

**AN EXPLANATION OF THE  
1:250 000 HYDROGEOLOGICAL MAP SERIES, MAP SHEET 2326  
LEPHALALE**



**By**

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## 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.

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**Cover page:** Tafelkoppe, one of three mesa-type (flat-topped hills), made up of whitish, feldspathic, coarse-grained, and cross-bedded sandstone of the Swartrant Formation. The other nearby hills are Ga-Mabula and Tambotiepiek which is along the R518 approximately 25 km east-south-east of Lephalale. (Photograph: Louwlardus Safaris, 18 November 2020).

## **PREFACE**

Except for air, water can, with little doubt, be defined as mankind'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 thus 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 Lephalale 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 thus 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 thus features median borehole yield per aquifer unit, 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 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.

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## **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**

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## 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 <i>exempli gratia</i> , meaning "for example."
ELU	Existing Lawful Water Use
ERM	Enterprise risk management, Exxaro Resources
EMR	Exxaro Mineral Resources
Et al.	An abbreviation for the Latin phrase <i>et alia</i> , 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 <i>id est</i> , 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 Data Base
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
RHP	River Health Programme
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

Abbreviation	Description
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
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 <sup>2</sup>	Square kilometer
ℓ/s	Liters per second
m	Meter
M	Million
Mm <sup>3</sup>	Million cubic meters
meq	Milli-equivalents
mm	Millimeter
mm <sup>2</sup>	Square millimeter
mm/a	Millimeters per Annum
m <sup>2</sup>	Square meters
m <sup>3</sup>	Cubic meter
m <sup>3</sup> /annum	Cubic meters per annum
m <sup>3</sup> /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 **Lephalale Hydrogeological Map, sheet 2326**, 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 resources. 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, p140). 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 and 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 LEPHALALE MAP SHEET					
NGA and GRIP-(Yield)		WMS and GRIP (chemistry)			
Total Number of Borehole Yields	Total Number of sources with 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
1536 wet and 1676 with zero yields, 11 monitor	473	1727	994	633	410
Total records evaluated after adding Polokwane sheet information for adjacent similar cross border units (5 units Viz. Mpa, Mn, Vv, Zms, Zma)					
NGA and GRIP-(Yield)		WMS and GRIP (chemistry)			
Total Number of Borehole Yields	Total Number of sources with 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
1873 wet and 1815 with zero yields, 11 monitor	557	2855	1813	955	476

### 2.2 Main map: Lephalale hydrogeological map scale 1:250 000

The total map sheet covers an area of approximately 22 633km<sup>2</sup> of which 14 917.3km<sup>2</sup> falls within Botswana. As one of four hydrogeological maps sheets, it represents a 10.8% 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 130km<sup>2</sup> (Botswana excluded). The section of the Lephale map sheet within South-Africa is 7 715.7km<sup>2</sup>.

The 1: 500 000 Polokwane map sheet is bordered by latitudes 23° and 25° south and longitudes 26° and 30° east whereas the 1: 250 000 Lephale Hydrogeological map is bordered by latitudes 23° and 24° and longitudes 26° and 28°. The Limpopo River that forms the international boundary between South Africa and Botswana divides the map area (34% in RSA and 65.9% in Botswana). The aquifer units within Botswana are not included in the map sheet. Future incorporation may be possible under SADC-GMI.

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 Lephale 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 exceptions are the Aquifer Unit i.e. Undifferentiated Goedgedacht Formation that combined four geological units that occur as narrow strips. In areas where these Formations had a larger areal extent it was divided into separate aquifer units that correspond to the relevant geological formations as depicted on the 1: 250 000 geological map sheet Ellisras 2326.

For the Beit Bridge Complex lithological unit, it was divided into three groups as indicated on the geological map sheet. The area is extensively covered by soil and sand, and the actual 'outcrop' of each group is not defined. It was decided to use the Aquifer Unit i.e. Undifferentiated Beit Bridge Complex for areas without 'outcrop'.

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)**. On all the map sheets, the legend will include these 4 occurrences even if one of these does not occur on a particular map sheet. As an example, the Lephale map sheet does not have the groundwater occurrence '**Karst**' (dolomitic rocks). It is, however, included in the legend as these maps' forms part of a larger hydrogeological map series.

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 is recommended as a suitable measure of centrality rather than the average. The median is also found to be a reasonable discriminator between hydrogeological regions and is 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<sup>3</sup>/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 Lephalale Hydrogeological map sheet 2326:

An **east-west or north-south hydrogeological cross-section**, based on limited geological information and the author's own interpretation of the available information. The cross-section displays 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:** A 1:1 000 000 scale map to represent 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:** a 1:1 000 000 scale, contour intervals relevant to the map at 200m. The elevation in the map area varies between 400-2000mamsl.

**Mean annual precipitation:** a 1:1000 000 scale, 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:** a 1:1 250 000 scale map 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. demanded 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 Lephalale 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 hydrogeological map series.

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

On the Lephalale map sheet Karst groundwater occurrences do not occur but for consistency between the individual map sheets that form part of the hydrogeological map series, it is part of the map legend and brochure index.

Where two modes of groundwater occurrences occur at the same site such as along the Palala or Mokolo River, it is depicted as a two-layered aquifer (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 Lephalale 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 lithological ornaments and chronostratigraphy by alphabetical symbols. Production ranges are defined as follows:

- Very high borehole yields, generally greater than  $>10\text{l/s}$ . Can be used for large scale urban and rural water supply, industry, or large-scale irrigation, (42 boreholes on the map).
- High borehole yields, generally greater than  $5 -10\text{l/s}$ . Can be used for urban and rural water supply, industry, or large-scale irrigation, (117 boreholes on the map).

- Moderate borehole yields generally, 2ℓ/s - 5ℓ/s. Can be used for urban and rural water supply to small towns, industry, or small-scale irrigation, (266 boreholes on the map).
- Low borehole yields generally, 0.5ℓ/s 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, (565 boreholes on the map).
- Very low borehole yields generally 0.1-0.5ℓ/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, (431 boreholes on the map).
- Un-economical boreholes with yields generally, ranging from 0.0001 to 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 (340 boreholes on the 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											
<p>A water saturated zone, generally unconsolidated but occasionally semi-consolidated. Groundwater is stored and transmitted through intergranular interstices in porous and permeable medium.</p>				<p>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.</p>											
				<p>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.</p>			<p>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</p>			<p>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 &amp; 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.</p>					
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	
<p>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.</p>				<p>Sedimentary rocks of arenaceous origin. Acid volcanic rocks and other igneous rocks with very limited overlying residual weathered products.</p>			<p>Carbonate rocks including dolomite, limestone of marine origin.</p>			<p>Sedimentary. Igneous and Metamorphic rocks with significant thicknesses of overlying saturated residual weathering.</p>					
INTERGRANULAR				FRACTURED			KARST			INTERGRANULAR AND FRACTURED					

## 4. PHYSICAL ENVIRONMENT

### 4.1 General

The Lephalale hydrogeological map sheet which is bounded by latitudes 23°S and 24°S and longitudes 26°E and 28°E, covers an area of approximately 7 715.7km<sup>2</sup>. The total area covered by the map when the Botswana portion is added amounts to 22 451km<sup>2</sup>. The characterization of the aquifers within the Botswana portion was not included in the upgrade of the map sheet.

The map area covers two local municipalities namely Lephalale and Thabazimbi Local Municipalities, both are within the Waterberg District Municipal area. The section under the management of the Thabazimbi Municipality is a small farming area in the south-western section of the map area. For the Lephalale Municipal area approximately 30% of the municipal boundary falls outside the map area.

Most of the people in the Lephalale area live in urban settlements namely Lephalale town, Marapong, and Onverwacht; the rural population concentration points are Thabo Mbeki, Ga-Seleka and Shongoane. The rest of the population is dispersed in rural areas that include farms and service points (Steenbokpan, Marnitz and Tomburke). The population figures given in the IDP, (2024-2025) document of the Municipality is 130 081 people with 40.7% falling in the youth category, the source quoted in the IDP document is (stats' 2022).

*Table 3: Regional Water Schemes within the Waterberg District, Lephalale and Thabazimbi Local Municipalities.*

Water Scheme Name	Water Scheme number	Settlement or Settlements	Scheme description	Water sources
Tom Burke Supply	LEP0/2	Tom Burke	Internal bulk	Ground Water
Lephalale Urban RWS	LEP01	Lephalale, Marapong, Marapong Squatter	Internal bulk	Combination (Conjunctive Use)
Lephalale LM Farms Supply	LepFS	Farms Lephalale LM	Individual	Ground Water
Witpoort RWS	NW114	Kgobagodimo, Letlora	Internal bulk	Combination (Conjunctive Use)
Ga-Seleka RWS	NW115	Ga-Seleka, Kauletsi, Lebu, Madibaneng, Magadimela, Mothlasedi, Sefithlogo, Tshelamfake	Internal bulk	Combination (Conjunctive Use)
Thabazimbi LM Farms Supply	ThbFS	Farms Thabazimbi LM	Individual	Groundwater

Note: The source of information on water schemes is the DWS water schemes shape file. (Villages and Regional Water Schemes outside the map area are not listed.)

## 4.2 Terrain Morphology

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

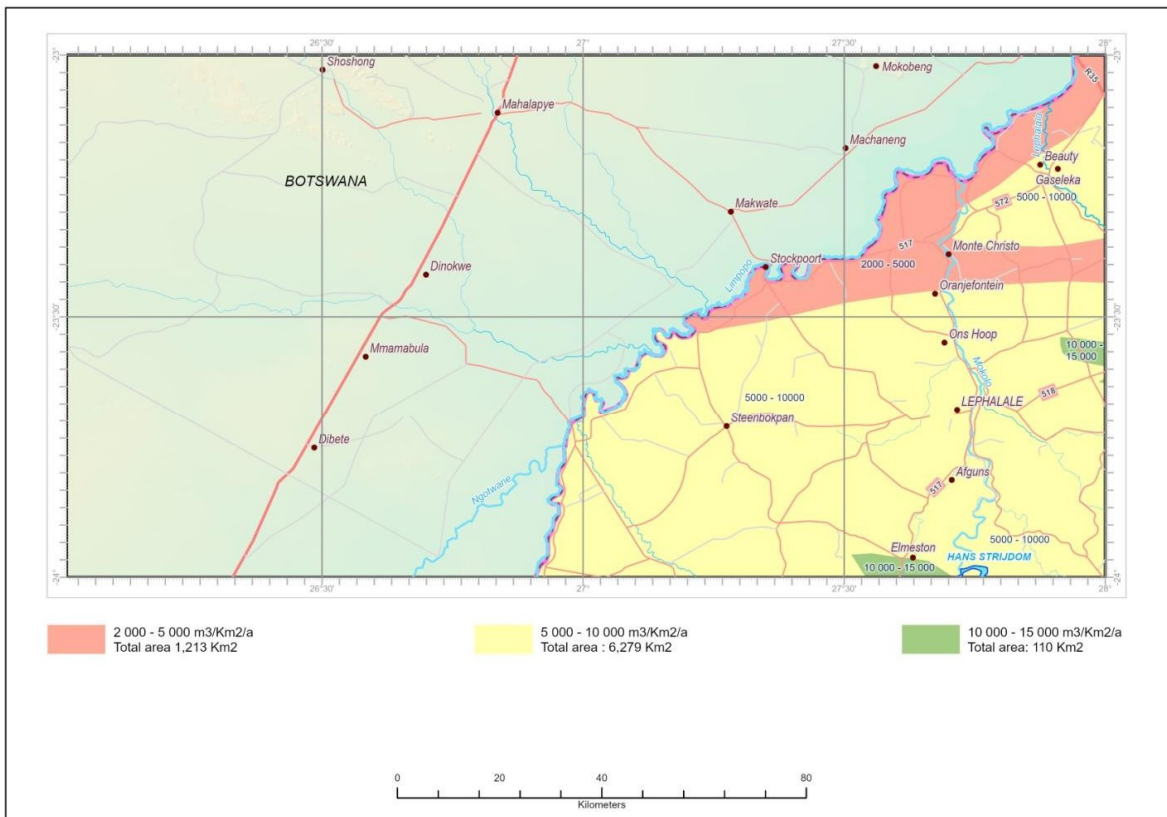


Figure 1: Terrain Morphology (Kruger, 1983)

Table 4: Detailed explanation for Figure 1, Terrain Morphology

BROAD DIVISION	MAP SYMBOL	DESCRIPTION	DRAINAGE DENSITY* (km/km <sup>2</sup> )	% OF AREA WITH SLOPES <5%
Plains with low relief	1	Plains	low - medium 0 - 2	> 80%
Tablelands with moderate to high relief	30	Tablelands (mountain and hill plateau)	Medium 0.5 - 2	< 80%

\* Total length of drainage channels per km<sup>2</sup>

## 4.3 Elevation

The elevation within the map sheet is predominantly between 800 to 1200mamsl. The Waterberg plateau within the south-eastern section of the map is between 1200 and 1600mamsl and the area along the Limpopo Valley in the northeast are between 400 and 800mamsl.

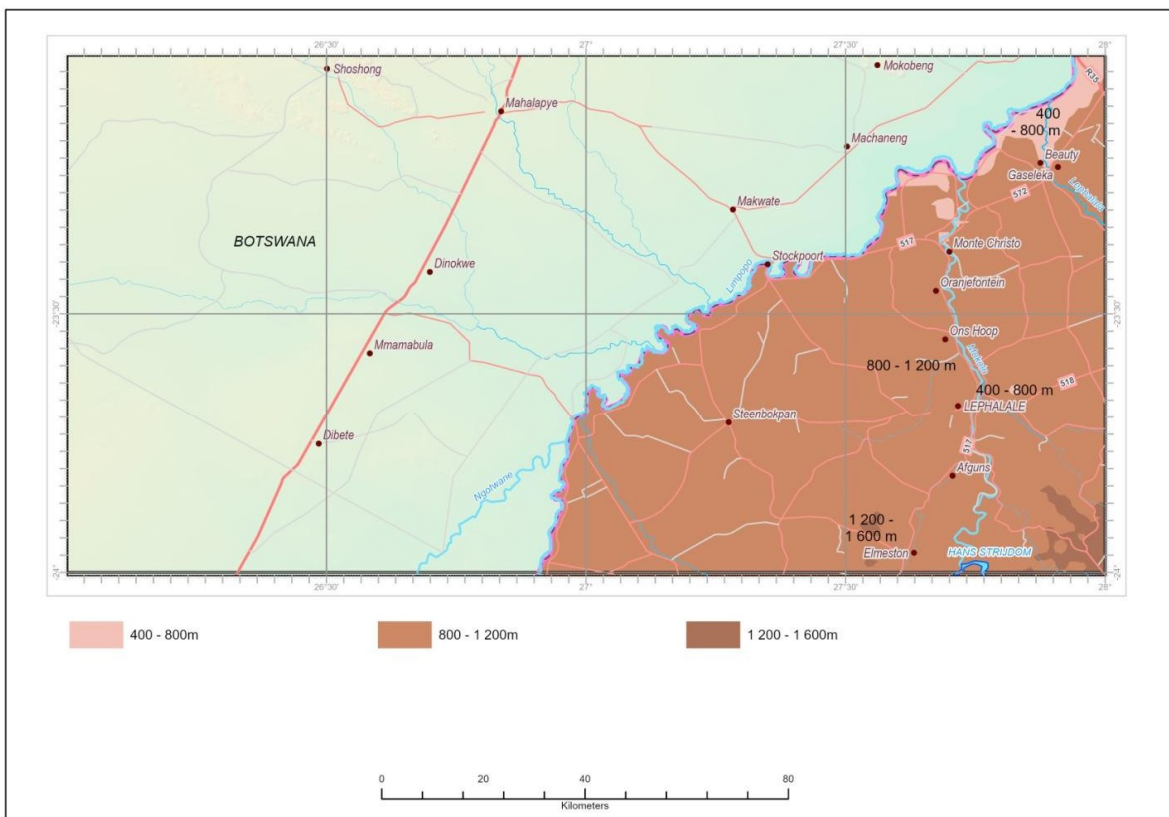


Figure 2: Elevation

#### 4.4 Climate

The long-term average annual rainfall is around 400-600mm, while average daily temperatures vary between 16°C and 32°C in summer and between 2°C and 24°C in winter. The area receives 97.6% of its annual rainfall between October and January, (A4E003) generally in the form of convection thunderstorms. This is especially true for the north and western section of the map sheet i.e. Limpopo Plain Ecoregion (ER) where the Coefficient of Variation of annual precipitation is between 25-40%, while the rest of the area is between 20 to 35%, Refer to Table 5 (*data obtained from A Level 1 River Ecoregional Classification System*), Kleynhans et al., (2005).

Table 5: Limpopo Ecoregions and Coefficient of Variation

Ecoregion (ER)	Winter (July)		Summer (February)		Coefficient of Variation (% of annual precipitation)
	mean daily minimum temperature	mean daily minimum temperature	mean daily minimum temperature	mean daily minimum temperature	
North and west (Limpopo Plain ER)	2 to >10°C	20 to >24°C	16 to >20°C	26 to 32°C	25 to 40%
South-east (Waterberg plateau ER)	2 to 6°C	16 to 24°C	12 to 20°C	24 to 32°C	20 to 35%

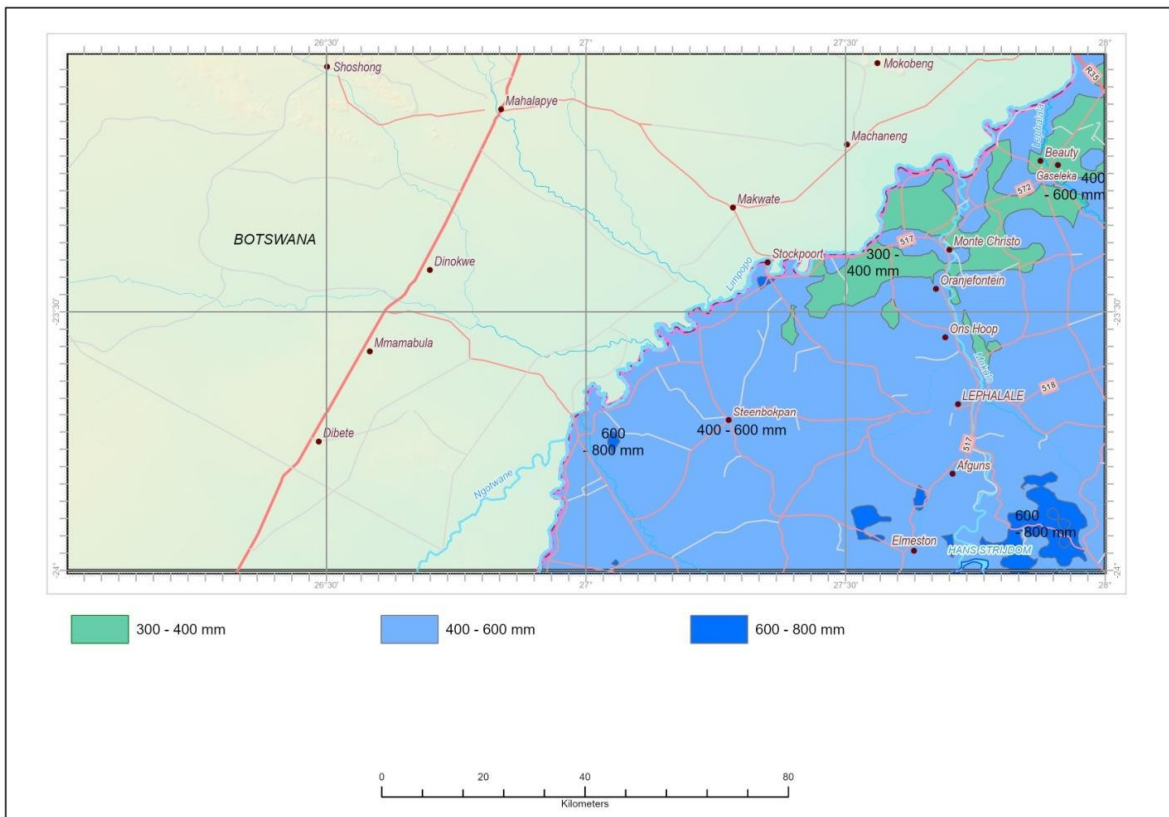


Figure 3: Mean Annual Precipitation

Mean Annual Precipitation (MAP) (Figure 3), varies from between 300 and 800mm/annum over most of the map area. The lowest rainfall is in the north (300-400mm/annum) and the highest (600-800mm/annum) in the south-east in the mountainous area underlain by rocks of the Waterberg Group. Rainfall occurrence over the largest part of this area is very erratic and unreliable resulting in long dry periods.

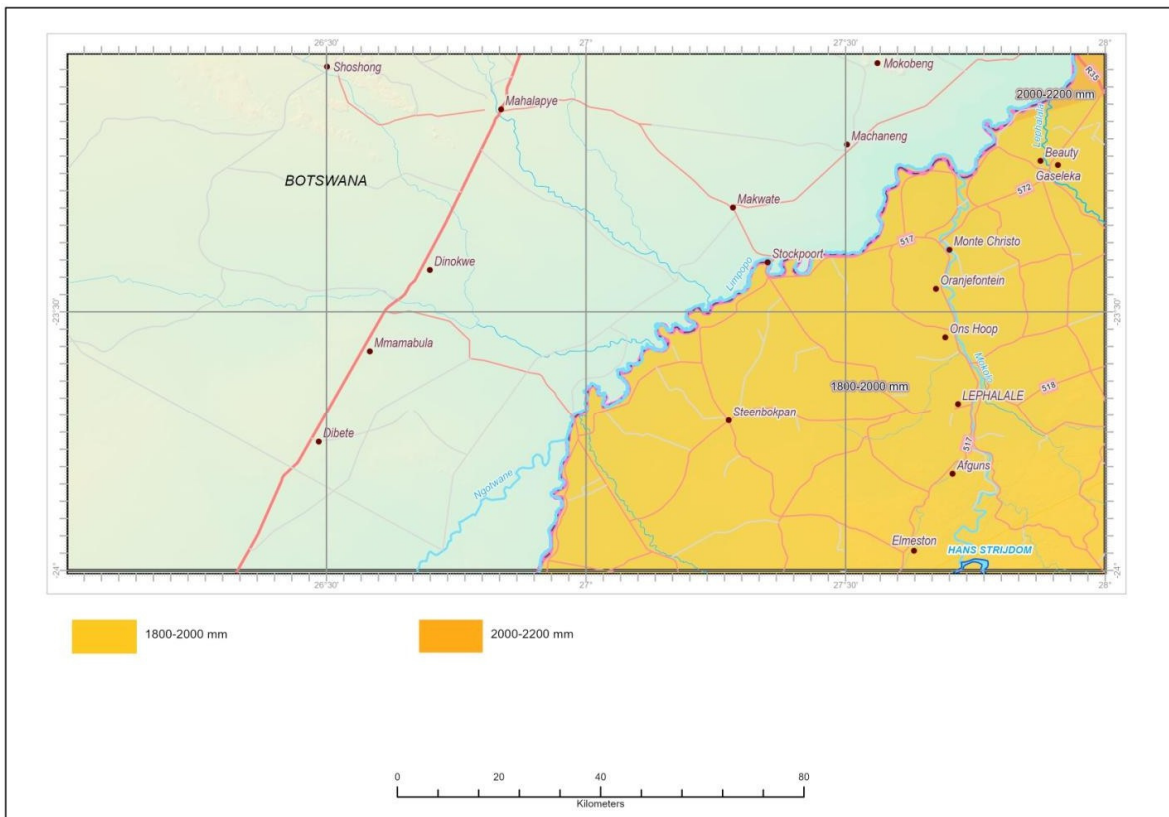


Figure 4: Mean annual evaporation

Mean Annual Evaporation (MAE) (Figure 4), varies between 1800-2000mm over most of the map area except in the northeast within the Limpopo Valley where it is the highest, (2000-2200mm).

#### 4.5 Surface Hydrology

The area falls in **one main drainage region** i.e. the Limpopo system (A). The major Tributaries for the Limpopo River in the map area arise from the Waterberg plateau. This area in the south-eastern section of the map receives in general higher rainfall than the regional average. In addition, the impermeable nature of the predominant sandstone strata favors runoff to groundwater recharge.

The Tributaries are the north-western flowing Matlabas, the north flowing Mokolo and Palala Rivers. The Mokolo River is fed by various tributaries namely, the Bulspruit, Rietspruit, Sandloop, Poer se Loop and Tambotie Rivers.

West of the Limpopo River and within Botswana the tributaries are the Ngotwane, Bonwapitse, Mhalatswe and Taupye Rivers.

Only one **major dam** occurs within the map area; Table 6 lists the basic site information and storage capacity.

Mode and irregular frequency of precipitation, combined with high evaporation rates, results in droughts and periodical flows in most, if not, all 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, type of riverbed material, structural geology, riparian vegetation, abstraction points near the river, and the static water level in the vicinity of the river.

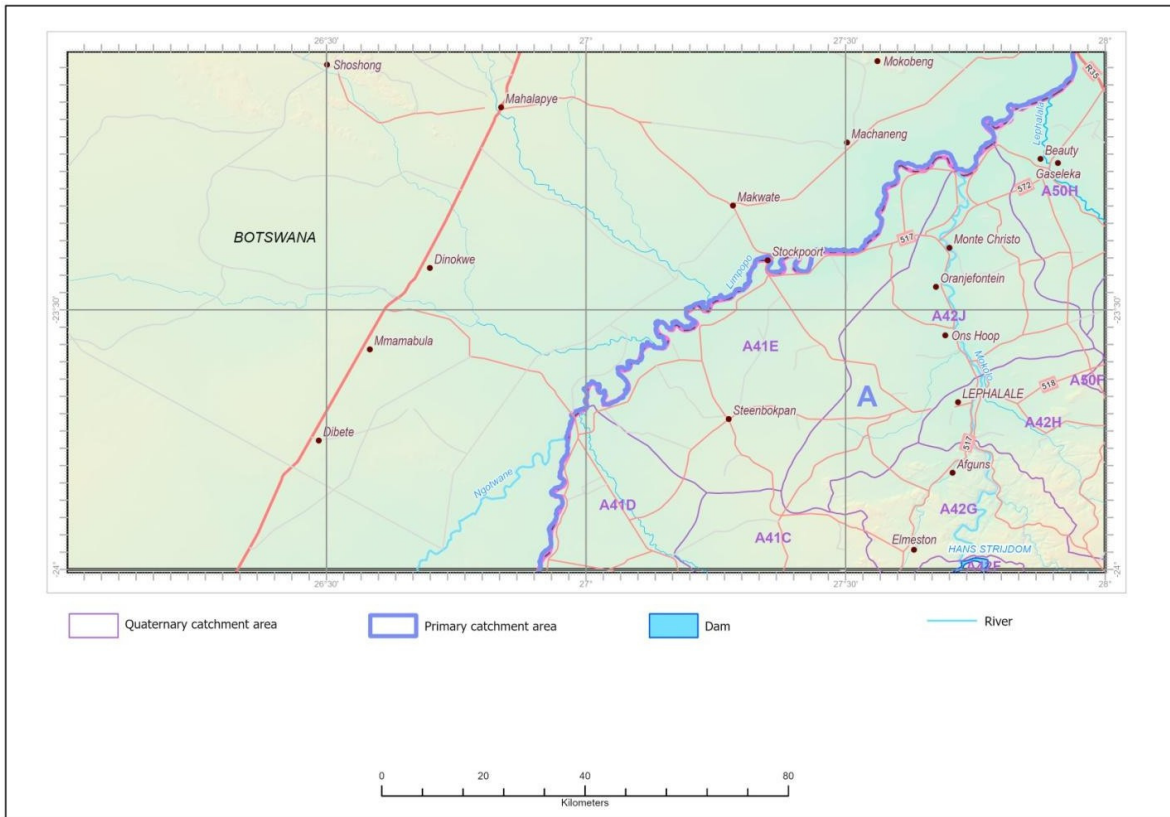


Figure 5: Drainage regions and major dams (HRU, 1981)

The Mokolo Dam supplies water as follows:

- Grootegeluk Mine and the town of Lephalale: allocated 10.1 million cubic meters per year (Mm<sup>3</sup>/annum).
- Matimba Power Station: allocated 7.1 million cubic meters per year (Mm<sup>3</sup>/annum).
- Additionally, irrigation users depend heavily on consistent releases from the dam to maintain agricultural activities.

Table 6: Major dams, drainage basin, supplying river and storage capacity (HRU, 1981)

DAM NAME	DRAINAGE BASIN	RIVER	Firm yield (Mm <sup>3</sup> /annum)	STORAGE CAPACITY (Mm <sup>3</sup> )
Mokolo (Hans Strijdom)	A4	Mokolo	27	146

## 5. GEOLOGY

### 5.1 Regional geology

The geology occurring on the Ellisras 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 6) was compiled from the 1: 250 000 Ellisras published geological map sheet and explanatory brochure (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 hydrogeological aquifer units are in most cases like the geological boundaries. The major stratigraphic groups are as follows:

- The Basement Complex
- Granite intrusives
- Bushveld Complex
- Waterberg Supergroup
- Glenover Complex
- Karoo Supergroup
- Quaternary

#### **The Basement Complex**

The Basement Complex of Swazian age is visible as scattered outcrops in the plains that occur within the northern section of the map sheet, north of latitude S23° 23' 00". Extensive quaternary sand and soil overlay large portions of the bedrock making it difficult to conclude the covered rock type beyond any doubt. The basement complex consists essentially of a succession of supracrustal gneisses (Beit Bridge Complex) that was divided into 3 groups namely, undifferentiated metamorphic rocks (Mount Dove Group, Malala Drift Group, Gumbu Group) and intrusive layers and lenses of mafic and ultramafic rocks (Messina Suite) and granitoid rocks (Alldays Gneiss).

A very well-known geological feature occurring on both Ellisras and Polokwane maps is the Limpopo Mobile Belt. It is a zone of complexly deformed Archean gneiss units and rocks of high metamorphic grade. The Limpopo belt separates Archean greenstone belts and gneiss units of lower metamorphic grade in the Rhodesian craton to the north from similar lower grade rocks in the Kaapvaal craton to the south. It is postulated that the Limpopo Mobile Belt formed ~ 3570 Ma ago with the establishment of a continental rise that collapsed into an aulacogen. The aulacogen and the sedimentary and igneous rocks that filled it were successively deformed because of differential movements between crustal plates encompassing what are now commonly termed the Rhodesian and Kaapvaal Cratons. The timing of events in the evolution of the Limpopo Mobile Belt correlates well with the chronology of the tectonic development of the granite-greenstone terrains of the Rhodesian and Kaapvaal Cratons. The pattern of crustal evolution in southern Africa may be viewed in terms of the accretion of a series of deformed back-arc basins and island arcs onto a nucleus of continental rocks including the Limpopo Mobile Belt.

It occurs in South Africa and Zimbabwe, runs E-NE, and joins the Kaapvaal Craton to the south with the Zimbabwe Craton (Rhodesian) to the north. The Central Zone of the Limpopo Mobile Belt strikes east-north-east across the northern part of the map sheet and is bounded in the south by major faults i.e. Abbotspoort, Melinda and Vivo faults which have exposed deeper levels of the earth's crust, hence the high grade of metamorphism of the rocks that prevails within the belt.

## **Granite Intrusives**

Various granite types form small, isolated exposures, mainly in the bed of the Limpopo River, (Brandl, 1996). These units are not linked to any of the groundwater units within this report. Other granite intrusions such as the Nebo Granite and Palala Granite are described as part of the Bushveld Complex.

## **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 Raseebie 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).

The Bushveld Complex in the map area is represented by the Villa Nora Gabbro-Anorthosite compartment that is seen as a separate intrusion to the main Complex. It is also represented by the Nebo Granite of the Lebowa Granite Suite and Palala Granite intrusion. The Palala Granite belongs to the Lebowa suite of granites as an ultimate fractionation of the Bushveld Igneous Complex magma (Journal of African Earth Sciences, Volume 175. March 2921). It is found within the Palala Shear Zone (PSZ), a tectonic lineament in Southern Africa that forms the southern boundary of the Limpopo Belt's Central Zone:

Outcrops fall within the central eastern side of the Lephalale hydrogeological map sheet and the central western side of the Polokwane hydrogeological map sheet. To the west it is overlain by Karoo rocks and to the south by Waterberg rocks. Groundwater units discussed in the report combined the information within the two map sheets for each unit as it does not make sense to split the available information according to a map boundary.

## **Waterberg Supergroup**

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 Thabazimbi-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 map sheet). The Langkloof beds 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.

Within the map area rocks outcrop occur south of the Eenzaamheid fault zone that is at latitude  $\pm S23^{\circ} 40' 00''$ . Between the Eenzaamheid fault and the Zoetfontein fault (Ellisras Karoo Basin), rocks of the Waterberg Supergroup, (predominantly of the Mogalakwena Formation) are overlain by Karoo Supergroup rocks mainly of sedimentary origin.

The Waterberg plateau in the south-eastern section of the map sheet is largely a succession of cross-bedded sandstone 1 250 m thick. The plateau is formed by resistive rocks of the Mogalakwena Formation with elevations between 800 and 1200mamsl.

To the west the Aasvoëlkop Formation dominates the topography comprising of plains with an elevation of between 400 to 800mamsl. Intrusive into the Aasvoëlkop Formation, is the **Glenover Complex** that forms a circular structure comprising a central breccia body of biotite, pyroxenite, and carbonate surrounded by fine and fenitised sandstone (Brandl, 1996).

In the north-western section of the adjacent geological map sheet, Thabazimbi, the Waterberg beds of the Ootse basin in Botswana occupy a small area. Part of the succession is indicated as Smelterskop Stage on Sheet 2425D (Gaborone). It has not been subdivided, but the basal beds are most likely of early Waterberg age, because in this area they conformably overlie the Transvaal beds, with a locally developed breccia at the base. This correlation agrees with the hypothesis of the overlapping of Bushveld and Waterberg periods based on relationships in the Nylstroom syncline and other areas.

### **Karoo Supergroup**

Within Southern Africa, rocks of the Karoo Supergroup were preserved within two major depositories in Southern Africa namely Main Karoo and the Kalahari Basin. The accumulation of the sedimentary fill of these Karoo basins was under the influence of two main controls: tectonism and climate (Rust, 1975, Catuneanu et al, 2005). Tectonic regimes during the Karoo time varied from dominantly flexural in the south, in relation to processes of subduction, accretion and mountain building along the Panthalassan (palaeo-Pacific) margin of Gondwana, to extensional to the north, in relation to spreading processes along the Tethyan margin of Gondwana, (Rust, 1975, Tankard et al, 1982, Turner, 1986, Smith et al, 1993, Veevers et al, 1994a, Veevers et al, 1994b, Veevers et al, 1994c, Johnson et al, 1996, Visser and Praekelt, 1996, Selley, 1997, Catuneanu et al, 1998, Pysklywec and Mitrovica, 1999).

As stated in the previous paragraph, for the smaller basins north of the main Karoo basin, such as the Springbok Flats, the Tuli, the Lebombo and Ellisras basins, tectonic regimes were dominated by extensional stresses or transtensional stresses. Extensional stresses will lead to linear zones of localized crustal extension (Rifts). Typical rift features are central linear depressions called grabens or more commonly a half-graben with normal faulting and rift-flank uplifts mainly on one side. Superimposed on the tectonic control on basin development, climatic fluctuations also left a mark on the stratigraphic record, which shows evidence of a general shift from cold and semi-arid conditions during the Late Carboniferous-earliest Permian interval, to warmer and eventually hot climates with fluctuating precipitation during the rest of Karoo time (Keyser, 1966, Johnson, 1976, Visser and Dukas, 1979, Stavakis, 1980, Tankard et al, 1982, Visser, 1991a, Visser, 1991b).

The Ellisras sub-basin is considered as a half-graben (Fourie et al, 2009) or graben structure (Sullivan et al, 2013). In terms of economic value, the Ellisras Basin is important as a source of coal used for the generation of power. (Fourie et al, 1996) refers to this coalfield as the Waterberg Coalfield and describes it as containing approximately 44% of South Africa's in situ reserves of bituminous coal. Within this report the name Ellisras Basin is used for the Karoo sediments depository basin.

From the oldest to the youngest the Supergroup is represented within the map sheet by Waterkloof, Wellington, Swartrant, Goedgedacht, Grootegeluk, Eendragtpan, Greenwich, Lisbon, Clarens and Letaba Formations. All the formations are comprised of clastic sedimentary rocks (except for the Letaba Formation), with coal seams developed near the base of the sequence (Brandl, 1996). The stratigraphic succession as depicted on the geological map was proposed by Siepker, (1986a; b); it has been correlated with the stratigraphy developed in the main Karoo Basin, (Johnson et al, 2006).

The sedimentary rocks were deposited in several environments including glacial lacustrine at the base of the sequence, braided and meandering rivers with adjacent over bank deposits, deltaic plains (coal bearing), alluvial fans, and desert settings towards the top (Ryan, 1966; Beukes., 1985; Siepker, 1986a; b; Faure et al, 1996a; Cairncross, 2001).

The basement rock is metaconglomerates and metaquartzite of the Waterberg Group and Transvaal Supergroup, and/or basic rocks of the Bushveld Complex (Johnson et al, 1996). The total thickness of the Karoo Supergroup within the basin is variable with a reported maximum depth of about 800m (Siepker, 1986b). Modelling of airborne geophysical data confirms the half-graben structure of the basin; the thickness of the Basin was inferred to be 580m in the east and 480m in the west; 120m in the south and 580m in the north, (C.J.S. Fourie, G. Henry and L.P. Mare, 2014).

Structurally the sedimentary rocks of the Karoo Supergroup within the basin are highly faulted as depicted on the geological map sheet and as inferred from data obtained from an aerial magnetic survey done in 2008. The Letaba Formation (basalt), that represents the final stage in the succession was removed over time by erosion and only remained in two small areas within the map sheet. The Ellisras Basin is flanked by two major fault zones, i.e. the near vertical Eenzaamheid fault with a displacement of 250m, (IGS, 2010), that forms the southern boundary predominantly against the Mogalakwena Formation of the Waterberg Supergroup and the Zoetfontein fault that is block-faulted and generally steeply dipping, (Fourie, 2014).

North of the Zoetfontein fault, rocks of the Limpopo Mobile Belt occur. The Daarby fault strikes east-north-east and north-westerly. The two sections of the fault are assumed to be the same fault as both legs of the fault exhibit the same throw and throw direction. The displacement is between 250m, (WRC, 2011) and 360m to the north, (ERM, 2008). It subdivides the coalfield into the shallow western part (open cast mining) and the deeper north-eastern part of the coalfield (a displacement of approximately 400m), (IGS, 2010). The Zoetfontein fault resulted from pre-/during Karoo depositional tectonism, whilst the Eenzaamheid and Daarby faults resulted from post-Karoo depositional tectonism (WRC, 2011). To the east, the Karoo rocks are unconformably developed on rocks of the Limpopo Belt and Bushveld Complex rocks (Fourie, 2014).

The Daarby Fault is reported as impermeable that acts as a barrier for groundwater flow near Grootegeluk Mine. It subdivides the aquifer into two separate aquifer compartments; evidence thereof is that groundwater levels differ on each side, (EMR, 2008 & 2012). From regional yield data the Daarby Fault may contribute to some higher yielding boreholes east of Lephalale. The Eenzaamheid fault is regarded as highly conductive, with transmissivity values predicted to be in the range 50m<sup>2</sup>/day, to 400m<sup>2</sup>/day, (Golder Associates, 2007). This prediction corresponds to high yielding boreholes developed in 2008 under a project initiated by DWS that targeted the fault zone.

### **Quaternary**

The Quaternary strata are characterised by thin sequences of Quaternary to Tertiary Aeolian Kalahari sand (not shown on map). However, it is the alluvial sand and gravel (Q) along the major drainages in the area that are the main targets for groundwater development and abstraction via sand points in the riverbed. The water occurs in tertiary-quaternary alluvial deposits within floodplains and river terraces of the Limpopo River and its tributaries. The main tributaries of the Limpopo River in the map area are the Palala, Mokolo and Matlabas Rivers.

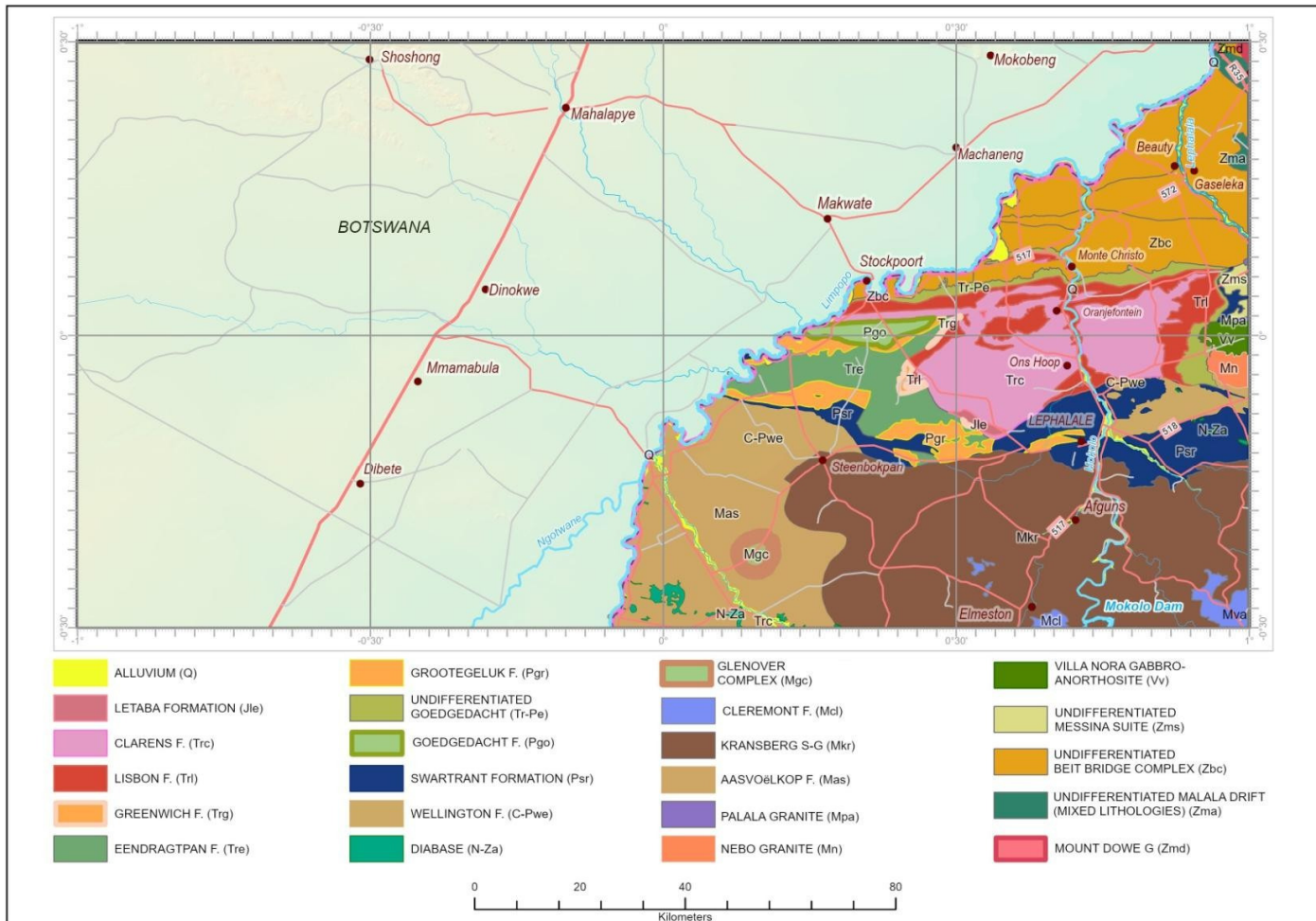


Figure 6: Simplified regional geology of the map area

## 5.2 Structural geology

### Diabase dykes and sills

Diabase dykes and sills (N-Za) are predominantly depicted to occur within the rocks of the Waterberg Supergroup that contribute to groundwater occurrences in that area. The only outcrops shown on the map sheet is of sills within the Aasvoëlkop Formation in the south-western section of the map. Dykes and sills were reported to contribute to high yielding boreholes in that area, (W.D. Rech, 1970). This observation was also reported for the dykes found in the basement rocks near the Palala River. Due to the many higher yielding boreholes (> 2l/s) scattered over the basement rocks the dykes can be regarded as targets throughout the northern area of the map sheet. The occurrence of dykes is more abundant than depicted on the geological map sheet, this is evident from the results of remote sensing interpretation work (DWS, GRIP) and from the interpretation of an aerial geophysical survey that covers a large section of the map sheet, (2008).

