1,03	12,45	4,84	15,30	17,79	7,31	58,7%
Fluoride (mg/l F)	5	0,10	3,37	0,24	0,87	0,14	0,30	2,18	1,40	160,7%
Silicon as Si	5	16,51	42,60	25,45	28,59	18,86	24,60	40,31	10,79	37,7%
Iron (Fe)	4	0,01	0,05	0,02	0,03	0,01	0,04	0,05	0,02	70,2%
Manganese (Mn)	2	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,00	0,0%
Ortho Phosphate as Phosphorus as PO4	5	0,02	0,80	0,03	0,33	0,02	0,04	0,80	0,42	126,9%
ZAR	5	0,55	1,99	0,98	1,34	0,57	1,65	1,96	0,71	52,9%
LSI	3	Langelier Saturation Index (LSI)			Slightly Scaling		**33,3%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**66,7%**

Table 36 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. Only five chemical analyses were available for the unit. The overall water quality is ideal to good when discarding one sample with a high Fluoride concentration. Electrical conductivity (EC) values vary between 40 and 119mS/m. The Total Dissolved Solids (TDS) is acceptable in all the samples (TDS ≤ 1200mg/l).

The Langelier Saturation Index (LSI) indicates that the water may be slightly scaling (33.3%) and 66.7% is balanced. The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3). Take note that the sample population is limited.

According to Bond (1947) the water is suitable for most purposes although some very high Fluoride levels (up to 15mg/l) have been found in boreholes in the Ellisras area for this unit. The source of the high concentrations is not known. This finding corresponds with the high Fluoride concentration identified in a single borehole; it represents 20% of the available analysis from boreholes within this unit.

Groundwater is abstracted for livestock watering, rural domestic purposes and to a lesser extent for irrigation. The irrigation within the unit is centralized along the Sterkrivier. It is most likely that the largest volume used for irrigation is from surface water and lesser from groundwater as the yield diagram indicates that only 11.1% of successful boreholes yield more than 5ℓ/s.

7.2.1.9 SCHILPADKOP FORMATION (Msc)

The Schilpadkop Formation, which comprises sandstone, grit, conglomerate, and boulder conglomerate with fine-grained sandstone at the top, forms the bottom layer of the Nylstroom Subgroup. It comprises approximately 0.96% of the mapped area. The Schilpadkop and locally the Makgabeng Formation form the base of the succession in the younger, larger, but shallower basin (Council for Geoscience). It occurs as a narrow rim between the Aasvoëlkop and Alma Formations south of the Waterberg Mountains, (Figure 33).

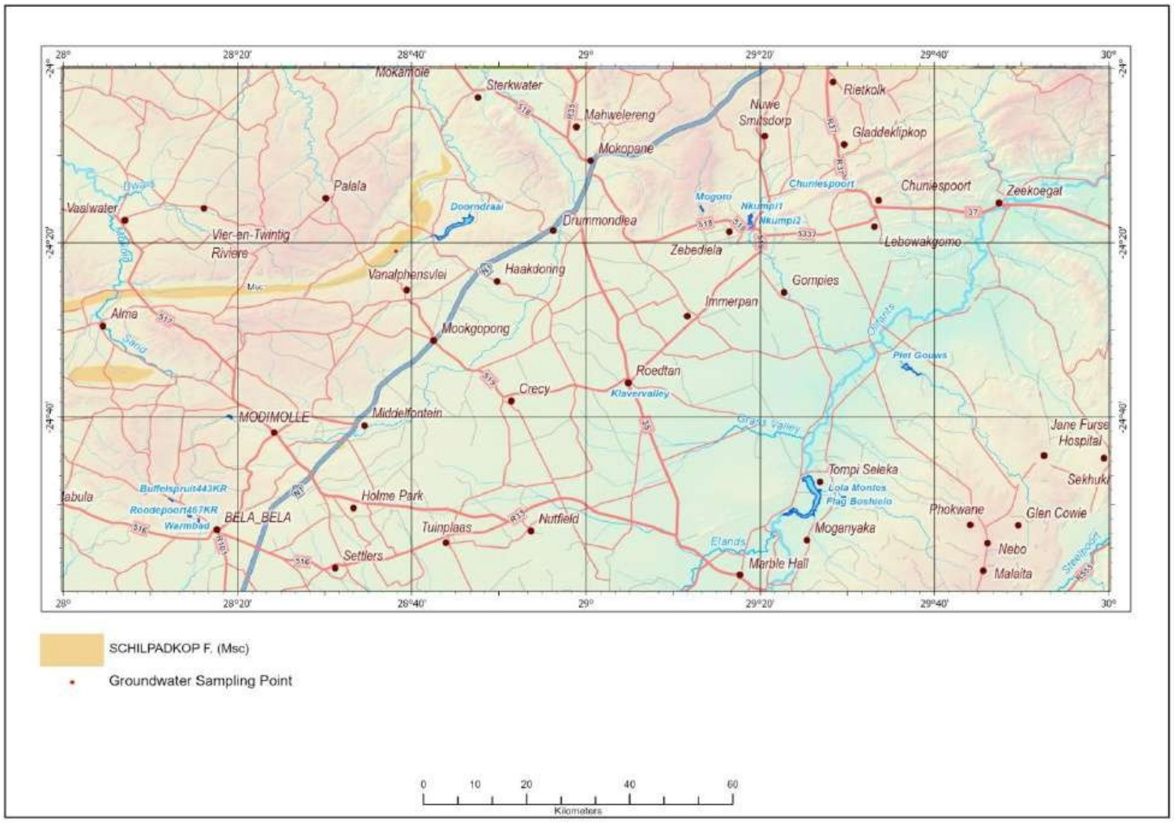


Figure 33: Geographical distribution of the Schilpadkop Formation (Msc)

Groundwater is found in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has indicated that fractures do occur at these depths and is thus a target for good supplies. It is, however, difficult to trace these deeply seated fractures using geophysical methods.

Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone (generally resulting in the formation of depression) but also produces a more fertile soil that stimulates a dense vegetation growth along the dykes.

These can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them, (See also chapter 7.2.3.3, page 143). The permeability and storage capacity of the Schilpadkop Formation are generally low. Yields tend to diminish quickly during periods of drought.

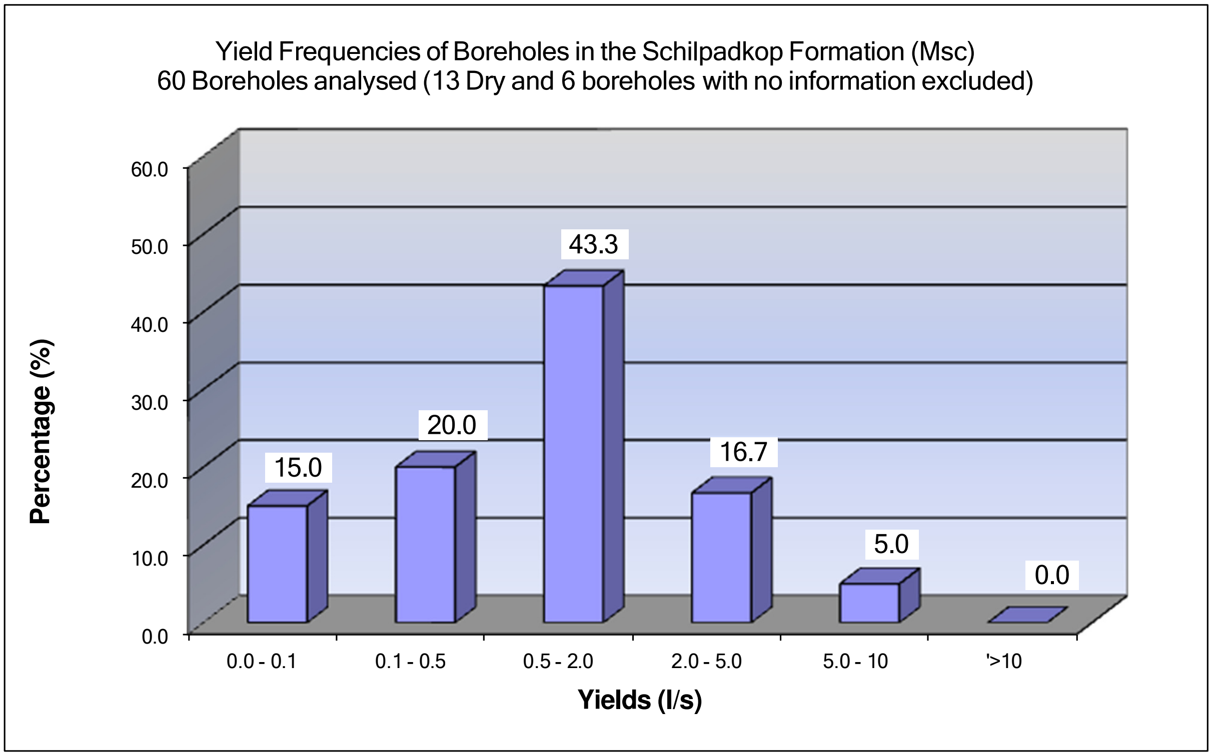


Figure 34: Yield frequency for fractured aquifers of the Schilpadkop Formation (Msc).

The yield frequency distribution, (Figure 34) indicates that the maximum yield for 35% of the boreholes is less than 0.5ℓ/s, with 43.3% of the boreholes yielding between 0.5ℓ/s to 2ℓ/s and 21.7% of the boreholes yielding more than 2ℓ/s.

The static water level ranges from 9.56 meters below ground level, (mbgl) to 36.4mbgl, with a median of 18.28mbgl and an average static water level of 19.86mbgl, (based on 5 data records). The maximum depth recorded is 150m, (2 data records). No other data was available for detailed analysis.

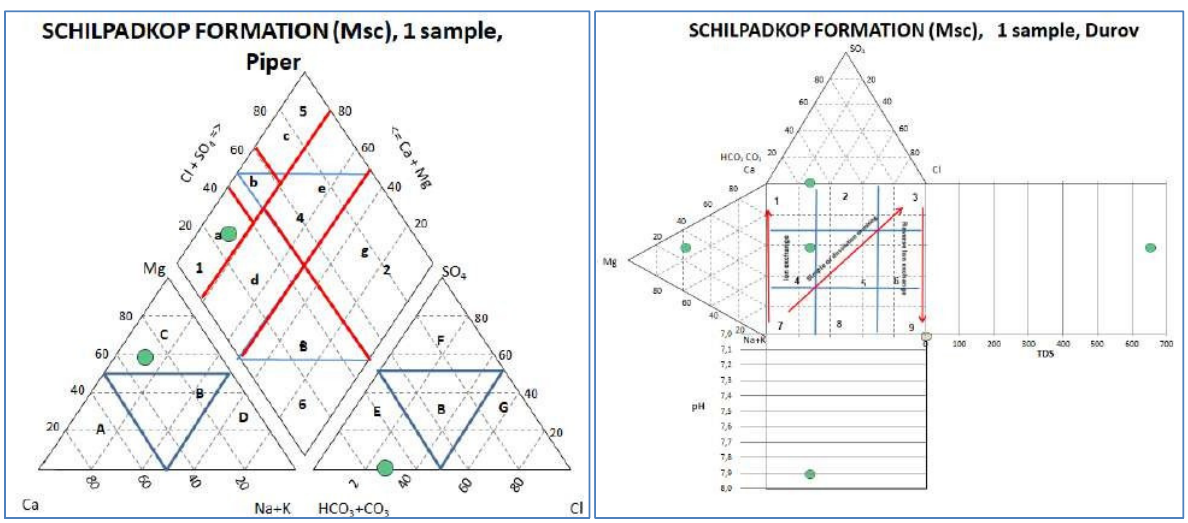


Figure 35: Trilinear diagrams, Piper and Durov for the Schilpadkop Formation (Msc).

The trilinear Piper diagram, (Figure 35) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths >

Alkali (100%), Weak acidic anions > Strong acidic anions (100%); Alkali >Alkali earths (0%); Strong acids > Weak acids (0%).

The water type is Magnesium-Bicarbonate. Magnesium dominant groundwater is not common especially in alkali earth's dominant water. For the sample the Ca/Mg ratio is 0.5:1. The Calcium to Magnesium ratio in most water bodies is 4:1 to 2:1 for TDS values less than 500mg/l. With increasing TDS the Magnesium ratio increases.

Table 37: Chemical statistics for the Schilpadkop Formation (Msc)

Element / Parameter	Statistics Drawn from a population of only 1 data point for the Schilpadkop Formation (Msc)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	1	7,90	7,90	7,90	7,90	7,90	7,90	7,90		
Electrical Conductivity (mS/m EC)	1	85,60	85,60	85,60	85,60	85,60	85,60	85,60		
Total Dissolved Salts (mg/l TDS)	0	0,00	0,00							
Calcium (mg/l Ca)	1	62,00	62,00	62,00	62,00	62,00	62,00	62,00		
Magnesium (mg/l Mg)	1	74,00	74,00	74,00	74,00	74,00	74,00	74,00		
Sodium (mg/l Na)	1	30,00	30,00	30,00	30,00	30,00	30,00	30,00		
Potassium (mg/l K)	0	0,00	0,00							
Chloride (mg/l Cl)	1	57,00	57,00	57,00	57,00	57,00	57,00	57,00		
Sulphate (mg/l SO_4)	1	2,00	2,00	2,00	2,00	2,00	2,00	2,00		
Total Alkalinity (mg/l) $CaCO_3$)	1	425,70	425,70	425,70	425,70	425,70	425,70	425,70		
Nitrate (mg/l N)	1	5,65	5,65	5,65	5,65	5,65	5,65	5,65		
Fluoride (mg/l F)	1	0,05	0,05	0,05	0,05	0,05	0,05	0,05		
Silicon as Si	0	0,00	0,00							
Iron (Fe)	0	0,00	0,00							
Manganese (Mn)	0	0,00	0,00							
Ortho Phosphate as Phosphorus as PO4	0	0,00	0,00							
ZAR	1	0,61	0,61	0,61	0,61	0,61	0,61	0,61		
LSI	0	Langelier Saturation Index (LSI)			Slightly Scaling			Highly Scaling		
		Highly corrosive			Slightly corrosive			Balanced Corrosion		

Table 37 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Only one chemical analysis was available for the unit. The electric conductivity (EC) value is 85.6mS/m (ideal) and the concentration of Magnesium is 74mg/l, therefore falling within the marginal range.

Groundwater is abstracted for game, livestock watering, rural domestic purposes. Although irrigation covers a large section of the aquifer unit the scale of irrigation from groundwater is not known. The overall water quality is ideal to marginal.

7.2.1.10 ALMA FORMATION (Mag)

Of the two overlapping sedimentary basins, beds of the Swaershoek, Alma and Sterkrivier Formations were laid down in the Alma trough which is the deeper basin. It comprises 3.82% of the map sheet area. The oldest sub-division (Nylstroom) of which the lower portion consists of the Swaershoek Formation is of late-Bushveld age and confined to proto basins of which the largest coincides approximately with the Nylstroom syncline (Counsil for Geoscience). The Alma Formation forms the outer rim around the Waterberg Mountains and occurs some distance to the north and north-west of Modimolle, (Figure 36). The Formation is poorly exposed and mostly only the conglomerate beds are seen.

The Alma Formation has been intruded extensively by sills and dykes of predominantly diabasic composition. These diabase intrusions (N-Za) especially when targeting the contact zones between the diabase and the sedimentary rock, play a major role in the occurrence of groundwater. Groundwater is found in fault zones, fracture zones and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has indicated that fractures do occur at these depths and is therefore a target for good supplies. It is, however, difficult to trace these deeply seated fractures using geophysical methods. As mentioned above, diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone (generally resulting in the formation of depression) but also produces a more fertile soil that stimulates a dense vegetation growth along the dykes. These can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them, (See also chapter 7.2.3.3, page 143). The permeability and storage capacity of Alma Formation are generally low. Yields tend to diminish quickly during periods of drought especially if the main source is deep seated fractures.

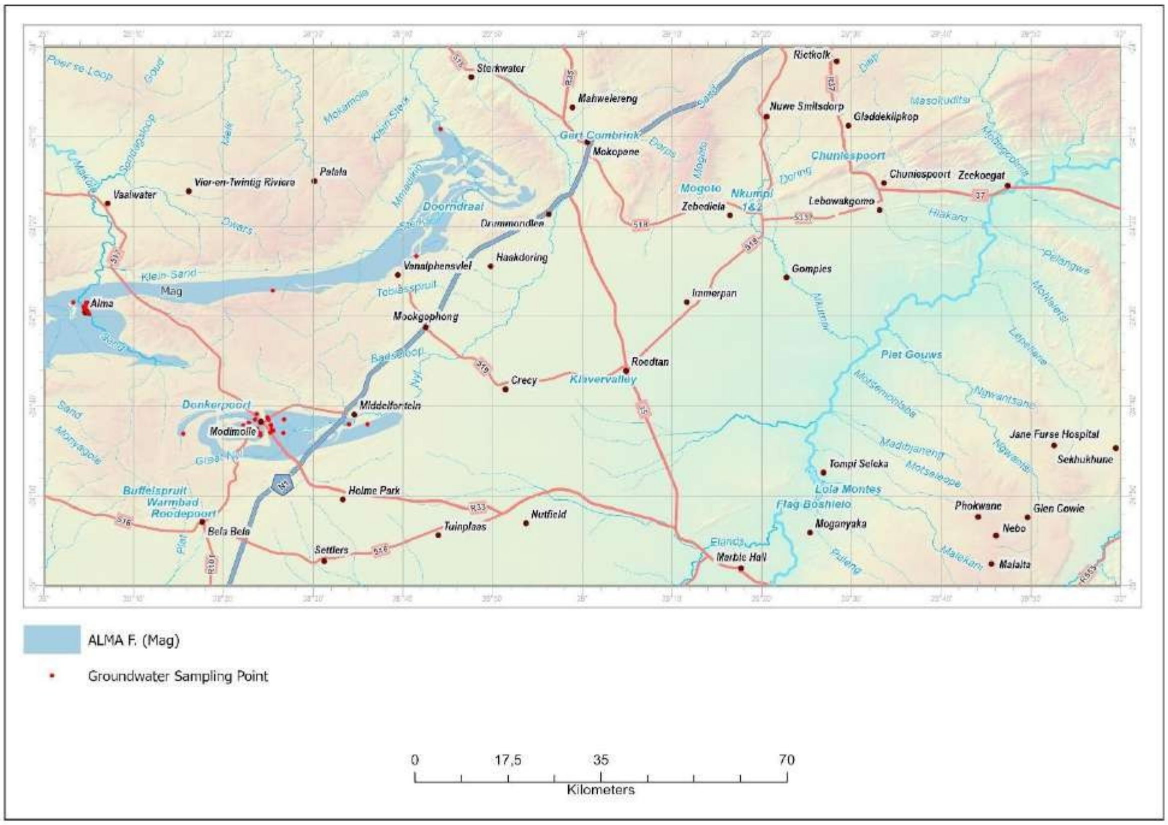


Figure 36: Geographical distribution of the Alma Formation (Mag) and the associated groundwater sampling points

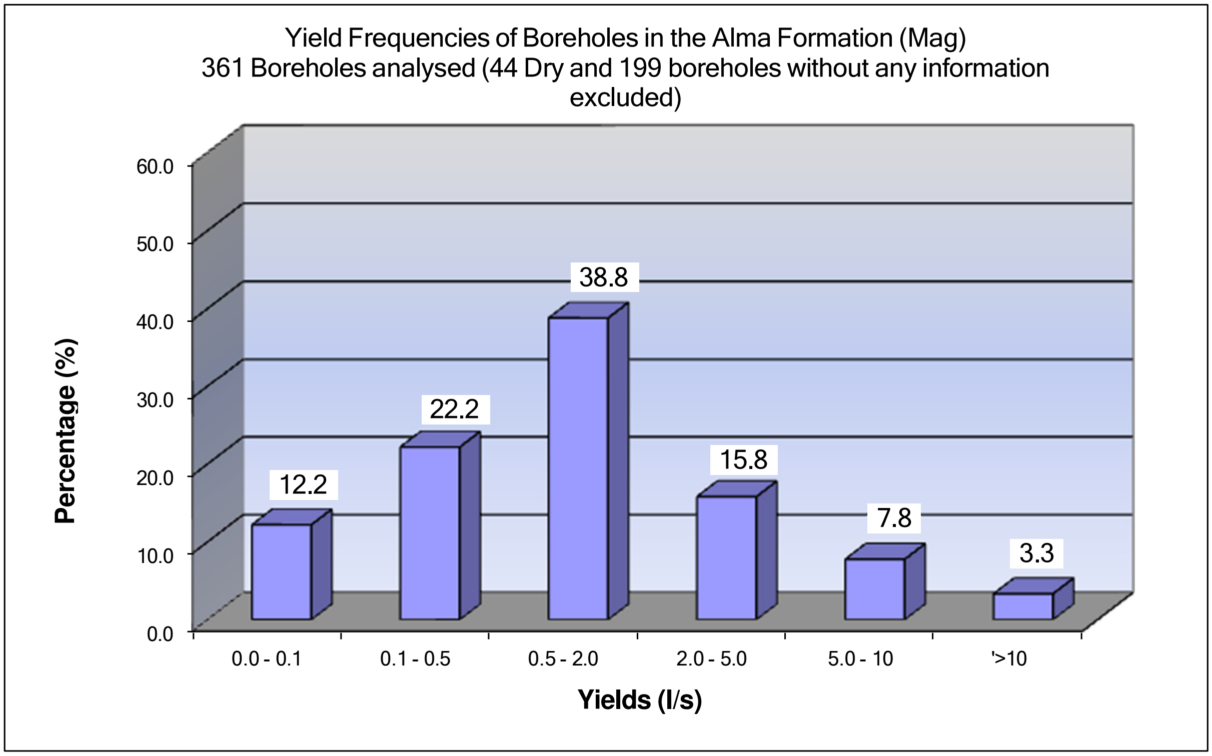


Figure 37: Yield frequency for fractured aquifers of the Alma Formation (Mag).

Statistics from the yield frequency diagram, (Figure 37) indicates that 34.4% of boreholes have maximum yields that are less than 0.5ℓ/s. A further 38.8% of boreholes yield between 0.5ℓ/s to 2ℓ/s and 26.9% are more than 2ℓ/s that includes 3.3% that is above 10ℓ/s. Groundwater in the area is mostly abstracted for domestic and livestock watering.

The static water level ranges from artesian to 70 meters below ground level (mbgl), with a median static water level of 9.14mbgl and an average static water level of 11.57mbgl, (based on 72 data records). The maximum depth recorded is 205.6m, with an average depth of 103.9m and a median depth of 92.2m, (58 data records). The maximum installation depth is 100m and the average depth of 50m, (30 data records). The installation depth can be indicative of deep fractures that relate to water strike depths.

The maximum recommended daily abstraction on record is 432 cubic meters per day (m^3/day) and the average is 131.7m^3/day. The 90th percentile is 345.6m^3/day and the median is 86.4m^3/day. The total number of boreholes subjected to pump testing within this unit is 30.

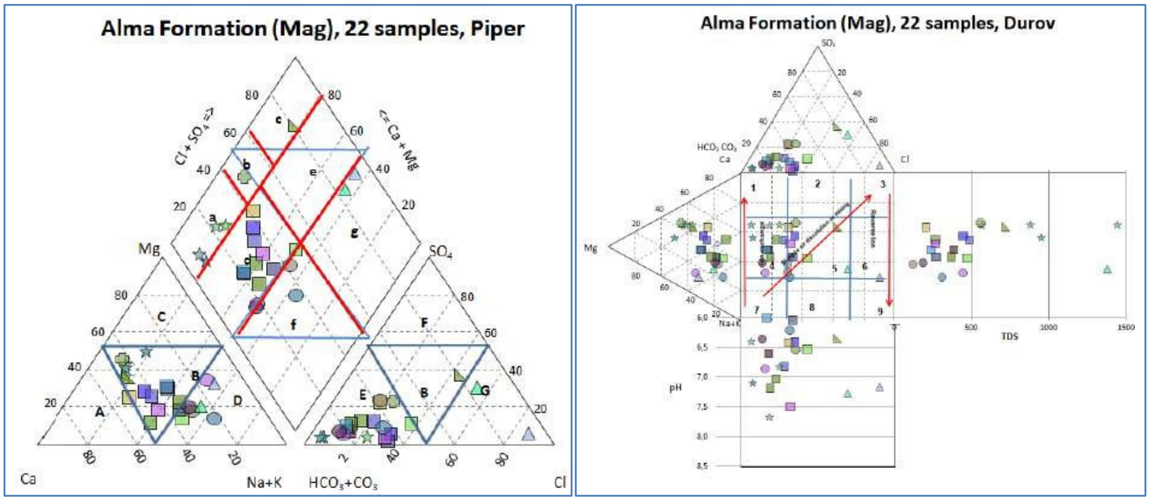


Figure 38: Trilinear diagrams, Piper and Durov for the Alma Formation (Mag).

The trilinear Piper diagram, (Figure 38) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (72.7%), Weak acidic anions > Strong acidic anions (84.1%); Alkali >Alkali earths (27.3%); Strong acids > Weak acids (15.9%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type (45.5%),
- Calcium-Magnesium-Bicarbonate type (18.2%),
- Sodium-Bicarbonate type (18.2%),
- Sodium-Chloride type (9.1%),
- Mixed Calcium-Magnesium-Bicarbonate-Chloride (4.5%),
- Mixed Calcium-Magnesium-Chloride-Sulphate type (4.5%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (56.5%),
- No dominant anion or cation can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing (39.1%), points plot along the dissolution or mixing line,
- Cl and Na dominant is indicating end-point gradient water through dissolution (4.4%),
- The high TDS within two of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 38: Chemical statistics for the Alma Formation (Mag)

Element / Parameter	Statistics Drawn from a population of 41 data points for the Alma Formation (Mag)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	41	4,67	9,00	7,29	7,36	6,95	7,30	8,00	0,65	8,9%
Electrical Conductivity (mS/m EC	41	7,60	278,70	28,81	53,88	15,00	36,84	112,70	50,78	94,2%
Total Dissolved Salts (mg/l TDS)	39	49,00	1468,00	190,05	333,71	105,10	239,37	738,60	280,03	83,9%
Calcium (mg/l Ca)	33	2,92	104,00	16,17	37,81	9,73	26,75	89,99	30,90	81,7%
Magnesium (mg/l Mg)	33	0,11	157,00	2,45	25,53	3,63	11,00	58,90	32,74	128,2%
Sodium (mg/l Na)	40	5,26	307,70	19,62	39,16	11,40	25,89	65,27	50,89	129,9%
Potassium (mg/l K)	32	0,49	11,70	1,22	2,04	0,78	1,22	3,55	2,29	112,3%
Chloride (mg/l Cl)	41	2,97	717,40	9,51	48,13	4,56	11,37	72,30	123,16	255,9%
Sulphate (mg/l SO_4)	41	0,78	143,00	4,57	16,43	2,00	6,68	39,55	26,50	161,3%
Total Alkalinity (mg/l) $CaCO_3$)	31	15,20	449,18	84,25	171,51	47,20	131,80	400,00	134,53	78,4%
Nitrate (mg/l N)	39	0,02	28,03	0,13	2,19	0,04	0,44	3,30	5,80	265,1%
Fluoride (mg/l F)	40	0,05	2,16	0,19	0,55	0,10	0,28	1,48	0,61	110,5%
Silicon as Si	30	1,95	33,70	9,49	16,47	4,72	14,26	29,04	9,54	57,9%
Iron (Fe)	21	0,01	1,48	0,01	0,09	0,01	0,01	0,05	0,32	353,0%
Manganese (Mn)	22	0,01	28,50	0,02	1,35	0,01	0,01	0,25	6,06	447,7%
Ortho Phosphate as Phosphorus as PO4	26	0,01	5,00	0,03	0,41	0,01	0,04	0,80	1,01	246,5%
ZAR	33	0,36	10,55	0,91	1,61	0,46	0,97	2,36	1,92	119,8%
LSI	29	Langelier Saturation Index (LSI)			Slightly Scaling		6,9%	Highly Scaling		0,0%
		Highly corrosive		6,9%	Slightly corrosive		41,4%	Balanced Corrosion		44,8%

Table 38 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In terms of the electric conductivity (EC), the overall water quality is good to marginal with values between 7.6 and 278.7mS/m. The Total Dissolved Solids (TDS) is acceptable in 97.4% of the samples (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions of 41 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 10%; Nitrate (N >10mg/l) in 5.5%; Magnesium (Mg > 100mg/l) in 3% and Chloride (Cl > 600mg/l) in 2.4% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is corrosive (48.3%) to balanced corrosive (44.8%) to slightly scaling in 6.9% of the analysis. The ZAR index indicates that 90.9% of the water is of a fair quality for irrigation (ZAR < 3).

Groundwater is abstracted for game, livestock watering, rural domestic purposes. Although irrigation covers a large section of the aquifer unit the scale of irrigation from unlicensed groundwater is not known. In 10% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride.

7.2.1.11 SWAERSHOEK FORMATION (Ms)

The oldest sub-division (Nylstroom) of which the lower portion consists of the Swaershoek Formation is of late-Bushveld age and confined to proto basins of which the largest coincides approximately with the Nylstroom syncline (Council of Geoscience). It occupies a large area around Modimolle close to the center of the map sheet and comprises sandstone, pebble sandstone, tuffaceous graywacke, siltstone, shale, and conglomerate, (Figure 39). It is one of three Formations that were laid down in the Alma through. Trachytic lavas are well developed, and quartz porphyry occurs locally in the Swaershoek Formation. In the Sterk River area the Swaershoek Formation decreases in thickness. It occupies approximately 5.57% of the mapped area, (Figure 39).

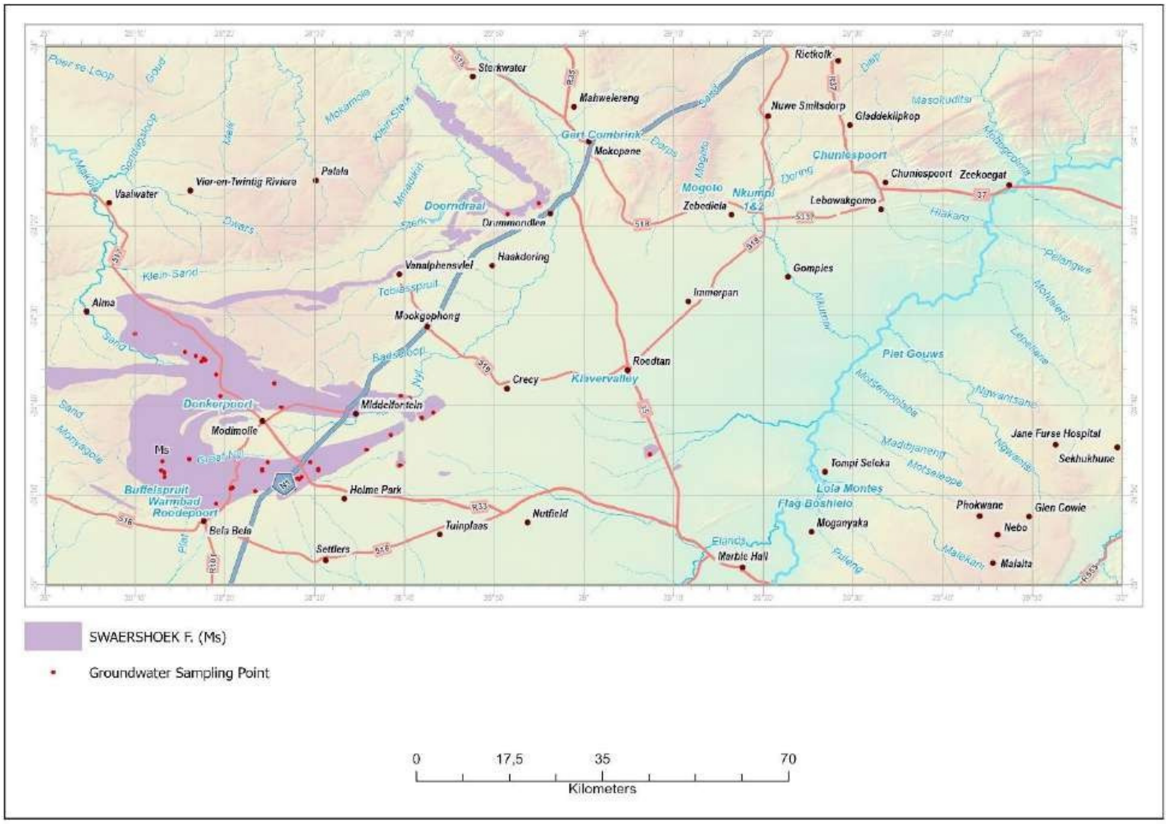


Figure 39: Geographical distribution of the unnamed Swaershoek Formation (Ms) and the associated groundwater sampling points

The Swaershoek Formation has been intruded extensively by sills and dykes of predominantly diabasic composition. These diabase intrusions (N-Za) play a major role especially along dyke/sill contacts, in the occurrence of groundwater. If dykes and sills are ignored, the groundwater potential of the unit is generally low with 73.6% of boreholes yielding less than 2ℓ/s, (Figure 41).

Groundwater also occurs in fault zones, fracture zones and fractures related to anticlines and bedding planes. Deep drilling in similar geological settings (up to 250m) has indicated that fractures do occur at these depths and is therefore a target for good supplies. It is, however, difficult to trace these deeply seated fractures using geophysical methods. Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone (generally resulting in the formation of depression) but also produces a more fertile soil that stimulates a dense vegetation growth along the dykes. These can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them, (See also chapter 7.2.3.3, page 143). The permeability and storage capacity of the Swaershoek Formation are generally low. Yields tend to diminish quickly during periods of drought.

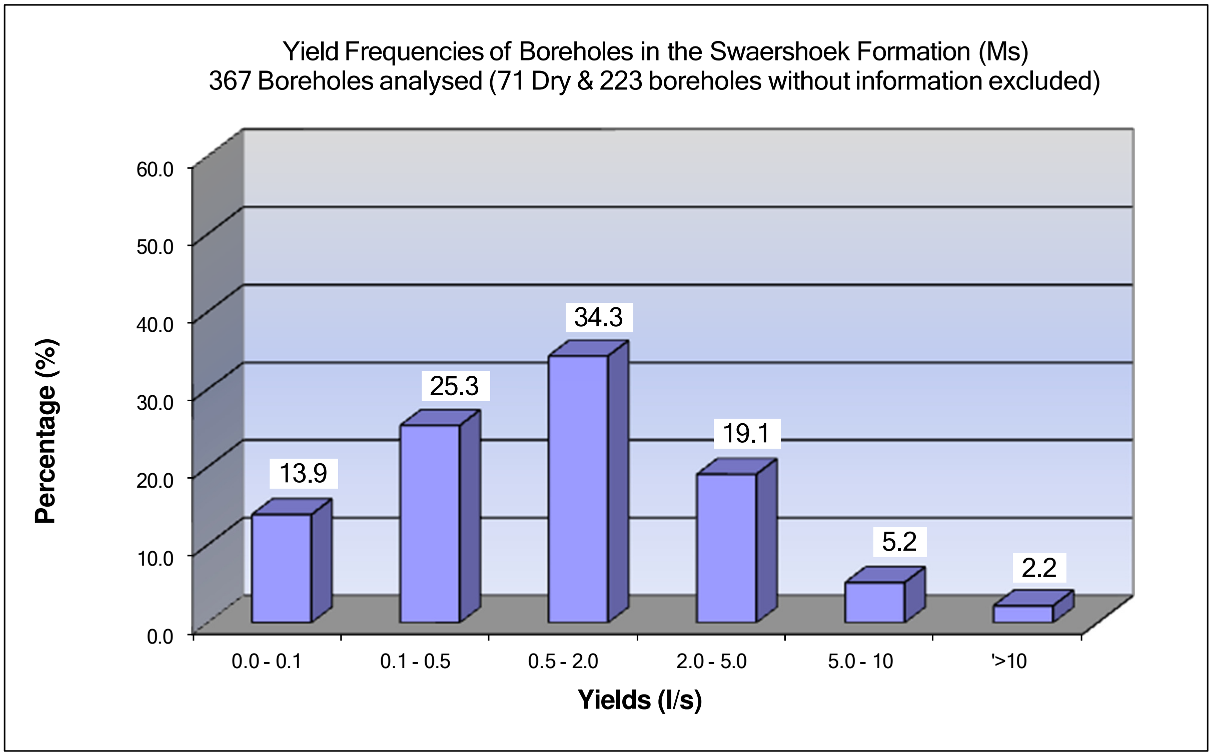


Figure 40: Yield frequency for fractured aquifers of the Swaershoek Formation (Ms).

Figure 40 represents a plot of maximum yields available for interpretation in the unit; 34.3% of successful boreholes yield between 0.5ℓ/s and 2ℓ/s and 26.4% exceeds 2ℓ/s.

The static water level ranges from 0.8 meters below ground level (mbgl) to 65mbgl, with a median static water level of 18.28mbgl and an average static water level of 17.83mbgl, (based on 38 data records). The maximum depth recorded is 162.2m, with an average depth of 86.9m and a median depth of 88m, (17 data records). The maximum installation depth is 85m and the average is 52m.

The maximum recommended daily abstraction on record is 229 cubic meters per day (m³/day) and the average is 51.5m³/day. The 90th percentile is 174.5m³/day with a median daily abstraction of 15.1m³/day. The total number of boreholes subjected to pump testing within this unit on record is 14.

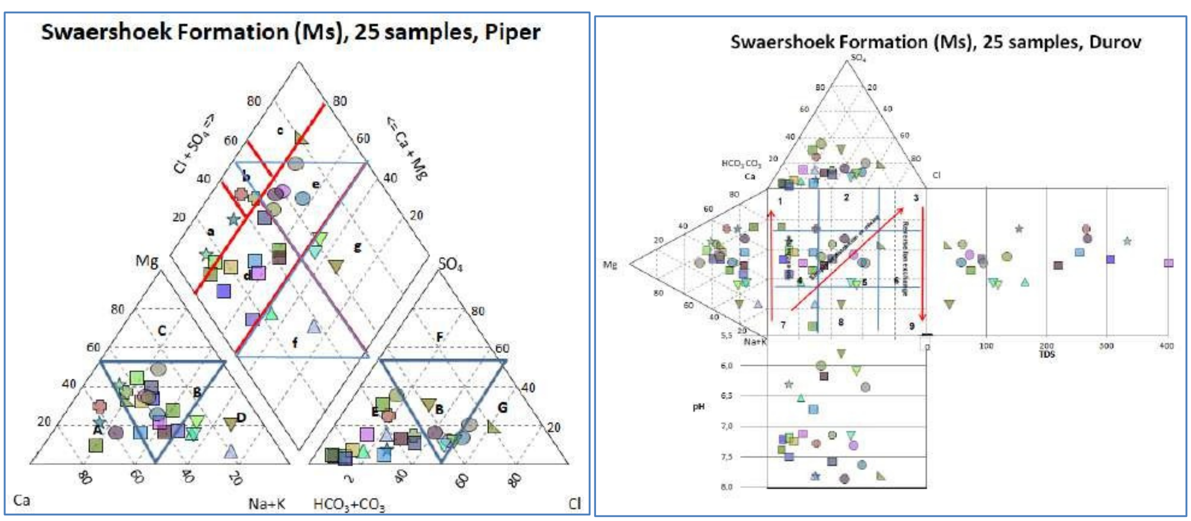


Figure 41: Trilinear diagrams, Piper and Durov for the Swaershoek Formation (Ms).

The trilinear Piper diagram, (Figure 41) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (76%), Weak acidic anions > Strong acidic anions (64%); Alkali >Alkali earths (24%); Strong acids > Weak acids (36%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type (40%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (28%);
- Sodium-Chloride type (12%);
- Sodium-Bicarbonate type (8%);
- Calcium-Bicarbonate type (8%);
- Mixed Calcium-Magnesium-Chloride type (4%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (40%),
- Anion discriminate and Ca dominant can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing (36%), points plot along dissolution or mixing line,
- HCO_3 and Ca dominant indicates recharge in sandstone aquifer (12%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (8%),
- SO_4 dominant or anion discriminant and Na dominant indicate probable mixing or uncommon dissolution influences (4%).

Table 39: Chemical statistics for the Swaershoek Formation (Ms)

Element / Parameter	Statistics Drawn from a population of 52 data points for the Swaershoek Formation (Ms)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	52	1,00	8,16	6,29	6,99	6,01	7,33	7,90	1,13	16,1%
Electrical Conductivity (mS/m EC	52	2,00	209,50	7,74	25,26	3,07	9,85	41,85	41,11	162,7%
Total Dissolved Salts (mg/l TDS)	44	12,00	1304,00	49,82	179,75	20,12	63,08	347,00	277,23	154,2%
Calcium (mg/l Ca)	44	0,50	177,70	4,12	23,54	2,32	12,17	43,60	38,37	163,0%
Magnesium (mg/l Mg)	44	0,50	134,50	2,53	10,01	1,11	3,29	22,43	21,33	213,0%
Sodium (mg/l Na)	44	1,00	135,70	4,33	17,31	2,49	7,05	35,62	26,07	150,6%
Potassium (mg/l K)	43	0,15	15,67	0,85	2,98	0,42	0,92	6,08	3,96	133,1%
Chloride (mg/l Cl)	51	1,00	441,90	4,04	31,95	1,50	5,40	48,00	88,01	275,5%
Sulphate (mg/l SO_4)	51	0,30	77,00	1,44	5,76	0,30	2,00	10,20	11,06	192,0%
Total Alkalinity (mg/l) $CaCO_3$)	41	2,00	230,90	15,05	67,34	5,30	49,80	153,50	64,50	95,8%
Nitrate (mg/l N)	47	0,02	64,10	0,18	4,53	0,07	0,64	13,94	10,93	241,4%
Fluoride (mg/l F)	51	0,05	9,60	0,13	0,68	0,05	0,18	1,21	1,63	238,0%
Silicon as Si	37	0,05	38,87	0,57	9,89	4,09	6,63	20,11	7,94	80,3%
Iron (Fe)	18	0,01	0,29	0,02	0,06	0,01	0,05	0,11	0,07	117,3%
Manganese (Mn)	15	0,02	0,51	0,06	0,12	0,05	0,05	0,31	0,15	126,8%
Ortho Phosphate as Phosphorus as PO4	37	0,01	1,10	0,02	0,25	0,01	0,02	0,80	0,36	146,9%
ZAR	44	0,12	3,96	0,40	0,72	0,20	0,60	1,29	0,69	95,4%
LSI	33	Langelier Saturation Index (LSI)			Slightly Scaling		**3,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**48,5%**	Slightly corrosive		**27,3%**	Balanced Corrosion		**21,2%**

Table 39 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In terms of the electric conductivity (EC), the overall water quality is good to marginal with values between 2 and 209.5mS/m. The Total Dissolved Solids (TDS) is acceptable in 97.7% of the samples (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions in 52 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 7.8%; Nitrate (N >10mg/l) in 4.3%; and Magnesium (Mg > 100mg/l) in 2.3% of the analysis. The pH value is unacceptable in 1.9% (pH >10 & <4).

The Langelier Saturation Index (LSI) indicates that the water is corrosive (75.8%), to balanced corrosive (21.2%), to slightly scaling in 3% of the analysis. The ZAR index indicates that 97.7% of the water is of a fair quality for irrigation (ZAR < 3).

Groundwater is abstracted for game, livestock watering, rural domestic purposes and irrigation. In 7.8% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride.

7.2.1.12 GLENTIG FORMATION (Vgl)

A small occurrence of the Glentig Formation is located approximately 10km north of Modimolle town. It borders the Swaershoek Mountains that are north of it, (Figure 42). It occupies only approximately 0.02% of the mapped area. It overlies the Rooiberg Group concordantly and is regarded as the last deposit in the Transvaal basin (Council of Geoscience).

It comprises both sedimentary (conglomerate, sandstone, and siltstone) as well as intrusive rocks (volcanic rocks, quartz porphyry, and altered lava). The succession is intermediate in character between Rooiberg and Waterberg Groups. Very little is known about the characteristics of groundwater occurrence in this Formation, but it is assumed that groundwater will be found in contact zones along dyke intrusions as well as within fault and fracture zones.

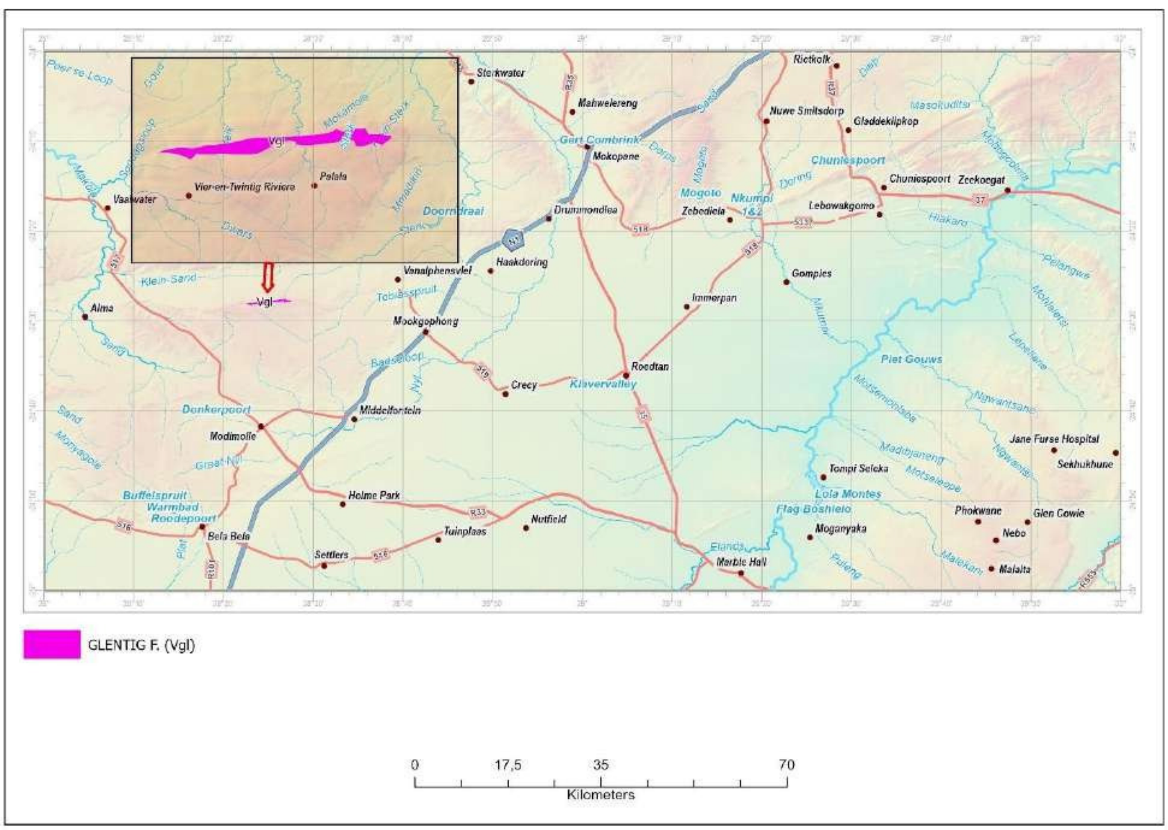


Figure 42: Geographical distribution of the Glentig Formation (Vgl) and the associated groundwater sampling points

No chemistry or yield data was available to compile Piper, Durov and yield diagrams for the Glentig Formation. This aquifer unit could therefore not be characterised in terms of groundwater occurrence and water quality.

7.2.1.13 SCHRIKKLOOF FORMATION (Vsc) (ROOIBERG GROUP)

The Scrikkloof Formation is the younger of the two members of the Rooiberg Group. It comprises volcanic rocks (fine-grained, porphyritic rhyolite) with flow structures, intercalated pyroclasts, sandstone, and quartzite. It is at present, together with Kwagasnek Formation, regarded as part of the Transvaal Supergroup. The Rooiberg lava attains its maximum development around the Nylstroom syncline where it is divided into the two Formations i.e. Schrikkloof and Kwaggasnek. Schrikkloof Formation is found to the east and west of Bela Bela (Warmbad). Another large occurrence is north-north-east of Modimolle (Nylstroom). Smaller scattered occurrences are north and north-west of Marble Hall and south-west and north-west of Mokopane, (Figure 43). The groundwater resource uit covers approximately 2.59% of the total map area.

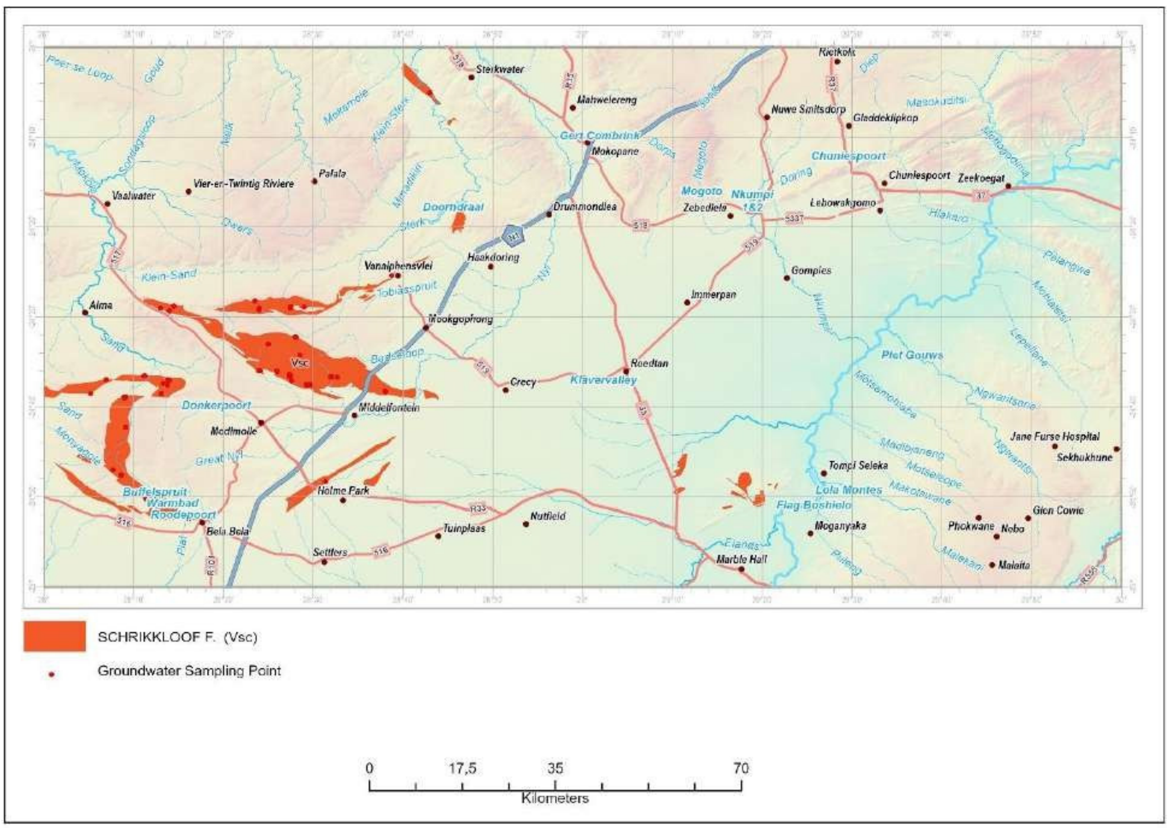


Figure 43: Geographical distribution of the Schrikkloof Formation (Vsc) and the associated groundwater sampling points

The groundwater potential of this unit is generally poor due to the low permeability and storativity of the rhyolite resulting in diminishing or failing yields after prolonged use of production boreholes. The above and its limited extent restrict the unit to an insignificant aquifer. Groundwater targets include faults and associated shear zones, fracture zones, and dyke contacts.

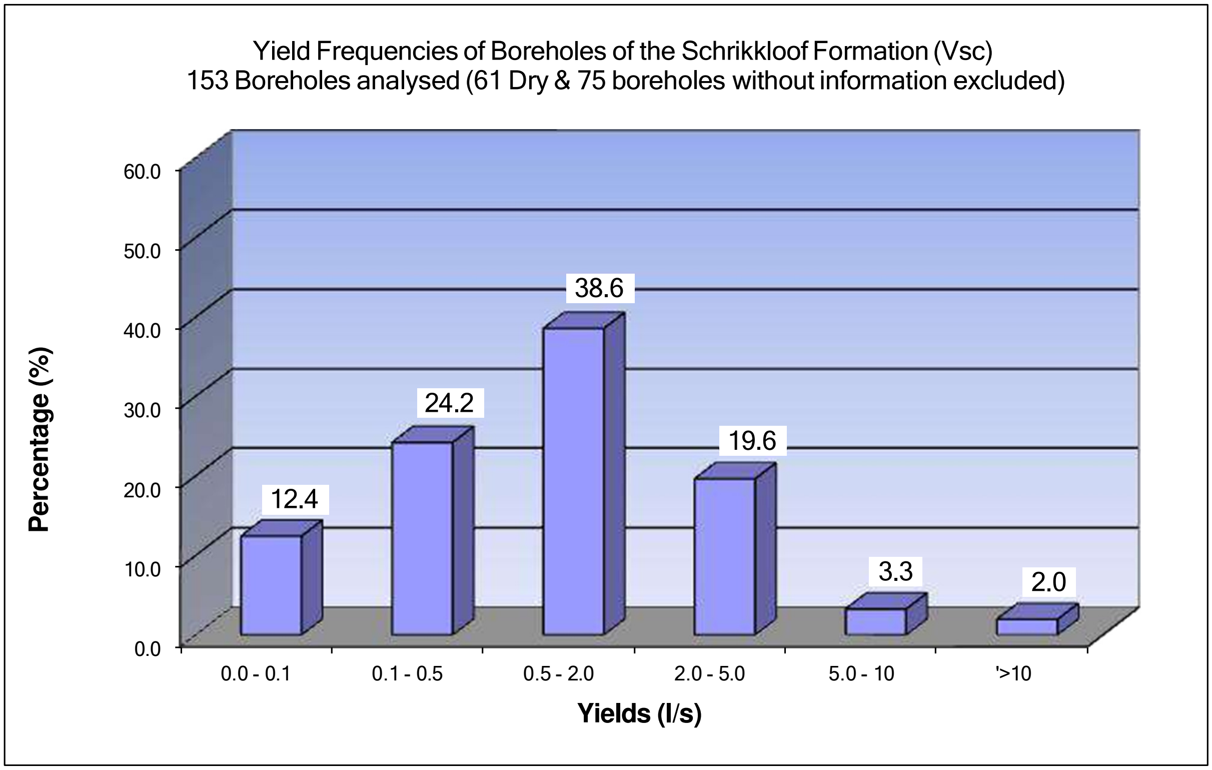


Figure 44: Yield frequency for fractured aquifers of the Schrikkloof Formation (Vsc).

Information for the unit indicates that 75.2% of the successful boreholes have maximum yields less than 2ℓ/s. A further 19.6% of the boreholes yield between 2ℓ/s and 5ℓ/s and 5.3% exceeds 5ℓ/s.

The static water level ranges from 11.95 meters below ground level (mbgl) to 45.72mbgl, the median is 32.67mbgl and the average static water level is 30.75mbgl, (based on 4 data records). The maximum depth recorded is 150m and the average is 133.3m, (3 data records). The minimum recommended daily abstraction on record is 95m^3/day and the minimum is 69.1m^3/day, (2 data records). The total number of boreholes subjected to pump testing within this unit on record is 2. Drilling depths within this groundwater resource unit can be planned to at least 150m.

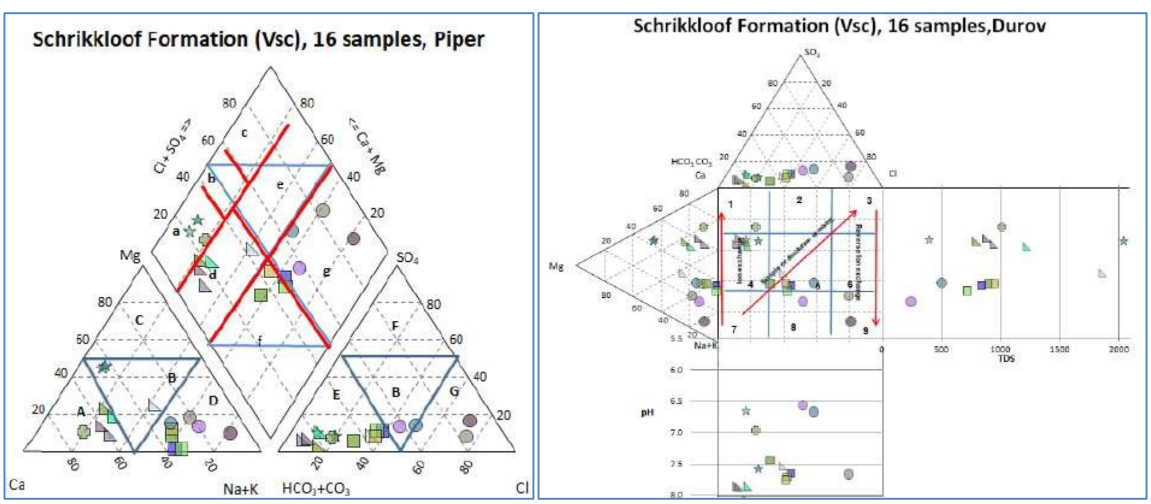


Figure 45: Trilinear diagrams, Piper and Durov for the Schrikkloof Formation (Vsc).

The trilinear Piper diagram, (Figure 45) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths >

Alkali (50% Weak acidic anions > Strong acidic anions (71.9%); Alkali >Alkali earths (50%); Strong acids > Weak acids (28.1%).

The second evaluation was on the water type:

- Calcium-Bicarbonate type (31.3%),
- Sodium-Bicarbonate type (25%),
- Mixed Calcium-Magnesium-Bicarbonate type (12.5%),
- Sodium-Chloride type (12.5%),
- Sodium-Bicarbonate-Chloride type (12.5%);
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (6.3%),

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- Anion discriminate and Ca dominant frequently indicates recharge water in lava and gypsiferous deposits otherwise mixed water or water exhibiting simple dissolution (38%),
- No dominant anion or cation. This trend can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing (31%). Plots along the mixing line.
- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (13%),
- HCO_3 and Ca dominant, frequently indicates recharging water in sandstone (6%),
- -Anion discriminate and Na dominant, indicates probable mixing or uncommon dissolution influences (6%),
- Cl dominant anion and Na dominant cation, indicate that the groundwater is related to reverse ion exchange of Na-Cl waters (6%).

Table 40: Chemical statistics for the Schrikkloof Formation (Vsc).

Element / Parameter	Statistics Drawn from a population of 26 data points for the Schrikkloof Formation (Vsc), Rooiberg									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	26	5.70	8.70	7.37	7.43	6.66	7.67	7.95	0.64	8.6%
Electrical Conductivity (mS/m EC)	26	10.00	312.00	29.59	66.99	13.90	32.20	170.31	78.68	117.5%
Total Dissolved Salts (mg/l TDS)	20	69.00	2006.00	225.86	479.39	109.62	263.00	1420.59	526.86	109.9%
Calcium (mg/l Ca)	26	3.60	107.00	17.86	39.14	8.40	30.14	85.82	31.17	79.6%
Magnesium (mg/l Mg)	26	0.50	86.60	2.56	17.22	0.85	5.85	45.92	22.56	131.1%
Sodium (mg/l Na)	26	1.00	571.60	7.17	71.20	3.45	22.74	191.95	126.54	177.7%
Potassium (mg/l K)	21	0.77	20.88	3.11	7.12	1.10	7.03	14.43	5.45	76.6%
Chloride (mg/l Cl)	26	2.91	726.00	11.19	93.19	4.60	21.85	284.16	202.26	217.0%
Sulphate (mg/l SO_4)	26	2.00	227.10	5.84	22.97	2.29	7.92	54.30	45.41	197.7%
Total Alkalinity (mg/l) $CaCO_3$)	26	4.30	328.20	43.44	144.16	21.00	124.87	291.35	102.19	70.9%
Nitrate (mg/l N)	25	0.02	82.84	0.06	8.31	0.02	0.12	21.79	18.13	218.1%
Fluoride (mg/l F)	26	0.05	8.22	0.23	2.00	0.08	1.01	5.29	2.38	119.1%
Silicon as Si	18	1.44	34.90	9.02	16.21	6.05	14.51	27.78	8.99	55.5%
Iron (Fe)	3	0.005	0.007	0.005	0.006	0.005	0.005	0.006	0.001	18.1%
Manganese (Mn)	2	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.000	0.0%
Ortho Phosphate as Phosphorus as PO4	14	0.005	0.088	0.012	0.023	0.006	0.013	0.047	0.023	100.9%
ZAR	26	0.07	14.87	0.43	2.23	0.28	0.85	5.57	3.27	146.8%
LSI	20	Langelier Saturation Index (LSI)			Slightly Scaling		**10.0%**	Highly Scaling		**0.0%**
		Highly corrosive		**15.0%**	Slightly corrosive		**15.0%**	Balanced Corrosion		**60.0%**

Table 40 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In terms of the electric conductivity (EC), the overall water quality is ideal to be good, with values between 10 and 312mS/m. Total Dissolved Solids (TDS) are acceptable in 85% of the samples (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions of 26 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 38.5%; Nitrate (N >10mg/l) in 12%; Chloride (Cl > 600mg/l) in 7.7% and Sodium (Na > 400mg/l) in 3.8% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is corrosive (30%); slightly scaling (10%) and predominantly balanced (60%). The ZAR index indicates that 84.6% of the water is of a fair quality for irrigation (ZAR < 3).

Water from this unit is abstracted at Bela-Bela to supplement surface water supply. The water is obtained from various boreholes within the unit (abstraction < 100m³/day per borehole) and another drilled within a fault zone (691m³/day). The water from this unit is also used to supply rural farms for domestic use, game and livestock watering. Irrigation fields occur in the unit, but it is expected that the water is predominantly sourced from surface streams. In 38.5% of the water samples at least one element exceeds the maximum allowed limit for domestic use. The anion of concern is Fluoride.

7.2.1.14. KWAGGASNEK FORMATION (Vkw) (ROOIBERG GROUP)

The Kwagasnek Formation, the second and older member of the Rooiberg Group, is together with the Scrikkloof Formation, regarded as part of the Transvaal Supergroup. The Rooiberg Group attains its maximum development around the Nylstroom syncline where it is devided into the two Formations i.e. Schrikkloof (younger member) and Kwaggasnek. The Kwaggasnek Formation (Vkw) is occurring north-north-east of Modimolle and extends further north-west as a narrow strip west of Mokopane (Potgietersrus), (Figure 46).

Plate 5: Graben structure in rhyolite of the Kwaggasnek Formation in a road cutting along the N1 about 10 km south of Mookgophong (Naboomspruit), photograph WH du Toit.

Plate 5 Shows outcrops of the Kwaggasnek Formation (lower one) that is exposed in a road cutting along the N1 about 10 km south of Mookgopong (Naboomspruit). The Formation consists largely of massive homogeneous lava, quartzite, and xenoliths.

The groundwater unit covers approximately 1.58% of the total map area.

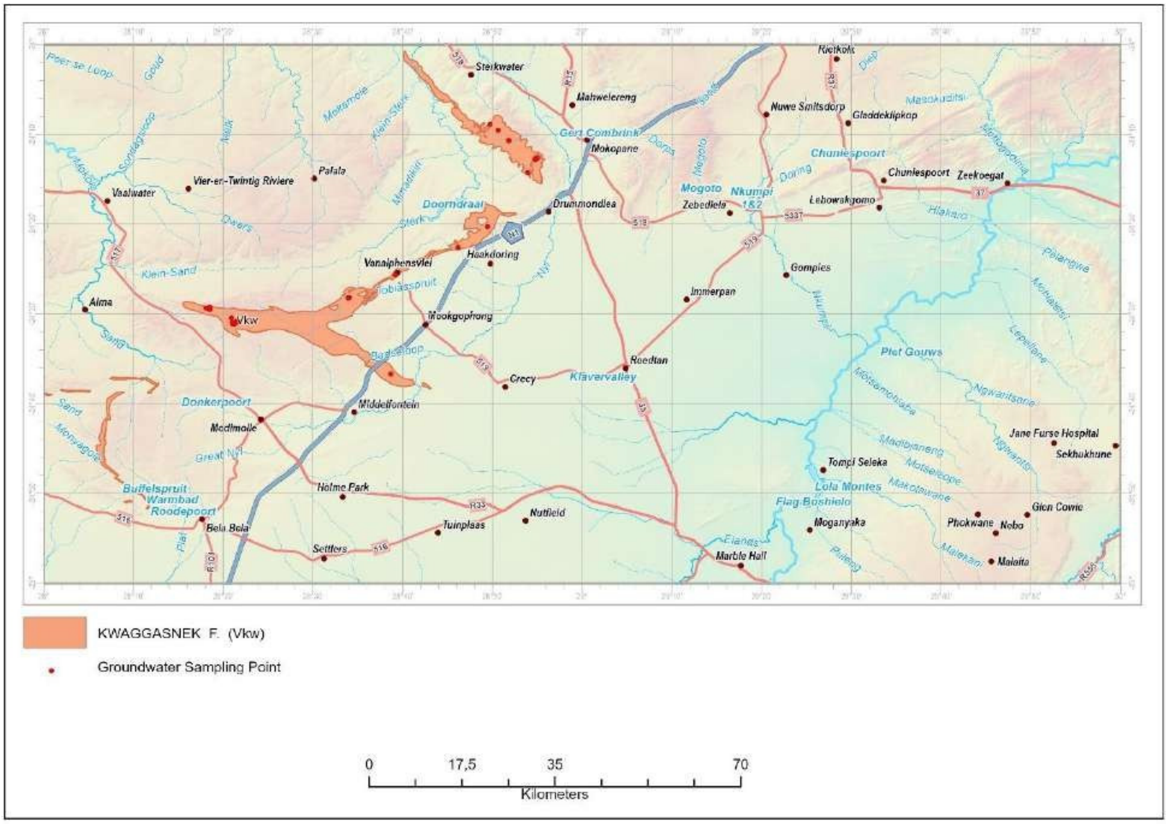


Figure 46: Geographical distribution of the Kwagasnek (Vkw) Formation and the associated groundwater sampling points

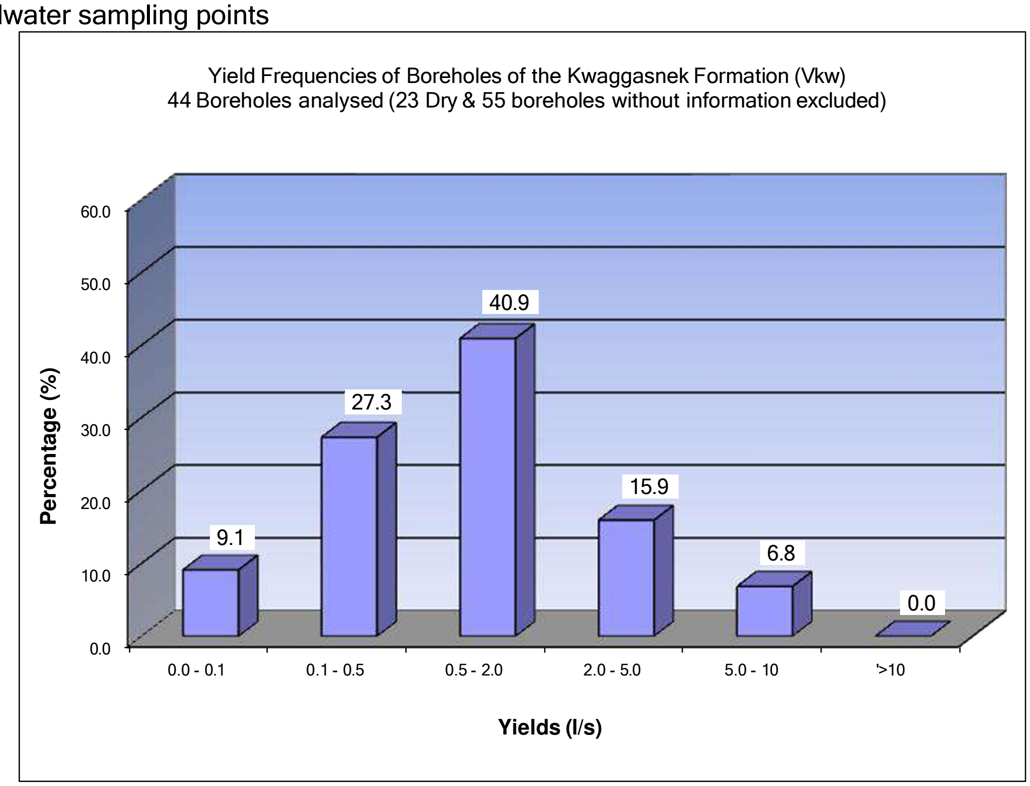


Figure 47: Yield frequency for fractured aquifers of the Kwaggasnek Formation (Vkw).

Information for the unit indicates that 77.3% of the successful boreholes have maximum yields less than 2ℓ/s. A further 15.9% of the boreholes yield between 2ℓ/s and 5ℓ/s and 6.8% exceeds 5ℓ/s.

The static water level ranges from 18 meters below ground level (mbgl) to 31.2mbgl, (based on 2 data records). A static water level reported as 113mbgl was not taken into account as it may represent a pumped water level. The borehole depths are reported as 51m and 52.4m, (2 data records). No pump test data was available for characterization.

Drilling depths within this groundwater resource unit can be planned to at least 150m.

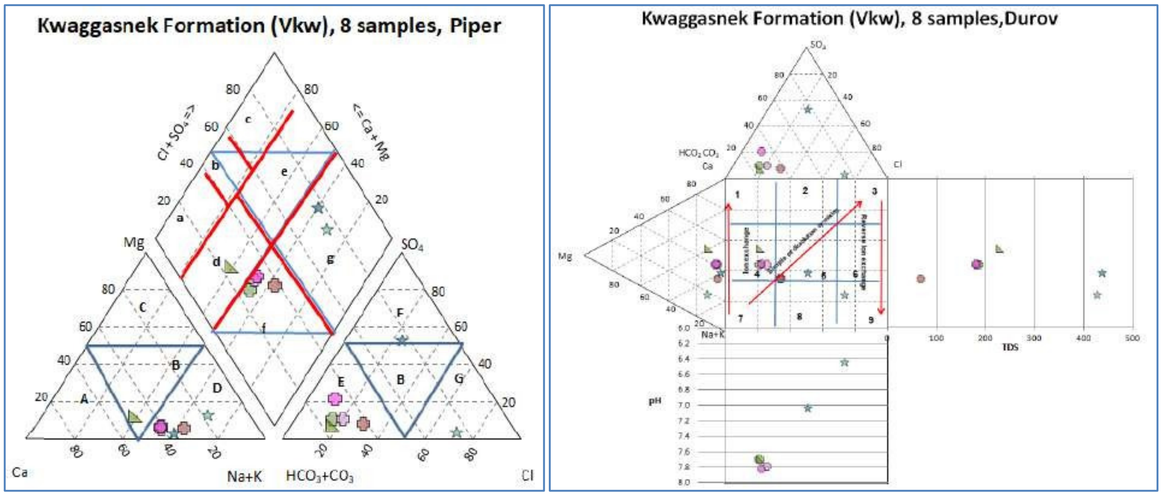


Figure 48: Trilinear diagrams, Piper, and Durov for the Kwaggasnek (Vkw) Formation.

The trilinear Piper diagram, (Figure 48) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (12.5% Weak acidic anions > Strong acidic anions (75%); Alkali >Alkali earths (87.5%); Strong acids > Weak acids (25%).

The second evaluation was on the water type:

- Sodium-Bicarbonate type (62.5%);
- Sodium-Chloride type (12.5%);
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (12.5%);
- Sodium-Sulphate (12.5%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- Anion discriminate and Ca dominant frequently indicates recharge water in lava otherwise mixed water or water exhibiting simple dissolution (63%),
- No dominant anion or cation, based on the classification of Lloyd and Heathcoat (1985). This trend can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing (25%),
- Cl and Na dominant are frequently indicative of end-point gradient waters through Dissolution (13%).

Table 41: Chemical statistics for the Kwaggasnek (Vkw) Formation).

Element / Parameter	Statistics Drawn from a population of 12 data points for the Kwaggasnek Formation Vkw (Rooiberg Group)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	12	6.65	7.98	7.55	7.57	7.17	7.71	7.90	0.41	5.4%
Electrical Conductivity (mS/m EC)	12	8.60	81.20	27.13	40.83	18.46	29.00	69.48	24.26	59.4%
Total Dissolved Salts (mg/l TDS)	12	67.00	643.00	206.06	296.10	142.20	234.00	457.39	168.63	57.0%
Calcium (mg/l Ca)	12	4.80	85.30	19.37	31.26	16.82	25.80	46.50	21.00	67.2%
Magnesium (mg/l Mg)	12	0.50	39.60	1.74	9.08	0.60	3.25	22.69	12.18	134.1%
Sodium (mg/l Na)	12	9.70	106.20	24.65	36.43	17.71	25.55	77.00	28.61	78.5%
Potassium (mg/l K)	12	1.31	8.47	2.48	3.19	1.46	2.38	4.27	1.94	61.0%
Chloride (mg/l Cl)	12	5.40	119.90	10.30	24.26	5.70	10.40	40.08	32.72	134.9%
Sulphate (mg/l SO_4)	12	2.00	120.70	4.77	16.44	2.00	6.80	14.99	33.09	201.3%
Total Alkalinity (mg/l) $CaCO_3$)	12	32.80	254.80	93.73	119.97	74.73	113.25	200.08	59.33	49.5%
Nitrate (mg/l N)	12	0.02	36.10	0.13	4.80	0.06	0.43	16.01	11.04	230.0%
Fluoride (mg/l F)	12	0.17	12.05	0.66	3.91	0.21	4.07	6.16	3.46	88.4%
Silicon as Si	12	14.12	40.46	20.19	22.40	16.76	18.04	34.81	8.52	38.0%
Iron (Fe)	1	0.006	0.006	0.006	0.006	0.006	0.006	0.006		
Manganese (Mn)	0	0.00	0.00							
Ortho Phosphate as Phosphorus as PO4	7	0.006	0.102	0.011	0.025	0.007	0.011	0.056	0.035	139.7%
ZAR	12	0.44	4.57	1.19	1.64	0.84	1.33	2.97	1.12	68.4%
LSI	12	Langelier Saturation Index (LSI)			Slightly Scaling		**0.0%**	Highly Scaling		**0.0%**
		Highly corrosive		**8.3%**	Slightly corrosive		**25.0%**	Balanced Corrosion		**66.7%**

Table 41 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem.

The overall water quality in terms of the Electrical conductivity (EC) is ideal to be good, with values ranging between 8.6 and 81.2mS/m.

The Total Dissolved Solids (TDS) is acceptable in all the samples (TDS ≤ 1200mg/l). The evaluation of the major cations and anions from 12 samples shows elevated concentrations of Fluoride (F >1.5mg/l) in 66.7% and Nitrate (N >10mg/l) in 8.3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be slightly to highly corrosive (33.3%) and 66.7% balanced. The ZAR index indicates that 83.3% of the water is of a fair quality for irrigation (ZAR < 3).

The water in this unit is used for game, livestock watering and rural farms. Due to the rugged terrain irrigation is limited.

7.2.1.15 RASHOOP GRANOPHYRE SUITE (Mr)

The Rashoop Granophyre Suite comprises the Waterval- and Stavoren Granophyre. The Waterval Granophyre occurs at the base of the granite and overlies leptite and basic rocks. The Stavoren granophyre forms the roof phases of the granite in contact with quartzite of the Stavoren Fragment and with Rooiberg Lava in other parts of the area.

The Bushveld Complex has been divided into a mafic portion termed the Rustenburg Layered Suite and a felsic portion represented by the Rashoop Granophyre Suite and Lebowa Granite Suite. The Rashoop Granophyre Suite is genetically related to the volcanic rocks of the Rooiberg Group (Walraven, 1982). It occurs as scattered clusters north-west of Mokopane and north of Marble Hall, (Figure 49) and consists of Quartz-feldspar porphyry, granite, and granophyre. It forms high ground; soil cover is limited, and scattered boulders are prominent. It occupies approximately 1% of the map sheet, (Figure 49).

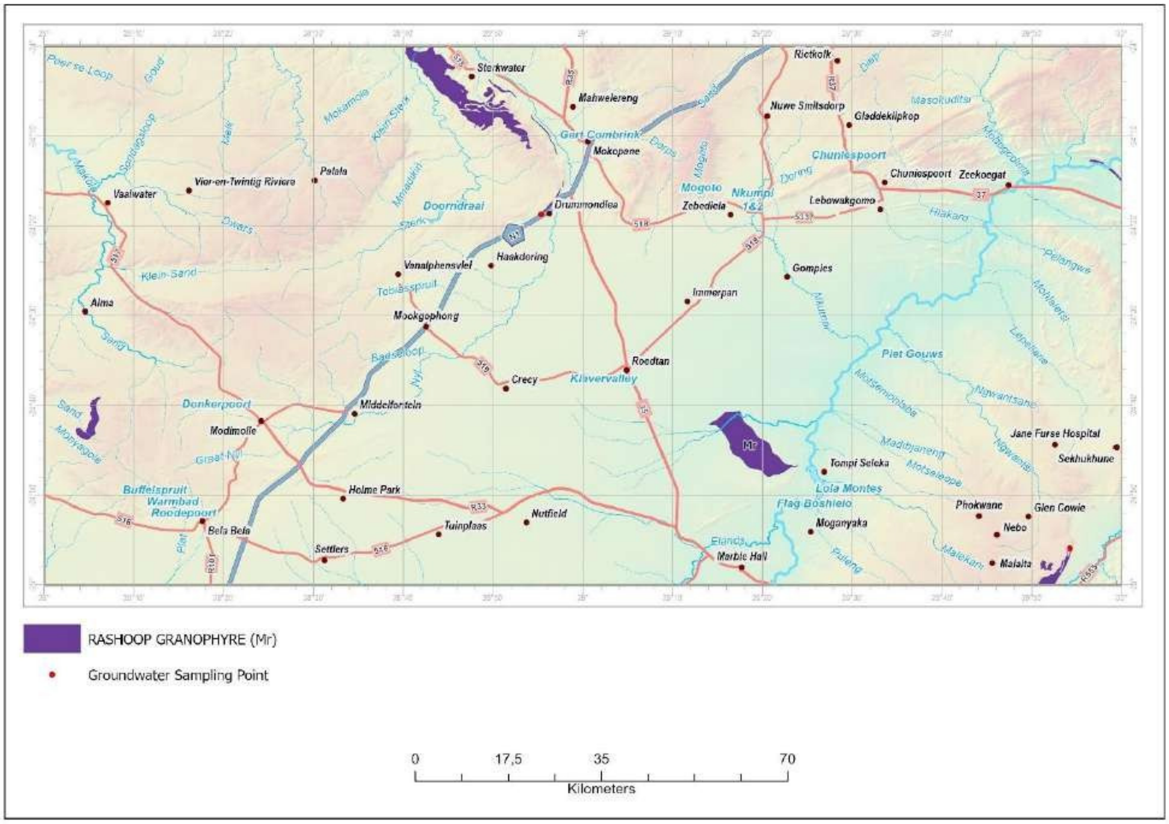


Figure 49: Geographical distribution of the Rashoop Suite (Mr) and the associated groundwater sampling points.

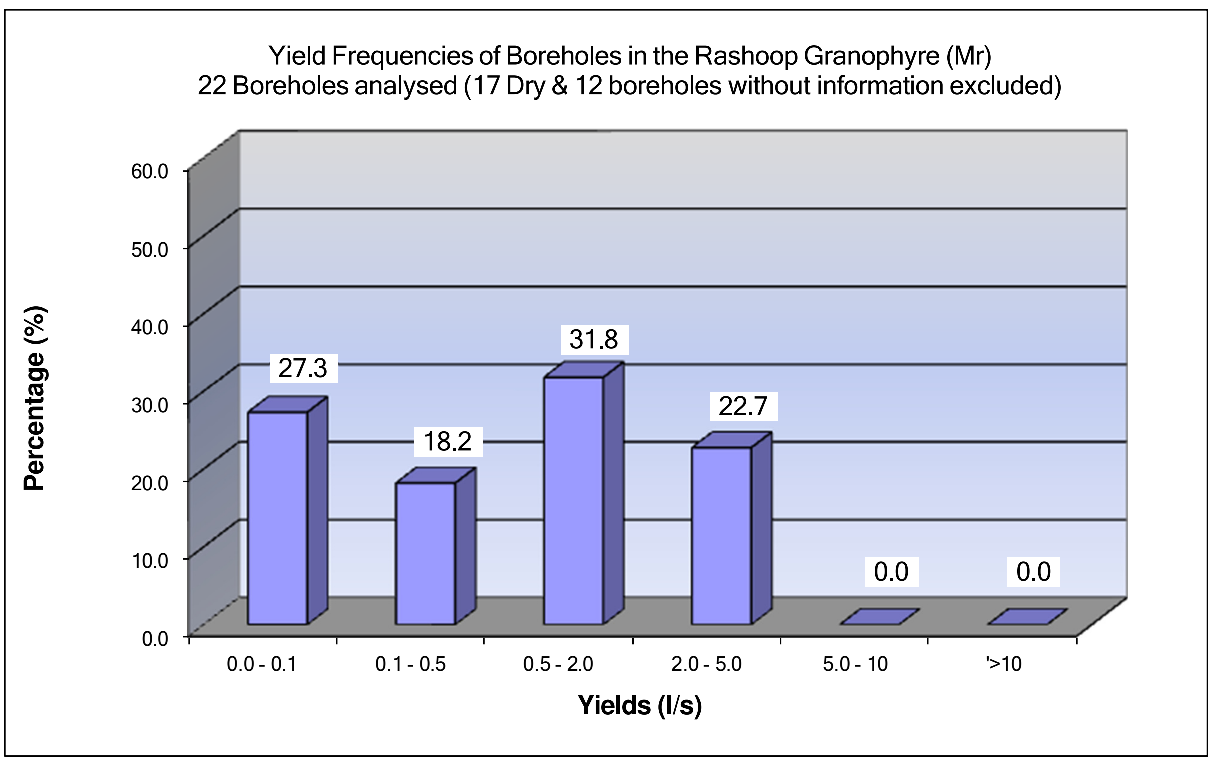


Figure 50: Yield frequency for fractured aquifers of the Rashoop Granophyre Suite (Mr).

The groundwater potential of this Suite is generally poor but occasionally good yields can be found. The frequency diagram in Figure 50 indicates that 45.5% of boreholes have maximum yields is less than 0.5ℓ/s. A further 31.8% of boreholes yield between 0.5ℓ/s to 2ℓ/s and 21.7% of the yields are between 2ℓ/s and 5ℓ/s. No boreholes have yields that exceed 5ℓ/s. The storage capacity of this unit is very low. Water strikes are associated with faults, fracture zones and dyke contacts.

The static water level ranges from 3 meters below ground level (mbgl) to 31mbgl, with a median static water level of 11.85mbgl and an average static water level of 14.36mbgl, (based on 10 data records). The maximum depth recorded is 150m, with an average depth of 123.3m and a median depth of 136.7m, (5 data records). The maximum installation depth is 65m and the average installation depth is 47.3m, (3 data records).

The maximum recommended daily abstraction on record is 2.9 cubic meters per day (m^3/day) and the average is 1.7m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 3.

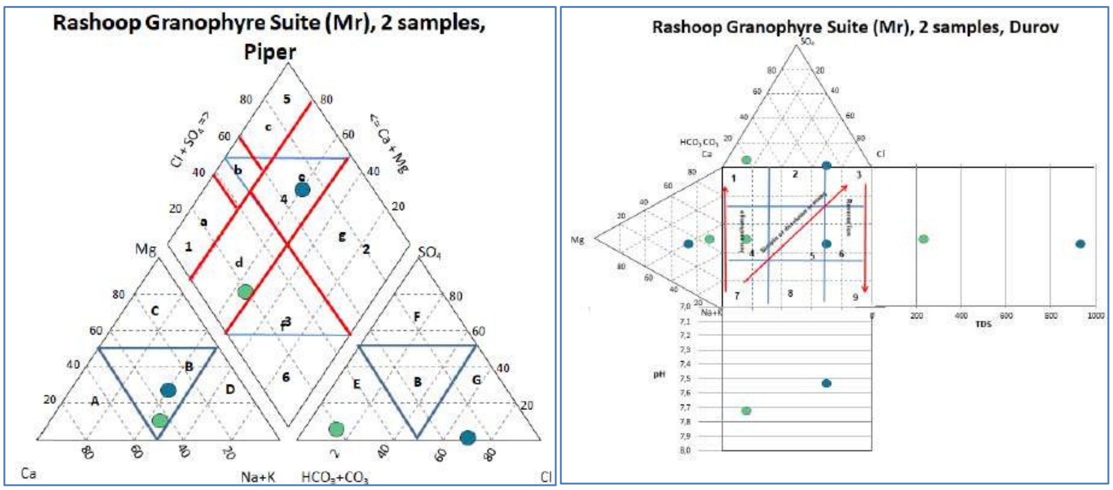


Figure 51: Trilinear diagrams, Piper and Durov for the Rashoop Granophyre Suite (Mr).

The trilinear Piper diagram, (Figure 51) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.

The initial evaluation of chemical dominance is as follows:

- Alkali earths > Alkali (100%);
- Weak acidic anions > Strong acidic anions (50%);
- Strong acids > Weak acids (50%);
- Alkali >Alkali earths (0%).

From the evaluation two water types were identified:

- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (50%),
- Mixed Calcium-Magnesium-Chloride type with increased Sodium (50%).

The trilinear Durov diagram defines hydrochemical processes along with the water type: The indication is mixed water exhibiting simple dissolution and probable mixing or uncommon dissolution influences.

Table 42: Chemical statistics for the Rashoop Granophyre Suite (Mr)

Element / Parameter	Statistics Drawn from a population of 2 data points for the Rashoop Granophyre Suite (Mr)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10^{th} percentile	50^{th} percentile (median)	90^{th} percentile	Standard Deviation	Coefficient of Variation
pH	2	7,52	7,72	7,62	7,62	7,54	7,62	7,70	0,14	1,8%
Electrical Conductivity (mS/m EC	2	30,68	142,30	50,48	86,49	41,85	86,49	131,14	78,92	91,3%
Total Dissolved Salts (mg/l TDS)	2	235,17	939,00	376,14	587,09	305,56	587,09	868,62	497,68	84,8%
Calcium (mg/l Ca)	2	25,06	94,20	39,58	59,63	31,97	59,63	87,29	48,89	82,0%
Magnesium (mg/l Mg)	2	3,63	47,20	6,74	25,42	7,99	25,42	42,84	30,81	121,2%
Sodium (mg/l Na)	2	27,65	134,50	45,86	81,07	38,33	81,07	123,81	75,56	93,2%
Potassium (mg/l K)	2	0,68	3,10	1,12	1,89	0,92	1,89	2,86	1,71	90,6%
Chloride (mg/l Cl)	2	6,31	255,00	12,31	130,65	31,18	130,65	230,13	175,85	134,6%
Sulphate (mg/l SO_4)	2	3,93	6,10	4,78	5,02	4,15	5,02	5,88	1,53	30,6%
Total Alkalinity (mg/l) $CaCO_3$)	2	109,16	307,00	161,05	208,08	128,94	208,08	287,22	139,89	67,2%
Nitrate (mg/l N)	2	5,71	6,99	6,28	6,35	5,84	6,35	6,86	0,90	14,2%
Fluoride (mg/l F)	2	0,56	1,10	0,74	0,83	0,61	0,83	1,05	0,38	46,5%
Silicon as Si	2	25,51	36,05	29,88	30,78	26,56	30,78	35,00	7,45	24,2%
Iron (Fe)	1	0,12	0,12	0,12	0,12	0,12	0,12	0,12		
Manganese (Mn)	1	0,02	0,02	0,02	0,02	0,02	0,02	0,02		
Ortho Phosphate as Phosphorus as PO4	2	0,04	0,18	0,07	0,11	0,05	0,11	0,17	0,10	88,8%
ZAR	2	1,37	2,82	1,84	2,10	1,51	2,10	2,68	1,03	49,2%
LSI	2	Langelier Saturation Index (LSI)			Slightly Scaling		0,0%	Highly Scaling		0,0%
		Highly corrosive		0,0%	Slightly corrosive		0,0%	Balanced Corrosion		100,0%

Table 42 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is good to marginal. Limited analysis was available for accurate characterization. The evaluation is based on 2 samples. The electric conductivity (EC) values vary between 30.6 and 142.3 mS/m and the Total Dissolved Solids (TDS) are acceptable in all the samples (TDS ≤ 1200mg/l).

The Langelier Saturation Index (LSI) from the 2 samples indicates that the water is balanced (100%). The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3).

The water in this unit is used for game, livestock watering and rural farms. Due to the rugged terrain irrigation is limited.

7.2.1.16 LAKENVALEI FORMATION (Vla)

The Lakenvalei Formation comprises quartzite with subordinate hornfels and dolomitic marble. It overlies the Vermont Formation and is part of the Pretoria Group. It is located some distance north-east of Roedtan, (Figure 52). Water occurs mostly in fractures, dyke contacts and faults. It occupies less than approximately 0.01% of the mapped area and is therefore extremely insignificant.

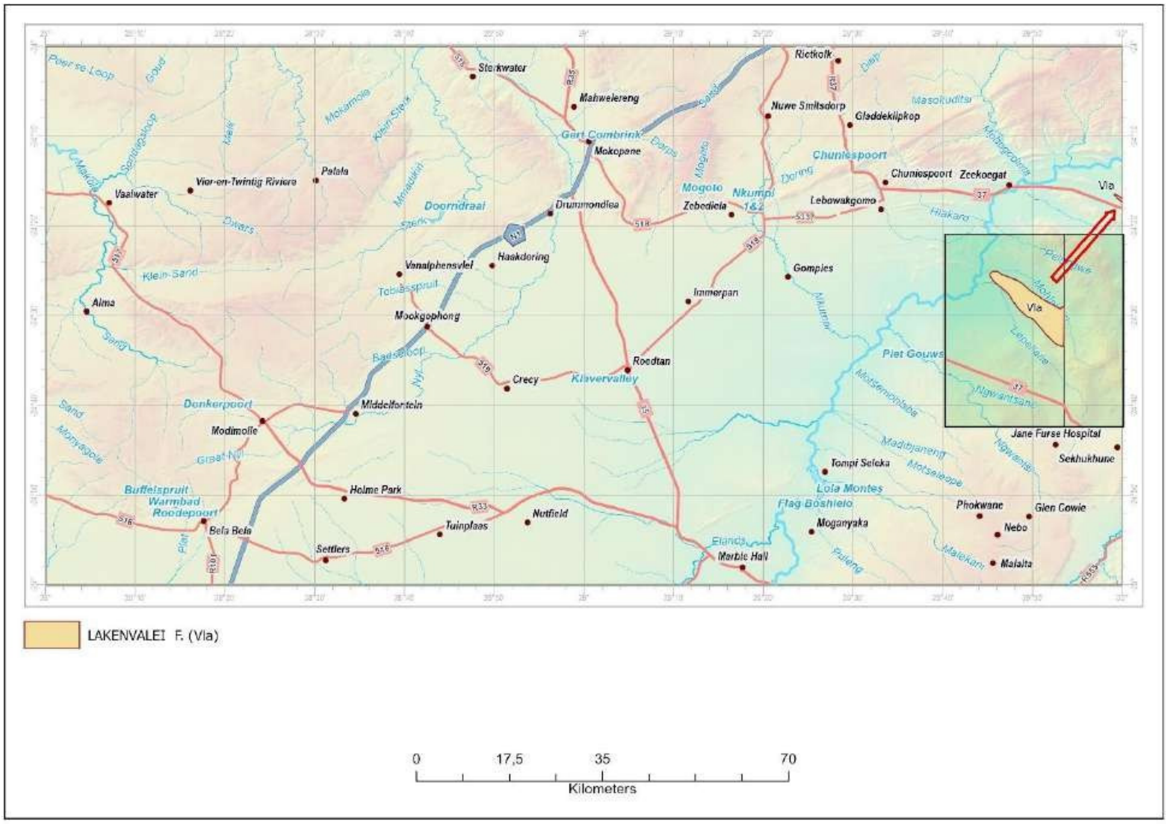


Figure 52: Geographical distribution of the Lakenvalei Formation (Vla) and the associated groundwater sampling points

No chemistry or yield data was available to compile Piper, Durov and yield diagrams for the Lakenvalei Formation. This aquifer unit could therefore not be characterised in terms of water quality and groundwater occurrence.

7.2.1.17 TIMEBALL HILL FORMATION (Vti)

The Timeball Hill Formation occurs south, north, and east of Mookgophong and north of Mokopane, (Potgietersrus), (Figure 53) and comprises shale, hornfels, and subordinate schist. It occupies approximately 0.03% of the map sheet. Groundwater can be present in fractures, faults, and fractured contact zones of dykes and sills.

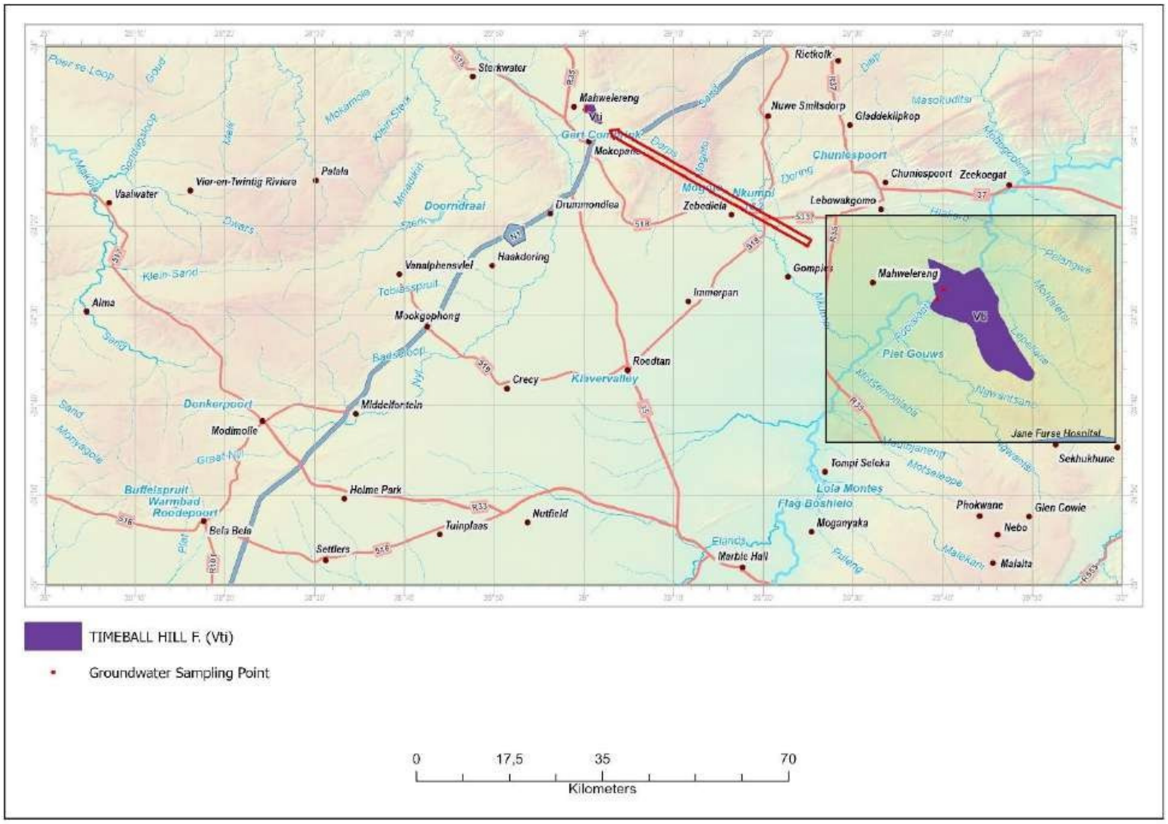


Figure 53: Geographical distribution of the fractured aquifers of the Timeball Hill Formation (Vti)) and the associated groundwater sampling points.

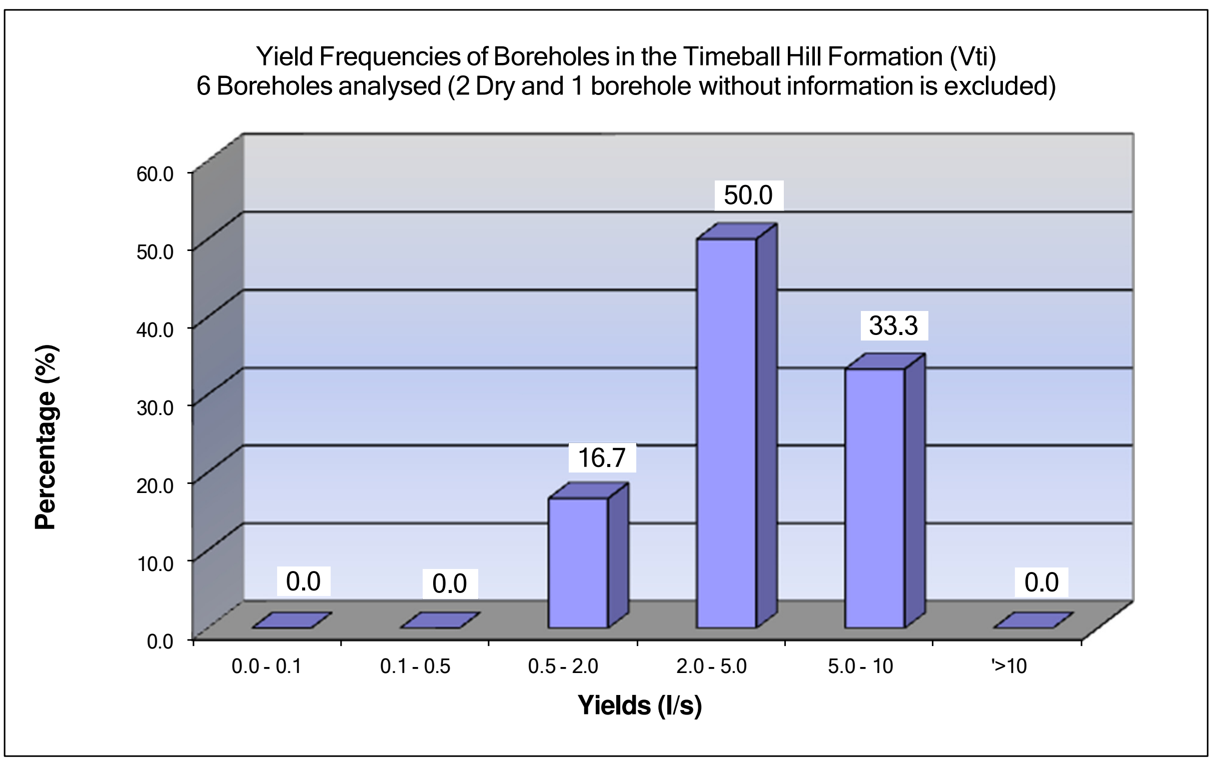


Figure 54: Yield frequency for fractured aquifers of the Timeball Hill Formation (Vti)

Only 6 boreholes were analysed and therefore, may not represent a true reflection of the characteristics of the unit. The yield frequency diagram indicates that 16.7% of the reported maximum yields are between 0.5ℓ/s and 2ℓ/s and 83.3% of the yields exceed 2ℓ/s, (Figure 54). The areas of the groundwater resource unit underlain by shale are considered to have a higher potential than the areas underlain by hornfels. Low yielding aquifers are usually associated with Hornfels.

The static water level ranges from 4.23 meters below ground level (mbgl) to 11.64mbgl, with a median static water level of 9.82mbgl and an average static water level of 8.63mbgl, (based on 7 data records). The maximum depth recorded is 180m, with an average depth of 79.6m and a median depth of 60m, (7 data records). The installation depth of 2 data records is 30 and 35m.

The recommended daily abstraction volumes on record are 172.8 cubic meters per day (m³/day) and 518.4(m³/day). The total number of boreholes subjected to pump testing within this unit on record is 2.

Table 43: Chemical statistics for the Timeball Hill Formation (Vti)

Element / Parameter	Statistics Drawn from a population of 2 data points for the Timeball Hill Formation (Vti)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	2	7,62	7,78	7,70	7,70	7,64	7,70	7,76	0,11	1,5%
Electrical Conductivity (mS/m EC)	2	64,20	67,60	65,86	65,90	64,54	65,90	67,26	2,40	3,6%
Total Dissolved Salts (mg/l TDS)	2	495,00	549,00	520,60	522,00	500,40	522,00	543,60	38,18	7,3%
Calcium (mg/l Ca)	2	38,20	55,40	45,22	46,80	39,92	46,80	53,68	12,16	26,0%
Magnesium (mg/l Mg)	2	74,60	83,80	78,93	79,20	75,52	79,20	82,88	6,51	8,2%
Sodium (mg/l Na)	2	26,00	29,30	27,55	27,65	26,33	27,65	28,97	2,33	8,4%
Potassium (mg/l K)	2	2,74	3,09	2,90	2,92	2,78	2,92	3,06	0,25	8,5%
Chloride (mg/l Cl)	2	58,80	71,10	64,37	64,95	60,03	64,95	69,87	8,70	13,4%
Sulphate (mg/l SO_4)	2	43,00	51,50	46,87	47,25	43,85	47,25	50,65	6,01	12,7%
Total Alkalinity (mg/l) $CaCO_3$)	0	0,00	0,00							
Nitrate (mg/l N)	0	0,00	0,00							
Fluoride (mg/l F)	1	0,04	0,04	0,04	0,04	0,04	0,04	0,04		
Silicon as Si	0	0,00	0,00							
Iron (Fe)	0	0,00	0,00							
Manganese (Mn)	0	0,00	0,00							
Ortho Phosphate as Phosphorus as PO4	0	0,00	0,00							
ZAR	2	0,54	0,61	0,57	0,57	0,54	0,57	0,60	0,05	8,8%
LSI	0	Langelier Saturation Index (LSI)			Slightly Scaling			Highly Scaling		
		Highly corrosive			Slightly corrosive			Balanced Corrosion		

The available data for chemistry did not pass the plausibility checks for the compilation of the Piper and Durov diagrams. Therefore, the characterization of the water type and the dominant hydrochemical processes is not included. Information on the occurrence of groundwater within this aquifer unit that falls outside the boundary of the study area indicates that the water is of a Sodium-Calcium-Bicarbonate type.

7.2.1.18 PENGE FORMATION (Vpe) (Banded Ironstone)

Within the map sheet this occurrence of the Penge Formation occurs east of Chuniespoort and comprises banded ironstone, carbonaceous shale, subordinate carbonate rocks and breccia overlying the dolomites of the Malmani Subgroup. Small occurrences appear east of Mokopane (Potgietersrus) but are not shown on the map. It covers approximately 0.97% of the total map area, (Figure 55).

Formation occurs in mountainous areas and is generally inaccessible. Due to its inaccessibility and limited occurrence in the area, the groundwater role of the unit is regarded insignificant. Little is known about its groundwater potential but is expected to be moderate to good as it is situated in a high rainfall area and the fractured appearance of the banded ironstone in the field. Geophysical surveys (resistivity, magnetic, and electromagnetic) may be hampered due to the iron content in the rock.

In 7.7% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Nitrate. Statistics indicates that 54.5% of the boreholes yield less than 2ℓ/s but that 27.3% of the boreholes have yields exceeding 10ℓ/s.

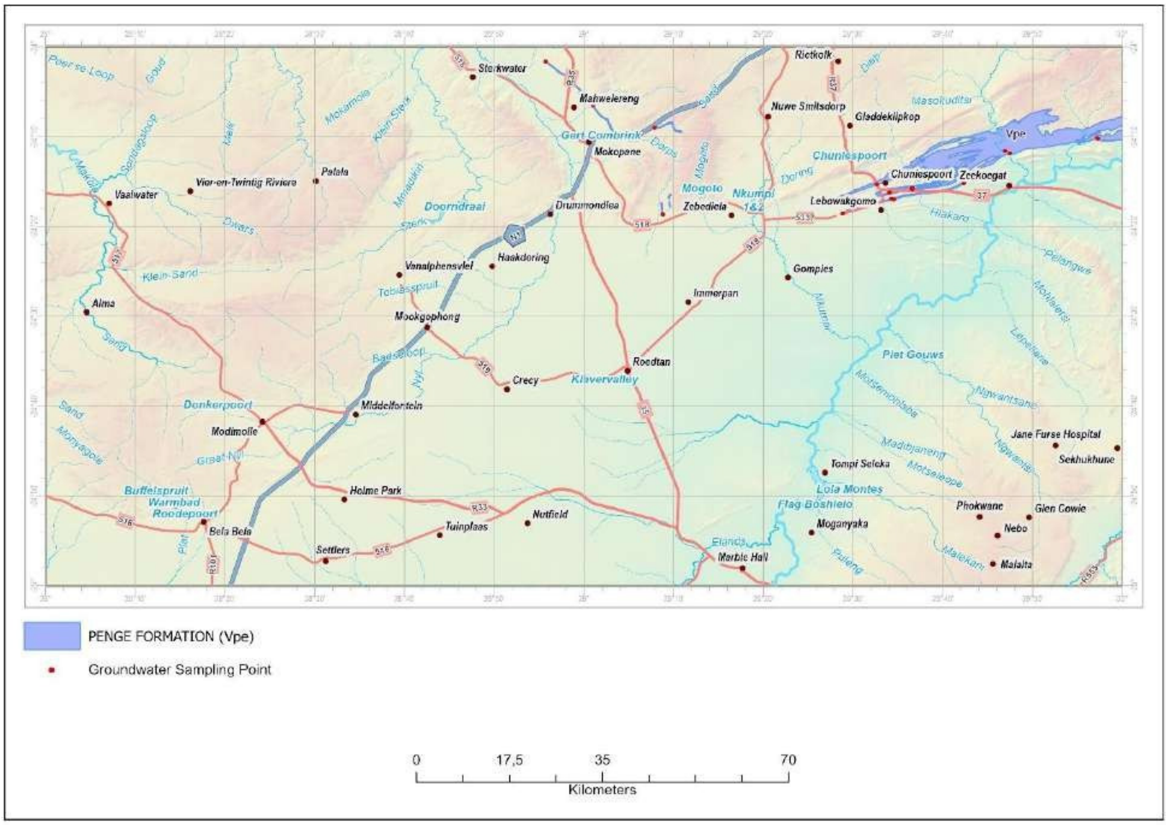


Figure 55: Geographical distribution of the fractured aquifers of the Penge Formation (Vpe) (banded ironstone) and the associated groundwater sampling points.

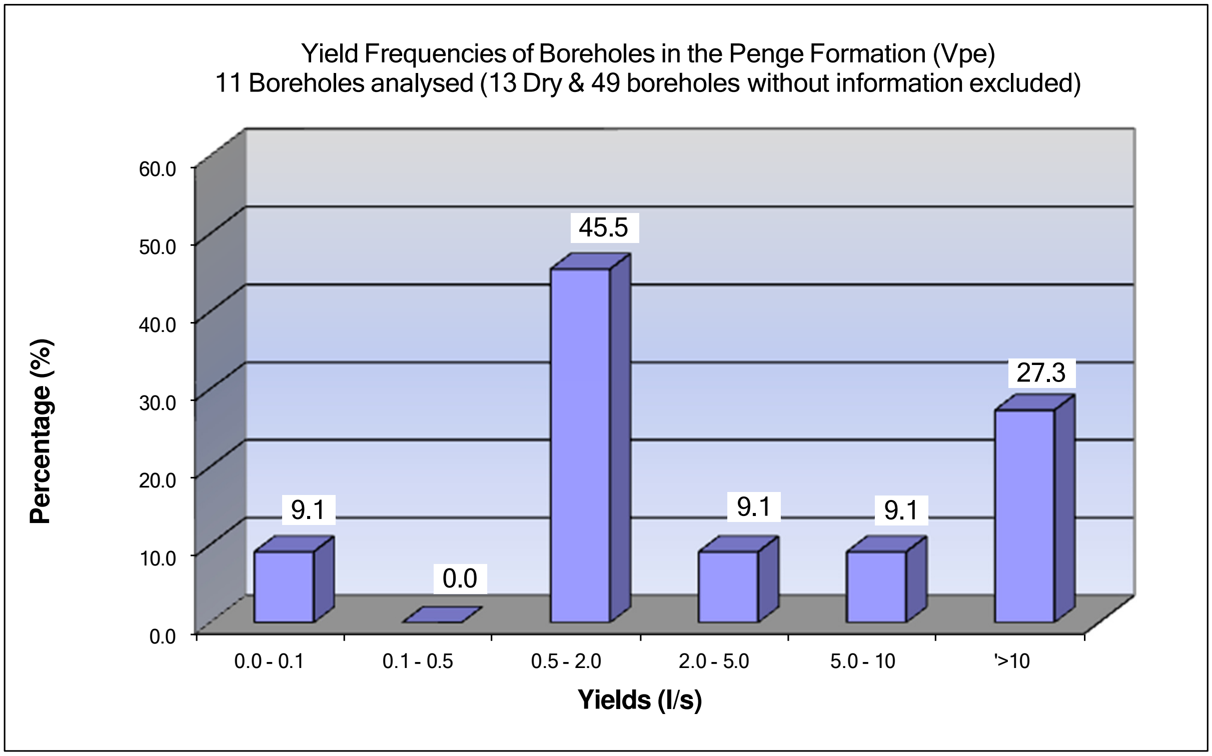


Figure 56: Yield frequency for the fractured aquifers of the Penge Formation (Vpe) (banded ironstone)

The yield frequency diagram, (Figure 56) indicates that 54.5% of boreholes yield between 0.5ℓ/s to 2ℓ/s and 45.5% yield more than 2ℓ/s. The maximum yield for 27.3% of the boreholes exceeds 10ℓ/s supporting the notion that the unit have a moderate to good potential.

The static water level ranges from 5.63 meters below ground level (mbgl) to 53.77mbgl, with a median static water level of 19.57mbgl and an average static water level of 22.24mbgl, (based on 26 data records). The maximum depth recorded is 156m, with an average depth of 80.6m and a median depth of 84.1m, (24 data records). The maximum installation depth is 68m with an average of 68m (9 data records). The installation depth is indicative of deep fractures that relate to water strikes.

The maximum recommended daily abstraction on record is 518 cubic meters per day (m³/day) and the average is 178.8m³/day. The 90th percentile is 449.3m³/day with a median or 50th percentile daily abstraction of 69.1m³/day. The total number of boreholes subjected to pump testing within this unit on record is 9.

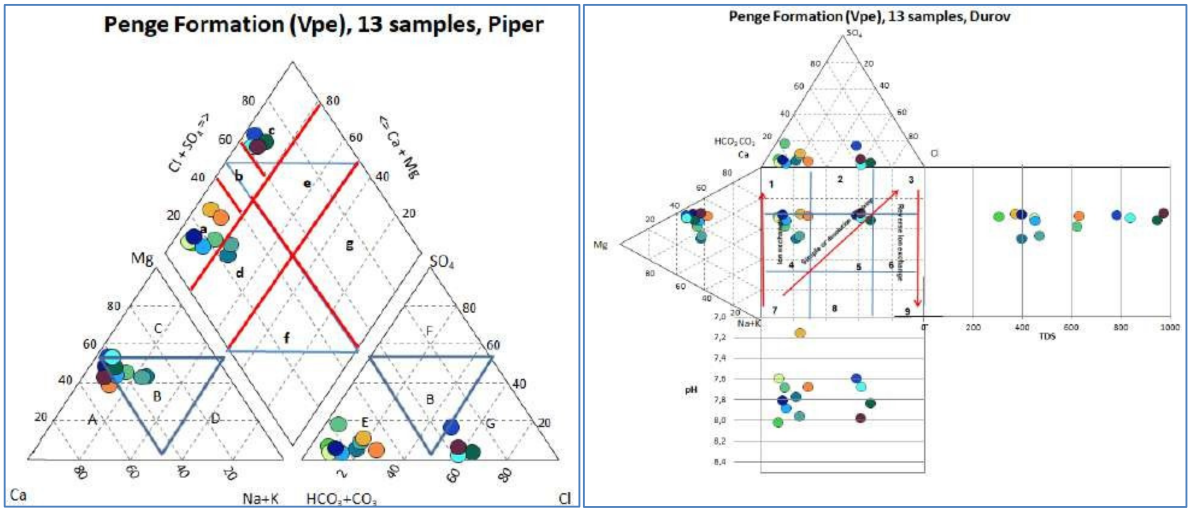


Figure 57: Trilinear diagrams, Piper and Durov for the Penge Formation (Vpe).

The trilinear Piper diagram, (Figure 57) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.

The initial evaluation of chemical dominance is as follows:

- Alkali earths > Alkali (100%),
- Weak acidic anions > Strong acidic anions (69.2%);
- Strong acids > Weak acids (30.8%);
- Alkali >Alkali earths (0%).

The second evaluation is the water type, the findings is as follows:

- Mixed Calcium-Magnesium-Bicarbonate type (53.8%),
- Mixed Calcium-Magnesium-Chloride type (30.8%).
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (15.4%),

The Ca-Mg-HCO_3 is associated with dolomitic aquifers and therefore indicates a strong interaction between the Penge Formation with the underlying Malmani subgroup.

The trilinear Durov diagram defines hydrochemical processes along with the water type; the indication is that recharge dominates (69.2%). The Ca-Mg-Cl type is dominated by simple dissolution or mixing (30.7%). Points plot along the dissolution or mixing line, (Figure 57, Durov diagram).

Table 44: Chemical statistics for the Penge Formation (Vpe)

Element / Parameter	Statistics Drawn from a population of 17 data points for the Penge Formation (Vpe)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	13	7,17	8,34	7,95	7,96	7,76	8,01	8,27	0,31	3,8%
Electrical Conductivity (mS/m EC	13	36,80	133,50	68,31	78,88	50,88	67,09	123,69	31,69	40,2%
Total Dissolved Salts (mg/l TDS)	13	302,04	975,75	511,53	586,50	375,00	468,38	926,43	231,05	39,4%
Calcium (mg/l Ca)	13	34,61	147,70	61,04	72,37	42,32	65,76	111,71	32,88	45,4%
Magnesium (mg/l Mg)	13	23,01	79,75	41,88	48,44	31,07	40,97	77,50	19,79	40,9%
Sodium (mg/l Na)	13	6,00	36,41	13,52	19,57	7,44	21,90	31,74	10,91	55,8%
Potassium (mg/l K)	13	0,33	3,80	1,31	2,26	0,65	2,65	3,53	1,18	52,1%
Chloride (mg/l Cl)	13	5,00	205,98	17,30	67,49	8,02	23,45	184,79	78,75	116,7%
Sulphate (mg/l SO_4)	13	5,20	69,20	11,03	18,51	6,71	11,07	36,91	18,02	97,3%
Total Alkalinity (mg/l) $CaCO_3$)	13	180,18	353,58	273,90	285,70	199,36	295,85	339,99	54,39	19,0%
Nitrate (mg/l N)	13	0,12	22,40	0,60	6,55	0,21	3,45	18,42	7,64	116,6%
Fluoride (mg/l F)	13	0,13	0,48	0,25	0,29	0,17	0,26	0,45	0,12	39,8%
Silicon as Si	13	4,59	17,31	10,58	11,56	9,91	11,58	13,86	2,86	24,8%
Iron (Fe)	8	0,01	0,14	0,02	0,04	0,01	0,02	0,08	0,04	107,4%
Manganese (Mn)	2	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,00	1,4%
Ortho Phosphate as Phosphorus as PO4	12	0,01	0,80	0,02	0,09	0,01	0,02	0,10	0,22	235,7%
ZAR	13	0,17	1,01	0,32	0,45	0,19	0,43	0,85	0,28	61,2%
LSI	13	Langelier Saturation Index (LSI)			Slightly Scaling		**84,6%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**15,4%**

Table 44 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In regard to electrical conductivity (EC), the overall water quality is ideal to good with values between 36.8 and 133.5 mS/m. The Total Dissolved Solids (TDS) is acceptable in all the analysis, (TDS ≤ 1200mg/l).

The evaluation of 13 analysis shows that Nitrate (N > 10mg/l) exceeds the maximum allowable limit in 7.7% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (84.6%) and 15.4% balanced. The ZAR index indicates that for all the samples analysed, the water is of a fair quality for irrigation (ZAR < 3).

The water abstracted supply a large number of people in rural areas to semi-formal settlements and parts of Lebowakgomo town for domestic use. It may also be used for livestock watering and for the Wolkberg Nature Reserve although no boreholes are available on the system for confirmation. No irrigation is done within this unit as the terrain is predominantly rocky and / or mountainous. The settlements are predominantly located on the level accessible areas at the foot of the mountains.

7.2.1.19 BLACK REEF FORMATION (Vbr)

The formation is composed almost entirely of greyish white medium-grained quartzite, with lenticular beds of grit and conglomerate. Shale is always present, particularly near the top close to the contact with the overlying dolomite Council of Geoscience. Dips are shallow and everywhere towards the inside of the Transvaal basin. It occurs in a narrow strip from Mokopane (Potgietersrus), towards Zebediela and within the Strydpoort Mountains up to the Wolkberg area, (Figure 58), where it rests unconformably on the Archaean granite and paraconformably on the Wolkberg Group respectively.

The Wolkberg Group and Black Reef Formation together give rise to a prominent escarpment. The unit underlay approximately 0.5% of the total map sheet area and has a minimum thickness of 50m. Water in the Black Reef Formation is obtained in fractures, dyke contacts and faults.

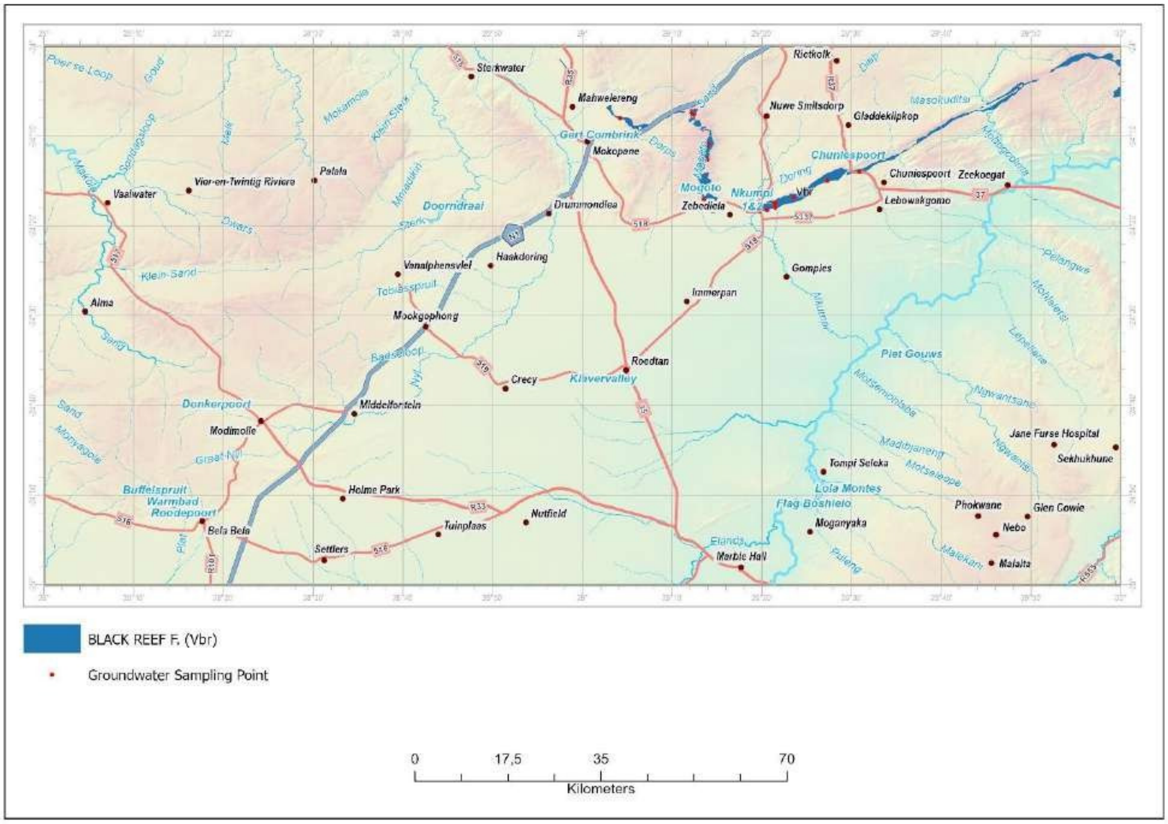


Figure 58: Geographical distribution of the Black Reef Formation (Vbr) and the associated groundwater sampling points.

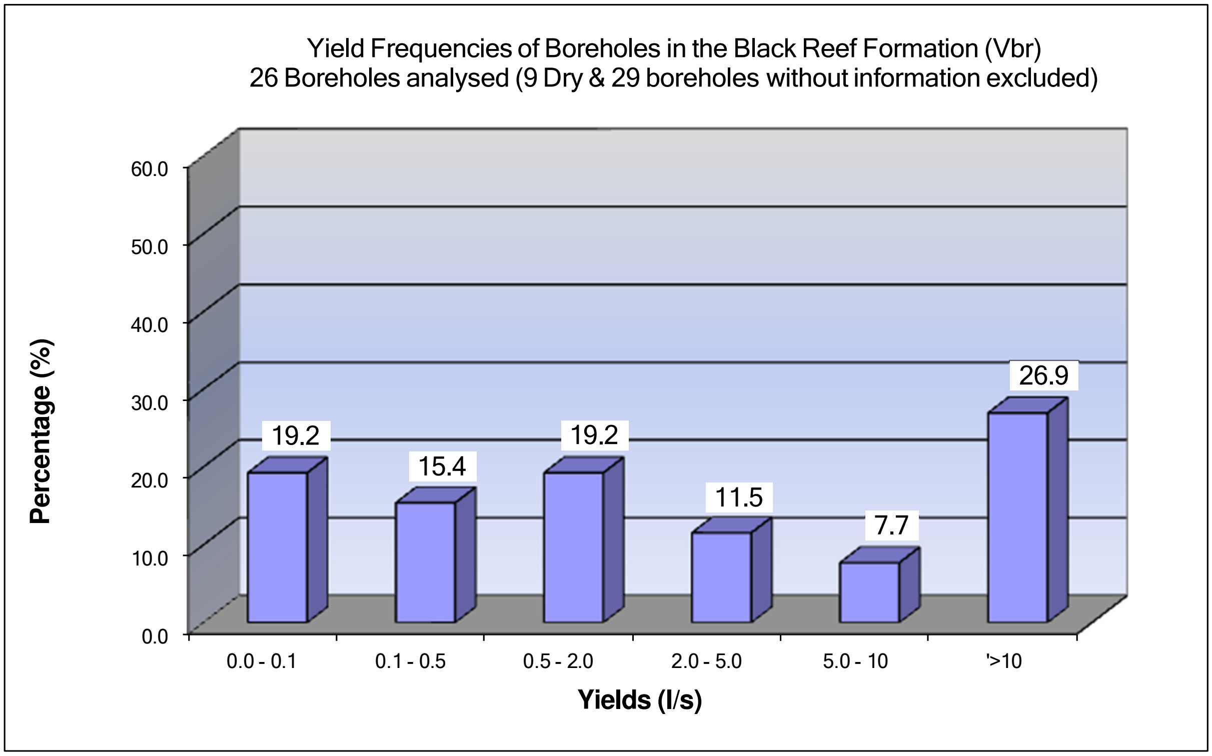


Figure 59: Yield frequency for fractured aquifers of the Black Reef Formation (Vbr).

The yield frequency diagram, (Figure 59) indicates that 53.8% of successful boreholes have maximum yields less than 2ℓ/s. A further 19.2% have yields between 2ℓ/s and 5ℓ/s, with 7.7% yielding between 5ℓ/s and 10ℓ/s and 26.9% of boreholes yielding more than 10ℓ/s.

The static water level ranges from 11.58 meters below ground level (mbgl) to 62.71mbgl, with a median static water level of 25.3mbgl and an average static water level of 29.34mbgl, (based on 21 data records). The maximum depth recorded is 161m, with an average depth of 91.5m and a median depth of 96.3m, (10 data records). The maximum installation depth is 63m and an average of 45m. The installation depth can be indicative of deep fractures that relate to water strikes.

The maximum recorded daily abstraction from this unit is 864 cubic meter per day (m^3/day) and an average daily abstraction of 176.5m^3/day. The 90th percentile daily abstraction volume is 449.3m^3/day, while the median (50th percentile) daily abstraction is significantly lower, at 51.8m^3/day. A total of seven boreholes within this unit have been subjected to pump testing, as per available records.

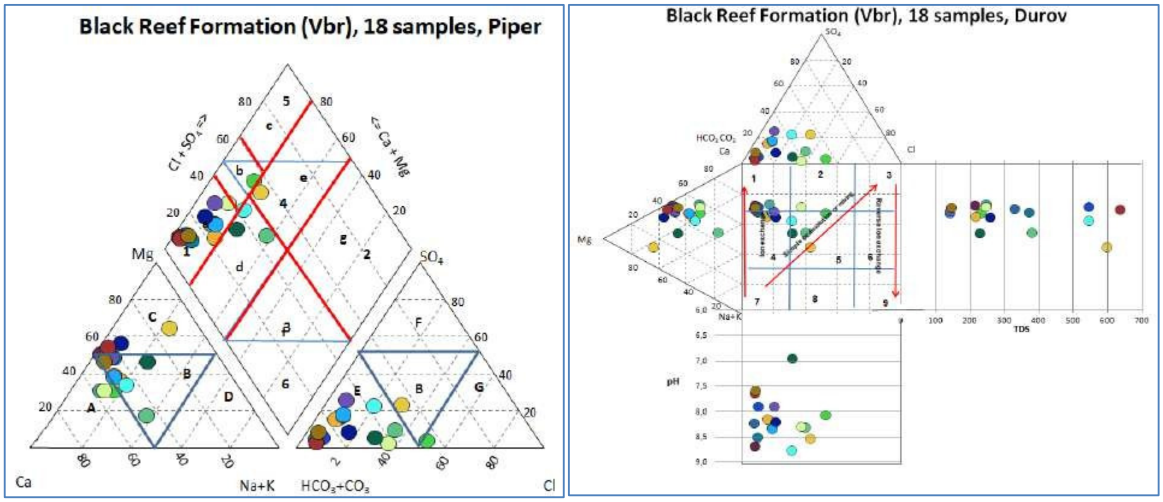


Figure 60: Trilinear diagrams, Piper and Durov for the Black Reef Formation (Vbr).

The trilinear Piper diagram, (Figure 60) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.

The initial evaluation of chemical dominance is as follows:

- Alkali earths > Alkali (100%),
- Weak acidic anions > Strong acidic anions (91.7%);
- Strong acids > Weak acids (8.3%);
- Alkali >Alkali earths (0%).