As indicated above, the Waterberg Group has been intruded extensively by sills and dykes (N-Za) of predominantly diabasic composition which 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. Diabase dykes and sills 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 kilometers. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them.

### Dolerite dykes and sills

Intrusions after the deposition of the Karoo rocks are listed as dolerite intrusions. It is predominantly confined to the Karoo Supergroup and was considered rare with limited outcrops only observed in some of the pans. In the pre-Karoo rocks, it seems to be very rare or absent (Brandl, 1996). The occurrence of dykes is more abandoned than depicted on the geological map sheet. This is evident from the results of remote sensing interpretation exercise (DWS, GRIP) as well as from the interpretation of an aerial geophysical survey over a large section of the map sheet (2008). The latter identified numerous subtle magnetic anomalies, (Fourie, 2014).

The Beit Bridge Complex is part of the Limpopo Metamorphic Belt which is subdivided into three domains, i.e. a Central Zone and two flanking Marginal Zones. They are separated from each other and from the neighbouring Kaapvaal and Zimbabwe Cratons (Rhodesian Craton), by major shear zones.

The Sunnyside Shear occurs in the north-eastern part of the map area characterized by a strong planar mylonitic fabric parallel to the strike of shearing. It was re-activated over time as a normal fault (Brandl, 1996).

The Palala shear zone is fault bounded, marks the southern boundary of the Central Zone and is approximately 10km wide occurring in the central eastern section of the map sheet as an east-west lineament. The feature forms a linear feature between the Melinda fault in the north and the Beaufort Shear Zone. The Beaufort Shear Zone and Abbotspoort Shear Zone (20m wide) is regarded to have a similar sense of movement, and it is believed that both were activated over time as brittle faults, (Brandl, 1996).

The northern margin of the Waterberg rocks is bounded by the Eenzaamheid Fault with a vertical displacement of 250m with a downthrow to the north. The Karoo Basin is bounded in the north by the Zoetfontein Fault with a moderate vertical displacement and downthrow to the north. Recent research indicated block faulting, (Fourie, 2008).

The Daarby Fault consists of two branches i.e. a north-west trending branch that 'connect' the Eenzaamheid and Zoetfontein faults and an east-north-east striking branch. Near the Grootegeluk coal mine, where it is considered impermeable the maximum throw is approximately 300m.

Various north-west trending brittle faults transect the Waterberg strata; the most prominent is the Boleleme Fault with a northern downthrow and a vertical displacement of approximately 50m, (Brandl, 1996).

Constantia Fault is north of the Eenzaamheid Fault; it is bounded by a small Karoo outlier in the south. The maximum vertical displacement is 160m, (Brandl, 1996).

The Karoo strata are transected by numerous north-west to north-east trending faults that transect all the Formations in the Ellisras Basin.

Figure 7 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 7) 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 Ellisras 2326 geological map.

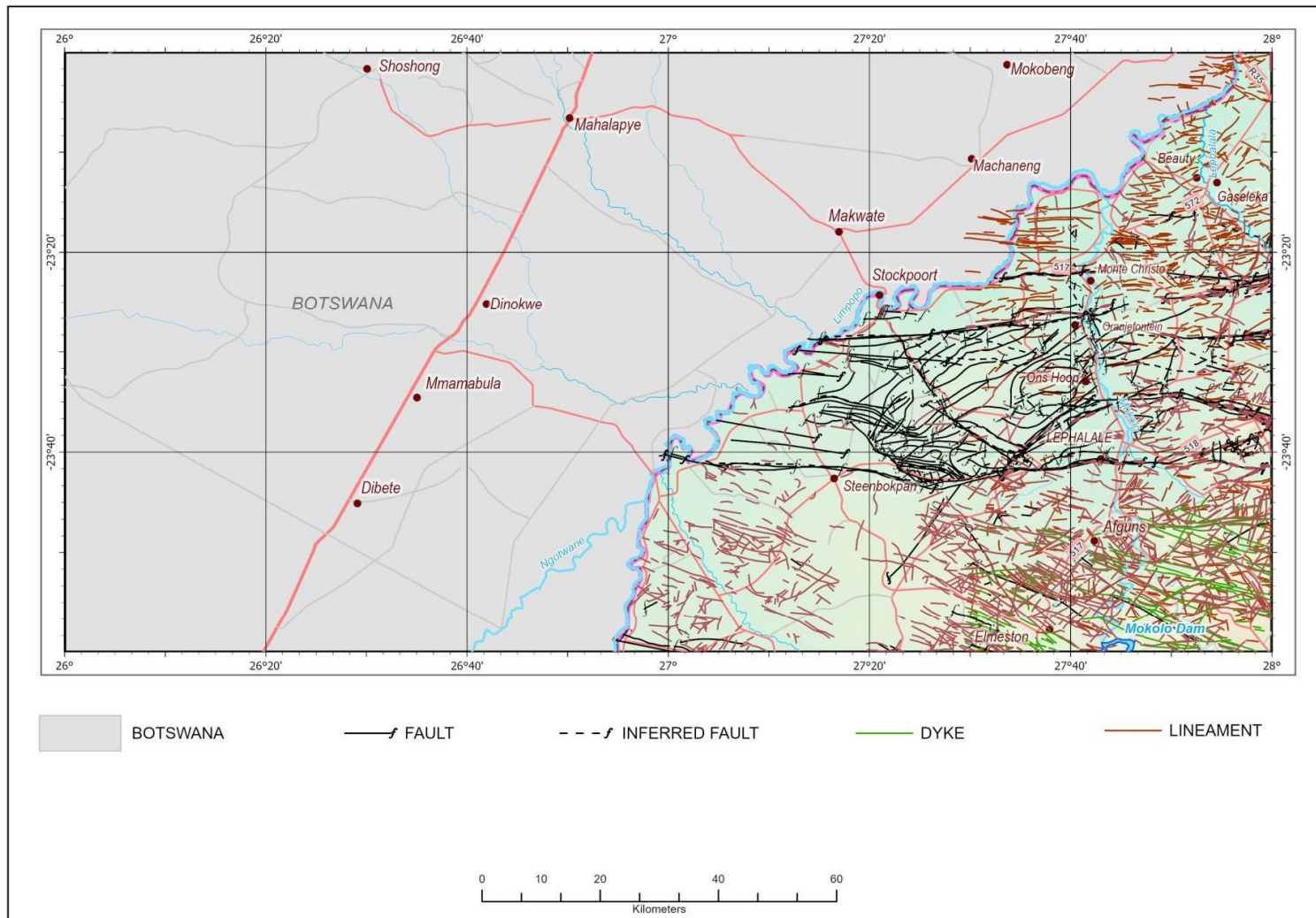


Figure 7: Inferred and observed geological lineaments.

## 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 955 groundwater samples, taken during the period from 1970 to 2008, was utilized.

The chemical data was predominantly obtained from WMS, NGA, e-WULAAS and from the database of the consultancy. The first combined data worksheet consisted of 41 942 data points for the area covered by the 1:500 000 Polokwane map sheet. 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 Ellisras map sheet was separated. Therefore, the total number of duplicates removed for the Ellisras area is not known as being part of the statistics for the larger area. The time series data were however counted for each borehole point. For the Ellisras map sheet and the cross over units in the Polokwane map sheet, 2855 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 1042 thus 1813 samples represent time series data. Of these data, 955 analyses were used for the evaluation of chemistry with the results summarized in various tables. In total 476 analyses were 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:  $EC = \frac{[\sum \text{anions (meq/L)}] + [\sum \text{cations (meq/L)}]}{100} (\mu\text{S/cm})$  and for the E.N. it was calculated as follows,  $\frac{[\sum \text{cations (meq/L)}] - [\sum \text{anions (meq/L)}]}{[\sum \text{cations (meq/L)}] + [\sum \text{anions (meq/L)}]} * 100\%$ , ( $\leq 10\%$ ). 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, that present statistical information, such as the maximum and minimum concentration for elements, some of the analysis was used for the tables, even if the plausibility checks (accuracy) 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 Ellisras 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 possible future smaller scale hydrogeological maps

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 un- acceptable 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 ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^{+} + \text{K}^{+}$ ) and anions ( $\text{HCO}_3^{-}$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^{-}$ ) 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 ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ) and one “Alkali” that is sodium ( $\text{Na}^{+}$ ). For the plot, sodium and potassium ( $\text{K}^{+}$ ) are combined on one axis. The most common anions are, one “weak acid” namely, bicarbonate
- ( $\text{HCO}_3^{-}$ ) and two “strong acids” namely, sulphate ( $\text{SO}_4^{2-}$ ) and chloride ( $\text{Cl}^{-}$ ).

### Interpretation of the Piper and Durov diagrams:

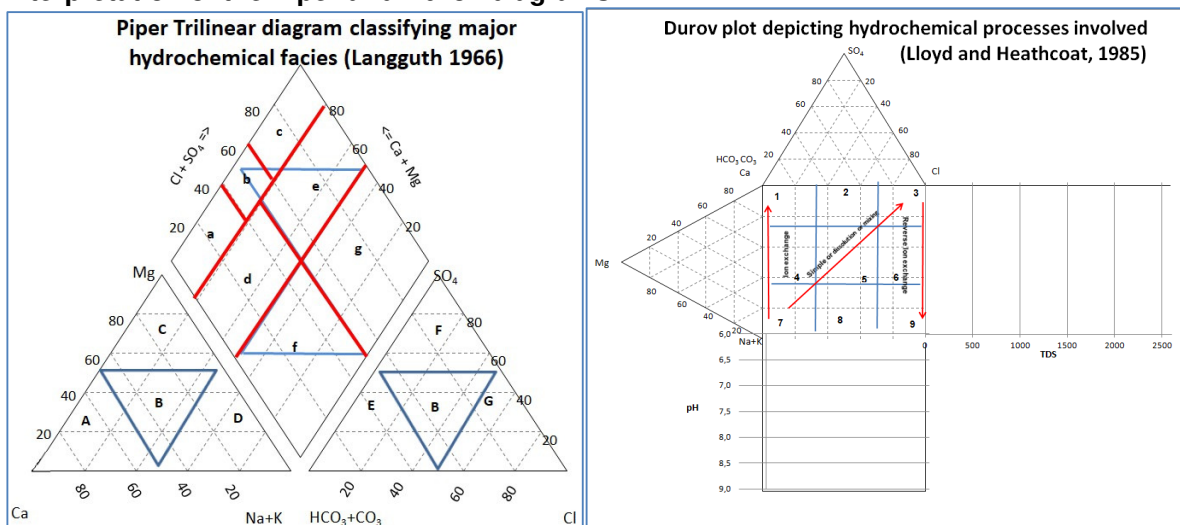


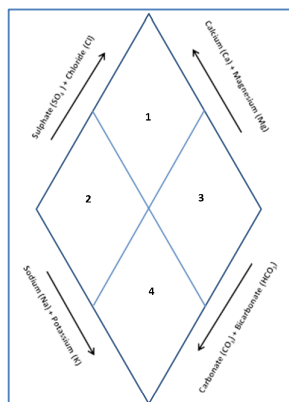
Table 7: Classification of water types based on Piper diagram (Langguth, 1966)

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

Table 8: Classification of water types based on Durov diagram (Lloyd and Heathcote, 1985).

Section	Water Types
1	HCO <sub>3</sub> <sup>-</sup> and Ca <sup>2+</sup> dominant frequently indicates recharging waters in limestone, sandstone and many other aquifers
2	The water is dominated by Ca <sup>2+</sup> and HCO <sub>3</sub> <sup>-</sup> , which typically suggests fresh, recharging groundwater, but if Mg <sup>2+</sup> is also present in significant amounts, it suggests ion exchange processes might be occurring. However, those samples in which Na <sup>+</sup> is significant and Ca <sup>2+</sup> /Mg <sup>2+</sup> < 1 an important ion exchange is presumed.
3	HCO <sub>3</sub> <sup>-</sup> and Na <sup>+</sup> are dominant, normally indicates ion exchanged water, although the generation of CO <sub>2</sub> at depth can produce HCO <sub>3</sub> <sup>-</sup> where Na <sup>+</sup> is dominant under certain circumstances.
4	SO <sub>4</sub> <sup>2-</sup> dominates, or anion discriminate and Ca <sup>2+</sup> dominant, Ca <sup>2+</sup> and SO <sub>4</sub> <sup>2-</sup> 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 <sub>4</sub> <sup>2-</sup> dominates, or anion discriminate and Na <sup>+</sup> dominant, is a water type that is not frequently encountered and indicate probable mixing or uncommon dissolution influences.
7	Cl <sup>-</sup> and Na <sup>+</sup> dominant is frequently encountered unless cement pollution is present. Otherwise, the water may result from reverse ion exchange of Na-Cl waters.
8	Cl <sup>-</sup> dominant anion and Na <sup>+</sup> dominant cation, indicate that the ground waters be related to reverse ion exchange of Na-Cl waters
9	Cl <sup>-</sup> and Na <sup>+</sup> dominant is frequently indicated endpoint 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).

Table 9 below (after DWA, 1996), was used as reference document. The words in the table, namely, suitable, tolerable, unacceptable, and totally unacceptable were not used in the document. The terminology, ideal, good, moderate and unacceptable was used. This corresponds to the terminology used in the document 'Quality of Domestic Water Supplies, Volume 1: Assessment Guide, DWA 1998'.

*Table 9: Guidelines for groundwater quality and suitability (DWA, 1996)*

ELECTRICAL CONDUCTIVITY RANGE (mS/m)	SUITABILITY		
	DOMESTIC	LIVESTOCK	IRRIGATION
<70	Suitable	Suitable	Suitable
70 - 150	Suitable - slightly salty taste	Suitable	Suitable - salt sensitive crops may show a 10% decrease in yield. Wetting of foliage should be prevented
150 - 370	Tolerable - a marked salty taste	Suitable	Suitable for moderately salt tolerant crops although a 10% decrease in yield can be expected. Wetting of foliage should be prevented
370 - 520	Unacceptable - tolerable for short term consumption	Suitable - some loss in productivity	Tolerable for moderately salt tolerant crops although a 20% decrease in yield can be expected. Wetting of foliage should be prevented
>570	Totally unacceptable	Tolerable - may be refused by animals not accustomed to the water	Generally unacceptable

Note: The water quality in terms of EC in the document 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, e-WULAAS and the groundwater data bank of the consultancy were utilised for hydrochemical data analysis and interpretation. Data was also received from various groundwater consultants in the Limpopo Province. The data points were plotted and sorted for each aquifer unit.

Data is presented in various tables of which Table 10 to Table 21 are within Section 6 viz. General: Hydrochemistry and Aquifer Units.

Table 10 & Table 11 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.

Table 12 & Table 13 summarize statistics for the major cations and anions within each aquifer unit. In the summary table the median value (50<sup>th</sup> 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 14 & Table 15 summarize the values of the 90<sup>th</sup> percentile for the major anions and cations.

Table 16 & Table 17 summarize statistics for the major anions and Table 18 & Table 19 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 are 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 20 & Table 21 represent the physical properties viz. Electrical Conductivity and pH as well as the anion Fluoride. The same methodology was followed as in Table 16 to Table 19.

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 90<sup>th</sup> 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 three (3) aquifer units did not have any chemistry data available for analysis. They are Greenwich Formation (Trg); Letaba Formation (Jle) and the Mount Dowe Group (Zmd).

Another three (3) 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. For some of these, the reader can consult the adjacent hydrogeological map sheets, as they may contain additional information regarding specific groundwater resource units. Units without sufficient data are usually small in areal extent or fall outside rural villages. In areas with rural villages, groundwater data is more comprehensive and readily available. This availability can be attributed to the Department of Water and Sanitation's Groundwater Resource Information Project (GRIP). During this project, hydrogeological information for these areas was collected, verified against existing data in the groundwater databank, and updated. Groundwater resources were also tested. The decision to test was based on a grid system; therefore, if no information was available for a certain area, a borehole was selected for pump testing and chemical analysis.

## **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 dolomites. No dolomite occurs within the map area. It was however identified as a non-dominant water type in two of the units; it constitutes less than 9.1%.

### **•Calcium Bicarbonate water**

This water type is dominated by the cation  $Ca^{2+}$  and the anion  $HCO_3^-$ . The units dominated by this water type are predominantly within the dolomites or the aquifers are connected to limestone within the dolomites. No limestone occurs within the map area. It was however identified as a non-dominant water type in two of the units; it constitutes less than 3.2%.

### **•Magnesium Bicarbonate water**

This water type is dominated by the cation  $Mg^{2+}$  and the anion  $HCO_3^-$ . The aquifer unit, Diabase (N-Za,) is partly (20%), dominated by this water type. It was identified as a non-dominant water type in another three of the units; it constitutes less than 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 ( $CaSO_4 \cdot 2H_2O$ ); 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.

### **•Calcium Magnesium Bicarbonate Chloride water**

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

### **•Calcium Bicarbonate Chloride water**

This water type is dominated by the cation  $Ca^{2+}$  and the anions  $HCO_3^-$  and  $Cl^-$ . No units were identified with this water type as the dominant type. Two units exhibit a small percentage (< 4%) that is leaning to a Calcium Bicarbonate type.

### **•Magnesium Bicarbonate Chloride water**

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

### **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<sub>3</sub> 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<sup>2+</sup> and Ca<sup>2+</sup> and the anion SO<sub>4</sub><sup>2-</sup>. The sulphate water is usually associated with groundwater encountered in lavas and gypsum deposits. No units were identified with this water type. The evaluation of the water types in the Tertiary-Quaternary aquifer unit (alluvium) indicated that 1.7% of the water lean towards a Calcium-Bicarbonate- Chloride type.

#### **•Calcium Magnesium Chloride water**

This water type is dominated by the cations Mg<sup>2+</sup> and Ca<sup>2+</sup> and the anion Cl<sup>-</sup>. Where Ca<sup>2+</sup> and Mg<sup>2+</sup> are dominant, water is related to reverse ion exchange (replacement of Na<sup>+</sup> with Ca<sup>2+</sup> and Mg<sup>2+</sup>). No units were identified with this water type.

#### **•Magnesium Chloride water**

This water type is dominated by the cation Mg<sup>2+</sup> and the anion Cl<sup>-</sup>. Although this water type was identified within 3 of the units it never exceeds 10%. The type is indicative of reverse ion exchange. The evaluation of the water type in another aquifer unit was found to lean towards a Magnesium-Bicarbonate-Chloride type (5.6%).

#### **•Calcium Chloride water**

This water type is dominated by the cation Ca<sup>2+</sup> and the anion Cl<sup>-</sup>. No units were identified with this water 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<sub>3</sub>) and sodium-bicarbonate (Na-HCO<sub>3</sub>) or mixed-alkali-bicarbonate (Na-K-HCO<sub>3</sub>) 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<sup>+</sup> and K<sup>+</sup>, it includes Feldspar-bearing rocks (granite, gneiss, arkosic sandstone) where the weathering of alkali feldspars (e.g., orthoclase, plagioclase) releases Na<sup>+</sup> and K<sup>+</sup>. This increases Na<sup>+</sup> and K<sup>+</sup> concentrations, shifting the water type toward an alkali dominance. Clay minerals such as illite, montmorillonite, and kaolinite participate in cation exchange reactions, replacing Ca<sup>2+</sup> and Mg<sup>2+</sup> with Na<sup>+</sup> and K<sup>+</sup>. 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<sup>+</sup> and K<sup>+</sup>, thus increasing the alkali contribution.

#### **•Mixed Calcium Magnesium Bicarbonate water**

This water type is dominated by the cations Mg<sup>2+</sup> and Ca<sup>2+</sup> but with increased Na<sup>+</sup> concentration with the dominant anion HCO<sub>3</sub><sup>-</sup>. In all (8) intergranular and fractured aquifer units this type was identified; it dominates the water type in 6 of these. These units do not fall within the Ellisras Karoo Basin and represents the basement and intrusive rocks. The following units are dominated by this type: Diabase (N-Za, 60%); Glenover Complex (Msc, 80%); Villa Nora Gabbro-Anorthosite (Vv, 36.3%); Messina Suite (Zms, 57.2%) and Undifferentiated Malala Drift Gneiss (Zma, 40%).

Other units with a high percentage of this type but not the dominant type are Undifferentiated Beit Bridge Complex (Zbc, 25.7%); Palala Granite (Mpa, 27.3%) and the Kransberg Subgroup (Mkr, 18%).

### **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 ( $\text{SO}_4^{2-}$ ) and chloride ( $\text{Cl}^-$ ) 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  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$ . With the dissolution of gypsum, anhydrite, halite, and sylvite  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{SO}_4^{2-}$ , and  $\text{Cl}^-$  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  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  is replaced with  $\text{Na}^+$  and  $\text{K}^+$  and will lead to a progressive shift from Ca-Mg- $\text{SO}_4$ -Cl water to Na-K- $\text{SO}_4$ -Cl water.

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

#### **•Mixed Calcium Magnesium Sulphate water**

This water type is dominated by the cations  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  but with increased  $\text{Na}^+$  concentrations and the anion  $\text{SO}_4^{2-}$ . None of the units are dominated by this type of water. The water type accounts for 20% of the types within the aquifer, Diabase N-Za. A mixed Calcium-Magnesium Bicarbonate with increased Sodium and Sulphate constitute 31.6% of the water types of the aquifer, Aasvoëlkop Formation.

#### **•Mixed Calcium Magnesium Chloride water**

This water type is dominated by the cations  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  but with increased  $\text{Na}^+$  concentrations and the anion  $\text{Cl}^-$ . In 13 of the aquifer units this type was identified, it dominates in two namely, Eendragtpan Formation (Tre, 40.9%) and Undifferentiated Goedgedacht Formation (Tr-Pe, 40%).

Other units where this type constitute a high percentage are Tertiary Quaternary Alluvial Deposits (Q, 26.7%); Lisbon Formation (Trl, 33.3%); Grootegeluk Formation (Pgr, 16.6%); Nebo Granite (Mn, 19.4%); Villa Nora Gabbro-Anorthosite (Vv, 18.2%); Undifferentiated Malala Drift Gneiss (Zma, 20%).

#### **•Mixed Calcium Magnesium Bicarbonate Chloride water**

This water type is dominated by the cations  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  but with increased  $\text{Na}^+$  concentrations and the anions  $\text{HCO}_3^-$  and  $\text{Cl}^-$ . This water type was identified within 9 of the units and dominates in three of those. The units are Palala Granite (Mpa, 36.4%); Tertiary Quaternary Alluvial Deposits (Q, 26.8%) and Undifferentiated Beit Bridge Complex (Zbc, 27.2%).

Another unit where this type accounts for a high percentage is for the unit, Undifferentiated Malala Drift Gneiss (Zma, 20%)

#### •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  $SO_4^{2-}$ . This water type was identified within one of the units where it accounts for 8% of the water types found in the unit.

#### 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 or seawater intrusion.

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 7 units, it does not dominate in any of these, but it constitutes 20% of the aquifer unit, Undifferentiated Malala Drift Gneiss (Zma).

#### G: Alkaline water with prevailing Sulphate or Chloride

This water type is dominated by  $Na^+$  and  $K^+$  as the primary cations, with  $SO_4^{2-}$  and/or  $Cl^-$  as the dominant anions. It is commonly associated with evaporite dissolution, cation exchange, and prolonged groundwater residence time. It often occurs in arid or semi-arid regions, deep aquifers, or coastal settings.

Associated rock types include evaporites (gypsum, anhydrite, halite, sylvite), feldspar-rich igneous/metamorphic rocks (granite, gneiss), volcanic rocks, (basalt, andesite, rhyolite, trachyte and tuff) and clay-rich sediments.

#### •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 2 aquifer units but as a low percentage < 2.8%.

#### •Sodium Chloride water

This water type is dominated by the cation  $Na^+$  and the anion  $Cl^-$ . Within 15 units this water type was identified. The units that have a large percentage of water falling within this type are the Karoo formations within the Ellisras Basin. The units that are dominated by this type are Clarens Formation (Trc, 100%); Lisbon Formation (Trl, 66.7%); Grootegeluk Formation (Pgr, 72.2%); Goedgedacht Formation (Pgo, 100%); Swartrant Formation (Psr, 93%); Wellington Formation (C- Pwe, 85%); Kransberg Subgroup (Mkr, 58%); Aasvoëlkop Formation (Mas, 48.8%) and Nebo Granite (Mn, 25.8%).

Other units where this type is of a high percentage are for the units, Tertiary Quaternary Alluvial Deposits (Q, 25.9%); Eendragtpan Formation (Tre, 31.8%); Undifferentiated Goedgedacht Formation (Tr-Pe, 36%) and Undifferentiated Beit Bridge Complex (Zbc, 27.1%).

• **Sodium Chloride Sulphate water**

This water type is dominated by the cation  $\text{Na}^+$  and the anions  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$ . This water type was identified within 3 aquifer units but only dominant in one namely, Nebo Granite (Mn, 25.8%).

Other problematic chemical species, which occur in the area covered by the map sheet, include Nitrate and Fluoride (Figure 8). 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 10: Interpretation of the hydrochemical facies as percentages, water type; first 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 Bicarbonate	Calcium Bicarbonate	Magnesium Bicarbonate	Calcium Bicarbonate Sulphate	Calcium Magnesium Bicarbonate Chloride	Calcium Bicarbonate	Magnesium Bicarbonate Chloride	Calcium Bicarbonate Chloride	Calcium Bicarbonate Chloride	Calcium Magnesium Chloride	Magnesium-Bicarbonate-Chloride	Calcium-Chloride	Mixed Calcium Magnesium Bicarbonate	Mixed Calcium Magnesium Bicarbonate	Mixed Calcium Magnesium Chloride	Mixed Calcium Magnesium Bicarbonate Chloride	Mixed Calcium Magnesium Chloride-Sulphate	Sodium Bicarbonate water	Sodium Sulphate water	Sodium Chloride water	Sodium Mixed Chloride Sulphate
<b>Category A: Intergranular aquifers</b>																						
Q	58							1,7					10,3		26,7	26,8		8,6		25,9		
<b>Category B: Fractured aquifers</b>																						
Trc	6																				100,0	
Trl	6														33,3						66,7	
Trg	0	No chemical data was available for this unit																				
Tre	20													4,5	40,9	9,1		13,7			31,8	
Tr-Pe	25						4,0								40,0	8,0	8,0	4,0			36,0	
Pgr	18										5,6		5,6		16,6						72,2	
Pgo	1																				100,0	
Psr	14														7,0						93,0	
C-Pwe	20														5,0						85,0	10,0
Mcl	0	No chemical data was available for this unit																				
Mkr	50			2,0			2,0						18,0	10,0		8,0			2,0		58,0	
Mas	101		1,0											31,6		13,9		1,9	2,8		48,8	
<b>Category C: Karst aquifers</b>																						
No Karst aquifers appear within the map sheet																						
Note: Dominant type highlighted, values represent percentages (%)																						

Table 11: Interpretation of the hydrochemical facies as percentages, 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 Chloride-Sulphate	Sodium Bicarbonate water	Sodium Sulphate water	Sodium Chloride water	Sodium Mixed Chloride Sulphate	
<b>Category D: Intergranular and Fractured aquifers</b>																					
Jle	No chemical data was available for this unit																				
N-Za	5			20,0								60,0	20,0								
Msc	10									10,0		80,0		10,0							
Mpa	11			9,1						9,1		27,3		36,4		18,1					
Mn	31		3,2									9,7	19,4			16,1		25,8	25,8		
Vv	11	9,1										36,3	18,2	9,1				18,2	9,1		
Zms	14	7,1		14,3								57,2	7,1					14,3			
Zbc	70									7,1		25,7	12,9	27,2				27,1			
Zma	5											40,0	20,0	20,0		20,0					
Zmd	No chemical data was available for this unit																				
Note: Dominant type highlighted, values represent percentages (%)																					

Table 12: Hydrochemistry of the Lephalale Map Area, 50<sup>th</sup> percentile (median); first page.

Symbol	Total number of samples				50 <sup>th</sup> 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	NO <sub>3</sub>	F	TAL as (CaCO <sub>3</sub> )	Na	Mg	SO <sub>4</sub>	Cl	K	Ca
							mS/m	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
<b>Category A: Intergranular aquifers</b>																
<b>Q</b>	<b>74</b>	<b>3</b>	<b>64.9%</b>	<b>58</b>	<b>7.6</b>	<b>121</b>	<b>1.1</b>	<b>0.8</b>	<b>176</b>	<b>111</b>	<b>25</b>	<b>64</b>	<b>116</b>	<b>3.3</b>	<b>55.3</b>	
<b>Category B: Fractured aquifers</b>																
<b>Trc</b>	<b>13</b>	<b>6</b>	<b>38.5%</b>	<b>6</b>	<b>7.5</b>	<b>89</b>	<b>5.1</b>	<b>0.4</b>	<b>321</b>	<b>176</b>	<b>29</b>	<b>10</b>	<b>210</b>	<b>5.9</b>	<b>80</b>	
<b>Trl</b>	<b>11</b>	<b>4</b>	<b>63.6%</b>	<b>6</b>	<b>7.6</b>	<b>97</b>	<b>10.4</b>	<b>0.3</b>	<b>250</b>	<b>159</b>	<b>33</b>	<b>45</b>	<b>251</b>	<b>7.8</b>	<b>92</b>	
<b>Trg</b>	<b>No chemical data was available for this unit</b>															
<b>Tre</b>	<b>25</b>	<b>3</b>	<b>80.0%</b>	<b>20</b>	<b>7.6</b>	<b>150</b>	<b>0.1</b>	<b>0.8</b>	<b>377</b>	<b>161</b>	<b>31</b>	<b>30</b>	<b>228</b>	<b>13.7</b>	<b>81</b>	
<b>Tr-Pe</b>	<b>30</b>	<b>2</b>	<b>66.7%</b>	<b>25</b>	<b>7.2</b>	<b>140</b>	<b>3.4</b>	<b>0.8</b>	<b>246</b>	<b>132</b>	<b>32</b>	<b>55</b>	<b>183</b>	<b>10.0</b>	<b>78</b>	
<b>Pgr</b>	<b>18</b>	<b>0</b>	<b>88.9%</b>	<b>18</b>	<b>7.3</b>	<b>98</b>	<b>0.1</b>	<b>0.7</b>	<b>234</b>	<b>128</b>	<b>20</b>	<b>19</b>	<b>174</b>	<b>7.5</b>	<b>42</b>	
<b>Pgo</b>	<b>1</b>	<b>0</b>	<b>100.0%</b>	<b>1</b>	<b>7.3</b>	<b>383</b>	<b>0.1</b>	<b>2.1</b>	<b>521</b>	<b>652</b>	<b>32</b>	<b>1.9</b>	<b>1100</b>	<b>27.0</b>	<b>53</b>	
<b>Psr</b>	<b>26</b>	<b>6</b>	<b>61.5%</b>	<b>14</b>	<b>7.6</b>	<b>89</b>	<b>0.2</b>	<b>0.8</b>	<b>124</b>	<b>157</b>	<b>8</b>	<b>50</b>	<b>209</b>	<b>4.0</b>	<b>24</b>	
<b>C-Pwe</b>	<b>24</b>	<b>2</b>	<b>79.2%</b>	<b>20</b>	<b>8.1</b>	<b>156</b>	<b>0.3</b>	<b>1.6</b>	<b>181</b>	<b>298</b>	<b>12</b>	<b>104</b>	<b>286</b>	<b>3.7</b>	<b>34</b>	
<b>Mcl</b>	<b>31</b>	<b>0</b>	<b>35.5%</b>	<b>19</b>	<b>7.4</b>	<b>15</b>	<b>1.1</b>	<b>0.1</b>	<b>51</b>	<b>8</b>	<b>3</b>	<b>4</b>	<b>7</b>	<b>0.9</b>	<b>8</b>	
<b>Mkr</b>	<b>67</b>	<b>2</b>	<b>76.1%</b>	<b>50</b>	<b>7.4</b>	<b>93</b>	<b>0.8</b>	<b>0.6</b>	<b>132</b>	<b>111</b>	<b>14</b>	<b>19</b>	<b>150</b>	<b>6.6</b>	<b>20</b>	
<b>Mas</b>	<b>132</b>	<b>1</b>	<b>54.5%</b>	<b>101</b>	<b>7.6</b>	<b>140</b>	<b>5.3</b>	<b>0.8</b>	<b>294</b>	<b>137</b>	<b>51</b>	<b>28</b>	<b>148</b>	<b>5.6</b>	<b>80</b>	
<b>Category C: Karst aquifers</b>																
<b>No Karst aquifers appear within the map sheet</b>																
<b>Manipulation of samples:</b> removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC. In most of the unit's analysis with EN up to ±15% was used if the calculated EC difference was acceptable.																

Table 13: Hydrochemistry of the Lephale Map Area, 50<sup>th</sup> percentile (median); second page.

Symbol	Total number of samples				50 <sup>th</sup> percentile (median) and comparison to SANS 241:2015 maximum acceptable limits										
	after manipulation	missing major anions or cations	E.N. ? $\pm$ 10% & EC ? 20%	used for piper and Durov	pH ideal 6 to 9	EC	NO <sub>3</sub>	F	TAL as (CaCO <sub>3</sub> )	Na	Mg	SO <sub>4</sub>	Cl	K	Ca
						mS/m	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
<b>Category D: Intergranular and Fractured aquifers</b>															
Jle	No chemical data was available for this unit														
N-Za	5	0	20.0%	5	7.60	127	5.12	0.90	418	86	71	12	100	4.1	97
Mgc	12	0	33.3%	10	7.76	92	4.26	2.59	310	66	47	33	70	9.2	63
Mpa	26	3	15.4%	11	8.17	141	32.08	2.07	386	141	70	34	129	8.7	65
Mn all	177	0	41.2%	n/a	7.98	105	8.56	1.64	252	104	33	27	119	2.3	62
Mn cross boundary	66	0	42.4%	31	7.99	109	8.65	2.79	218	141	25	41	136	1.9	53
Vv	24	0	29%	11	7.99	160	26.83	0.62	347	155	62	47	183	2.0	74
Zms	29	0	13.8%	14	7.60	122	25.05	0.85	375	93	60	37	71	6.4	76
Zbc	185	9	39.5%	70	7.65	166	21.63	1.04	289	138	68	66	191	8.1	88
Zma	9	1	11.1%	5	8.03	120	21.42	1.00	360	124	53	27	94	10.8	69
Zmd	No chemical data was available for this unit														
<p><b>Manipulation of samples:</b> removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC. In most of the unit's analysis with EN up to <math>\pm</math>15% was used if the calculated EC difference was acceptable. (Mn all) is all the occurrences on the Polokwane and Lephale Map sheet, (Mn cross boundary) is only the occurrence that is cross boundary thus the occurrence is within the eastern section of the Lephale map and the western section of the Polokwane map sheet.</p>															

Table 14: Hydrochemistry of the Lephalale Map Area, 90<sup>th</sup> percentile (median); first page.

Symbol	Total number of samples	90 <sup>th</sup> percentile (median) and comparison to SANS 241:2015 maximum acceptable limits														
Aquifer Unit	after manipulation	pH ideal 6 to 9	EC	NO <sub>3</sub>	F	TAL as (CaCO <sub>3</sub> )	Na	Mg	SO <sub>4</sub>	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	mg/l
			370	20	1.5		400	200	600	600	100	300	2	1	10	
<b>Category A: Intergranular aquifers</b>																
Q	74	8.3	333.9	16.8	8.6	375.8	380.1	103.1	406.0	738.4	8.2	200.5	0.7	0.7	0.1	
<b>Category B: Fractured aquifers</b>																
Trc	13	8.6	161.4	7.3	1.7	531.5	605.2	47.6	324.6	583.0	89.0	111.8	8.51	0.14	0.05	
Trl	11	8.8	250.0	27.1	1.3	363.4	1553.4	395.0	453.3	3927.1	38.9	831.9	0.19	0.05	0.05	
Trg	No chemical data was available for this unit															
Tre	25	8.2	246.6	3.6	3.9	534.0	313.8	57.1	148.4	436.6	19.9	140.5	1.5	0.55	0.16	
Tr-Pe	30	8.0	615.4	26.7	3.2	528.7	634.7	70.9	448.8	1179.1	20.6	371.9	2.7	0.33		
Pgr	18	7.7	238.4	0.7	5.7	463.0	377.7	62.5	149.3	357.5	18.2	89.5	34.7	0.49	0.12	
Pgo	1	7.3	383.0	0.1	2.1	521.0	652.0	31.7	1.9	1100.0	27.0	53.0	0.1	0.05	0.05	
Psr	26	8.3	182.8	4.9	9.8	286.8	368.2	58.3	221.0	388.0	18.3	101.0	3.8	0.84	0.93	
C-Pwe	24	8.3	251.8	7.6	14.7	332.1	459.3	39.3	227.8	595.8	7.4	77.8	0.1	0.19	0.01	
Mcl	31	8.0	43.2	4.4	0.4	160.7	24.1	14.5	12.6	26.6	1.5	34.1	0.1	0.1	0.7	
Mkr	67	8.2	213.6	11.3	8.4	370.4	357.4	64.5	167.9	430.6	38.7	88.3	6.8	0.35	0.16	
Mas	132	7.9	352.3	24.0	1.9	445.1	361.8	111.7	303.3	857.1	13.9	241.7				
<b>Category C: Karst aquifers</b>																
No Karst aquifers appear within the map sheet																
<b>Manipulation of samples:</b> removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC. In most of the unit's analysis with EN up to ±15% was used if the calculated EC difference was acceptable.																

Table 15: Hydrochemistry of the Lephalale Map Area, 90th percentile (median); second page.

Symbol	Total number of samples	90 <sup>th</sup> percentile (median) and comparison to SANS 241:2015 maximum acceptable limits														
Aquifer Unit	after manipulation	pH ideal 6 to 9	EC	NO <sub>3</sub>	F	TAL as (CaCO <sub>3</sub> )	Na	Mg	SO <sub>4</sub>	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	mg/l
			370	20	1.5		400	200	600	600	100	300	2	1	10	
<b>Category D: Intergranular and Fractured aquifers</b>																
Jle	No chemical data was available for this unit															
N-Za	5	7.8	204.4	11.5	1.49	497.6	177.1	84.4	517.3	187.0	10.3	216.2				
Mgc	12	7.9	179.8	44.7	5.44	375.8	162.3	136.8	159.4	487.7	24.2	74.2				
Mpa	26	8.7	431.6	71.3	4.11	454.3	444.1	108.7	190.6	982.5	13.4	196.6	0.04	0.64	0.01	
Mn all	177	8.3	299.0	38.0	4.14	481.4	300.4	74.3	92.8	483.6	13.7	129.5	0.05	0.21	0.31	
Mn cross boundary	66	8.3	228.0	73.4	5.42	373.3	298.3	57.8	98.3	374.0	7.9	120.1	0.04	0.24	0.85	
Vv	24	8.1	234.8	58.0	1.72	428.1	292.9	105.8	126.1	487.7	6.8	111.6	0.05	0.05	0.06	
Zms	29	7.9	208.2	42.8	1.55	437.8	181.9	113.4	83.3	298.7	8.8	107.5	0.02	0.08	0.11	
Zbc	185	8.4	459.2	84.4	2.17	399.9	423.9	181.5	352.0	944.9	14.9	287.6	0.06	0.04	0.07	
Zma	9	8.4	148.4	30.2	1.15	395.4	139.2	78.4	43.8	173.5	22.1	85.7	0.02	0.01	0.10	
Zmd	No chemical data was available for this unit															
<p><b>Manipulation of samples:</b> removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC. In most of the unit's analysis with EN up to ±15% was used if the calculated EC difference was acceptable. (Mn all) is all the occurrences on the Polokwane and Lephalale Map sheet, (Mn cross boundary) is only the occurrence that is cross boundary thus the occurrence is within the eastern section of the Lephalale map and the western section of the Polokwane map sheet.</p>																

Table 16: Summarized Major Anions: Chloride, Nitrate and Sulphate concentration ranges within aquifer units, first page

Anions		Chloride Cl (mg/l)				Nitrate NO <sub>2</sub> + NO <sub>3</sub> as N (mg/l)				Sulphate SO <sub>4</sub> (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Un-acceptable
Limit Ranges		100	200	600	>600	6	10	20	>20	200	400	600	>600
<b>Category A: Intergranular aquifers</b>													
<b>Q</b>	74	47.2%	13.9%	25.0%	13.9%	80.6%	2.8%	10%	6.9%	87.1%	1.4%	5.7%	5.7%
<b>Category B: Fractured aquifers</b>													
<b>Trc</b>	13		28.6%	57.1%	14.3%	71.4%	28.6%			85.7%		14.3%	
<b>Trl</b>	11	12.5%	25.0%	37.5%	25.0%	16.7%	33.3%	33.3%	16.7%	85.7%			14.3%
<b>Trg</b>	No chemical data was available for this unit												
<b>Tre</b>	25	13.6%	27.3%	54.5%	4.5%	100.0%				91%	9.1%		
<b>Tr-Pe</b>	30	22%	33.3%	29.6%	14.8%	53.6%	7.1%	17.9%	21.4%	79%	10.7%		10.7%
<b>Pgr</b>	18		61.1%	38.9%		100.0%				89%	11.1%		
<b>Pgo</b>	1				100.0%	100.0%				100%			
<b>Psr</b>	26	33%	14%	42.9%	9.5%	90%	10%			85%	15.0%		
<b>C-Pwe</b>	24		13.6%	77.3%	9.1%	86%	9.1%		4.5%	86%	13.6%		
<b>Mcl</b>	31	100.0%				93%	3.3%		3.3%	100%			
<b>Mkr</b>	67	35.4%	27.7%	29.2%	7.7%	79.7%	9.4%	3.1%	7.8%	93.8%	3.1%	1.5%	1.5%
<b>Mas</b>	132	27.5%	35.9%	19.8%	16.8%	54.2%	18.3%	16.0%	11.5%	80.2%	9.9%	3.8%	6.1%
<b>Category C: Karst aquifers</b>													
No Karst aquifers appear within the map sheet													
<b>Note:</b> 0% occurrences removed to make the table more readable													

Table 17: Summarized Major Anions: Chloride, Nitrate and Sulphate concentration ranges within aquifer units, second page.