Groundwater encountered in the Black Reef Formation can be classified as:

- Calcium-Magnesium-Bicarbonate water type (61.1%);
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (16.7%),
- Magnesium-Bicarbonate type (11.1%),
- Magnesium-Bicarbonate-Chloride type (5.6%),
- Calcium-Chloride type (5.6%).

This type of water confirms recharge from the overlying dolomites as the water chemistry with HCO_3^-, Ca^{2+} and Mg^{2+} with Mg^{2+} or Ca^{2+}being dominant, is typical of groundwater associated with dolomitic aquifers. The samples with dominant Calcium may relate to groundwater interaction from limestone. Dolomite of the Chuniespoort Group is overlying the quartzitic rocks of the Black Reef Formation. Together, it forms part of the watershed between the two primary drainage regions A and B that occurs within the map sheet boundary, (Figure 4). Some of the analysis indicates a Magnesium-Bicarbonate-Chlorite water type (5.6%) and a Calcium-Bicarbonate-Chloride type (5.6%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- HCO_3 and Ca dominant, indication of recharging water in limestone (33.3%),
- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (33.3%), points plot along the dissolution or mixing line,
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (27.8%),
- The water type is dominated by Ca and HCO_3, typical of dolomite environments as the Mg concentration is significant (5.6%).

Table 45: Chemical statistics for the Black Reef Formation (Vbr)

Element / Parameter	Statistics Drawn from a population of 22 data points for the Black Reef Formation (Vbr)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	22	6,90	8,75	8,03	8,06	7,56	8,16	8,51	0,49	6,0%
Electrical Conductivity (mS/m EC	22	5,00	84,80	21,30	34,47	13,85	30,96	67,22	22,16	64,3%
Total Dissolved Salts (mg/l TDS)	19	78,00	637,00	219,77	299,54	140,00	245,37	557,50	169,93	56,7%
Calcium (mg/l Ca)	22	4,00	74,50	18,86	30,01	12,95	24,05	61,92	18,84	62,8%
Magnesium (mg/l Mg)	22	6,00	67,30	12,48	19,57	7,22	11,95	39,52	16,52	84,4%
Sodium (mg/l Na)	22	1,00	45,10	4,36	10,41	2,30	5,91	29,98	12,41	119,2%
Potassium (mg/l K)	19	0,64	4,69	1,71	2,41	0,89	2,04	4,30	1,27	52,9%
Chloride (mg/l Cl)	22	1,50	53,50	5,71	13,60	3,22	6,60	36,19	14,74	108,4%
Sulphate (mg/l SO_4)	22	1,47	52,60	4,22	10,65	2,00	6,01	14,63	13,98	131,3%
Total Alkalinity (mg/l) $CaCO_3$)	21	2,00	389,20	31,59	150,79	77,30	124,95	273,54	94,46	62,6%
Nitrate (mg/l N)	22	0,02	19,61	0,07	2,50	0,02	0,27	9,32	5,16	206,3%
Fluoride (mg/l F)	22	0,05	0,59	0,12	0,17	0,06	0,15	0,35	0,13	72,5%
Silicon as Si	19	3,86	32,69	7,95	11,17	4,96	7,90	18,71	8,19	73,3%
Iron (Fe)	5	0,01	0,03	0,01	0,01	0,01	0,01	0,02	0,01	71,8%
Manganese (Mn)	2	0,01	0,02	0,01	0,02	0,01	0,02	0,02	0,01	47,1%
Ortho Phosphate as Phosphorus as PO4	18	0,01	0,08	0,01	0,02	0,01	0,01	0,06	0,02	117,3%
ZAR	22	0,04	1,44	0,17	0,36	0,10	0,23	0,80	0,35	98,2%
LSI	18	Langelier Saturation Index (LSI)			Slightly Scaling		**44,4%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**16,7%**	Balanced Corrosion		**38,9%**

Table 45 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In terms of the electric conductivity (EC), the overall water quality is ideal to good with values between 5mS/m and 84.8mS/m. The Total Dissolved Solids (TDS) is acceptable in all the analysis, (TDS ≤ 1200mg/l).

The evaluation of the analysis of 22 samples shows that none of the major cations and anions as well as pH values, exceed the maximum allowed limits for human consumption.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive in 16.7% of the analysis and slightly scaling in 44.4% and 38.9% balanced. The ZAR index indicates that for all the samples analysed, the water is of a fair quality for irrigation (ZAR < 3).

The unit occurs in mountainous areas and is in many cases inaccessible. Rural and semi-rural settlements along the southern side of the Strydpoort Mountains (between Zebediela and Lebowakgomo) use groundwater from this unit for domestic use. In the Makapansgat area (Makapan Valley World Heritage Site) a single (1) borehole is used for domestic supplies. Although no irrigation boreholes plots within this unit the closeness of these boreholes to irrigation boreholes located within the Malmani Subgroup will influence the static water level within this unit. The evaluation of the chemistry indicates that this aquifer is interconnected with the dolomite of the Malmani Subgroup.

7.2.1.20 WOLKBERG GROUP (Vwo)

As part of the Transvaal Sequence, the Wolkberg Group attains a maximum thickness of 700m, and wedges out north of Mokopane (Potgietersrus). The Wolkberg Group underlying the Black Reef Formation consists of shale, quartzite, and lava, (Figure 61). It occupies approximately 0.6% of the mapped area. Statistics indicate that the Wolkberg Group has a moderate to good potential as 58.7% of boreholes yield more than 2ℓ/s. Similar as the Black Reef Formation, it occurs in mountainous terrain. Accessibility and extend controls the importance of this unit as an aquifer. Water strikes relate to fractures, faults and shear zones, dyke contacts and bedding planes.

Plate 6: Chuniespoort is a famous landmark along the Polokwane/Burgersfort Road where the Chunies River has carved a path through very resistant shale and quartzite of the Wolkberg Formation (Photograph: WH du Toit).

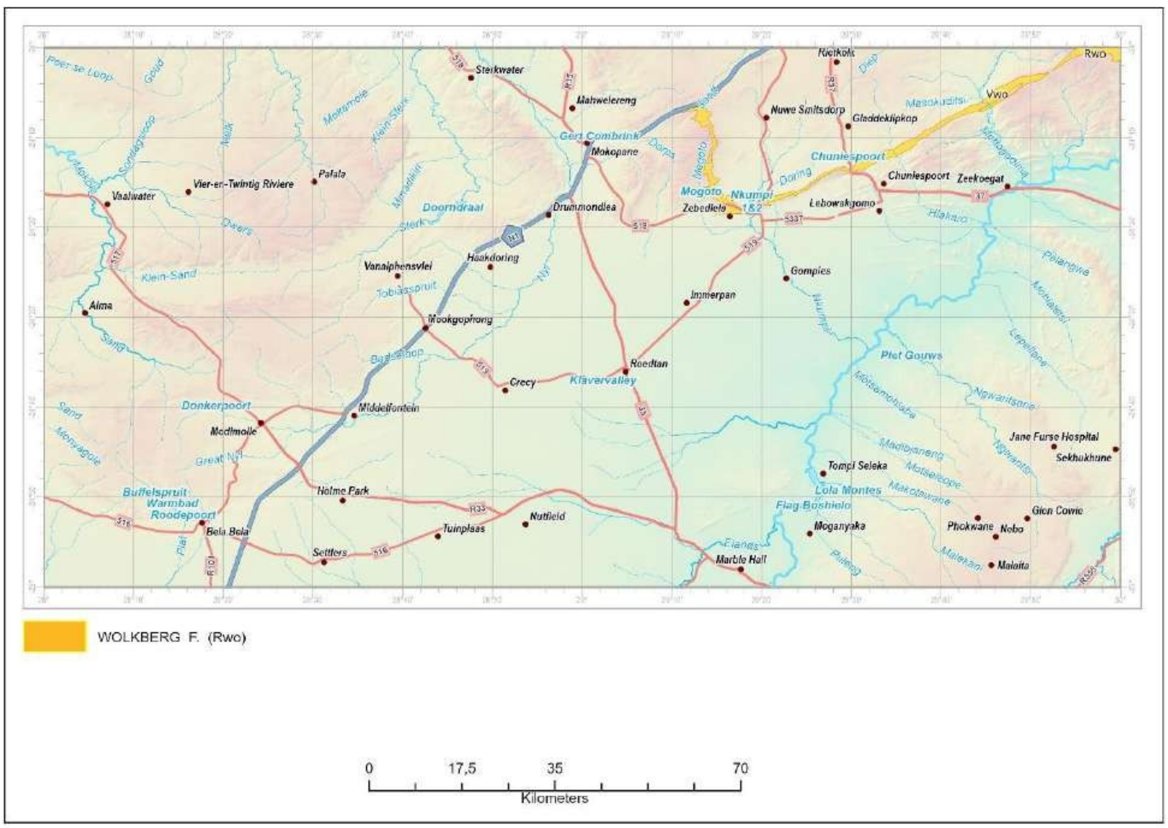


Figure 61: Geographical distribution of the Wolkberg Group (Vwo) and the associated groundwater sampling points.

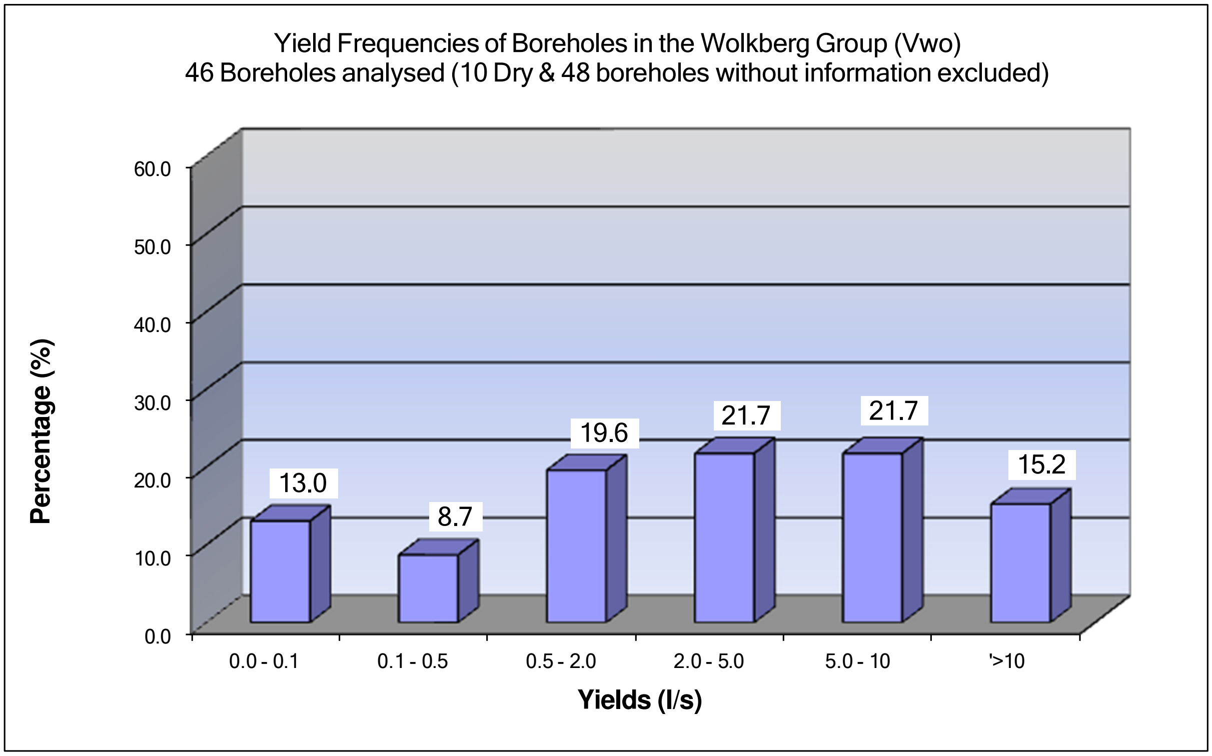


Figure 62: Yield frequency for the fractured aquifers of the Wolkberg Group (Vwo).

The yield frequency diagram, (Figure 62) indicates that 41.3% of successful boreholes have maximum yields less than 2ℓ/s. A further 21.7% have yields between 2ℓ/s and 5ℓ/s, with 21.7% yielding between 5ℓ/s and 10ℓ/s and 15.2% of boreholes yielding more than 10ℓ/s.

The static water level ranges from 4 meters below ground level (mbgl) to 82.3mbgl, with a median static water level of 17.37mbgl and an average static water level of 20.13mbgl, (based on 51 data records). The depth of boreholes based on 2 data records is 109m and 169m and the installation depth from the same records is 64m and 80m. The maximum installation depth can be indicative of deep fractures that relate to water strikes.

The maximum recommended daily abstraction from boreholes is 30.2 cubic meters per day (m^3/day) and 172.8m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 2.

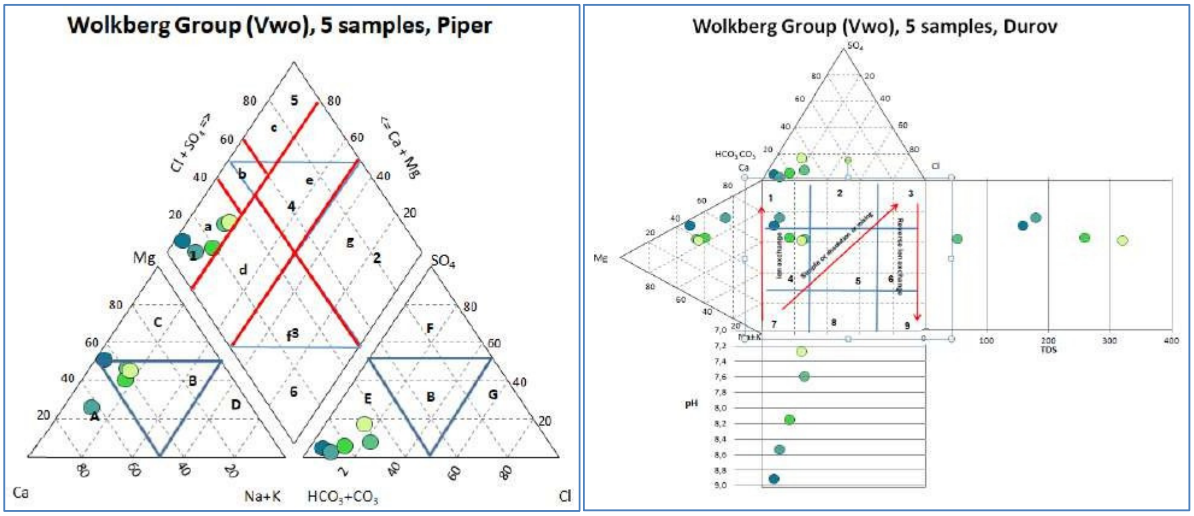


Figure 63: Trilinear diagrams, Piper and Durov for the Wolkberg Group (Vwo).

The trilinear Piper diagram, (Figure 63) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.
The initial evaluation of chemical dominance is as follows:

- Alkali earths > Alkali (100%),
- Weak acidic anions > Strong acidic anions (100%);
- Alkali >Alkali earths (0%);
- Strong acids > Weak acids (0%).

The water of the unit is characterised by a very high content of HCO^-, Ca^{2+}_3 and Mg^{2+}. It is a Calcium-Magnesium-Bicarbonate water type. One of the samples is a Calcium-Bicarbonate type as Calcium dominates the cations. This water type is associated with dolomitic aquifers that indicate strong interaction between the water of the Wolkberg Group with the overlying Malmani subgroup.

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- HCO_3 and Ca dominant, indication of recharging water in limestone (60%),
- Anion discriminant and Ca dominant indicative of mixed water or water exhibiting simple dissolution or mixing (40%).

Table 46: Chemical statistics for the Wolkberg Group (Vwo)

Element / Parameter	Statistics Drawn from a population of 8 data points for the Wolkberg Group (Vwo)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	8	7,10	8,90	7,90	7,94	7,19	8,05	8,63	0,62	7,8%
Electrical Conductivity (mS/m EC)	8	10,30	78,32	29,25	40,58	22,90	35,07	66,62	21,16	52,1%
Total Dissolved Salts (mg/l TDS)	6	65,00	400,40	170,25	236,93	131,50	216,98	362,32	115,14	48,6%
Calcium (mg/l Ca)	7	5,80	52,00	22,08	37,30	22,70	38,47	49,70	15,46	41,4%
Magnesium (mg/l Mg)	7	4,20	55,69	13,62	26,01	7,08	23,23	42,68	17,27	66,4%
Sodium (mg/l Na)	6	2,20	20,20	4,43	8,51	2,31	5,40	17,83	7,50	88,1%
Potassium (mg/l K)	5	0,55	5,25	1,41	2,68	0,78	2,68	4,66	1,92	71,8%
Chloride (mg/l Cl)	8	3,00	51,04	7,38	15,21	3,77	12,04	27,91	15,56	102,3%
Sulphate (mg/l SO_4)	7	1,50	24,49	3,19	7,77	1,80	3,77	18,20	8,58	110,4%
Total Alkalinity (mg/l) $CaCO_3$)	7	36,70	303,18	117,54	176,26	93,76	185,46	256,09	82,81	47,0%
Nitrate (mg/l N)	8	0,01	14,68	0,05	3,32	0,02	1,58	7,48	4,99	150,1%
Fluoride (mg/l F)	8	0,10	0,76	0,17	0,24	0,14	0,17	0,37	0,21	90,6%
Silicon as Si	4	7,48	13,53	9,34	9,83	7,71	9,15	12,49	2,69	27,4%
Iron (Fe)	4	0,01	0,09	0,01	0,03	0,01	0,01	0,07	0,04	151,8%
Manganese (Mn)	2	0,01	0,04	0,02	0,03	0,01	0,03	0,04	0,02	84,9%
Ortho Phosphate as Phosphorus as PO4	5	0,01	0,05	0,01	0,02	0,01	0,006	0,04	0,02	122,8%
ZAR	6	0,08	0,55	0,17	0,27	0,11	0,20	0,52	0,20	71,9%
LSI	5	Langelier Saturation Index (LSI)			Slightly Scaling		**40,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**20,0%**	Balanced Corrosion		**40,0%**

Table 46 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In terms of the electric conductivity (EC), the overall water quality is ideal to good with values between 10.3 and 78.3mS/m. The Total Dissolved Solids (TDS) is acceptable in all the analysis, (TDS ≤ 1200mg/l).

The evaluation on the analysis of 22 samples shows that none of the major cations and anions as well as pH values exceed the maximum allowed limits for human consumption.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive in 20% of the analysis and slightly scaling in 40% and 40% balanced. The ZAR index indicates that for all the samples analysed, the water is of a fair quality for irrigation (ZAR < 3).

The unit occurs in mountainous areas and is in many cases inaccessible. The water is mainly used for domestic supply. The boreholes available for analysis predominantly occur within the northern section of Zebediela Estate. This is an old residential area with a school, a police station and some houses. No boreholes were identified within this groundwater resource unit that are used for agriculture irrigation water supply.

7.2.2 CATEGORY C: KARST AQUIFERS

Karst aquifers which cover approximately 3.4% of the total map area comprise of 1 aquifer units.

7.2.2.1 MALMANI SUBGROUP (Vma) (Carbonate rocks)

The Chuniespoort Group includes the Duitschland and Pence Formations, as well as the Malmani Subgroup. For the Malmani Subgroup groundwater resource unit, the Malmani subgroup (Predominantly dolomite, with some chert, stromatolitic structures, and occasional limestone) has been grouped together with the Duitschland Formation (Primarily dolomite and limestone, with shale, siltstone, and quartzite interlayers), while the Pence Formation (banded ironstone) is discussed as a separate groundwater resource unit (see section 7.2.1.17, page 113). The Malmani Subgroup carbonate rock unit covers approximately 3.4% of the total map sheet area. It occurs mainly at two separate localities, namely, Mokopane (Potgietersrus) within the Buffelshoekberge and within the Wolkberg Mountains. Smaller occurrences are found in Bela-Bela (Warmbaths) and Marble Hall areas, (Figure 64).

The Malmani Subgroup consists of an alteration of chert-bearing and chert-free dolomite with an approximate thickness of 1300m. The dolomite (Malmani Subgroup) is overlain by thin or absent banded ironstone of the Penge Formation, as well as the carbonate and clastic sedimentary rocks of the Duitschland Formation.

Plate 7: Dolomite of the Malmani Subgroup in a road cutting along the N1 toll road on the farm Planknek 43KS. (Photograph: WH du Toit).

The following relevant information was obtained from the Council for Geoscience:

Within the Mogalakwena area, a significant portion of the geological unit forms a karst landscape characterized by sinkholes and caves. It is believed that more caves existed formerly in what are now open valleys, but these valleys have been so deeply eroded that very little evidence of the caves remains above the water table. Nevertheless, presence of underground cave systems has however been revealed by boreholes.

In the Dorps River Valley, subterranean passageways have developed between Peppercorn Cave on Makapansgat 39 KS and the Ysterberg Fault. Vertical karstic erosion shafts are present on the western side of the Mogoto Valley, particularly on Buffelshoek 53 KS.

Sinkholes have formed on the farm Portugal 55 KS, which are attributed to historical over- abstraction of groundwater. In particular, water for irrigation at the Zebediela Estate was excessively abstracted from the farms Portugal and Grootvalley, located within the Mogoto Mountain / Buffelshoekberge in the north. Daily abstraction from these farms reportedly reached up to 4.3 million liters per day (Mℓ/day) when the Gompies and Mogoto Dams were dry (D.A. Pretorius, 1970).

As a consequence of subsurface dissolution, the surface topography of this karst region is marked by numerous depressions of varying sizes. In many areas across the Buffelshoekberge, the original land surface has collapsed into solution caverns, leaving behind a highly rugged terrain. Surface drainage has largely been replaced by subterranean flow through conduits, and the general absence of perennial surface streams, along with valley morphology, suggests a mature stage of karst denudation.

Scarp retreat is evident from hillside caves and the collapse of overhanging cave roofs. The presence of hanging cave systems points to an earlier juvenile stage of erosion. The elevated positions of these caves and collapsed tunnels suggest they are of similar age and remain active features in ongoing karst development.

Locally, especially at the eastern side of Grootvalley 57 KS, the quartzite of the Black Reef Formation underlying the dolomite is delaying the easterly retreat of the dip slope escarpment. On the floor of the Mogoto Valley, a large, elongated depression in the dolomite is completely concealed by the surficial soils. This depression, filled with dolomite breccia, talus and coarse detritus, likely formed as the valley sink due to cave collapse. The slumped material, due to its high void content, forms an exceptionally productive aquifer with significant storage capacity.

Surface collapse into caverns remains active, and the alignment of sinkholes in a linear array parallel to the Mogoto Fault strongly suggests structural control of karst processes.

The dolomite terrain can be subdivided by dykes into several compartments, though in practice they are often hydraulically connected.

Groundwater occurs along **dykes, fault and shear zones** associated with intense deformation resulting in the occurrence of fractures, joints, and cavities subsequently enlarged by dissolution processes in the dolomites. The groundwater potential of the carbonate rocks in primary form is generally poor. Groundwater also occurs in weathered and fractured shale of the Duitschland Formation.

Borehole yields are generally moderate to high with 54.4%, (Figure 62), of boreholes yielding more than 2ℓ/s. Access to these dolomitic areas is severely hampered by the mountainous terrain especially in the Wolkberg area.

In 4.3% of the water samples at least one element exceeds the maximum allowed limit for domestic use. The cation of concern is Magnesium.

Except for the Mokopane (Potgietersrus) occurrence within the Mogoto Mountain or Buffelshoek Mountains, which has been thoroughly studied and its groundwater resources extensively utilized (3m^3/annum to 5m^3/annum), very little is known about the groundwater resources of the other two major areas. The abstraction at the Mokopane occurrence is mostly from the Duitschland Formation (Weenen and Planknek well fields) underlying the Dorps River valley and less within the Malmani dolomites (Uitkyk well field). Within the Lebowakgomo area water is abstracted but virtually no groundwater is abstracted from the Wolkberg dolomites in the east as it is a nature reserve.

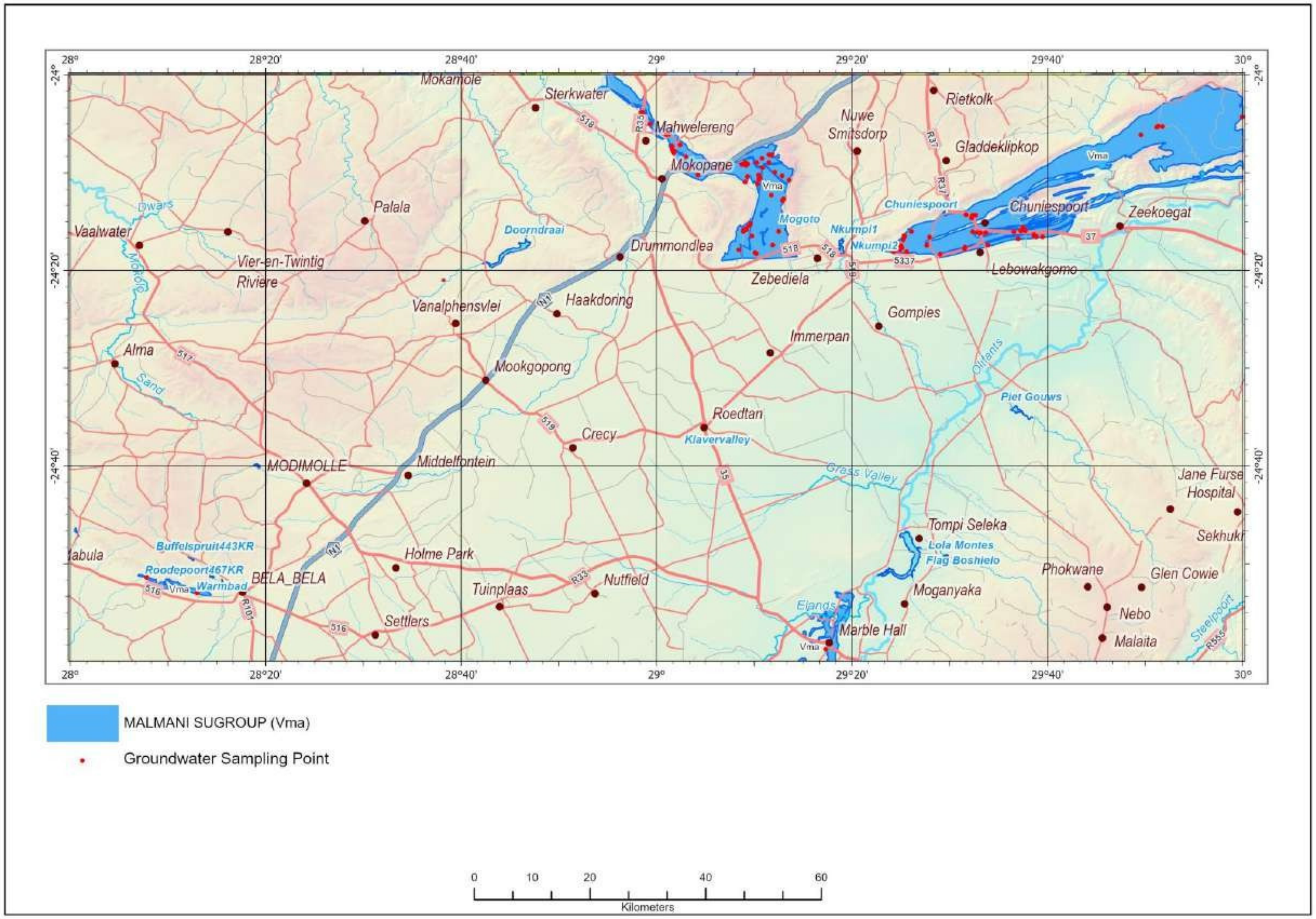


Figure 64: Geographical distribution for the Karst aquifers of the Malmani Subgroup (carbonate rocks) and the associated groundwater sampling points

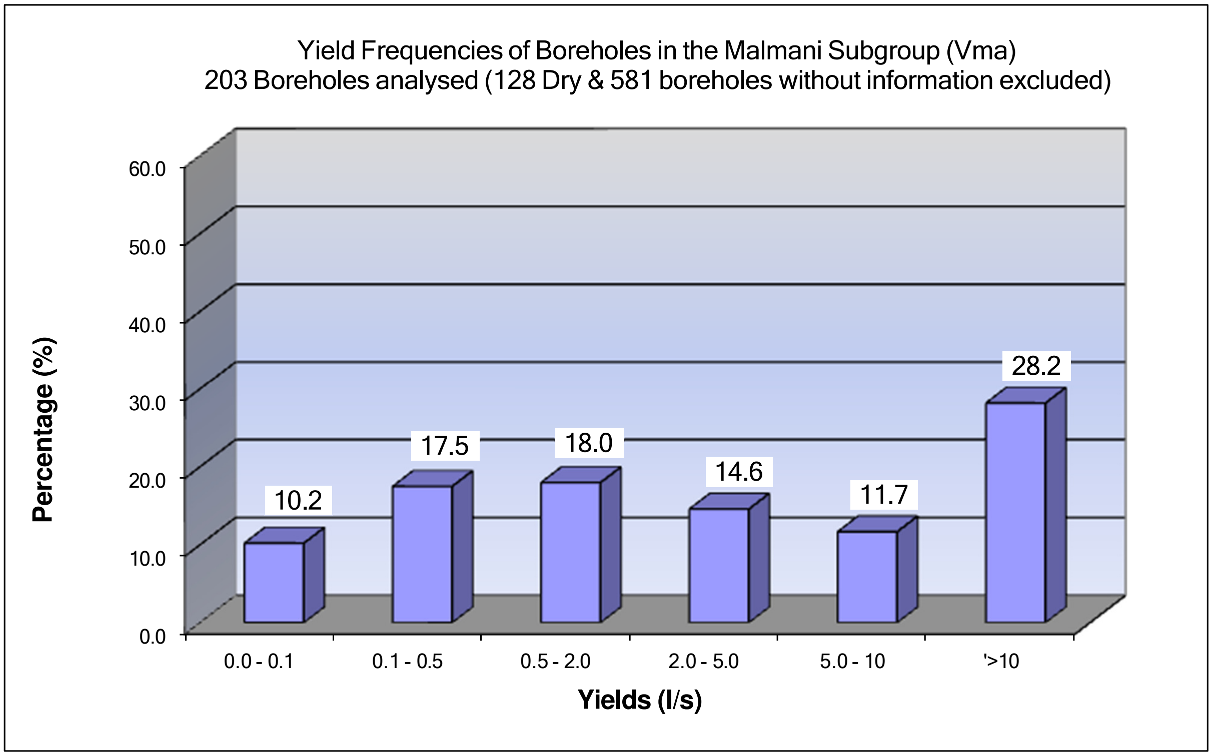


Figure 65: Yield frequency for Karst aquifers of the Malmani Subgroup (Vma) (carbonate rocks).

Numerous seasonal and in many cases perennial springs occur in all cluster areas. This contributes significantly to the base flow component in major rivers such as the Olifants and Dorps. Some springs occurring in the lower Dorps River catchment have been affected by abstraction from boreholes for the town of Mokopane (Potgietersrus). The yield frequency diagram indicates that 28.2% of boreholes are reported with maximum yields that exceeds 10ℓ/s.

The static water level ranges from 1.33 meters below ground level (mbgl) to 121.9mbgl, with a median static water level of 17.43mbgl and an average static water level of 22.1mbgl, (based on 301 data records). The maximum depth recorded is 250m, with an average depth of 66.1m and a median depth of 64m, (169 data records). The maximum installation depth is 120m and an average of 47m. The installation depth can be indicative of water strike depths.

The maximum recommended daily abstraction on record is 864 cubic meters per day (m^3/day) and the average is 187m^3/day. The 90th percentile is 478.7m^3/day and the median or 50th percentile is 129.6m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 62.

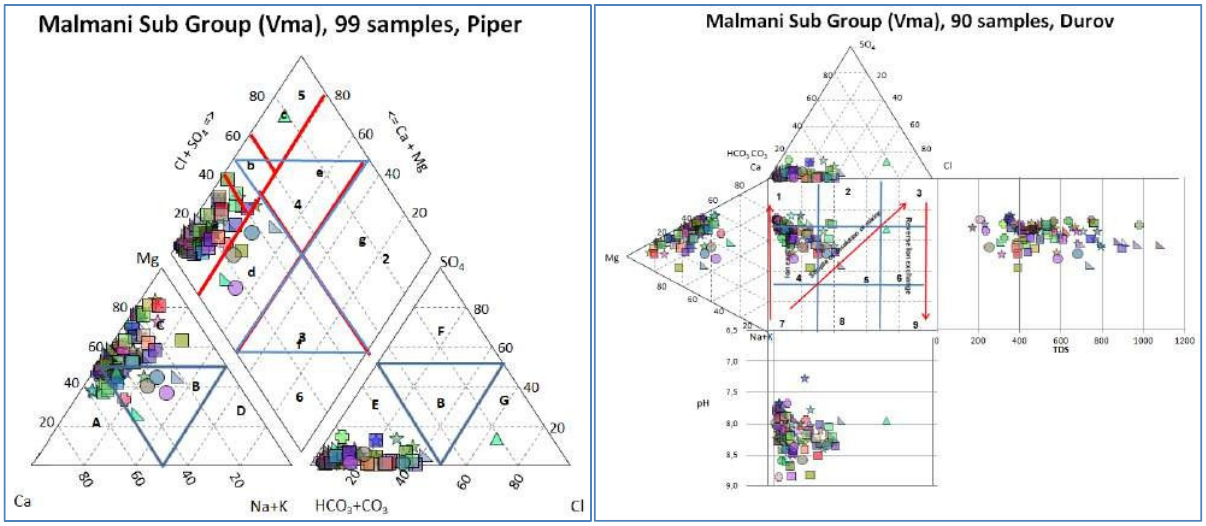


Figure 66: Trilinear diagrams, Piper and Durov for the Malmani Subgroup (Vma).

The trilinear Piper diagram, (Figure 66) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.

The initial evaluation of chemical dominance is as follows:

- Alkali earths > Alkali (100%),
- Weak acidic anions > Strong acidic anions (100%);
- Alkali >Alkali earths (0%);
- Strong acids > Weak acids (0%).

The second evaluation was on the water type: The water of the unit is characterised by a very high content of HCO_3^-, Ca^{2+} and Mg^{2+}, with Mg^{2+} or Ca^{2+} being dominant, is typical of groundwater associated with dolomitic aquifers.

The water classification is:

- Magnesium-Bicarbonate type (66%),
- Calcium-Bicarbonate type (15.2%),
- Calcium-Magnesium-Bicarbonate type (13.1%),
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (5.1%).

In samples where the cation Calcium dominates, it may indicate the presence of limestone.

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (57%),
- HCO_3 and Ca dominant, an indication of recharge in limestone (30%),
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (11%);
- Dominant Ca and HCO_3, ion exchange water, Mg concentration is significant (2%), typical water associated with dolomite.

Table 47: Chemical statistics for the Malmani Subgroup (Vma)

Element / Parameter	Statistics Drawn from a population of 122 data points for the Malmani Subgroup (Vma)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	94	7,36	9,51	7,99	8,00	7,52	8,00	8,40	0,36	4,5%
Electrical Conductivity (mS/m EC)	94	10,00	347,60	56,10	70,36	42,02	63,25	100,87	37,92	53,9%
Total Dissolved Salts (mg/l TDS)	87	193,0	2177,0	487,7	557,7	358,2	518,4	788,6	247,7	44,4%
Calcium (mg/l Ca)	94	5,82	102,95	38,25	53,99	20,79	53,78	85,71	24,01	44,5%
Magnesium (mg/l Mg)	94	2,00	170,40	32,74	50,08	23,16	48,11	81,14	25,07	50,1%
Sodium (mg/l Na)	93	1,00	445,10	5,96	20,25	3,20	9,00	48,54	47,88	236,5%
Potassium (mg/l K)	90	0,15	17,00	0,72	2,21	0,27	1,75	3,64	2,49	112,6%
Chloride (mg/l Cl)	94	1,50	682,80	9,47	33,75	5,00	12,96	70,81	74,88	221,8%
Sulphate (mg/l SO_4)	94	1,50	419,60	4,00	15,02	2,00	6,34	21,51	45,21	301,1%
Total Alkalinity (mg/l) $CaCO_3$)	94	55,0	586,0	264,1	313,2	193,5	320,8	429,8	104,4	33,3%
Nitrate (mg/l N)	94	0,02	16,92	0,15	3,03	0,03	1,85	7,71	3,50	115,7%
Fluoride (mg/l F)	90	0,03	4,71	0,15	0,36	0,05	0,21	0,71	0,57	158,1%
Silicon as Si	85	1,48	37,49	7,80	12,39	5,63	11,48	21,43	7,47	60,3%
Iron (Fe)	42	0,01	0,07	0,01	0,02	0,01	0,01	0,05	0,02	112,9%
Manganese (Mn)	13	0,01	0,21	0,01	0,04	0,01	0,01	0,08	0,06	157,3%
Ortho Phosphate as Phosphorus as PO4	83	0,01	0,80	0,01	0,05	0,01	0,02	0,09	0,13	237,6%
ZAR	93	0,03	6,97	0,16	0,46	0,08	0,21	0,94	0,84	183,6%
LSI	87	Langelier Saturation Index (LSI)			Slightly Scaling		64,4%	Highly Scaling		0,0%
		Highly corrosive		0,0%	Slightly corrosive		1,1%	Balanced Corrosion		34,5%

Table 47 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In regard to the electric conductivity (EC), the overall water quality is ideal to good with values between 10mS/m and 347.6mS/m, the 90th percentile is 100.9mS/m. The Total Dissolved Solids (TDS) is acceptable in 98.8% of the analysis, (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions of 22 samples shows elevated Magnesium (Mg > 100mg/l) in 4.3%, Fluoride (F > 1.5mg/l) in 2.2%; Chloride (Cl > 600mg/l) in 1.1%; and Sodium (Na > 400mg/l) in 1.1% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive in 1.1% of the analysis and slightly scaling in 64.4% and 34.5% balanced. The ZAR index indicates that 97.8% of all the samples analysed, the water is of a fair quality for irrigation (ZAR < 3).

As discussed, the unit is an important aquifer within the map sheet and water from this unit, is and was, extensively abstracted. The Planknek, Weenen and Uitloop well field that supplies Mokopane town with portable water is located within this unit. Rural and semi-rural villages south of the Strydpoort Mountain Range, uses water from this aquifer for portable water supply as well as various sections of Lebowakgomo town and some smaller rural villages that are more to the east. Water from this aquifer is also used for industrial use in Lebowakgomo as well as in Mokopane. The Platinum mine near Lebowakgomo that is currently not active; developed a well field (with an active water user license) within the unit. This water was pumped via pipelines to the mine that is located more in the south.

To the east a large section of the Wolkberg Nature Reserve is underlain by the unit and groundwater in the form of springs and interflow, supply water to game. The Zebediela Estate has a well field within this unit with an 80% yield assurance of 1.15Mm³/annum, (J.J.P. Vivier 2024). Within the Makapansgat area (Makapan Valley World Heritage Site) water was also abstracted for irrigation in the past; currently water is only abstracted for livestock watering and domestic purposes.

7.2.3 CATEGORY D: INTERGRANULAR AND FRACTURED AQUIFERS

- Letaba Formation (Jle)
- Ecca Group (Ppe) (Shale, grit, and sandstone)
- Diabase (N-Za)
- Spitskop Complex (Msp)
- Klipkloof & Makhutso Granite (Mkk)
- Nebo Granite (Mn)
- Rustenburg Layered Suite (Vrs)
- Pretoria Group (Vpg)
- Meinhardskraal Granite (Vme)
- Unnamed Granite (Vz) (Vaalian Rocks)
- Uitloop Granite (Ru-Vu)
- Lunsklip Granite (Rl-Vl)
- Turfloop Granite (Rt-Vt)
- Geyser Granite (Rge)
- Hout River Gneiss (Rho)
- Goudplaats Gneiss (Zgo)
- Pietersburg Greenstone Belt (Zpg)

Intergranular and fractured aquifers which cover approximately 55.3% of the total map area and comprise of 17 aquifer units. Figure 67 shows the Geographical distribution of the intergranular and fractured aquifers.

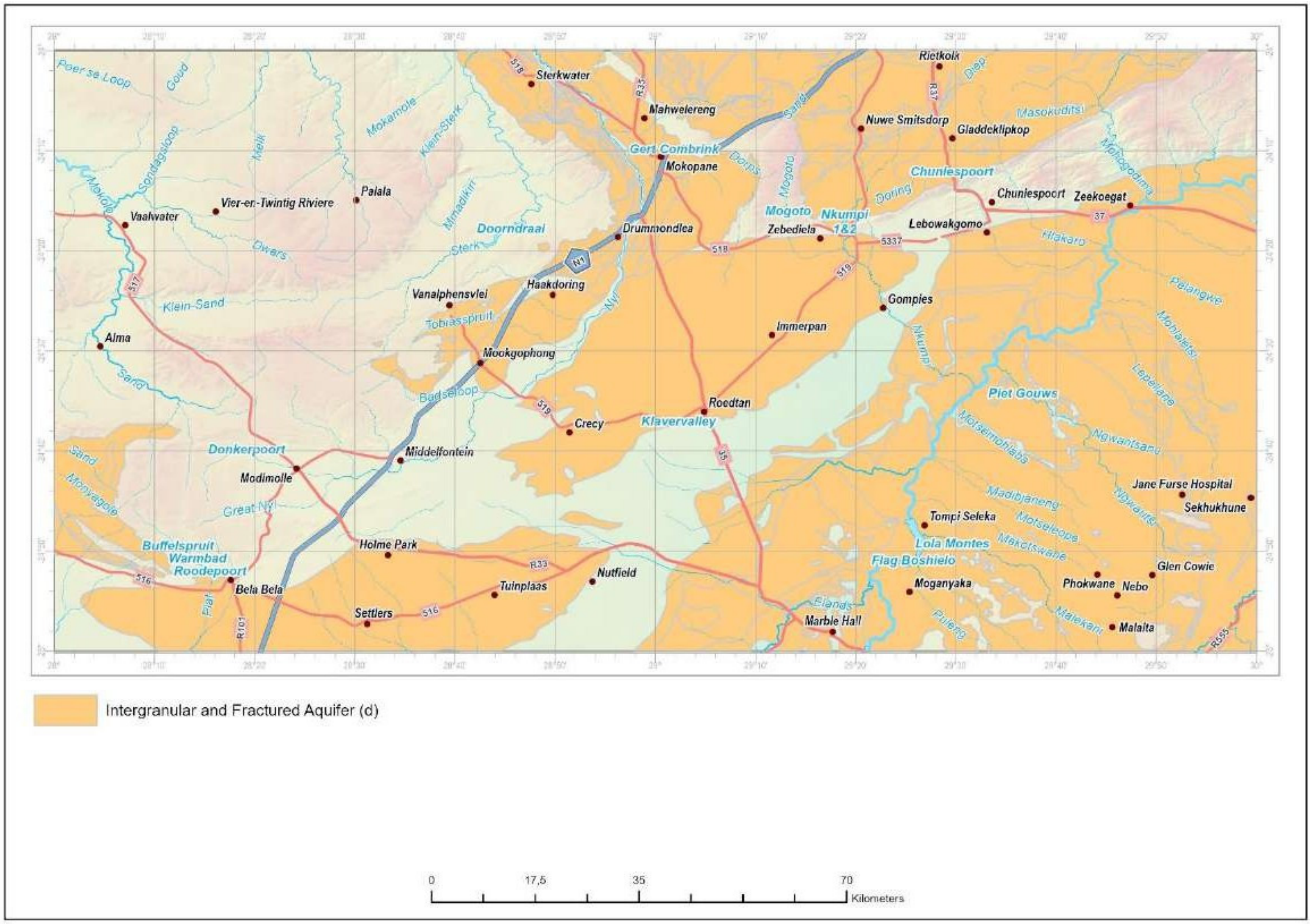


Figure 67: Geographical distribution of the intergranular and fractured aquifers

7.2.3.1 LETABA FORMATION (Jle)

Structurally, the Springbok Flats Karoo Basin comprises two elongated sub-basins: the Roedtan Basin in the north and the Settlers-Tuinplaats Basin in the south. These basins are bounded by prominent pre-Karoo tectonic features. The Thabazimbi-Murchison Lineament forms the northern boundary of the Roedtan Basin, while the Droogekloof Fault Zone delineates the northern boundary of the Settlers-Tuinplaats Basin.

The Letaba Formation, a name applied to all basaltic lava of Karoo age in Limpopo province prominently follows and overlies the Clarens Formation. The Springbok Flats occurrence is delineated on its northern boundary by major fault zones known as the Zebediela and Welgevonden faults respectively.

The Letaba Formation is present in both sub-basins within the map sheet area. It consists of a succession of multiple amygdaloidal lava flows, with the amygdales (pine-cone-like gas cavities) typically filled with zeolites (group of minerals consisting of hydrated aluminosilicates of sodium, potassium, calcium, and barium) and other secondary minerals. Due to extensive coverage by black clayey soils, natural outcrops of the Formation are limited. Where exposed, the fresh rock is predominantly basalt.

This unit covers approximately 13.8% of the total map area, (see Figure 68), making it the second-largest groundwater resource unit in terms of surface area within the map sheet.

Plate 8: View of the Springbok Flats from the R101 approximately 20 km north of Naboomspruit (Mookgophong). The Springbok Flats is a well-known geographical landmark in Limpopo and regarded by many in the region as the breadbasket of the province. Groundwater is abstracted extensively from Karoo lavas and sediments underlying the Flats for irrigation purposes. (Photograph: WH du Toit).

In 48% of the water samples at least one element exceeds the maximum allowed limit for domestic use. The anion of concern is Nitrate, and the cation of concern is Magnesium with elevated concentrations in 10.8% of the analysis.

Isotopic studies done by the Council for Scientific and Industrial Research, (Heaton, 1985) on the source of the elevated Nitrate content indicated that the Nitrate was derived solely from nitrification of the soil and not from the use of fertilizer or other sources. The high Chloride concentration is a result of irrigation practices and a shallow groundwater level, (Fayazi, 1994). Where this unit is in contact with dolomitic aquifers (Zebediela area) the water is a calcium-Magnesium-Bicarbonate type.

Statistics indicate that the groundwater potential of the groundwater resource unit is moderate to good as 61.4% of the boreholes yield more than 2ℓ/s.

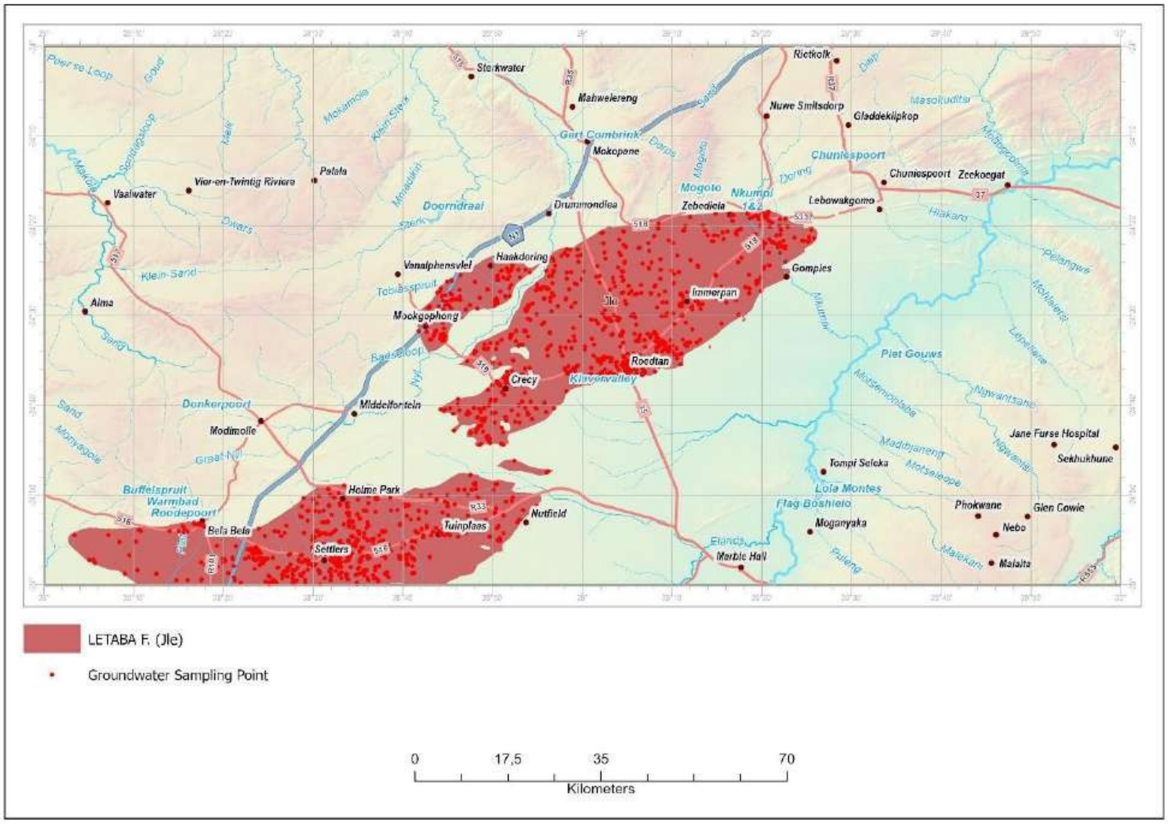


Figure 68: Geographical distribution for the intergranular and fractured aquifers of the Letaba Formation (Jle) and associated groundwater sampling points.

This high potential basaltic aquifer is of great agricultural importance in the area. During 1987 a study estimated groundwater abstraction to be as much as 40.6 x 10^6 m^3/a for irrigation purposes. Water is obtained in shallow weathered and fractured basalt (up to 50m from the surface) and deep fractures within the fresh basalt, which occur at depths of 150m, (Fayazi, 1994). The weathering and fracturing resulted in the development of secondary porosity and permeability, which control the storage and movement of the groundwater in this formation. Water also occurs on the contact between different lava flows and the contact between the basalt and underlying Clarens Formation.

Statistics revealed that 61.4%, (Figure 69) of the successful boreholes yield between 2ℓ/s to 10ℓ/s and 19.6% of the boreholes yield more than 10ℓ/s. The general depth of groundwater level varies between 10 and 30m. Some of the deeper groundwater levels are related to over-pumping as in the Roedtan area where a water level of 86.59m is reported. A study of the results from groundwater level recorders situated in the unit revealed that the annual rise in the groundwater level in the basalt and basalt/sandstone (underlying Clarens Formation) aquifer varies with the annual rainfall where a minimum annual rainfall of 300mm to 600mm is required to generate a rise in the groundwater level, (Fayazi, 1994).

The static water level ranges from 0.15 meters below ground level (mbgl) to 86.59mbgl, with a median of 17.82mbgl, and an average of 19.7mbgl, (based on 277 data records). The maximum depth recorded is 395m, with an average depth of 77.1m and a median depth of 61m, (199 data records). The maximum installation depth is 140m and the average is 50.8m. The installation depth can be indicative of water strike depths.

The maximum recommended daily abstraction on record is 1123.2 cubic meters per day (m^3/day) and the average is 118.4m^3/day. The median or 50th percentile for daily abstraction is 58.3m^3/day, with a 90th percentile of 259.2m^3/day and a 95th percentile of 380.4m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 114.

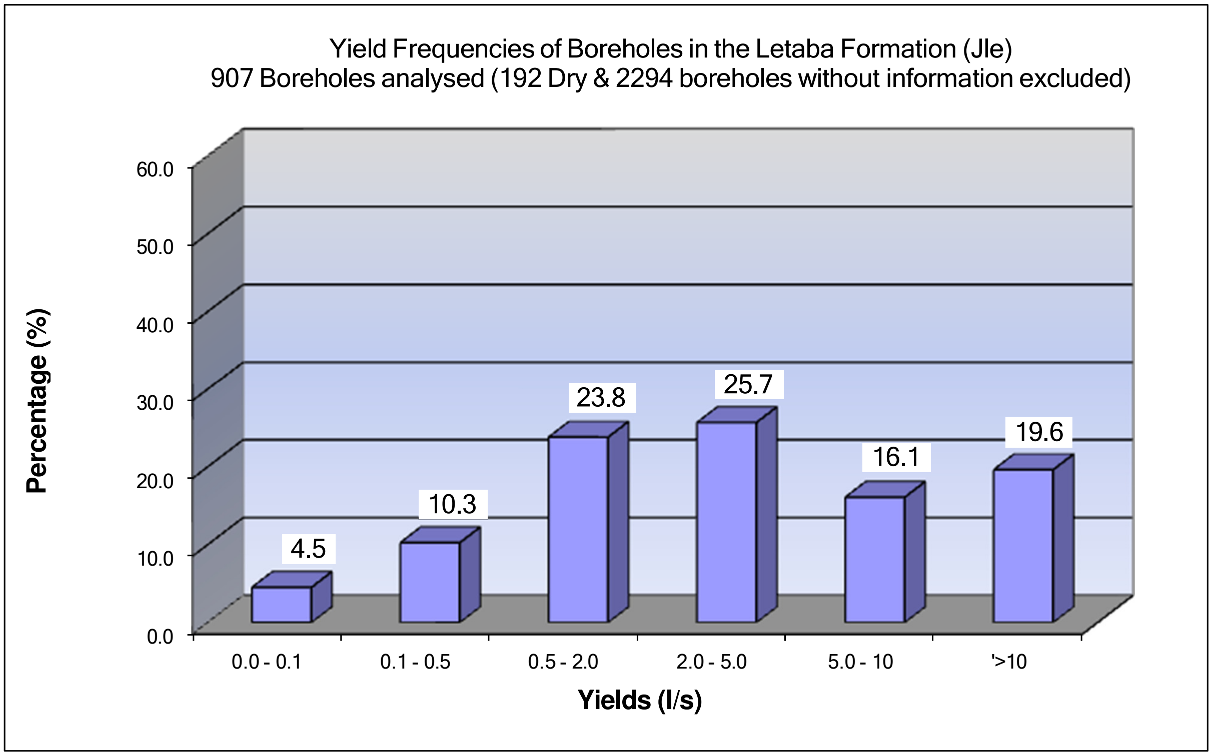
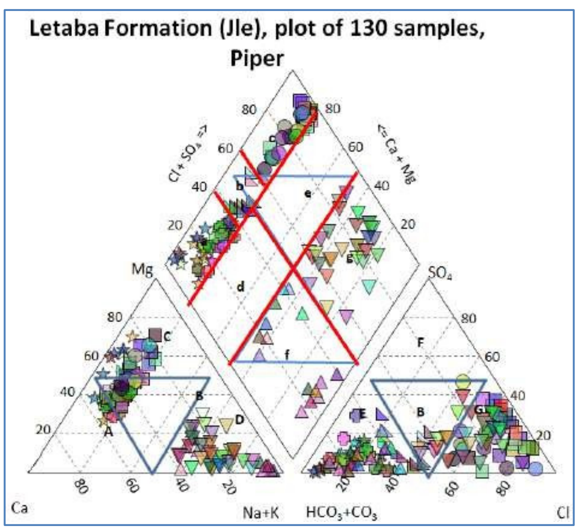
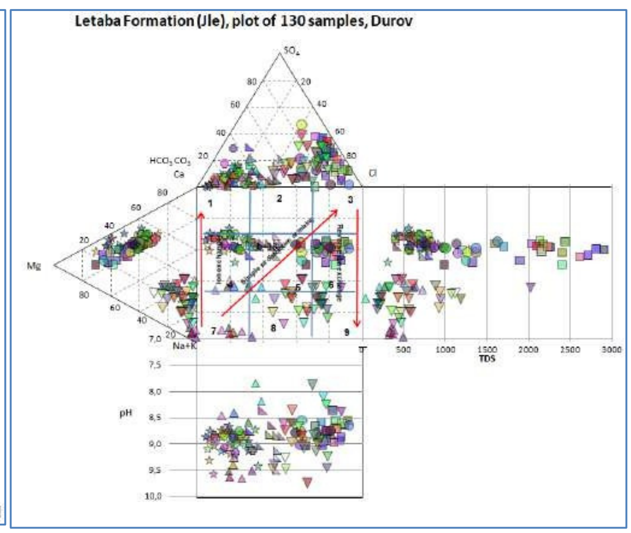


Figure 69: Yield frequency for the intergranular and fractured aquifers of the Letaba Formation (Jle).





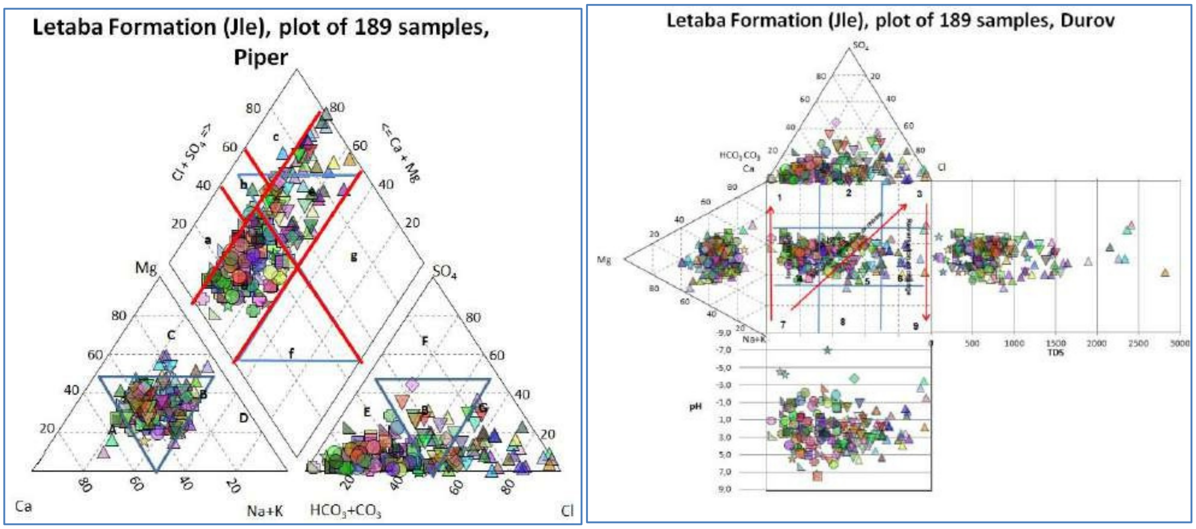


Figure 70: Trilinear diagrams, Piper and Durov for the Letaba Formation (Jle).

The trilinear Piper diagram, (Figure 70) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.

The initial evaluation of chemical dominance is as follows:

- Alkali earths > Alkali (85.9%),
- Weak acidic anions > Strong acidic anions (40.8%);
- Strong acids > Weak acids (59.2%);
- Alkali >Alkali earths (14.1%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type with or without increasing Sodium (44.5%);
- Mixed Calcium-Magnesium-Chloride type with some samples exhibiting increasing Sodium (23.8%);
- Sodium-Bicarbonate type (7.2%);
- Sodium-Chloride type (6.5%);
- Calcium-Magnesium Chloride type (6.3%);
- Magnesium Chloride type (4.1%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (2.5%);
- Calcium-Bicarbonate type (1.9%);
- Magnesium-Bicarbonate-Chloride type (1.6%);
- Magnesium-Bicarbonate type (1.6%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (53%),
- Mixed water exhibiting simple dissolution (22.6%),
- Anion discriminate and Ca dominant, probable mixing or uncommon dissolution influences (15.7%),
- Cl and Na dominant, indicate that the groundwater be related to reverse ion exchange of Na-Cl waters (6%),
- Cl and Na dominant are frequently indicative of end-point gradient waters through Dissolution (2.8%).

Table 48: Chemical statistics for the Letaba Formation (Jle)

Element / Parameter	Statistics Drawn from a population of 998 data points for the Letaba Formation (Jle)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	998	6,3	9,6	7,8	7,8	7,4	7,8	8,3	0,4	4,7%
Electrical Conductivity (mS/m EC)	995	4,9	584,9	76,2	108,0	50,5	86,3	201,5	74,9	69,4%
Total Dissolved Salts (mg/l TDS)	680	37,0	3517,0	586,7	809,9	385,8	685,6	1424,2	495,2	61,1%
Calcium (mg/l Ca)	971	1,8	538,7	48,7	83,3	32,4	73,5	138,0	58,8	70,6%
Magnesium (mg/l Mg)	973	0,5	453,0	18,8	54,1	15,0	41,0	105,6	51,3	94,9%
Sodium (mg/l Na)	985	1,0	498,2	32,0	59,7	19,0	48,5	117,0	48,1	80,6%
Potassium (mg/l K)	688	0,2	49,9	1,8	4,0	0,8	2,9	8,9	4,0	100,6%
Chloride (mg/l Cl)	998	1,5	1553,0	24,8	123,4	11,4	40,1	328,8	212,1	172,0%
Sulphate (mg/l SO_4)	988	1,7	627,0	9,7	48,3	3,0	22,0	108,6	80,6	166,8%
Total Alkalinity (mg/l) $CaCO_3$)	967	2,0	930,0	164,8	256,1	145,0	258,3	363,6	91,0	35,5%
Nitrate (mg/l N)	997	0,0	250,0	0,5	21,2	1,5	19,3	40,6	18,8	88,4%
Fluoride (mg/l F)	987	0,05	9,65	0,15	0,34	0,05	0,25	0,58	0,61	178,0%
Silicon as Si	652	0,2	53,9	21,1	30,3	17,8	32,4	37,5	8,2	0,3
Iron (Fe)	80	0,01	0,15	0,01	0,02	0,01	0,01	0,05	0,03	109,6%
Manganese (Mn)	45	0,01	0,23	0,01	0,02	0,01	0,01	0,06	0,04	156,3%
Ortho Phosphate as Phosphorus as PO4	524	0,01	0,80	0,01	0,04	0,01	0,00	0,06	0,10	259,2%
ZAR	968	0,02	15,89	0,81	1,43	0,47	1,10	2,45	1,41	98,6%
LSI	650	Langelier Saturation Index (LSI)			Slightly Scaling		**51,2%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,5%**	Slightly corrosive		**3,5%**	Balanced Corrosion		**44,8%**

Table 48 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. An example is Chloride with a maximum concentration of 1553mg/l. The 90th percentile is 328.8mg/l meaning that 898 of the samples have a Chloride concentration that is less than 328.8mg/l. In terms of electrical conductivity (EC), the water quality is good to marginal in 98.3% of the samples; it varies between 4.9mS/m and 584.9mS/m. The Total Dissolved Solids (TDS) is acceptable in 86.3% of the samples (TDS ≤ 1200mg/l).

The analysis indicates elevated concentrations of Nitrate (N >10mg/l) in 48%; Magnesium (Mg > 100mg/l) in 10.8%, Chloride (Cl > 600mg/l) in 4.7%; Fluoride (F >1.5mg/l) in 1.4%; Calcium (Ca > 300mg/l in 1.3%; and Sodium (Na > 400mg/l) in 0.2%; Sulphate (SO_4 > 600mg/l) in 0.1% of the samples.

The Langelier Saturation Index (LSI) indicates that the water is corrosive (4%) to balanced corrosive (44.8%) to slightly scaling in 51.2% of the analysis. The ZAR index indicates that 93.3% of the water is of a fair quality for irrigation (ZAR < 3).

Agriculture (irrigation) is the biggest user of groundwater in the area. Water is also used for game, livestock watering and rural farms for domestic purposes. In many places it is the only source of water despite the high Nitrate concentration that is evenly distributed throughout the unit. Water is also used to supply semi-rural settlements that are within the north-eastern sector of the Roedtan basin as well as for Roedtan town.

7.2.3.2 ECCA GROUP (Ppe) (Shale, grit, and sandstone)

The Ecca Group occurs on the map sheet as an intergranular and fractured aquifer. The intergranular and fractured aquifer unit occur predominantly in the marginal areas of the Springbok Flats basin, namely, west of Bela-Bela (Warmbaths) and north-west of Marble Hall, (Figure 71). The Bela-Bela (on the adjacent Thabazimbi map sheet) and Marble Hall occurrences consist of an unclassified succession of shale, shaly sandstone, grit, sandstone, conglomerate at the base and in places coal near the base and top.

This unit covers approximately 2.18% of the total map area.

High Fluoride levels occur throughout this cluster although more elevated levels are reported near the contact with sediments of the Pretoria Group. It most probably washed into the basin from the older Bushveld Granites which is known for high Fluoride concentrations.

Rocks in this unit have a low to very low primary permeability with low storage potential. Statistics indicate that 78.8%, (Figure 72), of the successful boreholes yield less than 2ℓ/s. Some high yields were obtained in the Bela-Bela (Warmbaths) area on the contact zone between the overlying Irrigasie Formation and Ecca Group. Water is generally obtained in fractures and joints locally developed along bedding plains; contact zones between sediments; fault and associated shear zones and extensively developed fractures and joints due to regional tectonics of the two synclinal flexures and post-Karoo tectonic episodes (Fayazi, 1994). Water also occurs in fractures developed at the contact zones with intrusive dolerite sills and dykes. An impervious thick intrusive dolerite sill causes artesian conditions in the eastern part of the northern Springbok Flats. The depth to the static groundwater level is generally between 10 and 20mbgl.

In 83.3% of the water samples at least one element exceeds the maximum allowed limit for domestic use. In this unit Fluoride is the most problematic anion followed by Chloride and Nitrate that exceeds the maximum allowable concentration in 45.5% and 20% of the analysis respectively. The cations of concern are Magnesium and Sodium that exceed the maximum allowable concentration in 39.5% and 45.5% of the analysis respectively.

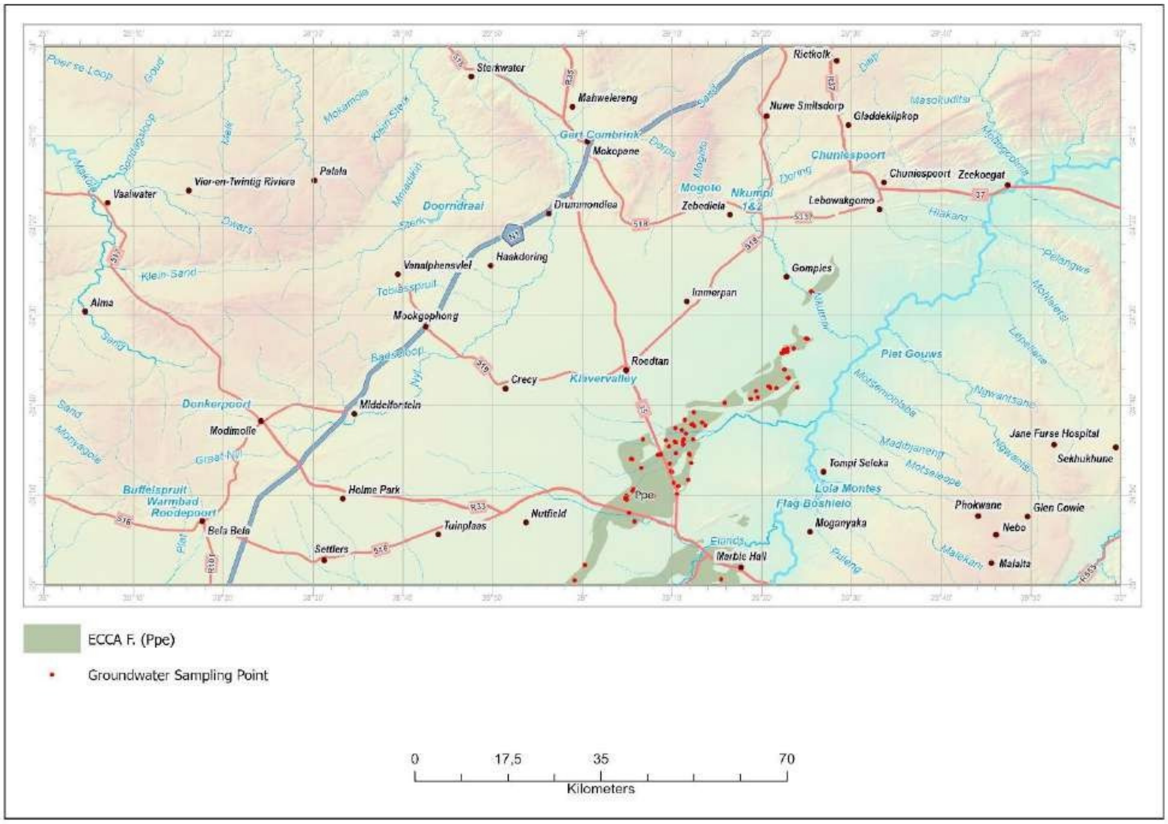


Figure 71: Geographical distribution of the Ecca Group (Ppe) (shale, grit & sandstone) and the associated groundwater sampling points.

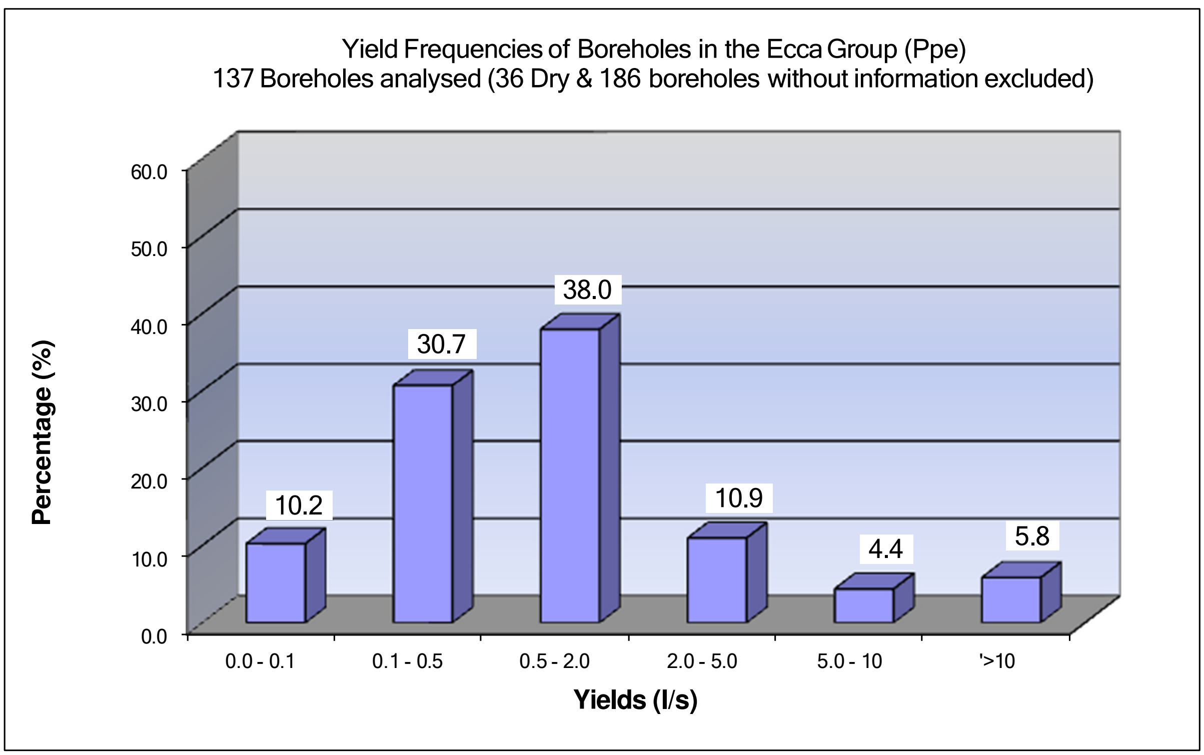


Figure 72: Yield frequency for the intergranular and fractured aquifers of the Ecca Group (Ppe) (shale, grit & sandstone).

The yield frequency diagram, (Figure 72) indicates that 78.8% of successful boreholes have maximum yields less than 2ℓ/s. A further 10.9% have yields between 2ℓ/s and 5ℓ/s, with 4.4% yielding between 5ℓ/s and 10ℓ/s and 5.8% of boreholes yielding more than 10ℓ/s.

The static water level ranges from 0.44 meters below ground level (mbgl) to 27.28mbgl, with a median static water level of 6.45mbgl and an average static water level of 10.78mbgl, (based on 17 data records). The maximum depth recorded is 228.4m, with an average depth of 88.2m and a median depth of 81.6m, (21 data records). The maximum installation depth is 120m and the average is 45m, (17 data records). The average installation depth of 45.4m can be indicative of the intergranular character of the unit. The deeper installation depths will relate to deeper fractured zones.

The maximum recommended daily abstraction on record is 155.5 cubic meters per day (m^3/day) and the average is 38.9m^3/day. The 90th percentile is 116.6m^3/day and the median or 50th percentile of daily abstraction is 6m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 15.

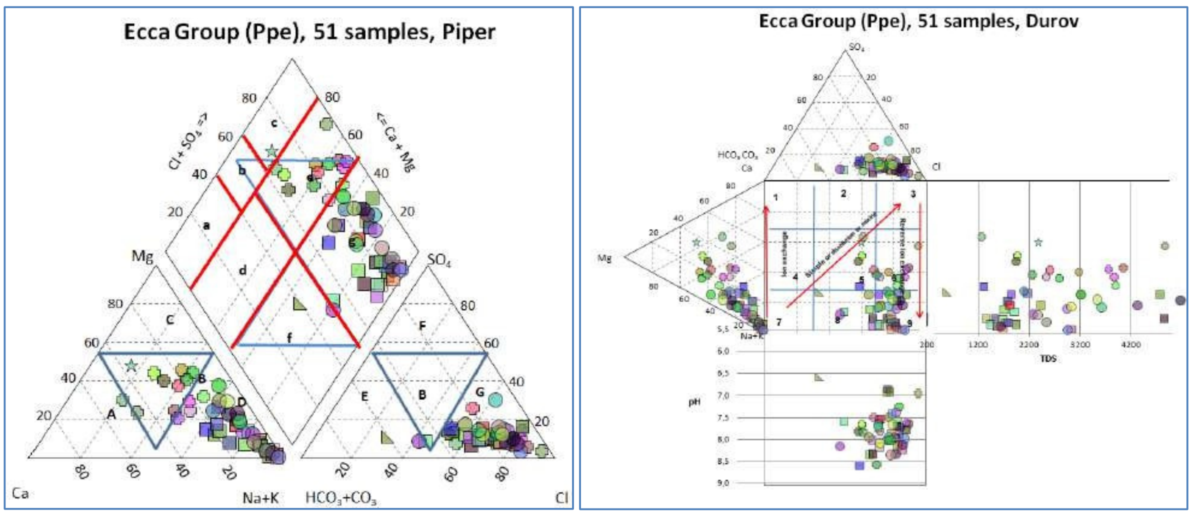


Figure 73: Trilinear diagrams, Piper and Durov for the Ecca Group (Ppe).

The trilinear Piper diagram, (Figure 73) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (27.5%), Weak acidic anions > Strong acidic anions (2%); Alkali >Alkali earths (72.5%); Strong acids > Weak acids (98%).

The second evaluation was on the water type:

- Sodium-Chloride type dominates (70.5%);
- Mixed Calcium-Magnesium-Chloride type with increasing Sodium (25.5%);
- Mixed Calcium-Magnesium-Chloride type (2%);
- Sodium-Bicarbonate type (2%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- Cl and Na dominancy is frequently indicating endpoint down gradient waters through dissolution (54.9%),
- Cl dominant anion and Na dominant cation, indicate that the groundwater be related to reverse ion exchange of Na-Cl waters (19.6%),
- Anion discriminate and Na dominant indicate probable mixing or uncommon dissolution influences (13.7%),

- No dominant anion or cation which indicates water exhibiting simple dissolution or mixing (11.7%).

Table 49: Chemical statistics for the Ecca Group (Ppe)

Element / Parameter	Statistics Drawn from a population of 66 data points for the Ecca Group (Ppe)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	66	6,88	8,62	7,91	7,93	7,48	7,94	8,38	0,36	4,5%
Electrical Conductivity (mS/m EC	66	39,40	1050,00	228,40	325,00	149,71	258,95	551,01	203,43	62,6%
Total Dissolved Salts (mg/l TDS)	64	290,00	7148,00	1542,59	2158,25	993,42	1787,50	3508,19	1346,48	62,4%
Calcium (mg/l Ca)	66	5,60	524,20	31,34	90,67	10,60	62,05	214,36	90,90	100,3%
Magnesium (mg/l Mg)	66	1,40	464,60	16,48	89,43	7,20	71,15	166,75	89,96	100,6%
Sodium (mg/l Na)	66	42,09	1564,50	284,99	481,01	189,01	354,05	899,80	334,34	69,5%
Potassium (mg/l K)	64	3,99	59,40	11,34	17,77	5,62	13,90	36,75	12,29	69,2%
Chloride (mg/l Cl)	66	23,70	3158,40	354,33	758,20	225,40	536,10	1450,85	624,53	82,4%
Sulphate (mg/l SO_4)	66	12,30	1021,90	85,27	189,29	49,65	106,12	445,24	231,75	122,4%
Total Alkalinity (mg/l) $CaCO_3$)	66	140,70	1100,00	313,57	363,86	206,93	317,10	545,42	156,62	43,0%
Nitrate (mg/l N)	66	0,02	52,49	0,17	9,42	0,07	2,91	27,74	12,16	129,0%
Fluoride (mg/l F)	66	0,16	19,22	2,07	5,60	1,12	3,49	13,77	5,26	94,0%
Silicon as Si	64	5,65	38,97	14,06	18,44	7,31	17,81	30,06	8,85	48,0%
Iron (Fe)	7	0,01	0,11	0,01	0,03	0,01	0,01	0,07	0,04	120,4%
Manganese (Mn)	4	0,01	0,36	0,02	0,11	0,02	0,04	0,26	0,16	146,9%
Ortho Phosphate as Phosphorus as PO4	52	0,01	0,37	0,01	0,03	0,01	0,01	0,08	0,06	199,0%
ZAR	66	0,96	52,60	6,20	11,67	3,37	10,13	22,10	9,03	77,3%
LSI	64	Langelier Saturation Index (LSI)			Slightly Scaling		**65,6%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**6,3%**	Balanced Corrosion		**28,1%**

Table 49 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. An example is Sulphate with a maximum concentration of 1021.9mg/l. The 90th percentile is 445.24mg/l meaning that 59 out of 66 samples have a Sulphate concentration that is less than 445.24mg/l.

In terms of electrical conductivity (EC), the water quality is unacceptable in 33.3% of the samples; it varies between 39.4mS/m and 1050mS/m. The Total Dissolved Solids (TDS) is acceptable in only 26.5% of the samples (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions for 66 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 83.3%; Chloride (Cl > 600mg/l) in 45.5%; Sodium (Na > 400mg/l) in 45.5%; Magnesium (Mg > 100mg/l) in 39.4%; Nitrate (N >10mg/l) in 20%; Sulphate (SO_4 > 600mg/l) in 9.1% and Calcium (Ca > 300mg/l in 1.5% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive (6.3%); balanced corrosive (28.1%) and predominantly slightly scaling in 65.6% of the analysis. The ZAR index indicates that only 6.1% of the water is of a fair quality for irrigation (ZAR < 3).

Due to the low yield and poor water chemistry the water from this unit area is not used for irrigation. Irrigation fields occurring within this unit are ‘dry land’ farming, except for the area near Marble Hall that is part of the Loskop Dam Water Scheme (supplied by surface water).

7.2.3.3 DIABASE (N-Za)

This unit consists of diabase intrusions from Swazian age up to Namibian that includes sills and dykes that occur in almost all the pre-Karoo formations in the area. Sills occur north of Marble Hall and east of Makgabeng, around Modimolle and some distance north of Mookgophong, (Figure 74). Numerous dykes occur in the Waterberg Group. Targets for groundwater supplies can be found in fractured contact zones with host rock, faults and fractures within the diabase.

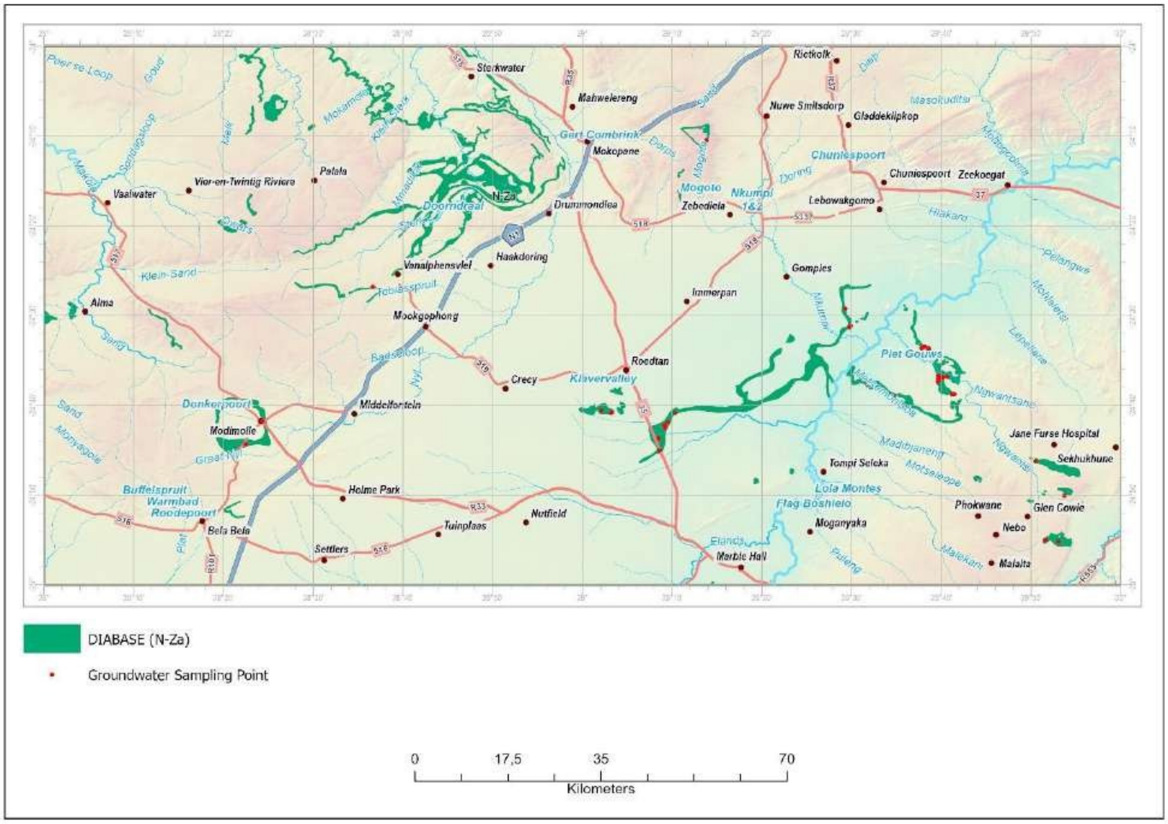


Figure 74: Geographical distribution of the Diabase intrusions (N-Za) and the associated groundwater sampling points.

In the Swazian rocks and in the Hout River Gneiss, dykes often give rise to ridges but in the sedimentary rocks they usually form negative topographic features. Within the Waterberg Supergroup 'U-shape valleys' often indicates the presence of diabase dykes especially in the Vaalwater area. Geophysical data interpretation usually identifies the dyke on either side of these valleys and not within as expected. The scale of the map excludes the inclusion of all dyke intrusions, (Figure 6, page 30), but it gives some indication of frequency and trend of occurrence in certain areas.

Diabase occurrences within the map sheet vary from aphanitic (very fine, crystals cannot be distinguished with the naked eye) to coarse-grained, are greenish black, of gabbroic composition and have an ophitic texture (random plagioclase laths are enclosed by pyroxene or olivine). A specimen from north of Villa Nora consists typically of augite, oligoclase plagioclase and hornblende with accessory hypersthene, quartz, biotite, and iron ore (Geological map sheet explanatory brochure). The unit underlies approximately 1.9% of the map sheet area.

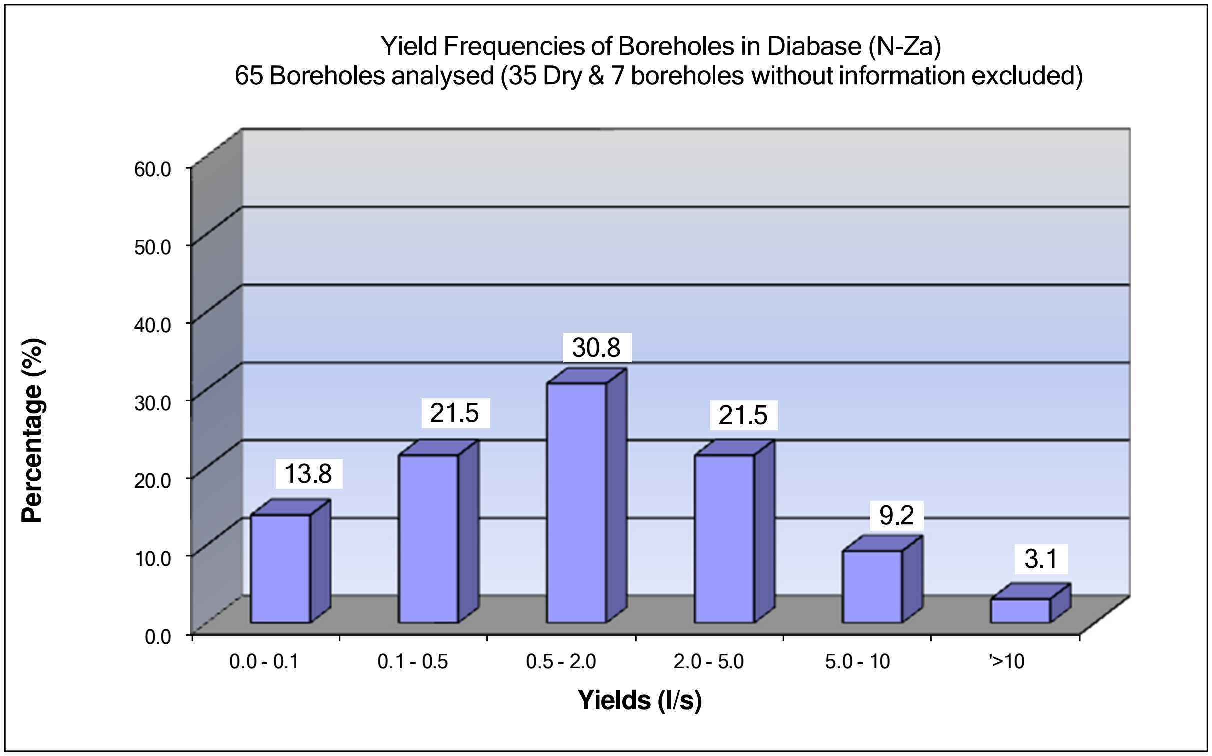


Figure 75: Yield frequency for the intergranular and fractured aquifers of the Diabase intrusions (N-Za).

Figure 75 shows the yield frequency diagram. The indication is that 66.2% of successful boreholes have maximum yields that are less than 2ℓ/s and 12.3% more than 5ℓ/s. A further 21.5% of boreholes have yields between 2ℓ/s and 5ℓ/s.

In the search for groundwater, secondary fractures in the host rock associated with the diabase intrusion are sometimes targeted. Important detail to consider when choosing a drilling site in the vicinity of a dyke intrusion is the static water table, host rock type, the width, strike, dip and the lateral extent of the dyke. A general rule is to position the drill site within the dyke when the dyke is thin (less than 7m). The expectation is to find water within the dyke. With wider dykes (7m to 15m) the most successful zone is usually within 2m of the contact zone. Very wide dykes are usually not good targets as the secondary fractures may be further developed from the contact zone (10m to 20m). Yields can differ on each side of the dyke as well as along the strike.

When using interpreted aerial magnetic data such as maps that show the magnetic intensity over a large area, dykes are usually targeted on the ground in areas along the strike where there is possible weathering (lower background readings), or where joints or fracture zones transect the dyke (displacement). Sills are usually more difficult to drill successfully in search of water, but the upper contact with the host rock can be targeted, or weathered and fractured zones within the sill, or the lower contact zone. The above is a general approach and depends on the geological, hydrogeological, and physiographical settings of the target area.

The static water level ranges from 0.09 meters below ground level (mbgl) to 56 meters below ground level (mbgl), with a median static water level of 8.03mbgl and an average static water level of 11.57mbgl, (based on 67 data records). The maximum depth recorded is 150.3m, with an average depth of 80.3m and a median depth of 66.1m, (43 data records). The maximum installation depth is 100m, which can be indicative of deep fractures that result in water strike depths. The average installation depth is 48.7m that is indicative of the intergranular character of the unit.

The maximum recommended daily abstraction on record is 216 cubic meters per day (m^3/day) and the average is 38.4m^3/day. The 90[th] percentile is 172.8m^3/day and the median or 50[th] percentile is 8.6m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 31.

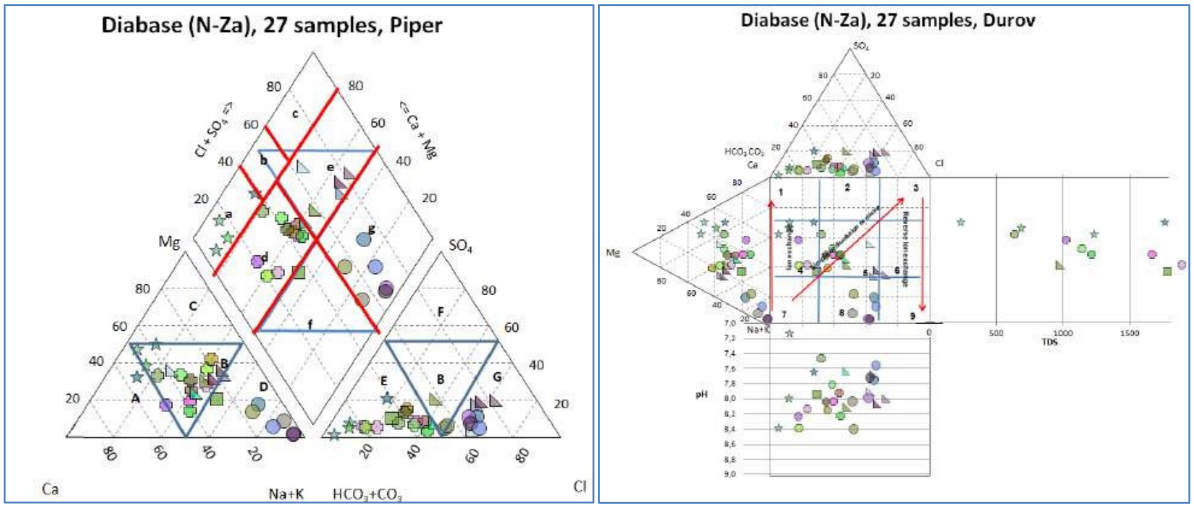


Figure 76: Trilinear diagrams, Piper and Durov for Diabase (N-Za).

The trilinear Piper diagram, (Figure 76) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.

The initial evaluation of chemical dominance is as follows:

- Alkali earths > Alkali (58.8%),
- Weak acidic anions > Strong acidic anions (29.4%);
- Strong acids > Weak acids (70.6%);
- Alkali >Alkali earths (41.2%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (40.7%),
- Sodium-Chloride type (22.2%),
- Calcium-Magnesium-Bicarbonate type (11.1%),
- Mixed Magnesium-Calcium-Chloride type (11.1%),
- Mixed Magnesium-Calcium-Bicarbonate-Chloride type (3.7%)
- Sodium-Bicarbonate type (3.7%);

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing and / or minor recharge (29.6%),
- Mixed water exhibiting simple dissolution (44.4%); points plot along the dissolution or mixing line,
- Anion discriminates and Na dominant indicative of probable mixing or uncommon dissolution influences (3.7%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (22.2%).

Table 50: Chemical statistics for the Diabase intrusions (N-Za)

Element / Parameter	Statistics Drawn from a population of 30 data points for Diabase (N-Za)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	30	6,90	8,38	7,88	7,89	7,51	7,97	8,36	0,36	4,5%
Electrical Conductivity (mS/m EC)	30	10,40	274,90	67,05	107,30	41,35	104,44	180,88	60,22	56,1%
Total Dissolved Salts (mg/l TDS)	28	78,00	1754,00	463,52	734,64	298,18	699,95	1286,50	405,63	55,2%
Calcium (mg/l Ca)	30	9,70	97,31	31,31	50,06	12,45	42,70	90,71	28,39	56,7%
Magnesium (mg/l Mg)	30	3,10	122,20	15,53	35,55	8,94	27,45	80,06	29,89	84,1%
Sodium (mg/l Na)	30	1,00	333,70	19,71	127,72	19,86	97,39	286,78	101,58	79,5%
Potassium (mg/l K)	28	0,43	18,03	1,93	5,62	0,90	4,33	13,47	5,06	90,1%
Chloride (mg/l Cl)	30	1,50	503,50	19,62	129,48	11,33	93,29	312,04	123,58	95,4%
Sulphate (mg/l SO_4)	30	2,00	218,50	12,95	41,62	5,50	26,17	83,82	48,60	116,8%
Total Alkalinity (mg/l) $CaCO_3$)	29	44,50	604,93	225,09	301,58	143,48	311,80	420,90	120,74	40,0%
Nitrate (mg/l N)	30	0,02	25,62	0,39	5,17	0,40	5,00	10,37	5,40	104,4%
Fluoride (mg/l F)	30	0,05	13,09	0,39	2,28	0,20	1,34	4,41	3,30	144,6%
Silicon as Si	28	6,05	51,10	21,60	29,41	10,34	32,13	41,27	11,49	39,1%
Iron (Fe)	16	0,01	0,26	0,01	0,03	0,01	0,01	0,05	0,06	188,2%
Manganese (Mn)	7	0,01	1,20	0,04	0,28	0,03	0,10	0,65	0,42	151,3%
Ortho Phosphate as Phosphorus as PO4	24	0,01	1,38	0,02	0,13	0,01	0,03	0,12	0,31	245,6%
ZAR	30	0,06	20,39	0,88	4,32	0,56	2,45	12,12	5,22	120,7%
LSI	27	Langelier Saturation Index (LSI)			Slightly Scaling		55,6%	Highly Scaling		0,0%
		Highly corrosive		0,0%	Slightly corrosive		3,7%	Balanced Corrosion		40,7%

Table 50 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. It may also relate to a different water type. An example is Total Alkalinity with a maximum concentration of 604.9mg/l. The 90th percentile is 420.9mg/l meaning that 27 out of 30 samples have a Total Alkalinity concentration that is less than 420.9mg/l. The interpretation of the piper diagram indicates that four water types can be associated with this unit. The regional geology into which the dyke intruded will have an impact on the water constituent.

In terms of electrical conductivity (EC), the water quality is ideal to good in 80% and marginal in 20% of the samples; it varies between 10.4mS/m and 274.9mS/m. The Total Dissolved Solids (TDS) is acceptable in 85.7% of the samples (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions of 30 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 47%; Nitrate (N >10mg/l) in 3% and Magnesium (Mg > 100mg/l) in 3.3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive (3.7%); balanced corrosive (40.7%) and predominantly slightly scaling in 55.6% of the analysis. The ZAR index indicates that 56.7% of the water is of a fair quality for irrigation (ZAR < 3).

This unit includes sills and diabase dykes. Irrespective of the regional geology, diabase dykes are widespread in comparison with other geological lineaments such as faults. Thus, in many cases the only available groundwater target in an area earmarked for development (schools, hospitals etc.) will be a diabase dyke, therefore this unit will represent all types of water users namely, Domestic, commercial, agriculture, mining etc.

In 47% of the water samples at least one element exceeds the maximum allowed limit for domestic use. In this unit the anion of concern is Fluoride.

7.2.3.4 SPITSKOP COMPLEX (Msp)

The Complex is intrusive into the Nebo Granite and consists predominantly of alkaline rocks with a wide range of compositions (Council of Geoscience). The outer zones comprise fenite and umptekite and the inner zones gabbroic rocks (theralite, fayalite diorite) which are probably fenitised gabbroic and pyroxenitic rocks. The Complex is located ± 50km east of Marble Hall and ±10km south-east of Nebo, (Figure 77). It underlies approximately 0.1% of the map sheet area. Ring dykes and cone sheets consist mainly of foyaitic rocks and radial dykes of microijolite and foyaitic rocks. Although the lateral extent of this unit is relatively small, it is regarded as an important groundwater aquifer as its potential is much higher than the surrounding Nebo Granite.

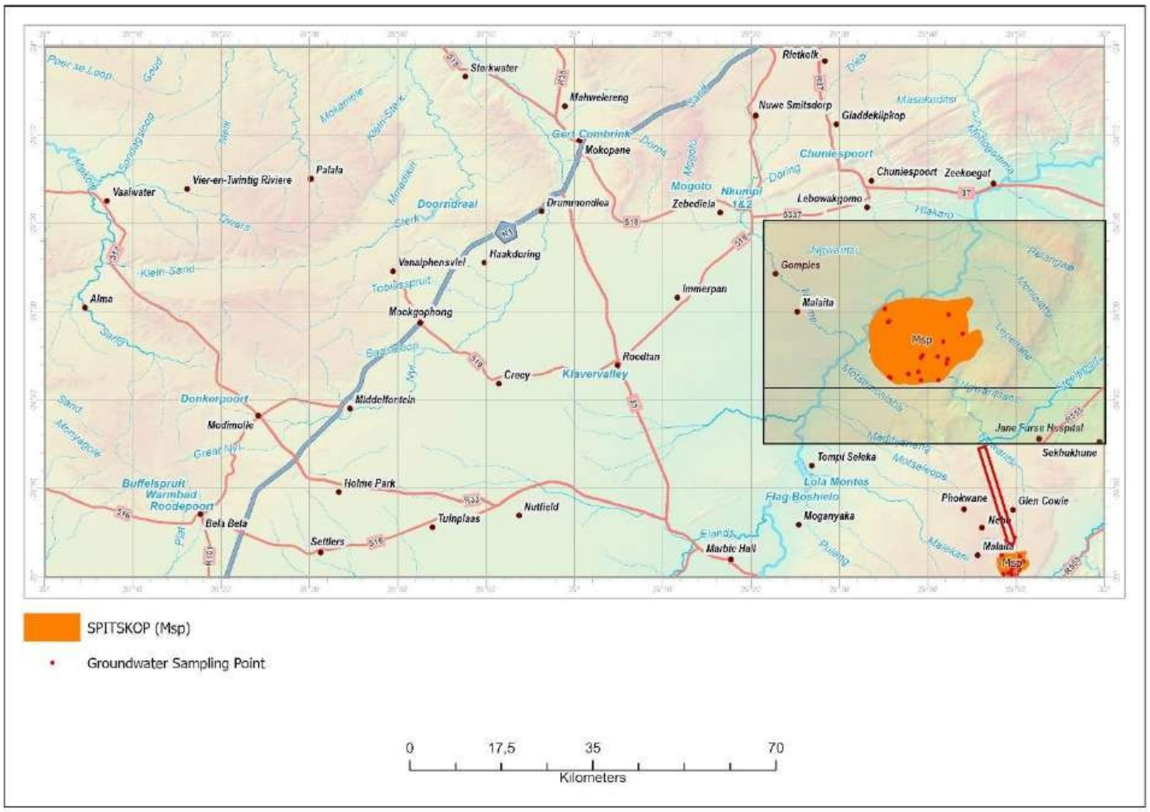


Figure 77: Geographical distribution of the Spitskop Complex (Msp) and the associated groundwater sampling points.

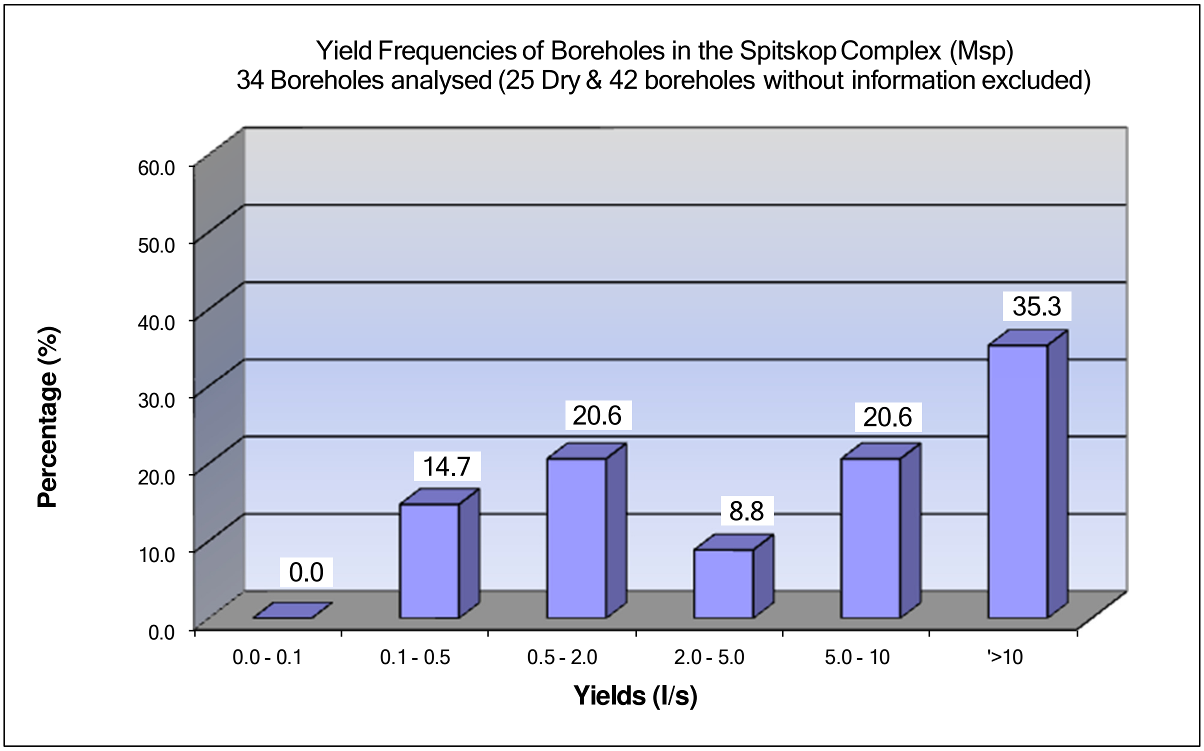


Figure 78: Yield frequency for the intergranular and fractured aquifers of the Spitskop Complex (Msp).

Although only 34 boreholes occur within this unit, the yield frequency diagram (Figure 78) provides a good indication of expected conditions. The possibility of drilling a high yielding borehole is high, as 55.9% of successful boreholes yields more than 5ℓ/s. In comparison within the surrounding Nebo Granite aquifer unit only 6% of the maximum yields exceed 5ℓ/s.

The static water level ranges from 1.22 meters below ground level (mbgl) to 98.15mbgl, with a median static water level of 20.05mbgl and an average static water level of 22.62mbgl, (based on 23 data records). The maximum depth recorded is 150m, with an average depth of 92.3m and a median depth of 84.8m, (35 data records). The maximum installation depth is 66m and the average is 42.2m, which can be indicative of water strike depths.

The maximum recommended daily abstraction on record is 518.4 cubic meters per day (m^3/day) and the average is 186.3m^3/day. The 90th percentile is 440.6m^3/day and the median or 50th percentile is 103.6m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 19.

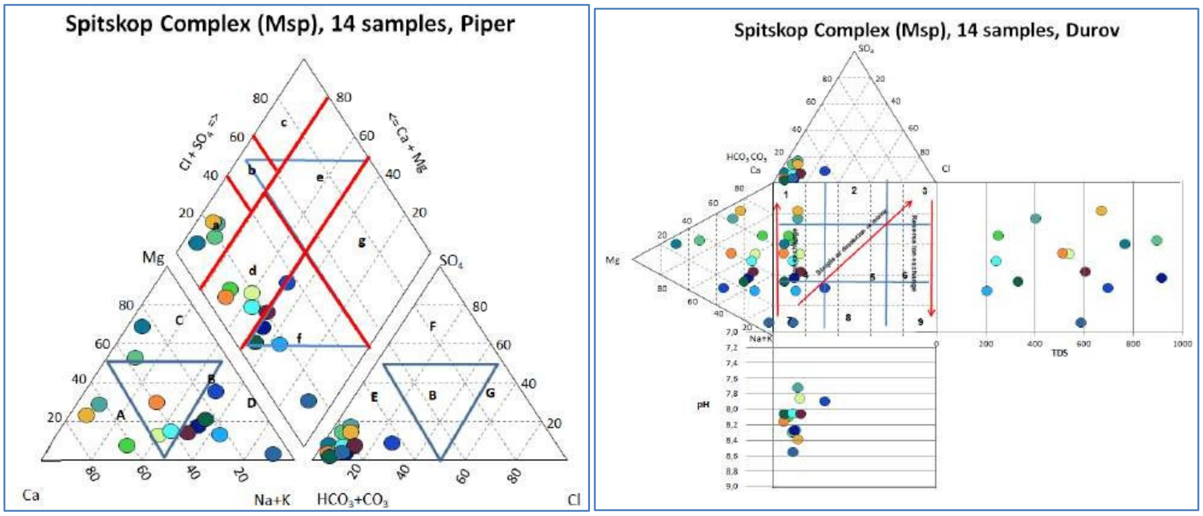


Figure 79: Trilinear diagrams, Piper and Durov for the Spitskop Complex (Msp).

The trilinear Piper diagram, (Figure 79) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.

The initial evaluation of chemical dominance is as follows:

- Weak acidic anions > Strong acidic anions (100%);
- Alkali earths > Alkali (57.1%),
- Alkali >Alkali earths (42.9%);
- Strong acids > Weak acids (0%).

The second evaluation was on the water type:

- Sodium-Bicarbonate type (42.9%);
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (28.5%);
- Calcium-Bicarbonate type (14.3%);
- Magnesium-Bicarbonate type (14.3%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- Anion discriminate and Ca dominant indicating mixed water exhibiting simple dissolution (64.3%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (21.4%),
- HCO_3 and Ca dominant that frequently indicate recharge (14.3%).

Table 51: Chemical statistics for the Spitskop Complex (Msp)

Element / Parameter	Statistics Drawn from a population of 17 data points for the Spitskop Complex (Msp)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	17	7,69	8,54	8,10	8,10	7,78	8,07	8,38	0,24	3,0%
Electrical Conductivity (mS/m EC)	17	24,40	114,20	54,86	66,08	33,20	71,10	99,86	25,85	39,1%
Total Dissolved Salts (mg/l TDS)	17	206,15	970,76	443,85	559,83	250,51	591,11	910,58	247,94	44,3%
Calcium (mg/l Ca)	17	9,89	123,45	29,60	51,20	12,89	51,16	86,27	32,62	63,7%
Magnesium (mg/l Mg)	17	3,00	83,80	10,08	24,60	3,87	22,11	58,16	23,68	96,3%
Sodium (mg/l Na)	17	9,80	149,77	30,54	57,99	11,94	46,20	110,76	41,98	72,4%
Potassium (mg/l K)	17	2,51	12,95	5,54	7,18	2,94	7,30	10,99	3,34	46,5%
Chloride (mg/l Cl)	17	4,50	46,30	8,27	14,37	4,84	10,06	31,36	12,91	89,8%
Sulphate (mg/l SO_4)	17	2,00	46,62	8,07	16,61	4,80	14,13	34,76	13,41	80,7%
Total Alkalinity (mg/l) $CaCO_3$)	16	114,61	536,72	269,87	324,29	168,04	309,62	495,75	125,39	38,7%
Nitrate (mg/l N)	17	0,02	19,81	0,14	4,02	0,07	1,44	10,27	5,53	137,6%
Fluoride (mg/l F)	17	0,15	4,80	0,32	0,67	0,17	0,38	0,96	1,11	164,7%
Silicon as Si	16	12,82	36,35	22,65	25,09	14,23	27,29	33,04	7,36	29,3%
Iron (Fe)	5	0,01	0,05	0,01	0,02	0,01	0,01	0,04	0,02	84,2%
Manganese (Mn)	2	0,05	1,20	0,10	0,63	0,17	0,63	1,09	0,81	130,1%
Ortho Phosphate as Phosphorus as PO4	16	0,01	0,80	0,02	0,12	0,01	0,03	0,32	0,21	177,9%
ZAR	17	0,20	10,71	0,81	2,22	0,28	2,04	3,03	2,40	108,4%
LSI	16	Langelier Saturation Index (LSI)			Slightly Scaling		**68,8%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**31,3%**

Table 51 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. An example is Fluoride with a maximum concentration of 4.8mg/l. The 90th percentile is 0.96mg/l meaning that 15 of the 17 samples have a Fluoride concentration that is less than 0.96mg/l.

In terms of electrical conductivity (EC), the water quality is ideal in 47.1% and good in 52.9% of the samples; it varies between 24.4 and 114.2mS/m. The Total Dissolved Solids (TDS) is acceptable in 100% of the samples (TDS ≤ 1200mg/l). The analysis indicates elevated concentrations of Fluoride (F >1.5mg/l) in 11.8% of the samples.

The Langelier Saturation Index (LSI) indicates that the water is balanced corrosive (31.3%) and predominantly slightly scaling in 68.8% of the analysis. The ZAR index indicates that 88.3% of the water is of a fair quality for irrigation (ZAR < 3).

The water in this unit is predominantly used for domestic water supply to rural villages. In 11.8% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride. The relatively lower percentage of Fluoride concentrations compared to the surrounding Nebo Granite can be an indication that groundwater flow or interaction between the Spitskop Complex resource unit and Nebo Granite is limited. The percentage boreholes with unacceptable Fluoride concentrations in the granite are 45.5%.

7.2.3.5 KLIPKLOOF & MAKHUTSO GRANIET (Mkk)

Several varieties of Nebo Granite are distinguishable on the map of which the Klipkloof Granite is one. The aplitic and porphyritic Klipkloof Granite forms dykes and undulating sills near the roof of the Nebo Granite and occurs in a north-south striking belt. Its ferromagnesium content is low (3%) and granophyric intergrowths are common (Council of Geoscience).

The Makhutso Granite, according to field relationships and U-Pb age determinations (1 670 Ma) on the other hand, is much younger than the Nebo Granite and is probably not related to it in origin (Council of Geoscience). The Makhutso Granite is coarse-grained porphyritic biotite granite with a fine-grained chill margin. The intrusions form small dykes, sills, and steeply dipping bodies which are aligned in a north-west to south-east striking belt in the Nebo Granite (Council of Geoscience).

Since both Granites have approximately the same hydrogeological features and characteristics they are discussed as a single aquifer unit. This unit covers approximately 0.34% of the total map area, (Figure 80).

Limited data is available for this unit, but statistics indicates that the potential is low, as 85.7% of boreholes have yields that are less than 2ℓ/s.

In 70% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride. The surrounding Nebo Granite is also characterized by high Fluoride concentrations.

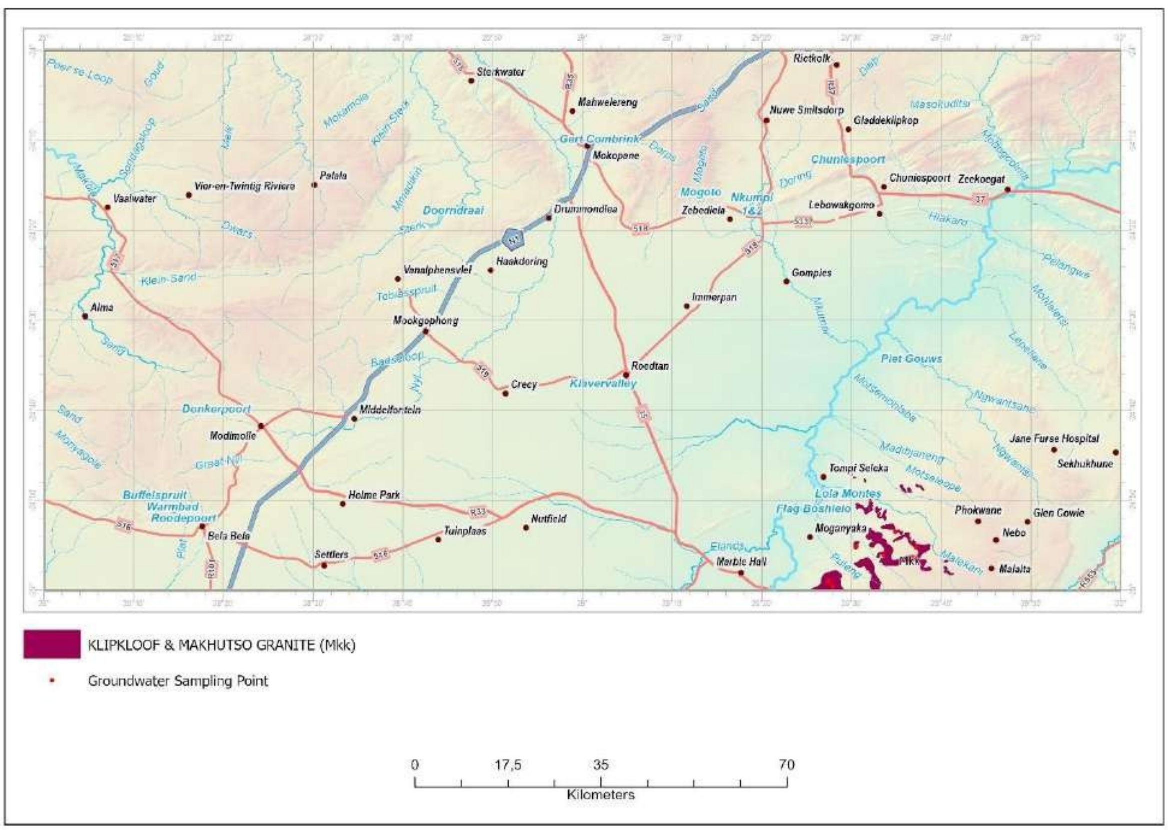


Figure 80: Geographical distribution for the intergranular and fractured aquifers of the Klipkloof & Makhutso Granite (Mkk) and the associated groundwater sampling points

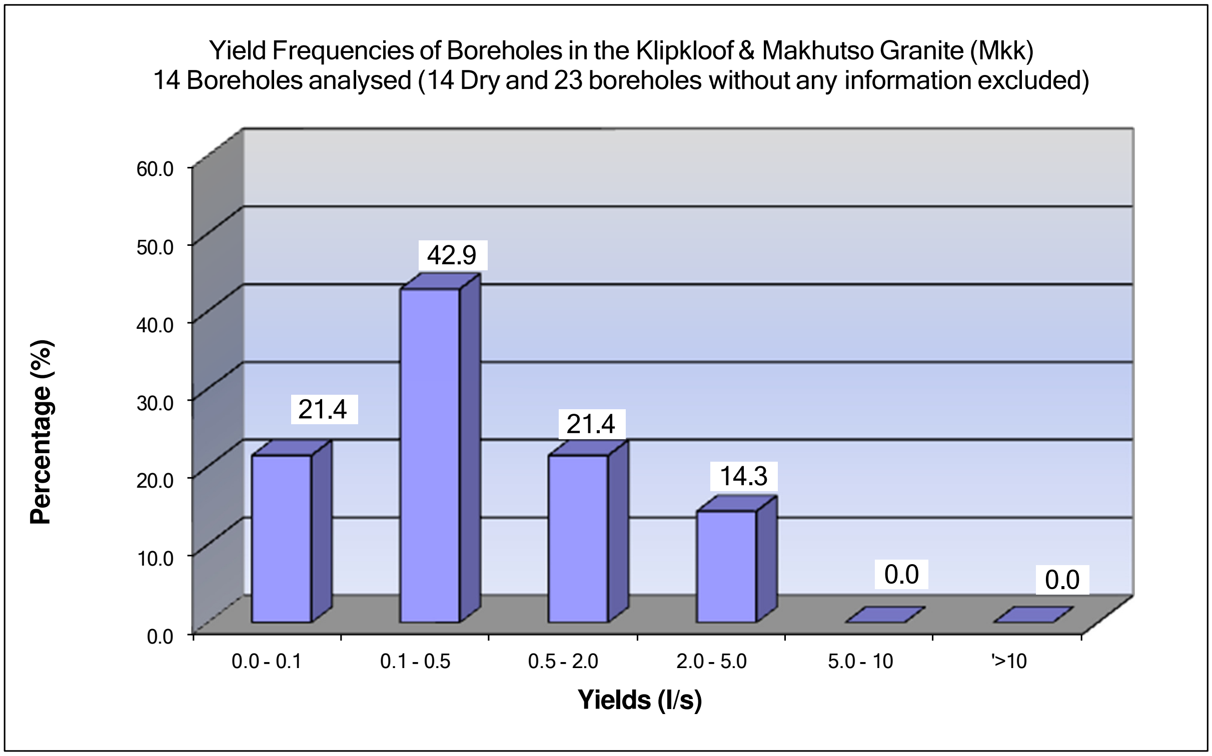


Figure 81: Yield frequency for intergranular and fractured aquifers of Klipkloof & Makhutso Granite (Mkk)

These granitic rocks are less prone to weathering and jointing and lack the occurrence of pegmatitic bodies, which are known to significantly enhance groundwater potential, as seen in the Hout River and Goudplaats Gneiss groundwater resource units. Similar to Nebo Granite, the Klipkloof & Makhutso Granite generally exhibits a poor groundwater potential and limited storage capacity. A scientific approach to borehole siting is strongly recommended. This approach includes, but is not limited to, the use of remote sensing techniques to identify potential geological lineaments that may not be depicted on the Nylstroom Geological Map Sheet. Geophysical methods are employed in the field to pinpoint these lineaments if present. The response of the geophysical instruments is plotted, anomalies identified and interpreted to locate groundwater targets such as deeply weathered and fractured zones, dyke contacts, and fault zones. Low laying areas are more prone to contain deeper weathered zones than in the higher laying areas where these granites tend to outcrop as fresh bedrock.

Statistics indicate that 64.3% of boreholes yield between 0.01ℓ/s and 0.5ℓ/s. A further 21.4% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, and 14.3% yield between 2ℓ/s and 5ℓ/s, while no borehole records show yields that exceeds 5ℓ/s.

The static water level ranges from artesian to 66.94 meters below ground level (mbgl), with a median of 5.31mbgl, and an average of 13.44mbgl, (based on 12 data records). The maximum depth recorded is 151m, with an average depth of 86.6m and a median depth of 84.4m, (15 data records). The maximum installation depth is 100m and an average depth of 58.6m which can be indicative of water strike depths, (10 data records).

The maximum recommended daily abstraction on record is 34.6 cubic meters per day (m^3/day) and the average is 14.9m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 10.

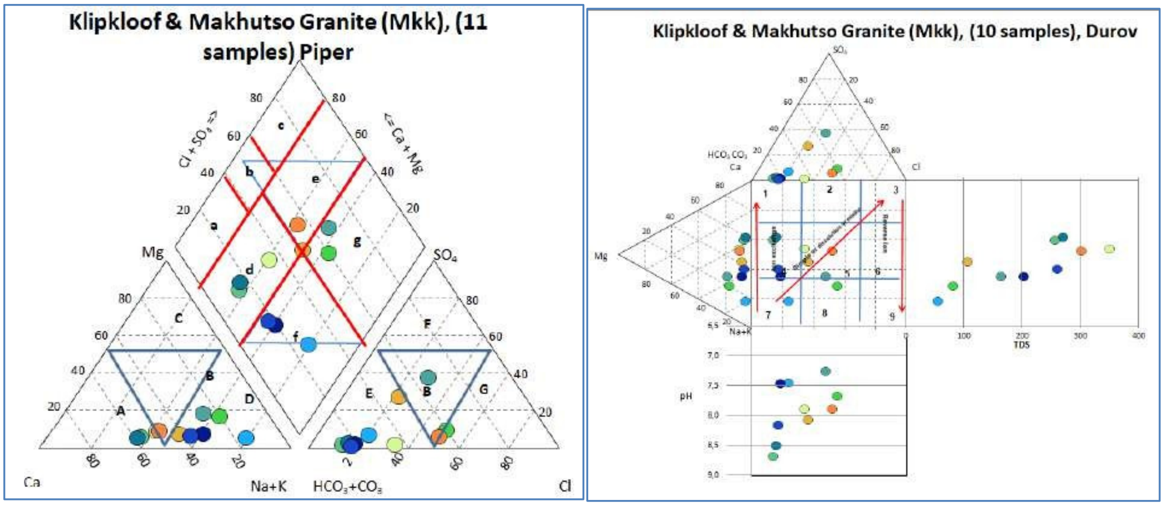


Figure 82: Trilinear diagrams, Piper and Durov for the Klipkloof & Makhutso Granite (Mkk).

The trilinear Piper diagram, (Figure 82) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.

The initial evaluation of chemical dominance is as follows:

- Weak acidic anions > Strong acidic anions (70%);
- Alkali earths > Alkali (50%);
- Alkali >Alkali earths (50%);
- Strong acids > Weak acids (30%).

The water type is:

- Sodium-Bicarbonate type (27.3%);
- Mixed Calcium-Magnesium-Bicarbonate type with increasing Sodium (18.2%);
- Calcium-Bicarbonate-Chloride type with increased Sulphate (18.2%),
- Sodium-Chloride-Bicarbonate type (18.2%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (9.1%),
- Sodium-Chloride-Sulphate type (9%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- No dominant anion or cation, can be indicative recent recharge water exhibiting simple dissolution or mixing (36.3%), points plot along the dissolution or mixing line,
- Mixed water or water exhibiting simple dissolution or mixing (36.4%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (27.3%).

Table 52: Chemical statistics for the Klipkloof & Makhutso Granite (Mkk)

Element / Parameter	Statistics Drawn from a population of 10 data points for the Klipkloof & Makhutso Granite (Mkk)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	10	6,87	8,61	7,62	7,66	7,09	7,64	8,41	0,56	7,4%
Electrical Conductivity (mS/m EC)	10	8,54	52,37	23,09	31,23	11,46	32,05	47,09	13,79	44,1%
Total Dissolved Salts (mg/l TDS)	10	53,76	350,40	144,45	204,39	77,60	229,50	306,84	100,33	49,1%
Calcium (mg/l Ca)	10	2,40	59,41	10,12	26,69	3,68	24,72	45,18	18,32	68,6%
Magnesium (mg/l Mg)	10	0,47	6,58	1,90	3,14	1,74	2,58	5,16	1,82	58,0%
Sodium (mg/l Na)	10	10,35	54,61	23,58	31,32	11,89	27,81	46,77	15,13	48,3%
Potassium (mg/l K)	10	2,23	12,30	3,39	4,22	2,60	3,17	5,86	2,96	70,2%
Chloride (mg/l Cl)	10	2,82	51,90	9,10	16,78	6,97	9,96	40,07	15,74	93,8%
Sulphate (mg/l SO_4)	10	0,57	27,60	1,90	7,00	1,26	2,29	22,48	9,69	138,5%
Total Alkalinity (mg/l) $CaCO_3$)	10	23,47	213,50	66,27	107,77	27,96	125,50	155,12	60,29	55,9%
Nitrate (mg/l N)	9	0,07	3,86	0,23	1,06	0,08	0,36	2,31	1,26	118,3%
Fluoride (mg/l F)	10	0,48	5,20	1,58	3,18	0,73	3,68	4,87	1,83	57,6%
Silicon as Si	10	9,48	24,04	16,08	17,52	12,11	16,34	23,69	5,10	29,1%
Iron (Fe)	10	0,01	0,38	0,02	0,10	0,01	0,04	0,28	0,13	131,0%
Manganese (Mn)	4	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,00	0,0%
Ortho Phosphate as Phosphorus as PO4	10	0,01	0,80	0,01	0,33	0,01	0,03	0,80	0,40	122,7%
ZAR	10	1,08	2,44	1,49	1,62	1,08	1,62	2,28	0,48	29,8%
LSI	10	Langelier Saturation Index (LSI)			Slightly Scaling		**20,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**20,0%**	Slightly corrosive		**20,0%**	Balanced Corrosion		**40,0%**

Table 52 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the variation. In terms of electrical conductivity (EC), the water quality is ideal in all the samples (100%); it varies between 8.54 and 52.37mS/m. The Total Dissolved Solids (TDS) is acceptable in 100% of the samples (TDS ≤ 1200mg/l). The analysis indicates elevated concentrations of Fluoride (F >1.5mg/l) in 70% of the samples.

The Langelier Saturation Index (LSI) indicates that the water is highly too slightly corrosive (40%) balanced corrosive (40%) and slightly scaling in 20% of the analysis. The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3).

The water in this unit is predominantly used for domestic water supply to rural villages.

7.2.3.6 NEBO GRANITE (Mn)

The Lebowa Granite Suite includes all the granite rocks of the Bushveld Complex. Several types of granite ranging from very coarse-grained to fine-grained may be distinguished but have not been separated on the map sheet. The Nebo Granite aquifer unit includes these granites except for the Klipkloof and Makhutso Granites that were divided into separate aquifer unit. The largest occurrence of the Nebo Granite aquifer unit is north and north-east of Marble Hall; west-north-west of Bela-Bela and within an elongated strip west of Mookgophong that extents to west to north-west of Mokopane (Potgietersrus), (Figure 83). It covers approximately 15.55% of the total map sheet making it the largest unit in terms of occurrence within the map sheet.

In 45.5% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride. Another anion of concern is Nitrate as 13.3% of the samples have elevated concentrations that exceed the maximum allowable limit for human consumption. A comparative summary of fluoride and nitrate concentrations across adjacent 1:250 000 geological map sheets is provided in Table 53.

Table 53: Fluoride and Nitrate concentrations within the adjacent 1:250 000 map sheets.