Anions		Chloride Cl (mg/l)				Nitrate NO <sub>2</sub> + NO <sub>3</sub> as N (mg/l)				Sulphate SO <sub>4</sub> (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Un-acceptable
Limit Ranges		100	200	600	>600	6	10	20	>20	200	400	600	>600
<b>Category D: Intergranular and Fractured aquifers</b>													
<b>Jle</b>	No chemical data was available for this unit												
<b>N-Za</b>	5	60.0%	20.0%	20.0%		60%	20.0%	20.0%		80.0%			20.0%
<b>Mgc</b>	12	67%	16.7%	8.3%	8.3%	50%	8.3%	8.3%	33.3%	92%	8.3%		
<b>Mpa</b>	26	26.9%	46.2%	11.5%	15.4%	4%	12.0%	8.0%	76%	91.3%	0.0%	4.3%	4.3%
<b>Mn all</b>	177	44.9%	19.3%	28.4%	7.4%	46%	7.4%	23.9%	23%	98.3%	1.7%		
<b>Mn cross boundary</b>	66	40.9%	22.7%	31.8%	4.5%	47%	7.8%	17.2%	28%	98.4%	1.6%		
<b>Vv</b>	24	25.0%	29.2%	37.5%	8.3%	17%		16.7%	67%	91.7%	8.3%		
<b>Zms</b>	29	64.3%	17.9%	17.9%		11%		14.3%	75%	96.2%	3.8%		
<b>Zbc</b>	185	31.3%	22.0%	28.0%	18.7%	25.3%	6.6%	16.5%	51.6%	81.5%	9.0%	5.1%	4.5%
<b>Zma</b>	9	50.0%	37.5%	12.5%		33.3%		11.1%	55.6%	100.0%			
<b>Zmd</b>	No chemical data was available for this unit												
<b>Note:</b> 0% removed to make the table more readable, (Mn all) is all the occurrences on the Polokwane and Lephalale Map sheet, (Mn cross boundary) is only the occurrence that is cross boundary thus the occurrence is within the eastern section of the Lephalale map and the western section of the Polokwane map sheet.													

Table 18: 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	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	70	100	200	>200	100	200	400	>400
<b>Category A: Intergranular aquifers</b>																	
<b>Q</b>	74	69.0%	18.3%	7.0%	5.6%	100%				74.6%	14.1%	5.6%	5.6%	46.5%	21.1%	25.4%	7.0%
<b>Category B: Fractured aquifers</b>																	
<b>Trc</b>	13	57.1%	42.9%			83.3%			16.7%	57.1%	42.9%				57.1%	14.3%	28.6%
<b>Trl</b>	11	42.9%	42.9%		14.3%	85.7%		14.3%		85.7%			14.3%	14.3%	42.9%	28.6%	14.3%
<b>Trg</b>	No chemical data was available for this unit																
<b>Tre</b>	25	50.0%	50.0%			91%	9.1%			90.9%	9.1%			18.2%	50.0%	31.8%	
<b>Tr-Pe</b>	30	53.6%	28.6%	3.6%	14.3%	96%	3.6%			89.3%		7.1%	3.6%	28.6%	32.1%	21.4%	17.9%
<b>Pgr</b>	18	78%	22.2%			94%	5.6%			89%	5.6%		5.6%	22%	50.0%	16.7%	11.1%
<b>Pgo</b>	1	100.0%					100.0%			100.0%							100.0%
<b>Psr</b>	26	85.0%	10.0%	5.0%		94%	5.9%			90.0%	5.0%	5.0%		42%	10.5%	42.1%	5.3%
<b>C-Pwe</b>	24	90.9%	4.5%	4.5%		100%				95.5%			4.5%		9.1%	68.2%	22.7%
<b>Mcl</b>	31	100.0%				100%				100.0%				100.0%			
<b>Mkr</b>	67	89.2%	6.2%	3.1%	1.5%	87.1%	6.5%	6.5%		90.8%	4.6%	4.6%		43.1%	26.2%	23.1%	7.7%
<b>Mas</b>	132	50.4%	28.2%	15.3%	6.1%	96.2%	3.8%			76.3%	11.5%	6.9%	5.3%	35.1%	34.4%	22.9%	7.6%
<b>Category C: Karst aquifers</b>																	
No Karst aquifers appear within the map sheet																	
Note: 0% removed to make the table more readable																	

Table 19: 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	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	70	100	200	>200	100	200	400	>400
<b>Category D: Intergranular and Fractured aquifers</b>																	
<b>Jle</b>	No chemical data was available for this unit																
<b>N-Za</b>	5	40.0%	40.0%	20.0%		100.0%				40.0%	60.0%			80.0%		20.0%	
<b>Mgc</b>	12	91.7%	0.0%	8.3%		92%		8.3%		66.7%	8.3%	17%	8.3%	75%	16.7%		8.3%
<b>Mpa</b>	26	65.2%	13.0%	17.4%	4.3%	95.7%	0.0%	4.3%	0.0%	47.8%	34.8%	17.4%	0.0%	8.7%	65.2%	13.0%	13.0%
<b>Mn all</b>	177	65.5%	27.5%	6.4%	0.6%	96.5%	3.5%			87.1%	5.8%	4.7%	2.3%	46.8%	31.0%	16.4%	5.8%
<b>Mn</b>	66	72.6%	22.6%	4.8%		96.8%	3.2%			95.2%		3.2%	1.6%	35.5%	30.6%	33.9%	
<b>Vv</b>	24	56.5%	39.1%		4.3%	100.0%				56.5%	21.7%	17.4%	4.3%	26.1%	47.8%	26.1%	
<b>Zms</b>	29	57.7%	42.3%			100.0%				61.5%	23.1%	15.4%		57.7%	30.8%	11.5%	
<b>Zbc</b>	185	44.9%	29.5%	15.3%	10.2%	99%	0.6%			52.3%	18.2%	21.6%	8.0%	27.3%	44.9%	17.0%	10.8%
<b>Zma</b>	9	75.0%	25.0%			87.5%	12.5%			75.0%	25.0%			37.5%	62.5%		
<b>Zmd</b>	No chemical data was available for this unit																
<p><b>Note:</b> 0% removed to make the table more readable, (Mn all) is all the occurrences on the Polokwane and Lephalale Map sheet, (Mn cross boundary) is only the occurrence that is cross boundary thus the occurrence is within the eastern section of the Lephalale map and the western section of the Polokwane map sheet.</p>																	

Table 20: Summarized Electrical Conductivity, pH, and Fluoride concentration ranges within aquifer units, first page

Physical properties & F		Conductivity (mS/m)				pH (pH units)				Fluoride F (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Acceptable Acidic	Ideal	Acceptable Alkali	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
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
<b>Category A: Intergranular aquifers</b>													
<b>Q</b>	74	31.1%	35.1%	24.3%	9.5%	1.4%	95.9%	2.7%		38.0%	21.1%	14.1%	26.8%
<b>Category B: Fractured aquifers</b>													
<b>Trc</b>	13	46.2%	38.5%	7.7%	7.7%		100.0%			71.4%	14.3%		14.3%
<b>Trl</b>	11	36.4%	27.3%	27.3%	9.1%	9.1%	90.9%			71.4%		28.6%	
<b>Trg</b>	No chemical data was available for this unit												
<b>Tre</b>	25	4%	44%	44%	8.0%		100%			41%	31.8%		27.3%
<b>Tr-Pe</b>	30	3.3%	53.3%	23.3%	20.0%	6.7%	90%	3.3%		42.3%	15.4%	11.5%	30.8%
<b>Pgr</b>	18		72.2%	27.8%			100%			61.1%	5.6%	5.6%	27.8%
<b>Pgo</b>	1				100.0%		100.0%						100.0%
<b>Psr</b>	26	40.0%	20.0%	40.0%			96%	4.0%		45%	10.0%	5.0%	40%
<b>C-Pwe</b>	24	8.3%	25%	66.7%			100%			18%	22.7%		59.1%
<b>Mcl</b>	31	96.7%	3.3%				100.0%			90.3%	3.2%	3.2%	3.2%
<b>Mkr</b>	67	38.8%	34.3%	22.4%	4.5%	4.5%	95.5%			59.4%	4.7%	4.7%	31.3%
<b>Mas</b>	132	6.8%	47.0%	36.4%	9.8%	1.5%	98.5%			38.9%	27.5%	17.6%	16.0%
<b>Category C: Karst aquifers</b>													
No Karst aquifers appear within the map sheet													
Note: 0% occurrences removed to make the table more readable													

Table 21: Summarized Electrical Conductivity, pH, and Fluoride concentration ranges within aquifer units, second page

Physical properties & F		Conductivity (mS/m)				pH (pH units)				Fluoride F (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Acceptable Acidic	Ideal	Acceptable Alkali	Unacceptable	Class 0 (Ideal)	Class I (Acceptable )	Class II (Maximum Allowable)	Unacceptable
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
<b>Category D: Intergranular and Fractured aquifers</b>													
Jle	No chemical data was available for this unit												
N-Za	5		80%	20.0%			100%			20.0%	40%	20%	20.0%
Mgc	12		75.0%	25.0%			100.0%			8.3%		8.3%	83.3%
Mpa	26		58%	30.8%	11.5%		100%			8.0%	4%	8%	80.0%
Mn all	177	27.8%	43%	23.3%	6.3%		100%			26.9%	8%	11%	53.8%
Mn cross boundary	66	22.7%	48%	27.3%	1.5%		100%			24.2%	8%		68.2%
Vv	24	12.5%	25%	58.3%	4.2%		100%			58.3%	13%	17%	12.5%
Zms	29	3.6%	68%	28.6%			100%			39.3%	32%	18%	10.7%
Zbc	185	3.2%	38.4%	40.0%	18.4%	0.5%	99%		0.5%	23.9%	21.1%	32.8%	22.2%
Zma	9		88.9%	11.1%			100%			33.3%	11.1%	55.6%	
Zmd	No chemical data was available for this unit												
<b>Note: 0% removed to make the table more readable, (Mn all) is all the occurrences on the Polokwane and Lephalale Map sheet, (Mn cross boundary) is only the occurrence that is cross boundary thus the occurrence is within the eastern section of the Lephalale map and the western section of the Polokwane map sheet.</b>													

## 6.2 Aquifer Units

The lithostratigraphy of the hydrogeological map sheet is based on the existing 1:250 000 geological map sheet 2326 Ellisras, 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)**. No **Karst** (dolomitic rocks) occurs within the map sheet boundary.

For the Lephalale map, twenty-four (24) groundwater resource units were identified, characterized, and discussed in terms of areal extent, general geology and statistics on yield and water quality. The unit dolerite (Jdo) was included although no dolerite sills or dykes were identified on the map. It is mentioned in the explanatory booklet of the geological map sheet to occur within the map sheet but is also not shown on the geological map. Additional aspects that were covered in some of the units are groundwater targets, proven geophysical methods and references to findings in previous groundwater reports. The methodology used for the characterization of each unit is similar throughout the report and is based on the same methodology used for the 1:500 000 hydrogeological map series.

The Intergranular aquifer consists of a single (1) unit with an aerial extent of 283.6km<sup>2</sup> (3.7%); the Fractured aquifers consist of 12 units with an aerial extent of 6076.1km<sup>2</sup> (78.8%); the Karst aquifer does not occur within the map sheet and the Intergranular and Fractured aquifers consists of 10 units with an aerial extent of 1 355.9km<sup>2</sup> (17.6%) of the map area. The total map area in South Africa covers an area of 7 715.7km<sup>2</sup>. The total map area including Botswana is 22 632.9km<sup>2</sup>. Surface water bodies cover an area that is less than 5km<sup>2</sup> (0.06%) of the map area.

Table 22: Basic information for the aquifer units and areal extent, first page

Unit symbol	Lithostratigraphy	Geochronology	Geological time period	Geological description	Areal extent (km <sup>2</sup> )	% of map area
Botswana (The areal extent is 14 917,3km <sup>2</sup> but is not included in the % of map calculations. The areal extent of the South African units is 7715,7km <sup>2</sup> )						
Surface water bodies					5	0,06%
<b>Category A: Intergranular aquifers</b>						
Q	Alluvium	Tertiary Quaternary	Tertiary Quaternary	Alluvium	283,6	0,04
<b>Total for Alluvium aquifers</b>					283,6	0,04
<b>Category B: Fractured aquifers</b>						
Jdo	Dolerite Jurassic	Intrusion of Karoo age	Jurassic	Dolerite Jurassic, Karoo age intrusions-could not divine the areal extent		
Trc	Clarens Formation	Karoo Supergroup	Triassic	Fine-grained cream coloured sandstone	731,2	9,5%
Trl	Lisbon Formation	Karoo Supergroup	Triassic	Red mudstone and siltstone, minor sandstone	349,1	4,5%
Trg	Greenwich Formation	Karoo Supergroup	Triassic	Medium- to coarse-grained red sandstone, subordinate red/grey mudstone, thin conglomerate lenses	13,7	0,2%
Tre	Eendragtpan Formation	Karoo Supergroup	Triassic	Grey, red or purple mudstone, variegated shale	324,6	4,2%
Tr-Pe	Undifferentiated Goedgedacht Formation	Karoo Supergroup	Permian	Undifferentiated, various Karoo sedimentary rock formations grouped, includes argillaceous and arenaceous rocks, gritstones, coal	164,1	2,1%
Pgr	Grootegeeluk Formation	Karoo Supergroup	Permian	Dark (carbonaceous) mudrocks, sandstones and coal seams	215,0	2,8%
Pgo	Goedgedacht Formation	Karoo Supergroup	Permian	Gritty mudstone, sandstone, coal	68,7	0,9%
Psr	Swartrant Formation	Karoo Supergroup	Permian	Sandstone, "grit", siltstone, carbonaceous mudrock, coal seams	318,8	4,1%
C-Pwe	Wellington and lower Waterkloof Formation	Karoo Supergroup	Carboniferous to Permian	Mudrock (with angular dropstones), sandstone intercalations; Mudstone, siltstone, minor grit (Old Rock), diamictite	406,3	5,3%
Mcl	Cleremont Formation	Waterberg Supergroup	Mokolian	Very coarse-grained, white sandstone with fine-grained, purple, micaceous sandstone at the base	81,6	1,1%
Mkr	Kransberg Subgroup-Mogalakwena Formation	Waterberg Supergroup	Mokolian	Coarse-grained purplish brown sandstone, subordinate conglomerate, siltstone and shale	2490,8	32,3%
Mas	Aasvoëlkop Formation	Waterberg Supergroup	Mokolian	Fine-grained sandstone, siltstone, mudrock	912,2	11,8%
<b>Total for Fractured aquifers</b>					6076,1	78,7%
<b>Category C: Karst aquifers</b>						
No dolomitic or limestone rock occurs within the map sheet						
<b>Total for Karst aquifers</b>					0,0	0,0

Table 23: Basic information for the aquifer units and areal extent, second page

Unit symbol	Lithostratigraphy	Geochronology	Geological time period	Geological description	Areal extent (km <sup>2</sup> )	% of map area
<b>Category D: Intergranular and Fractured aquifers</b>						
Jle	Letaba Formation	Karoo Supergroup	Jurassic	Basalt, pyroclasts	16.9	0.2%
N-Za	diabase	Intrusions pre-Karoo age	Mokolian	Diabase	47.4	0.6%
Mgc	Glenover Complex	Intrusive	Mokolian	Undifferentiated, breccia, Carbonatite, biotite pyroxenite, fenite, fenitised sandstone	34.4	0.4%
Mpa	Palala Granite	Bushveld Complex	Vaalian	Mylonitised Bushveld, Beit Bridge and Constantia rocks	2.7	0.0%
Mn	Nebo Granite	Bushveld Complex	Vaalian	Coarse-grained granite	39.8	0.5%
Vv	Villa Norra Gabbro-Anorthosite	Bushveld Complex	Vaalian	Gabbro, anorthosite, norite, gabbro norite	42.5	0.6%
Zms	Undifferentiated Messina Suite	Beit Bridge Complex	Swazian	Mylonitised Bushveld, Beit Bridge and Constantia rocks	28.3	0.4%
Zbc	Undifferentiated Beit Bridge Complex	Beit Bridge Complex	Swazian	gneisses, metaquartzite, amphibolite, marble and calc-silicate rocks	536.2	6.9%
Zma	Undifferentiated Malala Drift Gneiss	Beit Bridge Complex	Swazian	Leuco gneiss with metaquartzite, granitoid hornblende gneiss, amphibolite, metapelite and calc-silicate rocks	466.8	6.1%
Zmd	Mount Dowe Group	Beit Bridge Complex	Swazian	Metaquartzite interlayered with leucocratic quartz-feldspathic gneiss, magnetite quartzite, metapelite, amphibolite, mafic granulite	140.8	1.8%
<b>Total for Intergranular and Fractured aquifers</b>					<b>1356.0</b>	<b>17.6%</b>
<b>Total areal extent of map area, South Africa</b>					<b>7715.7</b>	
<b>Total areal extent of map area including Botswana</b>					<b>22633.0</b>	

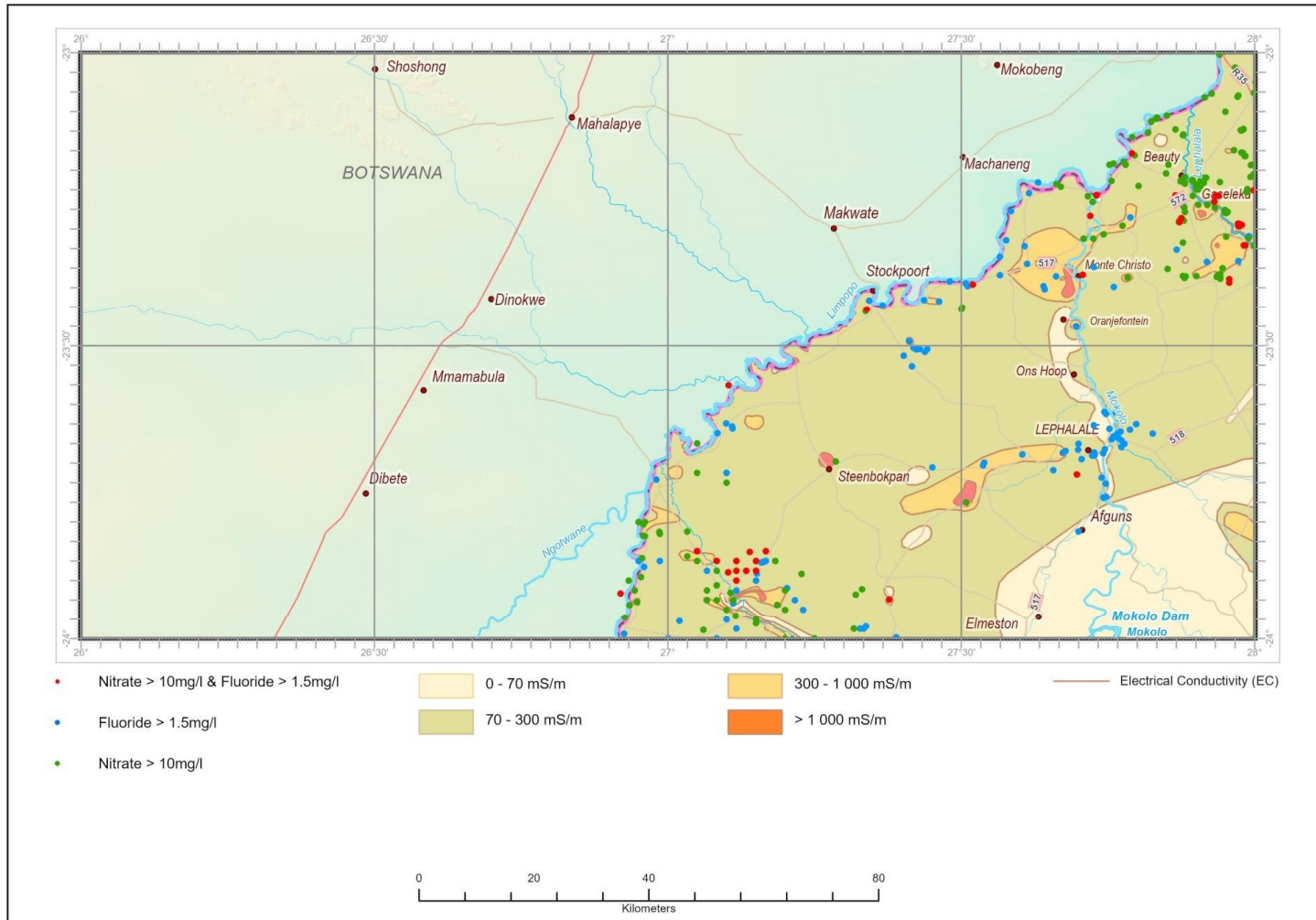


Figure 8: Distribution of Electrical conductivity (EC) and boreholes with Nitrate and Fluoride values exceeding the acceptable levels for human consumption.

## 7. HYDROGEOLOGY OF THE VARIOUS GEOLOGICAL GROUPS AND FORMATIONS

In this chapter the hydrogeology of the various geological groups and formations are 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 24 shows the percentage boreholes in each yield range as obtained from the yield frequency diagrams.

Table 24: 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)
<b>Category A: Intergranular aquifers</b>									
<b>Q</b>	11	72	152	8,3%	15,3%	22,2%	30,6%	18,1%	5,6%
<b>Category B: Fractured aquifers</b>									
<b>Jdo</b>	No information								
<b>Trc</b>	0	158	113	16,5%	39,9%	35,4%	6,3%	1,9%	
<b>Trl</b>	1	86	84	26,7%	29,1%	32,6%	5,8%	4,7%	1,2%
<b>Trg</b>	0	1	3				100,0%		
<b>Tre</b>	1	65	50	10,8%	32,3%	41,5%	9,2%	4,6%	1,5%
<b>Tr-Pe</b>	0	37	65	27,0%	13,5%	45,9%	10,8%		2,7%
<b>Pgr</b>	3	39	27	7,7%	17,9%	46,2%	20,5%	5,1%	2,6%
<b>Pgo</b>	0	9	1	33,3%	33,3%	33,3%			
<b>Psr</b>	1	136	110	21,3%	20,6%	36,0%	15,4%	4,4%	2,2%
<b>C-Pwe</b>	2	77	76	19,5%	11,7%	40,3%	18,2%	7,8%	2,6%
<b>Mcl</b>	0	41	25	36,6%	24,4%	22,0%	12,2%	4,9%	
<b>Mkr</b>	0	420	266	21,9%	29,8%	31,9%	12,1%	4,0%	0,2%
<b>Mas</b>	0	75	167	12,0%	13,3%	44,0%	17,3%	8,0%	5,3%
<b>Category C: Karst aquifers</b>									
No Karst aquifers appear within the map sheet									
<b>Category D: Intergranular and Fractured aquifers</b>									
<b>Jle</b>	0	5	26	40,0%	40,0%	20,0%			
<b>N-Za</b>	0	6	13		16,7%	50,0%	16,7%	16,7%	
<b>Msc</b>	0	7	12	14,3%		57,1%	28,6%		
<b>Mpa</b>	6	29	20	20,7%	17,2%	20,7%	17,2%	17,2%	6,9%
<b>Mn</b>	19	127	93	18,9%	25,2%	27,6%	17,3%	7,9%	3,1%
<b>Vv</b>	47	61	19	18,0%	13,1%	36,1%	18,0%	13,1%	1,6%
<b>Zms</b>	0	3	5	33,3%	66,7%				
<b>Zbc</b>	6	265	435	21,1%	21,1%	25,7%	19,2%	9,1%	3,8%
<b>Zma</b>	15	42	51	2,4%	19,0%	11,9%	33,3%	16,7%	16,7%
<b>Zmd</b>	No information								

## 7.1 PRIMARY AQUIFERS

### 7.1.1 CATEGORY A: INTERGRANULAR AQUIFERS

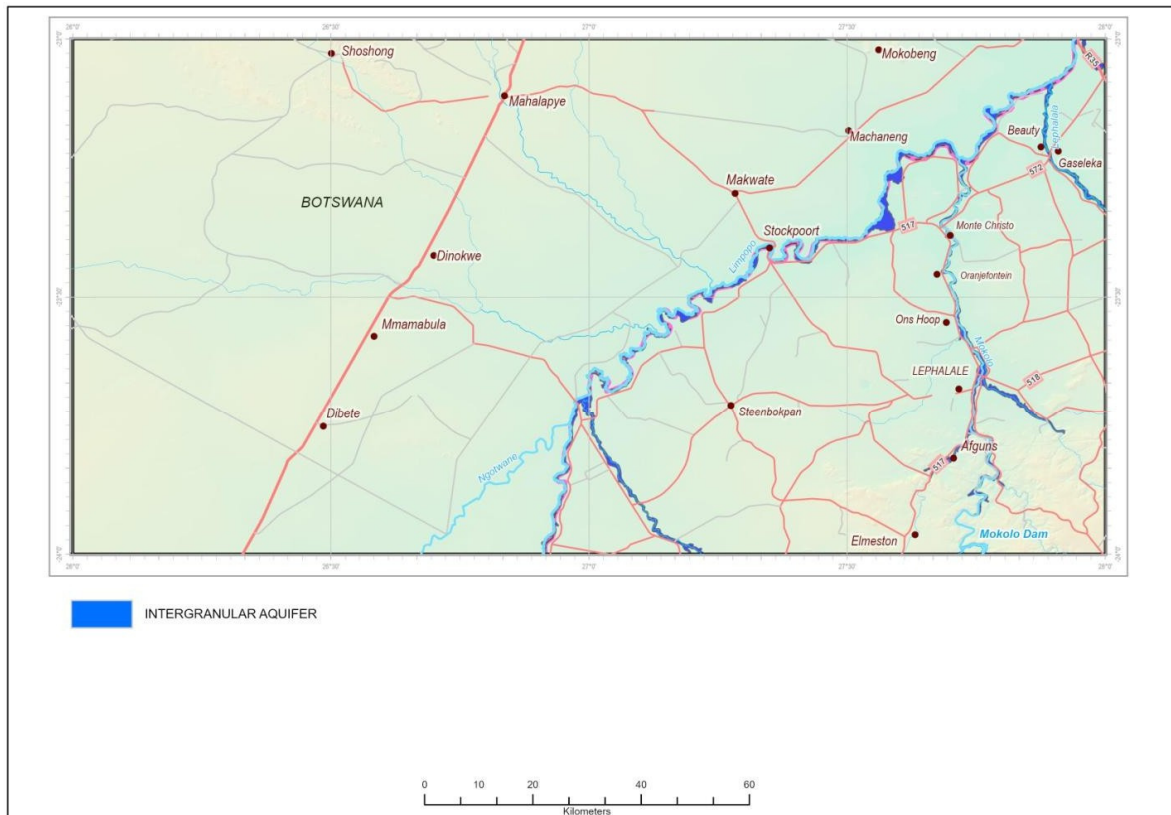


Figure 9: Geographical distribution of the intergranular aquifers.

Within the map sheet intergranular aquifers are restricted to the alluvial deposits within and in the immediate flood planes or palaeo channels near the Limpopo River and its Tributaries, (Figure 9). It covers 3.7% of the map area; the calculations do not include the theoretical total map area inclusive of Botswana.

#### 7.1.1.1 TERTIARY-QUATERNARY ALLUVIUM DEPOSITS (Q)

Groundwater occurs in tertiary-quaternary alluvium deposits within floodplains and river terraces of the Limpopo River and its tributaries. The main tributaries are the Palala, Mokolo, and Matlabas Rivers, (Figure 10).

The alluvium aquifer related to the **Limpopo River** consists of silt, clay and coarse sand that are developed on the flood plains along the Limpopo River and within the riverbed. On the farm Sannandale 9LQ the alluvium is 15m thick, (Brandl, 1996). This farm is 24km north-east along the river from the confluence of the Mahalapye River (Mhalatswe & Taupye) flowing from Botswana.

No studies could be found that relate to alluvial deposits within the Limpopo River that falls within the map sheet area. The increase in irrigation (centre pivots), east of the Mokolo River confluence gives an indication of the contribution of alluvium to water supply as well as the influence of surface water

releases from the Mokolo Dam. The sand in these areas is derived from basement gneisses thus the conditions will be similar as found in the Messina Well Field that was developed downstream of Beit Bridge.

Downstream from Beit Bridge water is abstracted from boreholes within and along the river that abstract water from fractured basement rock overlain by thick alluvial deposits 6-18m. The alluvial acts as storage (porosity estimated between 20 and 30%) while the fractured basement rock act as the conduit of water. At the confluence of the Shashe River from Botswana (Musina hydrogeological map sheet area), the Weipe farming area is known for abstracting large quantities of water from alluvial sand.

Within the south-western section of the Limpopo River underlain by Karoo sediments and the Aasvoëlkop Formation, records indicates that the average borehole yields are less within and along the river; this may be attributed to finer grained sand within the river. More studies need to be done to evaluate the potential of the alluvium in that section of the river.

No comprehensive studies could be found on the alluvium aquifer related to the Palala and Matlabas Rivers. Data obtained from a report by W.D. Rech, (1970) gives some details on water use for irrigation along the tributaries of Limpopo. For the **Matlabas River** the finding was that the alluvium associated with the river is of little significance as an aquifer. Silt and sand are mostly restricted to the riverbed with only one terrace developed along the river that consists predominantly of fine-grained material. A second higher terrace is only sporadically developed on some farms and at the confluence with the Limpopo River. Where the alluvium is not fine grained the sand points in the river were pumped at between 0.63ℓ/s to 18.9ℓ/s. The water quality was very good based on EC measurements. Current satellite imagery (Google Earth) reveals only small-scale irrigation fields along the Matlabas River.

Along the **Palala River** the report states that water for irrigation was mostly from surface water, there were numerous boreholes and shallow wells along and within the river but the contribution to water demand was less than direct surface water abstraction from the river. Satellite imagery reveals large scale irrigation along the river with some high yielding boreholes that plots near the river. Near Setateng village (along the Palala River but outside the map area) a borehole log indicates coarse grained alluvial sand up to 3m with a blow yield of 0.6ℓ/s; the main water strike was however within fractured Nebo Granite that resulted in a blow yield of 7ℓ/s. Shallow wells (10) were reported to be operated and managed by the Witpoortjie cost centre; it was reported that in times when the river dries up the shallow well dries up as well.

The alluvium aquifer related to the **Mokolo River** is discussed in more detail as data and findings from a recent study were available.

The following section that describes the Mokolo River of the Tertiary-Quaternary Alluvial Deposits unit was obtained from a report and references quoted in the report by Rivers for Africa eFlows Consulting, 2010.

The study area covered the river section from the Mokolo Dam (Hans Strijdom Dam) up to the confluence with the Limpopo River. Based on topography, underlying geology, typical thickness, and transmissivity of the alluvial, the alluvial aquifer was subdivided into 4 segments. The model used ignored the interaction between regional and the alluvium aquifers and focused on the water within the river and the alluvium aquifer. The dimensions of the alluvial aquifer were set up as numerous straight rectangular stretches (width and depth). As mentioned in the previous paragraph the river was divided into 4 sections based on topography, underlying geology, typical thickness, and transmissivity of the alluvial. Estimates for the physical and hydraulic properties were initially assigned for each of the sections for the set-up of the model. Findings are summarized below in Table 25 and in the text.

Table 25: Alluvial Aquifer Properties, after Vipond (1988), WSM (1999) and Rivers for Africa eFlows consulting.

Section	Geology	Average depth	Estimated Hydraulic Conductivity (K-value)	Calibrated Hydraulic Conductivity (K-value)	Hydrolic gradient (i)	Average Transmissivity (T-value)
A	Waterberg (mountainous)	12,4m	175m/d	67m/d	0,00073	1489m <sup>2</sup> /d
B	Waterberg (flat)	8,5m	175m/d	175m/d	0,00043	1489m <sup>2</sup> /d
C	Karoo Supergroup	7,5m	132m/d	110m/d	0,00045	992m <sup>2</sup> /d
D	Basement	6,5m	117m/d	150m/d	0,00043	810m/d

- Water released from the Mokolo Dam is essential to irrigation along the river and most likely to the ecological functioning of the Mokolo River. All water users depend heavily on the releases from the Mokolo Dam. The releases are usually high volume / low frequency flows maintained for several days, the idea being to enable surface flow to reach the Limpopo Confluence. This is not possible until the sand aquifer on the 118km stretch between the dam, and the Limpopo River has been fully recharged, (Vipond, 1988),
- The study confirmed this finding as quantitative observation and correlated groundwater levels from boreholes in the river with weir flow data, dam releases and rainfall data,
- The model was used to estimate the storage depletion time in the alluvial aquifer due to receding water levels following releases. The storage depletion curve showed exponential recession behavior as typically observed for aquifer discharges under drought (no recharge) conditions.
- The relative fast depletion of the alluvial aquifer storage renders the aquifer vulnerable to intermittent and limited discharges from the dam. Without sufficient discharge over short periods from the dam the saturation level in the alluvial aquifer will decrease.
- It takes approximately 15 days for a volume of water released from the Mokolo dam to reach the Limpopo River,
- Low amplitude surface flows are generally attributed to subsurface inflows,
- Both the direction and rate of exchange of water between the river and /or pools and the surrounding groundwater systems is dependent on the river stage and/or pool levels,
- Groundwater contribution to baseflow, emanating from the regional aquifers, is insignificant.
- Regionally the exchange of water between the alluvial aquifer and the Mokolo River is more significant (depending on the river stage), than exchange between the alluvial aquifer and the regional aquifer systems.
- Groundwater samples located in quaternary catchment A42J tend to be more Chloride dominant with higher TDS values. This catchment is underlain by Karoo Sediments.
- Groundwater samples in quaternary catchment A42G have a HCO<sub>3</sub><sup>-</sup> enriched groundwater signature with lower TDS values. This is an indication that quaternary catchment A42G, predominantly within the elevated Waterberg mountainous regions, represents a recharge zone whereas groundwater within quaternary catchment A42J probably represents a hydro-geochemically evolved groundwater with varied recharge mechanisms. The Na-Cl facies represent the dominant groundwater type, (Titus, 2010).

The general characteristics of the alluvial sand and boreholes occurring within the Mokolo River channel are as follows, (Vipond, 1987):

- Sands are typically medium grained (0.2mm to 0.6mm) and moderately sorted.
- The volume of water constrained in the superficial sands of the channel per meter thickness is between 3Mm<sup>3</sup> to 3.6Mm<sup>3</sup>.
- Aquifer coefficients were determined through pumping tests and resulted in average transmissivity values of 591 square meters per day (m<sup>2</sup>/d) from boreholes close to the confluence of the Limpopo and Mokolo River; 865m<sup>2</sup>/d that is close to the contact between the basement and Karoo Supergroup rocks and 1835m<sup>2</sup>/d for the tested boreholes in the Waterberg formation.

- The porosity of the sands associated with the Mokolo River was determined to be between 20 and 25%.
- There is a relationship between TDS and borehole depth; water abstracted from river sand has a TDS concentration less than 100 milligrams per liter (mg/l). Boreholes up to 60m deep have TDS concentrations that are usually less than 1000mg/l. Boreholes deeper than 150m are often artesian with TDS concentrations between 2500mg/l and 4000mg/l.

To address water shortages in the Mokolo catchment; the MCWAP 2A project was initiated to transfer water from the Crocodile catchment to the Mokolo catchment. The available surface water to the urban node (LLM) with the completion of MCWAP 2A will be 13.88 million cubic meters per annum (Mm<sup>3</sup>/annum) in 2040, equivalent to 38.03 megaliters per day (Mℓ/d), (Lephalale IDP., 2024-2025).

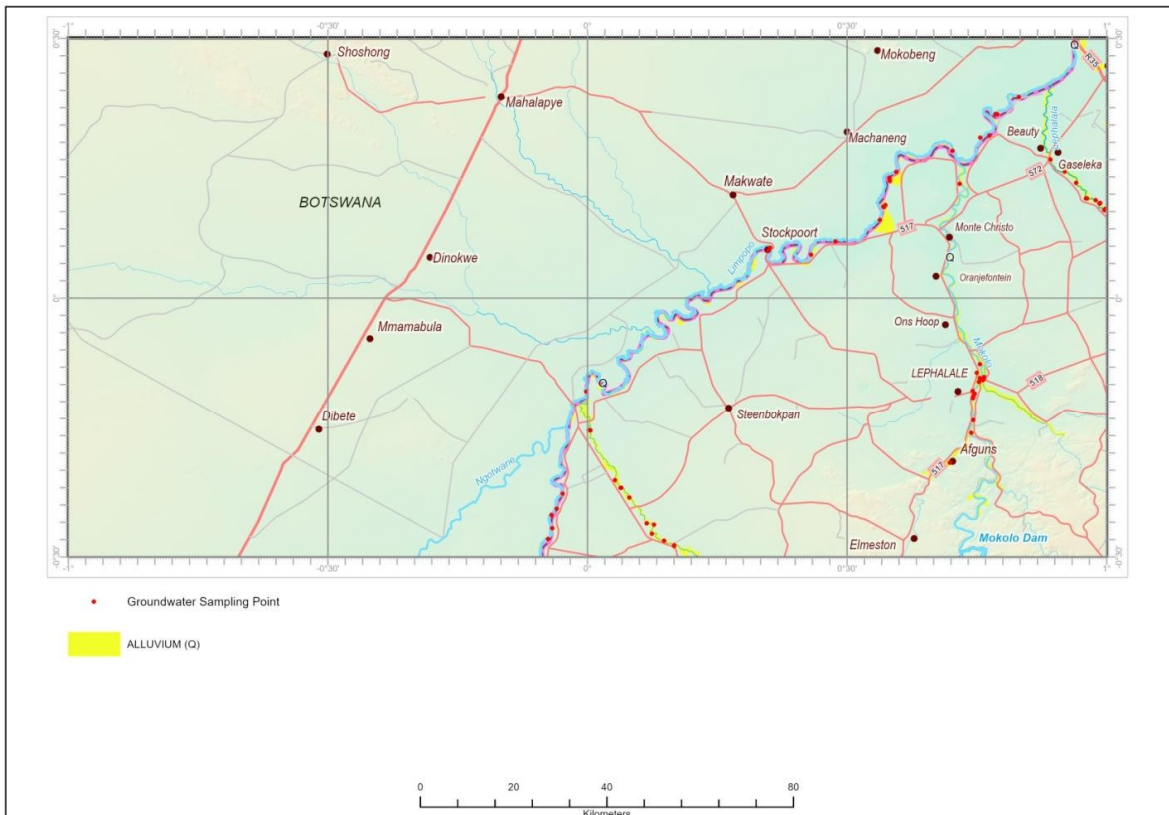


Figure 10: Geographical distribution of the Tertiary-quaternary alluvial deposits (Q) and the associated groundwater sampling points.

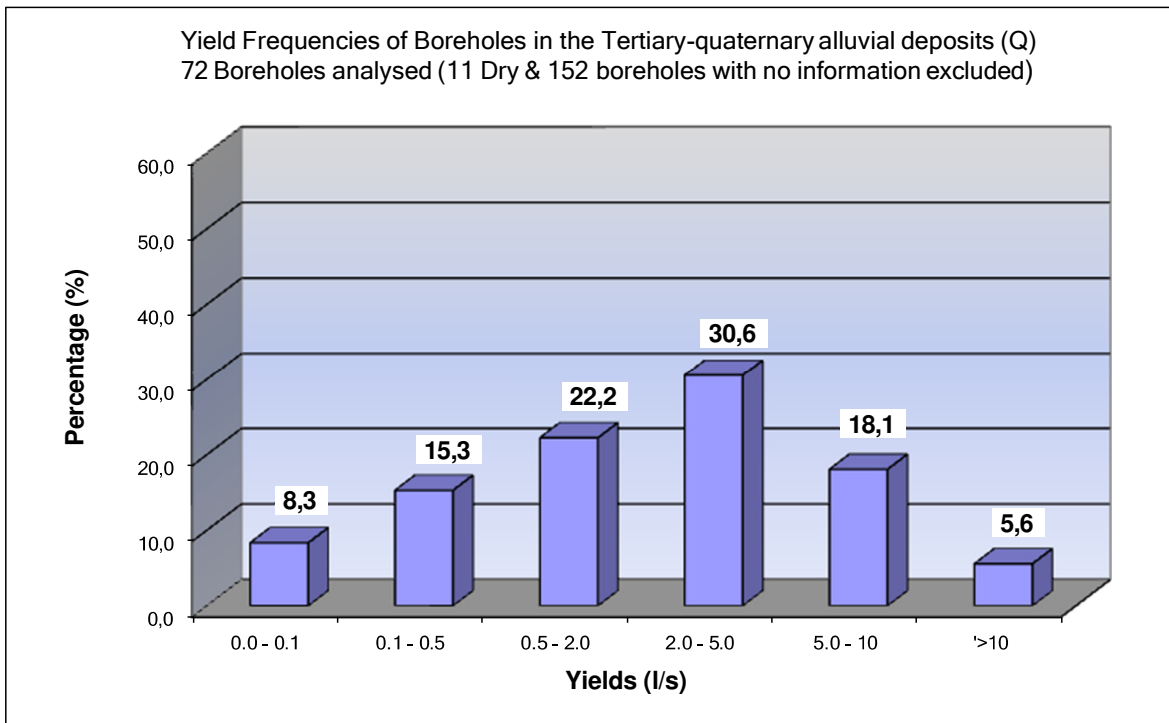


Figure 11: Yield frequency for Tertiary-Quaternary alluvial (Q) aquifers.

Figure 11 is a representative yield frequency diagram of yields within the alluvial aquifers. The diagram shows that 45.8% of the existing boreholes yield between 0.1 l/s and 2 l/s. A further 30.6% of the boreholes yield between 2 l/s and 5 l/s and 24.1% of the boreholes yield more than 5 l/s.

The static water level ranges from 0 meters below ground level (mbgl) to 46 mbgl, with a median of 3.42 mbgl and an average static water level of 6.17 mbgl, (based on 71 points). The maximum depth recorded is 305m, with an average depth of 63.18m and a median depth of 32.45m, (47 points).

The minimum installation depth is 6 meters, which aligns with the expected depth of a point source within an alluvial aquifer. The maximum installation depth is 120 meters, with an average installation depth of 38.1 meters. From the statistics on installation and borehole depths, it is evident that many boreholes targeted deeper fractured zones overlain by alluvium.

The maximum recommended daily abstraction recorded is 777 cubic meters per day (m<sup>3</sup>/day), with an average daily abstraction of 118 m<sup>3</sup>/day. A total of 28 boreholes were tested within this unit according to available records.

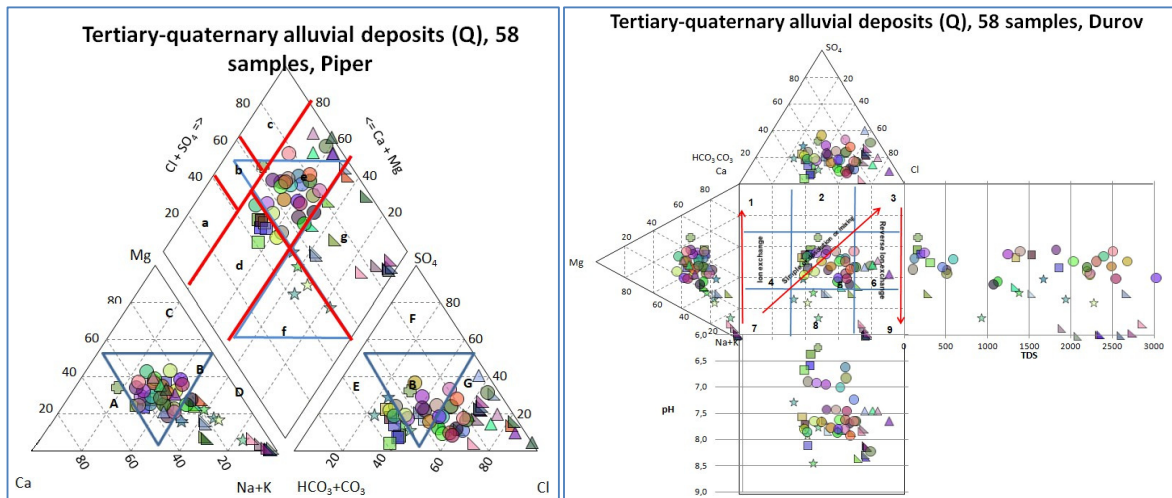


Figure 12: Trilinear diagrams, Piper and Durov for the Tertiary-quaternary alluvial deposits (Q).

The trilinear Piper diagram, (Figure 12) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (65.5%), Weak acidic anions > Strong acidic anions (19%); Alkali > Alkali earths (34.5%); Strong acids > Weak acids (81%).

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 classifies as:

- Mixed Calcium-Magnesium-Bicarbonate-Chloride water type (26.8%),
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (26.7%),
- Sodium-Chloride type (25.9%),
- Mixed-Calcium-Magnesium-Bicarbonate-type with prevailing Sodium (10.3%),
- Sodium-Bicarbonate type (8.6%),
- Calcium Mixed Bicarbonate-Chloride type with some samples exhibiting prevailing Sulphate (1.7%).

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 (63.8%), points plot along the dissolution or mixing line,
- Anion discriminate and Na dominant, probable mixing, or uncommon dissolution influences (19%),
- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (12.1%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (5.2%),
- The high TDS is some of the samples that may be indicative of long residence times in the aquifer allowing reactions to be complete. These samples may relate to the underlying geology, thus deeper fractures contributing more to the supply than from the alluvium. In another study on a section of the Limpopo River, high TDS values were found in the sand aquifer after a very high local rainfall event. The section of the river affected was downstream from the inflow point of a local tributary i.e. Soutsloot. The high TDS was contradictory to the expectation. It was concluded that local rainfall events in the surrounding arid environment mobilized build up salts to wash into the Limpopo River.

Table 26: Chemical statistics for the Tertiary-quaternary alluvial deposits (Q)

Element / Parameter	Statistics Drawn from a population of 74 data points for the Tertiary-quaternary alluvial deposits (Q)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	74	5,81	9,26	7,54	7,59	6,79	7,62	8,28	0,63	8,3%	
Electrical Conductivity (mS/m EC)	74	0,4	1835,7	15,9	170,9	12,7	120,8	333,9	250,2	146,4%	
Total Dissolved Salts (mg/l TDS)	71	39,0	10485,0	296,2	1124,5	96,0	858,5	2307,0	1487,8	132,3%	
Calcium (mg/l Ca)	71	3,37	1105,80	18,58	86,30	6,40	55,30	200,50	149,00	172,6%	
Magnesium (mg/l Mg)	71	0,21	769,30	3,41	54,38	1,98	24,50	103,10	101,74	187,1%	
Sodium (mg/l Na)	71	2,20	1669,90	24,86	203,98	8,40	111,00	380,10	278,37	136,5%	
Potassium (mg/l K)	70	0,89	15,93	2,78	4,10	1,60	3,27	8,16	2,94	71,6%	
Chloride (mg/l Cl)	72	1,20	6474,80	29,30	369,23	12,14	115,86	738,37	851,08	230,5%	
Sulphate (mg/l SO <sub>4</sub> )	70	2,00	746,50	17,05	123,59	7,32	64,40	405,97	171,88	139,1%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	67	10,00	582,00	93,74	207,39	36,58	175,90	375,78	128,28	61,9%	
Nitrate (mg/l N)	72	0,02	43,66	0,19	4,96	0,06	1,13	16,81	9,12	184,1%	
Fluoride (mg/l F)	71	0,05	16,06	0,48	2,37	0,20	0,84	8,62	3,95	166,7%	
Silicon as Si	66	1,70	42,45	11,08	21,77	5,05	25,92	38,17	12,92	59,4%	
Iron (Fe)	17	0,001	4,580	0,008	0,389	0,004	0,050	0,658	1,13	290,2%	
Manganese (Mn)	16	0,001	1,410	0,004	0,198	0,001	0,039	0,711	0,45	226,2%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	66	0,003	0,800	0,014	0,111	0,006	0,020	0,719	0,25	225,3%	
ZAR	71	0,18	34,38	1,41	6,51	0,58	2,82	24,75	9,32	143,1%	
LSI	66	Langelier Saturation Index (LSI)			Slightly Scaling		27,3%		Highly Scaling		0,0%
		Highly corrosive		9,1%	Slightly corrosive		18,2%		Balanced Corrosion		45,5%

Table 26 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 for the unit in terms of Electrical conductivity (EC) is ideal to be good in 66.2% of the analysis, of a moderate quality in 24.3% and unacceptable only in 9.5% (values above 370mS/m). The Total Dissolved Solids (TDS) is acceptable in 78.9% of the samples, (TDS ≤ 1200mg/l).

An evaluation of the major cations and anions of 74 samples show that elevated concentrations of Nitrate (N >10mg/l) in 6.9%; Fluoride (F >1.5mg/l) in 26.8%; Sodium (Na > 400mg/l) in 7%; Chloride (Cl > 600mg/l) in 13.9%; Calcium (Ca > 300) in 5.6%; Magnesium (Mg > 200mg/l) in 5.6% and Sulphate (SO<sub>4</sub> >600mg/l) in 5.7% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is corrosive (27.3%); slightly scaling (27.3%) and 45.5% balanced. The ZAR index indicates that 52.1% of the water is of a fair quality for irrigation (ZAR < 3).

Due to the shallow nature of the aquifer micro bacteriologic risks will always be a factor to consider when using it for domestic purposes.

## 7.2 SECONDARY AQUIFERS

Consolidated hard rocks cover a large section of the map area (± 78.7%). The map area does not include the section within Botswana. The rock mass was formed over a span of around 3 800 million years, nearly covering the entire geological history of South Africa. Tectonic deformation processes (such as folding and faulting), along with weathering, dissolution, (carbonate rocks), and erosion-driven unloading, have generated or enhanced fractures, interstices, and solution cavities within the hard rocks. These processes have significantly influenced the current groundwater environment across various geological groups and formations. Accordingly, the aquifer types represented on the Hydrogeological Map Sheets for secondary aquifers are classified as karst, fractured, and intergranular & fractured.

## 7.2.1 CATEGORY B: FRACTURED AQUIFERS

- Dolerite Jurassic (Jdo)-Occurs as intrusions within the map area, but no outcrop was mapped
- Clarens Formation (Trc)
- Lisbon Formation (Trl)
- Greenwich Formation (Trg)
- Eendrachtpan Formation (Tre)
- Undifferentiated Goedgedacht Formation (Tr-Pe)
- Grootegeluk Formation (Pgr)
- Goedgedacht Formation (Pgo)
- Swartrant Formation (Psr)
- Wellington Formation (C-Pwe)
- Cleremont Formation (Mcl)
- Kransberg Subgroup (Mkr)
- Aasvoëlkop Formation (Mas)

The geographical distribution of the fractured rock aquifers is shown as Figure 13.

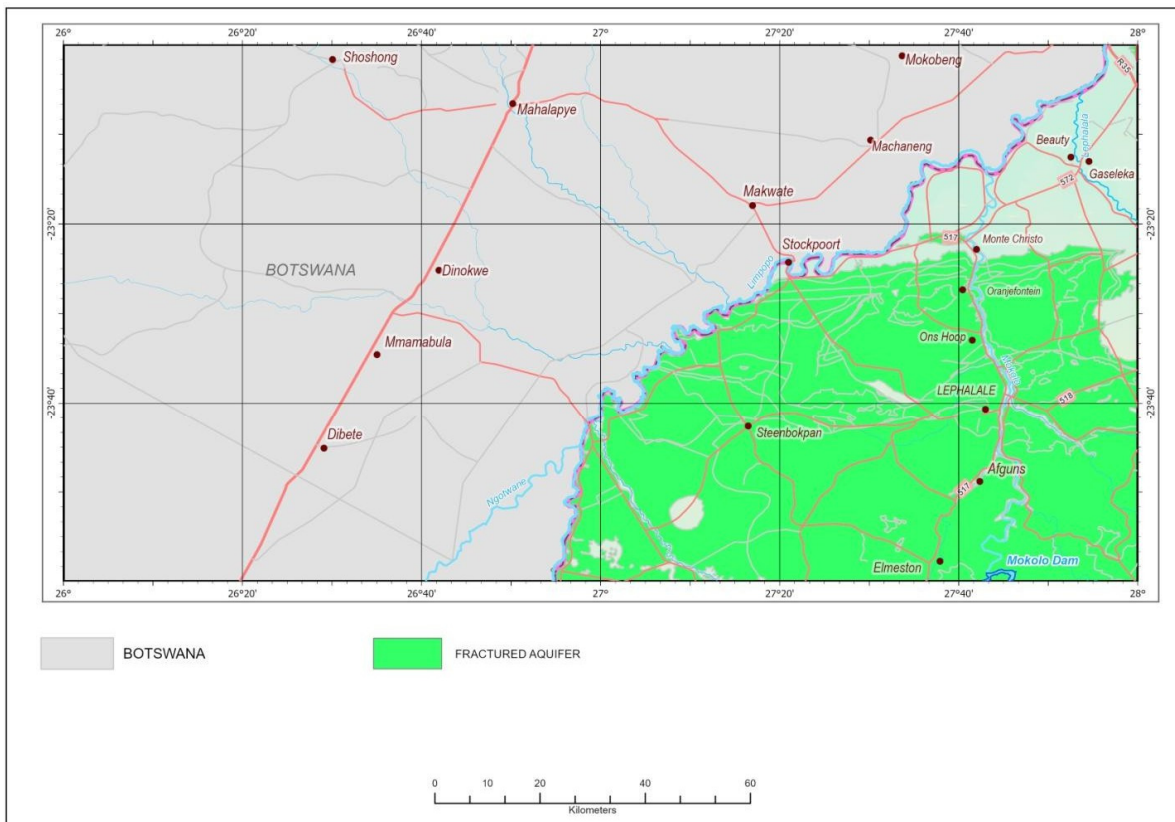


Figure 13: Geographical distribution of the fractured rock aquifers

### **7.2.1.1 DOLERITE JURASSIC (Jdo)**

Dolerite outcrops are rare within the map area, with exposures mostly observed in pans occurring in the Ellisras Karoo Basin. The dolerite is fine-grained and black; plagioclase phenocrysts, pyroxene and olivine can be distinguished macroscopically in some of the rocks, (Visser, 1953). Dolerite intrusions in the pre-Karoo rocks are rare or even absent, (Brandl, 1996). On the geological map sheet, no dolerite dykes are shown but numerous faults are depicted within the Karoo Basin.

An aerial magnetic survey covering the basin was done in 2008 with the objective to improve the geological understanding of the basin in terms of identifying all the weak to strong magnetic lineaments associated with faults and dykes. The findings were that the total field magnetic data did not show significant lineaments that supported the belief that the basin did not experience significant structural alterations through faulting, dyke, and sill intrusions. The calculation of the phase magnetic data however showed an abundance of subtle magnetic structures within the Karoo rocks that may relate to faults and dykes, (C.J.S. Fourie, G. Henry and L.P. Maré, 2014).

As no data is available regarding dolerite intrusions or their positions, no geographical distribution map has been included, and no characterization of yield and chemistry was compiled for this unit. However, for dykes, the inset map, (Figure 7, page 21) provides an indication of their distribution across the map area.

A proper scientific project to research the contribution of dolerite intrusions to successful boreholes needs to be investigated.

### **7.2.1.2 CLARENS FORMATION (Trc)**

Constituting the largest part of the Karoo outcrop in the Ellisras basin is the Clarens Formation. It attains a maximum thickness of 130m within the map sheet area. Figure 14 show the Geographical distribution of the unit with the data points on record, used for the characterization; it occurs north of Lephalale with the southern and western border delineated by the Daarby Fault and the northern boundary by the Zoetfontein Fault. It covers approximately 9.5% of the map area.

The paleontological record of the Clarens Formation is diverse, (Meijs, 1960; Beukes, 1970; Ellenberger, 1970; Van Dijk et al., 1978; Kitching and Raath, 1984; Tasch, 1984; Olsen and Galton, 1984; Smith, 1990; Van Dijk, 2001; Bamford, 2004), implying that the palaeo-environments of the Clarens Formation were capable of sustaining, at least episodically, a relatively varied biota, and therefore could not have been overly resource-limited. Harsh settings did not occur throughout the deposition of the unit. This interpretation is further corroborated by integrated sedimentary facies analyses (Beukes, 1970; Van Dijk et al., 1978; Eriksson, 1981, 1986; Eriksson et al., 1994; Bordy and Catuneanu, 2002; Holzförster, 2007), which suggest that the Clarens Formation was deposited in an overall aeolian environment, with wetter interludes during which ephemeral streams, lakes and wet inter-dune areas existed, (M.E. Bordy, 2008).

Although plains dominate the terrain morphology with limited outcrop due to extensive sand and soil cover, sandstone outcrop is preserved as prominent hills or ridges such as Thaba Ya Pesa on Vaalkoppies 187 LQ and Bulkop on Wildebeestpan 173 LQ. These features correspond to the barchans dune shaped ridges found in the Nzhelele area. The sandstone is generally massive, well sorted and fine grained, though medium- to coarse-grained units and thin pebbly horizons are locally developed. The contact between this formation and the underlying Lisbon Formation is gradational, (Dreyer, 2008).

In other basins such as the Tulip and Springbok Flats basin, thick basalt overlays the Clarens Sandstone; in these areas deep weathered zones within the basalt, the contact zone and deeper fractures within the sandstone is targeted in the search for groundwater. Within the Ellisras basin the younger basalt eroded away with only two small outcrops preserved. The larger is reported to be 125m thick, (Brandl, 1996) and within this area the same methodology will apply as in the other basins when searching for groundwater. In areas where no basalt is present numerous fault zones are indicated on the geological map sheet; a plot of the higher yielding boreholes indicates that some relate to the positions of the fault zones while others are randomly scattered. It is concluded that site specific conditions need to be considered when developing production boreholes within this unit.

Water abstracted from this unit is predominantly supplying game and livestock farming. The only known irrigation is along the Limpopo River where the water is predominately abstracted from the river and associated alluvial deposits.

An assessment undertaken by SRK in 2004 concluded that step faults occur south of the Grootegeluk mine near the Daarby Fault Zone. Drilling in the area resulted in boreholes with high yields and transmissivity values within the contact zone between the basalt and sandstone; the contact zone was found at depths between 20-40m. Non-fractured semi confined Clarens sandstone was found to have low permeability but relatively high storativity, (Dames and Moore, 1984). Around the mine registered water dewatering, production (657kl/day) and monitoring boreholes occurs; the water is primarily abstracted from the Clarens Formation north of the impermeable Daarby Fault zone. It also includes boreholes drilled through the basalt into the sandstone as well as boreholes within the Ecca Group located in the mine pit.

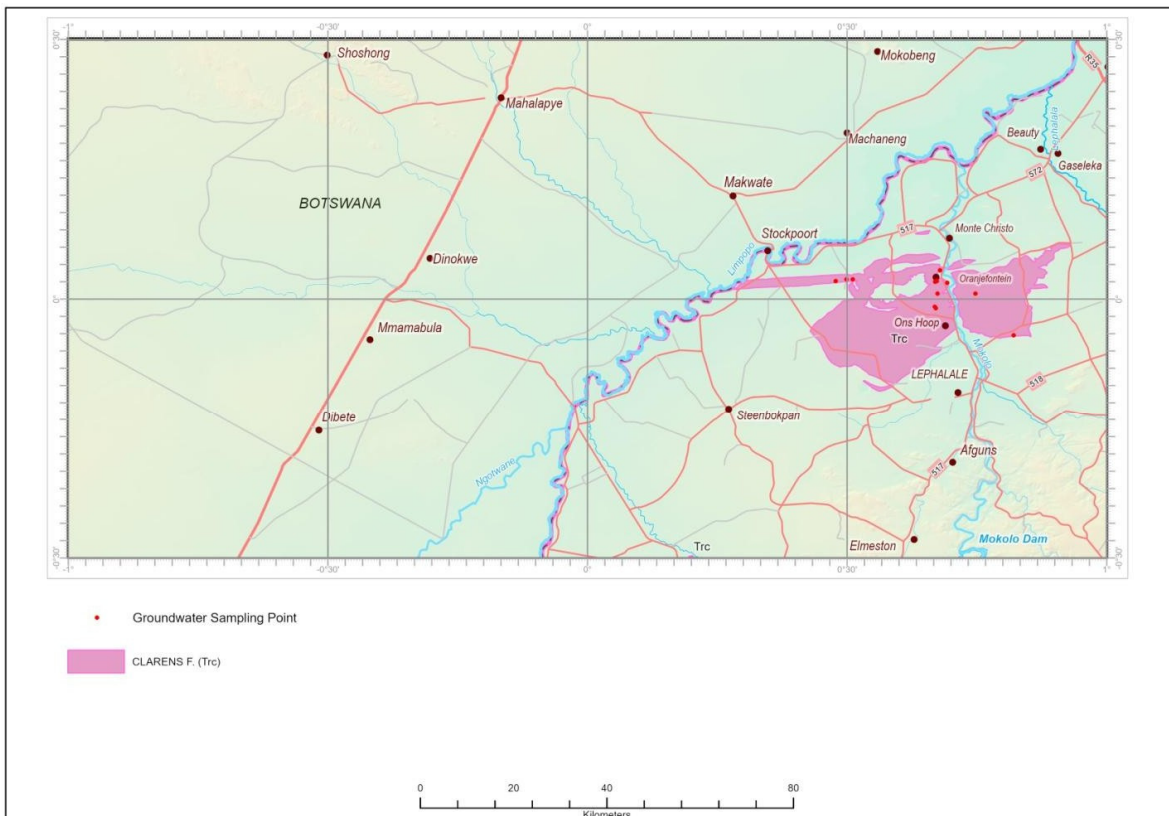


Figure 14: Geographical distribution of the Clarens Formation (Trc) and the associated groundwater sampling points.

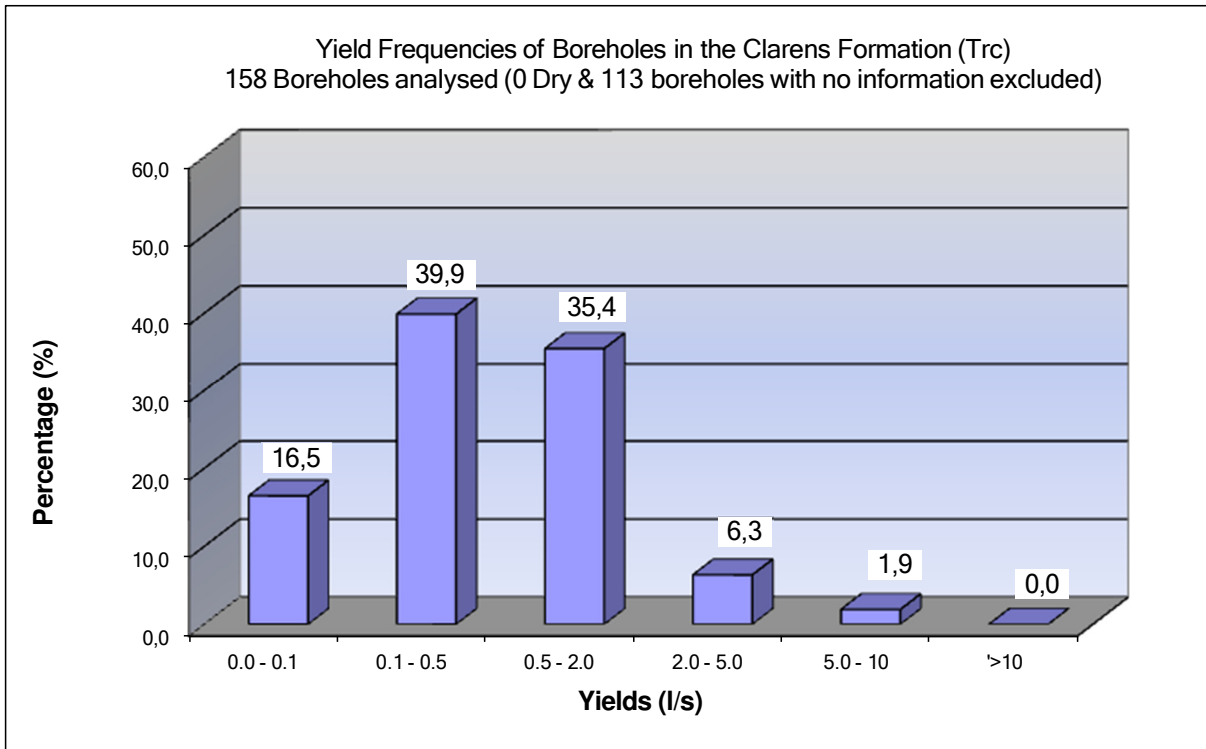


Figure 15: Yield frequency for the fractured aquifers of the Clarens Formation (Trc).

The sandstone has a low to very low primary permeability with low storage potential. Statistics reveal that 91.8% of successful boreholes yield less than 2l/s, (Figure 15).

The static water level ranges from 2.36 meters below ground level (mbgl) to 56.51mbgl, with a median of 30mbgl and an average static water level of 30.05mbgl; (based on 15 data points). The maximum depth recorded is 400m, with an average of 123.9m and a median depth of 108.4m, (158 data points). This implies that groundwater development in this aquifer predominantly penetrates the Clarens Formation in full during drilling as the maximum thickness is reported as 130m.

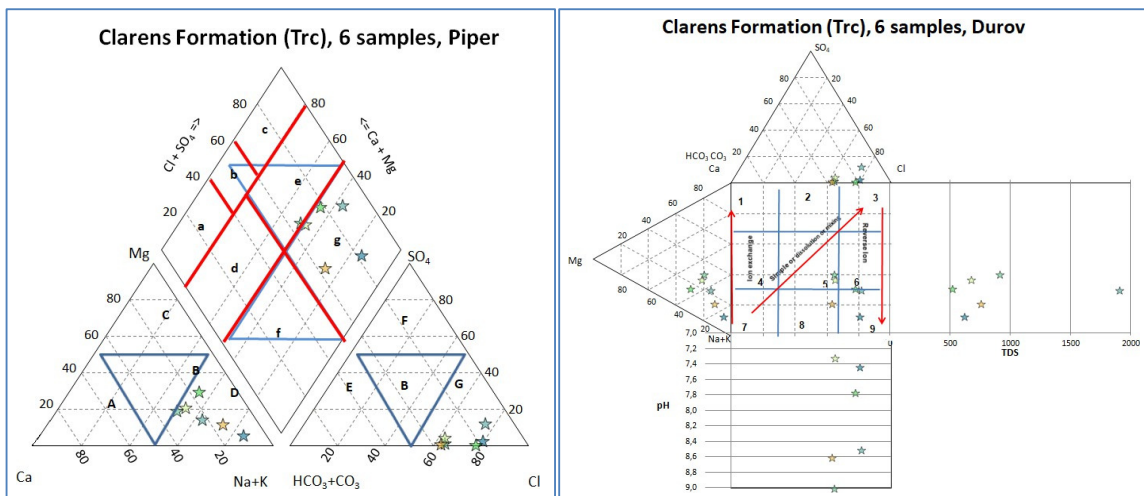


Figure 16: Trilinear diagrams, Piper and Durov for the Clarens Formation (Trc).

The trilinear Piper diagram, (Figure 16) facilitates the visualization of water chemistry by representing the concentrations of major cations and anions, enabling the classification of

hydrochemical facies. The initial evaluation of ionic dominance is as follows: 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 hydrochemical processes along with the water type. The interpretation is as follows:

- Cl and Na dominant, frequently indicative of end-point gradient waters through Dissolution (50%),
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (33.3%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (16.7%),
- The high TDS is some of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 27: Chemical statistics for the Clarens Formation (Trc)

Element / Parameter	Statistics Drawn from a population of 13 data points for the Clarens Formation (Trc)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	13	6,89	9,00	7,68	7,72	7,16	7,46	8,58	0,63	8,2%	
Electrical Conductivity (mS/m EC)	13	1,10	388,90	4,66	85,56	1,52	89,40	161,40	109,33	127,8%	
Total Dissolved Salts (mg/l TDS)	6	517,00	1912,00	751,21	897,50	567,50	713,00	1412,00	514,61	57,3%	
Calcium (mg/l Ca)	7	17,30	140,00	44,55	70,89	22,76	80,00	111,80	42,71	60,2%	
Magnesium (mg/l Mg)	7	5,00	56,00	13,93	28,49	5,78	29,40	47,60	18,51	65,0%	
Sodium (mg/l Na)	7	100,60	835,00	193,78	320,77	108,64	175,80	605,20	264,97	82,6%	
Potassium (mg/l K)	6	3,72	169,00	6,19	32,94	3,95	5,88	89,00	66,68	202,4%	
Chloride (mg/l Cl)	7	139,00	712,00	235,39	314,97	160,42	210,10	583,00	210,97	67,0%	
Sulphate (mg/l SO <sub>4</sub> )	7	2,00	576,00	6,45	110,04	2,90	9,50	324,60	212,93	193,5%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	7	133,70	715,20	236,63	321,73	136,40	321,00	531,48	202,14	62,8%	
Nitrate (mg/l N)	7	0,41	7,68	1,77	4,38	1,46	5,06	7,33	2,72	62,1%	
Fluoride (mg/l F)	7	0,30	2,80	0,43	0,77	0,30	0,37	1,66	0,92	118,8%	
Silicon as Si	2	6,99	35,56	11,68	21,28	9,85	21,28	32,70	20,20	95,0%	
Iron (Fe)	3	0,05	10,40	0,14	3,79	0,23	0,93	8,51	5,74	151,3%	
Manganese (Mn)	4	0,05	0,15	0,09	0,10	0,07	0,11	0,14	0,04	40,1%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	6	0,03	0,80	0,06	0,20	0,03	0,12	0,46	0,30	146,5%	
ZAR	7	3,20	24,48	5,54	8,69	3,25	8,17	15,31	7,44	85,6%	
LSI	13	Langelier Saturation Index (LSI)			Slightly Scaling		30,8%		Highly Scaling		0,0%
		Highly corrosive			46,2%		Slightly corrosive		7,7%		Balanced Corrosion

Table 27 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 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication of the scale of the problem.

The overall water quality in terms of Electrical conductivity (EC) is ideal to moderate with values varying between 1.1 and 166mS/m in 92.3% of the analysis, only 7.7% is above 370mS/m. The Total Dissolved Solids (TDS) is acceptable in 83.3% of the samples (TDS ≤ 1200mg/l).

An evaluation of the major cations and anions for 13 samples shows elevated concentrations of Sodium (Na > 400mg/l) in 28.6%; Potassium (K > 100mg/l) in 16.7%; Chloride (Cl > 600mg/l) in 14.3% and Fluoride (F > 1.5mg/l) in 14.3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be corrosive (53.9%) or slightly scaling (30.8%) and 15.4% balanced. The ZAR index indicates that none of the water analysis is of a fair quality for irrigation (ZAR < 3).

In 28.6% of the water samples, at least one element occurs that exceeds the maximum allowed limits for domestic use. For this unit the cations of concern are Sodium followed by Potassium in 16.7% of the analysis.



evaluation by comparing the positions of the higher yielding boreholes with these smaller fault zones did not result in significant correlation to statistically attribute the higher yielding boreholes with these fault zones. In the Tuli Basin that falls within the Musina 1:500 000 hydrogeological map sheet, it was found that the background geophysical detectable properties of the mudstone (such as the magnetic signature), are very similar over the fault zones, thus complicating the identification of the fault zones as anomalies in the data obtained. It corresponds to the findings of the aerial magnetic survey done in 2008 that covered the Ellisras Basin.

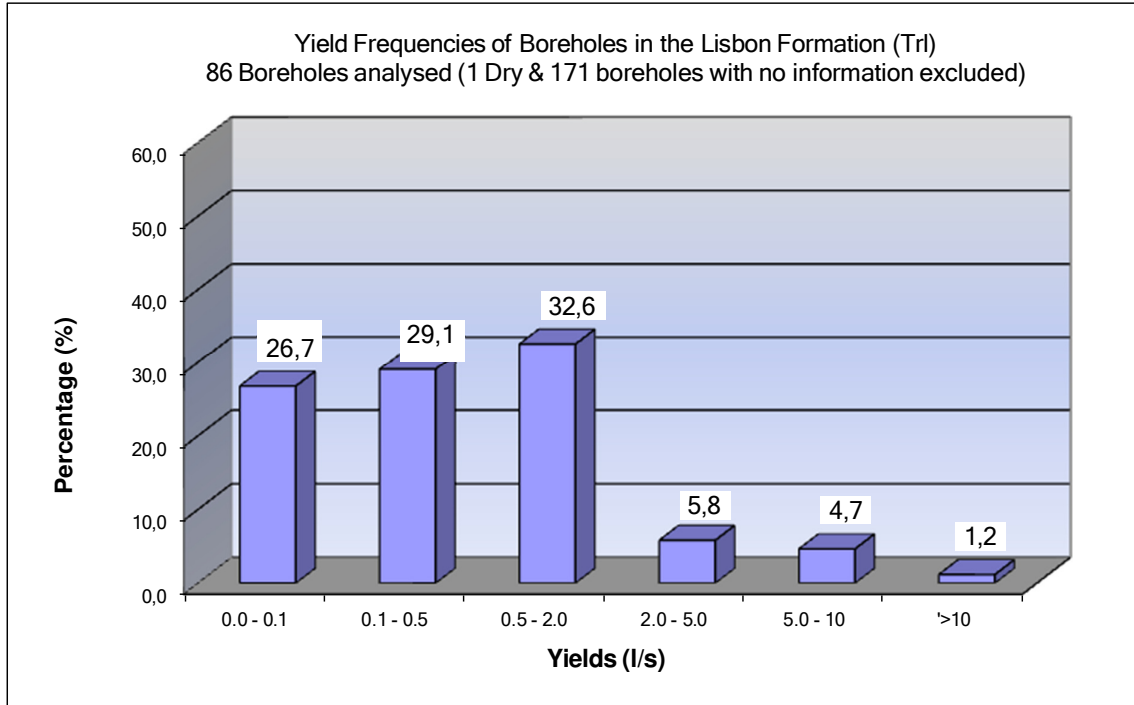


Figure 18: Yield frequency for the fractured aquifers of the Lisbon Formation (Trl).

The static water level ranges from artesian (one data point) to 57 meters below ground level (mbgl), with a median of 22mbgl and an average static water level of 25.15mbgl, (based on 7 data points). The maximum depth recorded is 260 meters (m), with an average depth of 138m and a median depth of 120m. No information is available on tested boreholes within unit.

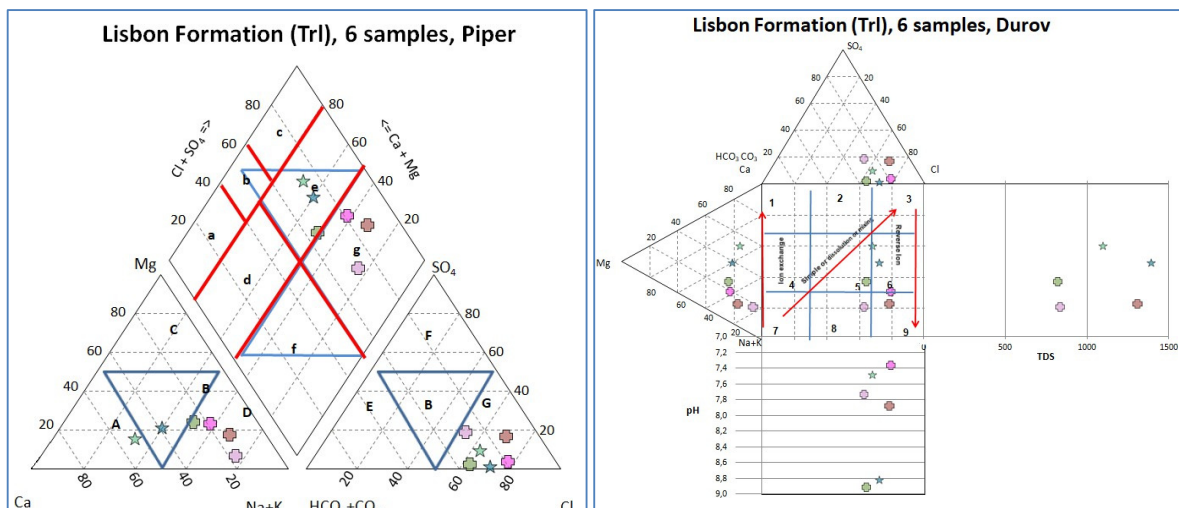


Figure 19: Trilinear diagrams, Piper and Durov for the Lisbon Formation (Trl)

The trilinear Piper diagram, (Figure 19) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (33%), Alkali > Alkali earths (66.7%), Strong acids > Weak acids (100%).

The second evaluation was on the water type: Sodium-Chloride type (66.7%); Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (33.3%).

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

- Anion discriminates and Na is dominant, probable mixing or uncommon dissolution influences (33.3%),
- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (33.3%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (16.7%),
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (16.7%),
- 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 28: Chemical statistics for the Lisbon Formation (Trl)

Element / Parameter	Statistics Drawn from a population of 11 data points for the Lisbon Formation (Trl)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	11	4,30	8,90	7,22	7,47	7,08	7,58	8,80	1,20	16,0%	
Electrical Conductivity (mS/m EC)	11	1,90	3160,00	10,06	377,70	2,60	96,70	250,00	926,12	245,2%	
Total Dissolved Salts (mg/l TDS)	8	497,00	19102,00	920,99	3198,75	608,30	964,00	6864,60	6435,42	201,2%	
Calcium (mg/l Ca)	7	32,80	1870,00	69,73	336,61	39,46	91,70	831,94	677,49	201,3%	
Magnesium (mg/l Mg)	7	7,40	886,00	25,05	155,79	18,38	32,80	394,96	322,52	207,0%	
Sodium (mg/l Na)	7	92,40	3417,00	172,16	639,81	102,36	158,60	1553,40	1227,01	191,8%	
Potassium (mg/l K)	7	4,20	67,50	7,84	17,19	4,75	7,82	38,94	22,80	132,7%	
Chloride (mg/l Cl)	8	63,00	11674,00	185,99	1679,15	116,90	250,60	3927,10	4041,89	240,7%	
Sulphate (mg/l SO <sub>4</sub> )	7	7,00	995,00	19,59	178,66	7,12	45,40	453,32	361,26	202,2%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	7	153,30	421,00	241,57	263,87	186,60	250,00	363,40	86,71	32,9%	
Nitrate (mg/l N)	6	0,05	35,94	0,29	13,76	3,73	10,45	27,12	12,40	90,1%	
Fluoride (mg/l F)	7	0,10	1,30	0,28	0,59	0,16	0,30	1,29	0,51	87,1%	
Silicon as Si	3	5,09	47,00	11,60	25,53	8,97	24,50	42,50	20,97	82,2%	
Iron (Fe)	3	0,00	0,22	0,00	0,09	0,01	0,05	0,19	0,11	127,2%	
Manganese (Mn)	2	0,00	0,05	0,00	0,03	0,01	0,03	0,05	0,03	135,9%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	5	0,01	0,80	0,03	0,20	0,02	0,05	0,53	0,34	168,6%	
ZAR	6	1,88	6,72	3,60	4,52	2,39	4,55	6,62	2,13	47,1%	
LSI	6	Langelier Saturation Index (LSI)			Slightly Scaling			33,3%		Highly Scaling	
		Highly corrosive			0,0%			Slightly corrosive		0,0%	
							Balanced Corrosion		66,7%		

Table 28 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 90<sup>th</sup> 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 good (63.6%); marginal in 27.3% and unacceptable in 9.1% of the analysis (EC > 370mS/m). The values range from 1.9mS/m to 3160mS/m, the 90<sup>th</sup> percentile is 250mS/m. The Total Dissolved Solids (TDS) is acceptable in 75% of the samples (TDS ≤ 1200mg/l).

An evaluation of the major cations and anions from 11 samples shows elevated concentrations of Chloride (Cl > 600mg/l) in 25%; Nitrate (N > 10mg/l) in 16.7%; Sodium (Na > 400mg/l) in 14.3%; Calcium (Ca > 300) in 14.3%; Magnesium (Mg > 200mg/l) in 14.3% and Sulphate (SO<sub>4</sub> > 600mg/l) in 14.3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is not corrosive but slightly scaling (33.3%) and predominantly 66.7% balanced. The ZAR index indicates that 33.3% of the water is of a fair quality for irrigation (ZAR < 3).

The water is abstracted for livestock, game watering and domestic purposes. Irrigation fields occur near Lephalale; the water supply is most likely from the nearby Daarby Fault zone, the Mokolo River and associated alluvium. The highest number of irrigation fields is within the northern part of the unit along the Zoetfontein Fault and in the west along the Limpopo River.

In 25% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anions of concern are Chloride followed by elevated concentrations of Nitrate in 16.7% of the analysis.

#### **7.2.1.4 GREENWICH FORMATION (Trg)**

The Clarens, Lisbon and Greenwich Formations are part of the Stormberg Group of the Karoo Supergroup. The Greenwich Formation (like the Molteno Formation of the main Karoo Basin), outcrop within the Ellisras basin in a narrow band in the northern, eastern, and central part of the Ellisras Basin. Figure 20 does not show the occurrences of the unit north of the Zoetfontein Fault and Constantia Fault as it was included as part of the Undifferentiated Goedgedacht Unit.

The Greenwich Formation rests with a sharp, erosive contact on the underlying Eendragtpan Formation. The thickness of the Greenwich formation varies between 7 and 33m. The formation comprises mainly medium- to coarse-grained purplish - red, whitish, or greenish sandstone and grit with local thin conglomerate lenses, (Brandl, 1996). It covers approximately 0.18% of the total map area.

The sandstone rocks of this unit can be considered a confined aquifer with low to very low primary permeability yet reasonable porous, (Dames and Moore, 1984).

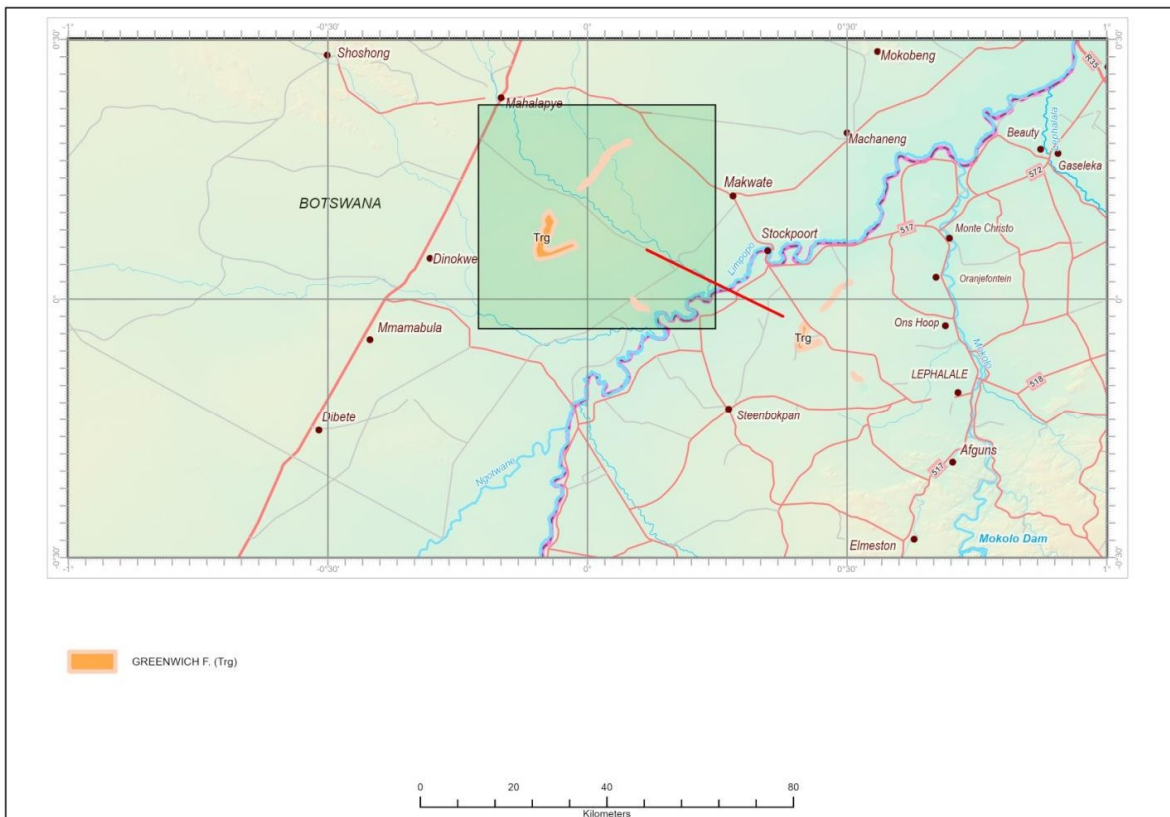


Figure 20: Geographical distribution of the Greenwich Formation (Trg) and the associated groundwater sampling points.