Map Sheet	Fluoride (F >1.5mg/l) (% unacceptable)	Nitrate (N >10mg/l) (% unacceptable)
Thabazimbi	26.5%	11.8%
Lephalale	68.2%	28%
Modimole	45.5%	13.3%
Polokwane	39.2%	17.9%

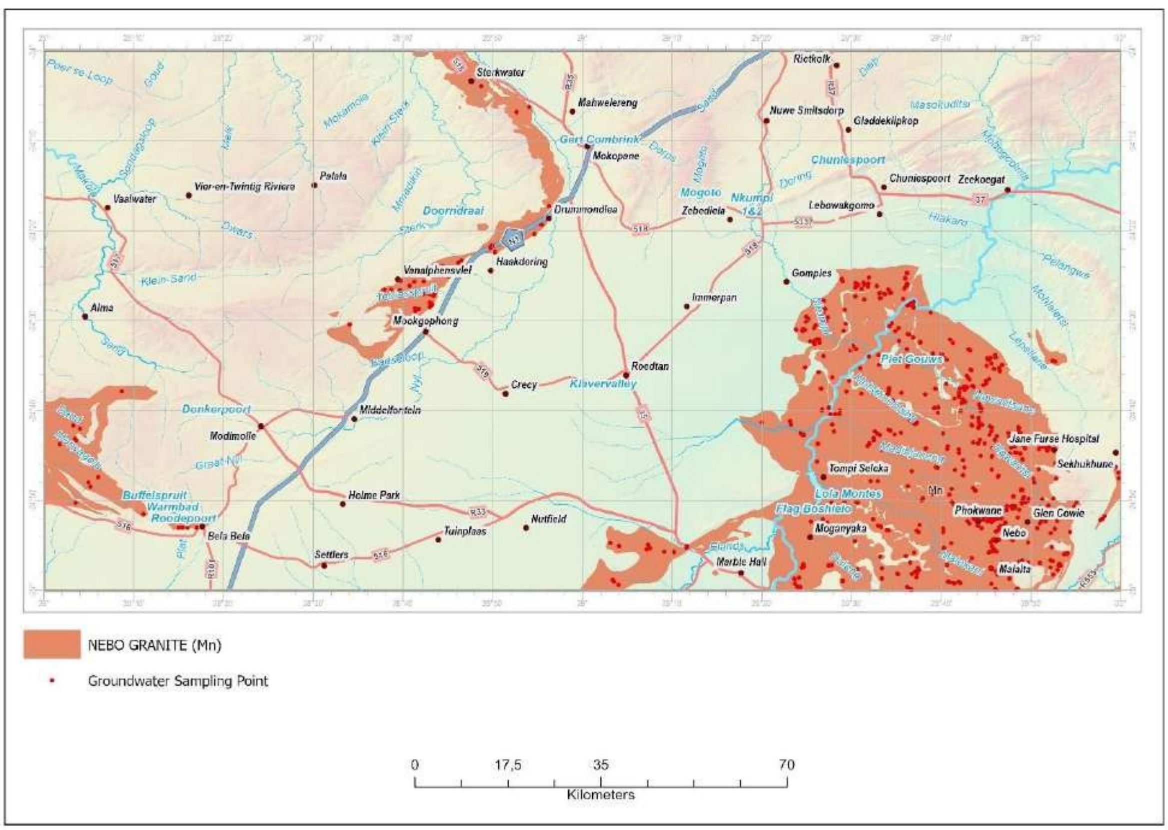


Figure 83: Geographical distribution of the Nebo Granite (Mn) and the associated groundwater sampling points

These granitic rocks are less prone to weathering and jointing and lack the presence of pegmatitic bodies, which are known to significantly enhance groundwater potential, as observed in the Hout River and Goudplaats Gneiss groundwater resource units. The groundwater potential and storage capacity of the unit is generally poor although the occasional good yield (>5ℓ/s) does occur.

The statistical analysis conducted during the Department of Water Affairs (DWA) drought relief programme in 1992/93 and 1995 indicated that only one out of every five boreholes drilled, (equivalent to a 20% success rate) was successful. This highlights the importance of adopting a scientific approach when exploring for groundwater. Such an approach should include desktop studies using remote sensing techniques, followed by field investigations that employ geophysical methods. These techniques significantly enhance the likelihood of locating higher-yielding boreholes. This is supported by the evaluation of hydrogeological reports, which trace the siting of high-yielding boreholes to the use of geophysical surveys, as opposed to random drilling.

After recharge events, in certain places, the water level tends to rise to above ground level forming numerous springs and seepages, (Elandskraal approximately 20km north of Marble Hall). This causes engineering problems and hampers development in some of the more densely populated areas. Possible pollution, especially microbiologic surface or near surface sources (pit latrines) is a threat to nearby sources due to thin overburden development and high permeable top sandy soil combined with a shallow static water table.

Groundwater in this area is typically found in deeply weathered zones, fault zones, fractured rock formations, and along dyke contact/metamorphosed zones. However, deep drilling beyond 180 meters has shown limited success in producing high-yielding boreholes. In cases where development is focused on 'low yielding', (not village supply) boreholes, such as for schools, clinics, or other sites with restricted investigation areas, deep drilling is recommended. Boreholes yielding less than 0.3 ℓ/s can still be encountered at depths between 90 and 140 meters, provided that a thorough scientific survey, including geophysical investigations, is conducted to determine optimal drilling locations.

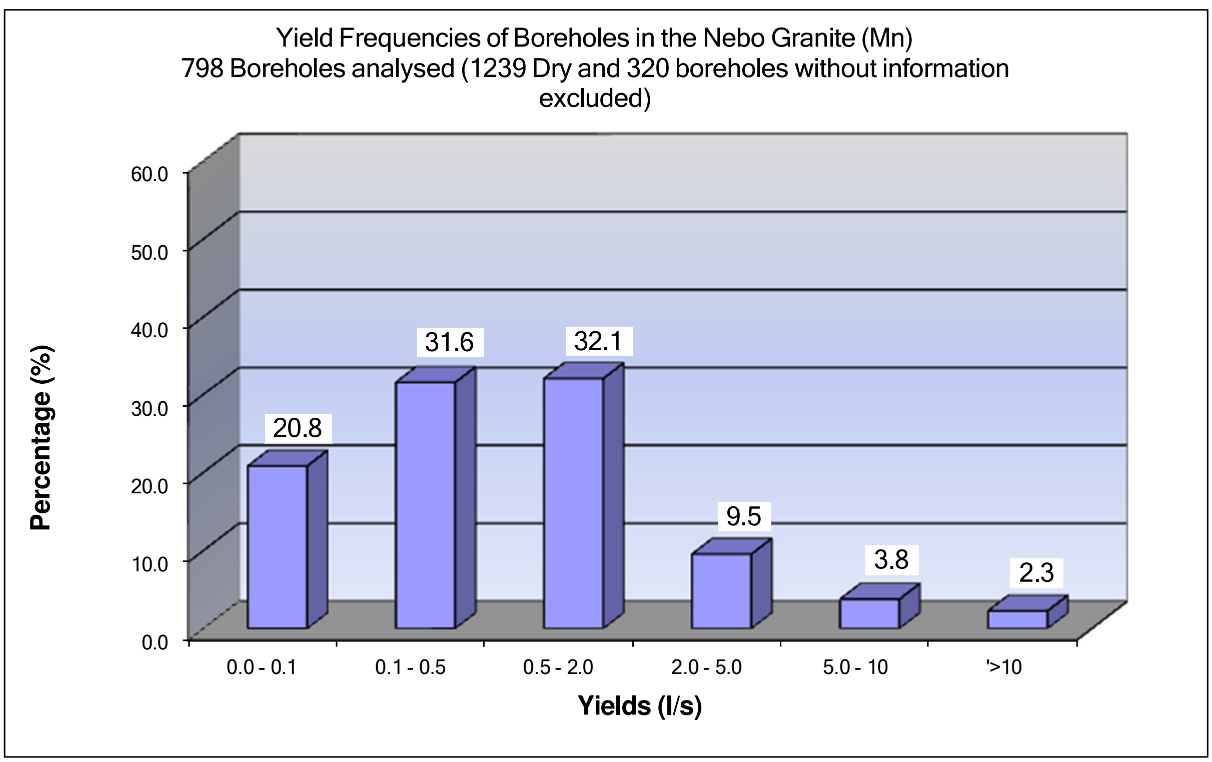


Figure 84: Yield frequency for the intergranular and fractured aquifers of the Nebo Granite (Mn).

Statistics indicate that 84.5%, (Figure 84) of successful boreholes yield less than 2ℓ/s. Groundwater in the area is mainly abstracted for livestock watering and domestic purposes. The cost implications taking in account the 6% chance to develop a borehole yielding more than 5ℓ/s with a low probability of finding groundwater limits the use for irrigation purposes.

The static water level ranges from artesian to 102.1 meters below ground level (mbgl), with a median static water level of 7.1mbgl and an average static water level of 10.36mbgl, (based on 563 data records). The maximum depth recorded is 237.8m, with an average depth of 81.4m and a median depth of 80m, (820 data records). The maximum installation depth is 120m and an average installation depth of 46.6m, (436 data records).

The maximum recommended daily abstraction on record is 388.8 cubic meters per day (m³/day) and the average is 28.2m³/day. The 90th percentile is 70m³/day and the median is 8.6m³/day. The total number of boreholes subjected to pump testing within this unit on record is 447.

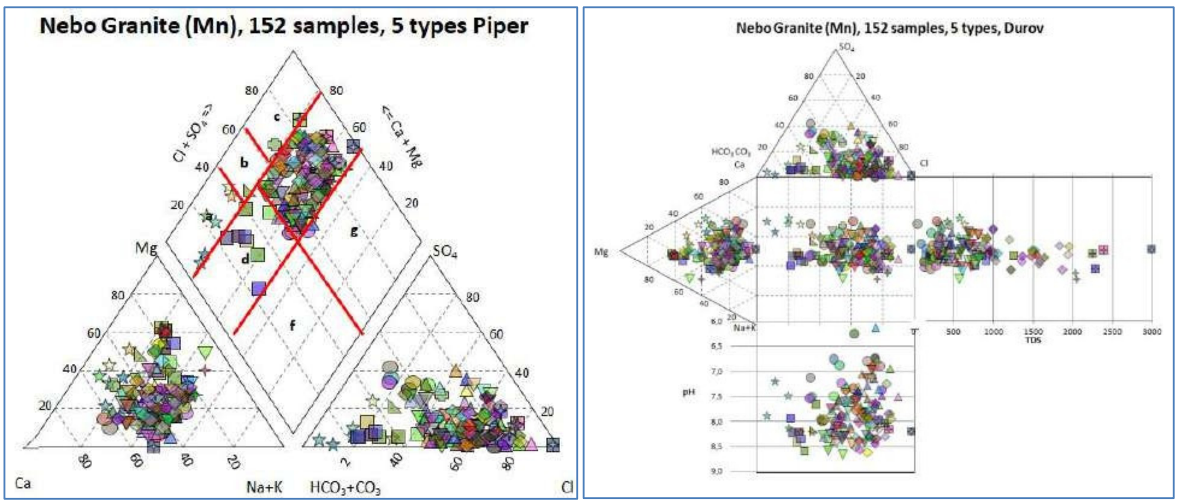


Figure 85: Trilinear diagrams, Piper and Durov for the Geyser Granite (Rge).

The above diagram Figure 85, show five water types: Calcium-Magnesium Bicarbonate type (1.1%); Calcium-Magnesium-Bicarbonate-Chloride type (0.2%); Calcium-Magnesium-Chloride type (0.2%); Mixed Calcium-Magnesium-Bicarbonate type with or not with increased Sodium (24.7%), see also the additional 24.5% of samples in the next diagram that falls within these types.

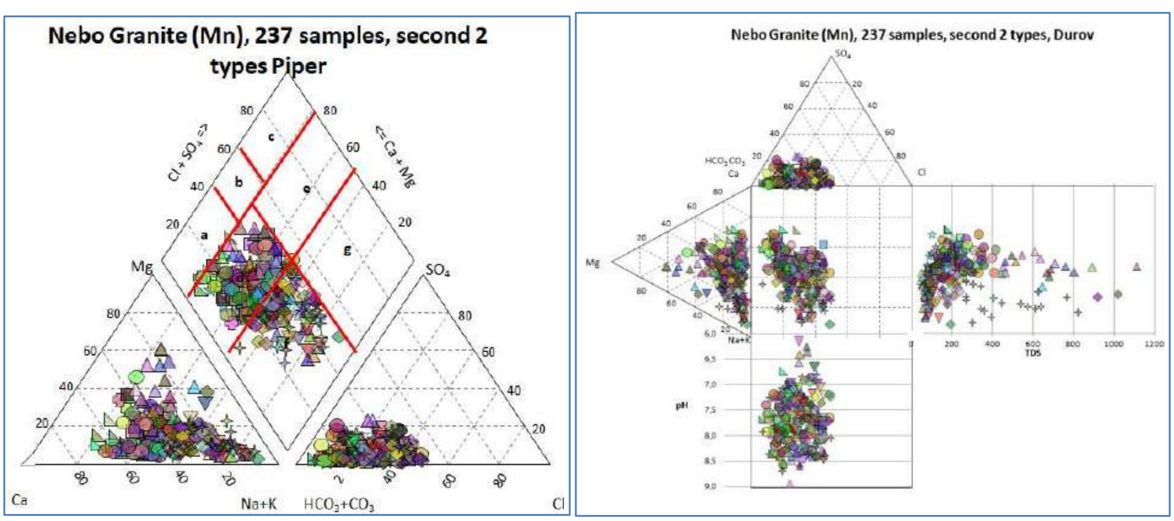


Figure 86: Trilinear diagrams, Piper and Durov for the Nebo Granite (Rge).

The above diagram Figure 86, show 2 water types: Mixed Calcium-Magnesium Bicarbonate type with or not with increased Sodium (24.5%), it also includes types where Calcium or Magnesium dominates, see also the additional 24.7% of samples in the previous diagram that falls within these types. Another water type identified is a Sodium-Bicarbonate type and/or with prevailing Chloride (19.9%).

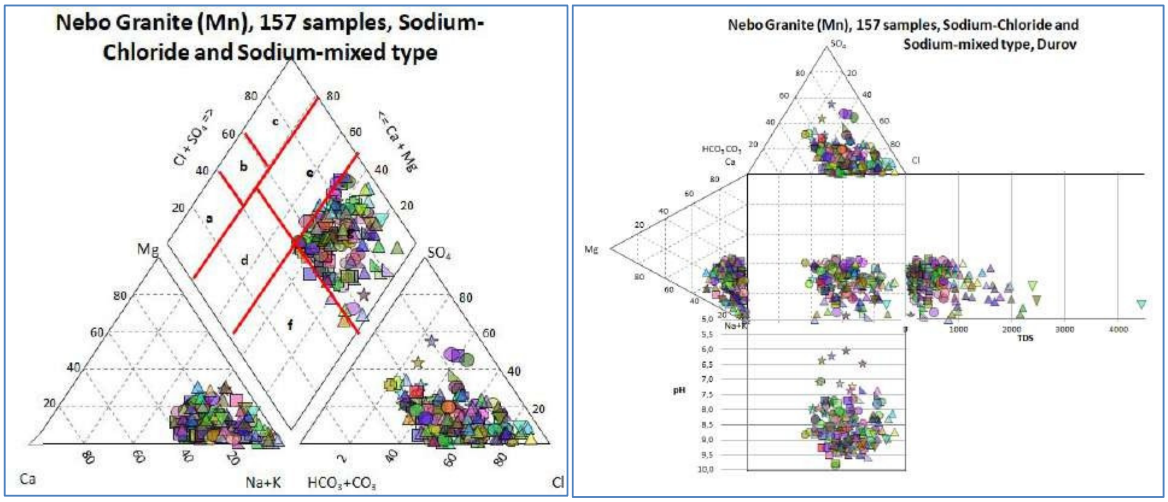


Figure 87: Trilinear diagrams, Piper and Durov for the Nebo Granite (Rge).

The trilinear Piper diagram, (Figure 85 to Figure 87) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (50.7%), Weak acidic anions > Strong acidic anions (45.5%); Alkali >Alkali earths (49.3%); Strong acids > Weak acids (54.5).

The above diagram, (Figure 87) was used to identify three additional water types within this unit, the types are as follows:

- Sodium-Chloride type (13.1%),
- Sodium-Bicarbonate-Chlorite type (13.1%),
- Sodium-Sulphate type (3.2%),

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- Mixed water exhibiting simple dissolution or mixing (39.3%) with some minor recharge,
- No dominant anion or cation indicates that the water exhibiting simple dissolution or mixing (43.6%),
- Cl and Na dominant indicate reverse ion exchange of Na-Cl waters (11.2%),
- Cl and Na dominant, indicating endpoint down gradient waters through dissolution (4.9%). The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be fairly complete.

Table 54: Chemical statistics for the Nebo Granite (Mn)

Element / Parameter	Statistics Drawn from a population of 668 data points for the Nebo Granite (Mn)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	565	5,75	8,93	7,67	7,71	7,01	7,80	8,34	0,54	7,0%
Electrical Conductivity (mS/m EC)	565	3,79	724,91	31,12	69,65	13,42	43,60	147,68	75,40	108,3%
Total Dissolved Salts (mg/l TDS)	557	38,64	4451,57	219,61	468,57	95,20	298,80	979,75	481,97	102,9%
Calcium (mg/l Ca)	565	0,50	479,62	14,03	38,58	5,63	29,10	79,43	39,91	103,5%
Magnesium (mg/l Mg)	565	0,34	225,18	3,46	16,30	1,57	5,92	41,17	26,16	160,5%
Sodium (mg/l Na)	563	1,50	1316,80	27,40	76,95	12,36	42,52	172,75	108,13	140,5%
Potassium (mg/l K)	558	0,15	55,64	2,38	5,52	1,22	3,36	11,77	6,58	119,1%
Chloride (mg/l Cl)	565	1,23	2105,30	13,54	93,88	5,00	32,97	236,91	178,82	190,5%
Sulphate (mg/l SO_4)	565	0,13	299,40	3,63	26,08	1,81	8,60	75,69	42,48	162,9%
Total Alkalinity (mg/l) $CaCO_3$)	542	11,83	581,10	71,51	148,30	29,03	120,95	320,68	115,65	78,0%
Nitrate (mg/l N)	564	0,02	103,62	0,23	8,36	0,08	2,89	23,73	12,96	155,0%
Fluoride (mg/l F)	563	0,09	16,57	0,60	1,96	0,23	1,29	4,40	2,06	105,2%
Silicon as Si	543	0,10	204,56	10,33	23,46	12,76	22,92	34,89	11,81	50,3%
Iron (Fe)	323	0,01	1,25	0,02	0,05	0,01	0,02	0,10	0,11	211,8%
Manganese (Mn)	217	0,01	1,11	0,02	0,11	0,01	0,05	0,28	0,19	164,9%
Ortho Phosphate as Phosphorus as PO4	514	0,01	3,50	0,02	0,10	0,01	0,03	0,20	0,26	257,5%
ZAR	563	0,20	30,19	1,53	2,70	0,84	1,75	5,40	2,97	110,1%
LSI	534	Langelier Saturation Index (LSI)			Slightly Scaling		**22,5%**	Highly Scaling		**0,0%**
		Highly corrosive		**10,3%**	Slightly corrosive		**29,8%**	Balanced Corrosion		**37,5%**

Table 54 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the problem. An example is Nitrate; the maximum concentration is 103.6mg/l, which is extremely high. The 90th percentile is 23.7mg/l that means that 601 samples have Nitrate concentrations that are less than 23.7mg/l. The 50th percentile indicates that 334 samples have Nitrate concentrations that are less than 2.89mg/l.

In terms of electrical conductivity (EC), the water quality is ideal (68.1%), good to marginal (31.2%) and unacceptable (0.7%), it varies between 3.79 and 724.9mS/m. The Total Dissolved Solids (TDS) is acceptable in 92.5% of the samples (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions using 668 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 45.5%; Nitrate (N >10mg/l) in 13.3%, Chloride (Cl > 600mg/l) in 2.3%;; Calcium (Ca > 300mg/l in 0.2%; Magnesium (Mg > 100mg/l) in 2.3% and Sodium (Na > 400mg/l) in 2.1%; of the analyses.

The Langelier Saturation Index (LSI) indicates that the water is highly and slightly corrosive (40.1%); balanced corrosive (37.5%) and slightly scaling in 22.5% of the analysis. The ZAR index indicates that 74% of the water is of a fair quality for irrigation (ZAR < 3).

The water in this unit is predominantly used for domestic water supply to rural villages.

7.2.3.7 RUSTENBURG LAYERED SUITE (Vrs)

The mafic rocks of the Bushveld Complex constitute the most voluminous preserved mafic, layered intrusion in the world. They underlie an area of approximately 65,000 Km^2 from Zeerust in the west to Burgersfort in the east, and from Bethal in the south to Villa Nora in the north. The maximum vertical thickness of layered rocks approaches 8km. Some individual layers can be traced for over 150km along strike. The world's largest ore reserves of platinum-group elements, chromium and vanadium are being exploited in this intrusion. The associated felsic volcanic rocks are also among the most voluminous known. The various units and limbs of the Bushveld Complex are generally tabular and emplaced slightly discordantly to the Pretoria Group of the Transvaal Supergroup. The Bushveld Complex forms two large occurrences, one situated in the Villa Nora area and another east of the main Waterberg outcrop zone, which trends northerly and is known as the Potgietersrus limb. The Complex has been divided into a mafic portion termed the Rustenburg Layered Suite and a felsic portion represented by the Rashoop Granophyre Suite and Lebowa Granite Suite. The Rashoop Granophyre Suite is genetically related to the volcanic rocks of the Rooiberg Group (Walraven, 1982). The groundwater resource unit covers approximately 9.24% of the total map area.

Plate 9: Western view from near Moorddrift 289KR of the Nyl River. The mountains in the background comprise of Bushveld Granite with gabbro of the Rustenburg Layered Suite in the foreground (Photograph: WH du Toit).

Plate 10: Calcrete veins crisscrossing through mafic rocks of the Rustenburg Layered Suite in a road cutting between Chuniespoort and Burgersfort (Photograph: WH du Toit).

Plate 11: Eastern view of the Critical Zone of the Rustenburg Layered Suite outcropping in the foreground with the Pretoria Group dominating the background (Photograph: WH du Toit).

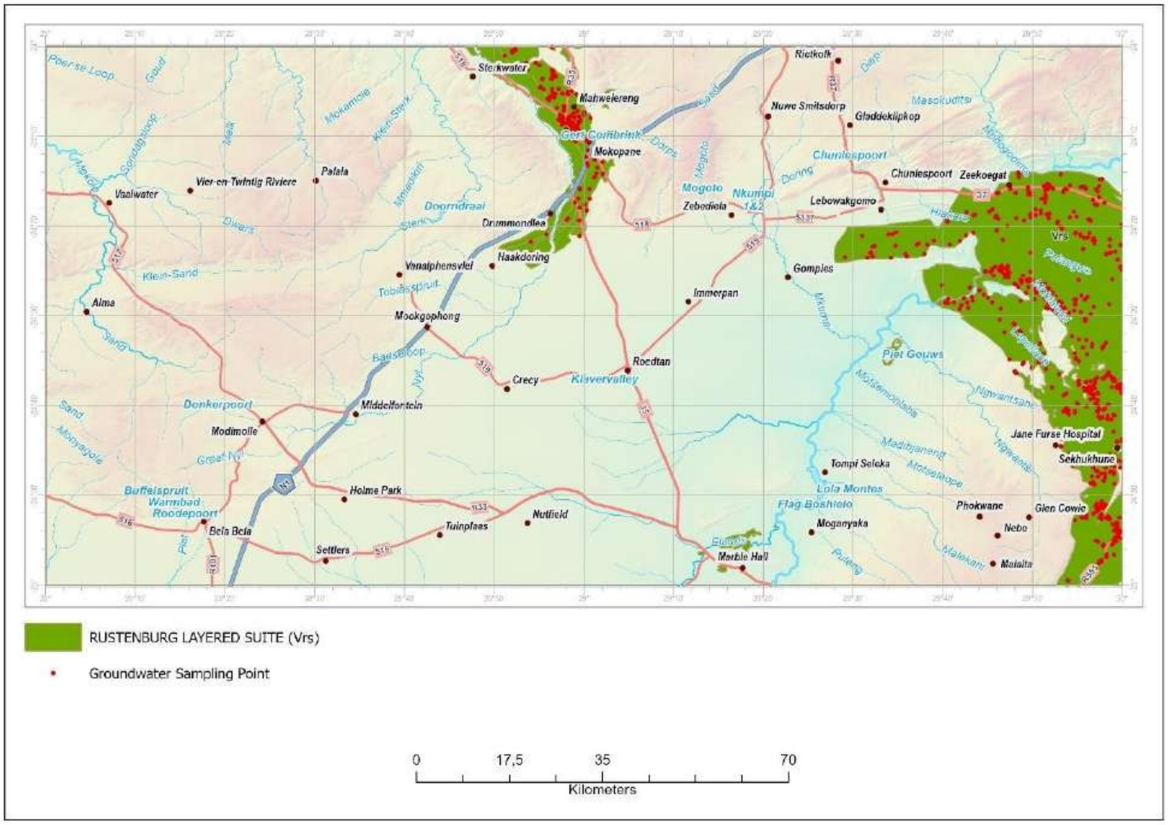


Figure 88: Geographical distribution of the Rustenburg Suite (Vrs) and the associated groundwater sampling points

The currently accepted subdivisions and nomenclature of the Rustenburg Layered Suite show that it comprises five zones, all intrusive above the Rooiberg volcanic rocks:

- **Upper Zone:** Sub-Zone C: Diorite; Sub-Zone B: Gabbronorite; Sub-Zone A: Gabbronorite. The Molendraai Formation represents the Upper Zone.
- **Main Zone:** Upper Sub-Main Zone; Lower Sub-Main Zone. The Mapela Formation represents the Main Zone.
- **Critical Zone:** Upper Subdivision: Norite, Anorthosite, Pyroxenite; Lower Subdivision: Pyroxenite.
- **Lower Zone:** Upper Pyroxenite Subzone; Harzburgite Subzone; Lower Pyroxenite Subzone.
- **Marginal Zone:** Norite.

(Source: The South African Geology, 2006, edited by Johnson M.R., Anhaeusser C.R., and Thomas R.J.)

In the western and far western limbs, the Rustenburg Layered Suite is generally concordant with the Magaliesberg Formation. In the eastern limb, emplacement occurred at the same stratigraphic level north of Steelpoort, but further south the intrusion transgressed upwards. Near Stoffberg, the upper part of the Pretoria Group and the Dullstroom Formation are preserved beneath the layered suite, and predominantly felsic volcanic rocks occur in the roof, (Button, 1976). In the northern limb, emplacement occurred at the level of the Magaliesberg Formation south of Mokopane (Potgietersrus), but the contact transgresses downward when traced to the north, such that ultimately the mafic rocks adjoin against Archaean granitic gneiss (White, 1994).

Precise ages on the volcanic rocks are difficult to obtain, because of metamorphism by the mafic geology

The Groundwater potential in the region is generally good, with 43% of successful boreholes yielding more than 2ℓ/s (Figure 89). In the Mokopane (Potgietersrus) area, groundwater is found primarily in deeply weathered and fractured mafic rocks. These rocks form highly permeable zones, making the associated weathered zones excellent aquifers. Additional groundwater can be obtained from fault zones, shear or fracture zones, contact zones, and dyke contacts.

While deep fractures can yield water, they are less frequently encountered compared to the more productive upper-weathered and fractured zones, as the rock often transitions quickly to unfractured, fresh bedrock at depth. The hydrogeological baseline study discussed in the following paragraph supports these observations.

As part of the hydrogeological baseline study done by Golder Associates Africa (Pty) Ltd in 2012 for Platreef Mine, 41 boreholes were drilled targeting various geological features in the Rustenburg Layered Suite. Although the study are predominantly in the section of the northern limb that falls just to the south of the Polokwane map sheet boundary the findings are relevant for the unit when employing a scientific approach for groundwater studies. The findings were as follows:

- Drilling depths range from 44m to 200m and final air-lift yields ranging from 0.1ℓ/s to 13ℓ/s,
- Ten boreholes have significant air-lift yields (> 5ℓ/s), mainly associated with near surface (< 45mbgl) fractured norite bedrock and occurrence of granite inclusions in the western part of the RLS,
- Weathering depths range from 5m to 45m, i.e., representing a fractured and weathered aquifer type,
- Groundwater mostly occurs in weathered and fractured bedrock at shallow depth (<45mbgl),
- Water interceptions in the weathered bedrock aquifer ranges from 12m to 20m, yielding 0.1ℓ/s to 1.0ℓ/s,
- Water interceptions in the near surface fractured bedrock (20mbgl to 42mbgl), underlying the weathered aquifer yield 1.0ℓ/s to 13ℓ/s,
- Water strikes in fractured bedrock at depth (>45mbgl) are minor and range from 0.1ℓ/s to 0.2ℓ/s, and Water strikes at RLS/ Macalacaskop dyke contact zones ranged from 1.0ℓ/s to 2ℓ/s at depths <45mbgl.

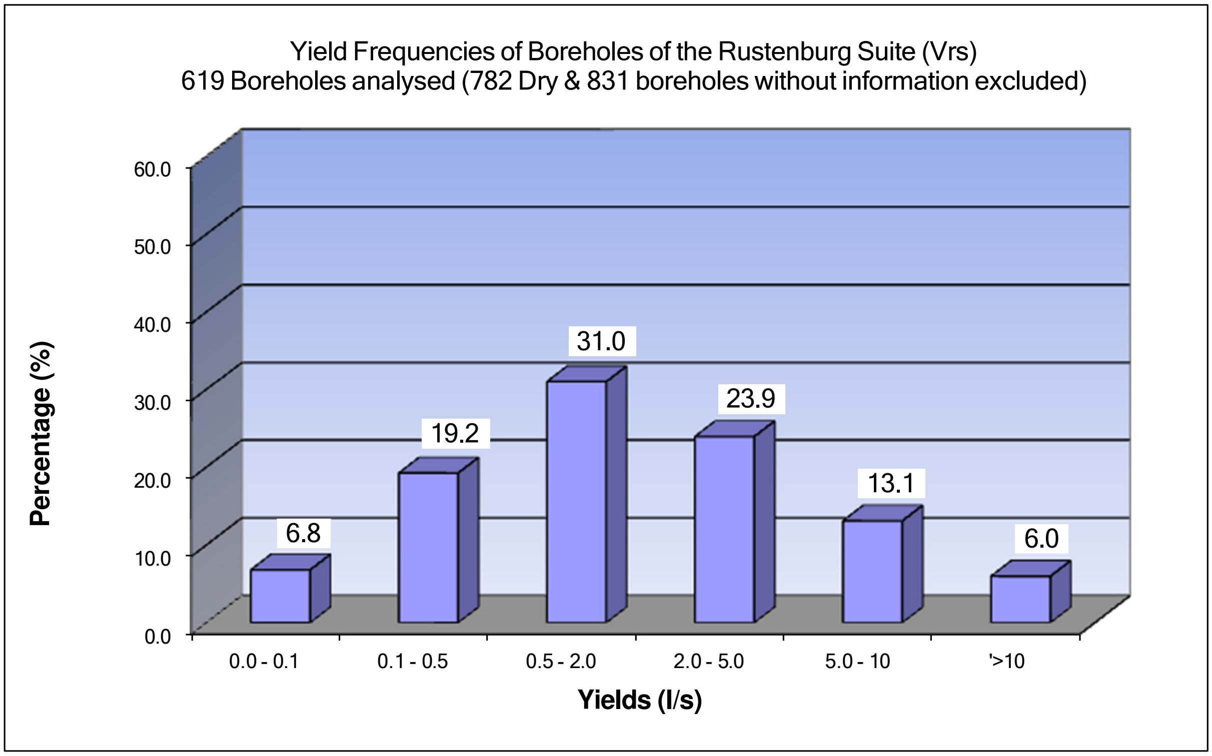


Figure 89: Yield frequency for the intergranular and fractured aquifers of the Rustenburg Suite (Vrs).

The static water level ranges from artesian to 65.18 meters below ground level (mbgl), with a median static water level of 11.53mbgl and an average static water level of 14.04mbgl, (based on 653 data points). The maximum depth recorded is 300m, with an average depth of 54.2m and a median depth 50m, (751 data points). Another 54 boreholes drilled as mine exploration boreholes were excluded from the calculation. The depth of the exploration boreholes varies from 657m to 1973m with an average of 1312m.

The maximum installation depth is 87m and the average is 23.9m that can be indicative of water strike depths (623 data points). The maximum recommended daily abstraction on record is 1036.8 cubic meters per day (m^3/day) and an average of 59.6m^3/day. The 90th percentile is 172.8m^3/day and the 95th percentile is 249.1m^3/day. The median or 50th percentile for abstraction is 18.1m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 623.

Limited de-watering has taken place in areas where large-scale abstraction is poorly managed such as at **Mahwelereng** just outside Mokopane (Potgietersrus), (Fayazi, 1995). Semi-urban to urban settlements as well as Mokopane town abstract water from this aquifer for domestic use. Other uses are, but to a lesser extent, irrigation, livestock watering, and mining activities.

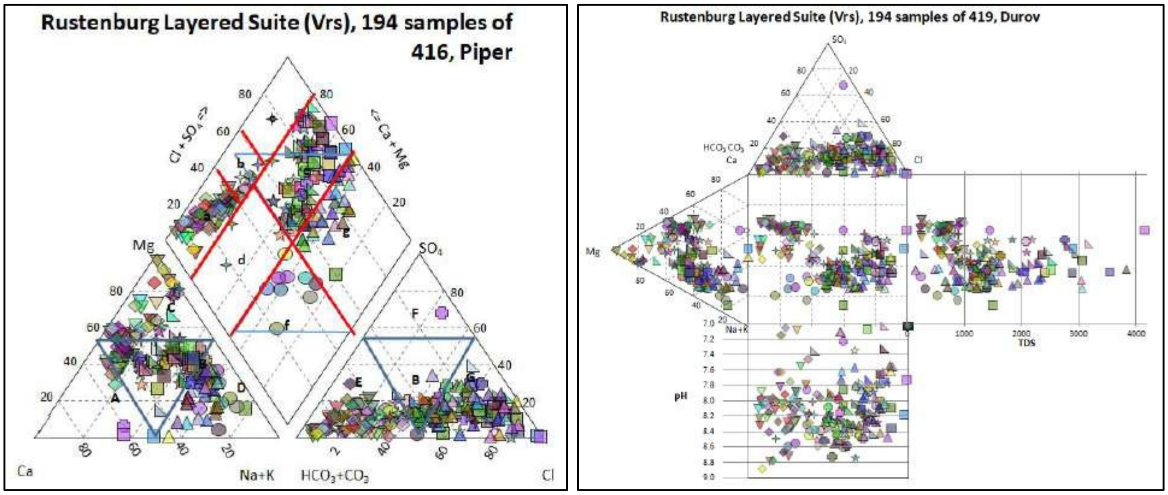


Figure 90: Trilinear diagrams, Piper and Durov for the Rustenburg Suite (Vrs),194 of 416.

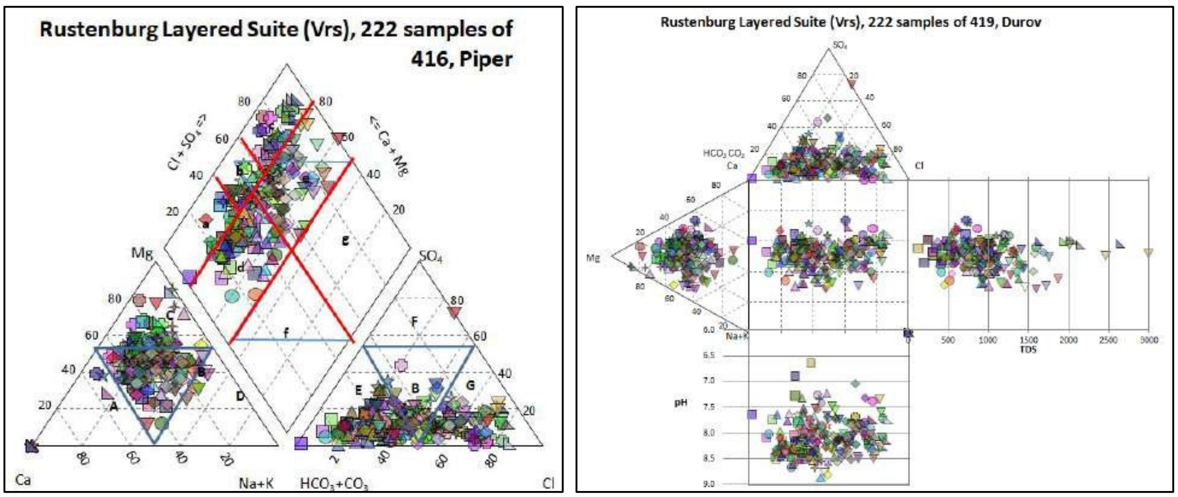


Figure 91: Trilinear diagrams, Piper and Durov for the Rustenburg Suite (Vrs), 222 of 416.

The trilinear Piper diagram, (Figure 90 & Figure 91) facilitates the visualization of water chemistry by representing the concentrations of major cations, anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (88.5%), Weak acidic anions > Strong acidic anions (41.1%); Alkali >Alkali earths (11.5%); Strong acids > Weak acids (58.9%).

The water types identified are:

- Magnesium-Bicarbonate type (27.1%),
- Mixed Calcium-Magnesium-Chloride type (24%),
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (20.7%),
- Sodium-Chloride type (10.3%),
- Mixed Calcium-Magnesium-Bicarbonate type (6.7%),
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (3.8%),
- Magnesium-Chloride type (2.9%),
- Magnesium-Bicarbonate Chloride type (1.2%),
- Sodium-Bicarbonate-Chloride type with increasing Sulphate (1.2%),
- Calcium-Chloride type (0.5%).
- Sodium-Bicarbonate (1.5%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (38.9%), points plot along the dissolution or mixing line,
- Anion discriminant and Ca dominant, frequently indicates recharge water in lava and gypsiferous deposits, otherwise mixed water or water exhibiting simple dissolution (25.2%),
- Anion discriminant and Na dominant, indicates probable mixing or uncommon dissolution influences (22.6%),
- Cl dominant anion and Na dominant cation, indicate that the groundwater be related to reverse ion exchange of Na-Cl waters (9.1%),
- Cl and Na dominant frequently indicating end-point gradient water through dissolution (2.4%).
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (1.7%),
- The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be fairly complete.

Table 55: Chemical statistics for the Rustenburg Suite (Vrs)

Element / Parameter	Statistics Drawn from a population of 909 data points for the Rustenburg Layered Suite (Vrs)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	894	6.61	8.89	7.99	8.01	7.42	8.08	8.46	0.41	5.1%
Electrical Conductivity (mS/m EC)	892	1.80	754.00	93.23	147.25	62.10	119.76	276.30	92.61	62.9%
Total Dissolved Salts (mg/l TDS)	882	84.4	6168.1	784.2	1074.8	486.2	917.4	1877.9	638.5	59.4%
Calcium (mg/l Ca)	883	0.45	910.91	39.14	82.79	29.50	69.35	144.59	62.46	75.4%
Magnesium (mg/l Mg)	882	1.00	428.47	43.55	89.03	26.60	77.76	158.13	57.01	64.0%
Sodium (mg/l Na)	879	3.10	735.68	42.72	104.72	19.02	65.70	251.37	105.69	100.9%
Potassium (mg/l K)	866	0.11	42.88	0.89	2.94	0.40	1.71	6.48	4.03	137.2%
Chloride (mg/l Cl)	892	1.5	2704.0	46.3	200.5	21.2	100.2	538.3	273.3	136.3%
Sulphate (mg/l SO_4)	890	0.1	1533.6	12.2	85.1	9.5	50.6	198.0	114.7	134.8%
Total Alkalinity (mg/l) $CaCO_3$)	781	19.6	954.0	282.1	351.5	201.3	353.0	508.0	121.9	34.7%
Nitrate (mg/l N)	887	0.02	182.82	0.78	20.51	1.13	14.53	44.99	23.26	113.4%
Fluoride (mg/l F)	881	0.03	5.23	0.20	0.47	0.10	0.27	1.13	0.53	112.1%
Silicon as Si	813	1.04	198.53	24.35	31.67	18.95	32.92	39.81	11.08	35.0%
Iron (Fe)	452	0.005	0.888	0.013	0.034	0.006	0.014	0.050	0.08	221.2%
Manganese (Mn)	237	0.005	2.647	0.014	0.065	0.006	0.012	0.103	0.25	384.7%
Ortho Phosphate as Phosphorus as PO4	765	0.005	0.800	0.018	0.063	0.010	0.021	0.096	0.15	239.2%
ZAR	878	0.11	10.67	0.91	1.89	0.42	1.27	4.34	1.64	86.7%
LSI	768	Langelier Saturation Index (LSI)			Slightly Scaling		**81.3%**	Highly Scaling		**0.0%**
		Highly corrosive		**0.4%**	Slightly corrosive		**2.0%**	Balanced Corrosion		**16.4%**

Table 55 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the problem. In terms of electrical conductivity (EC), the water quality is ideal to good (64.1%); marginal (32.8%) and unacceptable in 3% of the samples; it varies between 1.8 and 754mS/m. The Total Dissolved Solids (TDS) are acceptable in 69.4% of the samples (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions in 754 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 37.2%; Chloride (Cl > 600mg/l) in 8.5%; Magnesium (Mg > 100mg/l) in 5.1%; Fluoride (F >1.5mg/l) in 4.7%; Sodium (Na > 400mg/l) in 2%; Sulphate (SO_4 > 600mg/l) in 0.8% and Calcium (Ca > 300mg/l) in 0.7% of the samples.

The Langelier Saturation Index (LSI) indicates that the water is slightly too highly corrosive (2.4%); predominantly slightly scaling (81.3%) and balanced in 16.4% of the analysis. The ZAR index indicates that 80.1% of the water is of a fair quality for irrigation (ZAR < 3).

In 37.2% of the water samples at least one element exceeds the maximum allowed limit for domestic use. In this unit Nitrate is the most problematic anion followed by Chloride and Fluoride. Magnesium is the most problematic cation followed by Sodium and Calcium.

The groundwater level in this unit is usually less than 30m in the Mokopane area but limited de-watering has taken place in areas where large-scale abstraction is poorly managed such as at Mahwelereng just outside Mokopane (Potgietersrus), (Fayazi, 1995). Water for domestic use is abstracted by rural, semi-urban as well as Mokopane town. Other uses but to lesser extent is irrigation, livestock watering and mining activities.

7.2.3.8 PRETORIA GROUP (Vpg) (Shale, quartzite, and diabase)

Pretoria Group consists of several subdivisions. Due to similar hydrogeological characteristics and because of cartographic reasons, the different formations of the Pretoria Group in some areas have been grouped together (Figure 92). It is mainly composed of shale and clastic rocks including quartzite, conglomerate, and sandstone with the quartzite forming the characteristic hills and ridges in the map area. Other lithologies occurring are hornfels, and marble. The unit is classified as an intergranular and fractured aquifer.

The Pretoria Group was intruded on a large scale by diabase in the form of sills and dykes. The lithological boundaries within the Pretoria Group are not shown on the map. Diabase intrusions play a significant role in the occurrence of groundwater in the Pretoria Group. In general, the shaly groups with the associated diabase tend to occupy the lower ground while the quartzite stands out as ridges. The Pretoria Group covers approximately 4.8% of the total map area and is situated in different locations namely Mokopane (Potgietersrus)/Zebediela area, east of Lebowakgomo and north of Marble Hall, (Figure 92). A few scattered occurrences also appear in the south-eastern section of the map sheet area.

Plate 12: A beautiful example of a fault cutting through sediments of the Pretoria Group. Faults are generally good targets for groundwater exploration in Limpopo but can also under certain circumstances act as impermeable barriers to groundwater flow (Photograph: WH du Toit).

The water-bearing properties of the quartzite and shale are dependent on fracturing. The shale is in general far more favorable than the quartzite although the quartzite constitutes good aquifers when fractured. In areas where the shale has been metamorphosed and converted to hornfels by the heat of the Bushveld Complex, its water bearing properties diminished. The hornfels are usually very hard, equigranular and homogenous with limited fractures and joints. Water also occurs in fault and associated shear zones, upper and lower contact zones between diabase sills and the overlying or underlying shale and quartzite as well as dyke contacts. Water may be found in the diabase sills where these are weathered to deeper depths than the groundwater level. Water strikes may also be encountered during drilling within fresh intrusive diabase as it is occasionally jointed and fractured.

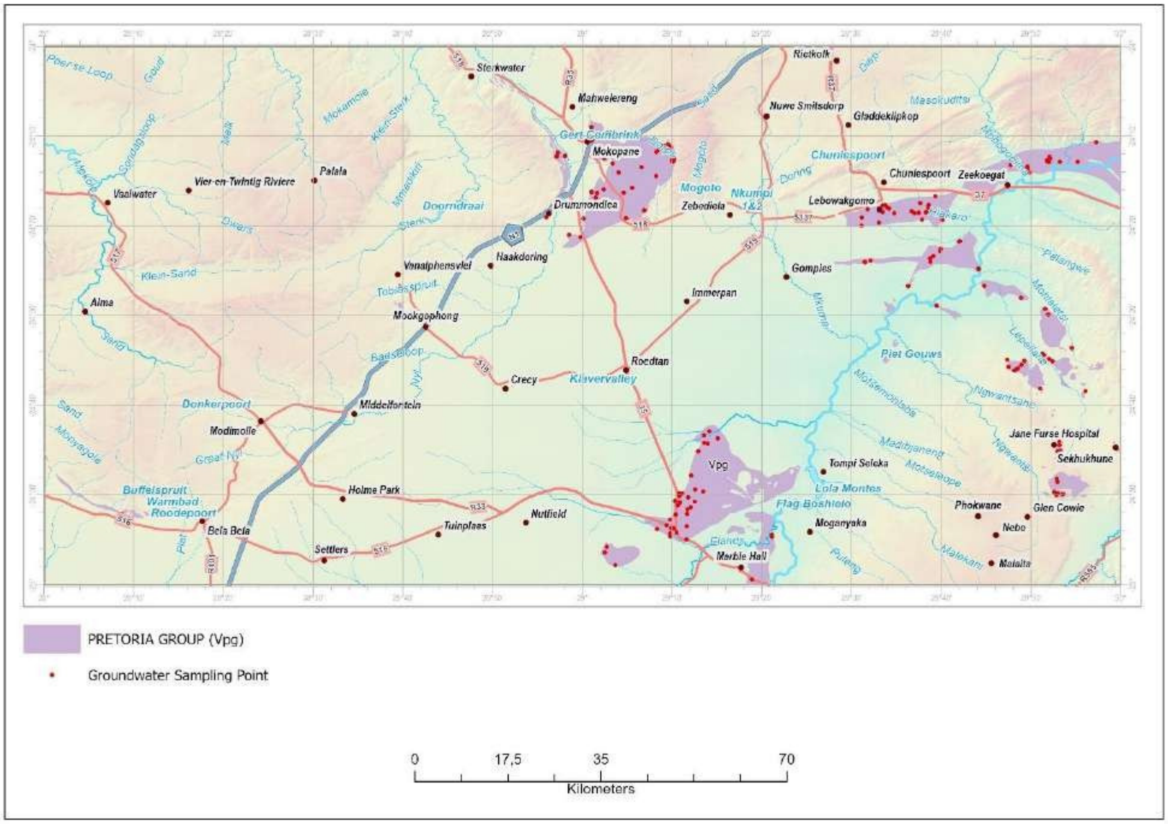


Figure 92: Geographical distribution of the Pretoria Group (Vpg) (shale, quartzite & diabase) and the associated groundwater sampling points

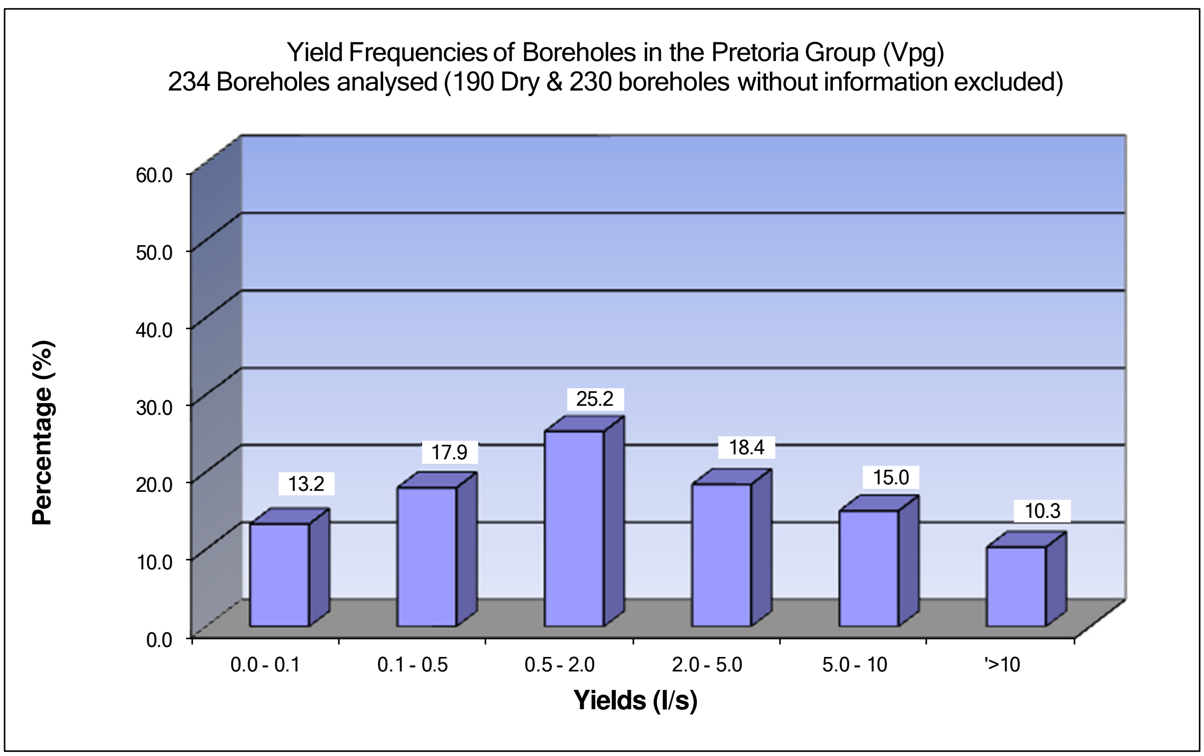


Figure 93: Yield frequency for the intergranular and fractured aquifers of the Pretoria Group (Vpg) (shale, quartzite & diabase).

The groundwater potential of the Pretoria Group is low to moderate as 56.4%, (Figure 93) of successful boreholes yield less than 2ℓ/s, while a reasonable 33.3% is between 2ℓ/s to 10ℓ/s and 10.3% yields above 10ℓ/s.

The static water level ranges from 0.27 meters below ground level (mbgl) to 79.67mbgl, with a median static water level of 12.45mbgl and an average static water level of 15.79mbgl, (based on 213 data records). The maximum depth recorded is 188m, with an average depth of 64.3m and a median depth 58.4m, (178 data records). The maximum installation depth is 120m and an average of 38.5m, (95 data records). Deep installation depths can be indicative of the deeper fracture, and the median installation depth may relate to the water strikes within the intergranular and fracture zone.

The maximum recommended daily abstraction on record is 518.4 cubic meters per day (m³/day) and the average is 80.8m³/day. The 90th percentile is 231.1m³/day and the median is 25.9m³/day. The total number of boreholes subjected to pump testing within this unit on record is 96.

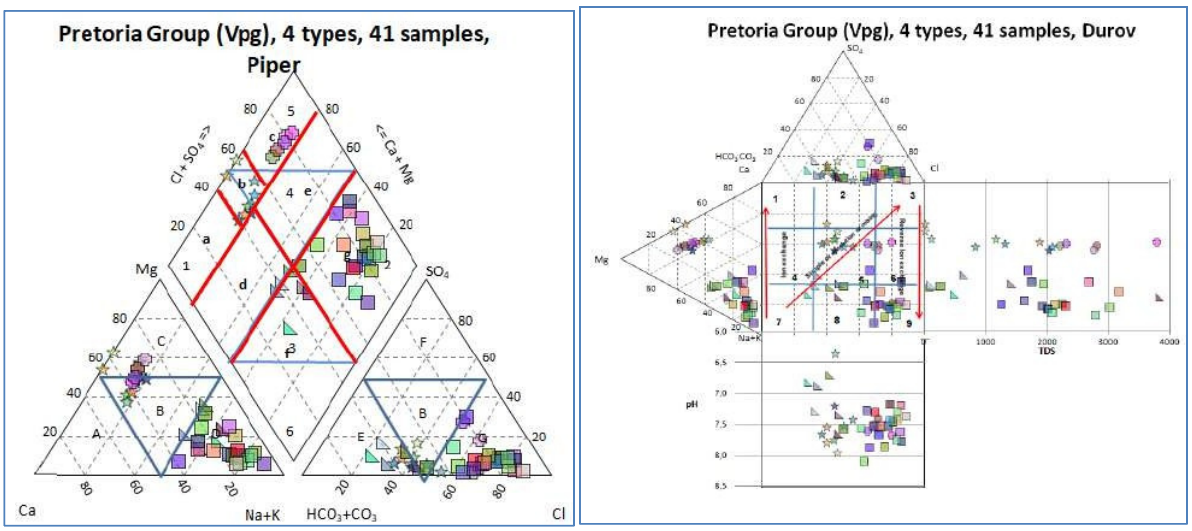


Figure 94: Trilinear diagrams, Piper and Durov for the Pretoria Group (Vpg).

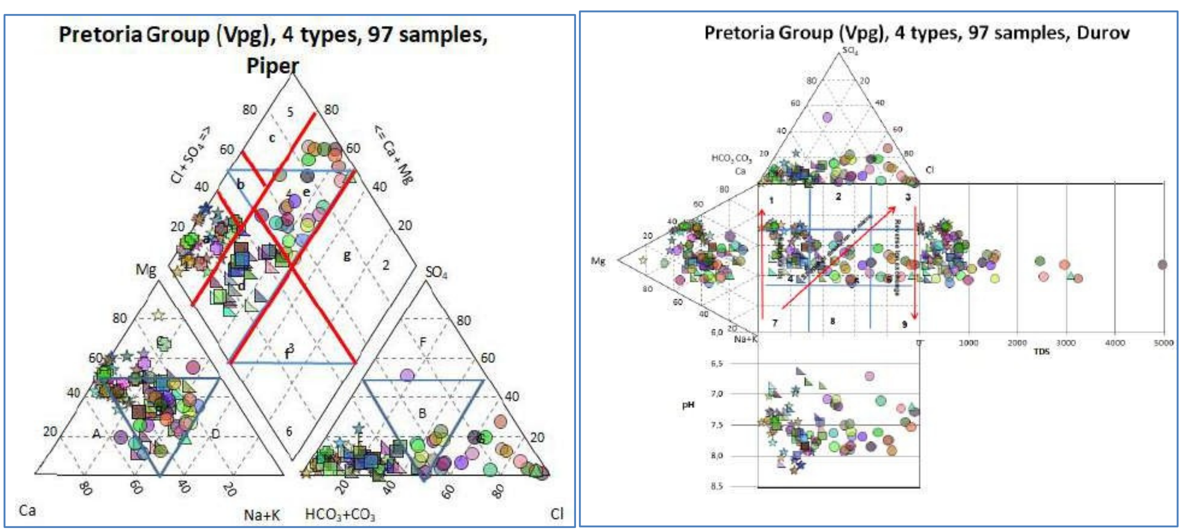


Figure 95: Trilinear diagrams, Piper and Durov for the Pretoria Group (Vpg).

The trilinear Piper diagram, (Figure 94 to Figure 95) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (80.4%), Weak acidic anions > Strong acidic anions (58.3%); Alkali >Alkali earths (19.6%); Strong acids > Weak acids (41.7%).

The water types identified are as follows:

- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (22.7%),
- Calcium-Magnesium-Bicarbonate type (18.8%),
- Sodium-Chloride type (15.2%),
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (13.7%),
- Mixed Calcium-Magnesium-Chloride type with increased Sodium (12.3%),
- Magnesium-Bicarbonate type (9.4%),
- Sodium-Bicarbonate type (4.3%),
- Magnesium-Chloride type (3.6%).

In one of the samples Sulphate is the dominant anion.

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- Anion discriminate and Ca dominant indicating mixed water exhibiting simple dissolution (34%),
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (26%),
- HCO_3 and Ca dominant, indication of recharge in sandstone (17%),
- Anion discriminate and Ca dominant, probable mixing or uncommon dissolution influences (9%),
- Cl and Na dominant is frequently indicative of end-point gradient waters through Dissolution (8%), The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be fairly complete,
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (6%).

Table 56: Chemical statistics for the Pretoria Group (Vpg)

Element / Parameter	Statistics Drawn from a population of 194 data points for the Pretoria Group (Vpg)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	148	6,36	8,67	7,77	7,79	7,26	7,80	8,29	0,42	5,4%
Electrical Conductivity (mS/m EC)	148	4,70	840,00	53,21	144,85	28,39	90,15	380,52	162,68	112,3%
Total Dissolved Salts (mg/l TDS)	141	34,00	4785,00	375,91	975,79	176,00	674,00	2371,00	973,25	99,7%
Calcium (mg/l Ca)	148	1,10	532,10	24,72	73,73	14,05	59,27	148,07	70,59	95,7%
Magnesium (mg/l Mg)	148	2,00	474,16	19,54	54,06	8,31	38,05	116,53	61,41	113,6%
Sodium (mg/l Na)	141	1,00	1427,20	17,08	149,70	6,00	53,10	424,07	239,62	160,1%
Potassium (mg/l K)	141	0,15	53,34	1,07	6,94	0,41	2,44	21,55	9,51	137,1%
Chloride (mg/l Cl)	148	1,50	2853,10	16,55	270,62	5,70	57,56	876,25	495,93	183,3%
Sulphate (mg/l SO_4)	148	0,27	603,04	8,18	43,21	4,28	19,09	102,84	81,33	188,2%
Total Alkalinity (mg/l) $CaCO_3$)	148	14,90	981,83	174,29	283,60	102,27	289,01	424,78	144,97	51,1%
Nitrate (mg/l N)	147	0,02	112,95	0,19	6,46	0,06	1,98	19,09	12,54	194,1%
Fluoride (mg/l F)	147	0,05	10,44	0,35	1,52	0,16	0,53	4,16	2,23	146,8%
Silicon as Si	146	0,43	45,34	11,87	19,42	7,39	18,73	32,34	9,48	48,8%
Iron (Fe)	49	0,01	0,45	0,01	0,05	0,01	0,01	0,08	0,09	189,2%
Manganese (Mn)	23	0,01	0,44	0,01	0,07	0,01	0,03	0,19	0,11	157,9%
Ortho Phosphate as Phosphorus as PO4	119	0,01	0,80	0,02	0,07	0,01	0,03	0,16	0,15	208,3%
ZAR	141	0,06	26,97	0,55	3,11	0,20	1,38	8,08	4,43	142,4%
LSI	141	Langelier Saturation Index (LSI)			Slightly Scaling		**51,1%**	Highly Scaling		**0,0%**
		Highly corrosive		**2,1%**	Slightly corrosive		**12,1%**	Balanced Corrosion		**34,8%**

Table 56 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the extent of the problem. The evaluation of the electrical conductivity (EC) indicates that the overall water quality is ideal to good (73%); marginal (16.9%); to unacceptable (10.1%), values vary between 4.7 and 840 mS/m.

The Total Dissolved Solids (TDS) is acceptable in 75.9% of the samples, (TDS $\leq$ 1200mg/l). The analysis of 194 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 25.2%; Magnesium (Mg > 100mg/l) in 14.2%; Nitrate (N >10mg/l) in 8%; Sodium (Na > 400mg/l) in 11.3%; Chloride (Cl > 600mg/l) in 10.8%; Calcium (Ca > 300mg/l in 2.7% and Sulphate (SO_4 > 600mg/l) in 0.7% of the analyses.

The Langelier Saturation Index (LSI) indicates that the water is corrosive (14.2%); slightly scaling (51.1%) and 34.8% balanced. The ZAR index indicates that 73% of the water is of a fair quality for irrigation (ZAR < 3).

In 25.2% of the water samples at least one element exceeds the maximum allowed limit for domestic use. In this unit Fluoride is the most problematic anion followed by Chloride, Nitrate and then Sulphate. Magnesium is the most problematic cation followed Sodium and Calcium.

The water from this unit is supplying domestic water to farms and rural settlements. Other uses include game and livestock watering. The topography underlain by this unit is in many places forming high ground thus restricting irrigation.

INTRUSIONS IN THE GNEISS AND GRANITE OF THE BASEMENT COMPLEX

The banded migmatitic gneiss is the oldest gneiss in the area. It has been intruded by the Geyser Granite, a homogeneous biotite granite-gneiss penetrated by leucocratic granite and pegmatite. The younger granitic intrusions in the Geyser Granitic rocks, which have been radiometrically dated, are the Turfloop, Lunsklip, Uitloop, and Meinhardskraal Granite.

7.2.3.9 MEINHARDSKRAAL GRANITE (Vme)

Intrusive into the Turfloop Granite and Wolkberg Group, the Meinhardskraal Granite is described as a medium to coarse grained, pink to red granite with pegmatite and subordinate grey granite and granophyre (Counsil of Geoscience). It occurs north-east of Zebediela and north of the Strydpoort Mountain Range, (Figure 96). Sand mining occurs within this unit.

Water occurs mainly in fractured and weathered zones, quartz veins, pegmatites and contact zones with the host rock. Water also occurs occasionally in minor fractures related to dyke intrusions. The contact zone between the intrusive and host rock was subjected to metamorphism and in some cases to such a degree that no open fractures occur as the two rocks are virtually fused together.

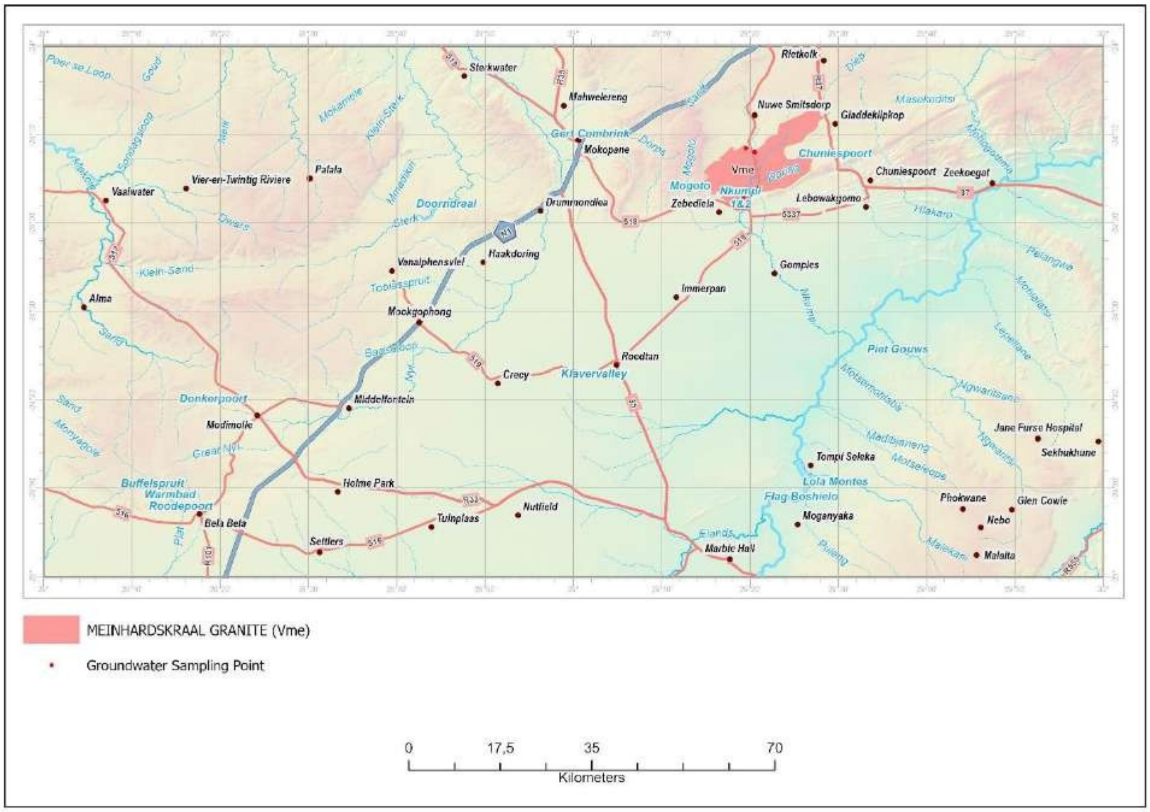


Figure 96: Geographical distribution of the Meinhardskraal Granite (Vme) and the associated groundwater sampling points.