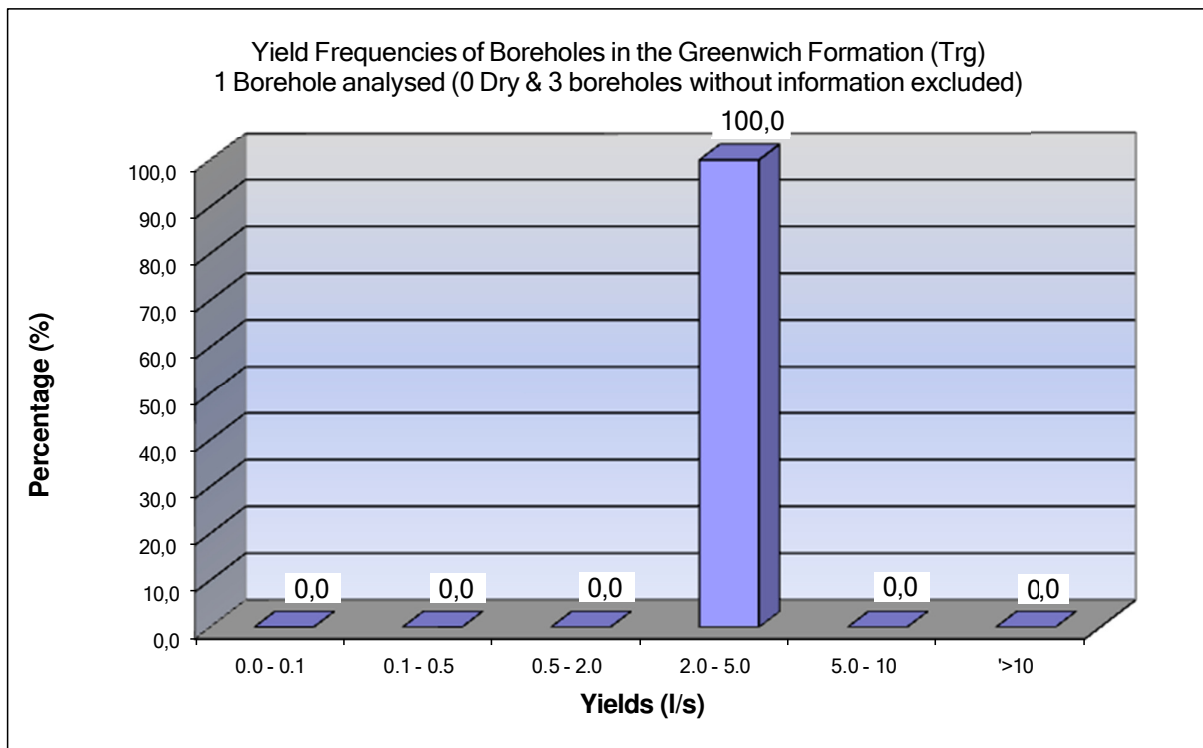


Figure 21: Yield frequency for the fractured aquifers of the Greenwich Formation (Trg).

There is only one borehole with information, the maximum yield is 3.6ℓ/s and drilled depth is 300m. There is no information available on water strike depths. The maximum thickness of the unit is 33m, and 110m in the underlying Eendragtpan Formation, therefore the water strike may relate to depositional contact zones in the Karoo sediments or to one of the numerous smaller fault zones as indicated on the geological map sheet. No clear conclusions can be made as all three data points within this unit plots on the same coordinate.

The depths of two other boreholes at this coordinate are 51.8m and 73m. There was no water chemistry available for this unit, therefore no characterization was done. Water is abstracted for livestock, game watering and domestic purposes.

#### **7.2.1.5 EENDRAGTPAN FORMATION (Tre)**

The Eendragtpan Formation, (like the Beaufort Formation of the Main Karoo Basin), outcrop predominantly within the central-western section of the Ellisras Basin. Figure 22 does not show the occurrences of the unit north of the Zoetfontein Fault and Constantia Fault and the occurrence in the eastern section of the map area. These areas were included as part of the Undifferentiated Goedgedacht Unit. The unit covers approximately 4.2% of the map area.

This formation signifies a dramatic change in prehistoric climate conditions. The notable changes are that there is a complete disappearance of coaly material and the appearance of reddish - to purplish - coloured sediments in succession. It conformably overlies the Grootegeluk Formation, except in the north-east where it transgresses onto Limpopo Belt gneisses, (Brandl, 1996).

The formation is comprised entirely of variegated mudstones which may become silty in the lower third of the succession. The colour varies between grey and bluish grey; towards the top purplish red colours are dominant. A maximum thickness of 110m is reached in the central part of the Ellisras Basin, decreasing gradually to 40m towards the north and east, (Brandl, 1996).

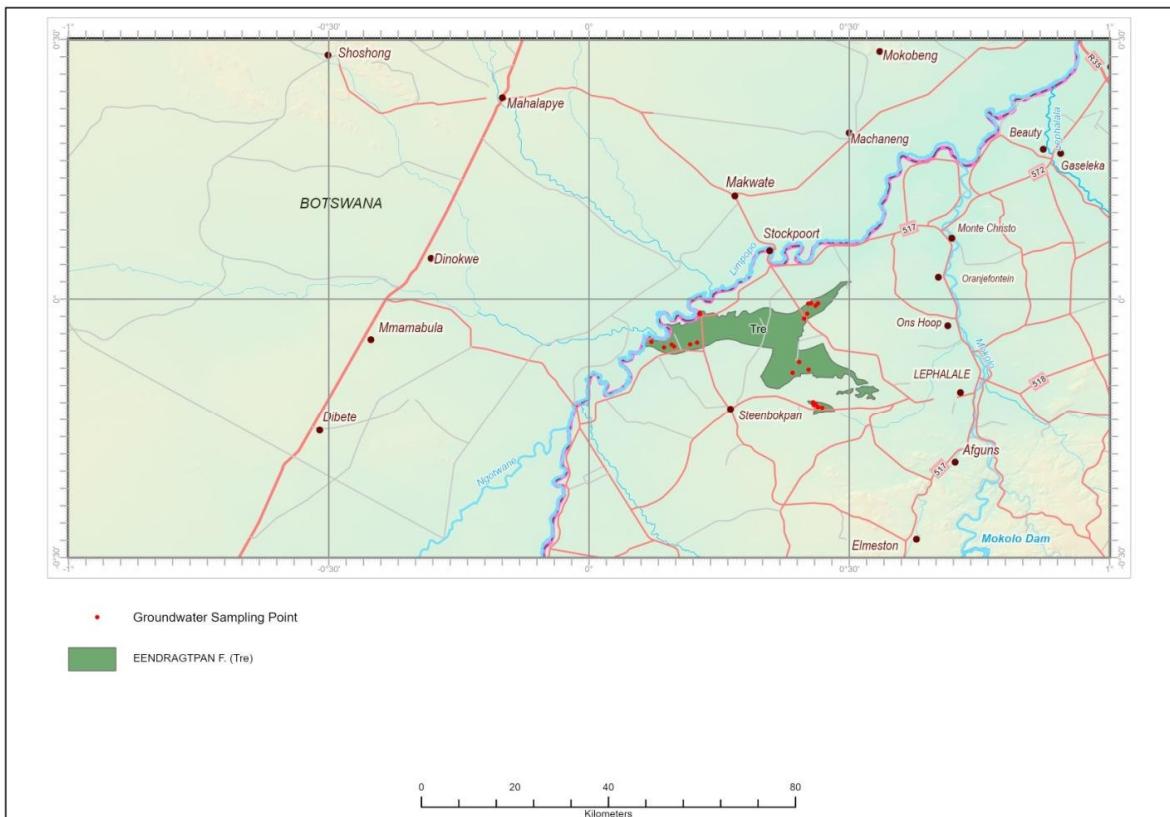


Figure 22: Geographical distribution of the Eendragtpan Formation (Tre) and the associated groundwater sampling points

The yield frequency distribution diagram indicates that 84.6% of successful boreholes have a maximum yield less than 2l/s. A further 9.2% of the boreholes yield between 2l/s and 5l/s and 6.1% of the boreholes is yielding more than 5l/s, (Figure 23).

In 27.3% 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 static water level ranges from 12.1 meters below ground level (mbgl) to 43.95mbgl, with a median of 26.4mbgl and an average static water level of 27.51mbgl, (based on 19 data points). The maximum depth recorded is 800 meters (m), with an average depth of 175m and a median depth of 144m, (66 data points). No information is available on pump tests or water strike depths. As the maximum thickness of the formation is 110m, the average drilling depth indicates that the full potential of the aquifer resource unit is usually targeted when developing groundwater sources, (top to bottom).

The very deep borehole (800m) was identified as a mine exploration borehole with a blow yield of 0.43l/s. The low yield is indicative that drilling into the basement rock at depth may not result in high yielding boreholes. Although the Karoo rocks were deposited on top of weathered basement rocks, an evaluation of deep boreholes drilled through the complete Karoo strata in similar environments, support the finding that on a regional scale, the deep (> 250m) basement contact is not a good target. In the vicinity of the Grootegeluk Mine, faults, fractures, joints planes and sedimentary bedding planes represent the main semi-confined aquifer of this unit, (Dames and Moore, 1984). A scientifically orientated project may be initiated to determine the potential of the contact with the basement rocks. It will also serve as an investigation into water strikes related to contact zones between the different formations or lithologies.

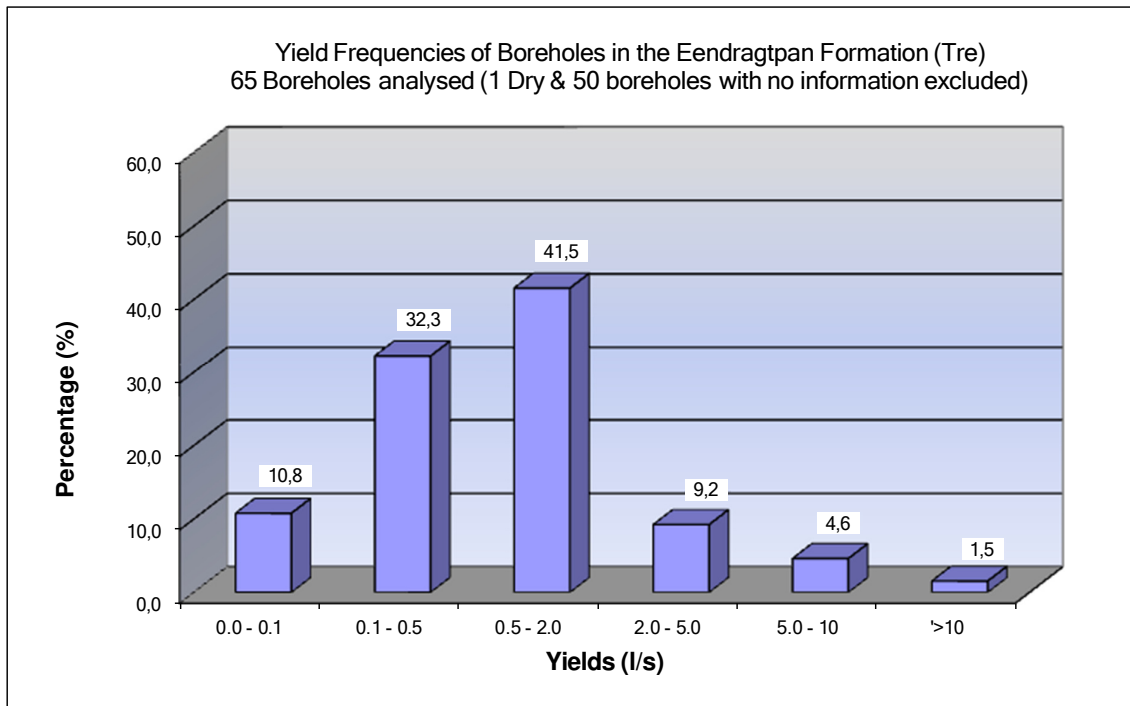


Figure 23: Yield frequency for the fractured aquifers of the Eendragtpan Formation (Tre).

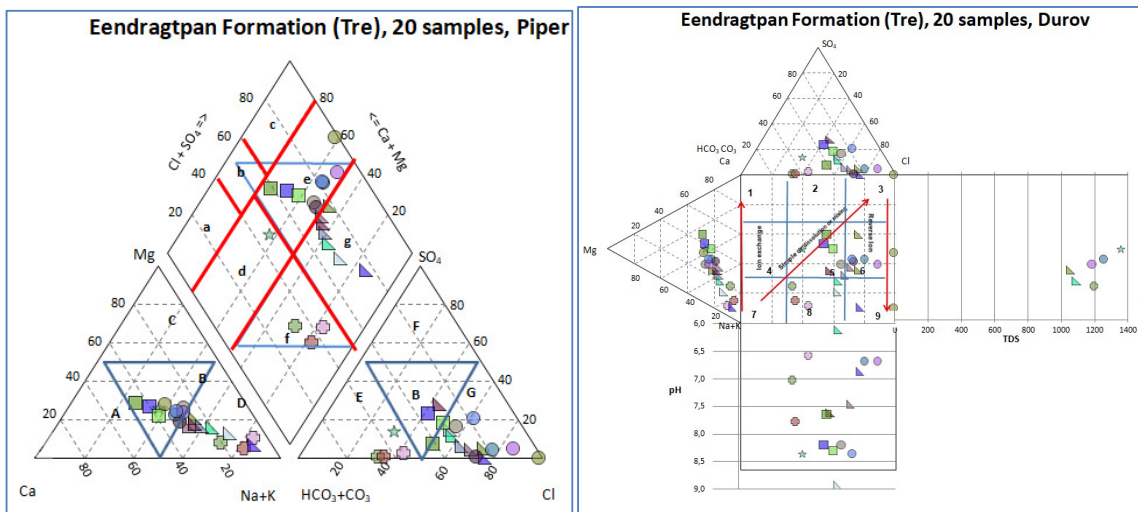


Figure 24: Trilinear diagrams, Piper, and Durov for the Eendragtpan Formation (Tre).

The trilinear Piper diagram, (Figure 24) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (50%), Weak acidic anions > Strong acidic anions (20%); Alkali > Alkali earths (50%); Strong acids > Weak acids (80%).

- The second evaluation was on the water type:
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (40.9%),
- Sodium-Chloride type (31.8%),
- Sodium-Bicarbonate type (13.7%),

- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with prevailing Sodium and Sulphate (9.1%),
- Mixed Calcium-Magnesium-Bicarbonate type with prevailing Sodium (4.5%).

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

- No dominant anion or cation, plots along the dissolution line can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing (38.1%),
- Anion discriminates and Na is dominant, probable mixing or uncommon dissolution influences (33.3%),
- Cl dominate anion and Na-Cl dominant cation, indicates that the ground water to relate to reverse ion exchange of Na-Cl waters (23.8%),
- Cl and Na dominant, is frequently indicative of end-point gradient waters through dissolution (4.8%),
- The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 29: Chemical statistics for the Eendragtpan Formation (Tre)

Element / Parameter	Statistics Drawn from a population of 25 data points for the Eendragtpan Formation (Tre)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation
pH	24	6,40	8,47	7,57	7,60	7,04	7,62	8,24	0,50	6,6%
Electrical Conductivity (mS/m EC)	25	7,96	1306,00	87,79	239,53	97,88	150,00	246,60	324,62	135,5%
Total Dissolved Salts (mg/l TDS)	22	528,00	1468,00	837,70	919,09	592,60	882,00	1317,80	283,57	30,9%
Calcium (mg/l Ca)	22	21,40	147,00	59,63	81,50	31,74	81,05	140,50	40,83	50,1%
Magnesium (mg/l Mg)	22	7,99	74,70	25,79	35,11	15,98	31,15	57,06	17,94	51,1%
Sodium (mg/l Na)	22	86,00	378,00	147,63	182,92	89,08	160,50	313,80	91,79	50,2%
Potassium (mg/l K)	22	2,80	30,40	10,60	14,00	7,35	13,70	19,89	6,61	47,2%
Chloride (mg/l Cl)	22	0,10	718,00	2,18	250,90	91,20	228,00	436,60	156,64	62,4%
Sulphate (mg/l SO <sub>4</sub> )	22	1,86	232,00	8,64	56,54	3,23	29,90	148,40	67,45	119,3%
Total Alkalinity (mg/l CaCO <sub>3</sub> )	21	28,00	725,00	207,22	376,52	132,00	377,00	534,00	177,60	47,2%
Nitrate (mg/l N)	20	0,02	4,07	0,05	0,63	0,02	0,07	3,55	1,35	212,1%
Fluoride (mg/l F)	22	0,20	5,48	0,70	1,44	0,43	0,80	3,91	1,51	104,4%
Silicon as Si	1	67,00	67,00	67,00	67,00	67,00	67,00	67,00		
Iron (Fe)	22	0,001	5,650	0,011	0,546	0,010	0,028	1,513	1,38	253,4%
Manganese (Mn)	22	0,003	0,640	0,023	0,175	0,010	0,050	0,550	0,22	127,7%
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	4	0,800	0,800	0,800	0,800	0,800	0,800	0,800	0,00	0,0%
ZAR	22	1,61	14,07	3,50	4,89	2,06	3,62	9,45	3,33	68,1%
LSI	21	Langelier Saturation Index (LSI)		Slightly Scaling		52,4%		Highly Scaling		0,0%
		Highly corrosive		0,0%		Slightly corrosive		19,0%		Balanced Corrosion

Table 29 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 90<sup>th</sup> 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 good at 48%, marginal in 44% and unacceptable in 8% of the samples (EC > 370mg/l). The values range from 7.9mS/m to 1306mS/m with 246mS/m representing the 90<sup>th</sup> percentile. The Total Dissolved Solids (TDS) is acceptable in 77.3% of the samples (TDS ≤ 1200mg/l).

An evaluation of the major cations and anions from 25 samples show elevated concentrations of Fluoride (F > 1.5mg/l) in 27.3% and Chloride (Cl > 600mg/l) in 4.5% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be slightly corrosive 19% but predominantly slightly scaling (52.4%) and balanced 28.6%. The ZAR index indicates that 40.98% of the water is of a fair quality for irrigation (ZAR < 3). In 27.3% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit it is the anion Fluoride.

The water is abstracted for livestock, game watering and domestic purposes. No large irrigation fields occur within the unit. There are some monitoring and dewatering boreholes in the Grootegeluk mine pit and immediate vicinity.

### 7.2.1.6 UNDIFFERENTIATED GOEDGEDACHT FORMATION (Tr-Pe)

The unit grouped together various small narrow occurrences of sedimentary rocks of the Greenwich, Eendragtpan, Grootegeluk, Goedgedacht and Swartrant Formations within the northern and eastern boundary of the Ellisras Basin. The larger outcrops or occurrences of these formations are discussed as separate groundwater units in the report. Outcrops are limited, the area is flat, and the area is mostly covered by sand and soil. The unit covers approximately 2.1% of the total map area, (Figure 25).

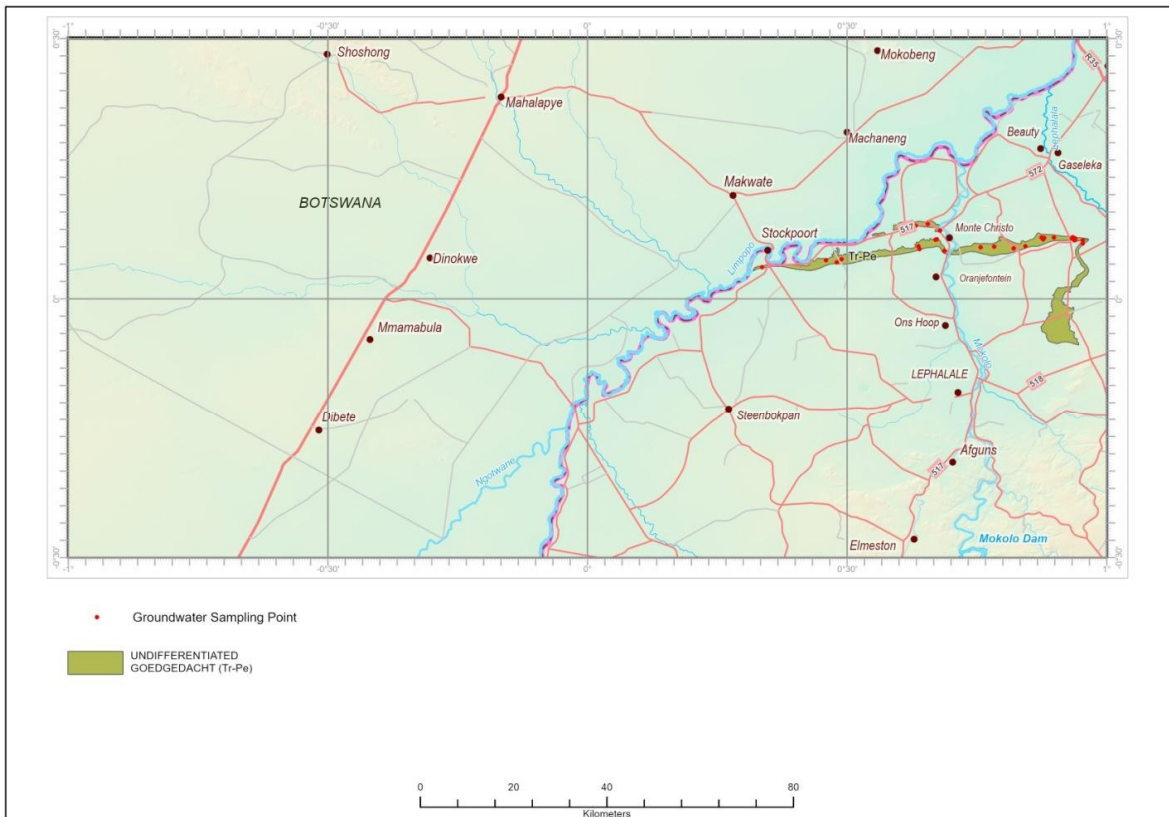


Figure 25: Geographical distribution of the Undifferentiated Goedgedacht Formation (Tr-Pe) and the associated groundwater sampling points

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 targets such as faults and dolerite dykes can also be targeted in the search for groundwater.

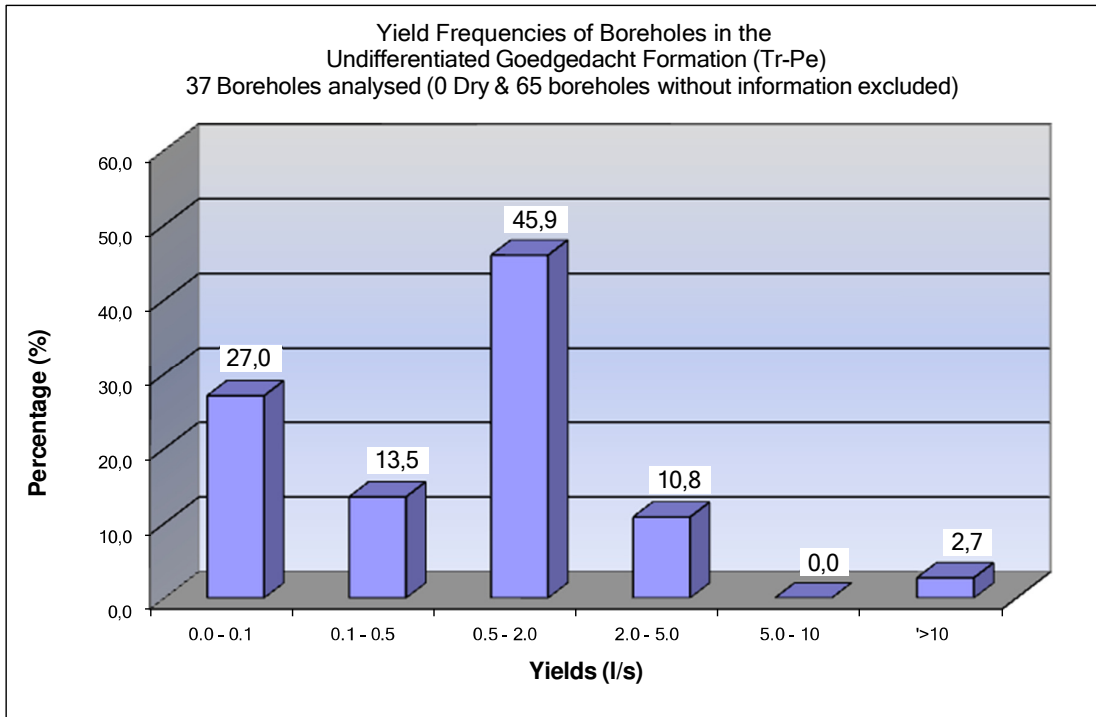


Figure 26: Yield frequency for the fractured aquifers of the Undifferentiated Goedgedacht Formation (Tr-Pe).

The sedimentary rocks grouped under this unit have a low to very low primary permeability with low storage potential. Statistics indicate that 86.4% of successful boreholes yield less than 2l/s and 10.8% of the boreholes yield between 2l/s to 5l/s. Only 2.7% of the boreholes yield more than 5l/s, (Figure 26). The high number of successful boreholes signifies that it is not difficult to find water for a single household, game, or livestock watering.

The static water level ranges from artesian to 30 meters below ground level (mbgl), with a median static water level of 15.48mbgl and an average static water level of 14.9 mbgl, (based on 6 data points). The maximum depth recorded is 130m, with an average depth of 87m and a median depth of 100m, (3 data points). No pump testing data is available for the unit to characterize the potential in terms of available abstraction volumes.

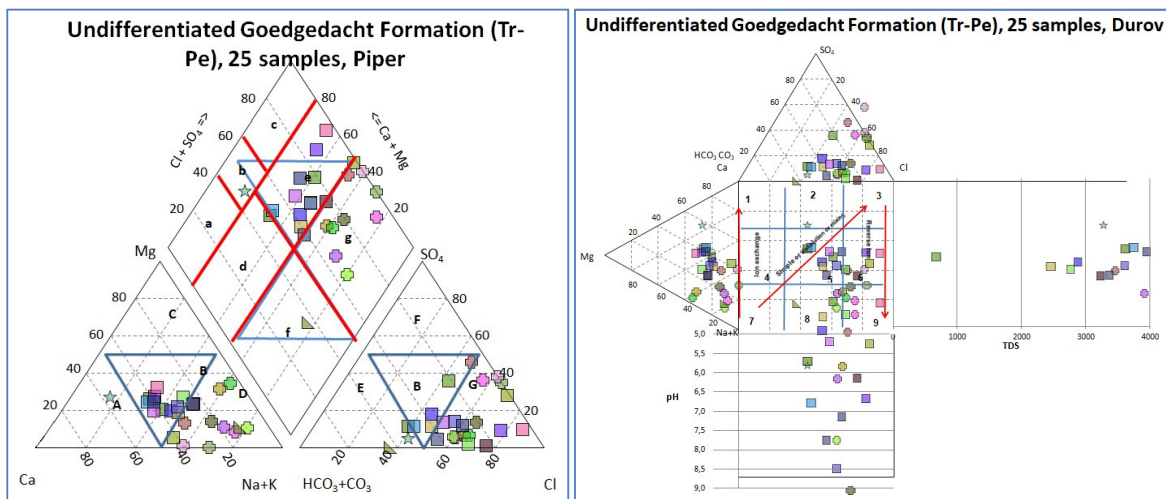


Figure 27: Trilinear diagrams, Piper, and Durov for the Undifferentiated Goedgedacht Formation (Tr-Pe).

The trilinear Piper diagram, (Figure 27) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (60%), Weak acidic anions > Strong acidic anions (6%); Alkali > Alkali earths (40%); Strong acids > Weak acids (94%).

The second evaluation was on the water type; the findings are as follows:

- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (40%),
- Sodium-Chloride type (36%),
- Mixed Calcium-Magnesium-Chloride-Sulphate type with prevailing Sodium (8%),
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with prevailing Sodium (8%),
- Calcium-Bicarbonate (4%),
- Sodium-Bicarbonate type (4%).

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

- No dominant anion or cation, plots along the dissolution line can be attributed to fresh recharged water exhibiting simple dissolution or mixing (36%),
- Anion discriminates and Na dominant, probable mixing, or uncommon dissolution influences (28%),
- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (12%),
- Water type is dominated by Ca and HCO<sub>3</sub> ions, indicative of recharging waters, (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 30: Chemical statistics for the Undifferentiated Goedgedacht Formation (Tr-Pe)

Element / Parameter	Statistics Drawn from a population of 30 data points for the Undifferentiated Goedgedacht Formation (Tr-Pe)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	30	5,50	9,10	7,21	7,27	6,82	7,25	7,96	0,68	9,3%	
Electrical Conductivity (mS/m EC)	30	29,50	9885,00	137,10	580,37	91,92	139,54	615,36	1788,26	308,1%	
Total Dissolved Salts (mg/l TDS)	28	146,00	3921,00	822,23	1335,46	625,50	865,57	2923,60	994,47	74,5%	
Calcium (mg/l Ca)	28	19,80	512,65	67,43	124,08	46,12	78,45	371,89	125,43	101,1%	
Magnesium (mg/l Mg)	28	1,40	214,00	14,90	40,68	13,66	31,80	70,89	41,53	102,1%	
Sodium (mg/l Na)	28	19,70	1005,80	93,63	247,58	58,13	131,90	634,69	245,26	99,1%	
Potassium (mg/l K)	28	3,71	32,00	8,67	12,24	4,42	10,01	20,60	7,24	59,1%	
Chloride (mg/l Cl)	27	30,70	1516,20	152,51	382,22	86,12	183,43	1179,08	443,34	116,0%	
Sulphate (mg/l SO <sub>4</sub> )	28	0,20	1059,40	4,70	161,18	10,31	55,40	448,80	270,32	167,7%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	28	2,00	960,00	36,53	277,29	66,03	246,23	528,68	213,42	77,0%	
Nitrate (mg/l N)	28	0,02	66,13	0,20	10,88	0,08	3,44	26,75	15,04	138,3%	
Fluoride (mg/l F)	26	0,20	6,24	0,74	1,48	0,44	0,77	3,25	1,43	96,4%	
Silicon as Si	25	6,21	49,87	17,93	26,80	8,14	27,07	45,00	13,83	51,6%	
Iron (Fe)	1	2,70	2,70	2,70	2,70	2,70	2,70	2,70			
Manganese (Mn)	1	0,33	0,33	0,33	0,33	0,33	0,33	0,33			
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	26	0,01	5,50	0,01	0,23	0,01	0,01	0,03	1,08	474,6%	
ZAR	11	0,48	15,29	1,89	4,51	0,99	3,42	9,25	4,42	98,2%	
LSI	28	Langelier Saturation Index (LSI)			Slightly Scaling		14,3%		Highly Scaling		3,6%
		Highly corrosive			7,1%		Slightly corrosive		17,9%		Balanced Corrosion

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 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication on the extent of the problem.

The overall water quality in terms of the Electrical conductivity (EC) is ideal to good (56.7%), marginal in 23.3% and unacceptable in 20% of the samples. The values range from 29.5mS/m to

9885mS/m with 1788.3mS/m representing the 90<sup>th</sup> percentile. The Total Dissolved Solids (TDS) is acceptable in 60.7% of the samples ( $TDS \leq 1200\text{mg/l}$ ).

An evaluation of the major cations and anions from 30 samples show elevated concentrations of Fluoride ( $F > 1.5\text{mg/l}$ ) in 30.8%; Nitrate ( $N > 10\text{mg/l}$ ) in 21.4%; Sodium ( $Na > 400\text{mg/l}$ ) in 17.9%; Chloride ( $Cl > 600\text{mg/l}$ ) in 14.8%; Calcium ( $Ca > 300$ ) in 14.3%; Sulphate ( $SO_4 > 600\text{mg/l}$ ) in 10.7% and Magnesium ( $Mg > 200\text{mg/l}$ ) in 3.6% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be corrosive at 25%, scaling (17.9%) and predominantly balanced 57%. The ZAR index indicates that 45.5% of the water is of a fair quality for irrigation ( $ZAR < 3$ ).

The water is abstracted for game, livestock watering and domestic purposes. Irrigation fields do occur on the unit, but the largest of those are along the Mokolo River. In 30.8% 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.

### **7.2.1.7 GROOTEGELUK FORMATION (Pgr)**

The Grootegeluk, Goedgedacht and Swartrant Formations are part of the Ecca Group of the Karoo Supergroup. The Grootegeluk Formation (like the Volksrust Formation of the main Karoo Basin), outcrop within the Ellisras basin in a few locations west to north-west of Ellisras. It covers approximately 2.8% of the total map area, (Figure 28). The occurrences of the unit north of the Zoetfontein Fault and Constantia Fault as well as the narrow occurrence in the eastern section of the map area, are not shown as it was included as part of the Undifferentiated Goedgedacht Unit.

This unit is economically the most important unit of the Karoo Supergroup in the Ellisras Basin, as it contains a few thick, mineable coal seams. The unit has a maximum thickness of 110m in the south, 40m to 60m in the northwest and north, 50m in the southeast and 10m to 20m in the northeast. It conformably overlies the Swartrant Formation in the east and the extreme southern part of the Ellisras Basin. In the central and northern part, the lower half of the formation interfingers with the Goedgedacht Formation, (Brandl, 1996).

The formation consists of mudstone, carbonaceous shale and coal which are repeated in a cyclical order. Individual cycles are developed on a micro- to macro scale and consist of a coal bed grading up into mudstone. The coal-bearing rocks can be correlated with the Ecca Group in the main Karoo Basin, (Johnson et al., 2006).

It was found that the unit is a semi-confined aquifer in the vicinity of the Grootegeluk Mine, (Dames and Moore, 1984). Mining exposed fractures, minor faults and sedimentary bedding planes within this unit resulted in seepage into the mine pit. This supports the general occurrence of groundwater in sedimentary rocks that 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.

The geographical distribution of numerous high yielding boreholes (yield  $> 2\text{l/s}$ ) corresponds to the location of smaller fault zones as depicted on the geological map sheet. A very high yielding borehole was drilled on the Eenzaamheid Fault zone using geophysical methods to locate the fault zone. The fault is near vertical and has a throw of 250m to the north bringing the upthrown Waterberg Group on the southern side of the fault into contact with the downthrown Beaufort and Ecca Groups on the northern side of the fault. The occurrence of Dolerite intrusive sills and dykes are limited in the Ellisras Basin and are therefore not expected to contribute much to groundwater occurrences.

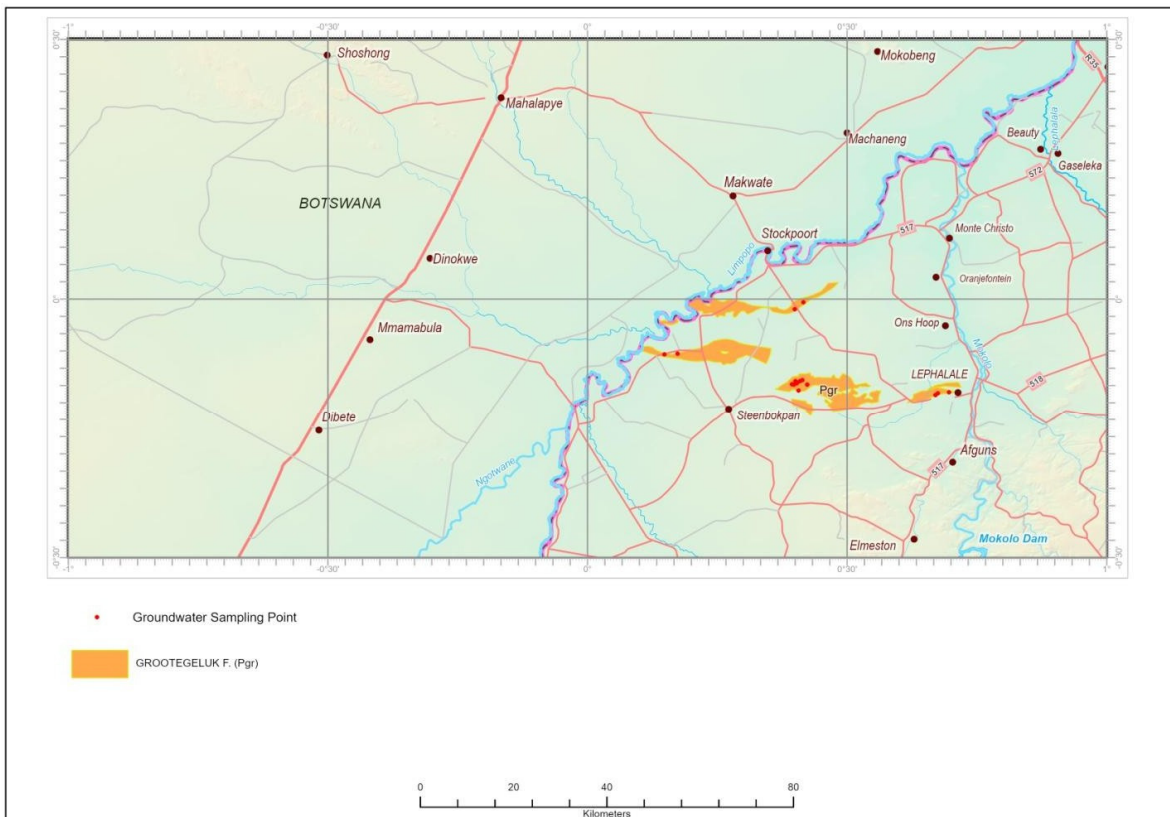


Figure 28: Geographical distribution of the Grootegeluk Formation (Pgr) and the associated groundwater sampling points.

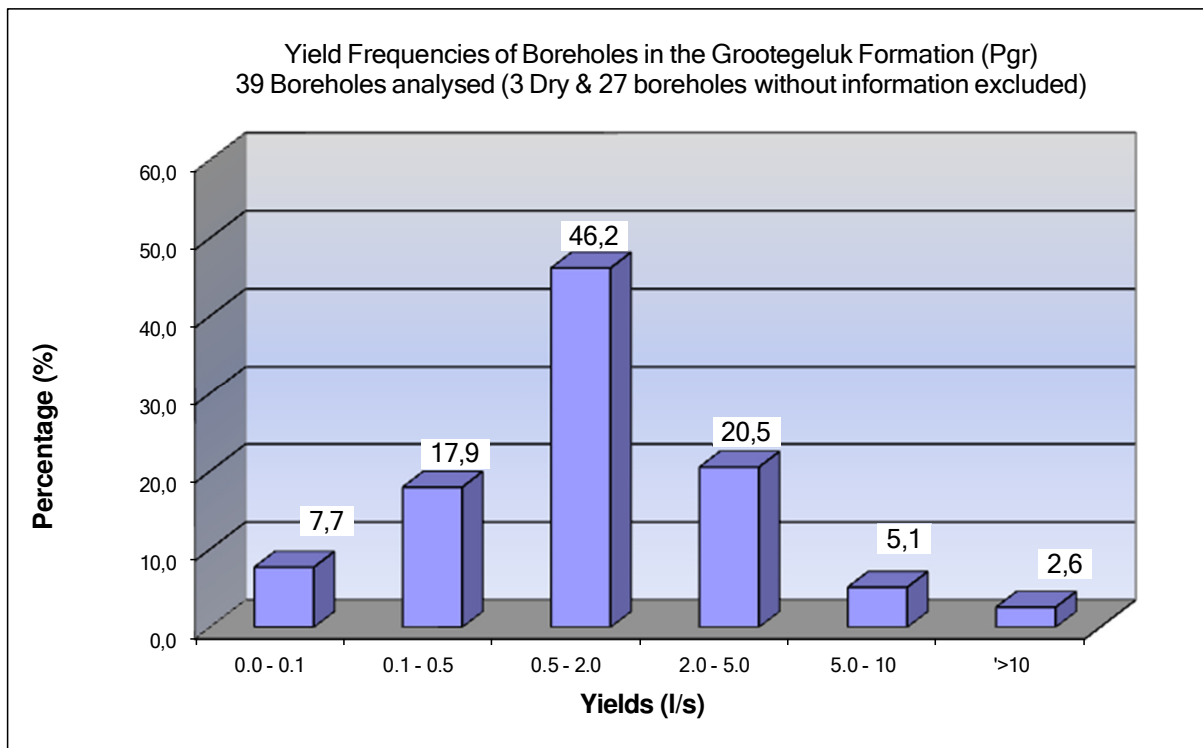


Figure 29: Yield frequency for the fractured aquifers of the Grootegeluk Formation (Pgr).

The yield frequency distribution indicates that 46.2% of successful boreholes have yields between 0.5l/s and 2l/s, while 25.6% of the boreholes yield less than 0.5l/s. Additionally, 20.5% of the boreholes yield between 2l/s and 5l/s, and 7.7% yield more than 5l/s, (Figure 29). Of the three boreholes with yields exceeding 5l/s, one was drilled along the Eenzaamheid Fault, while the other two were drilled along smaller easterly striking faults.

The sedimentary rocks of this Formation exhibit low to very low primary permeability and low storage potential. However, the high number of successful boreholes, even though many are low-yielding, indicates that it is not difficult to find sufficient water for single household use, game, and/or livestock watering.

The static water level ranges from 20.78 meters below ground level (mbgl) to 33.31mbgl, with a median of 29.47mbgl and an average of 28.03mbgl (based on 10 data points). The maximum borehole depth recorded is 300 meters, the average depth is 190 meters, and the median depth is 216 meters (based on 5 data points). The maximum installation depth is 102 meters, which can be indicative of water strike depths.

The maximum recommended daily abstraction recorded is 259 cubic meters per day (m<sup>3</sup>/day), associated with a borehole drilled targeting the Eenzaamheid Fault, while the minimum recorded abstraction is 69m<sup>3</sup>/day. The total number of boreholes tested in this unit on record is only 2.

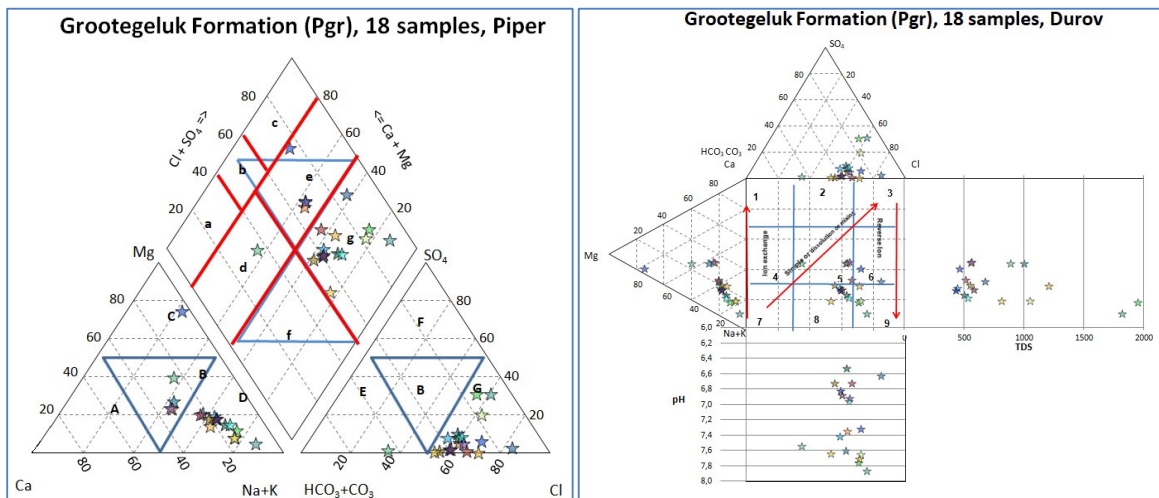


Figure 30: Trilinear diagrams, Piper and Durov for the Grootegeluk Formation (Pgr).

The trilinear Piper diagram, (Figure 30) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (27.8%), Weak acidic anions > Strong acidic anions (5.6%); Alkali > Alkali earths (72.2%); Strong acids > Weak acids (94.4%).

The second evaluation was on the water type; the findings are as follows:

- Sodium-Chloride type (72.2%),
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (16.6%),
- Mixed Calcium-Magnesium-Bicarbonate type with prevailing Sodium (5.6%),
- Magnesium-Chloride type (5.5%).

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

- Cl dominant anion and Na dominant cation, indicates that the groundwater to be related to reverse ion exchange of Na-Cl waters (38.9%),
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (27.8%),
- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (22.2%),
- Anion discriminate and Na dominant, probable mixing, or uncommon dissolution influences (11.1%),
- 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 the Grootegeluk Formation (Pgr)

Element / Parameter	Statistics Drawn from a population of 18 data points for the Grootegeluk Formation (Pgr)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	18	6,50	7,85	7,18	7,21	6,67	7,32	7,71	0,45	6,3%	
Electrical Conductivity (mS/m EC)	18	75,50	334,33	110,94	134,29	77,44	97,95	238,41	73,70	54,9%	
Total Dissolved Salts (mg/l TDS)	18	407,00	1858,00	622,12	765,86	430,30	541,00	1323,93	433,75	56,6%	
Calcium (mg/l Ca)	18	14,90	100,00	37,13	49,28	23,28	42,35	89,47	26,71	54,2%	
Magnesium (mg/l Mg)	18	12,90	206,00	21,56	37,12	13,71	20,40	62,47	45,88	123,6%	
Sodium (mg/l Na)	18	85,00	573,59	138,19	189,63	94,01	127,50	377,70	146,03	77,0%	
Potassium (mg/l K)	18	3,29	29,00	7,44	9,60	5,30	7,46	18,25	6,27	65,3%	
Chloride (mg/l Cl)	18	109,00	501,86	180,74	218,82	122,10	173,50	357,55	113,16	51,7%	
Sulphate (mg/l SO <sub>4</sub> )	18	2,00	348,21	7,48	52,30	2,94	19,20	149,26	93,79	179,3%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	18	141,00	646,00	251,55	291,27	198,70	234,00	463,00	132,94	45,6%	
Nitrate (mg/l N)	18	0,02	3,42	0,05	0,39	0,02	0,08	0,72	0,80	208,0%	
Fluoride (mg/l F)	18	0,26	6,99	0,66	1,88	0,35	0,67	5,70	2,31	123,0%	
Silicon as Si	3	6,25	13,85	9,21	10,27	7,14	10,70	13,22	3,82	37,2%	
Iron (Fe)	18	0,01	64,00	0,06	8,82	0,03	0,76	34,70	18,05	204,6%	
Manganese (Mn)	18	0,01	0,86	0,04	0,22	0,01	0,10	0,49	0,24	110,2%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	7	0,04	0,80	0,12	0,39	0,08	0,10	0,80	0,38	97,8%	
ZAR	18	1,70	17,38	3,88	5,45	2,40	4,02	9,54	3,98	73,0%	
LSI	18	Langelier Saturation Index (LSI)			Slightly Scaling		16,7%		Highly Scaling		0,0%
		Highly corrosive			0,0%		Slightly corrosive		44,4%		Balanced Corrosion

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 90<sup>th</sup> 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 good (72.2%) to marginal (27.8%) with values between 75.5mS/m and 334.3mS/m. The Total Dissolved Solids (TDS) is acceptable in 88.9% of the samples (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions from 18 samples show elevated concentrations of Fluoride (F > 1.5mg/l) in 27.8%; Sodium (Na > 400mg/l) in 11.1% and Magnesium (Mg > 100mg/l) in 5.6% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be slightly corrosive (44.4%); slightly scaling (16.7%) and 38.9% balanced. The ZAR index indicates that 22.2% of the water is of a fair quality for irrigation (ZAR < 3).

The water is abstracted for livestock, game watering and domestic purposes. The only irrigation fields within the unit are in the north-west and adjacent to the Limpopo River. The water needed for irrigation is most likely pumped from the river and associated with alluvium. Near the Grootegeluk Mine some monitoring and dewatering boreholes occur. In 27.8% 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.

### 7.2.1.8 GOEDGEDACHT FORMATION (Pgo)

The Grootegeluk, Goedgedacht and Swartrant Formations are part of the Ecca Group of the Karoo Supergroup. The Goedgedacht Formation outcrop in the north-western section of the Ellisras Basin, (Figure 31) and covers approximately 0.89% of the total map area. Thin sections north of the Zoetfontein Fault and in the eastern side of the Basin are not shown on the map as it is included under the Undifferentiated Goedgedacht Formation.

The thickness of the unit in the north is 80m but decreases to the south where it is interlocking with rocks of the Swartrant Formation. North of the Zoetfontein fault the rock rest unconformably on Constantia Suite rocks. In general, the formation comprises several mudstone beds of 0.5m to 4m thick characterized by graded bedding. In the lower part of these units, angular grains of quarts are present ranging in size from fine to medium to small pebbles. In places the individual units are capped by a thin bed of impure coal. Soft-sediment deformation and the presence of intraformational clay pellets and coaly material are common features of these units, (Brandl 1996).

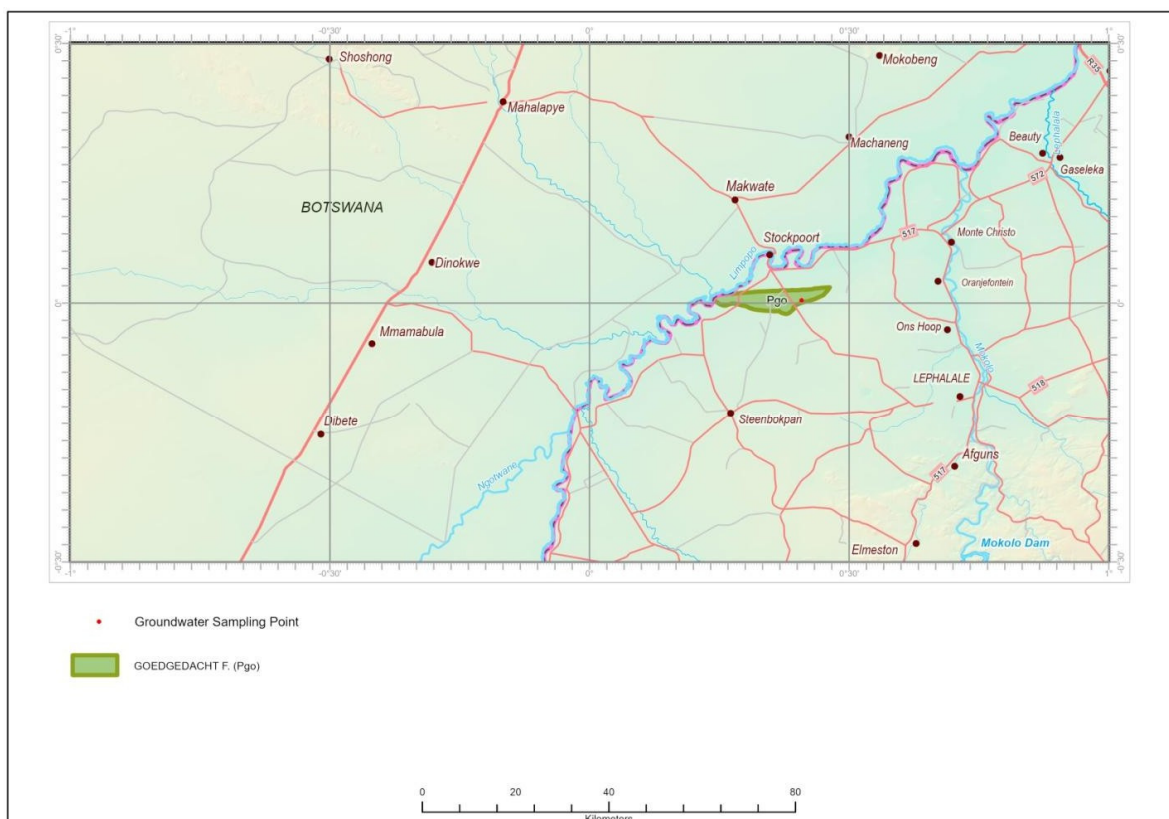


Figure 31: Geographical distribution of the Goedgedacht Formation (Pgo) and the associated groundwater sampling points.

Within the Grootegeluk mining area it was found that faults, fractures, joint planes, and sedimentary cycle bedding planes represent the main semi-confined aquifer of the Middle Ecca formations. The fluvial sandstones of the Middle Ecca are also relatively impervious, thus movement of groundwater is confined to fractures and along the contacts between sedimentary bedding planes. The Middle Ecca and Lower Ecca sandstones can be classed as confined aquifers since Piezometric levels in monitoring boreholes have indicated static water levels higher than those in the Upper Ecca. Some exploration boreholes which have been exposed in the lower

levels of the open pit that intersected Middle Ecca sandstones, have displayed artesian flow properties confirming the confined nature of the aquifer, (Dames and Moore, 1984).

In general, the groundwater occurrence in 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. There is not sufficient data available to confirm if the numerous small easts to north-east and north-west trending faults, as depicted on the geological map sheet, contribute to high yielding boreholes, as was found in some of the other Karoo units within the Ellisras Basin. The occurrence of Dolerite intrusive sills and dykes are limited in the Ellisras Basin and are therefore not expected to contribute much to groundwater occurrences.

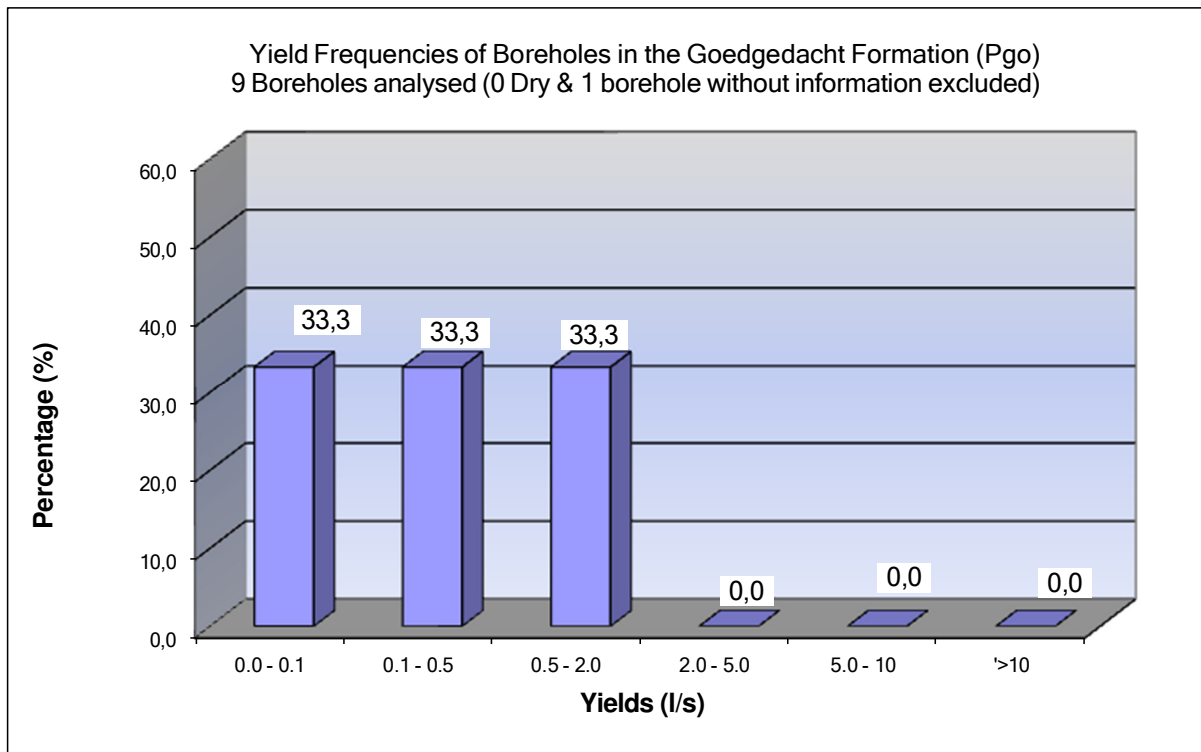


Figure 32: Yield frequency for the fractured aquifers of the Goedgedacht Formation (Pgo).

The yield frequency distribution indicates that all records of successful boreholes yield less than 2l/s, (Figure 32). Although the groundwater potential of the Goedgedacht Formation is expected to be low, the analysis is only based on 9 borehole resources with data. It can therefore not be accepted as a true reflection of the expected maximum yield of boreholes.

The maximum depth recorded is 216 meters (m), with an average depth of 91m and a median depth of 71m, (based on 5 data points). No information is available on static water levels, pump testing data and the depth of water strikes. The maximum depth of the formation (80m), compared to the average depth indicates that drilling usually penetrates the formation in full.

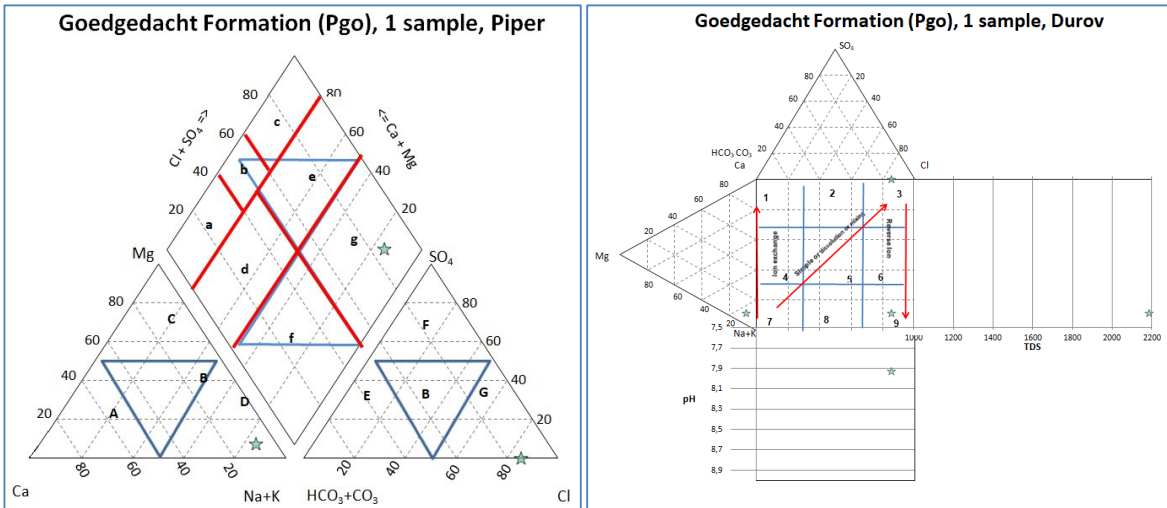


Figure 33: Trilinear diagrams, Piper, and Durov for the Goedgedacht Formation (Pgo).

The trilinear Piper diagram, (Figure 33) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali > Alkali earths (100%); Strong acids > Weak acids 100%.

The second evaluation was on the water type, it was identified as a Sodium-Chloride type (100%), based on a single chemical analysis.

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

- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (100%),
- The high TDS in the sample may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 32: Chemical statistics for the Goedgedacht Formation (Pgo).

Element / Parameter	Statistics Drawn from a population of 1 data point for the Goedgedacht Formation (Pgo)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	1	7,27	7,27	7,27	7,27	7,27	7,27	7,27			
Electrical Conductivity (mS/m EC)	1	383,00	383,00	383,00	383,00	383,00	383,00	383,00			
Total Dissolved Salts (mg/l TDS)	1	2180,00	2180,00	2180,00	2180,00	2180,00	2180,00	2180,00			
Calcium (mg/l Ca)	1	53,00	53,00	53,00	53,00	53,00	53,00	53,00			
Magnesium (mg/l Mg)	1	31,70	31,70	31,70	31,70	31,70	31,70	31,70			
Sodium (mg/l Na)	1	652,00	652,00	652,00	652,00	652,00	652,00	652,00			
Potassium (mg/l K)	1	27,00	27,00	27,00	27,00	27,00	27,00	27,00			
Chloride (mg/l Cl)	1	1100,00	1100,00	1100,00	1100,00	1100,00	1100,00	1100,00			
Sulphate (mg/l SO <sub>4</sub> )	1	1,87	1,87	1,87	1,87	1,87	1,87	1,87			
Total Alkalinity (mg/l CaCO <sub>3</sub> )	1	521,00	521,00	521,00	521,00	521,00	521,00	521,00			
Nitrate (mg/l N)	1	0,07	0,07	0,07	0,07	0,07	0,07	0,07			
Fluoride (mg/l F)	1	2,05	2,05	2,05	2,05	2,05	2,05	2,05			
Silicon as Si	0										
Iron (Fe)	1	0,05	0,05	0,05	0,05	0,05	0,05	0,05			
Manganese (Mn)	1	0,05	0,05	0,05	0,05	0,05	0,05	0,05			
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	1	0,80	0,80	0,80	0,80	0,80	0,80	0,80			
ZAR	1	17,50	17,50	17,50	17,50	17,50	17,50	17,50			
LSI	1	Langelier Saturation Index (LSI)			Slightly Scaling		0,0%		Highly Scaling		0,0%
		Highly corrosive			0,0%		Slightly corrosive		0,0%		Balanced Corrosion

The chemical data for this unit was from one sample only. The overall water quality in terms of the Electrical conductivity (EC) is unacceptable as the value is 383mS/m; the maximum allowable limit is 370mS/m. Unacceptable concentrations of Fluoride (F >1.5mg/l) and Sodium (Na > 400mg/l) are present in the water from a single available chemical analysis.

The Langelier Saturation Index (LSI) indicates that the water is balanced in the one sample analysed.

The water is abstracted for livestock, game watering and domestic purposes. No evidence of large-scale irrigation was found within the unit.

### 7.2.1.9 SWARTRANT FORMATION (Psr)

The Grootegeluk, Goedgedacht and Swartrant Formations are part of the Ecca Group of the Karoo Supergroup. The Swartrant Formation (similar to the Vryheid Formation of the main Karoo Basin), outcrop in various locations within the Ellisras Basin; the largest of these is south of the Daarby Fault zone around Lephallale; another outcrop is to the west of Lephallale extending up to the Limpopo River. The outcrop in the eastern side of the Basin forms a narrow north-south strip, (Figure 34). It covers approximately 4.1% of the total map area.

The thickness of this formation varies from 2m to 75m in the north, 7m to 50m in the east, and 130m in the central part around Lephallale. Borehole data was used to divide the formation into a lower, middle and upper zone. At the base of the lower zone a succession (6m to 10m) of alternating sandstone and siltstone is overlain by flaser-bedded and ripple cross-laminated sandstone. This is in turn overlain by medium- to coarse-grained cross-bedded sandstone with a thickness of 17m to 26m. Locally this coarse-grained sandstone is overlain by a meter thick coal seam (“No. 1 coal seam”). The lower zone consists of alternating sandstone and siltstone with the coarse-grained sandstone origin interpreted to be deposited in a delta front and the coal seam formed from a marshy cover on the delta plain when the progradation of the delta ceased, (Brandl, 1996).



*Plate 1: Tafelkoppe, one of three mesa-type (flat-topped hills), made up of whitish, feldspathic, coarse-grained, and cross-bedded sandstone of the Swartrant Formation. The other nearby hills are Ga-Mabula and Tambotiepiek which are along the R518 approximately 25km east-south-east of Lephallale. (Photograph: Louwlardus Safaris, 18 November 2020).*

At the base of the middle zone, with a thickness of 15m, a thin (<2m), coarse - grained, light- coloured sandstone is present, overlain by grey, horizontally laminated mudstone with a thickness of 1.5m to 3.6m. This mudstone grades into a fine- to coarse-grained, light-coloured sandstone

(0.2m to 5.9m), which becomes greyish towards the top. The zone is capped by a 3.2m to 5.9m thick unit of alternating coal and mudstone (No. 2 coal seam), (Brandl, 1996).

The upper zone has been divided into northern (13.6m to 36.4m) and southern (10m to 33m) facies. In the southern facies, the base of the upper zone consists of a thick (10m) greyish - white, coarse - to very coarse-grained, cross-bedded sandstone which has a sharp erosion contact with the underlying No. 2 coal seam. Near its top, the sandstone grades into a mudstone (up to 6m thickness) which locally contains a thin, impure coal seam. This unit is overlain by whitish, feldspathic, coarse-grained, and cross-bedded sandstone (up to 16m thick) which, grades up into a grey, carbonaceous fine-grained sandstone or siltstone, (Brandl, 1996).

The northern facies are characterised by a 3m to 13m basal unit consisting of alternating upward - coarsening mudstone and siltstone beds which are interspersed with coal seams and upward- fining sandstone beds. An erosion contact separates it from coarse-grained, cross-bedded, 16.5m to 30m thick feldspathic sandstone with a whitish colour, (Brandl, 1996).

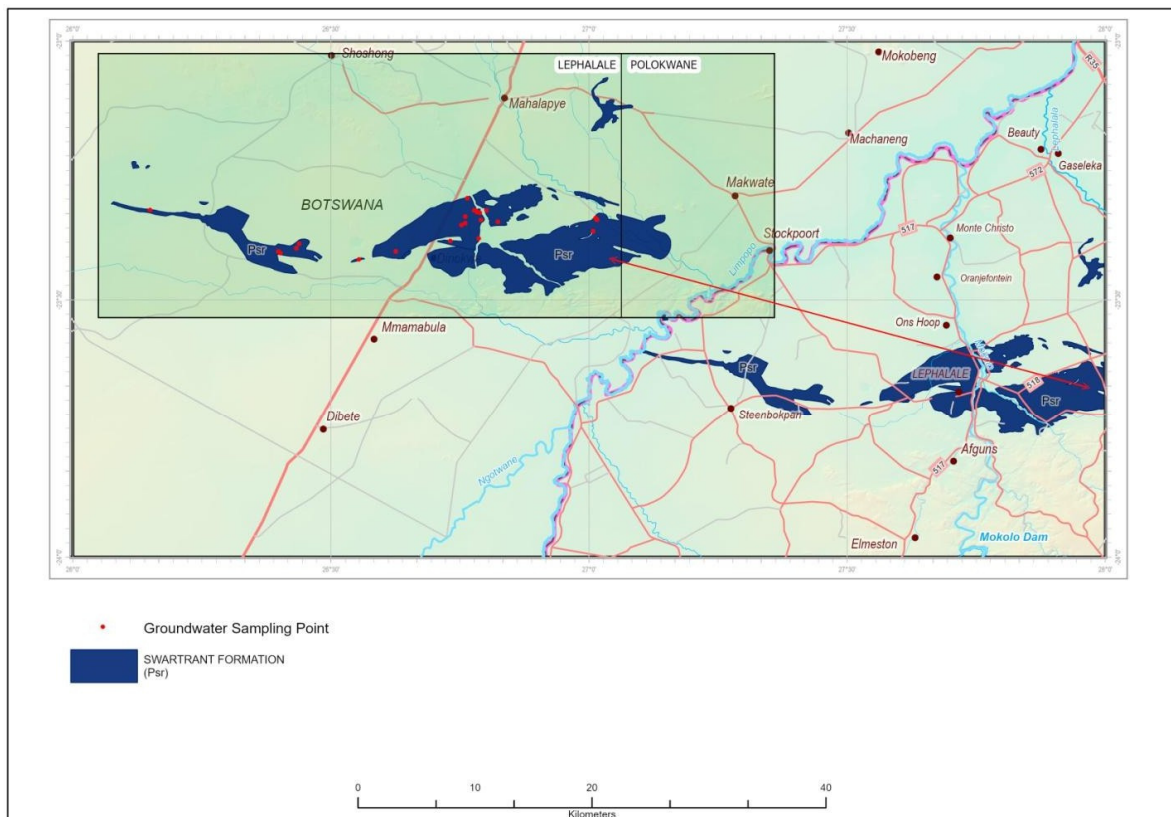


Figure 34: Geographical distribution of the Swartrant Formation (Psr) and the associated groundwater sampling points

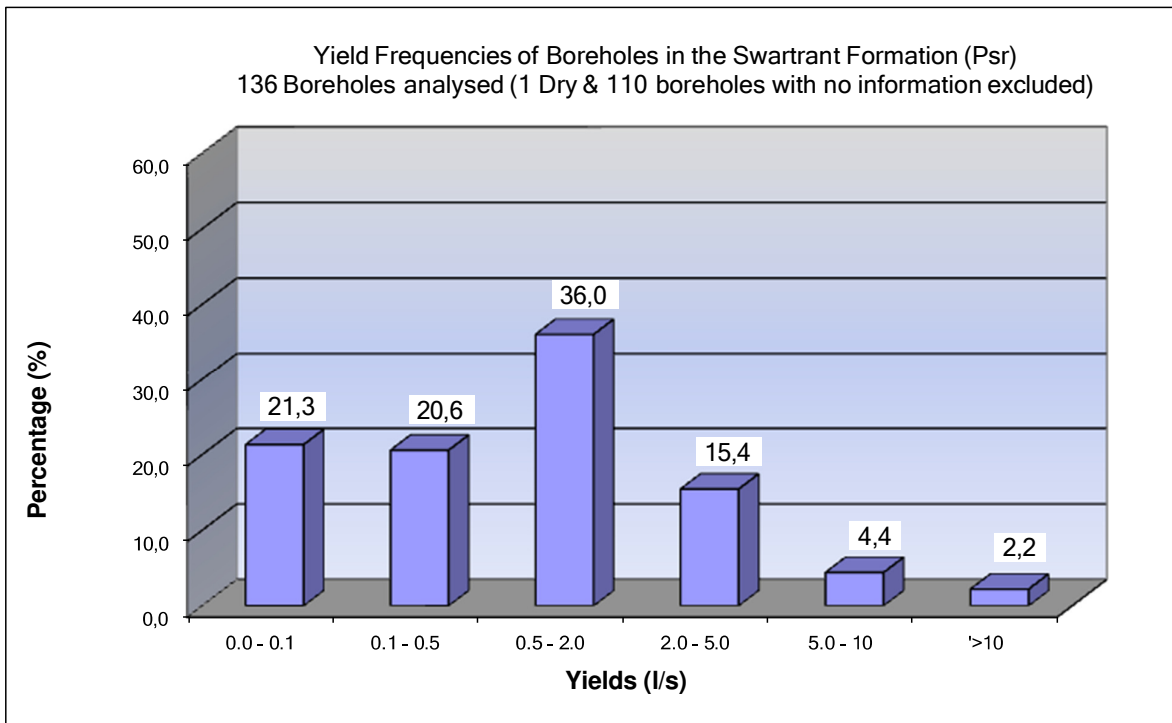


Figure 35: Yield frequency for the fractured aquifers of the Swartrant Formation (Psr).

Within the Grootegeluk mining area the Lower Ecca sandstones can be classed as a confined aquifer since Piezometric levels in monitoring boreholes have indicated static water levels higher than those in the Upper Ecca, (Dames and Moore, 1984).

The statistical analysis of 136 borehole records indicates that 36% of the maximum yields are between 0.5l/s and 2l/s, while 41.9% of the boreholes yield less than 0.5l/s and 22% of the boreholes are yielding more than 2l/s, (Figure 35). Only three boreholes (representing 2.2%) have yields exceeding 10l/s. A report indicates that these boreholes were drilled using the results of a geophysical survey. The target was the Eenzaamheid fault zone in areas where Waterberg Sandstones forms the foot wall section along the fault zone. The water strike depths of these boreholes were between 120m to 270m within the Waterberg rocks.

In general, the groundwater occurrence in 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. Records indicate 21 boreholes with moderate yields (2l/s to 5l/s) that occur throughout the unit. Assessing the positions of these boreholes and comparing it to the positions of the numerous small easts to north-east trending faults as depicted on the geological map sheet, a 23% correlation was found and a 19% correlation with the Daarby Fault zone (especially in the east). The occurrence of dolerite intrusive sills and dykes are limited in the Ellisras Basin and are therefore not expected to contribute much to groundwater occurrences.

The static water level ranges from artesian to 79.55 meters below ground level (mbgl), with a median of 9.23mbgl and an average static water level of 15.2mbgl, (based on 34 data points). The maximum depth reported is 296 meters (m), with an average depth of 157m and a median depth of 120m, (31 data points). This gives an indication that drilling within this unit penetrates the unit in full as the thickness of unit is between 2m and 130m.

The maximum installation depth is 144m and the average is 91.76m that can be indicative of water strike depths not related to the Eenzaamheid fault zone. The maximum recommended daily

abstraction on record is 1209.74 cubic meters per day (m<sup>3</sup>/day), with a median of 159.8m<sup>3</sup>/day and an average daily abstraction volume of 362.3m<sup>3</sup>/day. Ignoring the boreholes drilled on the Eenzaamheid fault zone the maximum recommended daily abstraction on record is 60.5m<sup>3</sup>/day, with a median of 10.4m<sup>3</sup>/day and an average of 24.8m<sup>3</sup>/day. The total number of boreholes subjected to pump testing within this unit on record is 10, of which 5 boreholes were drilled on the fault zone.

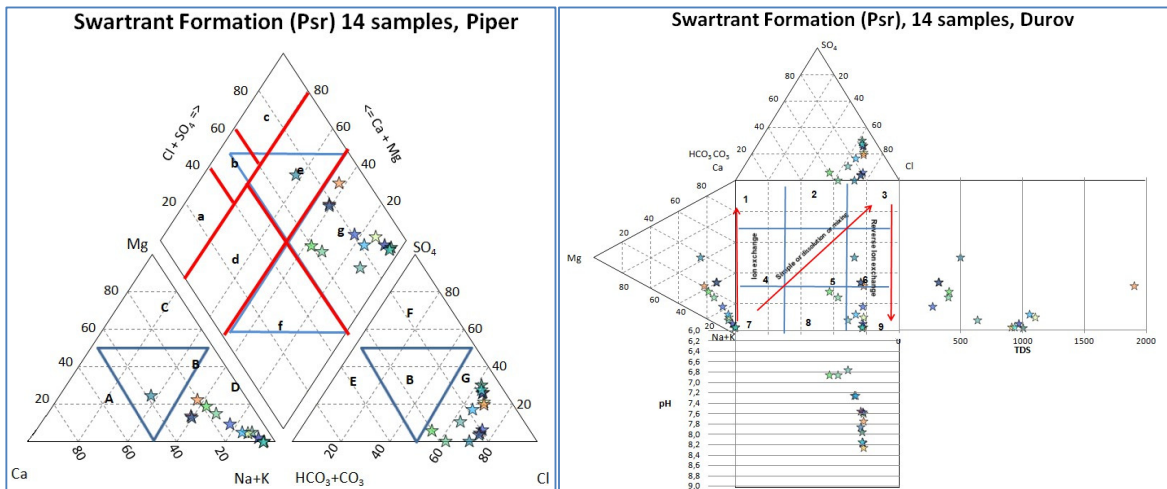


Figure 36: Trilinear diagrams, Piper and Durov for the Swartrant Formation (Psr).

The trilinear Piper diagram, (Figure 36) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (7.1%); Alkali >Alkali earths (92.9%); Strong acids > Weak acids (100%).

The second evaluation was on the water type; the findings are as follows:

- Sodium-Chloride type (93%),
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (7%).

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

- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (64.3%),
- Anion discriminate and Na dominant, probable mixing, or uncommon dissolution influences (21.4%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (14.3%),
- The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 33: Chemical statistics for the Swartrant Formation (Psr)

Element / Parameter	Statistics Drawn from a population of 26 data points for the Swartrant Formation (Psr)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation
pH	26	1,65	9,05	6,70	7,45	6,76	7,63	8,32	1,33	17,9%
Electrical Conductivity (mS/m EC)	25	1,40	332,00	10,62	107,37	3,22	88,80	182,80	93,41	87,0%
Total Dissolved Salts (mg/l TDS)	18	128,00	2534,00	522,21	871,40	316,70	877,82	1413,20	609,80	70,0%
Calcium (mg/l Ca)	20	8,80	167,00	20,33	41,06	11,89	24,00	101,04	44,92	109,4%
Magnesium (mg/l Mg)	20	0,50	116,00	2,93	21,01	1,31	8,21	58,28	31,80	151,4%
Sodium (mg/l Na)	19	1,00	434,00	14,21	194,83	11,00	157,00	368,24	149,53	76,7%
Potassium (mg/l K)	17	1,60	33,00	3,87	7,72	1,95	3,95	18,30	8,34	108,1%
Chloride (mg/l Cl)	21	11,00	744,00	60,02	230,26	14,80	209,00	388,00	193,12	83,9%
Sulphate (mg/l SO <sub>4</sub> )	20	2,00	382,00	7,61	95,23	2,00	50,00	220,96	111,64	117,2%
Total Alkalinity (mg/l CaCO <sub>3</sub> )	18	32,00	406,00	102,26	164,37	53,50	124,30	286,80	108,57	66,0%
Nitrate (mg/l N)	20	0,02	8,06	0,07	1,39	0,02	0,18	4,94	2,55	183,5%
Fluoride (mg/l F)	20	0,10	14,23	0,43	3,25	0,15	0,79	9,81	4,30	132,1%
Silicon as Si	12	6,21	20,80	10,81	12,12	6,93	11,70	17,60	4,21	34,7%
Iron (Fe)	15	0,006	36,000	0,022	3,090	0,006	0,050	3,820	9,20	297,7%
Manganese (Mn)	15	0,001	0,996	0,013	0,289	0,035	0,170	0,836	0,33	115,8%
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	14	0,012	0,800	0,034	0,261	0,015	0,073	0,800	0,36	136,2%
ZAR	10	0,03	13,83	0,24	5,95	1,66	4,04	11,95	4,76	80,0%
LSI	10	Langelier Saturation Index (LSI)		Slightly Scaling		20,0%		Highly Scaling		0,0%
		Highly corrosive		0,0%		Slightly corrosive		30,0%		Balanced Corrosion

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 90<sup>th</sup> 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 in 60% of the analysis and 40% marginal with values between 1.4 and 332mS/m.

The Total Dissolved Solids (TDS) is acceptable in 88.9% of the samples (TDS ≤ 1200mg/l). The evaluation of the major cations and anions from 26 samples shows elevated concentrations of Fluoride (F > 1.5mg/l) in 40%; Chloride (Cl > 600mg/l) in 9.5% and Sodium (Na > 400mg/l) in 5.3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be slightly corrosive (30%); slightly scaling (20%) and predominantly balanced (50%). The ZAR index indicates that 40% of the water is of a fair quality for irrigation (ZAR < 3).

The water is abstracted for livestock, game watering and domestic purposes. Irrigation fields occur along the Mokolo River near Lephalale and at a small area near the Grootegeluk Mine. Near mine some monitoring and abstraction boreholes occur. In 40% 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.

### 7.2.1.10 WELLINGTON FORMATION (C-Pwe)

Palynological evidence indicates that the Carboniferous/Permian boundary is roughly in the middle of the Wellington Formation, (MacRae, 1991), but there is no geological indication of this boundary in the lithological succession (Brandl, 1996). Therefore, some literature lists the unit as part of the Lower Ecca and some as part of the Dwyka Group. For the aquifer unit delineated in this report, the Wellington and underlying Waterkloof Formation is included as Dwyka Group.

The Aquifer Unit occurs within the southern section of the Ellisras Karoo Basin where it is preserved in two areas as depicted on the map, (Figure 37); one outcrop is east and the other outcrop is west of Lephalale. It covers approximately 5.3% of the total map area.

The thickness of the Wellington Formation is generally between 20m to 30m but reaches a maximum thickness of 160m in the south-western and 180m in the south-eastern section of the Basin. Where the formation is fully developed, the base comprises a unit with dark grey, horizontally laminated mudstone and siltstone containing sandstone lenses and scattered grit- sized grains, possibly small dropstones, (isolated fragments of rock found within finer-grained water-deposited sedimentary rocks). This unit becomes siltier and lighter coloured towards the top and exhibits upward - coarsening cycles, (Brandl, 1996).

The Waterkloof Formation represents the base of the Karoo Sequence. It consists of diamictite ( $\pm 9\text{m}$  thick), mudstone and conglomerate ( $\pm 17\text{m}$  thick). Although there are some outcrops in the Limpopo River Valley and within an area south of Lephalale, most of the available information was obtained from core-drilling logs. The Waterkloof Formation rests unconformably on Waterberg and pre-Waterberg rocks. The pre-Waterberg rocks are deeply weathered with palaeosol observed in some of the drilling samples recovered, (Brandl, 1996).

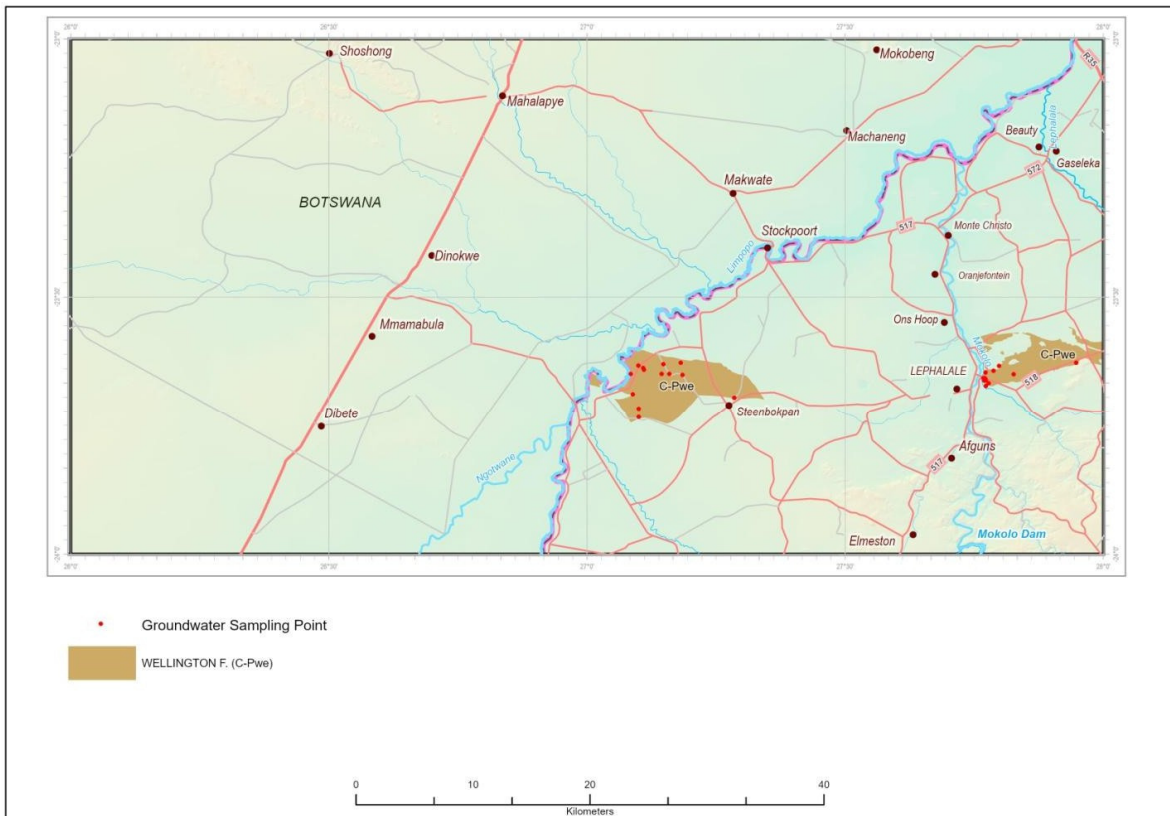


Figure 37: Geographical distribution of the Wellington Formation (C-Pwe) and the associated groundwater sampling points

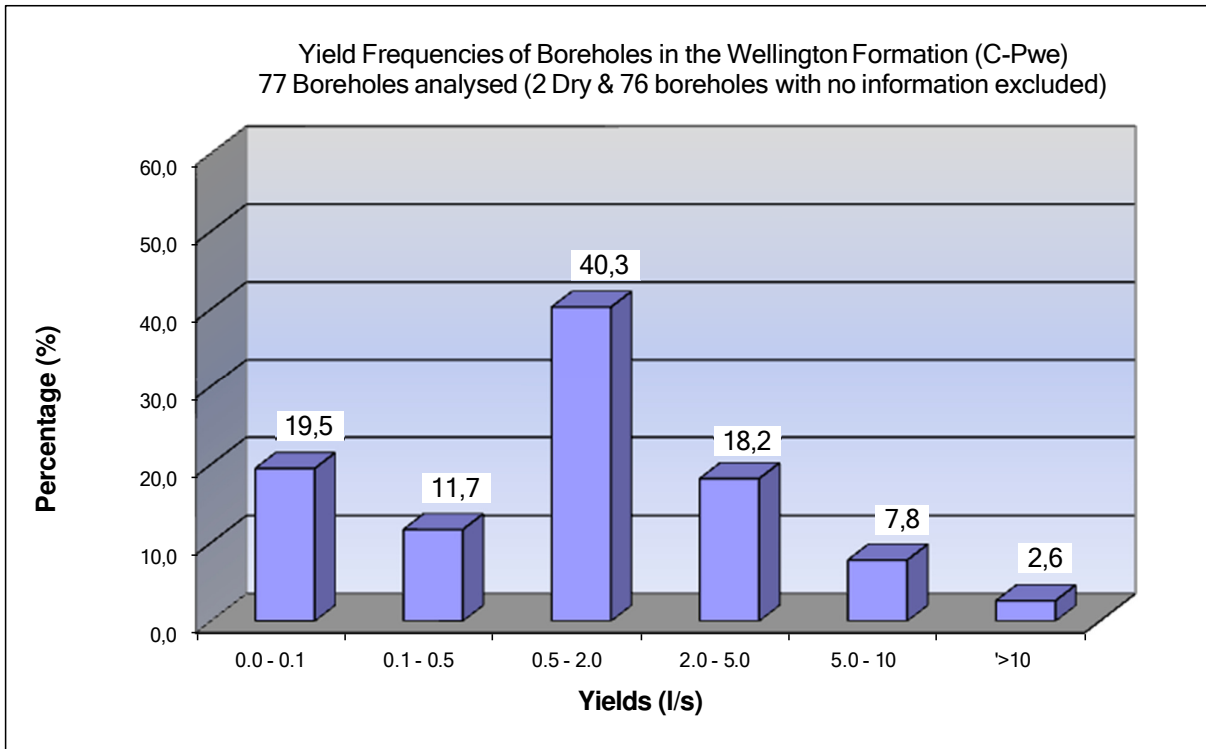


Figure 38: Yield frequency for the fractured aquifers of the Wellington Formation (C-Pwe).