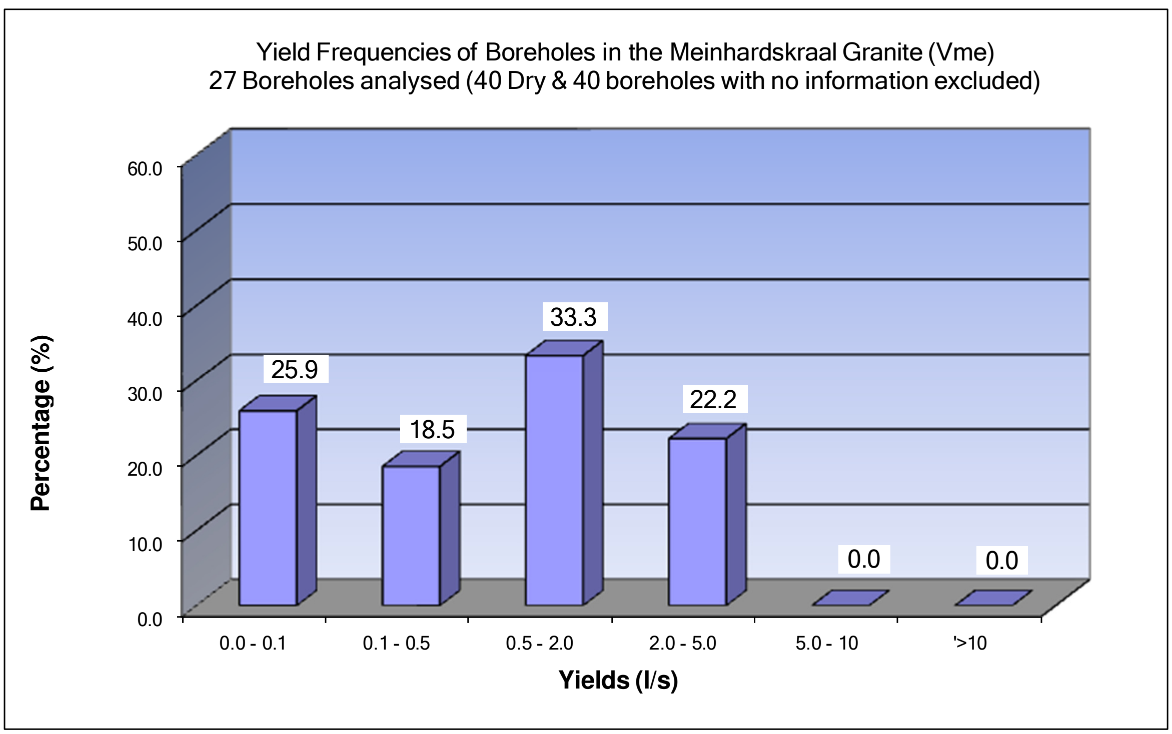


Figure 97: Yield frequency for the intergranular and fractured aquifers of the Meinhardskraal Granite (Vme).

The groundwater potential of this granite is generally low as 77.8% of the successful boreholes yield less than 2ℓ/s (Figure 97).

The static water level ranges from 3.65 meters below ground level (mbgl) to 46.84mbgl, with a median static water level of 14.87mbgl, and an average static water level of 16.51mbgl, (based on 29 data records). The maximum depth recorded is 117.2m, with an average depth of 60.4m, and a median static water level of 62.9m, (6 data records). The maximum installation depth is 75m and the average is 47.3m that can be indicative of water strikes.

The maximum recommended daily abstraction on record is 43.2 cubic meters per day (m^3/day), with an average of 30.2m^3/day. The 90th percentile is 38m^3/day and the median is 25.9m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 4.

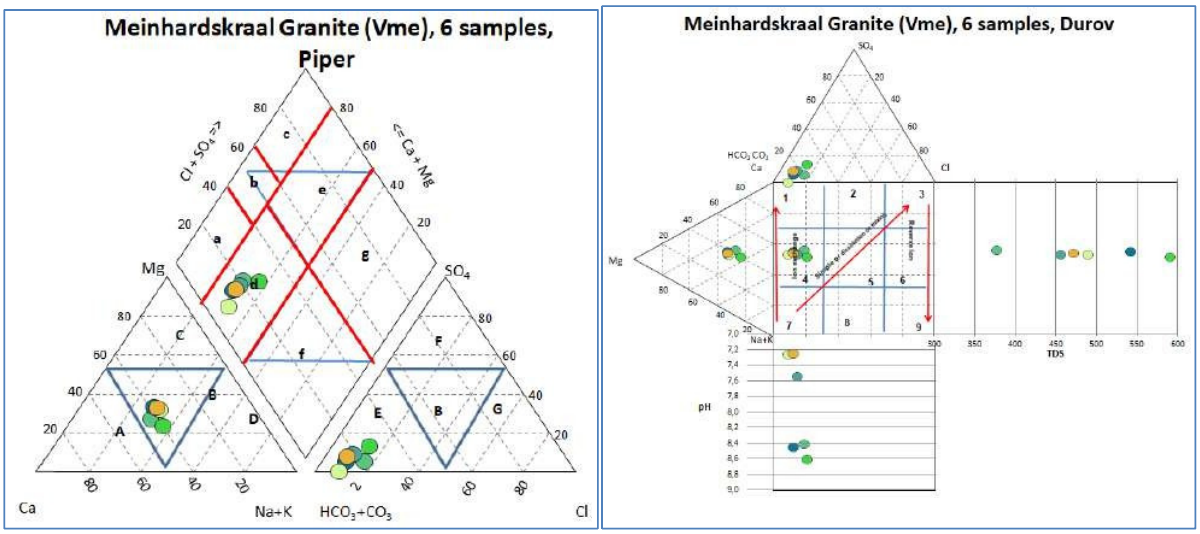


Figure 98: Trilinear diagrams, Piper and Durov for the Meinhardskraal Granite (Vme).

The trilinear Piper diagram, (Figure 98) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (100%); Alkali >Alkali earths (0%); Strong acids > Weak acids (0%).

The water type is mixed Calcium-Magnesium-Bicarbonate with increased Sodium. The trilinear Durov diagram defines hydrochemical processes along with the water type; the indication is that it is a mixed water or water exhibiting simple dissolution.

Table 57: Chemical statistics for the Meinhardskraal Granite (Vme)

Element / Parameter	Statistics Drawn from a population of 6 data points for the Meinhardskraal Granite (Vme)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	6	7,23	8,60	7,86	7,91	7,24	7,96	8,52	0,64	8,1%
Electrical Conductivity (mS/m EC	6	23,40	65,30	47,96	54,62	39,75	60,40	63,70	15,59	28,5%
Total Dissolved Salts (mg/l TDS)	6	152,00	582,42	314,11	375,90	232,00	362,00	533,71	148,19	39,4%
Calcium (mg/l Ca)	6	19,29	59,90	38,61	44,48	28,15	49,10	56,20	14,42	32,4%
Magnesium (mg/l Mg)	6	7,57	28,01	17,44	21,32	13,44	23,10	27,41	7,50	35,2%
Sodium (mg/l Na)	6	13,86	61,30	32,60	40,94	24,31	43,05	55,45	16,02	39,1%
Potassium (mg/l K)	6	0,95	3,60	1,59	2,01	1,06	1,62	3,35	1,09	54,3%
Chloride (mg/l Cl)	6	7,50	21,40	11,14	12,34	8,73	10,95	17,35	4,82	39,0%
Sulphate (mg/l SO_4)	5	3,46	27,50	8,62	13,79	5,44	14,10	22,70	9,04	65,5%
Total Alkalinity (mg/l) $CaCO_3$)	6	102,80	315,40	225,14	263,82	192,25	289,00	310,20	79,93	30,3%
Nitrate (mg/l N)	6	0,01	1,65	0,07	0,77	0,15	0,53	1,62	0,69	89,5%
Fluoride (mg/l F)	6	0,24	1,14	0,47	0,58	0,36	0,50	0,88	0,30	52,5%
Silicon as Si	5	15,40	31,20	21,97	24,04	15,87	27,30	30,60	7,49	31,1%
Iron (Fe)	4	0,01	0,02	0,01	0,01	0,01	0,01	0,02	0,01	40,0%
Manganese (Mn)	2	0,04	7,57	0,08	3,81	0,79	3,81	6,82	5,32	139,9%
Ortho Phosphate as Phosphorus as PO4	6	0,01	0,05	0,02	0,02	0,01	0,02	0,03	0,02	73,0%
ZAR	6	0,68	1,73	1,14	1,24	0,92	1,24	1,55	0,34	27,8%
LSI	6	Langelier Saturation Index (LSI)			Slightly Scaling		**33,3%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**66,7%**

Table 57 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the extent of the problem. The evaluation of the electrical conductivity (EC) indicates that the overall water quality is ideal for all the samples analysed. The Total Dissolved Solids (TDS) is acceptable in all the samples, (TDS ≤ 1200mg/l). The analysis available is only for 6 data points.

The Langelier Saturation Index (LSI) indicates that the water is slightly scaling (33.3%) and predominantly balanced (66.7%). The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3).

No water samples show the concentrations of the major anions or cations to exceed the maximum allowable limit. Fluoride is the only anion with a concentration outside the ideal water quality; it falls within the marginal water quality (F > 1 < 1.5mg/l) in 16.7% of the analysis.

The water from this unit is supplying domestic water to farms and partly to one semi-rural settlement (Bergnek). Other uses include game and livestock watering. The decommissioned Maandagshoek diamond mine is within this unit; a fracture zone was found at 140m with an inflow yield of 8l/s; the calculation is that the mine stores 2.5 Mm³, J.J.P. Vivier 2024.

7.2.3.10 UNNAMED GRANITE (Vz) (VAALIAN ROCKS)

This unit is predominantly located near Haenertsburg, in the southeastern corner of the Pietersburg 1:250 000 geological map sheet. It also extends across the map boundary into the Modimolle map sheet (Figure 99). The unit is composed of a leucocratic, whitish, medium- to coarse-grained granite, with biotite occurring as a minor mineral constituent (Explanation Booklet, Geological Map Sheet 2328). Additional information on this unit is available in the Polokwane 1:250 000 hydrogeological map sheet. Within the Modimolle map area, the unit occupies approximately 0.01% of the sheet.

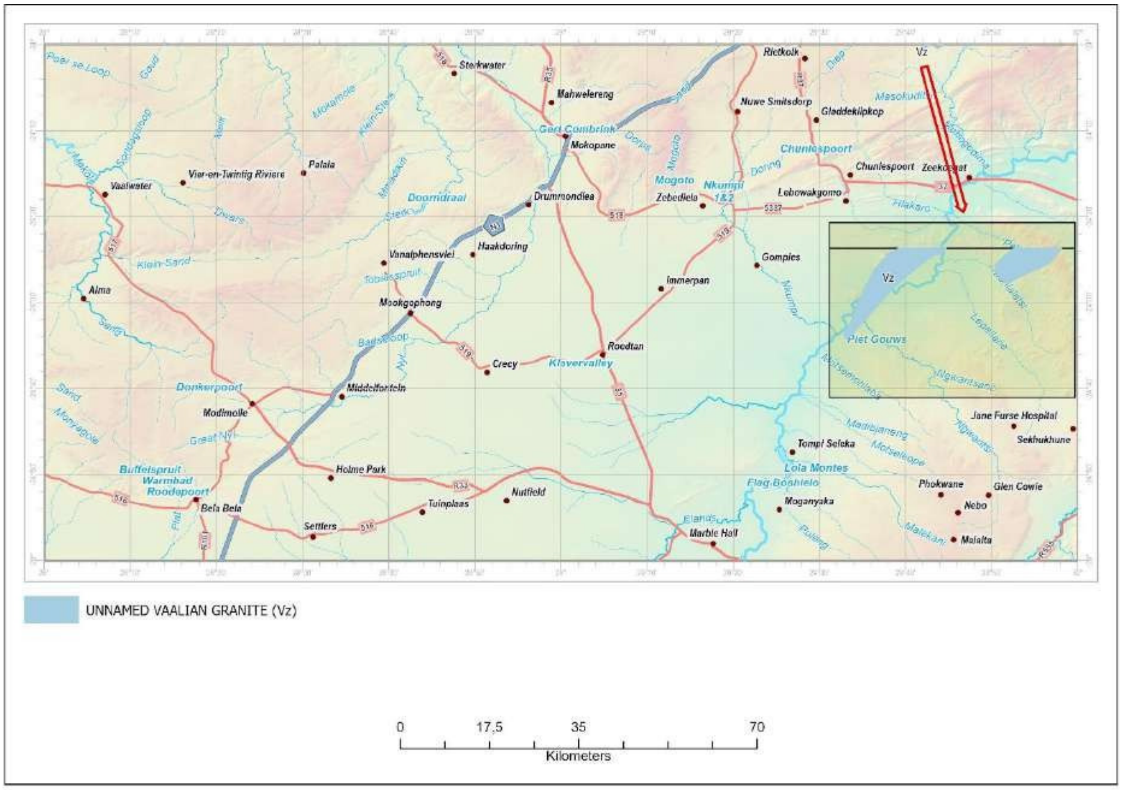


Figure 99: Geographical distribution of the unnamed Granite (Vz) (Vaalian Rocks) and associated groundwater sampling points.

No chemistry or yield data was available to compile Piper, Durov and yield diagrams for the unnamed Granite of Vaalian age. This aquifer unit could therefore not be characterised in terms of groundwater occurrence and water quality.

7.2.3.11 UITLOOP GRANITE (Ru-Vu)

Two occurrences of the Uitloop Granite appear on the map sheet namely north and north-east of Mokopane (Potgietersrus), (Figure 100). It contains minerals such as quartz, orthoclase, microcline-perthite, sodic plagioclase and biotite. The rock has an adamellitic composition, is medium- to coarse-grained and mainly reddish in colour. It covers approximately 0.19% of the map area. Various north-east orientated lineaments transect this unit, and further drilling is needed to investigate the groundwater potential. In general, the occurrence of groundwater in this granite is not expected to be different from that of the other granites on the map sheet.

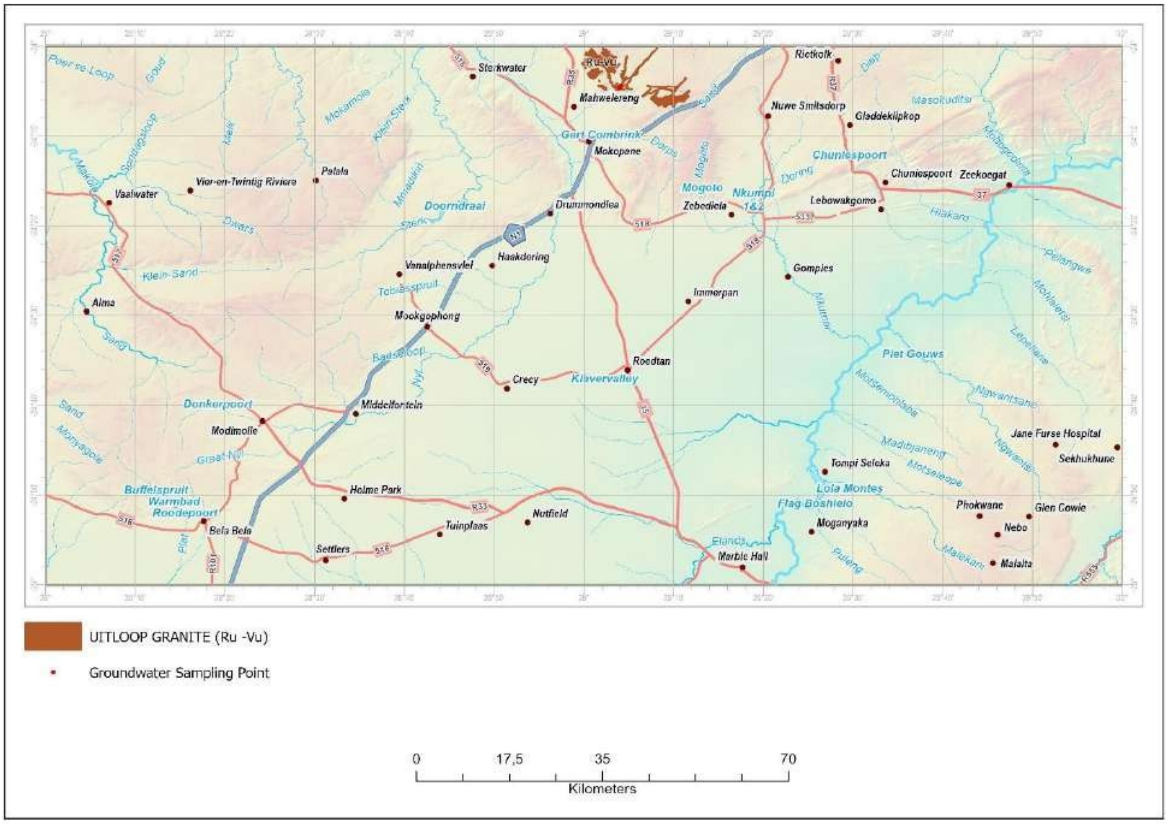


Figure 100: Geographical distribution of the Uitloop Granite (Ru-Vu)

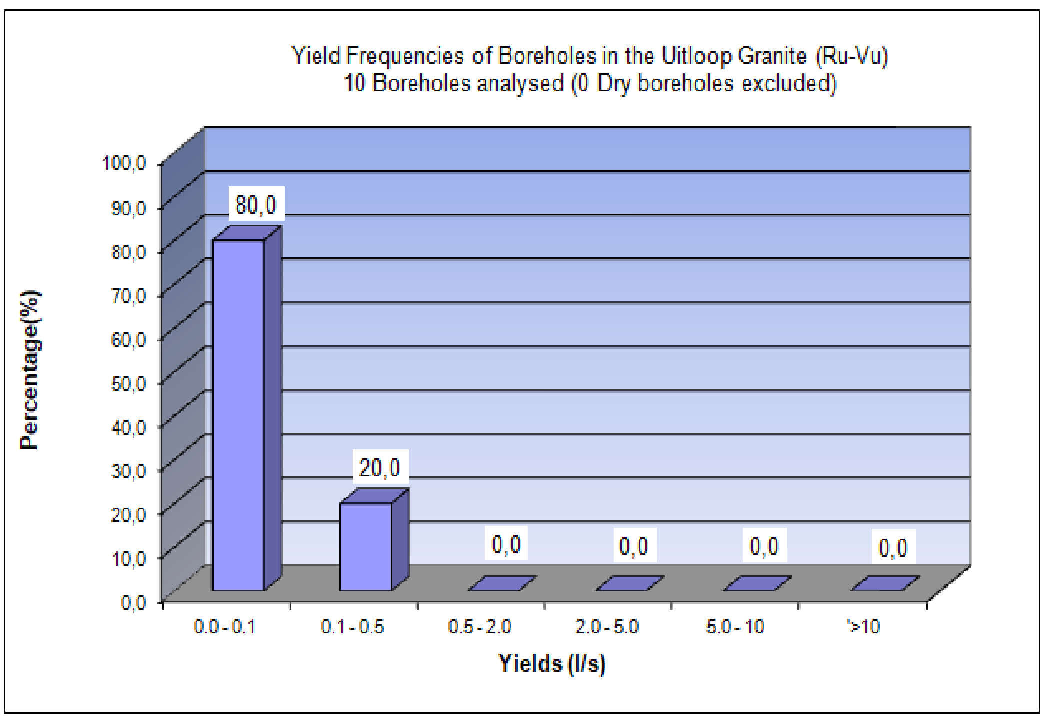


Figure 101: Yield frequency of the intergranular and fractured aquifers of the Uitloop Granite (Ru-Vu)

The yield frequency diagram, (Figure 101) does not represent a good overview of the groundwater potential as only 10 boreholes have been used in the analysis. The available information indicates that 80% of boreholes yield less than 0,1l/s and the remaining 20% yields less than 0.5l/s.

The static water level ranges from 4.57 meters below ground level (mbgl) to 57.91mbgl, with a median static water level of 21.34mbgl and an average static water level of 22.61mbgl, (based on 11 data records). No pump testing data was available for this unit.

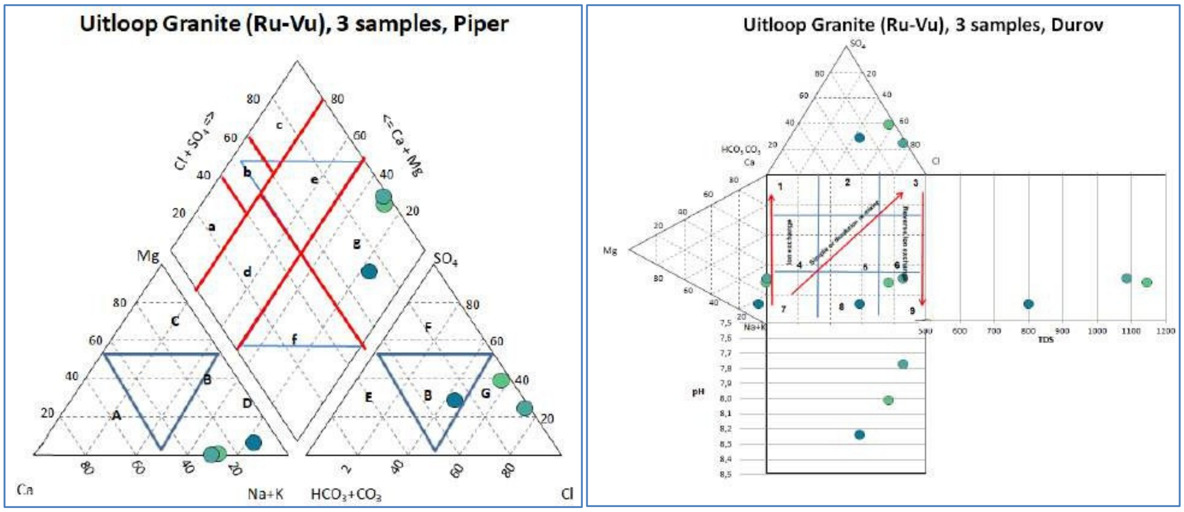


Figure 102: Trilinear diagrams, Piper and Durov for the Uitloop Granite (Ru-Vu).

The trilinear Piper diagram, (Figure 104) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (0%), Weak acidic anions > Strong acidic anions (0%); Alkali >Alkali earths (100%); Strong acids > Weak acids (100%).

The second evaluation was on the water type:

- Sodium-Chloride type (100%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- Cl and Na dominate, indicting reverse ion exchange of Na-Cl waters (33.3%),
- Cl and Na dominate, indicting end point down gradient waters through dissolution (66.7%). The elevated TDS is these samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 58: Chemical statistics for the Uitloop Granite (Ru-Vu)

Element / Parameter	Statistics Drawn from a population of 3 data points for the Uitloop Granite (Ru-Vu)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	3	7,54	8,49	8,00	8,02	7,64	8,02	8,40	0,48	5,9%
Electrical Conductivity (mS/m EC)	3	67,8	179,0	114,6	139,3	88,4	171,0	177,4	62,0	44,5%
Total Dissolved Salts (mg/l TDS)	3	511,0	1108,0	778,3	874,7	609,8	1005,0	1087,4	319,1	36,5%
Calcium (mg/l Ca)	3	14,8	98,3	34,0	69,6	31,0	95,7	97,8	47,5	68,2%
Magnesium (mg/l Mg)	3	0,50	5,30	1,08	2,50	0,74	1,70	4,58	2,50	99,9%
Sodium (mg/l Na)	3	135,8	286,0	202,4	224,8	159,1	252,5	279,3	78,8	35,1%
Potassium (mg/l K)	3	1,08	3,38	1,87	2,35	1,38	2,60	3,22	1,17	49,7%
Chloride (mg/l Cl)	3	85,2	410,3	174,1	274,4	133,7	327,6	393,8	169,0	61,6%
Sulphate (mg/l SO_4)	3	76,2	307,7	138,4	190,8	98,6	188,4	283,8	115,8	60,7%
Total Alkalinity (mg/l) $CaCO_3$)	3	36,2	151,9	60,8	84,8	42,2	66,2	134,8	60,0	70,8%
Nitrate (mg/l N)	3	0,02	0,25	0,04	0,11	0,03	0,05	0,21	0,12	116,3%
Fluoride (mg/l F)	3	4,72	7,24	6,06	6,28	5,15	6,89	7,17	1,37	21,7%
Silicon as Si	3	2,12	13,22	4,28	7,27	2,99	6,48	11,87	5,59	76,9%
Iron (Fe)	0	0,00	0,00							
Manganese (Mn)	0	0,00	0,00							
Ortho Phosphate as Phosphorus as PO4	3	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00	7,9%
ZAR	3	6,98	7,94	7,52	7,54	7,13	7,71	7,89	0,50	6,6%
LSI	3	Langelier Saturation Index (LSI)			Slightly Scaling		**0,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**100,0%**

Table 58 gives a summary of the physical properties, the major anions, cations and some of the minor elements. The evaluation of the electrical conductivity (EC) and Sodium concentrations from three analyses indicates that the overall water quality is ideal for one data point and moderate for the remaining two samples. The Total Dissolved Solids (TDS) is acceptable in all the samples, (TDS ≤ 1200mg/l).

The Langelier Saturation Index (LSI) indicates that the water falls within the balanced corrosion range. The ZAR index indicates that 0% of the water is of a fair quality for irrigation (ZAR < 3).

The Fluoride concentration exceeds the maximum allowable limit in all 3 samples (F > 1.5mg/l). The concentrations are very high as it ranges from 4.72mg/l and 7.24mg/l.

7.2.3.12 LUNSKLIP GRANITE (RI-VI)

The Lunsklip Granite occurs north-east of Mokopane (Potgietersrus), (Figure 103). The unit consists of a pinkish-grey, medium- to coarse-grained, hornblende-biotite granite and is part of the Mashashane Suite of intrusives. The presence of blue opalescent quartz is a characteristic feature of this intrusion (Counsil of Geoscience). The unit covers approximately 0.62% of the map sheet area.

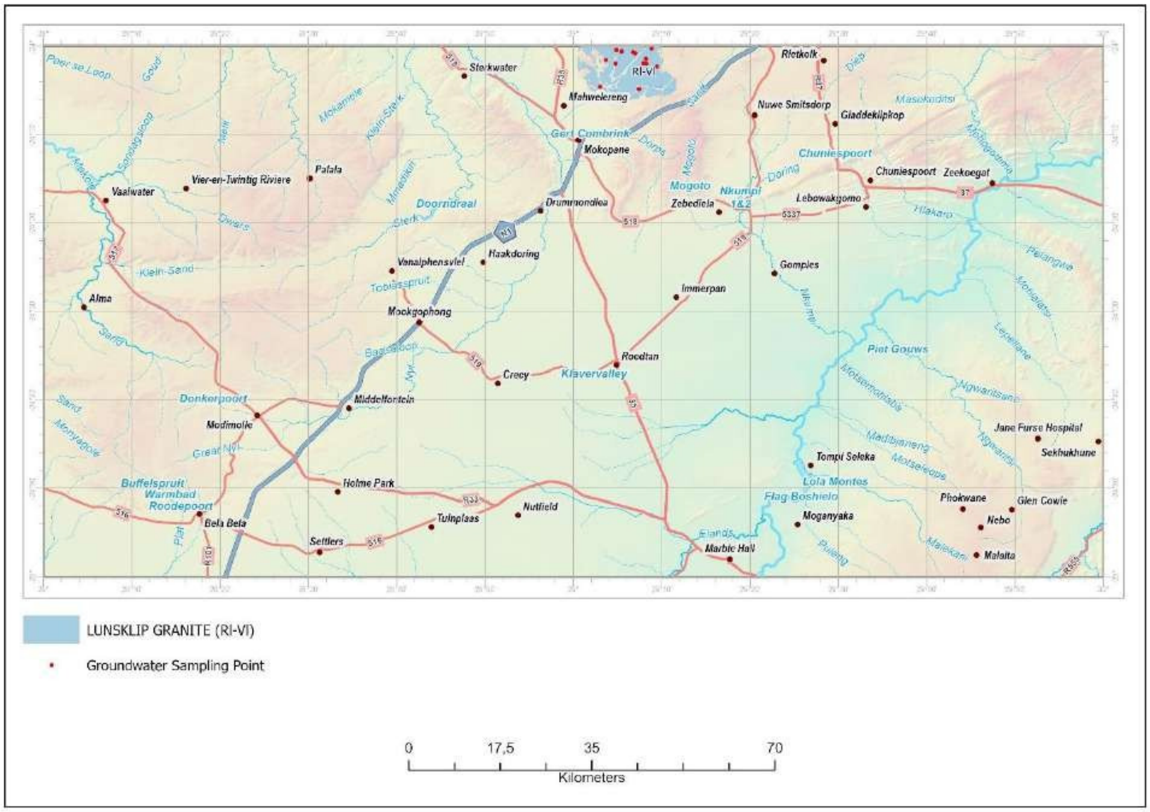


Figure 103: Geographical distribution of the Lunsklip Granite (RI-VI) and associated groundwater sampling points.

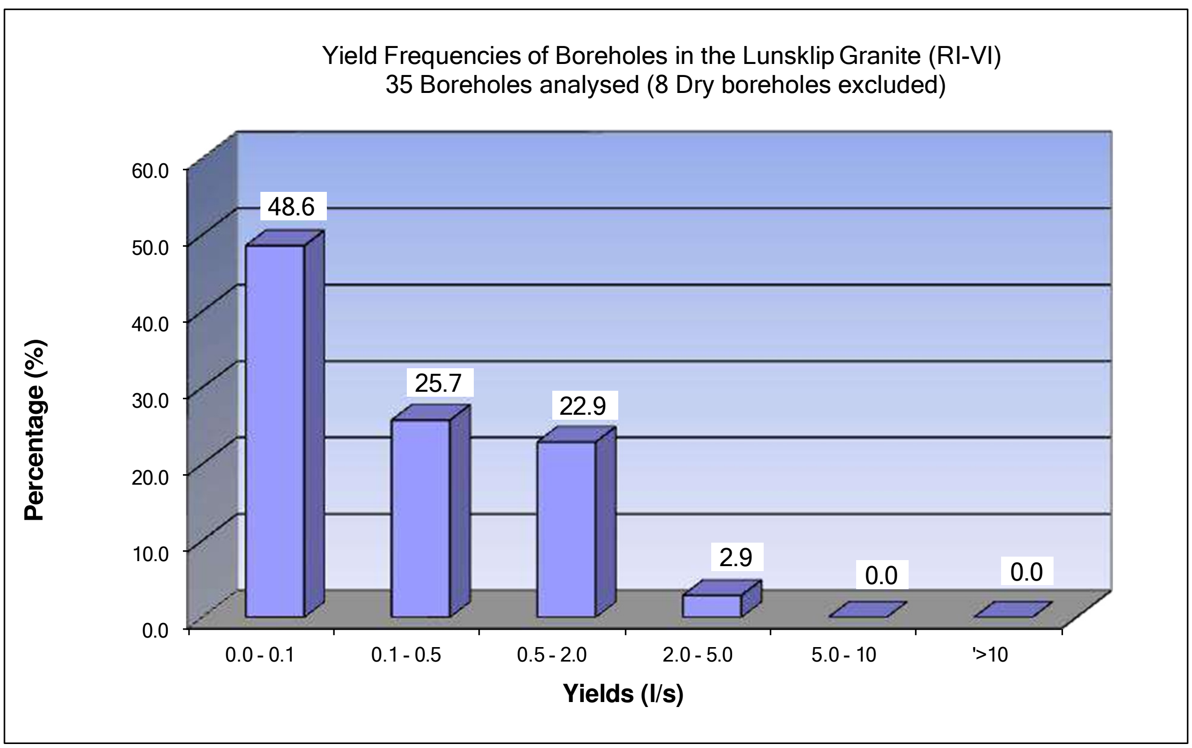


Figure 104: Yield frequency for the intergranular and fractured aquifers of the Lunsklip Granite (RI-VI)

From the yield frequency diagram, (Figure 104) indications are that the Lunsklip Granite has a low groundwater development potential as 97.1% of successful boreholes yield less than 2ℓ/s, with only 2.9% yields between 2ℓ/s to 5ℓ/s and with no boreholes yielding more than 5ℓ/s.

The static water level ranges from 0.61 meters below ground level (mbgl) to 60mbgl, with a median static water level of 10.06mbgl and an average static water level of 13.67mbgl, (based on 35 data records). No pump test data was available for this unit.

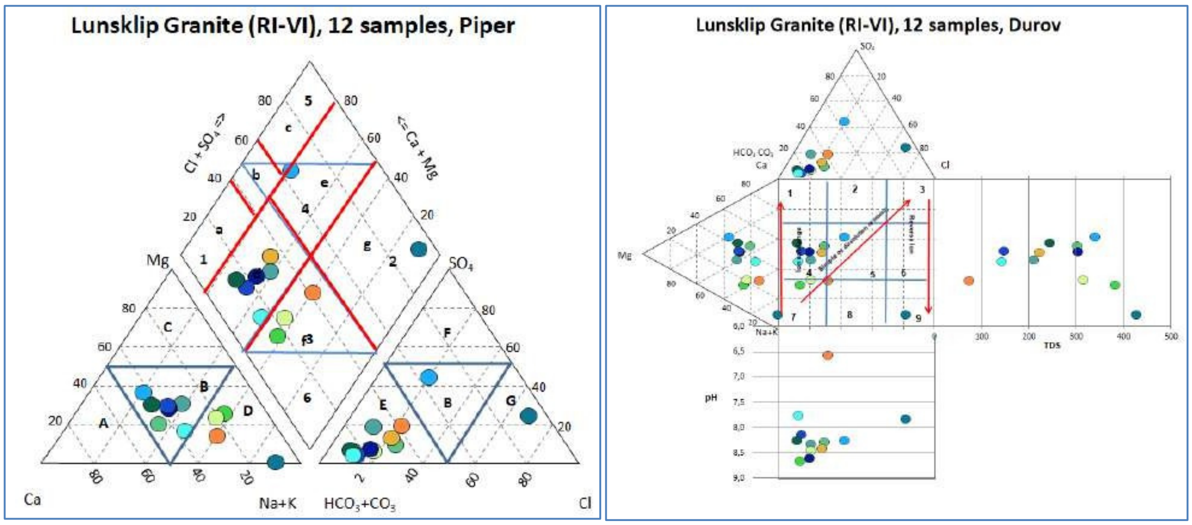


Figure 105: Trilinear diagrams, Piper and Durov for the Lunsklip Granite (RI-VI).

The trilinear Piper diagram, (Figure 105) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (66.7%), Weak acidic anions > Strong acidic anions (83%); Alkali >Alkali earths (33.3%); Strong acids > Weak acids (16.7%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type (58.4%);
- Sodium-Bicarbonate type (25%);
- Sodium-Chloride type (8.3%).
- Mixed Calcium-Magnesium-Chloride-Sulphate type (8.3%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- Mixed water or water exhibiting simple dissolution dominates (58.3%),
- Cl and Na dominate, indicting reverse ion exchange of Na-Cl waters (16.7%),
- Simple dissolution or mixing (16.7%),
- Cl and Na dominate, indicting end point down gradient waters through dissolution (8.3%).

Table 59: Chemical statistics for the Lunsklip Granite (RI-VI)

Element / Parameter	Statistics Drawn from a population of 13 data points for the Lunsklip Granite (RI-VI)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	12	6,53	8,65	8,07	8,11	7,74	8,25	8,58	0,57	7,0%
Electrical Conductivity (mS/m EC)	12	8,50	75,90	26,66	36,25	17,23	35,80	50,72	17,66	48,7%
Total Dissolved Salts (mg/l TDS)	12	73,00	428,00	204,33	258,67	141,50	273,00	377,70	105,55	40,8%
Calcium (mg/l Ca)	12	3,80	40,00	14,05	20,23	12,25	16,70	34,44	10,45	51,6%
Magnesium (mg/l Mg)	12	0,50	20,70	3,09	9,41	1,51	10,15	14,84	5,81	61,7%
Sodium (mg/l Na)	12	8,90	138,80	22,21	36,64	14,00	23,50	62,97	35,78	97,6%
Potassium (mg/l K)	12	0,39	3,45	0,78	1,18	0,53	0,83	2,51	0,95	80,2%
Chloride (mg/l Cl)	12	3,60	145,30	7,69	21,24	4,34	10,50	21,23	39,49	185,9%
Sulphate (mg/l SO_4)	12	2,00	69,80	5,73	17,01	2,36	7,40	60,68	23,97	140,9%
Total Alkalinity (mg/l) $CaCO_3$)	12	35,40	217,50	86,58	114,23	44,28	104,70	168,88	54,04	47,3%
Nitrate (mg/l N)	12	0,08	6,96	0,45	2,47	0,24	1,25	6,81	2,72	110,2%
Fluoride (mg/l F)	12	0,27	9,23	1,23	2,44	0,84	2,13	2,93	2,29	93,9%
Silicon as Si	12	13,35	25,21	19,05	19,55	15,55	20,09	21,54	3,10	15,8%
Iron (Fe)	0	0,00	0,00							
Manganese (Mn)	0	0,00	0,00							
Ortho Phosphate as Phosphorus as PO4	12	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00	28,1%
ZAR	12	0,64	10,39	1,15	2,03	0,76	1,16	2,73	2,71	133,7%
LSI	12	Langelier Saturation Index (LSI)			Slightly Scaling		**16,7%**	Highly Scaling		**0,0%**
		Highly corrosive		**8,3%**	Slightly corrosive		**16,7%**	Balanced Corrosion		**58,3%**

Table 59 gives a summary of the physical properties, the major anions, cations and some of the minor elements. The evaluation of the electrical conductivity (EC) from 13 analysis indicates that the overall water quality is ideal (91.7%) to good (8.3%) and ranges from 8.5mS/m to 75.9mS/m. The Total Dissolved Solids (TDS) is acceptable in all the samples, (TDS ≤ 1200mg/l).

The Langelier Saturation Index (LSI) indicates that the water is corrosive (25%); slightly scaling (16.7%) and balanced (58.3%). The ZAR index indicates that 91.7% of the water is of a fair quality for irrigation (ZAR < 3).

The Fluoride concentration exceeds the maximum allowable limit (F > 1.5mg/l) in 66.7% of the samples. The concentrations are very high as the median is 2.13mg/l and the maximum is 9.23mg/l. The other major anions and cations fall within the ideal to good water quality range.

The Percy Fyfe and Witvinger Nature Reserves are located within this unit. Groundwater in the area is primarily used for game and livestock watering, as well as for domestic supply to rural farms. Due to the unit's rugged topography and highly variable soil depth, characteristic of granite hills with rapidly changing profiles from deeply weathered zones to exposed outcrops, irrigation is not practiced.

7.2.3.13 TURFLOOP GRANITE (Rt-Vt)

Turfloop Granite is a medium to coarse-grained, grey to pinkish biotitic rock of adamellitic to granodioritic composition and contains orthoclase, microcline, quartz, sodic plagioclase, and biotite with sphene and zircon as accessories Counsil of Geoscience). It occupies the north-eastern part of the Modimolle map sheet and underlies approximately 3.05% of the map sheet area, (Figure 106).

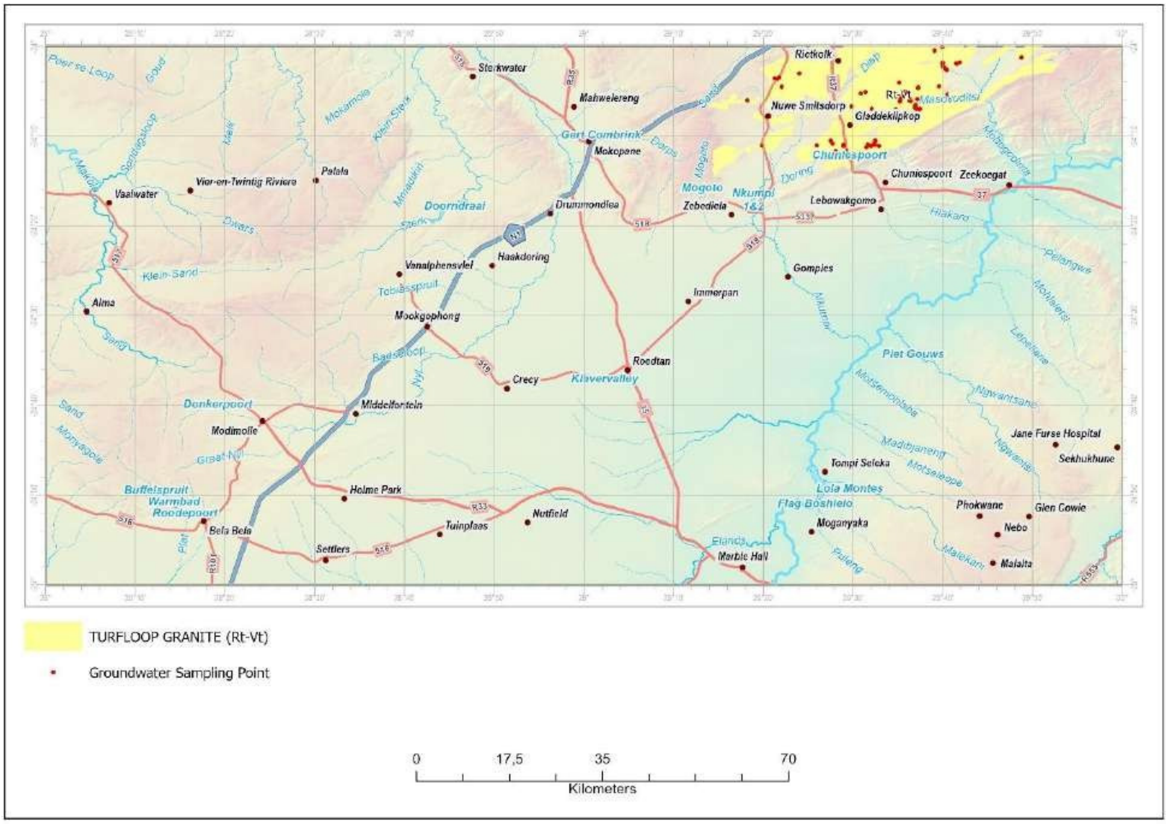


Figure 106: Geographical distribution of the Turfloop Granite (Rt-Vt) and the associated groundwater sampling points

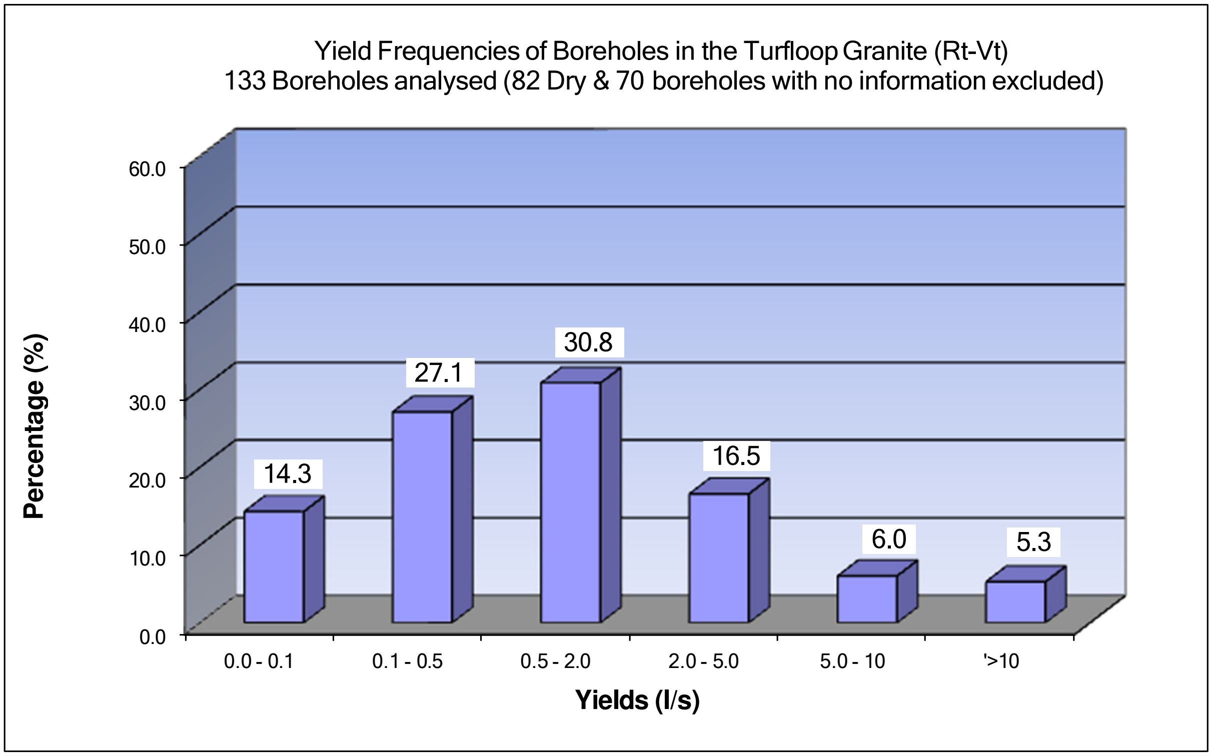


Figure 107: Yield frequency for the intergranular and fractured aquifers of the Turfloop Granite (Rt-Vt).

Like most of the granite intrusions in the map area, the potential of the Turfloop Granite is generally low with 72.2% of the successful boreholes yielding less than 2ℓ/s, (Figure 107). The higher yielding boreholes especially the 11.3% boreholes yielding more than 5ℓ/s usually relate to the Boyne shear zone or deep weathering and sediment formed at the base of lengthy valleys that is characteristic of the area. Water also occurs in weathered and fracture zones or occasionally in minor fractures related to dyke intrusions.

The static water level ranges from 1.82 meters below ground level (mbgl) to 70mbgl, with a median static water level of 14.14mbgl and an average static water level of 17.68mbgl, (based on 121 data records). The maximum depth recorded is 151m, with an average depth of 63.4m and a median depth of 60m, (91 data records). The maximum installation depth is 90m, with an average of 38.1m. The installation depth can be indicative of water strike depths, the average represents the intergranular aquifer, and the deep installation depth represents the deep fractured zones.

The maximum recommended daily abstraction on record is 518.4 cubic meters per day (m^3/day) and the average is 43.8m^3/day. The 90th percentile is 108m^3/day and the median or 50th percentile is 11.8m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 56.

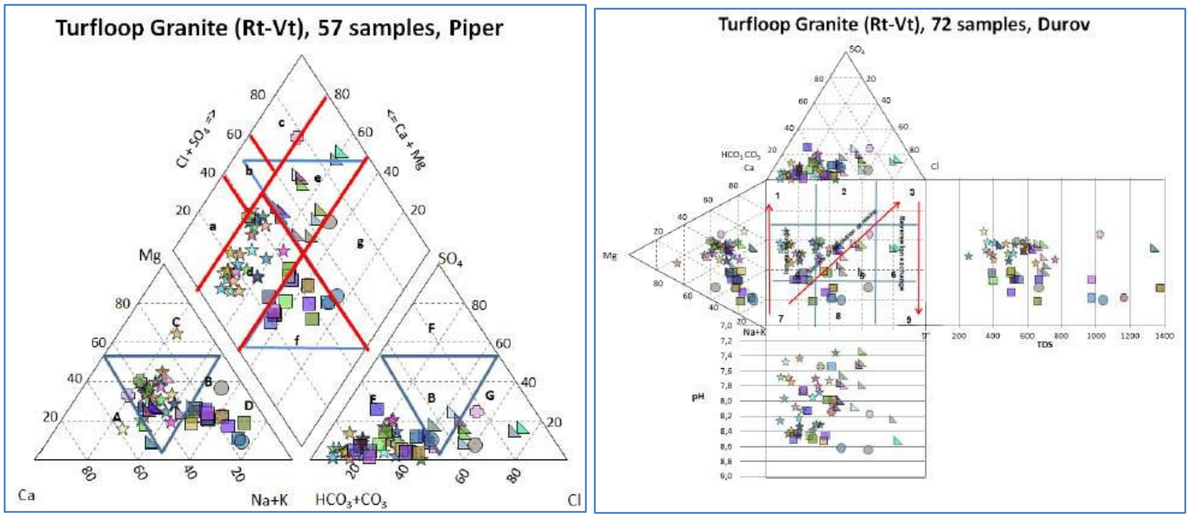


Figure 108: Trilinear diagrams, Piper and Durov for the Turfloop Granite (Rt-Vt).

The trilinear Piper diagram, (Figure 108) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (75.4%), Weak acidic anions > Strong acidic anions (73.7%); Alkali >Alkali earths (24.6%); Strong acids > Weak acids (26.3%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (52.7%);
- Mixed Calcium-Magnesium-Chloride type (22.8%);
- Sodium-Bicarbonate type (21%);
- Sodium-Chloride type (3.5%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- Mixed water or water exhibiting simple dissolution dominates (54.2%),
- No dominant anion or cations, the trend can be attributed to fresh recent recharged water exhibiting simple dissolution or mixing (33.9%), points plot along the dissolution or mixing line,
- Cl and Na dominate, indicting groundwater to be related to reverse ion exchange of Na-Cl waters (11.9%).

Table 60: Chemical statistics for the Turfloop Granite (Rt-Vt)

Element / Parameter	Statistics Drawn from a population of 86 data points for the Turfloop Granite (Rt-Vt)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	84	6,48	8,62	7,89	7,92	7,32	7,96	8,47	0,45	5,6%
Electrical Conductivity (mS/m EC)	83	33,83	214,00	75,21	87,09	51,22	76,00	137,19	37,87	43,5%
Total Dissolved Salts (mg/l TDS)	83	231,00	1382,00	550,47	639,16	365,79	580,10	1041,60	266,86	41,8%
Calcium (mg/l Ca)	79	3,46	210,30	41,24	60,73	30,16	55,65	90,86	37,36	61,5%
Magnesium (mg/l Mg)	80	0,14	71,10	8,05	31,65	15,84	28,67	52,05	14,20	44,9%
Sodium (mg/l Na)	79	7,11	268,00	53,47	80,48	36,42	57,27	168,14	60,36	75,0%
Potassium (mg/l K)	78	0,66	14,95	2,40	3,63	1,39	2,71	6,18	2,97	81,8%
Chloride (mg/l Cl)	84	5,00	493,80	32,78	75,73	16,24	47,36	153,15	81,54	107,7%
Sulphate (mg/l SO_4)	80	1,09	150,20	10,43	31,27	5,26	21,20	65,03	31,55	100,9%
Total Alkalinity (mg/l) $CaCO_3$)	72	140,29	658,00	251,66	280,23	173,81	254,50	370,59	107,76	38,5%
Nitrate (mg/l N)	82	0,03	84,80	0,47	11,59	0,12	5,76	26,18	17,30	149,2%
Fluoride (mg/l F)	82	0,08	4,54	0,41	1,12	0,20	0,65	3,19	1,15	102,5%
Silicon as Si	75	1,90	38,48	13,07	16,88	9,40	15,51	25,72	6,89	40,8%
Iron (Fe)	35	0,01	0,30	0,01	0,03	0,01	0,01	0,05	0,06	159,3%
Manganese (Mn)	25	0,01	2,38	0,03	0,25	0,01	0,05	0,50	0,55	223,1%
Ortho Phosphate as Phosphorus as PO4	73	0,01	0,80	0,02	0,08	0,01	0,018	0,09	0,19	249,0%
ZAR	79	0,19	8,21	1,44	2,26	0,94	0,94	4,13	1,80	79,8%
LSI	72	Langelier Saturation Index (LSI)			Slightly Scaling		**59,7%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**40,3%**

Table 60 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the extent of the problem. In terms of electric conductivity (EC), the overall water quality is good to marginal with values between 33.83 and 214mS/m. The Total Dissolved Solids (TDS) is acceptable in 95.2% of the samples, (TDS ≤ 1200mg/l).

The evaluation in regard to the main cations and anions of 86 analysis indicate elevated concentrations of Nitrate (N >10mg/l) in 19.3% and Fluoride (F >1.5mg/l) in 29.3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly scaling (59.7%) and balanced (40.3%). The ZAR index indicates that 75.9% of the water is of a fair quality for irrigation (ZAR < 3).

Water abstracted from this unit supplies a large number of people in rural settlements, predominantly in the Mankweng area. The water demand in these villages is met through the conjunctive use of surface water and groundwater. The only significant irrigation activity occurs at the Kuschke Agricultural School and in a small area south of this school. A nearby solar farm also operates within the unit, but its water usage is minimal. Other water users in the area fall under Schedule 1 use, which includes domestic consumption for rural farms and smallholdings.

Water quality data indicates that in 29.3% of samples, at least one element exceeds the maximum allowable limit for domestic use. Fluoride is the most problematic anion in this unit, followed by nitrate.

7.2.3.14 GEYSER GRANITE (Rge)

The Geyser Granite which occurs north-east and east of Mokopane (Potgietersrus), is described as a homogeneous biotite granite-gneiss intruded by leucocratic granite and pegmatite, (Counsil of Geoscience). The unit covers approximately 0.29% of the map sheet area, (Figure 109).

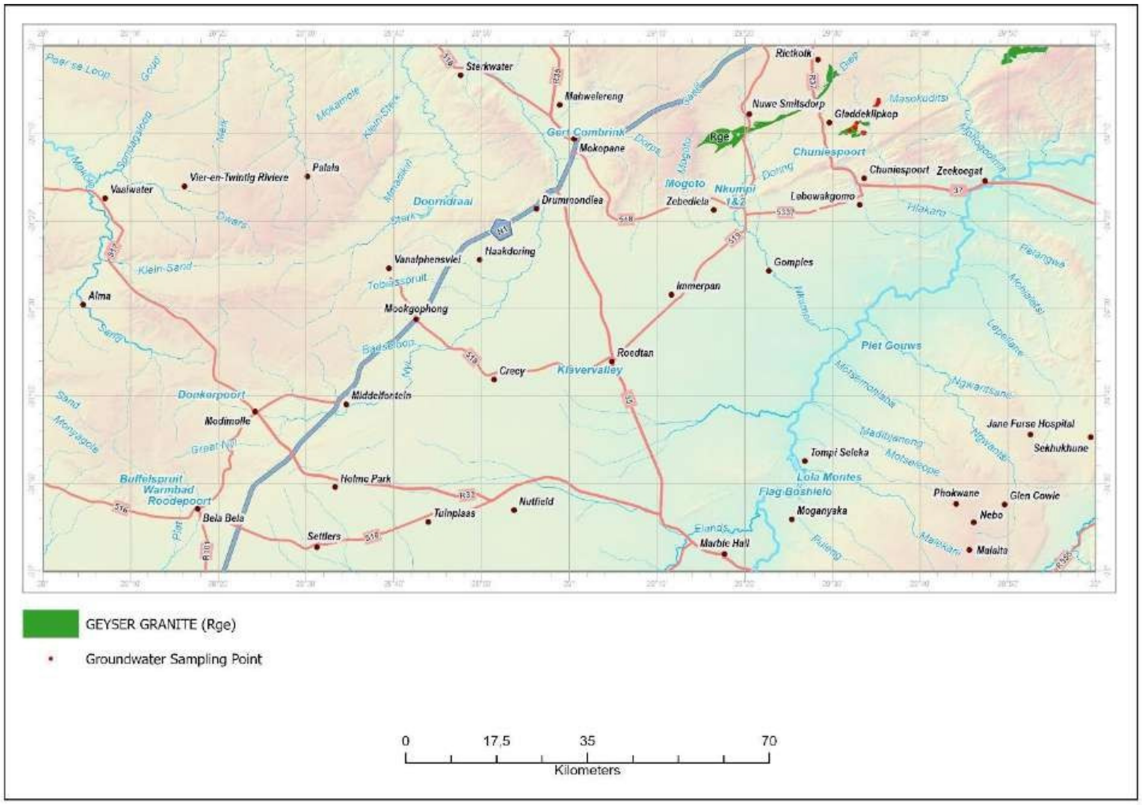


Figure 109: Geographical distribution of the Geyser Granite (Rge)

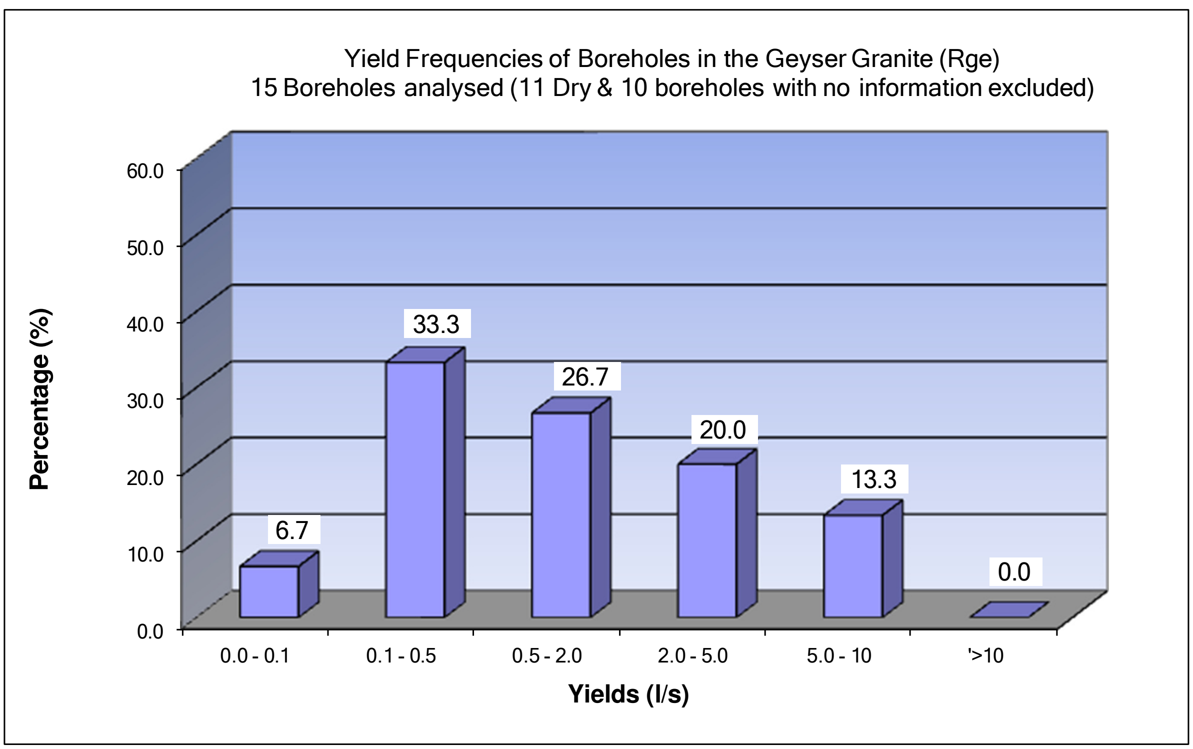


Figure 110: Yield frequency for the intergranular and fractured aquifers of the Geyser Granite (Rge)

The groundwater potential of the Geyser Granite is low to moderate as 66.7% of successful boreholes yield less than 2ℓ/s. A further 20% is yielding between 2 to 5ℓ/s with 13% of boreholes yielding between 5ℓ/s and 10ℓ/s, (Figure 110).

The static water level ranges from 1.26 meters below ground level (mbgl) to 40mbgl, with a median static water level of 12.77mbgl and an average static water level of 15.64mbgl. The maximum depth recorded is 151m, with an average depth of 74.1m and a median depth of 60m. The maximum installation depth is 42m and an average of 26.7m. This can be indicative of water strike depths.

The maximum recommended daily abstraction on record is 51.8 cubic meters per day (m^3/day) and the average is 24.8m^3/day. The 90^{th} percentile is 41m^3/day and the median or 50^{th} percentile is 25.9m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 6.

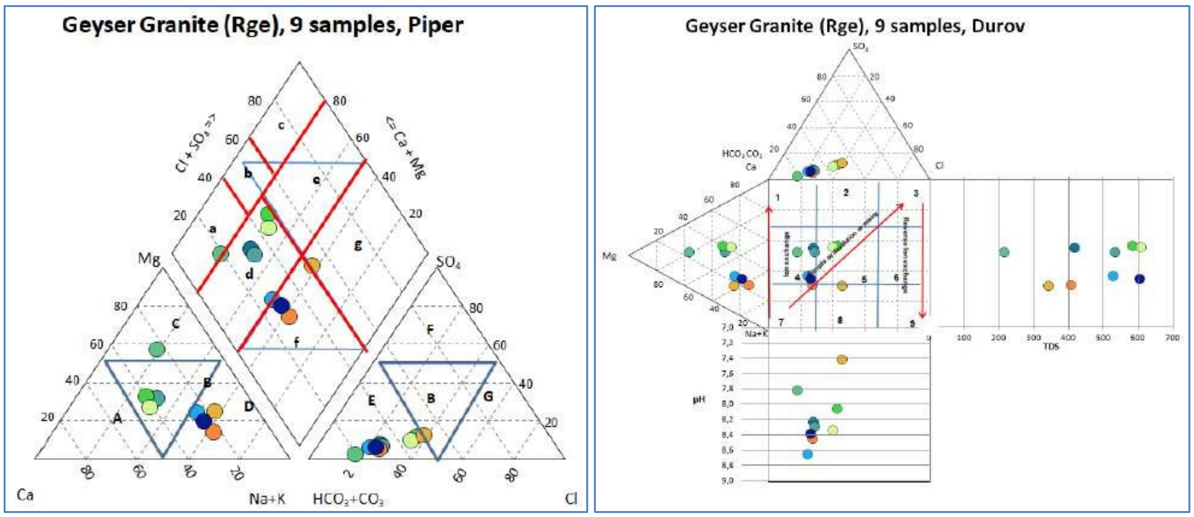


Figure 111: Trilinear diagrams, Piper and Durov for the Geyser Granite (Rge).

The trilinear Piper diagram, (Figure 111) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (55.6%), Weak acidic anions > Strong acidic anions (100%); Alkali >Alkali earths (44.4%); Strong acids > Weak acids (0%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type with increasing Sodium (44.5%);
- Sodium-Bicarbonate type (44.5%).
- Magnesium-Bicarbonate type (11%);

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- Mixed water or water exhibiting simple dissolution (54.5%),
- No dominant anion or cations, the trend can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing (45.59%), points plot along the dissolution or mixing line.

Table 61: Chemical statistics for the Geyser Granite (Rge)

Element / Parameter	Statistics Drawn from a population of 13 data points for the Geyser Granite (Rge)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	13	7,36	8,64	8,07	8,08	7,46	8,21	8,42	0,39	4,8%
Electrical Conductivity (mS/m EC)	13	33,75	84,40	57,84	61,25	49,23	62,60	76,88	14,17	23,1%
Total Dissolved Salts (mg/l TDS)	12	213,0	610,0	410,4	448,9	317,6	419,0	603,7	125,5	27,9%
Calcium (mg/l Ca)	10	16,09	69,37	32,28	41,06	17,18	40,03	66,70	18,99	46,3%
Magnesium (mg/l Mg)	10	8,97	38,70	19,91	23,26	14,67	22,08	34,74	8,70	37,4%
Sodium (mg/l Na)	10	14,18	99,02	43,34	56,68	32,29	54,51	82,08	23,83	42,0%
Potassium (mg/l K)	10	1,41	9,25	2,12	2,86	1,55	2,02	4,08	2,36	82,5%
Chloride (mg/l Cl)	13	11,44	68,70	28,75	37,13	17,82	33,80	61,35	17,92	48,3%
Sulphate (mg/l SO_4)	10	2,60	79,60	10,23	21,06	7,45	13,19	32,13	21,84	103,7%
Total Alkalinity (mg/l) $CaCO_3$)	10	150,9	322,8	212,0	226,1	157,3	227,9	280,2	58,7	26,0%
Nitrate (mg/l N)	11	0,06	24,08	0,37	7,30	0,12	4,21	22,72	8,57	117,4%
Fluoride (mg/l F)	13	0,14	4,65	0,51	1,44	0,26	0,67	3,80	1,50	104,4%
Silicon as Si	10	10,98	21,10	13,58	14,21	11,15	13,39	18,76	3,40	23,9%
Iron (Fe)	5	0,01	1,25	0,02	0,26	0,01	0,01	0,76	0,55	211,9%
Manganese (Mn)	3	0,01	0,14	0,02	0,07	0,02	0,05	0,12	0,07	101,2%
Ortho Phosphate as Phosphorus as PO4	9	0,01	0,80	0,02	0,14	0,01	0,02	0,42	0,27	189,1%
ZAR	10	0,53	3,29	1,39	1,88	1,03	0,58	3,24	0,98	52,2%
LSI	9	Langelier Saturation Index (LSI)			Slightly Scaling		**77,8%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**11,1%**	Balanced Corrosion		**11,1%**

Table 61 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the extent of the problem. In terms of the electric conductivity (EC), the overall water quality is ideal to good with values between 33.75 and 84.4 mS/m. The Total Dissolved Solids (TDS) is acceptable in all (100%) of the samples, (TDS ≤ 1200mg/l).