The analysis of 77 borehole records indicates that 40.3% of the maximum yields are between 0.5 l/s and 2 l/s. A further 31.2% of the boreholes yield less than 0.5 l/s and 28.6% of the boreholes are yielding more than 2 l/s, (Figure 38). Only one of the eight boreholes that yield more than 5 l/s plots near the Eenzaamheid fault, the other boreholes do not occur near any known fault zones.

The static water level ranges from artesian to 46.13 meters below ground level (mbgl), with a median of 15.13 mbgl and an average static water level of 15.6 mbgl, (based on 14 data points). The maximum depth recorded is 145 meters (m), with an average depth of 98m and a median depth of 100m, (17 data points). The only available installation depth on record is 58m and single available daily abstraction volume obtained from pump testing data is 17.28 cubic meters per day (m<sup>3</sup>/day).

The sedimentary rocks of this Formation have low to very low primary permeability with low storage potential. 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, game or for livestock watering. From the available records on drilling depths, it does not seem that the basement rock contact (Waterberg or pre-Waterberg) is targeted.

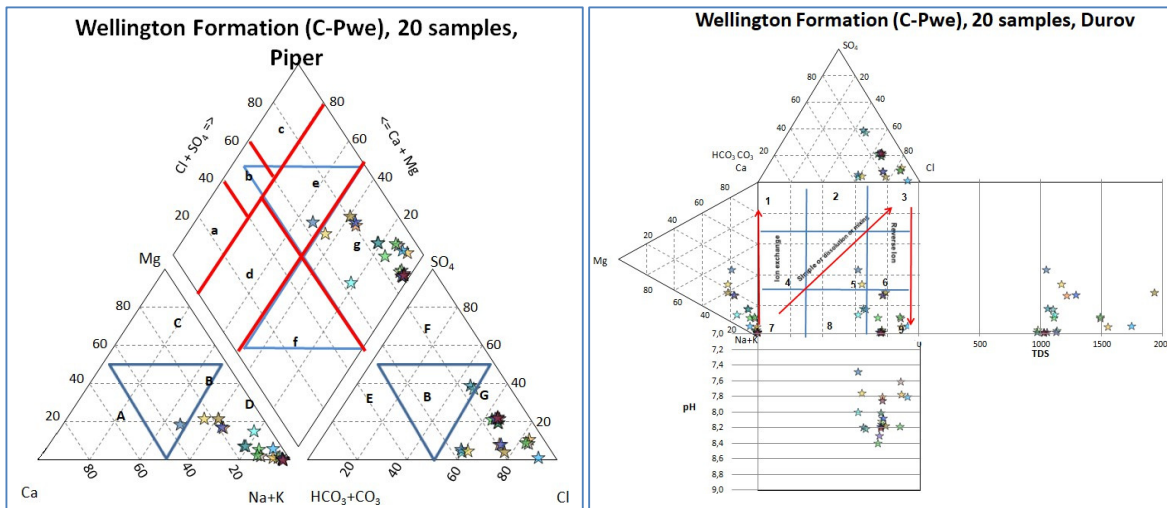


Figure 39: Trilinear diagrams, Piper, and Durov for the Wellington Formation (C-Pwe).

The trilinear Piper diagram, (Figure 39) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (5%); Alkali > Alkali earths (95%); Strong acids > Weak acids (100%).

The second evaluation was on the water type; the findings are as follows:

- Sodium-Chloride type (85%),
- Sodium-Chloride type with prevailing Sulphate (10%),
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (5%).

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

- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (75%),
- Cl dominant anion and Na dominant cation reverse ion exchange of Na-Cl waters (15%),
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (10%),
- The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 34: Chemical statistics for the Wellington Formation (C-Pwe)

Element / Parameter	Statistics Drawn from a population of 24 data points for the Wellington Formation (C-Pwe)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	24	6,79	8,38	7,93	7,94	7,60	8,06	8,25	0,35	4,4%	
Electrical Conductivity (mS/m EC)	24	1,50	324,00	22,21	168,95	124,50	155,50	251,80	73,36	43,4%	
Total Dissolved Salts (mg/l TDS)	22	873,00	2078,00	1081,60	1142,36	912,89	1005,50	1554,60	315,20	27,6%	
Calcium (mg/l Ca)	22	7,10	204,00	17,59	44,05	7,22	34,35	77,77	44,90	101,9%	
Magnesium (mg/l Mg)	22	0,50	204,00	2,72	25,09	1,19	11,75	39,33	43,32	172,7%	
Sodium (mg/l Na)	22	147,80	541,00	288,36	314,96	236,47	298,40	459,30	95,78	30,4%	
Potassium (mg/l K)	22	1,59	10,50	3,65	4,55	2,95	3,73	7,40	2,32	51,1%	
Chloride (mg/l Cl)	22	166,68	848,00	297,41	361,72	196,16	285,85	595,80	182,79	50,5%	
Sulphate (mg/l SO <sub>4</sub> )	22	15,00	324,00	55,42	108,30	20,77	104,25	227,77	79,11	73,0%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	21	132,00	765,00	197,10	236,35	148,80	180,70	332,10	140,76	59,6%	
Nitrate (mg/l N)	22	0,02	35,46	0,05	2,84	0,02	0,25	7,65	7,72	271,9%	
Fluoride (mg/l F)	22	0,40	17,25	1,20	5,37	0,57	1,63	14,73	6,46	120,2%	
Silicon as Si	13	5,36	42,88	10,10	15,53	7,31	8,89	36,68	13,02	83,8%	
Iron (Fe)	11	0,006	0,080	0,011	0,020	0,010	0,010	0,050	0,02	119,2%	
Manganese (Mn)	11	0,002	0,620	0,010	0,090	0,010	0,020	0,190	0,18	203,5%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	13	0,003	0,800	0,011	0,073	0,010	0,013	0,019	0,22	297,2%	
ZAR	22	3,34	29,52	9,69	15,38	5,53	13,18	28,30	9,53	62,0%	
LSI	21	Langelier Saturation Index (LSI)			Slightly Scaling		19,0%		Highly Scaling		0,0%
		Highly corrosive			0,0%		Slightly corrosive		9,5%		Balanced Corrosion

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 90<sup>th</sup> 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 for good (33.3%) and marginal in 66.7% of the samples; the values range between 1.5 and 324mS/m.

The Total Dissolved Solids (TDS) is acceptable in 72.7% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 24 samples show elevated concentrations of Fluoride (F >1.5mg/l) in 59.1%; Sodium (Na > 400mg/l) in 22.7%; Chloride (Cl > 600mg/l) in 9.1% Nitrate (N >10mg/l) in 4.5% and Magnesium (Mg > 200mg/l) in 4.5% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive (9.5%), slightly scaling (19%) and predominantly balanced (71.4%). The ZAR index indicates that none of the sampled water sources is of a fair quality for irrigation (ZAR < 3); it ranges from 3.34% to 29.52%.

The water is abstracted for livestock, game watering and domestic purposes for lodges and farm steads. Although some old irrigation fields that occur within the unit do not seem to be active, some are planted with grass for animal feeds, (Google Earth imagery).

In 59.1% 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, and the cation of concern is Sodium that exceeds the maximum allowable limit for human consumption in 22.7% of the analysis.

### 7.2.1.11 CLEREMONT FORMATION (Mcl)

Within the map area the Cleremont Formation outcrop in three localities, all of these are in the south-eastern section of the map sheet where it overlies the Mogalakwena Formation. Both formations form part of the Kransberg Subgroup of the Waterberg Supergroup.

The Cleremont Formation comprises of sandstone with minor shale and forms a thin cover on the Mogalakwena Formation. It reaches a maximum thickness within the map area of 60m, (Weinert, 1955 & Neetling, 1956).

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).

The section of the unit within the Lephalale map sheet covers approximately 1.1% of the total map area, (Figure 40). The unit extent east into Polokwane and south-west into the Thabazimbi map sheet and south-easterly into the Modimolle map sheet area. The combined larger outcrop when mapped appears to form a ring around the Vaalwater Formation, (see inset map Figure 40).

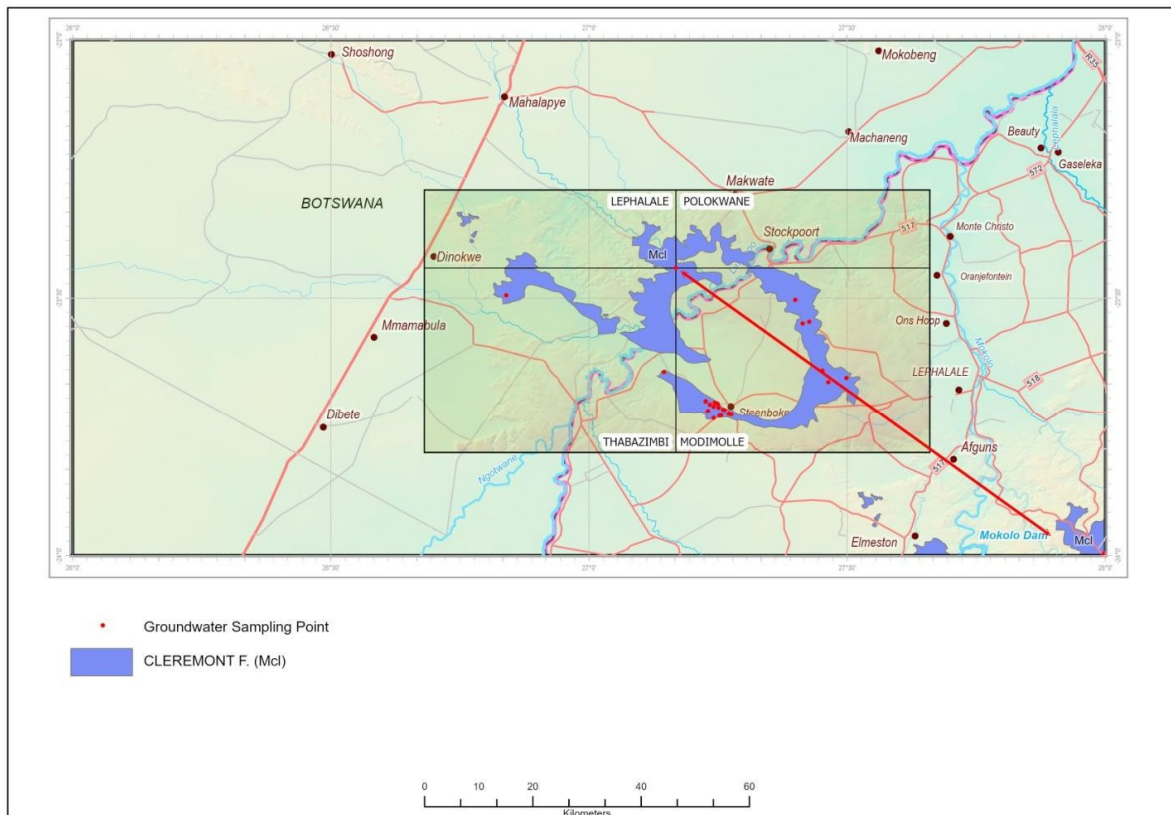


Figure 40: Geographical distribution of the Cleremont Formation (Mcl) and the associated groundwater sampling points

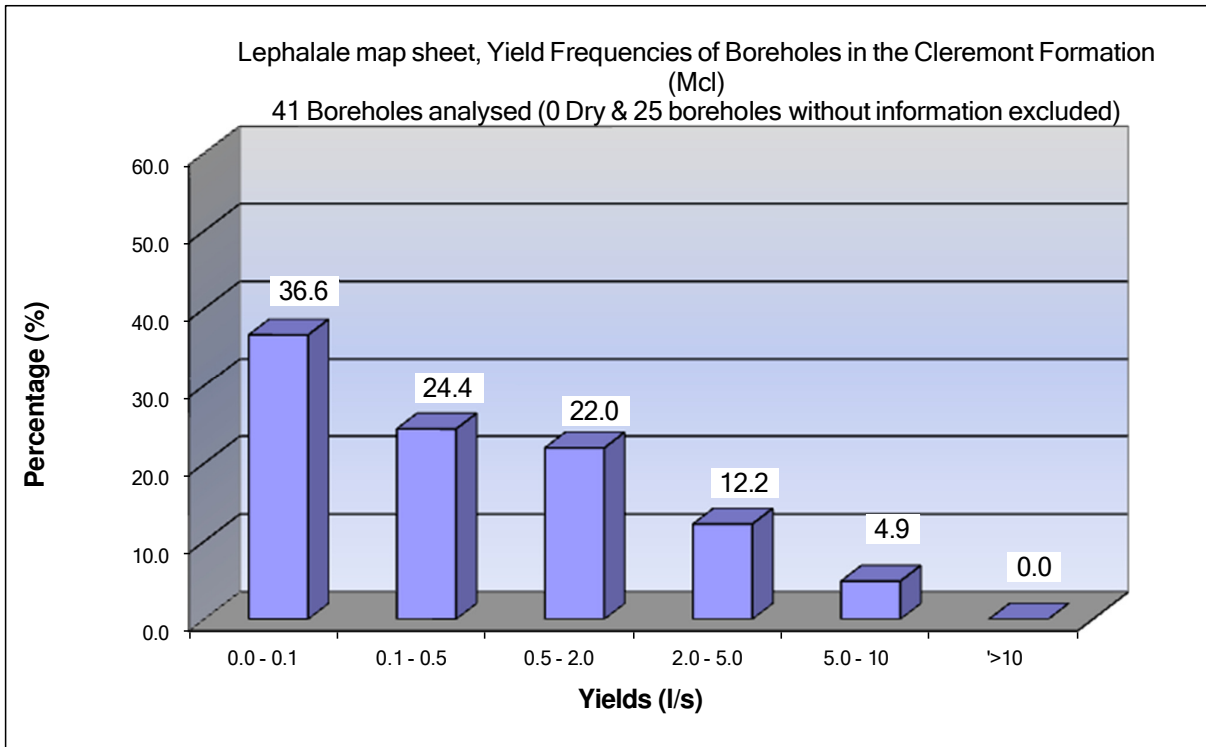


Figure 41: Yield frequency for fractured aquifers of the Cleremont Formation (Mcl), Lephalale map sheet data set.

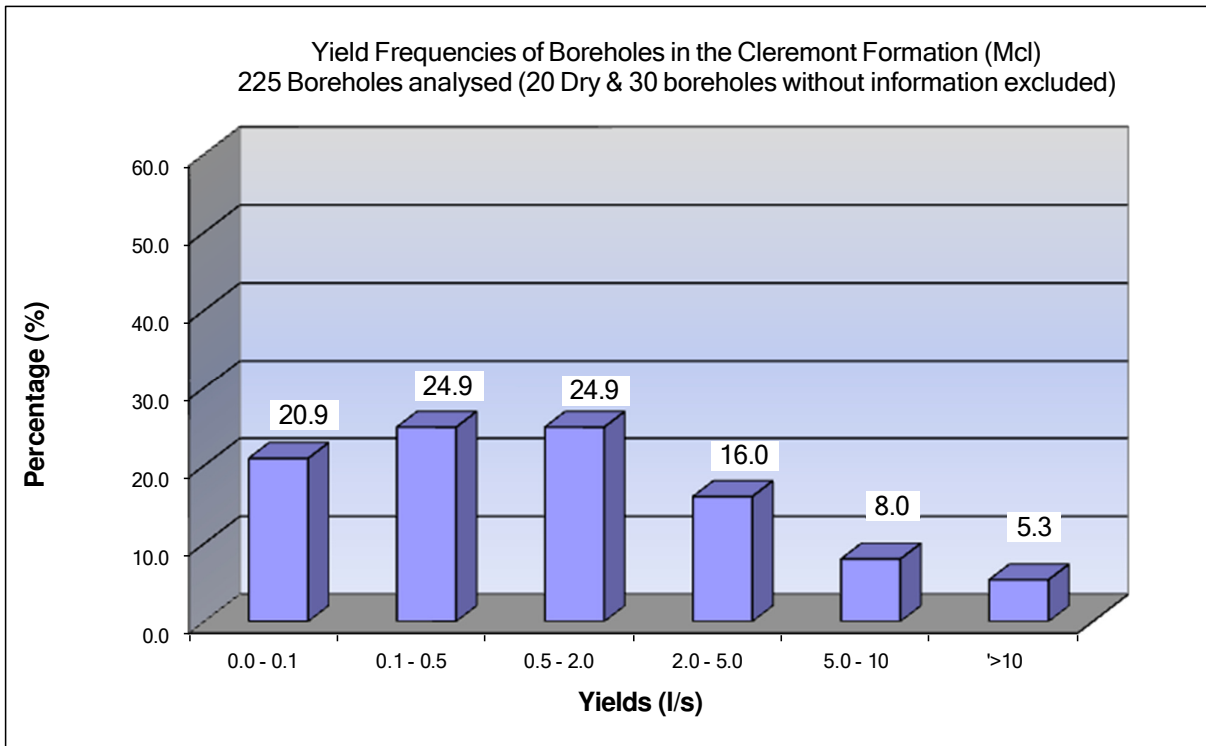


Figure 42: Yield frequency for fractured aquifers of the Cleremont Formation (Mcl), cross boundary data set.

The groundwater resource unit occurs at the intersection of four map boundaries: Modimolle, Lephallale, Polokwane, and Thabazimbi. For the yield frequency compilation of the cross boundary, 275 data points were available, of which 136 fall on the Modimolle map sheet, 41 on the Lephallale map sheet, 2 on the Polokwane map sheet, and 47 on the Thabazimbi map sheet. Only 225 data points have recorded water strikes, 20 were dry, and 30 had no information regarding yield.

For the cross boundary, the analysis of 225 borehole records indicates that 45.8% of the maximum yields are suitable for small households (>0.001l/s to 0.5l/s). A further 24.9% of the boreholes yield between 0.5l/s and 2l/s and 16% of the boreholes yield between 2l/s and 5l/s. In addition, 13.3% of the boreholes are yielding more that 5l/s, (Figure 42).

In comparison the analysis of 41 borehole records located within the Lephallale map sheet indicates that 61% of the maximum yields are very low ( $\leq 0.1$ l/s) to maximum yields that are suitable for small households (>0.1l/s to 0.5l/s). A further 22% of the boreholes have yields between 0.5l/s and 2l/s and another 17% have yields exceeding 2l/s, (Figure 41).

For the boreholes located within the Lephallale map sheet, the static water level ranges from 6 meters below ground level (mbgl) to 67mbgl, with a median of 20mbgl and an average static water level of 25.77mbgl, (based on 33 data points excluding 2 with water levels that exceed 148mbgl). No information is available on borehole depths; water strikes or pump testing data. The two boreholes with water levels exceeding 148mbgl were considered to represent pump drawdown levels.

Similar in characteristics to the Mogalakwena Formation, groundwater occurs mainly in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. No information is available to determine if the underlying contact with the Mogalakwena Formation will result in water strikes.

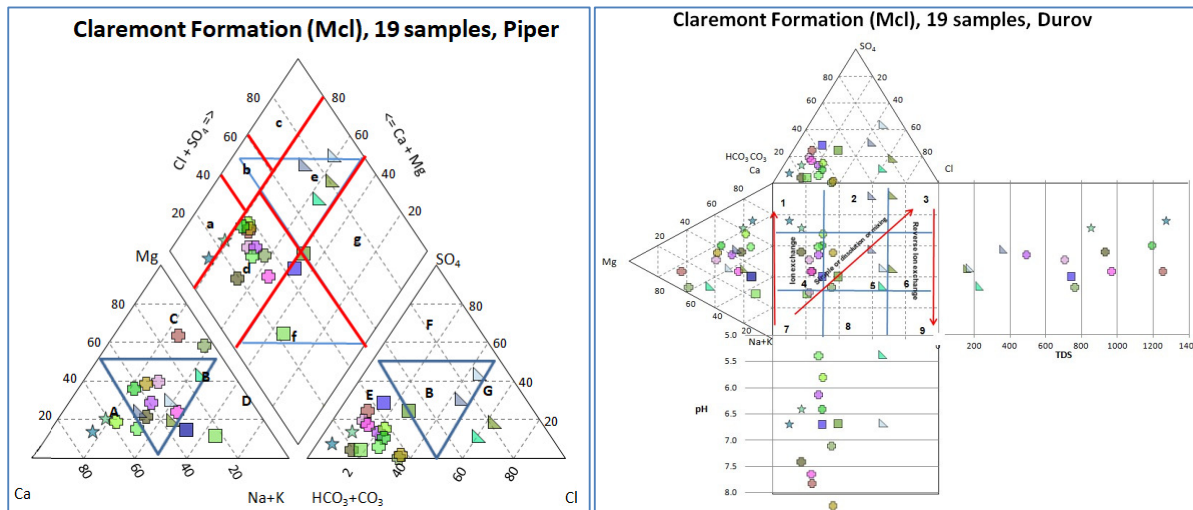


Figure 43: Trilinear diagrams, Piper and Durov for the Claremont Formation (Mcl).

The groundwater resource unit occurs on the boundaries of four adjacent map sheets namely Modimolle, Lephallale, Thabazimbi and Polokwane. For the chemical data 28 data points falls on the Modimolle map sheet: 2 on the Lephallale 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 43) 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 (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<sub>3</sub> and Ca dominant, indication of recharge in sandstone (14.3%),
- HCO<sub>3</sub> 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<sub>3</sub> 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	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> 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 <sub>4</sub> )	29	0.09	19.87	1.52	5.69	1.47	4.00	12.63	4.99	87.7%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	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 PO <sub>4</sub>	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

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 lodges. No evidence of large-scale irrigation could be found. A large section of the unit has minimal soil cover.

#### **7.2.1.12 KRANSBERG SUBGROUP (Mkr)**

The Waterberg Group has been sub-divided into three sub-groups, namely, Nylstroom, Matlabas and Kransberg. Within the adjacent hydrogeological map sheets, the unit includes the undifferentiated Sandriviersberg and Mogalakwena Formations. Within this map sheet and the adjacent Polokwane map sheet, the Kransberg Subgroup is represented by the Mogalakwena Formation. It outcrops within the south-eastern section of the map sheet, (Figure 44). It covers approximately 32.8% of the map sheet and is thus the largest unit within the Lephalale map.

The Mogalakwena Formation comprise mostly of coarse-grained sandstone, grit, and conglomerate. Due to the resistance of the rocks to weathering, the unit is characterized by rugged, mountainous terrain with steep narrow valleys, (Brandl 1996). These valleys are in many instances related to intrusive diabase dykes. It forms the Waterberg Plateau

The Cleremont and Mogalakwena Formations constitute the Waterberg plateau in the south- eastern part of the map sheet; the elevation is between 1200 meters above mean sea level (mamsl) and 1600mamsl and the MAP is between 600 millimeters per annum (mm/annum) to 800 mm/annum. The plateau area contributes predominantly to the flow of the major tributaries of the Limpopo River that arise within the plateau. The reason is that the resistive nature of the rock resulted in limited soil cover and the preservation of the plateau. These factors contribute that more outflows occur after rainfall events from the mountains.

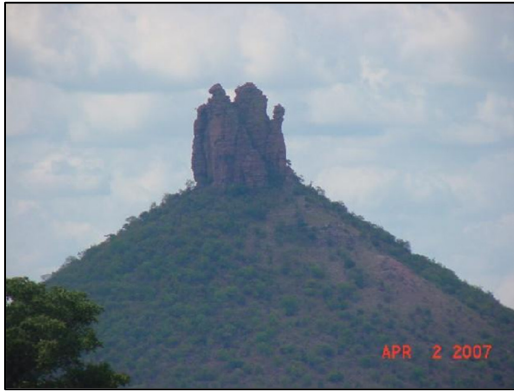
The unit extent eastwards into the adjacent 1:250 000 Polokwane map sheet boundary as well as to the south into the Thabazimbi map boundary. In a south-eastern direction the unit extent into the Modimolle map sheet. Although data is available within all map sheets the data was not combined for the characterization of the unit within the Lephalale map sheet, (see inset map Figure 44).

Statistics on the maximum yields of boreholes within the map sheet indicates that 82.6% of the boreholes yield less than 2l/s. The findings correlate with the 78.1% of the boreholes with yields less than 2l/s within the Polokwane map sheet and the 77.7% from the Thabazimbi and Modimolle map sheets.

In 31.3% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit the anion of concern is Fluoride. Within the Polokwane map sheet, elevated Fluoride concentrations that exceed the maximum allowable limit is only found in 5.1% of the samples while Nitrate concentrations exceed the maximum allowable limit in 22.2% of the analysis.



*Plate 2: 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)*



*Plate 3 & Plate 4: 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 5: Bushman paintings engraved in sandstone of the Mogalakwena Formation on the farm Waterval 601 LQ south of Lephale (Ellisras) (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 83.6% of the yields <math><2\text{l/s}</math>, (Figure 45).

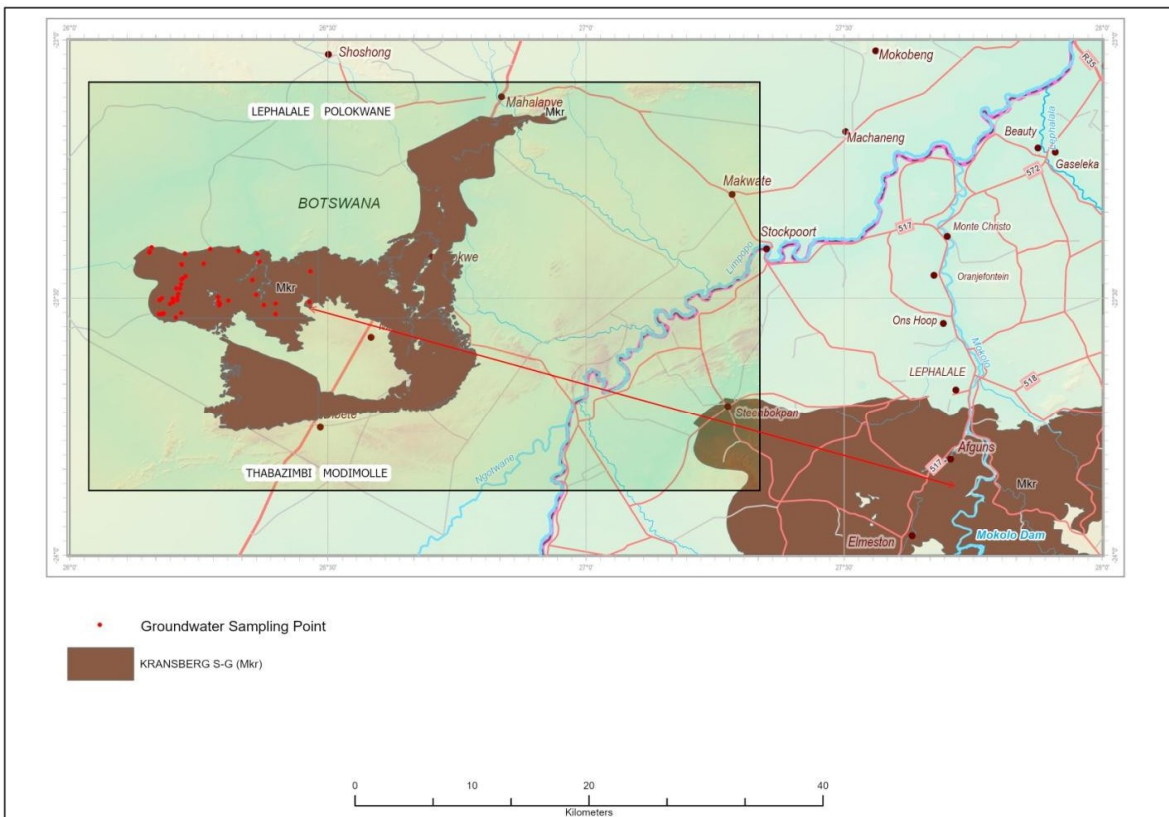


Figure 44: Geographical distribution of the Kransberg Subgroup (Mkr)

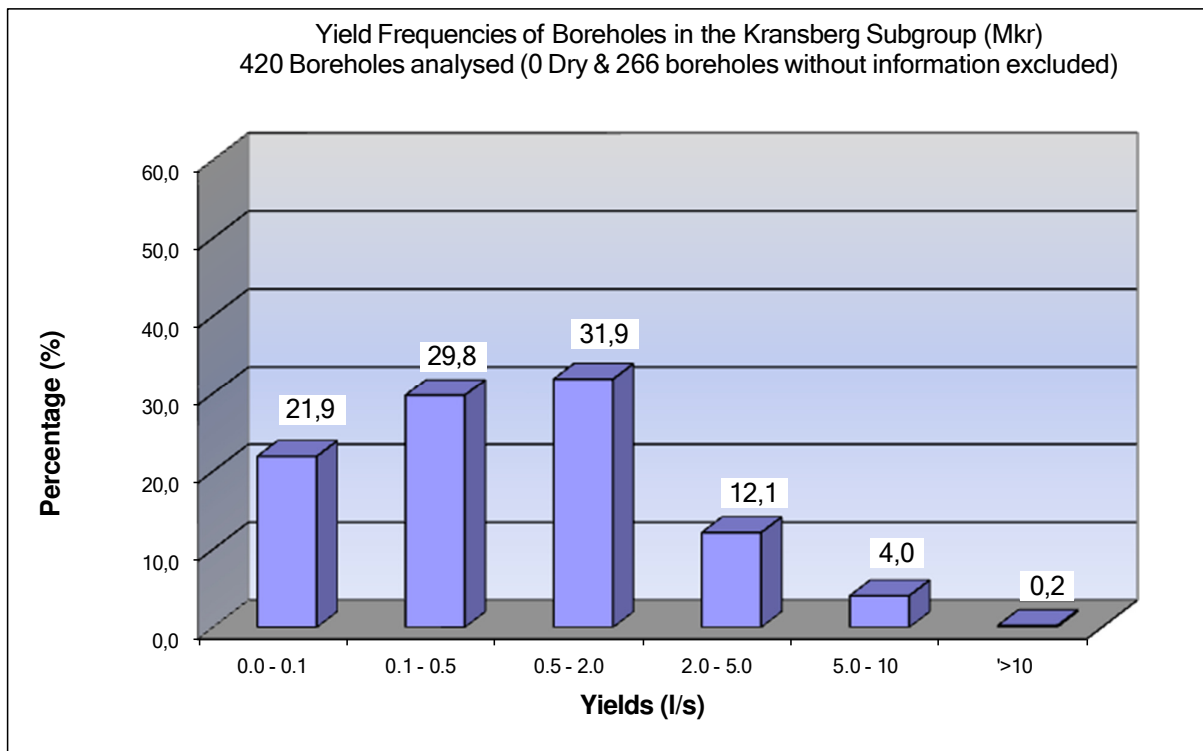


Figure 45: Yield frequency for fractured aquifers of the Kransberg Subgroup (Mkr).

The analysis of 420 borehole records indicates that 31.9% of the maximum yields are between 0.5ℓ/s and 2ℓ/s, with 51.7% of the boreholes yielding less than 0.5ℓ/s and 16.3% yielding more than 2ℓ/s, (Figure 45).

The static water level ranges from 1.22 meters below ground level (mbgl) to 76.2mbgl, with a median static water level of 25.46mbgl. The 90<sup>th</sup> percentile is 54.9mbgl and the average static water level is 28.36mbgl, (based on 121 data points). The maximum depth recorded is 308m, with an average depth of 186m and a median depth of 198m (7 data points). The data available on pump testing data is not sufficient to evaluate available daily abstraction volumes as only four boreholes were subjected to pump testing.

Only three boreholes listed under the Swartrant Formation (Psr) have yields exceeding 10ℓ/s. A report indicates that these boreholes were drilled targeting the Eenzaamheid fault zone in areas where Waterberg Sandstone forms the foot wall section along the fault zone. The water strikes depths of these boreholes were between 120m to 270m and within the Waterberg sandstones.

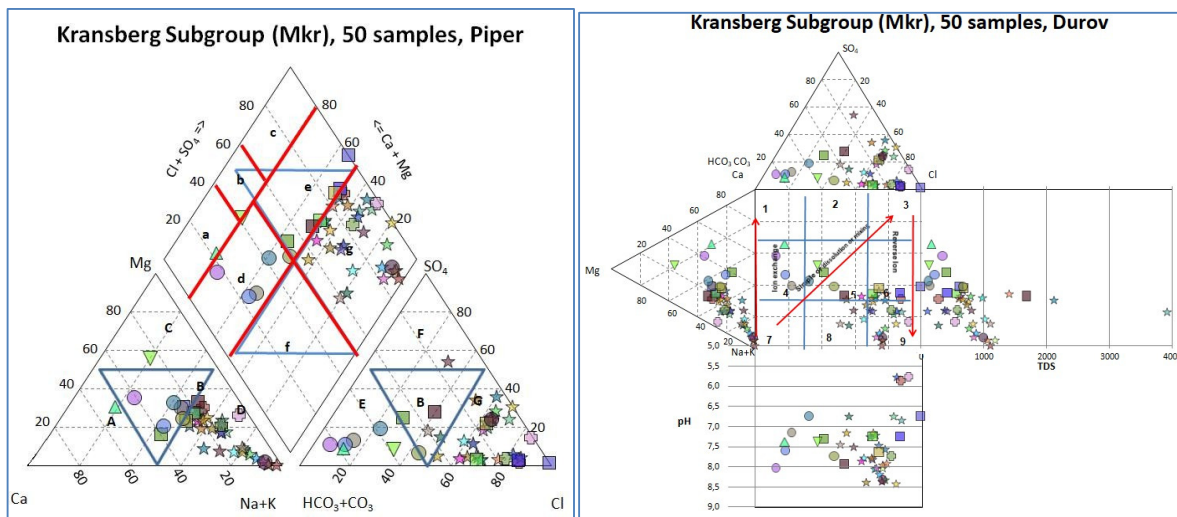


Figure 46: Trilinear diagrams, Piper, and Durov for the Kransberg Subgroup (Mkr).

The trilinear Piper diagram, (Figure 46) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (42%), Weak acidic anions > Strong acidic anions (21%); Alkali > Alkali earths (58%); Strong acids > Weak acids (79%).

The second evaluation was on the water type; the findings are as follows:

- Sodium-Chloride type (58%),
- Mixed Calcium-Magnesium-Bicarbonate type with prevailing Sodium (18%),
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (10%),
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with prevailing Sodium (4%),
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with prevailing Sodium and Sulphate (4%),
- Calcium-Bicarbonate type (2%),
- Magnesium-Bicarbonate type (2%),
- Sodium-Chloride type with prevailing Sulphate (2%).

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

- Cl and Na dominate; frequently indicate endpoint down gradient waters through dissolution (40%),

- Anion discriminant and Na dominate indicative of possible mixing or uncommon dissolution influences (26%),
- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (14%), plot along the dissolution or mixing line,
- Cl dominant anion and Na dominant cation, indicative of reverse ion exchange of Na-Cl waters (12%),
- SO<sub>4</sub> dominates, frequently indicates gypsiferous deposits or mixed water or water exhibiting simple dissolution (6%),
- HCO<sub>3</sub> and Ca dominant indicative of recharge in sandstone (2%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 36: Chemical statistics for the Kransberg Subgroup (Mkr)

Element / Parameter	Statistics Drawn from a population of 67 data points for the Kransberg Subgroup (Mkr).										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	66	5,70	8,40	7,29	7,35	6,55	7,40	8,16	0,67	9,2%	
Electrical Conductivity (mS/m EC)	67	1,30	1112,20	20,97	130,31	12,22	93,40	213,57	173,29	133,0%	
Total Dissolved Salts (mg/l TDS)	62	33,92	4542,00	274,25	766,53	104,50	632,24	1387,30	800,84	104,5%	
Calcium (mg/l Ca)	65	2,00	1080,00	13,31	53,68	6,10	20,31	88,34	136,86	255,0%	
Magnesium (mg/l Mg)	65	0,50	191,00	4,90	26,76	2,11	14,00	64,49	38,27	143,0%	
Sodium (mg/l Na)	65	1,00	931,00	21,14	161,83	7,68	111,00	357,42	175,11	108,2%	
Potassium (mg/l K)	62	0,25	61,00	3,29	11,18	1,78	6,56	38,70	14,95	133,7%	
Chloride (mg/l Cl)	65	1,55	37630,00	23,16	799,43	6,48	150,43	430,61	4651,21	581,8%	
Sulphate (mg/l SO <sub>4</sub> )	65	2,00	1920,00	10,40	92,66	4,44	19,00	167,91	246,84	266,4%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	59	5,00	608,00	52,16	170,98	21,38	132,00	370,40	150,43	88,0%	
Nitrate (mg/l N)	64	0,02	55,60	0,12	4,71	0,02	0,78	11,27	10,10	214,7%	
Fluoride (mg/l F)	64	0,05	12,70	0,32	2,52	0,19	0,61	8,39	3,59	142,2%	
Silicon as Si	46	0,40	113,00	7,58	27,00	6,30	18,01	73,50	27,17	100,6%	
Iron (Fe)	40	0,003	90,000	0,016	4,994	0,005	0,054	6,79	16,33	326,9%	
Manganese (Mn)	42	0,000	74,000	0,004	1,864	0,003	0,026	0,35	11,40	611,6%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	32	0,006	0,800	0,019	0,172	0,008	0,018	0,80	0,31	178,5%	
ZAR	65	0,12	35,26	1,47	5,69	0,57	3,55	12,38	6,74	118,5%	
LSI	56	Langelier Saturation Index (LSI)			Slightly Scaling		10,7%		Highly Scaling		0,0%
		Highly corrosive		21,4%	Slightly corrosive		21,4%	Balanced Corrosion		46,4%	

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 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication of the scale of the problem.

The overall water quality is ideal to good (73.1%), marginal in (22.4%) and unacceptable in (4.5%) in terms of the Electrical conductivity (EC) with values between 1.3 and 1112.2mS/m. The Total Dissolved Solids (TDS) is acceptable in 87.1% of the samples, (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions from 67 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 31.3%; Nitrate (N >10mg/l) in 7.8%; Sodium (Na > 400mg/l) in 7.7%; Chloride (Cl > 600mg/l) in 7.7%; Calcium (Ca > 300) in 1.5% and Sulphate (SO<sub>4</sub> >600mg/l) in 1.5% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is corrosive (42.8%); slightly scaling (10.7%) but predominantly balanced (46.4%). The ZAR index indicates that 36.9% of the water is of a fair quality for irrigation (ZAR < 3).

The water abstracted supply people in rural farmsteads and lodges; the water is also abstracted for livestock and game watering. As a large section of the unit in the south to south-east is mountainous, the area is used for nature conservation; minimal irrigation occurs along the Mokolo

River near Lephalale is within the river section underlain by this unit. The water for the irrigation in this area is obtained from the river and associated alluvium.

### 7.2.1.13 AASVOËLKOP FORMATION (Mas)

The Waterberg Group has been sub-divided into three sub-groups, namely, Nylstroom, Matlabas and Kransberg. The Aasvoëlkop Formation is the top layer of the Matlabas Subgroup and occurs within the centre-southern part of the map sheet, (Figure 47). Outcrop is limited as the area is flat and extensively covered with sand and soil. It covers approximately 11.8% of the map area that makes it the second largest groundwater unit in the Lephalale map sheet.

It comprises a sedimentary sequence of alternating arenaceous (sand sized particles) and argillaceous (clay sized particles) units, which become coarser towards the top. The reported thickness for the unit is 500m to 600m, (Jansen, 1982).

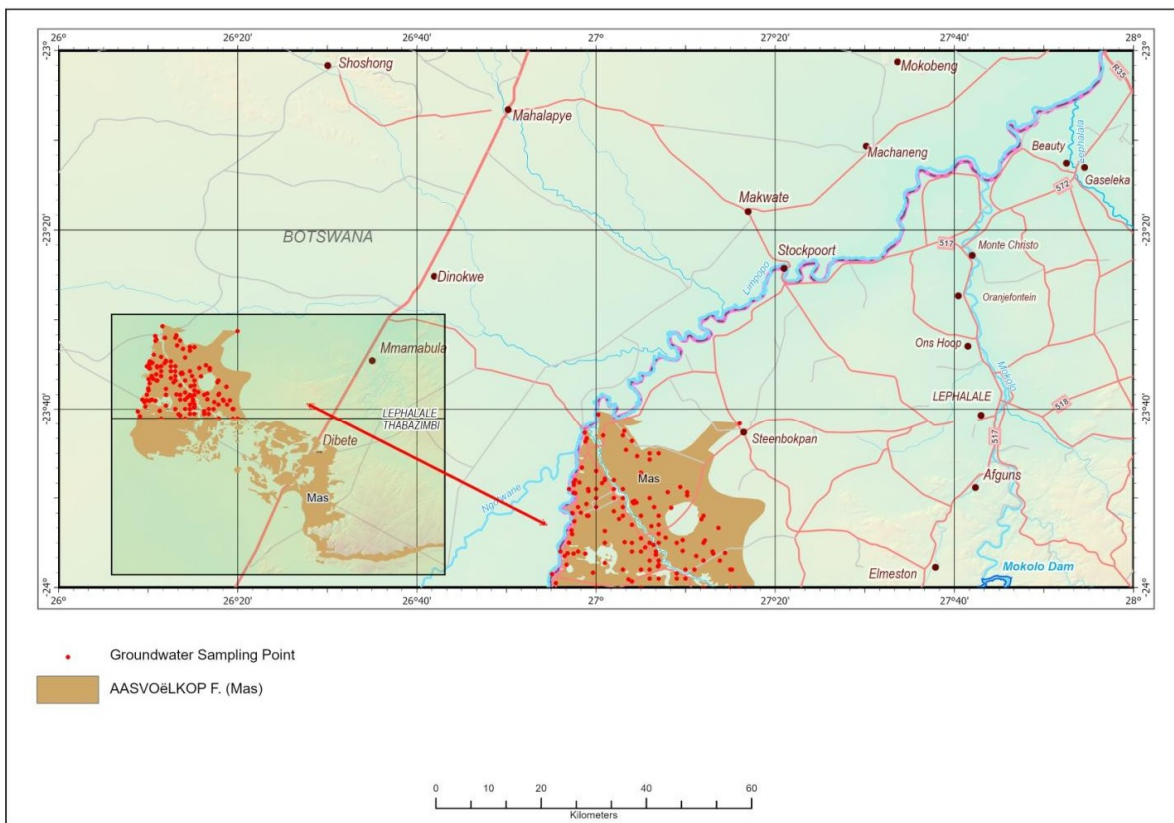


Figure 47: Geographical distribution of the Aasvoëlkop Formation (Mas) and the associated groundwater sampling points.