The evaluation in regard to the main cations and anions of 13 analysis indicates elevated concentrations of Nitrate (N >10mg/l) in 18.2% and Fluoride (F >1.5mg/l) in 23.1% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive (11.1%); predominantly slightly scaling (77.8%) and 11.1% balanced. The ZAR index indicates that 80% of the water is of a fair quality for irrigation (ZAR < 3).

Groundwater abstraction within this unit is minimal and primarily serves to supplement the water supply to a few rural settlements, predominantly in the Mankweng and Bergnek areas. The water demand in these villages is mainly met through surface water sources. Irrigation within this groundwater resource unit is limited. The stronger-yielding boreholes are generally associated with water strikes in low-lying areas characterized by deep weathering.

7.2.3.15 HOUT RIVER GNEISS (Rho)

Only two small occurrences of the Hout River Gneiss are present on the Modimolle map sheet, located to the north and northeast of Mokopane (Figure 112). The unit has been intruded by various granites and numerous diabase dykes, which predominantly trend in a north-west to north-east direction. Although it covers only about 0.63% of the total map sheet, the Hout River Gneiss is an important groundwater resource unit, supporting rural villages and agricultural activities, including irrigation and livestock watering. The area is generally flat and underlain by sandy soil.

The groundwater potential of the gneisses is generally good with 21.7% of boreholes yielding between 2ℓ/s and 5ℓ/s, (Figure 113). High-yielding boreholes in this unit are often associated with the presence of pegmatites. Pegmatite can cause significant variations in borehole yield over very short distances. Additional groundwater targets are deep weathered basins and the transitional zones between weathered material and solid gneiss. Weathering depths exceeding 40 meters are not uncommon, contributing to increased groundwater storage capacity.

Xenoliths of the Pietersburg Group are a common feature within this unit, with the north-east-trending Ysterberg Fault being the most prominent structural lineament transecting the area. Numerous smaller north-east-trending faults and fractured zones are also present and can be effectively targeted for groundwater development.

Fractures encountered at depth are often interpreted as the result of off-loading. Groundwater is also found in fault and shear zones, and to a lesser extent, along diabase dyke contacts. Some of the wider dykes are more fractured, fissured, or decomposed than the surrounding host rock, acting as preferred pathways for groundwater movement. These wider dykes, having cooled more slowly than narrower ones, are typically coarser grained and therefore more susceptible to weathering and fracturing (Du Toit, 1986).

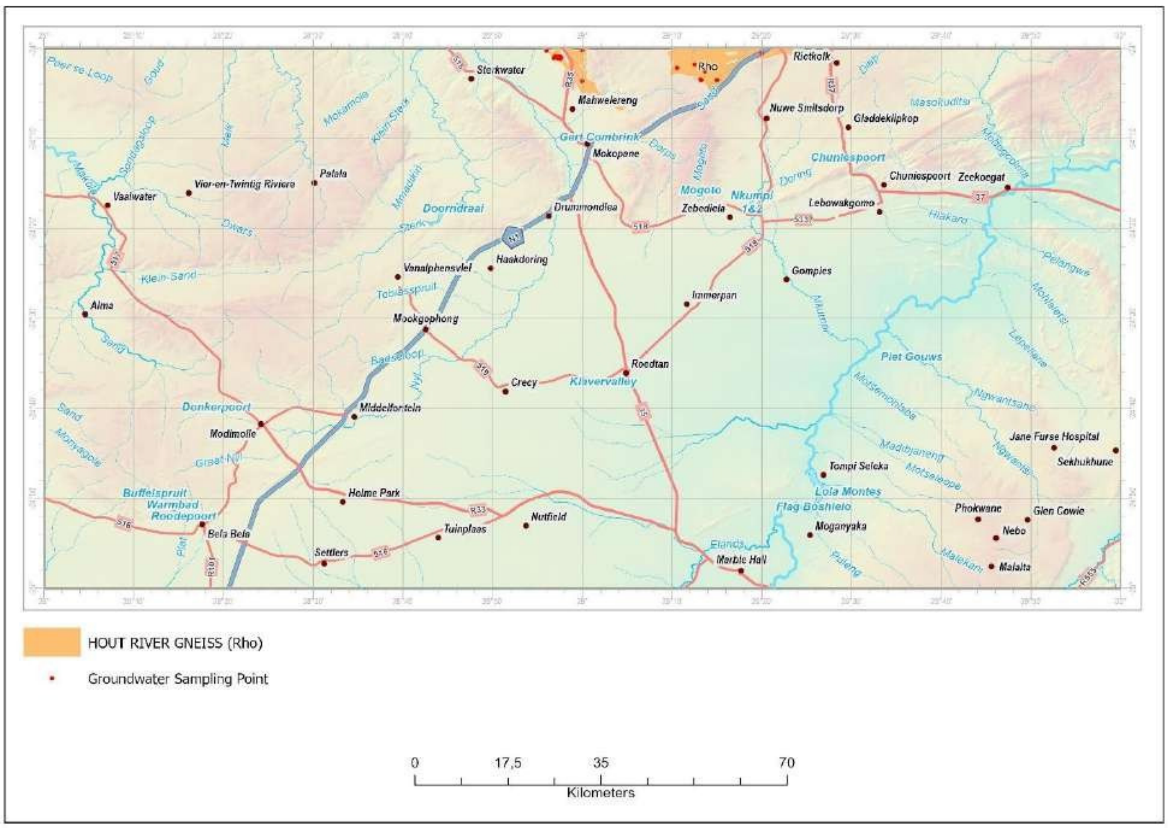


Figure 112: Geographical distribution of the Hout River Gneiss (Rho) and associated groundwater sampling points

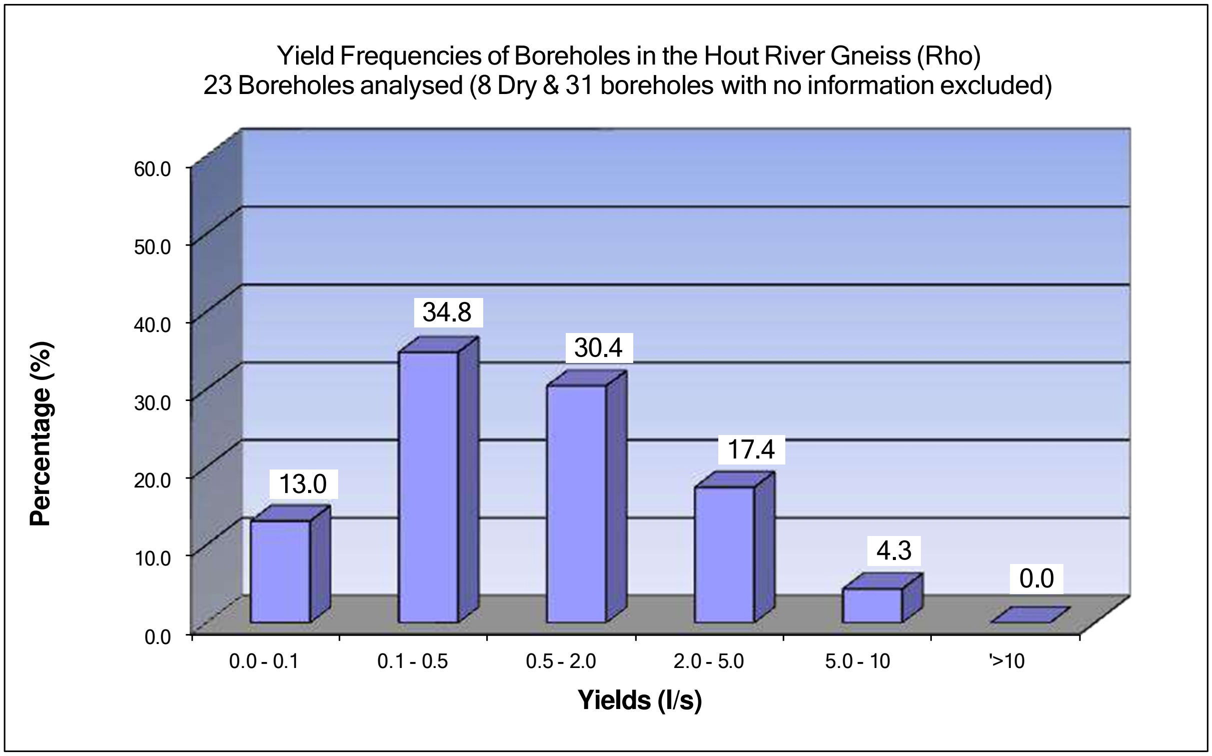


Figure 113: Yield frequency for the intergranular and fractured aquifers of the Hout River Gneiss (Rho).

Although the data is limited within this unit, the yield frequency distribution gives a good indication of the groundwater potential. Figure 113 shows that 47.8% of successful boreholes yield less than 0.5ℓ/s, while 30.4% yields between 0.5ℓ/s to 2ℓ/s and 21.7% of the boreholes yield between 2ℓ/s to 10ℓ/s.

The static water level ranges from 3.47 meters below ground level (mbgl) to 35mbgl, with a median static water level of 18.6mbgl, and an average of 18.96mbgl, (based on 26 data records). The maximum depth recorded is 100m, with an average depth of 57.6m, and a median depth of 60.7m, (13 data records). The maximum installation depth is 48m and an average of 30m, (7 data records).

The maximum recommended daily abstraction on record is 190.1 cubic meters per day (m^3/day), and the average is 79.3m^3/day. The 90th percentile is 179.7m^3/day and the 50th percentile (median) daily abstraction is 60.5m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 7.

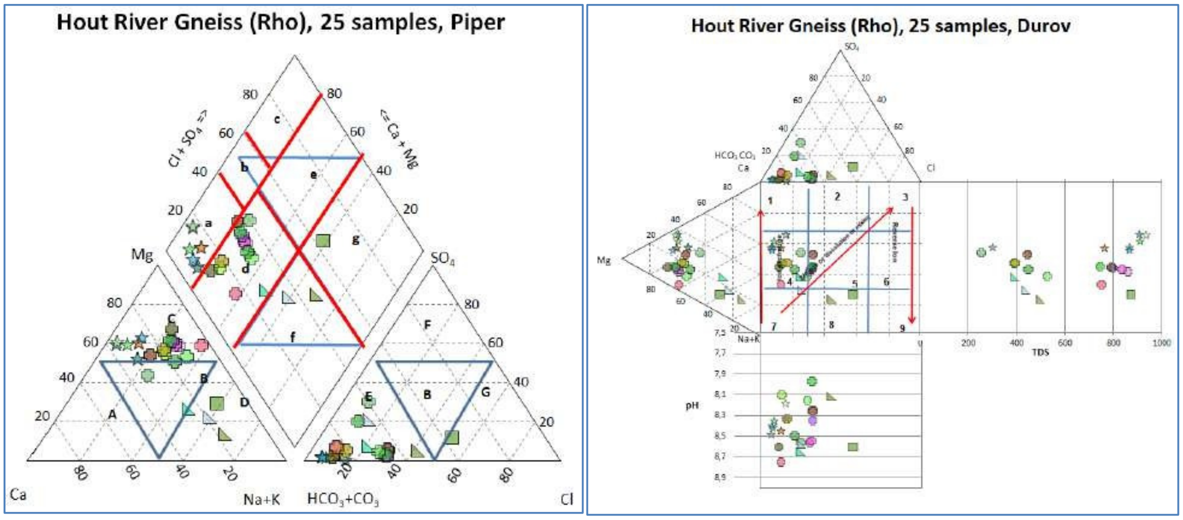


Figure 114: Trilinear diagrams, Piper and Durov for the Hout River Gneiss (Rho).

The trilinear Piper diagram, (Figure 114) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (87.5%), Weak acidic anions > Strong acidic anions (95.8%); Alkali >Alkali earths (12.5%); Strong acids > Weak acids (4.2%).

The second evaluation was on the water type:

- Magnesium-Bicarbonate type (80%);
- Sodium-Bicarbonate type (12%);
- Mixed Calcium-Magnesium-Bicarbonate type (4%);
- Sodium-Chloride type (4%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- Mixed water or water exhibiting simple dissolution or mixing (80%),
- Cl and Na dominate indicative of reverse ion exchange of Na-Cl water (12%),
- No dominant anion or cations, the trend can be attributed to fresh recent recharged water exhibiting simple dissolution or mixing (8%), points plot along the dissolution or mixing line,

Table 62: Chemical statistics for the Hout River Gneiss (Rho)

Element / Parameter	Statistics Drawn from a population of 28 data points for the Hout River Gneiss (Rho)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10^{th} percentile	50^{th} percentile (median)	90^{th} percentile	Standard Deviation	Coefficient of Variation
pH	28	7,32	8,66	8,10	8,11	7,73	8,14	8,46	0,32	4,0%
Electrical Conductivity (mS/m EC)	28	28,10	121,10	66,71	77,32	44,97	83,55	107,85	26,69	34,5%
Total Dissolved Salts (mg/l TDS)	28	176,0	937,8	516,5	628,9	361,5	749,0	884,2	238,3	37,9%
Calcium (mg/l Ca)	28	7,10	88,12	27,88	38,63	19,83	30,31	79,93	22,92	59,3%
Magnesium (mg/l Mg)	28	11,40	99,33	36,97	56,31	16,18	51,50	87,97	29,02	51,5%
Sodium (mg/l Na)	28	8,92	163,49	26,98	44,45	12,93	28,08	76,04	34,08	76,7%
Potassium (mg/l K)	28	1,00	27,06	3,40	5,61	1,80	4,47	8,57	5,23	93,2%
Chloride (mg/l Cl)	28	4,00	161,30	18,62	35,55	11,89	20,96	74,37	33,04	92,9%
Sulphate (mg/l SO_4)	28	2,00	50,29	7,07	12,10	4,62	8,49	30,13	10,98	90,7%
Total Alkalinity (mg/l) $CaCO_3$)	26	121,1	553,9	307,0	368,8	202,1	445,1	545,1	142,2	38,5%
Nitrate (mg/l N)	27	0,11	12,89	0,48	3,01	0,16	1,66	7,55	3,53	117,2%
Fluoride (mg/l F)	28	0,16	1,90	0,31	0,51	0,18	0,33	1,19	0,45	88,7%
Silicon as Si	26	6,5	42,4	21,8	27,1	12,8	30,4	36,3	9,8	36,3%
Iron (Fe)	4	0,01	0,06	0,01	0,02	0,01	0,01	0,05	0,03	111,7%
Manganese (Mn)	1	0,01	0,01	0,01	0,01	0,01	0,01	0,01		
Ortho Phosphate as Phosphorus as PO4	26	0,01	0,21	0,01	0,03	0,01	0,01	0,07	0,05	155,4%
ZAR	28	0,16	4,50	0,64	1,23	0,38	0,88	2,32	1,12	91,0%
LSI	26	Langelier Saturation Index (LSI)			Slightly Scaling		**61,5%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**38,5%**

Table 62 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the extent of the problem. In terms of the electric conductivity (EC), the overall water quality is ideal to good with values between 28.1 and 121.1mS/m. The Total Dissolved Solids (TDS) is acceptable in all (100%) of the samples, (TDS ≤ 1200mg/l). An evaluation of the major anions and cations of 28 samples indicates elevated concentrations of Fluoride (F >1.5mg/l), in 7.1% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is dominantly slightly scaling (61.5%) and balanced (38.5%). The ZAR index indicates that 89.2% of the water is of a fair quality for irrigation (ZAR < 3).

The water abstracted supplies two (2) rural settlements with potable water. Water is also abstracted for game, livestock watering and irrigation. In 7.1% of the water samples, at least one element exceeds the maximum allowed limits for human consumption. For this unit the anion of concern is Fluoride. The other major anions and cations fall within the ideal to marginal water class.

7.2.3.16 GOUDPLAATS GNEISS (Zgo)

Only a very small occurrence of the Goudplaats Gneiss appears along the north-eastern section of the map sheet. The Goudplaats Gneiss, (Figure 115) consists of gneiss, layered gneiss, migmatite and accompanying leuco-granite. Due to extended sandy soil cover, outcrop is mostly visible in ephemeral stream beds. The gneiss can be large unfoliated masses or can exhibit alternating bands of melanocratic and leucocratic material. This unit is believed to have formed the basement to the Bandelierskop Complex and the Pietersburg Group. It has been intruded by various granites and numerous diabase and dolerite dykes with a predominantly north-east to south-west orientation. The unit covers approximately 0.49% of the map sheet area.

The groundwater potential of the Goudplaats Gneiss is considered moderate, though it is not as favorable as that of the Hout River Gneiss. Groundwater levels typically range between 10 and 30 meters below ground level (mbgl). The groundwater resource unit is extensively used for both domestic and agricultural purposes and, in some rural areas, serve as the sole source of water supply for communities.

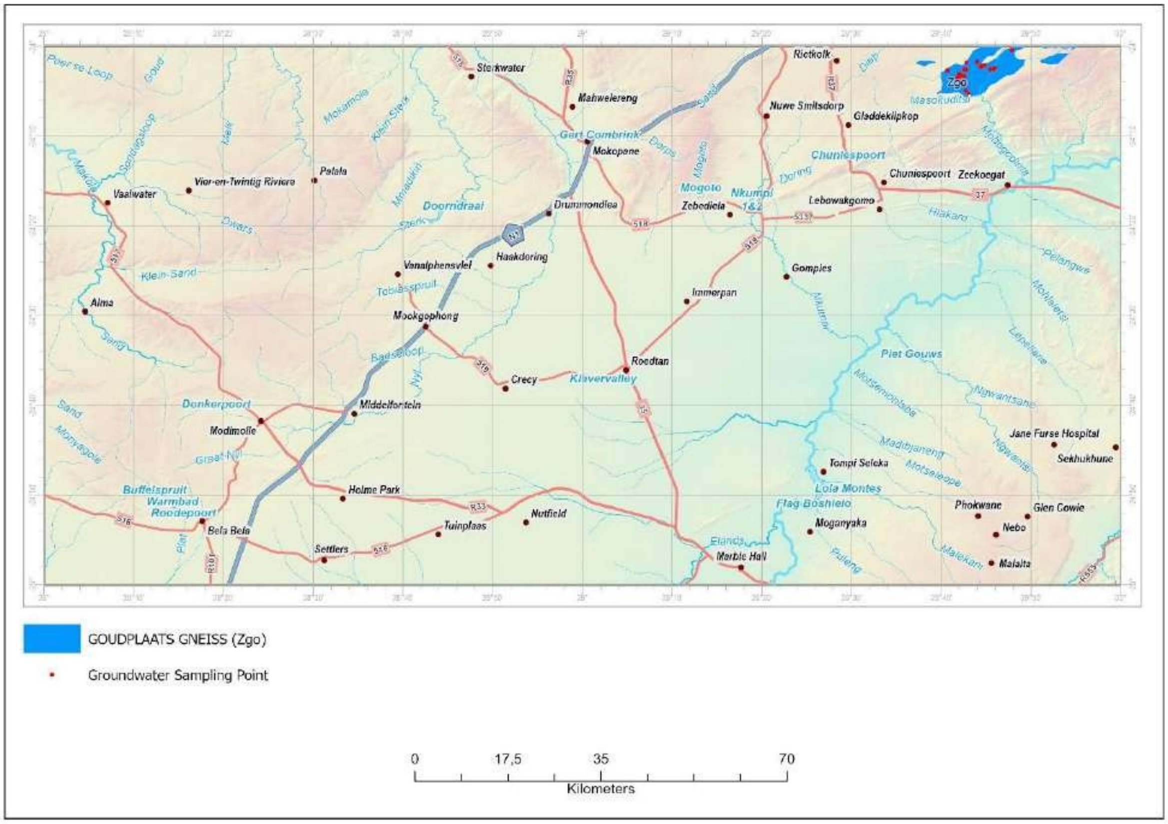


Figure 115: Geographical distribution of the Goudplaats Gneiss (Zgo) and associated groundwater sampling points.

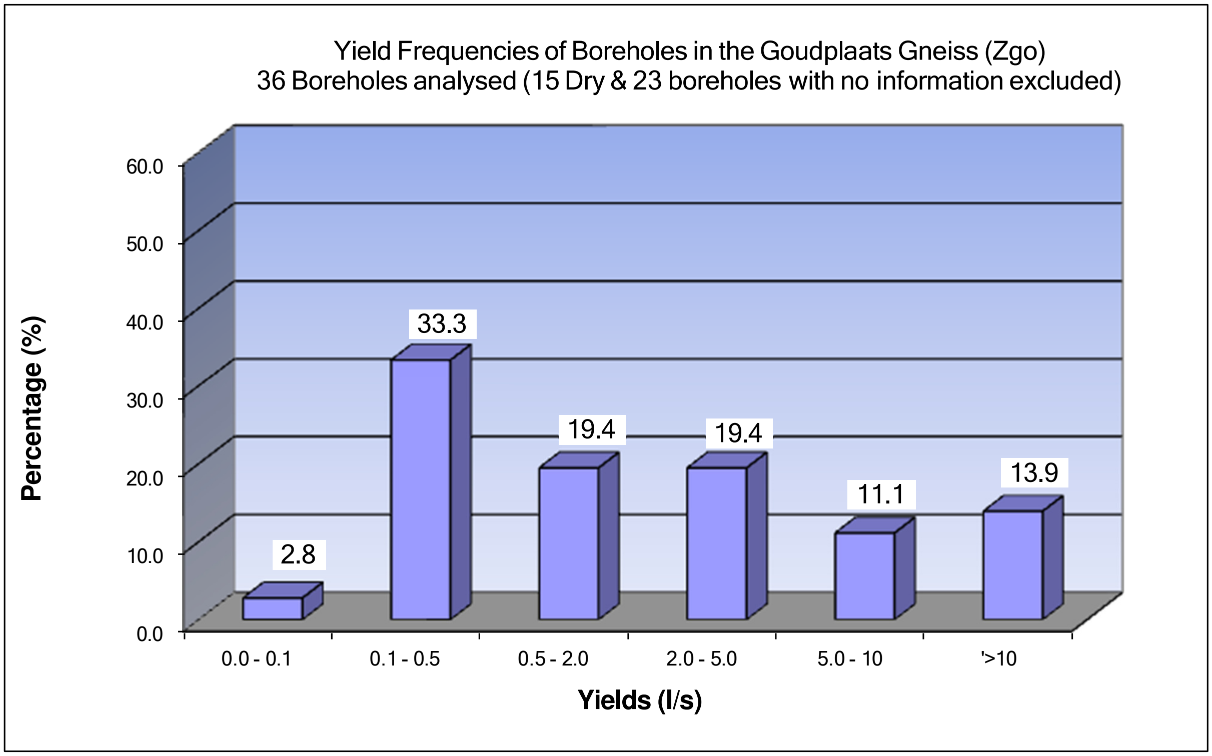


Figure 116: Yield frequency for the intergranular and fractured aquifers of the Goudplaats Gneiss (Zgo)

The yield frequency distribution diagram in Figure 116 gives a very good indication of the expected groundwater potential. For 55.6% of the successful boreholes the maximum yield is less than 2ℓ/s. A further 19.4% of boreholes yield between 2ℓ/s to 5ℓ/s and 25% yields more than 5ℓ/s. Geophysical methods have been successfully employed in the search for groundwater within this unit. Groundwater targets usually include deep weathering and fracturing, faults, pegmatite zones and secondary fracturing associated with dyke intrusions. The success rate increases in areas where the gneiss exhibits strong foliation and pegmatitisation.

The static water level ranges from 0.15 meters below ground level (mbgl) to 36.05mbgl, with a median static water level of 12.5mbgl, and an average static water level of 13.85mbgl, (based on 29 data records). The maximum depth recorded is 150.4m, with an average depth of 71.7m, and a median depth of 60.6m, (44 data records). The maximum installation depth is 120m, with an average of 39m. The maximum depth can be indicative of the depth of deep fractures while the average represents the intergranular fractured zone.

The maximum recommended daily abstraction on record is 432 cubic meters per day (m^3/day), and the average is 75.9m^3/day. The 90th percentile for daily abstraction is 172.8m^3/day and the 50th percentile (median) is 25.9m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 24.

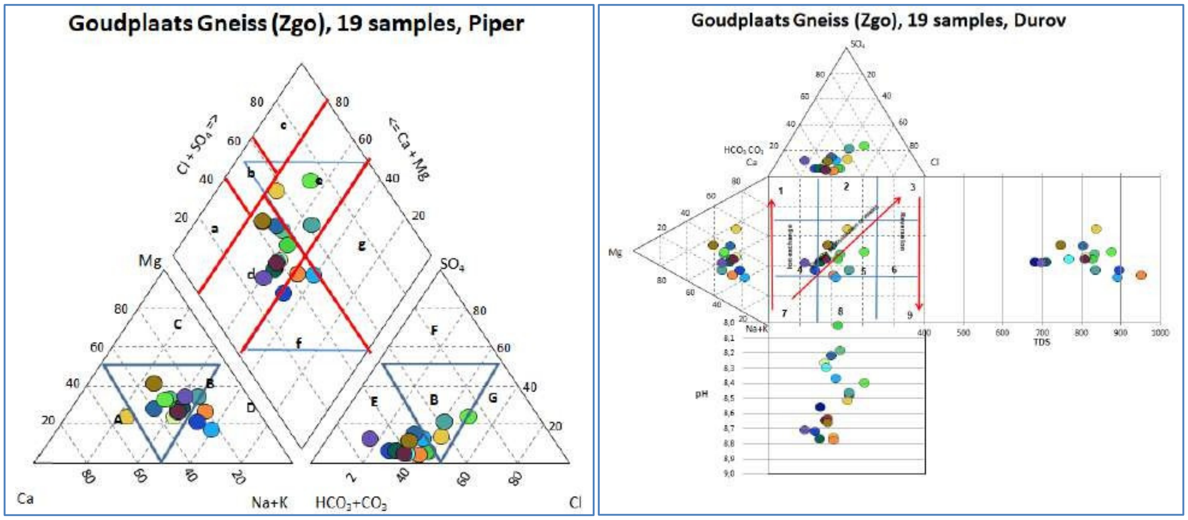


Figure 117: Trilinear diagrams, Piper and Durov for the Goudplaats Gneiss (Zgo).

The trilinear Piper diagram, (Figure 117) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The initial evaluation of chemical dominance is as follows: Alkali earths > Alkali (84.2%), Weak acidic anions > Strong acidic anions (79%); Alkali >Alkali earths (15.8%); Strong acids > Weak acids (21%).

The second evaluation was on the water type and is as follows:

- Mixed Calcium-Magnesium-Bicarbonate type with increasing Sodium (68%);
- Sodium-Bicarbonate type (16%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with increasing Sodium (11%);
- Calcium-Bicarbonate-Chloride type (5%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- No dominant anion or cations, the trend can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing (89%), points plot along the dissolution or mixing line,
- Mixed water or water exhibiting simple dissolution (11%).

Table 63: Chemical statistics for the Goudplaats Gneiss (Zgo)

Element / Parameter	Statistics Drawn from a population of 28 data points for the Goudplaats Gneiss (Zgo)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	28	6,70	8,54	7,81	7,84	7,19	7,92	8,44	0,52	6,6%
Electrical Conductivity (mS/m EC)	28	63,45	158,67	94,40	99,58	64,27	98,06	121,60	23,51	23,6%
Total Dissolved Salts (mg/l TDS)	28	417,30	1191,89	695,88	736,24	509,07	725,24	920,00	176,33	24,0%
Calcium (mg/l Ca)	27	31,33	126,84	57,97	64,84	39,42	57,90	93,62	23,30	35,9%
Magnesium (mg/l Mg)	27	24,00	97,97	36,33	39,86	26,36	40,90	50,85	14,60	36,6%
Sodium (mg/l Na)	27	40,02	167,57	79,38	91,73	50,24	88,10	153,16	35,51	38,7%
Potassium (mg/l K)	27	1,480	11,557	2,699	3,792	1,700	2,850	6,879	2,660	70,1%
Chloride (mg/l Cl)	28	19,75	270,10	69,58	90,96	42,68	83,13	120,42	49,19	54,1%
Sulphate (mg/l SO_4)	28	12,00	124,40	25,55	37,99	12,88	27,36	72,81	26,60	70,0%
Total Alkalinity (mg/l) $CaCO_3$)	24	174,34	444,00	282,55	302,08	231,01	262,90	424,39	80,89	26,8%
Nitrate (mg/l N)	28	0,70	66,96	3,85	16,60	1,58	8,97	45,89	18,30	110,2%
Fluoride (mg/l F)	27	0,080	1,637	0,385	0,578	0,230	0,510	1,016	0,363	62,9%
Silicon as Si	25	4,75	28,57	14,41	18,49	8,30	18,22	26,50	6,92	37,4%
Iron (Fe)	14	0,010	0,614	0,016	0,093	0,010	0,014	0,358	0,198	212,3%
Manganese (Mn)	14	0,006	0,769	0,016	0,123	0,006	0,025	0,371	0,221	179,9%
Ortho Phosphate as Phosphorus as PO4	24	0,006	0,800	0,015	0,057	0,010	0,014	0,050	0,159	281,9%
ZAR	27	1,080	4,575	1,941	2,277	1,169	2,057	3,789	0,943	41,4%
LSI	24	Langelier Saturation Index (LSI)			Slightly Scaling		**58,3%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**41,7%**

Table 63 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the extent of the problem. In terms of the electric conductivity (EC), the overall water quality is ideal to good (92.9%) to moderate, values range between 63.45 and 158.67mS/m.

The Total Dissolved Solids (TDS) is acceptable in all (100%) of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions of 28 available samples indicates elevated concentrations of Fluoride (F >1.5mg/l), in 7.4% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is dominantly slightly scaling (58.3%) and balanced (41.7%). The ZAR index indicates that 81.4% of the water is of a fair quality for irrigation (ZAR < 3).

Groundwater abstracted from this unit supplies some rural settlements in the Mankweng area with potable water, where it is used conjunctively with surface water sources. Within the map sheet area, no irrigation activities are associated with this unit. Water quality data indicates that in 7.4% of the samples, at least one element exceeds the maximum allowable limit for domestic use. The primary anion of concern is Fluoride, while the concentrations of other major anions and cations generally fall within the ideal to marginal water quality classes.

7.2.3.17 PIETERSBURG GREENSTONE BELT (Zpg) (PIETERSBURG GROUP)

The Pietersburg Greenstone Belt is a typical Archaean greenstone belt with exposures east of Mokopane (Potgietersrus), (Figure 118). It forms a series of well-defined ridges, including the well-known Mount Marè (not indicated on the map). Granodioritic and tonalitic gneisses flank the northern margin of the belt and massive unfoliated granite of various compositions flank its southern margin. It underlay approximately 1.17% of the map sheet.

Six formations (not separated on the map) were distinguished within the Group of which only the **Mothiba, Eersteling and Sandrivierspoort Formations** are of some importance in terms of groundwater.

The Mothiba Formation consists of ultramafic metavolcanics, Talc-Chloride and amphibole- Chloride schist, talc schist, serpentinite, and amphibolite with thinly interbedded banded ironstone and ferruginous quartzite. The Eersteling Formation consists of scattered xenoliths of amphibolites and the Sandrivierspoort Formation consists of mafic metavolcanic rock and intercalated magnetite quartzite, minor metaquartzite, quartz-sericite schist and calc-silicate rocks.

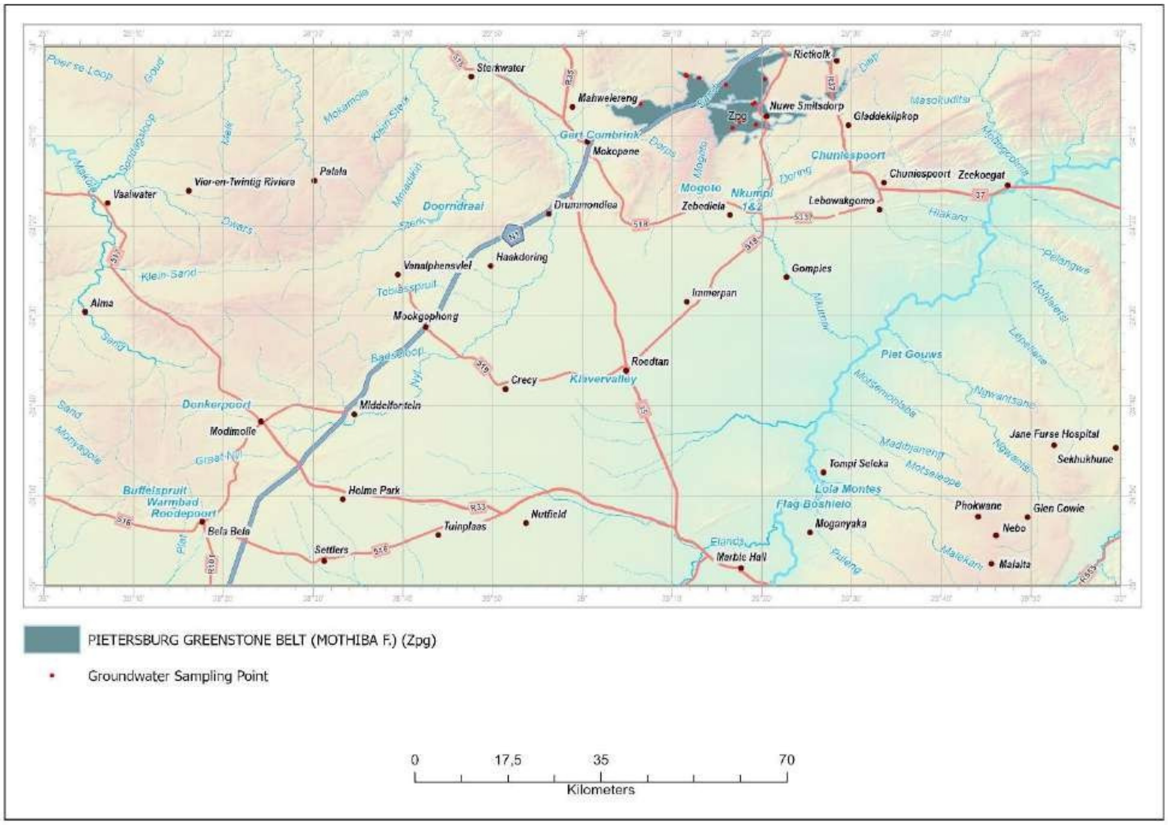


Figure 118: Geographical distribution of the Pietersburg Greenstone Belt (Zpg) (Pietersburg Group) and associated groundwater sampling points.

Groundwater occurs mainly in faults and associated shear zones, lithological contacts, dyke contacts and fractured lavas, quartzite, and schist. The Eersteling and Sandriviersspoort Formations have in general a low groundwater potential although some strong boreholes, related to the fractured Sandriviersspoort and Hout River Gneiss contact, have been reported. Deep weathering between 18m to 48m is found in the Mothiba Formation. However, a very low permeability, possibly due to excessive clay produced through the weathering processes, renders its basins of weathering extremely poor aquifers. Water is exclusively obtained in fissures and fractures below the weathering zone. Fissures and fractures in the Pietersburg Greenstone belt originate mainly from folding, faulting, assimilation and metamorphism, and intrusion of granitic batholiths, diabase dykes and other tectonic forces. Although the Belt possesses limited storage capacity, 41.5% of boreholes within the greenstones yield more than 2ℓ/s, (Figure 119).

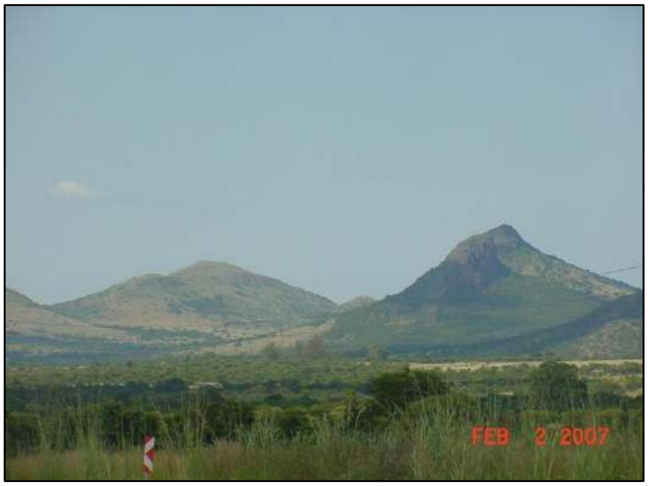


Plate 13: View of Ysterberg on the right looking south comprising banded ironstone of the Pietersburg Group and sediments of the Transvaal Sequence making up the mountain on the left with the Ysterberg fault running along the valley between them. The Ysterberg fault, which is of pre- Transvaal age, was re-activated on occasions until after deposition of the Transvaal Sequence. It has a lateral displacement of about 9 km (Photograph: WH Du Toit)

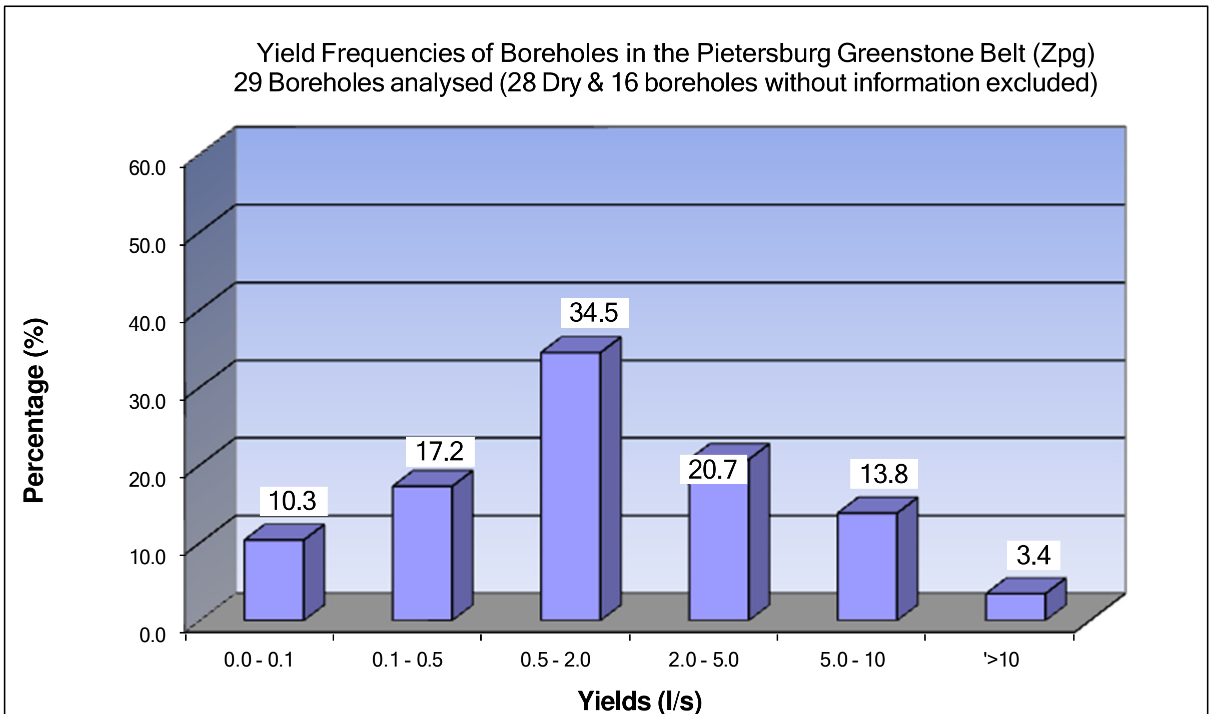


Figure 119: Yield frequency for the intergranular and fractured aquifers of the Pietersburg Greenstone Belt (Zpg)

The yield frequency diagram represents data from 41 borehole sources. Statistics show that 34.5% of boreholes yield between 0.5ℓ/s to 2ℓ/s, while 27.5% yields less than 0.5ℓ/s. A further 20.7% of boreholes yield between 2ℓ/s to 5ℓ/s, with 17.2% of the boreholes yielding more than 5ℓ/s.

The static water level ranges from 1.83 meters below ground level (mbgl) to 60mbgl, with a median static water level of 15.2mbgl, with an average static water level of 17.02mbgl, (based on 44 records). The maximum depth recorded is 65.1m, with an average depth of 39.2m, and a median depth of 39.7m, (6 data records). The maximum installation depth is 60m and an average installation depth of 31.5m, (4 data records).

The maximum recommended daily abstraction on record is 345.6 cubic meters per day (m³/day), and an average of 144.7m³/day. The 90th percentile is 291.2m³/day and the 50th percentile for daily or median for daily abstraction is 110.2m³/day. The total number of boreholes subjected to pump testing within this unit on record is 4.

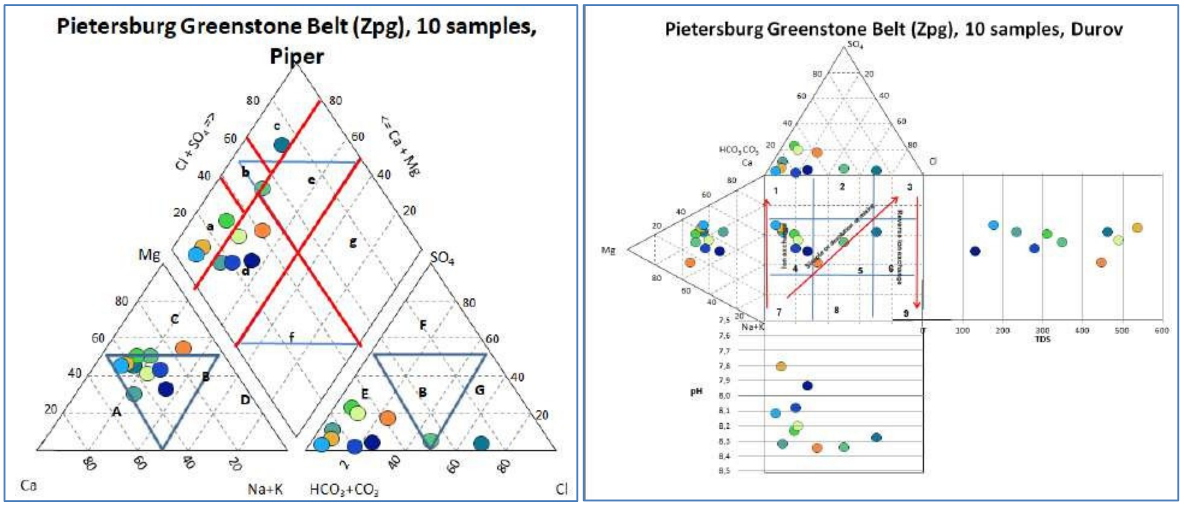


Figure 120: Trilinear diagrams, Piper and Durov for the Pietersburg Greenstone Belt (Zpg).

The trilinear Piper diagram, (Figure 120) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies.

The initial evaluation of chemical dominance is as follows:

- Alkali earths > Alkali (100%),
- Weak acidic anions > Strong acidic anions (85%);
- Alkali >Alkali earths (0%);
- Strong acids > Weak acids (15%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (50%);
- Calcium-Magnesium-Bicarbonate type (30%);
- Calcium-Magnesium-Chloride type (10%);
- Magnesium-Bicarbonate-Chloride (10%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type; the indication is that recharge and/or mixing dominates (80%) and simple dissolution or mixing (20%)

Table 64: Chemical statistics for the Pietersburg Greenstone Belt (Zpg)

Element / Parameter	Statistics Drawn from a population of 14 data points for the Pietersburg Greenstone Belt (Zpg)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	14	6,80	8,51	7,82	7,86	6,99	8,05	8,47	0,56	7,2%
Electrical Conductivity (mS/m EC)	14	18,00	82,90	43,24	52,85	26,86	58,00	79,68	20,96	39,7%
Total Dissolved Salts (mg/l TDS)	13	129,0	538,0	302,7	360,7	187,4	374,0	519,1	131,6	36,5%
Calcium (mg/l Ca)	13	11,40	79,84	29,51	40,35	18,96	29,50	72,01	22,26	55,2%
Magnesium (mg/l Mg)	13	7,00	53,68	21,52	30,54	11,20	31,41	47,47	14,51	47,5%
Sodium (mg/l Na)	13	5,90	43,90	17,20	22,32	12,68	21,50	34,94	10,49	47,0%
Potassium (mg/l K)	13	0,50	2,75	1,07	1,55	0,58	1,49	2,62	0,86	55,4%
Chloride (mg/l Cl)	14	2,31	125,50	7,89	24,51	3,59	12,70	52,75	33,28	135,8%
Sulphate (mg/l SO_4)	14	2,00	69,80	5,23	18,14	2,00	9,05	34,79	19,38	106,8%
Total Alkalinity (mg/l) $CaCO_3$)	10	66,4	442,9	148,6	185,9	114,6	156,3	271,2	103,5	55,7%
Nitrate (mg/l N)	14	0,07	21,46	0,54	3,73	0,36	1,93	6,44	5,54	148,6%
Fluoride (mg/l F)	13	0,100	2,220	0,199	0,619	0,102	0,200	1,922	0,767	123,8%
Silicon as Si	14	5,48	27,60	16,60	19,28	14,43	20,43	24,61	5,40	28,0%
Iron (Fe)	7	0,006	0,050	0,014	0,027	0,008	0,015	0,050	0,021	78,5%
Manganese (Mn)	5	0,010	0,050	0,019	0,034	0,010	0,050	0,050	0,022	64,4%
Ortho Phosphate as Phosphorus as PO4	13	0,005	0,930	0,013	0,211	0,005	0,024	0,800	0,362	171,9%
ZAR	13	0,237	1,295	0,555	0,670	0,400	0,615	0,957	0,287	42,8%
LSI	10	Langelier Saturation Index (LSI)			Slightly Scaling		**40,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**10,0%**	Balanced Corrosion		**50,0%**

Table 64 gives a summary of the physical properties, the major anions, cations and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the extent of the problem. The overall water quality is ideal to good with electric conductivity (EC) values varying between 18 and 82.9mS/m. The Total Dissolved Solids (TDS) is acceptable in all (100%) of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions of 14 available samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 15.4% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive (10%); slightly scaling (40%) and balanced (50%). The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3).

Groundwater abstracted from this aquifer unit supplies potable water to several rural settlements in the Mankweng area, where it is used in conjunction with surface water sources. Within the map area, no irrigation activities are associated with this unit. Water quality analysis indicates that in 15.4% of the samples, at least one element exceeds the maximum allowable limit for domestic use. The primary anion of concern is fluoride, while the concentrations of other major anions and cations fall within the ideal to marginal water quality classes.

8. SPRINGS AND ARTESIAN BOREHOLES

8.1 Hot Springs

Of the 90 (Kent, 1968) known hot springs in the Republic of South Africa, 8 occurs on the Nylstroom hydrogeological map sheet at the following locations:

- 15km north of Marble Hall (unnamed),
- 45km east of Roedtan (unnamed),
- Warmbaths (now Bela Bela),
- Loubad (25km north west of Modimolle, (Nylstroom)),
- Vischgat (10km south-west of Mookgophong, (Naboomspruit)),
- Libertas (10km north-west of Mookgophong, (Naboomspruit)),
- Die Oog (10km north-west of Mookgophong, (Naboomspruit)),
- Driefontein (10km north of Mookgophong (Naboomspruit)).

In all the above cases heated water rises along fault zones reaching the surface as springs on the topographically lowest points. Deep groundwater circulation related to fault zones is most likely the reason for the occurrence of several warm water boreholes in the area. Although not depicted on the map they occur at Stokkiesdraai and Wonderkrater just outside Modimolle (Nylstroom) and Mookgophong (Naboomspruit).

Since active volcanic regions are non-existent in South Africa, magmatic water can therefore not play a role regarding the origin (source) of the hot water, also not as a source of heat (Visser, 1989). The source of the water must therefore be meteoric. According to Kent (1949, 1968), the catchment areas are in the adjoining more elevated terrains, from where rainwater filters along joint and fracture planes and eventually into narrow conduits. Along these conduits, the water descends to such depths where the internal heat of the earth causes local convection cells to develop, and the water is heated. The descending of cold water and subsequent ascending of heated water is a gradual process. Isotope age determinations conducted at the Warmbaths spring, indicated the age of the water to be in the order of 20 000 years.

8.2 Cold Springs

Springs are natural exit points where groundwater emerges from an aquifer and flows across the surface as surface water. Interflow, on the other hand, refers to the lateral movement of water within the unsaturated (vadose) zone, which eventually returns to the surface or enters a stream, (Wikipedia).

Table 65: List of the cold springs within the map sheet with annual registered abstraction.

Description	Latitude	Longitude	Abstraction (m³/annum)
SPRING DAM 2	-24.314167	28.492778	444000
SPRING	-24.613890	28.263890	179491
SPRING	-24.375000	28.634720	144000
SPRING	-24.577780	28.147220	137250
SPRING	-24.489722	28.290556	137250
SPRING	-24.470278	28.362778	137250
SPRING	-24.484230	28.125530	91950
SPRING	-24.482500	28.113889	87420
SPRING	-24.484440	27.917780	62460
SPRING	-24.494340	27.907710	61490
UNKNOWN	-24.093100	28.605700	57000
SPRING	-24.597222	28.209722	56660
SPRING	-24.121667	28.806389	55522
SPRING	-24.450000	28.210000	52640
SPRING	-24.602780	28.265280	46488
SPRING	-24.613890	28.263890	44618
KAMEELFONTEIN SPRING	-24.236694	28.349778	40000
SPRING	-24.639600	28.291600	39934
UNKNOWN	-24.627780	28.200000	31625
SPRING	-24.596611	28.208583	30000
SPRING	-24.828610	28.392870	29190
SPRING	-24.602780	28.265280	26478
SPRING	-24.731200	28.161300	15950
SPRING	-24.427944	28.642444	14108
SPRING	-24.577340	28.502560	12000
SPRING	-24.209750	28.736750	11000
SPRING	-24.519370	28.290200	3650
SPRING DAM 1	-24.320306	28.502528	3650
			2053074

Within the Modimolle map sheet area, 28 cold springs are registered, with a combined registered abstraction volume of 2,053,740 cubic meters per annum (m³/annum). The data was obtained from the e-WULAAS database. Of these, six springs each abstract more than 100,000m³ annually. Many of the springs, especially the more perennial ones, are associated with dolomitic rock formations, such as those found in the Mokopane (Potgietersrus) and Wolkberg regions. These springs are important contributors to baseflow in rivers, such as the Olifants River. Exact flow rates and seasonal fluctuations are not well documented. Additional springs are also found in the Waterberg and Marble Hall areas.

Numerous farms in the map sheet area were named after springs that occur on them. However, most of these springs dried up when boreholes were drilled and the farms developed. An old (±1970) report for the Zebediela Estate mentioned two springs that dried due to abstraction of groundwater for irrigation. Surface abstraction and groundwater abstraction from the dolomites in the Buffelsberg (Mogoto Mountain) may have contributed to the decrease in recharge to these springs.

The cold springs on the map sheet area rise mostly in valleys on the upstream side of dykes, from geological contacts or fault zones or where the water level cuts the topography.

8.3 Artesian boreholes

The definition of an artesian borehole is a borehole that penetrated a confined aquifer in which the Piezometric surface is above ground level. This will result in water being discharged from the borehole without being pumped. The definition of a confined aquifer is a water bearing formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations thus a confined groundwater is generally subject to pressure greater than atmospheric, (DWS Groundwater Dictionary). In addition to the above, the confined water bearing formation must be exposed to recharge at some distance away, and the formation needs to be permeable to enable the flow of the water within the aquifer from the recharged area to the outlet point.

The Piezometric pressure or hydraulic head at the point of recharge that will be represented by the static water level needs to be at a higher altitude than the surface area at the discharge point. Artesian conditions that include outflow or the rate of outflow at a borehole may be seasonal due to the Piezometric pressure head at the recharge point being lowered by drought. To explain to a layman, it can be best illustrated by using a bend pipe with one end higher than the other; when water is added to the higher point it will flow out at the lower point at a yield equal to inflow. In a geological context the pipe is filled with material with small openings and cracks. The dominant forces that will determine the outflow rate and volume are inflow volume, hydraulic pressure, (difference in height), as well as permeability, (connection between openings).

Artesian conditions prevail in only four known areas within the map sheet. Possible explanations of the reasons for this phenomenon are given for each of the areas.

- Nylsvley between Modimolle (Nylstroom) and Mookgophong (Naboomspruit).
- Bela-Bela (Warmbaths).
- Eastern part of the northern Springbok Flats.
- Libertas, 10km northwest of Mookgophong (Naboomspruit).

The last three listed are not indicated on the map.

The artesian boreholes at **Nylsvley** flow under hydrostatic pressure from micro fractures, which are probably recharged from higher altitudes to the north of Nylsvley. The flow rate is at most not more than 0.2ℓ/s.

In the **Bela-Bela (Warmbaths)** case it was envisaged that the development of two major east-west trending faults that transect the area resulted in the formation of numerous minor fractures in the underlying granite. The fractures are aligned sub-parallel to the major fault direction (Verhagen, 1981). An artesian borehole, which is also hot (38°C), is drilled in such a fracture. It is considered that the artesian borehole and the hot spring have the same original source, which is being heated through the same deep convection processes. The water is transmitted along the fracture network and brought to the surface at pressures higher than atmospheric pressure resulting in artesian conditions. The borehole flows at a rate of 2.7ℓ/s. The isotope radiocarbon dating gives a conventional age of 27 000 years for the water flowing from this borehole. It was reported by Verhagen that the borehole was most likely been destroyed after his visit.

The artesian borehole at **Libertas** replaced the original hot spring as water source. Both are situated in the Welgevonden fault zone. The water has a temperature of 51.3°C and flows at a rate of approximately 10ℓ/s. As discussed under hot springs, it is most probably related to deep circulating water recharged at a higher altitude.

9. GROUNDWATER RELATED MATTERS

9.1 The National Water Act (Act 108 1998)

The **National Water Act** (Act 108 of 1998) replaces the old Water Act (Act 56 of 1956). Water resources are now recognised as scarce and unevenly distributed national assets. The most important implications to groundwater users are that groundwater is now considered as part of the larger **hydrologic cycle** and that **ownership** thereof is not private but belonging to all South Africans. The meaning of this is that landowners with strong groundwater sources or with a river occurring on his or her property do not have the right to use the water without authorization.

The Act makes provision for the separation of power between different spheres of government. The **Minister of the Department of Water and Sanitation is the custodian** (trustee) of water resources on behalf of the National Government, with the responsibility to provide a framework for the protection, to promote equitable access to water, to facilitate social and economic development, to protect aquatic and associated ecosystems and their biological diversity, and management of water resources for the country. It must be managed in an integrated manner according to the principles of the Act (sustainability, equity, and efficiency). It must also meet international obligations.

The Act allows the Minister to delegate most of his or her powers and duties to departmental officials, water management institutions, advisory committees, and water boards. The framework to achieve the principles and purpose of the Act is the National Water Strategy (NWS). To manage water resources on local level, Catchment Managing Agencies (CMAs) and Water User Associations (WUAs) must be established. These institutions must operate under the framework of the NWS and DWA guidelines. The CMA is responsible for a water allocation plan within their catchments and a Catchment Water Strategy (CWS) that is similar to the NWS. The WUA is responsible for a few functions such as the protection of water resources and to prevent water wastage. All South Africans should be able to participate in water management and participate meaningfully in decisions on water matters that affect them. In 2016 the minister of Water and Sanitation approved the establishment of 9 CMAs, due to the complicity DWS had to develop documents for the establishment of these CMAs. CMAs will be representative of, and facilitate the involvement, of communities and other stakeholders in decision making.

At present the Department of Water and Sanitation is responsible for administering all aspects of the Act on the Minister’s behalf. As regional CMA’s (19 Catchment Management Agencies or CMA’s are planned) and other local water management institutions are established, the Department will delegate or assign water resource management responsibilities to these institutions over time. In the longer term the Department’s role will mainly be to develop national policy and a regulatory framework to govern the way other institutions manage the water resources. The Department will maintain general oversight of these institutions’ activities and how well they perform.

The National Water Act is important because it provides a framework to protect water resources against over-exploitation and pollution as demand and stress on the environment is increasing. The Act must ensure that there is water for social and economic development for the present and the future. It’s also important because it recognises that water belongs to the whole nation for the benefit of all people. The only right to water ensured by the National Water Act is referred to as the reserve. Other users who are not falling under Schedule 1 must register their use or apply for a license. Aspects that will be considered before allocating water to users in a catchment, will be water needed for strategic purposes such as Eskom, inter catchment water transfers and international obligations.

9.1.1 Water user registration and licenses

Licensing water use is compulsory, reserving the right to the minister of DWA to publish a notice in the Government Gazette requiring all existing and potential water users except Schedule 1 users to apply for licenses. The application for a Water User's License does not differentiate between users of surface or groundwater. The notice is revised on a 5-year basis and published in the Government Gazette.

Schedule 1 users are relatively low water users such as reasonable domestic household supplies, small non-commercial gardens, livestock watering for subsistence use, (not feeding pens), storing and using run-off water from a roof, emergencies e.g. fire-fighting, recreation e.g. swimming, angling.

- The use is not excessive in relation to the available source and needs of other users.
- A Catchment Management Agency (CMA) may limit the taking of water in terms of Schedule 1 (Schedule 3(2)(e) of the Act.
- Water users in this category can commence with their activities without informing the Department.

Continuation of existing lawful use: Existing Lawful Water Use (ELU) means the use of water authorization by or under any law that took place at any time for a period of two years before the commencement of the NWA, 1998. Existing Lawful Water Use, with any conditions attached, is recognised but may continue only to the extent that it is not limited, prohibited or terminated by this Act.

- No license is required to continue with Existing Lawful Water Use until a responsible authority requires a person claiming such an entitlement to apply for a license.
- If a license is issued it becomes the source of authority for water use.
- If a license is not granted the use is no longer permissible.
- This authorization requires a registration with the Department in other words these users must inform DWA of their usage and DWA will verify if the use is legal.

General Authorization: General permission has been granted by the Minister for other slightly larger uses from certain less stressed sources. This permission has been given by means of general authorisations published in the Government Gazette. A general authorisation is only applicable to specific rivers or catchments and is not applicable to the whole country. The users must report their water use but due to the small volumes, they are not required to be licensed, this includes users such as small-scale farmers in low stressed areas.

- This authorization requires registration with the Department prior to exercising the water use(s).

Users who need to be licensed: Section 21 of the Act lists water use that must be licensed. Existing and potential water users must ensure that they comply and are familiar with the requirements of the Act. The following table was obtained from the E-WULAAS web site at: https://www.dws.gov.za/ewulaas/WUA.aspx

The following activities constitute water uses and require authorization in terms of Section 21 of the NWA:

Water Use	Example
Section 21 (a) Taking water from a water resource.	Abstracting water from a river or borehole for the following purposes: - domestic use - irrigation - watering of livestock - industrial - mining - water bottling, etc.
Section 21 (b) Storing water.	Raw water containment facilities constructed in-stream and in off-channel dams.
Section 21 (c) Impeding or diverting the flow of water in a watercourse.	Construction of structures/facilities within surface water resources, e.g. weirs, bridges, pipelines, etc.
Section 21 (d) Engaging in a stream flow reduction activity.	Plantation of forestry species (Eucalyptus, Pine and Wattle).
Section 21 (e) Engaging in a controlled activity identified as such in section 37(1) or declared under section 28(1) of the NWA.	Irrigation with water containing waste, artificial recharge of aquifer, modification of atmospheric precipitation and in-stream power generation activities.
Section 21 (f) Discharging waste or water containing waste into a water resource.	Discharging of water containing waste into a surface water resource, e.g. discharging treated effluent into a river or a wetland.
Section 21 (g) Disposing of waste in a manner which may detrimentally impact on a water resource.	Disposal of effluent into a water containment facility, dust suppression and stockpiles.
Section 21 (h) Disposing of waste in a manner which contains waster from or which has been heated in any industrial or power generation process.	Discarding of industrial/power generation waste water or water which has been heated.
Section 21 (i) Altering the bed, banks, courses or characteristics of a watercourse.	Construction of structures/facilities within surface water resources, e.g. weirs, bridges, pipelines, etc. Introduction of unnatural characteristic to the resource.
Section 21 (j) Removing, discharging or disposing of water found underground if it is necessary of the efficient continuation of an activity or for the safety of the people.	Extraction of water from underground workings for safe continuation of activities.
Section 21 (k) Using water for recreational purpose.	The use of surface water resources for fishing, boating, etc.

If the user receives water from a local government or any other bulk supplier there is no need to register. The local government or any other bulk supplier must register. All licenses will be issued with conditions to ensure that the water use authorized by the license does not have a negative impact on the water resource or other water users. These conditions will be negotiated with the water user wherever possible. Conditions can include a time interval period for the monitoring of quantity and quality.

9.1.2 The Reserve

The only right to water ensured by the National Water Act is referred to as the reserve. The Minister is required to determine the RESERVE for all, or part of any significant water resource unit. A water resource unit is usually a catchment area, or it can be smaller to differentiate between different hydrological settings, or it can be "hotspots". Hotspots are regions within a catchment that are completely different due to pollution or usage that can be related to industry or mining.

The reserve must be (set aside) before water is allocated for other uses. The reserve includes basic human needs (currently 25litre/person/day) and the ecological reserve needed to sustain ecosystems within the water resource unit such as the aquatic, riparian and their associated biological diversity ecosystems.

9.1.3 Resource Directed Measures

The National Water Act of 1998 places an emphasis on the protection of water resources for their sustainable utilisation. This is reflected in the subsequent development of Resource Directed Measures (RDM) by The Department of Water and Sanitation, which consists of three important aspects, namely: classification of each major resource unit, setting the reserve; and determination of resource quality objectives. The objective is to balance protection and development by assessing, as accurately as possible, how much water can be abstracted from a system before the reserve is affected.

The framework to achieve this objective of protecting water resources while optimising their utilisation in a sustainable and equitable manner is provided in the National Water Resource Strategy (NWRS)

The NWRS adopts two complementary strategies to achieve this balance:

- Resource Directed Measures (RDM) that undertake to protect water resources by setting goals and objectives for the desired condition of water resources in aquatic ecosystems,
- Source Directed Controls (SDC) specify criteria for controlling water resource use activities and their impact on aquatic ecosystems.

The core of the RDM, and the basis of water resource management in South Africa, is the determination of a Management Class (MC). The MC is defined in terms of the resource quality that must be maintained.

Resource quality: includes the water quantity and quality, as well as the “character and condition of in-stream and riparian habitats, and the characteristics, condition and distribution of the aquatic biota” (DWAF 2003).

Management Classes are determined using the Water Resource Classification System (WRCS).
The overall objective of the WRCS is to classify water resources in terms of:

- Class I (minimally used),
- Class II (moderately used),
- Class III (heavily used)

Based on the MC for each significant water resource, the Reserve and the resource quality objectives (RQOs) for that resource are prescribed.

A class is allocated to each resource unit representing the level of protection required for the water resource and to state the extent to which the water can be used. The classification is used to define the present status of the resource unit and to define the state towards which the water resource needs to be managed sustainable (future state). The classification process involves stakeholder participation and consultation as users must know the current state and to decide how the future state must look as development and usage must be balanced against the degradation of the environment.

During the **resource quality objectives** future quality and quantity of the source and conditions of the aquatic and riparian ecosystems are provided as an **environmental statement.** The minister of DWS is responsible to set the reserve. Basic human needs are set at 25 liter/person/day, and the ecological reserve is determined by investigation groundwater/surface interactions. Management of the resource units will be an ongoing process with emphasis on pollution prevention, emergency spillage and rehabilitation, monitoring of quantity and quality, monitoring abstraction and compliance of licensed water users. Availability and demand must be managed in an integrated manner to maintain the resource quality objectives.

9.1.4 Monitoring

Monitoring, recording, assessing and dissemination of information on water resources are critically important for achieving the objectives of the act. There are currently 30 active and 88 non-active monitoring stations on the Modimolle map (Figure 122). DWS is responsible to set up National water monitoring systems that will facilitate the continued and coordinated monitoring of various aspects of water resources. This is achieved by collecting relevant information and data through established procedures and mechanisms from a variety of sources. These include organs of state, water management institutions and water users. Monitoring aspects such as quantity, quality, use, and rehabilitation are some of the important ones.

As part of the water user license, users can be required to supply information on abstraction, water levels and quality on a time frequency negotiated between DWA and the license holder. The NWA is not the only Act requiring monitoring as it is also part of the environmental requirements for various other industrial, mining, sewerage, and landfill management. Monitoring equipment includes 31 electrical data loggers and 46 Autographic Recorders. The list of monitoring boreholes lists 41 boreholes without any equipment.

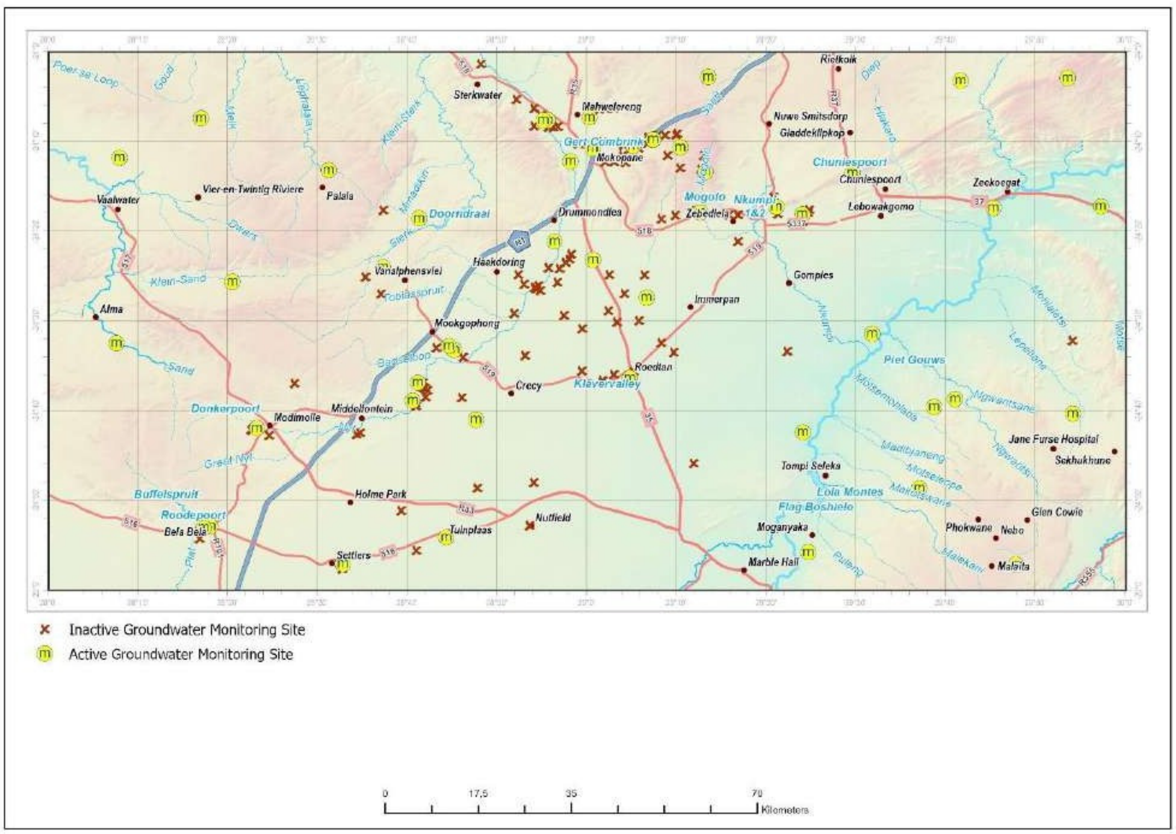


Figure 121: DWS monitoring boreholes.

Figure 122: DWA monitoring stations on the Modimolle hydrogeological map

Location	Station Number	Borehole number	Latitude	Longitude	Status	Monitoring	Date start	Date end	Installation date	Monitoring Equipment
Matalas location	A6N0618	M04-1456	-23.817560	29.040000	Unused	Not Active	20071018	20140409	20140409	No equipment
Matalas Location	A6N0636	M04-1458	-23.805090	29.040890	Unused	Not Active	20071026	20140409	20140409	No equipment
Matalas Location	A6N0630	M04-2273	-23.820340	29.044400	Unused	Not Active	20071019	20140409	20140409	No equipment
Matalas Location	A6N0624	M04-2277	-23.814690	29.044540	Unused	Not Active	20071019	20140409	20140409	No equipment
Matalas Location	A6N0632	M04-2270	-23.822290	29.044620	Unused	Not Active	20071019	20140409	20140409	No equipment
Matalas location	A6N0631	M04-2269	-23.822790	29.045010	Unused	Not Active	20071019	20140409	20140409	No equipment
Matalas Location	A6N0627	M04-2275	-23.815810	29.045110	Unused	Not Active	20071019	20140409	20140409	No equipment
Matalas Location	A6N0628	M04-2276	-23.814990	29.045460	Unused	Not Active	20071019	20140409	20140409	No equipment
Matalas Location	A6N0625	M04-2274	-23.814580	29.046410	Unused	Not Active	20071019	20140409	20140409	No equipment
Matalas Location	A6N0626	M04-2278	-23.815700	29.046550	Unused	Not Active	20071019	20140409	20140409	No equipment
Matalas Location	A6N0629	M04-2271	-23.820100	29.046560	Unused	Not Active	20071019	20140409	20140409	No equipment
Matalas Location	A6N0619	M04-2280	-23.818290	29.046920	Unused	Not Active	20071026	20140409	20140409	No equipment
Matalas Location	A6N0633	M04-0988	-23.815430	29.048410	Unused	Not Active	20071026	20140409	20140409	No equipment
Matalas Location	A6N0634	M04-1460	-23.810770	29.048440	Unused	Not Active	20071026	20140409	20140409	No equipment
Matalas Location	A6N0617	M04-1459	-23.817870	29.048880	Unused	Not Active	20071018	20140409	20140409	No equipment
Matalas Location	A6N0623	M04-2268	-23.823830	29.049200	In use	Active	20071019		20071019	Electr Data Logger
Matalas Location	A6N0621	M04-2266	-23.822600	29.049710	Unused	Not Active	20071018	20140409	20140409	No equipment
Matalas Location	A6N0622	M04-2267	-23.824160	29.050130	Unused	Not Active	20071018	20071018	20140409	No equipment
Matalas Location	A6N0615	M04-2281	-23.816330	29.050250	Unused	Not Active	20071018	20140409	20140409	No equipment
Matalas Location	A6N0614	M04-0986	-23.815750	29.050260	Unused	Not Active	20071018	20140409	20140409	No equipment
Matalas Location	A6N0612	M04-1457	-23.814890	29.050340	In use	Active	20071018		20071018	Electr Data Logger
Matalas Location	A6N0620	M04-2265	-23.820470	29.050520	Unused	Not Active	20071018	20140409	20140409	No equipment
Matalas location	A6N0616	M04-2264	-23.818790	29.051210	Unused	Not Active	20071018	20140409	20140409	No equipment
Matalas Location	A6N0613	M04-1049	-23.816140	29.051340	Unused	Not Active	20071018	20140409	20140409	No equipment
Matalas Location	A6N0635	M04-1461	-23.813770	29.052300	Unused	Not Active	20071026	20140409	20140409	No equipment
GLEN ROY PTN. GLEN ROY	A6N0599	M04-1562	-23.895430	29.095278	In use	Active	20070905		20070905	Electr Data Logger
Graafreinet Ptn. Rapitsi	A6N0586	M04-2261	-23.594590	29.120970	In use	Active	20060309		20060309	Electr Data Logger
Vaalkop Ptn. Doornspruit	A7N0635	M04-2262	-23.811760	29.216140	In use	Active	20060309		20090309	Electr Data Logger
Malietzies IOCATION	A7N0658	M04-2595	-23.661530	29.331580	Dry	Not Active	20130909		20220209	Electr Data Logger
Vaalwater	A7N0032	H04-2304	-23.815556	29.371111	Unused	Not Active	19861203	20060315	20060315	No equipment
Vaalwater Ptn. Seshego	A7N0637	M14-2241	-23.838920	29.378780	In use	Active	20050714		20050714	Electr Data Logger
Eerste Geluk	A7N0031	H04-1924	-23.831944	29.388056	Unused	Not Active	19870209	20040617	19870209	Autographic Recorder
Pilgrimshoop Ptn. Palmietgat Ptn. Plot 24	A7N0591	2329CD00039	-23.822500	29.405833	Unused	Not Active	19910628	20011008	19910628	No equipment
Pilgrimshoop Ptn. Palmietgat Plot 23	A7N0590	M16-1832	-23.819444	29.406667	Unused	Not Active	19901109	20071101	20071101	No equipment
Pilgrimshoop Ptn. Palmietgat Kleinhoewes	A7N0655	M16-1942	-23.817910	29.407710	In use	Active	20080611		20080718	Electr Data Logger
Sterkloop	A7N0512	26536	-23.916667	29.416667	Unused	Not Active	19720314	19890410	19720314	No equipment
Doornkraal	A7N0519	2329CD00053	-23.883056	29.416667	Unused	Not Active	19650303	19690915	19650303	Autographic Recorder
Sterkloop	A7N0549	M16-1827	-23.922290	29.417390	In use	Active	19711105		20060629	Electr Data Logger
MAKIBELO-MALIETZIES PTN. MAKIBELO	A7N0661	M04-2597	-23.659420	29.417920	In use	Active	20120205		20120507	Electr Data Logger
Pilgrimshoop	A7N0642	M16-1851	-23.820300	29.418610	In use	Active	20071110		20071110	Electr Data Logger
Sterkloop	A7N0013	31446	-23.897222	29.418611	Unused	Not Active	19790801	19941209	19790801	Autographic Recorder
Pilgrimshoop Ptn. Plot 19	A7N0588	M16-1831	-23.822778	29.422500	Unused	Not Active	19910613	20080522	20080522	No equipment
Doornkraal Ptn. New Pietersburg	A7N0560	28242	-23.872778	29.422778	Unused	Not Active	19771028	19890128	19771028	Autographic Recorder
Doornkraal	A7N0504	H16-0260	-23.865833	29.425278	Unused	Not Active	19680424	20060214	20060214	No equipment
Sterkloop	A7N0538	M16-0255	-23.887900	29.427890	In use	Active	19731112		20060628	Electr Data Logger
Springforbi	A7N0641	M11-2406	-23.536460	29.429470	In use	Active	20070627		20070627	Electr Data Logger
Sterkloop	A7N0561	M16-0257	-23.901200	29.435030	Destroyed	Not Active	19731112	20230714	20230714	Autographic Recorder
Doornkraal	A7N0029	M16-1149	-23.847300	29.438370	In use	Active	19850415		20060627	Electr Data Logger
Doornkraal	A7N0587	36229	-23.836389	29.440833	Unused	Not Active	19860204	20040615	19890605	Autographic Recorder
Munisipaliteit Ivydale-Pietersb.-Sterkloop	A7N0515	26484	-23.933056	29.441389	Unused	Not Active	19731112	19830722	19731112	Autographic Recorder
Weltevreden	A7N0514	2329CD00024	-23.933889	29.443333	Unused	Not Active	19720310	19950113	19720310	Autographic Recorder
Sterkloop Ptn. Ivydale Agricultural Holdings	A7N0509	26516	-23.918056	29.443611	Unused	Not Active	19720313	20040615	19720313	Autographic Recorder
Doornkraal	A7N0586	M16-1140	-23.833000	29.444120	In use	Active	19770126		20060627	Electr Data Logger
Doornbult	A7N0038	M16-1822	-23.813889	29.444167	Unused	Not Active	19850510	20080522	20080522	No equipment
Pietersburg	A7N0015	2329CD00015	-23.909167	29.445833	Unused	Not Active	19790910	20040615	19790910	Autographic Recorder
Doornkraal Ged Annadale	A7N0585	036273A	-23.865833	29.445833	Unused	Not Active	19851029	19980511	19851029	Autographic Recorder
Sterkloop	A7N0506	2329CD00013	-23.908333	29.446389	Unused	Not Active	19680724	20020108	19680724	Autographic Recorder
Doornbult	A7N0646	M16-1850	-23.807999	29.448120	In use	Active	20061010		20071110	Electr Data Logger
Munisipaliteit Van Pietersburg-Sterkloop	A7N0567	026538A	-23.943056	29.448333	Unused	Not Active	19731113	19850403	19731113	Autographic Recorder
Sterkloop	A7N0027	036222A	-23.928056	29.448889	Unused	Not Active	19850829	20030909	19850829	Autographic Recorder
Pietersburg	A7N0014	2329CD00016	-23.909722	29.448889	Unused	Not Active	19790808	19931026	19790808	Autographic Recorder
Weltevreden Witkop	A7N0559	2329CD00058	-23.933056	29.450000	Unused	Not Active	19540422	19600129	19540422	Autographic Recorder
Munisipaliteit Pietersburg-Sterkloop	A7N0541	2329CD00056	-23.900000	29.450000	Unused	Not Active	19540410	19600503	19540410	Autographic Recorder
Sterkloop Pietersburg	A7N0505	2329CD00048	-23.883056	29.450000	Unused	Not Active	19710115	19820318	19710115	Autographic Recorder
Palmietfontein Pietersburg	A7N0502	2329CB00038	-23.733056	29.450000	Unused	Not Active	19630701	19790427	19630701	Autographic Recorder
Sterkloop	A7N0647	M16-1819	-23.889200	29.451570	In use	Active	20060810		20071210	Electr Data Logger
Munisipaliteit Van Pietersburg-Sterkloop	A7N0568	026516A	-23.930556	29.451944	Unused	Not Active	19731113	19820723	19731113	Autographic Recorder
Sterkloop	A7N0510	26524	-23.916111	29.452222	Unused	Not Active	19720310	19901016	19720310	Autographic Recorder
Sterkloop	A7N0584	2329CD00018	-23.923889	29.453056	Unused	Not Active	19851030	19930819	19851030	Autographic Recorder
Sterkloop	A7N0539	M16-1826	-23.922800	29.453440	In use	Active	19731113		20060629	Electr Data Logger

9.2 Groundwater recharge, storage, and movement

Vegter (1995) states that groundwater recharge primarily depends on rainfall. He defines recharge as the process of water absorption and addition to the saturated zone. In the Modimolle (Nylstroom) map sheet area, groundwater recharge is influenced by effective rainfall, which refers to the portion of rainfall that infiltrates to the saturated zone after losses due to evaporation, transpiration, runoff, and interception. Recharge may also occur from rivers or dams with controlling factors such as open fracture zones and the infiltration potential of the bedding material underlying the surface water bodies. The infiltration potential will be influenced by various aspects such as the type of underlying material, the absence or presence of hard pan surfaces, duration of surface water availability, grain size and distribution.

The map area is generally classified as a "dry" region with frequent droughts. There are a few perennial rivers available to enable continuous recharge, making groundwater recharge a seasonal occurrence, which is primarily during the rainy season when rivers flow. In some cases, groundwater is lost to rivers through seepage and springs, which contribute to base flow. However, depending on local conditions, dams, particularly earth dams, can significantly contribute to groundwater recharge. Groundwater level responses to rainfall events may exhibit a time lag due to the time required for percolation through the unsaturated zone before reaching the saturated zone.

Some irrigation farmers on the Springbok Flats irrigate from earth dams, which are fed from boreholes. Recharge through leakage may be occurring from earth dams if not properly sealed. A small percentage of irrigation water is not absorbed by plants and may return to the aquifer. Where artificial recharge from earth dams is planned, various favorable conditions must be present such as, amongst other, sufficient availability of sub-surface storage. In suitable locations, a localized elevated water table may develop under the recharge area, migrating slowly through preferential pathways into the rest of the aquifer as the system is not entirely closed, (semi confined aquifer). The water table is a subdued replica of the topography that may inhibit the lateral expansion of the recharge mound that is being built up below the recharged zone and must therefore be taken into account for artificial recharge projects. Natural recharge is controlled by several factors, including rainfall intensity and frequency, vegetation cover, soil type, topography, slope, geology, and depth to the water table, among others.

The GRAII project of DWS calculated the estimated recharge for each quaternary catchment in South Africa. There are about 21 complete and 33 partly quaternary catchments on the Modimolle Hydrogeological map sheet. The recharge for each full and partly full quaternary catchment (using GRII recharge values) was calculated to obtain the volume of recharge to each of the full/partly quaternary catchments. These totals were all summed and converted to million cubic meters per annum i.e. 499,19Mm^3/annum to portray the annual recharge to the Modimolle map sheet. The total size of the map is 22,451km^2.

Surface water percolates through the unsaturated weathered zone into the saturated zone, where all available pore spaces and fractures are filled with water. Structural features such as faults, fractures, joints, and bedding planes often serves as conduits for groundwater movement rather than storage. In dolomitic formations, structural features such as fractures enhance the percolation of water that may result in the formation of large cavities due to solution processes. Solution cavities significantly increase the storage capacity in dolomite as fresh dolomite is fine- grained and dense with minimal storage capacity.

Unconfined aquifer storage occurs in unconsolidated alluvial deposits along rivers and in the weathered zone in certain areas. Specific yield (indication of storage capacity in unconfined or primary aquifers), is defined as the volume of water that will drain under gravity from a saturated rock of unit volume and is typically expressed as a percentage of the total volume. The volume of water stored in the weathered zone and alluvial deposits decrease with the decrease in the static water level.

In solid rock, water is stored within micro pores and fractures. Igneous and metamorphic rocks generally provide limited storage, whereas sedimentary rocks typically offer greater storage capacity. It is important to note that borehole yield is a function of an aquifer's permeability rather than an indication of the total volume of water in storage or its long-term sustainability. The sustainability of groundwater extraction is determined through the interpretation of scientifically conducted borehole pumping tests

Groundwater in the Modimolle map sheet area generally flows in the same direction as surface water. The groundwater table often mirrors topography, causing groundwater divides to approximately align with surface water divides. However, extensive groundwater abstraction can alter the natural flow pattern by creating cones of depression around extraction points. Once pumping ceases, natural groundwater flow is restored as water levels recover.

Vegter (1995) produced a recharge map for the Water Research Commission covering the whole of South Africa. The four 1:250 000 maps covering the 1:500 000 Polokwane Hydrogeological map, were cut from the Vegter recharge map (1995) and pasted in this document (Table 66). The recharge-related numbers obtained on the Vegter map for Modimolle, was used to determine the estimated mean annual recharge for the Modimolle map sheet.

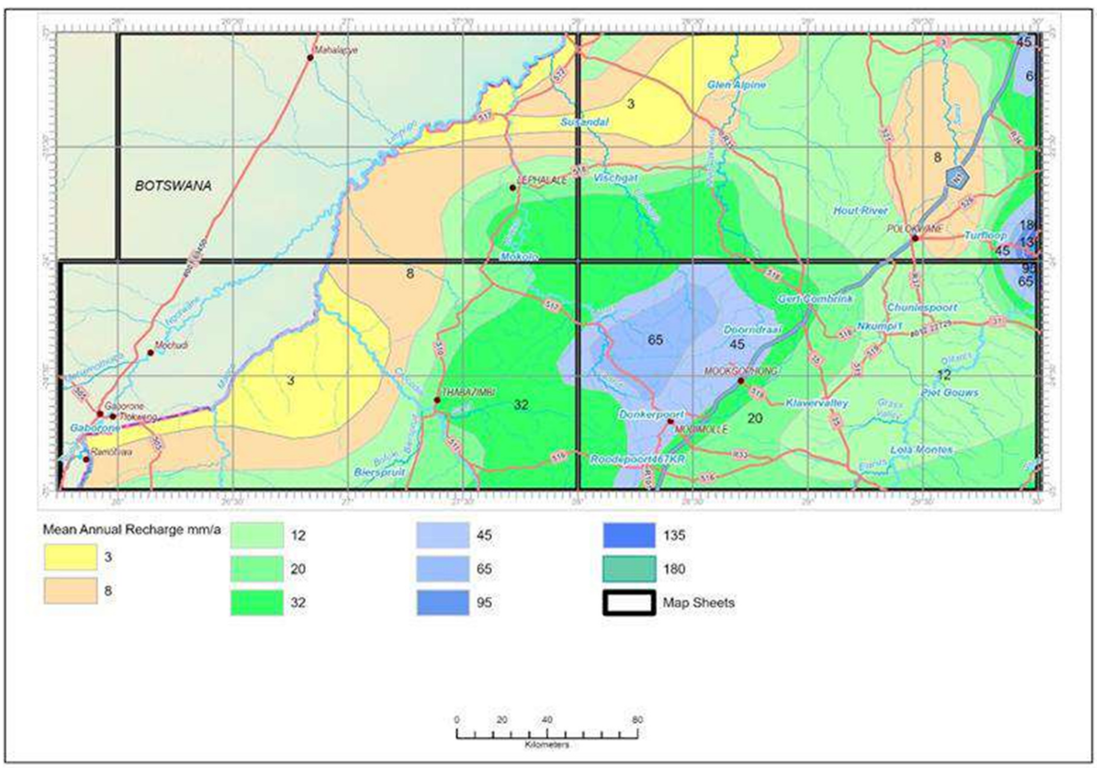


Table 66: Mean annual recharge in mm for the four, 1:250 000 maps that is the upgrade for the 1:500 000 Polokwane hydrogeological map (after Vegter, 1995). Modimolle is at the bottom right.

Table 67: Mean annual recharge calculated for the 1:250 000 Lephalale map (after Vegter, 1995).

Mean annual Recharge in zone	Mean annual Recharge in zone	Surface Area of zone	Surface Area of zone	Mean annual Recharge	Mean annual Recharge
mm/annum	m/annum	km²	m²	m³/annum	Mm³/annum
12	0,012	7993,83	7993830000	95925960	**95,92**
20	0,020	5229,98	5229980000	104599600	**104,6**
32	0,032	3807,35	3807350000	121835200	**121,83**
45	0,045	116,154	116154000	5226930	**5,23**
65	0,065	70,5521	70552100	4585886,5	**4,85**
95	0,095	50,7183	50718300	4818238,5	**4,82**
135	0,135	10,4324	10432400	1408374	**1,41**
45	0,045	3429,58	3429580000	154331100	**154,33**
65	0,065	1744,34	1744340000	113382100	**113,38**
		22452,937			**606,113**

Vegter divided the Modimolle map into 10 mean recharge zones, each with an allocated mean annual recharge value in millimeters (mm). Although the recharge is expressed quantitatively, it should be seen as depicting broad trends rather than laying claim to accurate regional recharge figures, (Vegter, 1995). However, these values were used to calculate the mean annual recharge volume for each zone. The volume for each zone was added to determine the total mean annual recharge volume for the Modimolle map, which amounts to 606.113 million cubic meters per annum (606.113Mm³/annum), (Table 67).

Another approach to estimating recharge is by utilizing data from the Department of Water and Sanitation's (DWS) GRAII project. However, in a 2024 email, DWS stated that the GRAII data has not been verified, and its use is not recommended without special permission.

No specialist hydrogeological reports accompanying e-WULAAS in the Modimolle area were made available by DWS. Groundwater data were however abstracted from other available reports and used as additional information to compile the brochure and the relevant sections for the map such as median yield and chemical data. In relation to recharge, the mining applications typically estimate recharge using numerical groundwater models, while smaller applications, such as farms, rely on localized recharge calculations or published values. These calculations are often based on the Chloride mass balance method; Vegter's recharge values, Harvest Potential values, the GRAII dataset, or a combination of the above. In addition to these methods, other techniques that can be used to estimate recharge include the water balance approach, the water table fluctuation method, Darcy's Law, isotopic tracer studies, and soil moisture balance assessments. Each method varies in applicability depending on data availability, scale, and site-specific hydrogeological conditions.

An alternative method for determining annual recharge or rather "safe abstraction", as referred to in the document, is the Harvest Potential approach proposed by A. Seymour and P. Seward (1995). Like Vegter's method, the Modimolle map area was divided into several safe abstraction zones. These zones have a minimum and a maximum volume (like the GRAII data set that refers to a minimum and maximum volume as 'dry' and 'wet' to take into consideration seasonal fluctuations in rainfall). Harvest Potential represent the maximum volume (m³/km²) that can be safely abstracted without depleting the aquifer (see Table 70, page 217).

9.3 Borehole siting

Table 68 depicts the different geophysical survey techniques / methods that were used in the past in the search for geological features that might relate to the occurrence of groundwater. The choice of technique / method for each of the different hydrogeological resource units is based on the proven track records of the application in each unit. This relates to the geological and hydrogeological setting and the expected groundwater target in each unit. The instruments / technique / method used must be as such to detect natural differences in the subsoil. The data obtained must be interpreted to identify and evaluate geological features e.g. dykes, deep-weathered / fracture zones, fault zones, joints, contact zones etc. that are known to relate to groundwater occurrences in each unit.

The table can be used as guidance as technology is evolving at a rapid rate with new instruments / techniques / methods becoming available.

Table 68: Recommended geophysical survey techniques to employ in each resource unit.

GROUP/FORMATION	HYDRO-GEOLOGICAL UNIT	CATEGORY	1a	1b	2a	2b	3	4	5
Tertiary - Quaternary alluvial deposits	Q	A	***	**	**			**	**
Letaba Formation	Jle	D	**	**	***	**	***		*
Triassic Dolerite	Jdo	B	**	**	**	**	***		
Clarens Formation	Trc	B		**	***	**	***		
Irrigasie Formation	P-Tri	B	*	**	***	**	***		
Ecca Group	Ppe	D	**	**	***	***	***		
Diabase	N-Za	D	**	**	***	**	***		*
Spitskop Complex	Msp	D	**	***	***	*	***		
Nebo Granite	Mn	D	***	**	**	*	**		*
Rashoop Suite	Mr	B	**	***	***	*	***		
Kransberg Sub-Group (Undifferentiated Sandriviersberg & Mogalakwena Formations)	Mkr	B	*	***	***	*	***		
Vaalwater Formation	Mva	B	*	***	***	*	***		
Cleremont Formation	Mcl	B	*	***	***	*	***		
Aasvoëlkop Formation	Mas	B	*	***	***	*	***		
Makgabeng Formation	Mma	B	*	***	***	*	***		
Schilpadkop Formation	Msc	B	*	***	***	*	***		
Alma Formation	Mag	B	*	***	***	*	***		
Swaershoek Formation	Ms	B	*	***	***	*	***		
Pretoria Group	Vpg	D	*	***	***	*	***		*
Schrikfontein Formations	Vsc	B	*	**	***	**	***		*
Kwaggasnek Formation	Vkw	B	*	**	***	**	***		*
Lakenvalei Formation	Vla	B	*	***	***	*	***		
Timeball Hill Formation	Vti	B	*	**	***	*	***		*
Penge Formation	Vpe	B		**	**	*	***		
Wolkberg Group	Vwo	B		**	***	**	***		
Malmani Sub-Group	Vma	C		*	*	*	***	***	

GROUP/FORMATION	HYDRO-GEOLOGICAL UNIT	CATEGORY	1a	1b	2a	2b	3	4	5
Rustenburg Layered Suite	Vrs	D	***	**	**	*	**		*
Meinhardskraal Granite	Vme	D	**	***	**	***	**		*
Unnamed Granitoid (Unnamed Vaalian rocks)	Vz	D	**	***	**	***	**		*
Uitloop Granite	Ru-Vu	D	***	**	**	***	***		*
Lunsklip Granite	Rl-Vl	D	***	**	**	***	***		*
Turfloop Granite	Rt-Vt	D	***	**	**	***	***		*
Geyser Granite	Rge	D	***	**	**	***	***		*
Hout River Gneiss	Rho	D	***	**	***	***	***		*
Goudplaats Gneiss	Zgo	D	***	**	***	***	***		*
Pietersburg Greenstone Belt	Zpg	D	**	*	***	**	***		*

The geophysical method is listed as follows:

- 1a Electrical Resistivity
- 1b Electrical Resistivity – profiling
- 2a Electromagnetic - EM-34
- 2b Electromagnetic - Genie SE / Stratagem / Max-Min Slingram
- 3 Magnetic
- 4 Gravity
- 5 Seismic

The rating for its successful application is as follows:

- *** Essential
- ** Useful
- * Not essential

Geological targets that can be related to the occurrence of groundwater are described for most of the hydrogeological units in Chapter 7. The success of the application is enhanced by using other available scientific aids such as aerial photographs, LANDSAT images, Terra Aster satellite imagery, geological maps, hydrogeological maps, existing information for the area and aeromagnetic data. Experienced geohydrologists also consider visible indicators such as vegetation patterns, topography, soil variations, and other surface features during field surveys. The value of a geohydrologist's expertise, particularly their understanding of geology and data interpretation techniques, cannot be overstated.

While geophysical methods are widely used in groundwater exploration, the use of these methods does not always guarantee successful water strikes (boreholes with water). This is not due to flaws in the instruments themselves since they are based on well-established natural laws, but rather to incorrect interpretations, influences on the response of the instruments not taken into account or natural subsurface conditions that are not favorable for groundwater.

For example, if a diabase dyke is the target the magnetic susceptibility between the host rock and the dyke will result in an interpretable anomaly in most of the units. The contact zone may however be fused together with no secondary fracturing resulting in a dry borehole. The target, however, was correctly identified. Other factors are if the available area is very small without any geological features or that man-made interferences such as power lines etc. cannot be avoided when working in urban or semi-urban areas. The above may lead to incorrect interpretation of data, and the effectiveness of the instruments is restricted. Another recent factor is the use of cheap unproven instruments by operators without the necessary knowledge of geology or geophysical applications.

Other factors that influence the effectiveness of geophysical methods include limitations in the area available for surveys, (such as small yards), where no discernible geological features associated with groundwater occurrence are present. Additionally, man-made interferences, such as power lines and other infrastructure, are often unavoidable in urban or semi-urban environments. These interferences can lead to incorrect data interpretation, as anomalies may not be related to natural geological phenomena, thereby reducing the effectiveness of the instruments. A further concern is the growing use of inexpensive, unverified instruments operated by individuals lacking the necessary geological or geophysical expertise. This trend further undermines the reliability of geophysical surveys.

9.4 Subterranean water control areas (managed by CMA)

Two subterranean water control areas appear on the map sheet namely Nyl River and Dorps River: As required by the new Water Act this control areas will be managed by the Water User Associations (WUAs). If established the areas will be managed under the framework of the NWS and DWA guidelines.

The Nyl River control area, situated between Modimolle (Nylstroom) and Mokopane (Potgietersrus), was proclaimed in March 1971 to protect abstraction from the alluvial aquifer along the Nyl River thus preserving this resource for future urban use. Farms within this controlled area are mostly privately owned.

The Dorps River control area is situated in the Dorps River catchment east of Mokopane (Potgietersrus). It was proclaimed in February 1990 to safeguard this dolomitic resource against over-abstraction and to preserve it for present and future urban utilization. The Mokopane (Potgietersrus) Municipality owns most of the land within this control area.

It is not known if the above water control areas are currently managed by the CMA for the area or by DWS.

9.5 Groundwater management

The **Minister of the Department of Water and Sanitation is the custodian** (trustee) of water resources on behalf of the National Government, with the responsibility to provide a framework for the protection, use, development, conservation, and management of water resources for the country. It must be managed in an integrated manner according to the principles of the Act (sustainability, equity, and efficiency).

To manage water resources on local level Catchment Managing Agencies (CMAs) and Water User Associations (WUAs) must be established that operates under the framework of the NWS and DWA guidelines. The CMA is responsible for a water allocation plan within their catchments and a Catchment Water Strategy (CWS) that is similar to the NWS. The WUA is responsible for a few functions such as the protection of water resources and to prevent water wastage.

At present the **Department of Water and Sanitation is responsible** for administering all aspects of the Act on the Minister's behalf as no CMA's or WUA is yet in operation within the map area.

Over-exploitation of groundwater resources is a general problem, especially where extensive irrigation is practiced such as the Springbok Flats areas, or in poorly managed well field areas utilized for large scale town supplies. This can be prevented and controlled through sound groundwater management practices.

Part of the license requirements can be that water users must monitor abstraction and quality at all levels from local authorities such as the Modimolle (Nylstroom), Mookgophong (Naboomspruit), and Mokopane (Potgietersrus) down to individual farmers. During the period or at the renewal date of the water user license DWA can request monitoring data from license holders. As licensing is compulsory, holders should familiarize themselves with the license requirements as the license can be cancelled. Regular or continuous measurements of groundwater level fluctuations together with accurate abstraction and rainfall measurements all displayed on one graph, is a sure way of keeping one's finger on an aquifer's pulse. Over-pumping can be detected in advance and the necessary precautionary measurements (reduction in abstraction, water restrictions etc.) taken to prevent borehole failure at critical times. Long-term accurate measurements of groundwater levels, abstraction, and rainfall are essential in the accurate assessment of recharge and storage of an aquifer and subsequent compilation and/or refining of a groundwater management model.

It is equally important to monitor the quality of the groundwater on a regular basis to detect any deterioration in the water quality in advance. The frequency of sampling for chemical analysis depends on the water usage (human, agricultural, industrial) and vulnerability of the aquifer to pollution or other influences but should be analysed at least once or twice a year for macro, tracer, and microbiological constituents. Further information on this can be obtained from the Institute for Resource Quality Studies of the Department of Water and Sanitation at Roodeplaat Dam.

In the license application no distinction is made between surface water or groundwater use as it is all part of the hydrological cycle. From a hydrogeological point of view conjunctive use of groundwater and surface water is recommended. During summertime when evaporation is at its highest resulting in high losses, surface water should be utilized extensively with groundwater only supplementing any shortages. During wintertime groundwater should be utilized extensively which could be recharged again during summertime. Evaporation losses should be at their lowest during wintertime. Surface water could thus only supplement shortages during this period.

For water level monitoring, observation boreholes are developed, especially where large well fields are established. A thorough knowledge of the geology of the terrain and an understanding of the anticipated groundwater flow, are requirements for the correct positioning of observation boreholes. The Department of Water and Sanitation have a considerable number of monitoring boreholes equipped with electronic data loggers and Autographic Recorders, (Figure 121, page 207). Most of them monitored ambient water level fluctuations and trends on a regional scale. There also use to be several specific purpose monitoring stations that monitored water level fluctuations in existing well fields such as those in and around Bela-Bela (Warmbaths), Modimolle (Nylstroom), Mookgophong (Naboomspruit), and Mokopane (Potgietersrus). The data are available on request from the Department's National Groundwater Archive (NGA) in Pretoria.

9.5.1 Groundwater contamination and pollution

Groundwater contamination is defined as the introduction of any substance into groundwater by the action of man, while pollution is the direct or indirect alteration of the physical, chemical, or biological properties of a water resource to make it:

a) Less fit for any beneficial purpose for which it may be expected to be used.
b) Harmful or potentially harmful:
   - To the welfare, health or safety of human beings,
   - To any aquatic or non-aquatic organisms,
   - To the resource quality, or to property,

(Source: National water Act, Act No 36 of 1998).

Pollution is one of the greatest threats of our time. Groundwater is, like surface water, very vulnerable to pollution. It is very difficult and expensive to rehabilitate an aquifer once it is polluted. In the environmental Act the principle of polluter pays for the rehabilitation is followed. Managers of companies responsible for the degradation of the environment can be held responsible even after a long time.

In the modelling of pollution mitigation sources, pollution sources are classified at first according to their geometry. Point sources are sources such as waste disposal, underground storage tanks, septic tanks and sewage works. These sites should be selected with utmost care, continuously monitored, and reported on by groundwater pollution specialists to protect vulnerable aquifers. The establishment or closure of such sites is strictly controlled by the Department of Water and Sanitation to protect the water resources of the country. Selling and storage points of petrol, diesel, chemicals, and fertilizers are widespread with waste disposal and sewerage works mostly confined to the bigger towns and cities within the map area. In the rural areas of the map a common problem is high concentrations of Nitrates which have been introduced into the water through pit-latrines and cattle-kraals. High Nitrates also occur in the Springbok Flat areas. Other occurrences are displayed on the map sheet.

Line sources are possible pollution sites such as sewage pipelines and railway lines (use of weed killing chemicals). Aerial sources are industrial, mining and irrigation areas with a big aerial discharge of contaminants. These sources are also widespread throughout the area. Mining activities such as around Mokopane (Potgietersrus) are all potential sources of pollution if not properly managed.

9.5.2 Groundwater utilization

Groundwater is in many cases the only source of supply, especially in the rural areas. The water is used for domestic, livestock watering, and irrigation purposes. Many of the larger towns such as Bela-Bela (Warmbaths), Modimolle (Nylstroom), Mookgophong (Naboomspruit), and Mokopane (Potgietersrus) use surface and groundwater conjunctively. Due to the lack of perennial rivers and suitable dam sites more and more users rely on groundwater to meet their demands. The agricultural sector is the largest consumer of groundwater in the map area. Large-scale groundwater abstraction occurs at several localities of which some are depicted in Table 69. The harvest potential map (Table 70, page 217) gives a quantitative depiction of sustainable volumes of groundwater potentially available for abstraction.

Table 69: Localities where large-scale groundwater abstraction (>400 000 Mm³/a) are taking place.

LOCALITY/AREA	APPROXIMATE ABSTRACTION (10^6 m³/a)	
	DOMESTIC	AGRICULTURAL
Mokopane (Potgietersrus)	5,0	
Bela-Bela (Warmbaths)	0,7	
Modimolle (Nylstroom)	0,6	
Springbok Flats		40,0
Mookgophong (Naboomspruit)	0,4	

9.5.3 Harvest potential

The information for the Harvest potential was obtained from the Groundwater Harvest Potential of the Republic of South Africa, A. Seymour, and P. Seward 1995. The harvest potential (safe abstraction volume) is the maximum amount of groundwater that can be abstracted per square kilometer per annum in South Africa without depleting the aquifers, (DWS groundwater dictionary). The Harvest Potential method was developed to provide a first estimate of the national sustainable groundwater resource. It considers recharge, storage, and time periods between recharge events.

For the largest sections of the map, the harvest potential is between 10 000 cubic meters per square kilometer per year ($m^3/km^2/annum$) and 15 000$m^3/km^2/annum$. Within the Modimolle map sheet, 4 harvest potential zones are depicted, (Figure 123). Using the values and the aerial extent of each zone the harvest potential for the Modimolle map sheet was calculated. The safe abstraction is 250.525 million cubic meters per annum ($Mm^3/annum$) that represents the low volume to 417.710$Mm^3/annum$ that represents the high volume. The average is 334.118$Mm^3/annum$.

Table 70: Harvest potential within the Modimolle map sheet.

Zone $m^3/km^2/annum$	Zone Areal extent km^2	Minimum safe abstraction m^3	Maximum safe abstraction m^3	Minimum safe abstraction Mm^3	Maximum safe abstraction Mm^3
5 000 - 10 000	3885	19425000	38850000	19.425	38.850
10 000 - 15 000	13284	132840000	199260000	132.840	199.260
15 000 - 25 000	3384	50760000	84600000	50.760	84.600
25 000 - 50 000	1900	47500000	95000000	47.500	95.000
Totals	**22453**	**250525000**	**417710000**	**250.525**	**417.710**
			Average:	334.118	

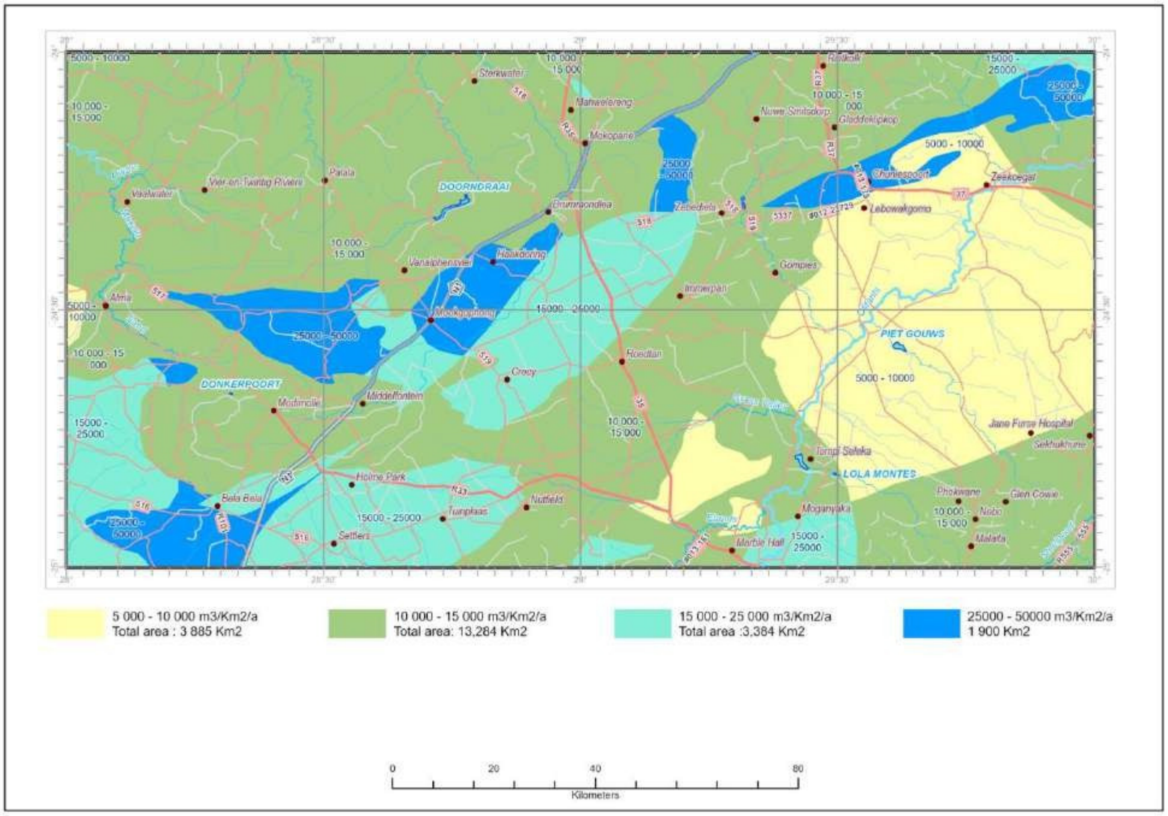


Figure 123: Harvest potential showing values in m^3/km^2/annum (Seward, Baron & Seymour, 1996).

The total safe abstraction arrived at for the Modimolle Map Sheet, using the Harvest potential amounts to 334.118 million cubic meters of water annually. This is a considerable amount of water if one considers that the total area covered by the Modimolle map, is approximately 22 453km².

9.6 Future groundwater and associated projects

The growing population and development in South Africa are bound to put the country's scarce water resources under tremendous pressure in years to come. As many of the aquifers in South Africa are past the development phase, management and intervention measures will start to dominate the groundwater industry. To be able to maintain water supply to the relevant sectors in South Africa, the country should invest in groundwater management and protection. Management is considered a strong groundwater database, monitoring of rainfall and water levels, updating of recharge estimates, research into mitigation actions such as artificial recharge, legal enforcements to protect aquifers from over exploitation and most importantly prevention of the pollution of water resources. The private sector is already willingly or legally bound to contribute to management by submitting data to DWS such as quarterly monitoring data.

The following possible subjects are suggested:

Monitoring Stations: Upgrades and Maintenance

- Investigate the current network of monitoring stations, including water level and meteorological stations.
- Upgrade and maintain stations where necessary to ensure accurate and continuous data collection.
- Assess the possible effects of environmental changes and large-scale abstraction on natural conditions and implement a monitoring framework.
- Recognize that long-term data collection is critical for scientifically measuring and quantifying the impacts of climate change.

Sanitation Audit and Improvements

- Conduct an audit of sanitation practices, identifying areas where improvements are required. On municipal level the IDP documents do address some of these. The methodology needs to be uniformly applied between the different spheres of Government to address sanitation. The framework of the Catchment Managing Agencies (CMAs) includes sustainability. As such, recommendations on mitigation measures should form part of management of the catchments with the Local or District Municipality or the implementing agent.
- Regular audits and investigations into the effectiveness of large sewage plants need to be done by DWS and/or CMA officials. The recommendations should be enforced on the relevant authorities to prevent pollution.
- Address high nitrate levels and bacteriological pollution, which are known to occur in rural communities. The slogan prevention is more effective than rehabilitation that needs to be applied.
- Investigate and mitigate sources of *e-coli* contamination, which have been detected in some groundwater sources. The bacteria were even detected in the water from groundwater resources where the water strike depth were deemed too deep (>30m) to be affected by bacterial pollution.

Groundwater Recharge and Artificial Recharge

- Investigate the feasibility of artificial recharge interventions in areas experiencing high abstraction rates.
- Assess the recharge potential in these areas; assess the potential increase in recharge by considering hydrogeological conditions and water availability.

Data Management and National Groundwater Archive (NGA)

- Invest in the National Groundwater Archive (NGA) to improve data accessibility and integrity.
- Ensure extensive use of the e-WULAAS system to maintain an up-to-date database.
- Incorporate all legally required groundwater data submissions into the NGA.
- Ensure that Hydrocensus data obtained through the WULA process include accurate geographic coordinates.
- Before capturing data, verify existing records to prevent duplication.
- If new sources are identified, ensure the inclusion of borehole logs, pump test results, and chemical analysis certificates in the documentation.
- Require geohydrological reports from consultants working for government or semi-government entities to be submitted to the Department of Water and Sanitation (DWS).
- Link municipal water source asset registers to the groundwater database for better resource management.

Water Use License Applications (WULA) and Compliance Monitoring

- Ensure that WULA approvals include conditions for quarterly water level measurements and chemical analysis where required.
- Incorporate this data into the NGA to support long-term monitoring efforts.
- Align measurement dates within specific timeframes to facilitate regional water level trend analysis.

Capacity-building and awareness

- Develop capacity-building programs for local authorities and stakeholders on groundwater monitoring and data management.
- Enhance public awareness and community participation in groundwater protection initiatives.
- Establish partnerships with research institutions to improve methodologies for groundwater assessment and recharge strategies.

10. REFERENCES

The Department of Water and Sanitation maintains a library with digital reports. The reports cited in this document can be obtained from the DWS website; some of the direct links are included. If not, the following link can be used with further search functions on the web site. (https://www.dws.gov.za/ghreport/Default.aspx).

- Callaghan, C.C., (1987). The geology of the Waterberg group in the southern Portion of the Waterberg basin. University of Pretoria.

- Crosby R., Pretorius S.J., Vivier J.J.P., (2000). Geohydrological Investigation to determine the groundwater potential of the Rooisloot Aquifer Potgietersrus. GC/9/00/09/04.

- Dziembowski, Z.M., Mew, A.C.W., (1973). Grondwatervoorraad op Altona 696LR, Potgietersrus Distrik. DWS Report No: GH1818, Directorate: Geohydrology, Department of Water Affairs and Forestry.
  https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh1818)

- Dziembowski, Z.M., (1976). Aanvulling van grondwater reservoir op Altona 696LR, distrik Potgietersrus, deur Matlalarivier tydens vloed. DWS Report No: GH2898, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh2898)

- Fayazi, M., and Potgieter, G., (1993). Groundwater development potential of the Wolkberg area as a possible source of water supply for Pietersburg and environs. DWS Report No. GH3816, Directorate: Geohydrology, Department of Water and Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3816)

- Fayazi, M., (1994). Regional groundwater investigation of the Northern Springbok Flats. DWS Report No. GH3684, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3684)

- Golder Associates Africa (Pty) Ltd., (2012). Platreef Project: Hydrogeological Baseline of Turfspruit 241KR, Macalacaskop 243KR and Rietfontein 2KS, Report No 11616141-11095-6, dated August 2012.

- Golder Associates Africa (Pty) Ltd., (2013). Integrated Water and Waste Management Plan for Platreef Bulk Sample Shaft in support of an Integrated Water Use Licence Application Volume 2. Report Number: 12614052/12456/2. DWS e-WULAAS, Ref: 27.2.2.A661.1.1 SUB-FILE VOL 2. DWS Consultant's Report: 2.2(5634). https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=(%20FORMSOF%20(INFLECTIONAL,%202.2)%20%20AND%20%20FORMSOF%20(INFLECTIONAL,%205634)%20)

- Golder Associates Africa (Pty) Ltd., (2014). Integrated Water and Waste Management Plan for Platreef Main Mine in support of an Integrated Water Use Licence Application Volume 1. Report Number: 12614052/12707/3. DWS e-WULAAS, Ref: 27.2.2.A661.1.1 SUB-FILE VOL 1. Consultant's Report: 2.2(5635). https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=(%20FORMSOF%20(INFLECTIONAL,%202.2)%20%20AND%20%20FORMSOF%20(INFLECTIONAL,%205635)%20)

- Golder Associates Africa (Pty) Ltd., (2021). Geohydrology Report for the Platreef Mine new Phase Development project. Report Reference No: 20394027-347249-6. DWS e-WULAAS, Ref: 5087960971084340137. DWS Consultant's Report: 2.2(5588). https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=(%20FORMSOF%20(INFLECTIONAL,%202.2)%20%20AND%20%20FORMSOF%20(INFLECTIONAL,%205588)%20)

- Grobler, D.F., Brits, J.A.N., Maier, W.D., Crossingham, A., (2018). Litho- and chemostratigraphy of the Flatreef PGE deposit, northern Bushveld Complex. Received: 26 May 2017 /Accepted: 12 March 2018 /Published online: 2 May 2018. Mineralium Deposita (2019) 54:3-28. https://doi.org/10.1007/s00126-018-0800-x.

- Heaton, T.H.E., (1985). Isotopic and chemical aspects of nitrate in the groundwater of the Springbok Flats. Water SA Vol. 11 No. 4, October 1985.

- Hewitt, R.F., Orpen, W.R.G., and Verhagen, B.Th., (1981). Investigation of the thermal water resources in Warmbaths, Northern Transvaal. DWS Report No. GH3192, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3192)

- Kinnaird, J.A., (2002). The Bushveld Large Igneous Province. School of Geoscience, University of the Witwatersrand.

- Kok, T.S., (1974). Beskikbare grondwater op 'n deel van die plaas Grootvalley 529KR Distrik Potgietersrus. DWS Report No.GH2808, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh2808)

- Kok, T.S., Steyn, M.J., (1976). Warmbad Warmbron. DWS Report No.GH 2871, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh2871)

- Kok, T.S., (1976). Die grondwater potensiaal van die gebied rondom Marble Hall. DWS Report No.GH 2884, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh2884)

- Kok, T.S., (1977). Geohidrologie van Naboomspruit omgewing. DWS Report No. GH2930, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh2930)

- Mogalakwena Local Municipality., (2024-2025). Integrated Development Plan, 2024-2025. https://www.mogalakwena.gov.za/mogalakwena-admin/pages/sites/mogalakwena/documents/idp/2024_2025_final_idp_review.pdf

- Molemole Local Municipality., (2024-2025). Integrated Development Plan, 2024-2025. https://www.molemole.gov.za/docs/idp/Final%202024_25%20Molemole%20IDP(1)(2).pdf.

- Orpen, W.R.G., (1981). Groundwater resources in the vicinity of Potgietersrus and recommendations on the possible augmentation of the Potgietersrus municipal water supply from these sources. DWS Report No. GH3191, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3191)

- Orpen, W.R.G., (1984). Re-evaluation of the groundwater potential of the Dorps River catchment, Potgietersrus. DWS Report No. GH3331, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3331)

- Orpen, W.R.G., Fayazi, M., (1985). Installation and devaluation of water boreholes in the Rooisloot Delta Area for the provision of a water supply for the Black township of Mahwelereng North-West of Potgietersrus. DWS Report No. GH3366. Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3366)

ADDITIONAL REPORTS COVERING ASPECTS WITHIN THE MAP AREA

- Brandl, G., (1986). The geology of the Pietersburg area, Geological map series 1:250 000, Council of Geoscience, South Africa, Single map sheet and Explanation, 2328 (Pietersburg).

- Brandl, G., (1993). The geology of the Ellisras area, Geological map series 1:250 000, Counsil of Geoscience, South Africa, Single map sheet and Explanation, 2326 (Ellisras).

- Bredenkamp, D.B., Janse Van Rensburg, H.J., Botha L.J., (1993). Estimation of the groundwater potential of the Dorps River aquifer by means of different methods and the compilation of a dynamical model of the aquifer system. DWS Report No. GH3793, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3793)

- Bond, G.W., (1947). 'n Geochemiese opname van die grondwatervoorade van die Unie van Suid-Afrika. Geological Survey Memoir No.41.

- CSS, (1991). Central Statistical Service, Population census, 1991. Summarised results after adjustment for undercount. CSS Report No. 03=01-01 (1991).

- Department of Water Affairs and Forestry, (1994). Department of Water and Sanitation, Republic of South Africa Magisterial Districts and Provinces, 1994. Unpublished map.

- Department of Water Affairs and Forestry, Department of Health, Water Research Commission, (1996). South African Water Quality Guidelines (Second edition). Volume 1: Quality of Domestic Waste Supplies, Volume 1, Assessment Guide.

- Department of Water Affairs and Forestry, (1996). South African Water Quality Guidelines (Second edition). Volume 5: Agricultural Use: Livestock Watering.

- Department of Water Affairs and Forestry, (1996). South African Water Quality Guidelines (Second edition). Volume 4: Agricultural Use: Irrigation.

- Department of Water Affairs and Forestry, (2005). Department of Water and Sanitation, Groundwater Resource Assessment II. (GRA II). Report 3aE constitutes the final report of Project 3a. https://www.dws.gov.za/Groundwater/GRAII.aspx

- Department of Water Affairs and Forestry, (2006). Report to Accompany Water Use Application in terms of the National Water Act, 1998(Act 36 of 1998).

- Department of Water Affairs and Forestry, (2007). External Guideline: Generic Water Use Authorisation Application Process.

- Department of Water Affairs and Forestry, (2008). Department of Water and Sanitation, Guide to the National Water Act.

- Department of Water and Sanitation (DWS), (2012). Aquifer Classification Map of South Africa. https://www.dws.gov.za/Groundwater/documents/Aquifer%20Classification.pdf

- Department of Water and Sanitation (DWS), (2013). Aquifer Vulnerability Map of South Africa. https://www.dws.gov.za/Groundwater/documents/Aquifer%20Vulnerability_1.pdf

- Department of Water & Sanitation (DWS), (2013). Groundwater Resource Directed Measures (GRDM) Software v 2.3.0.0.

- De Villiers, S.B., (1967). Fonteine in die Dolomiet-gebied ten ooste van Chuniespoort. DWS Report No: GH2849, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh2849)

- Durov, S.A., (1948)., Classification of natural waters and graphical representation of their composition. Dokl. Akad. Nauk. USSR. 59(1): 87-90.

- Du Toit, A.L., (1939). The geology of South Africa. 2nd edition, Oliver and Boyd, Edinburgh and London.

- Du Toit., W.H., & Sonnekus, C.J., (2014). An explanation of the 1:500 000 general hydrogeological map Polokwane 2326. DWS Report No. GH4170, Department of Water Affairs. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh4170)

- Enslin, J.F., (1970). Die grondwaterpotensiaal van Suid-Afrika. Waterjaar 1970. Gepubliseer deur konvensie: Water vir die toekoms.

- Enslin, J.F., (1990). Die potensiaal van die waterbronne van Warmbad waaruit Overvaal Oord sy benodighede verkry en die optimum benutting daarvan. DWS Report No. GH3731, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3731)

- Greer, S.E., (1979). The Warmbaths hot spring project - an interim report. DWS Report No. GH3098, Directorate: Geohydrology, Department of Water Affairs and Forestry. This Report is not registered on the Geohydrological Reports System.

- Ginsburg, A.E., Crafford, J.G., Harris K.R., (2010). Framework and Manual for the evaluation of aquatic ecosystems services for the Resource Directed Measures. WRC Report No. TT 462/10.

- HRU, (1981). Hydrogeological Research Unit. Surface Water Resources of South Africa. Volume 1, Drainage regions A and B. The Limpopo Olifants. Report No 9/81.

- Johnson, J.H., (1975). Hydrochemistry in groundwater exploration. Groundwater Symposium, Bulawayo, 1975.

- Kent, L.E., (1949). The thermal waters of the Union of South Africa and South West Africa: Trans. geol. Soc. S. Afr., 51.

- Kent, L.E., (1968). The thermal waters of the Republic of South Africa: 23 rd. Int. Geol. Congress, 19.

- Kruger, G.P., (1983). Soil and Irrigation Research Institute, Department of Agriculture, Pretoria. Terrain Morphological Map of Southern Africa. Published Map.

- Kurlov, M.G., (1928). Classification of mineral waters of Siberia, Tomsk, USSR.

- Langguth, H. R., (1966). Groundwater verhaltisse in Bereiech Des Velberter. Sattles. Der Minister Fur Eraehrung, Land Wirtsch Forste (pp. 127). Duesseldorf: NRW.

- Lin, L., Lin, H., Xu, Y., Ntuli, T., Mahlangu, F., (2015). Impact of Fault Structures on the Occurrence of Groundwater in Fractured Rock Aquifers. WRC Report No 2053/1/14. ISBN 978-1-4312-0641-4.

- Lloyd, J. A., and Heathcote, J.A., (1985). Natural inorganic hydrochemistry in relation to groundwater: An introduction. Oxford Uni. Press, New York p: 296.

- Lyness, L.S., (1980). Groundwater supply potential of selected areas near Potgietersrus. DWS Report No. GH3130, Directorate: Geohydrology, Department of Water and Sanitation and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3130)

- Nel, G.P., (1992). Regionale groundwater-ondersoek van die Springbokvlakte-Suid met spesiale verwysing na grondwater onttrekking - en aanvulling. DWS Report No. GH3787, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3787)

- North West University, (2020). Geo-Statistical Analysis and Sub-Delineation of all Vegter Regions. WRC Report No. 2745/1/19. ISBN 978-0-6392-0098-9.

- Orpen, W.R.G., (1994). A recommended map legend and mapping methodology for the compilation of regional hydrogeological maps of the Republic of South Africa at a scale of 1: 500 000. Unpublished Report. Directorate: Geohydrology, Department of Water Affairs and Forestry. Consultation provided by WSM.

- Parsons, P., Wentzel, J., (2006). Groundwater Resource Directed Measures-GRDM Manual. Water Research Commission with support from FET Water. WRC Project K5/1427.

- Piper, A. M., (1944). A graphic procedure in the geochemical interpretation of water analyses. American Geophysical Union Transactions, 25, 914-928.

- Porszasz, K., Bredenkamp, D.B., (1973). An investigation of the groundwater potential of the Nyl River Valley. DWS Report No. GH2932, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh2932)

- Ravikumar, P., Somashekar, R.K., and Prakash, K.L., (2015). A comparative study on usage of Durov and Piper diagrams to interpret hydrochemical processes in groundwater from SRLIS river basin, Karnataka, India. Department of Environmental Sciences, Bangalore University, Bangalore – 560056.

- Schylze, B.R., (1984). Climate of South Africa. Part 8, General Survey. Weather Bureau, Department of Transport. WB 28, Pretoria, Fifth edition 1984.

- Seward, P., Baron, J., (2001). An Investigation into the Groundwater Use in South Africa. DWS Technical Report GH3960. Department of Water Affairs and Forestry Pretoria. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3960)

- Seward, P., Baron, J., and Seymour, A., (1998). The Groundwater Harvest Potential Map of the Republic of South Africa (1996). DWS Report No. GH3917, Directorate Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3917)

- South African Committee for Stratigraphy, (1980). Stratigraphy of South Africa. Handbook 8, Geological Survey.

- South African National Standard. SANS 10299 1-9:2003. Development, maintenance and management of groundwater resources.

- South African National Standard. SANS 241:2015. Drinking water Part 1: Microbiological, physical, aesthetic and chemical determinants.

- Simonic, M., (1995). National groundwater quality assessment. Report in preparation.

- Steyn M.J., (1969). Dolomietstreek Thabazimbi - ondersoek na fonteine en boorgate. DWS Report No. GH2867, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh2867)

- Taylor, C.J., (1981). Regional groundwater investigation around Warmbaths. Northern Transvaal. DWS Report No. GH3145, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3145)

- Taylor, C.J., (1981). Geohydrology of the upper Magalakwena valley north-west of Potgietersrus, Transvaal. DWS Report No.GH3174, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3174)

- UNESCO, (1983). International Association of Hydrogeologist (IAH) International Association of Hydrogeological Sciences (IAHS) United Nations Education, Scientific and Cultural Organization (UNESCO). International Legend for Hydrogeological Maps, Revised version, 1983.

- Vegter, J.R., Dziembowski, Z.M., (1973). Grondwater geberg in die Mafiese waterdraer van die Bosveldstollingskompleks distrik Potgietersrus. DWS Report No. GH1861, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh1861)

- Venter, B.L., (1973). Grondwater studie van die Sisteem Waterberg in die Vaalwater - Visgatgebied. DWS Report No.GH2917, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh2917)

- Vegter, J.R., (1995). Groundwater Resources of South Africa: An Explanation of a Set of National Groundwater Maps. Water Research Commission, Pretoria: Report No. TT 74/95: A1-B33.

- Vipond, S.H., (1980). Hydrogeology of the area South-West of Crecy, Northern Transvaal. DWS Report No. GH3154, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3154)

- Walraven, F. (1986). The geology of the Nylstroom area. Geological map series 1:250 000, Council of Geoscience, South Africa, Single map sheet and Explanation, Map sheet 2428 (Nylstroom).

- Walton, D., (1989). Possible impact of the proposed Olifantspruit Dam on the groundwater resources of the Nyl River flood plain, in particular at Nylsvley Nature Reserve. DWS Report No.GH3638, Directorate: Geohydrology, Department of Water Affairs and Forestry. https://www.dws.gov.za/ghreport/Home/Result.aspx?Search=%20FORMSOF%20(INFLECTIONAL,%20gh3638)

- Water Research Commission, (2012). Report by Dennis, I., Witthüsser, K., Vivier, K., Dennis, R., Mavuray, A., Groundwater Resource Directed Measures. WRC Report No TT 506/12.

- Witthuser, K., Cobbing, J., Titus., R., (2009). Review of GRA1, GRA2 and international assessment methodologies. Project Name: National Groundwater Strategy. DWA Contract Number WP 9390. DWA Report Number P RSA 000/00/11609/6

- Xu, Y., Colvin, C., Van Tonder, G.J., Hughes, S., Le Maitre, D., Zang, J., Mafanya, T. and Braune, E. (2003). Towards the resource direct measures: Groundwater component (Version 1.1). Final report prepared for Water Research Commission on Projects. K5/1090, 1091 and 1092, WRC Report No. 1090-2/1/03, May 2003.

- Zaporozec, A., (1972). Graphical interpretation of water quality data. Ground Water Journal, Vol 10, No 2.

---oo0oo---