Several diabase sills and dykes are indicated on the geological map sheet. This will be the primary targets in the search for groundwater. Geophysical methods are recommended as the overburden will prevent the discovery of diabase rocks from observation. A correlation can be seen between the plot of the higher yielding (yield > 2l/s) boreholes and inferred lineaments depicted on the geological map sheet. Remote sensing interpretation of possible geological lineaments followed by a geophysical survey on an 11km<sup>2</sup> section of Wildebeesfontein 381LQ concluded that only two of ten interpreted lineaments were confirmed as diabase dykes. The rest of the interpreted lineaments did not show any variation using the magnetic (total field strength) and electromagnetic (conductivity), methods when transecting the expected location of these

lineaments. The difference between the response over the dykes and the average background readings, (anomaly) is only 60 nanotesla (nT). This corresponds to the findings of the aerial magnetic survey over the Ellisras Basin and immediate boundaries that included a small section of the Aasvoëlkop and Mogalakwena Formation. The findings were that the total magnetic field measurements did not identify lineaments over the Karoo rocks and rocks of the Aasvoëlkop Formation. Numerous subtle magnetic anomalies were only identified using the calculated phased magnetic response.

Regional remote sensing interpretation from the DWS GRIP project (Department of Water and Sanitation Groundwater Resource Information Project), Figure 7 indicates that lineaments (predominantly diabase dykes) within the Mogalakwena Formation of the Waterberg Supergroup are more numerous than within the Aasvoëlkop Formation. The remote sensing interpretation was hampered by extensive soil coverage over most of the map area especially over the Ellisras Basin and areas underlain by rocks of the Aasvoëlkop Formation; the Mogalakwena Formation however forms a plateau with less soil coverage.

More research work is needed to determine if dykes are as numerous in the Aasvoëlkop Formation as within the Mogalakwena Formation.

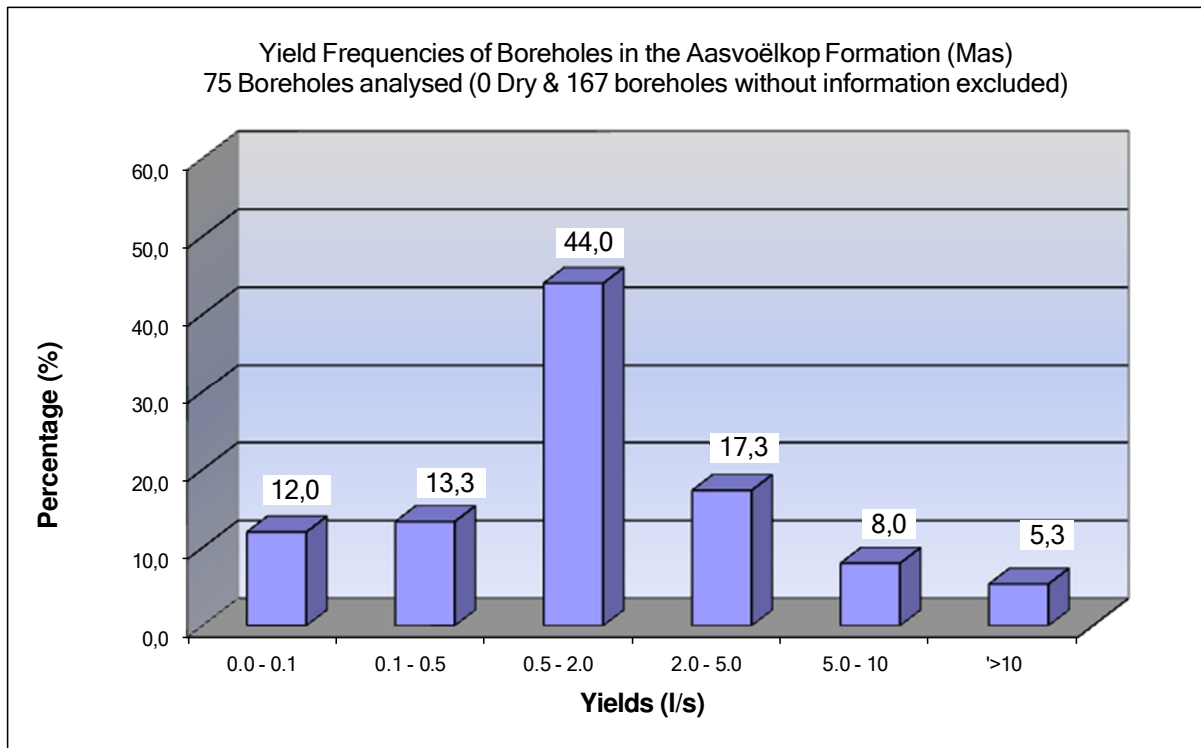


Figure 48: Yield frequency for fractured aquifers of the Aasvoëlkop Formation (Mas).

The yield frequency distribution indicates that 25.3% of the successful boreholes have a maximum yield less than 0.5l/s. Additionally 44% of the boreholes yield between 0.5l/s and 2l/s and 25.3% between 2l/s and 10l/s. Only 5.3% of the reported sources have maximum yields that exceed 10l/s, (Figure 48).

In comparison the boreholes located only within the Thabazimbi map sheet indicates that 74% of the boreholes yield less than 2l/s. The water chemistry shows that the anions Fluoride, Nitrate and Chloride exceed the maximum allowable concentration limits in 21.1%, 12.2% and 11.1% of the analyses respectively.

The static water level ranges from 2.5 meters below ground level (mbgl) to 60.96mbgl, with a median of 27mbgl. The 80<sup>th</sup> percentile of the static water level is 39.6mbgl and with an average of 27.76mbgl; (based on 45 data points). The maximum depth recorded is 206 meters (m), with an average depth of 127m and a median depth of 123m, (8 data points). No data was available on water strike depths, pump testing data and information on available abstraction volumes. The adjacent 1: 250 000 Thabazimbi map sheet can be consulted for more information on this unit.

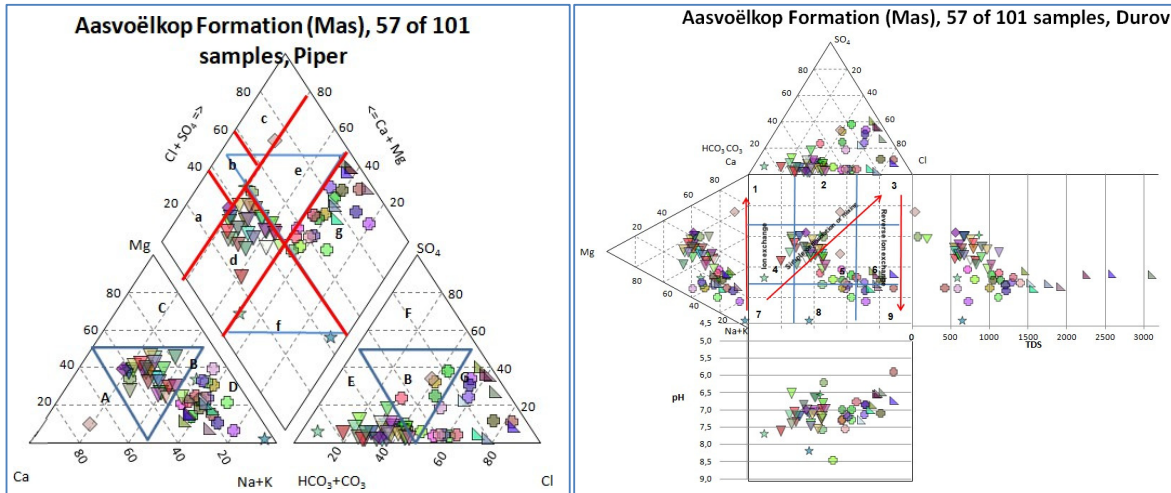


Figure 49: Trilinear diagrams, Piper and Durov for the Aasvoëlkop Formation (Mas) first plot of 57 data points.

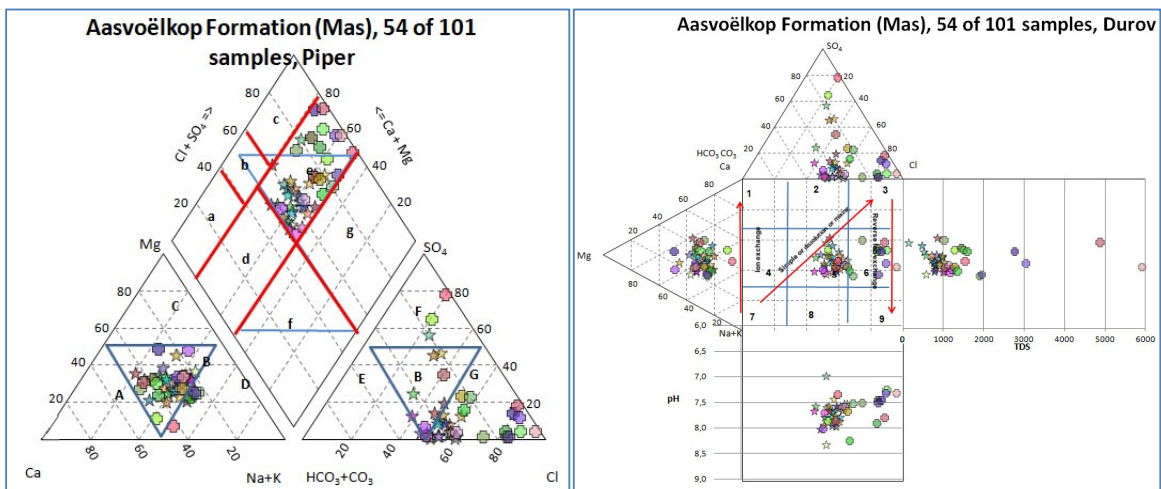


Figure 50: Trilinear diagrams, Piper, and Durov for the Aasvoëlkop Formation (Mas) second plot of 54 data points.

The trilinear Piper diagram, (Figure 49 and Figure 50) 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 (72.3%), Weak acidic anions > Strong acidic anions (29.2%); Alkali > Alkali earths (27.7%); Strong acids > Weak acids (70.8%).

The second evaluation was on the water type; the findings are as follows:

- Sodium-Chloride type (41.9%),
- Mixed Calcium-Magnesium-Bicarbonate type with prevailing Sodium (31.6%),

- Calcium-Magnesium-Bicarbonate-Chloride type with prevailing Sodium and Sulphate (13.9%),
- Sodium-Chloride type with prevailing Sulphate (6.9%),
- Sodium-Sulphate type (2.8%),
- Sodium-Bicarbonate type (1.9%),
- Calcium-Bicarbonate type (1%).

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 (58.4%), plot along the dissolution or mixing line,
- Anion discriminates and Na dominant, indicates probable mixing or uncommon dissolution influences (17.8%),
- Cl is the dominant anion and Na the dominant cation, indicative that the groundwater is related to reverse ion exchange of Na-Cl waters (8.9%),
- Cl is the dominant anion and Na the dominant cation, indicative of endpoint down gradient waters through dissolution (7.9%),
- SO<sub>4</sub> dominates, or anion discriminant and Ca dominant, frequently indicates recharge in gypsiferous deposits, otherwise mixed water or water exhibiting simple dissolution (5.9%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 37: Chemical statistics for the Aasvoëlkop Formation (Mas).

Element / Parameter	Statistics Drawn from a population of 132 data points for the Aasvoëlkop Formation (Mas)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	131	4,55	8,60	7,53	7,56	7,28	7,61	7,89	0,42	5,5%	
Electrical Conductivity (mS/m EC)	132	3,30	3027,20	80,82	218,99	80,08	140,41	352,27	308,87	141,0%	
Total Dissolved Salts (mg/l TDS)	131	22,0	18930,0	543,1	1483,4	571,0	1001,0	2335,0	2250,1	151,7%	
Calcium (mg/l Ca)	131	1,40	1549,60	43,71	124,99	32,30	79,50	241,70	167,67	134,2%	
Magnesium (mg/l Mg)	131	0,50	1340,50	16,75	75,30	24,39	50,50	111,70	130,63	173,5%	
Sodium (mg/l Na)	131	1,00	3531,20	35,46	206,46	54,30	136,56	361,80	335,06	162,3%	
Potassium (mg/l K)	131	0,66	40,95	4,65	7,55	2,69	5,62	13,91	6,15	81,5%	
Chloride (mg/l Cl)	131	1,50	15344,10	56,48	531,63	53,10	147,90	857,10	1694,72	318,8%	
Sulphate (mg/l SO <sub>4</sub> )	131	2,00	1320,40	16,31	125,85	6,60	27,78	303,30	226,76	180,2%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	131	2,0	560,0	102,4	288,7	105,7	294,4	445,1	122,4	42,4%	
Nitrate (mg/l N)	131	0,02	142,47	0,66	9,75	0,38	5,28	23,97	16,25	166,5%	
Fluoride (mg/l F)	131	0,05	8,05	0,58	1,07	0,42	0,81	1,87	1,02	95,4%	
Silicon as Si	130	0,60	73,68	18,38	31,67	12,22	34,48	45,42	12,69	40,1%	
Iron (Fe)	0										
Manganese (Mn)	0										
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	131	0,00	0,11	0,01	0,02	0,01	0,02	0,03	0,01	79,4%	
ZAR	131	0,11	15,86	1,75	3,46	1,18	2,73	6,77	2,51	72,5%	
LSI	131	Langelier Saturation Index (LSI)			Slightly Scaling		42,7%		Highly Scaling		0,0%
		Highly corrosive			1,5%		Slightly corrosive		6,9%		Balanced Corrosion

Table 37 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 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good (53.8%), marginal (36.4%) and unacceptable in (9.8%) of the analysis in terms of the Electrical conductivity (EC) with values ranging between 3.3 and 3027.2mS/m.

The Total Dissolved Solids (TDS) is acceptable in 63.4% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 132 samples indicates elevated concentrations of Chloride (Cl > 600mg/l) in 16.8%; Fluoride (F > 1.5mg/l) in 16%; Nitrate (N > 10mg/l) in 11.5%; Sodium (Na > 400mg/l) in 7.6%; Calcium (Ca > 300) in 6.1%; Sulphate (SO<sub>4</sub> > 600mg/l) in 6.1% and Magnesium (Mg > 200mg/l) in 5.3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is corrosive (8.4%); slightly scaling (42.7%) and predominantly balanced (48.9%). The ZAR index indicates that 51.1% of the water is of a fair quality for irrigation (ZAR < 3).

The water abstracted supply people in farmsteads and lodges; the water is also abstracted for livestock and game watering. No evidence of large-scale irrigation occurs in the unit.

In 16.8% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit the anions of concern are Chloride with Fluoride exceeding the maximum allowable limit in 16% of the analysis.

### **7.2.2 CATEGORY C: KARST AQUIFERS**

The hydrogeological map series and accompanied brochures follow the same methodology for consistency. Although no dolomitic rocks occur within the Lephalale map sheet the category is still included on the main map sheet as it forms part of the standard legend for the 1:250 000 hydrogeological map series.

### **7.2.3 CATEGORY D: INTERGRANULAR AND FRACTURED AQUIFERS**

- Letaba Formation (Jle)
- Diabase (N-Za)
- Glenover Complex (Mgc)
- Palala granite (Mpa)
- Nebo Granite (Mn)
- Villa Nora Gabbro-Anorthosite (Vv)
- Messina Suite (Zms)
- Undifferentiated Beit Bridge Complex (Zbc)
- Undifferentiated Malala Drift Gneiss (Zma)
- Mount Dowe Group (Zmd)

Intergranular and fractured aquifers cover approximately 17.6% of the total map area. Figure 51 show the Geographical distribution of the intergranular and fractured aquifers.

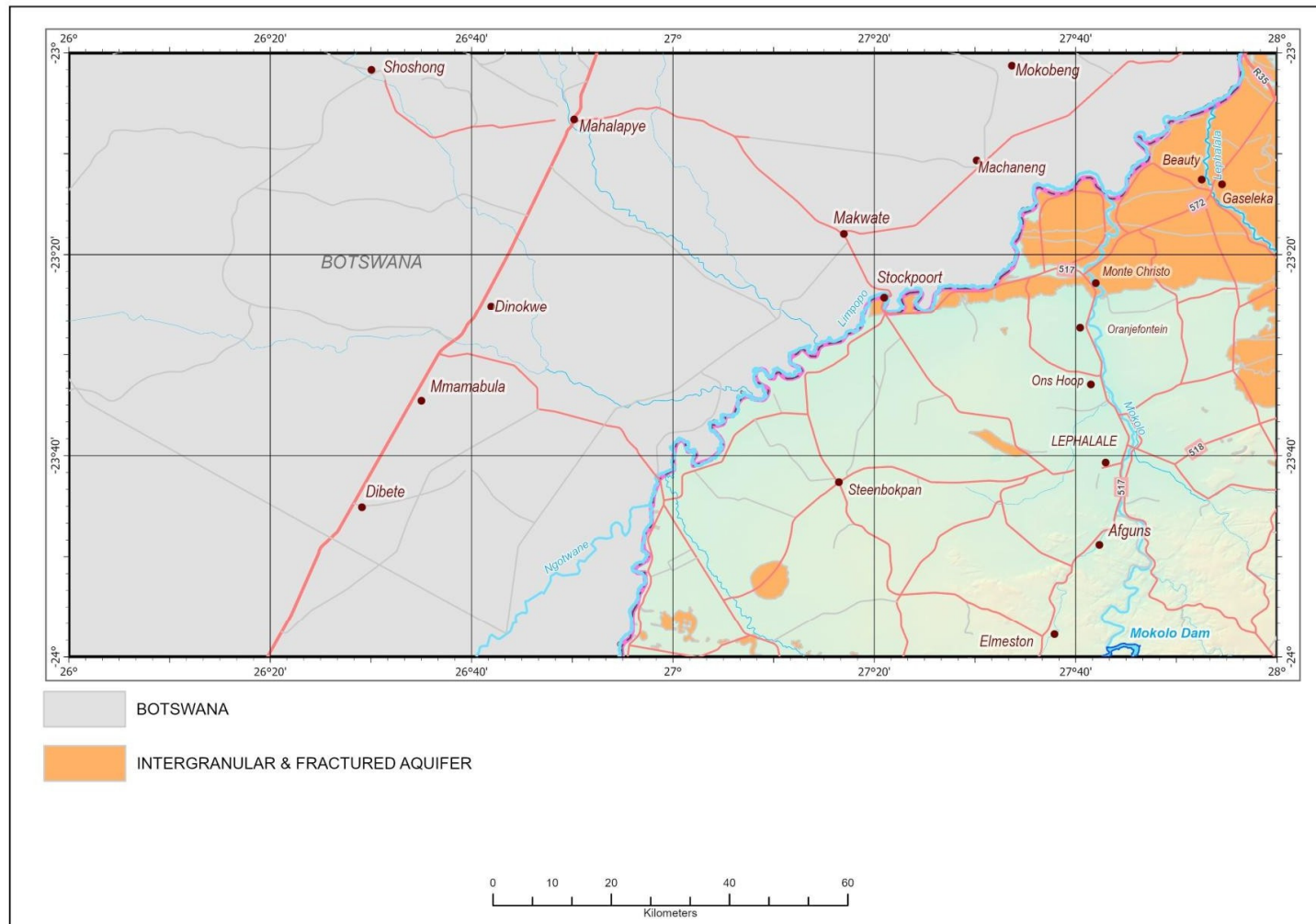


Figure 51: Geographical distribution of the intergranular and fractured aquifers

### 7.2.3.1 LETABA FORMATION (Jle)

The Letaba Formation, a name applied to all basaltic lava of Karoo age in the Limpopo province, occurs within the map area at two localities where it overlies the Clarens Formation, (Figure 52). The first occurrence is north-east of the Grootegeluk Mine; within a zone referred to as the Northern compartment in mine related literature. It occurs within a fault bounded lenticular wedge just north of the Daarby Fault. A maximum thickness for this occurrence is 125m as derived from borehole logs, (Brandl 1996). The second smaller outcrop falling within the boundaries of the map sheet is within the 'Centre-northern part of the Ellisras Basin', (Figure 52). The northern side of this outcrop is against the Zoetfontein Fault. The unit covers approximately 0.22% of the map area.

Of significance is the occurrence within the 'Northern compartment' near the Grootegeluk Coal Mine, where the basalt appears fractured and weathered between successive lava flows. The lower contact with the Clarens Sandstone is an erosion surface which resulted in the highest yields and transmissivity during exploration around the mine area, (Dames and Moore, 1984). This corresponds to findings in the Tuli Basin for this unit (Musina 1:500 000 hydrogeological map sheet).

For groundwater development where sandstone is overlain by basalt, the following targets can be considered within the unit namely, the upper basalt shallow weathered and fractured zone, the contact zone between the basalt and sandstone and possible fracturing within the Clarens sandstone. Drilling for water development is usually only terminated when the Clarens Sandstone Formation is fully penetrated. Findings reported in the 1:500 000 Musina hydrogeological map sheet 2127, is that the Electrical Conductivity values in the underlying sandstone are lower than in the basalt.

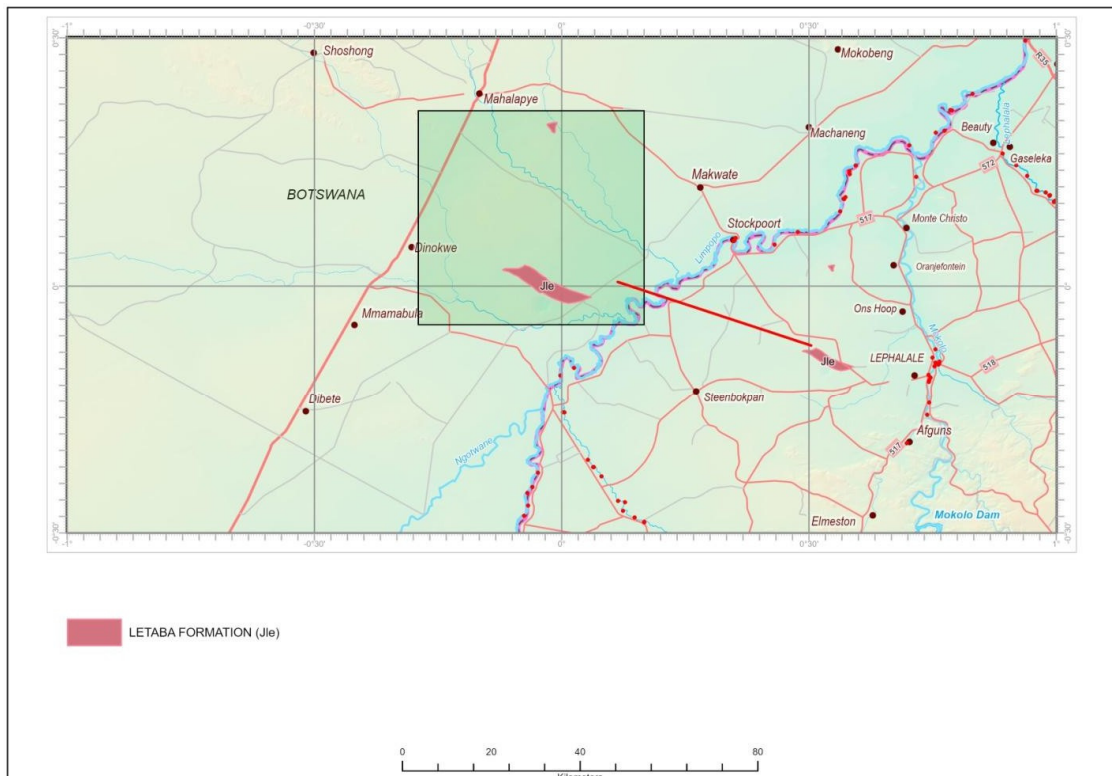


Figure 52: Geographical distribution for the intergranular and fractured aquifers of the Letaba Formation (Jle) and associated groundwater sampling points.

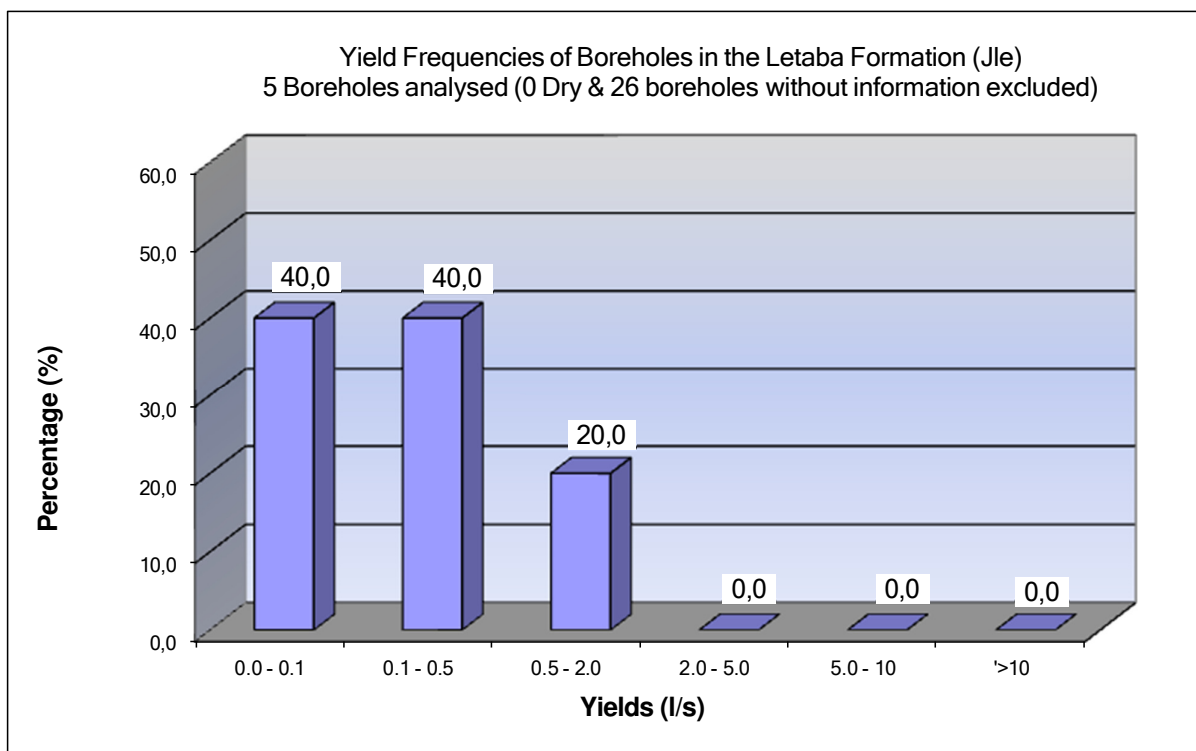


Figure 53: Yield frequency for the intergranular and fractured aquifers of the Letaba Formation (Jle).

Limited yield data was available for this unit, however from the statistics of 5 data points it indicates that 20% of the maximum yields are between 0.5l/s and 2l/s and 80% of the boreholes yield less than 0.5l/s, (Figure 53). The maximum yield distribution of the Letaba Formation in the adjacent Modimolle map sheet indicates that 42.4% of the boreholes yield between 2l/s and 10l/s and 20.2% of the boreholes yield more than 10l/s.

Although 31 data points are on record no borehole depths, water levels or pump testing data were available. There was also no chemical data available within the map sheet area to characterize the unit. Within the adjacent 1:250 000 hydrogeological map sheets; Modimolle and Polokwane, more information is available in regard to yield and chemistry.

### 7.2.3.2 DIABASE (N-Za)

This unit consists of diabase intrusions from Swazian age up to Namibian that includes sills and dykes that occur in all the pre-Karoo formations in the area.

Characterization of this unit was based only on boreholes located on diabase sills. It was not possible to reliably distinguish boreholes drilled on diabase dykes from those drilled into the surrounding host rocks. Therefore, boreholes on dykes were excluded from the characterization. The data used primarily comes from boreholes intersecting the major sills depicted on the geological map sheet, which were used to compile the Lephalele hydrogeological map.

Most sills depicted on the Lephalele map sheet occur in the south-western corner, within the Aasvoëlkop Formation, (Figure 54). Diabase intrusion in the form of sills underline approximately 0.61% of the map sheet area. For diabase occurring as dykes, the inset map,

(Figure 7, page 21) provides an overview of the distribution of lineaments across the map area. The lineaments shown are predominantly associated with diabase intrusions in the form of dykes.

Due to their abundance, sills and dykes is the most common target in the search for groundwater within the sedimentary rocks of the Waterberg Supergroup. For additional information refer to the sections covering the Kransberg Subgroup and the Aasvoëlkop Formation. The results when targeting diabase intrusions are however varied, but most of the time it will result in some water strikes. Sills are seen as difficult targets in the search for groundwater, the options when dealing with sills are as follows:

- Target either one or both contact zones (upper or lower). This option depends on the depth of the sill, if on the surface it will only be one contact (lower). The thickness of the sill must also be considered.
- When the sills occur near the surface, the first target is deeply weathered and fractured zones, followed by the lower contact zone. Deep weathered and fractured zones are structurally controlled by faults, joints, or younger dyke intrusions into the sill. Geophysical methods help detect these zones and determine the thickness of the sill
- Targeting the 'vertical' contact i.e. the edge of the sill. In such a case, the target zone will be similar as when dealing with a dyke.
- Sills are more likely to be found in the Waterberg and Soutpansberg Supergroups than in other pre-Karoo geological settings, where diabase dykes are more common. The term 'dolerite' is of similar composition but of post-Karoo age that intruded the Karoo Sedimentary rocks predominantly as dykes.
- The use of geophysical instruments and geological observations is highly recommended when searching for groundwater near diabase intrusions. Extensive soil coverage in the map area hampers visual discoveries, especially in the non-Waterberg Sediments.

When dealing with intrusive dykes, remote sensing techniques, areal magnetic surveys, and geophysical methods are highly recommended for groundwater exploration. In most cases, anomalies found in geophysical data will correspond to dykes. The magnetic method is particularly effective when searching for diabase dykes.

However, targeting dykes for groundwater exploration does not always result in successful water strikes. Several factors to be considered include:

- Type of host rock,
- Static water level,
- Lateral extent of the lineament,
- Regional stress directions,

Other rock types, such as amphibolite, syenite, and greenstone xenoliths, which are more common in the older gneissic areas, these may also produce anomalies during a magnetic survey.

Additional factors to consider when targeting diabase dykes include:

- Thickness/width of the dyke,
- Dip and strike of the dyke,
- Weathering characteristics, such as spherical weathering or 'blokkies klip' (blocky) fracturing.

Drilling positions in thin dykes (less than 7m) are positioned with the expectancy to find water within the dyke. With wider dykes (7m to 15m) the most successful zone is usually within 2m of the contact zone. When dealing with very wide dykes (> 40m) the contact zone may not be the best target. When dealing with these wide dykes the use of geophysical instruments may show weathered zones further from the dyke contact that can be targeted in the search for groundwater. Yields can differ on each side of the dyke as well as along the strike.

When using interpreted aerial magnetic data presented as maps showing 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, faults, or fracture zones transect the dyke (displacement).

In the Swazian rocks, dykes often give rise to ridges but in the sedimentary rocks they usually form negative topographic features characterized by dense vegetation. Within the Waterberg Supergroup 'U-shape valleys' often indicates the presence of diabase dykes especially in the plateau area (southeastern corner of the map sheet). 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 7, page 21), 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).

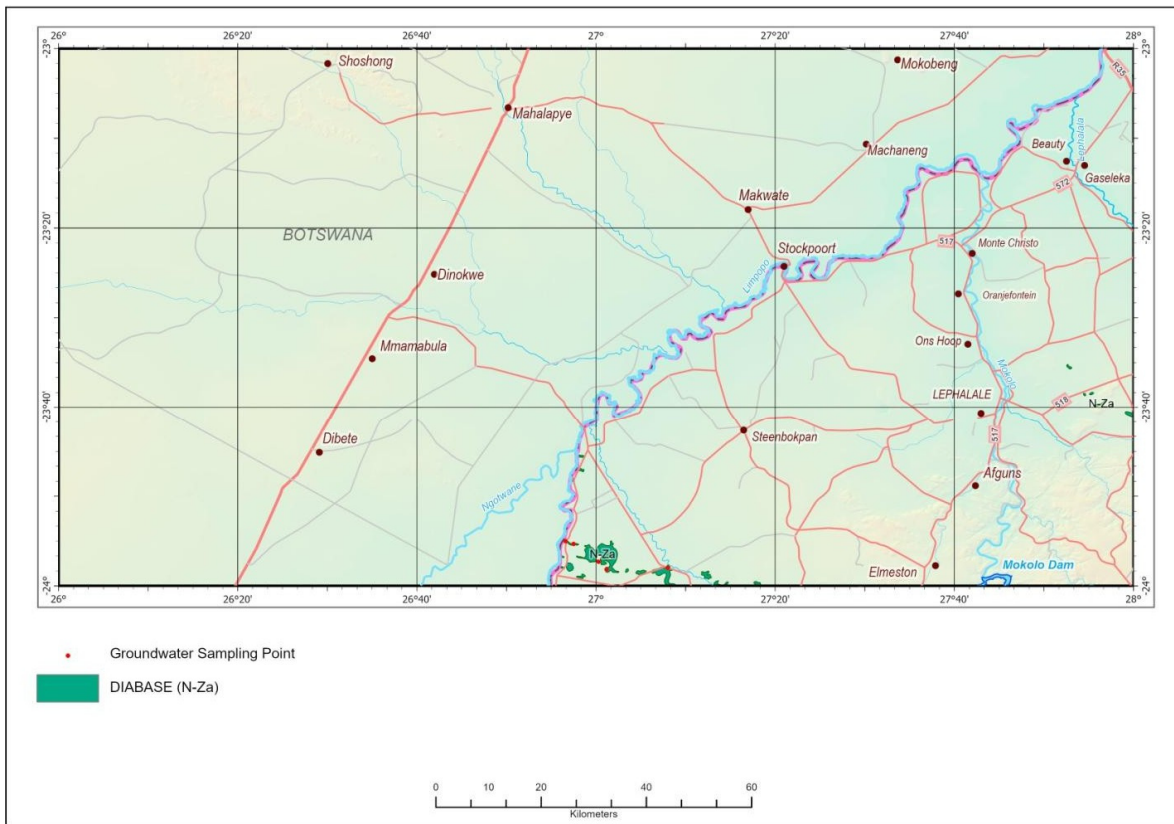


Figure 54: Geographical distribution of the Diabase intrusions (N-Za) and the associated groundwater sampling points.

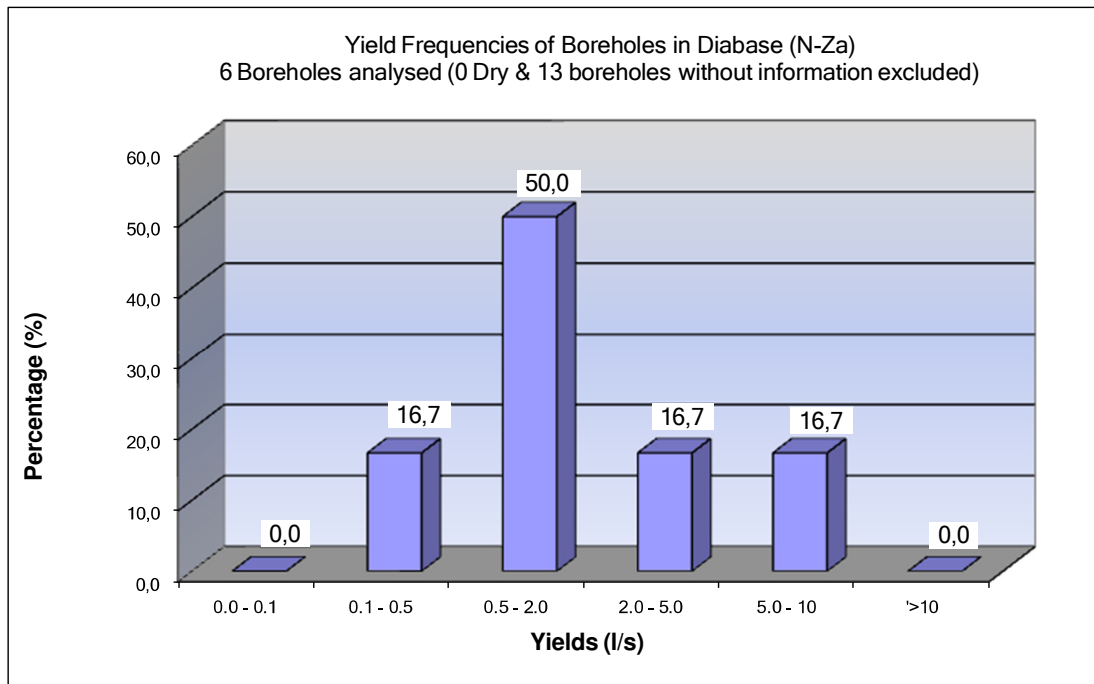


Figure 55: Yield frequency for the intergranular and fractured aquifers of the Diabase intrusions (N- Za).

For this unit, (Figure 55) represents the maximum yields of boreholes drilled into the diabase sill intrusions. Figure 54 show the positions of these sills. Boreholes drilled to target the numerous dyke intrusions are not included in the analysis due to the scale limitations of the map sheet. The data indicate that 66.7% of the successful boreholes have maximum yields of less than 2l/s, with 50% falling within the 0.5l/s to 2l/s range. A total of 33.3% of the boreholes yield more than 5l/s.

In comparison, statistics for diabase sills within the adjacent Thabazimbi map, where 117 borehole resources with yield data are recorded, show that 31.6% of the successful boreholes yield less than 0.5l/s. A further 35% of the boreholes yield between 0.5l/s and 2l/s, while 24.8% yield between 2l/s and 5l/s. Only 8.6% of the boreholes yield more than 5 l/s.

The static water level ranges from 5.6 meters below ground level (mbgl) to 42.1mbgl, with a median of 12.4mbgl and an average static water level of 14.76mbgl. No records are available on drilling depths, water strike depths or pump testing data. An exploration borehole P 188 (Renosterpan 361LQ) was drilled to a depth of 1415m in the Waterberg rocks; six sills were encountered ranging in thickness between 0.3m to 120m with a combined thickness of 162m, (Tickell, 1974).

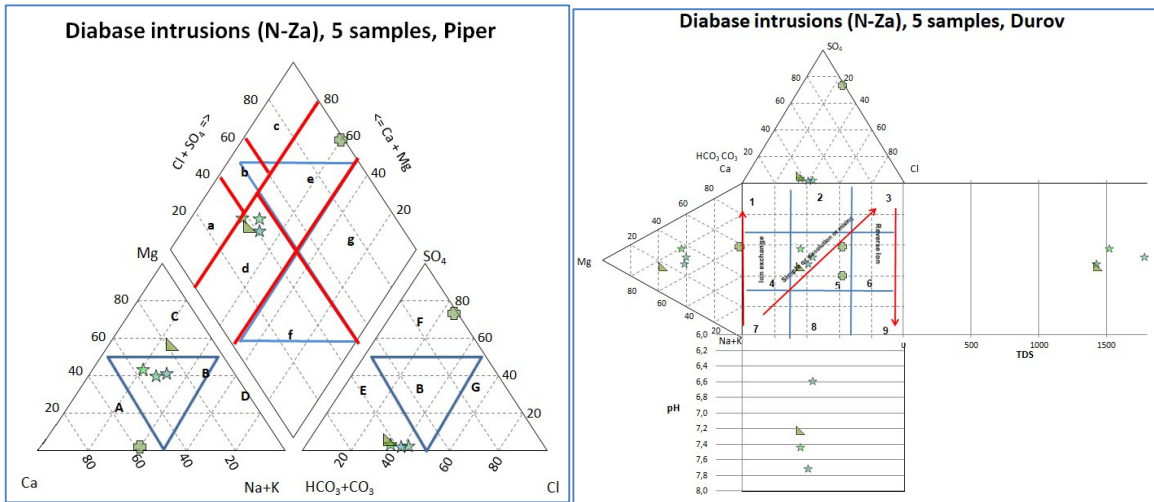


Figure 56: Trilinear diagrams, Piper, and Durov for Diabase (N-Za).

The trilinear Piper diagram, (Figure 56) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (80%); Alkali > Alkali earths (0%); Strong acids > Weak acids (20%).

The second evaluation was on the water type and the findings are as follows:

- Mixed Calcium-Magnesium-Bicarbonate type (60%),
- Magnesium-Bicarbonate type (20%),
- Calcium-Sulphate type (20%).

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

- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (100%), plotting along the dissolution or mixing line,
- The samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

The reason for higher-than-average Sulphate concentration in one of the analyses is unknown as the EN and EC plausibility for this analysis is within acceptable limits.

Table 38: Chemical statistics for the Diabase intrusions (N-Za)

Element / Parameter	Statistics Drawn from a population of 5 data points for Diabase (N-Za)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	5	6,60	7,85	7,38	7,41	6,87	7,60	7,79	0,50	6,7%	
Electrical Conductivity (mS/m EC)	5	119,60	242,20	141,50	151,68	120,56	127,00	204,36	51,79	34,1%	
Total Dissolved Salts (mg/l TDS)	5	871,00	1651,00	1023,09	1083,60	873,80	930,00	1425,80	329,02	30,4%	
Calcium (mg/l Ca)	5	45,80	291,60	84,11	121,60	55,72	96,90	216,20	97,72	80,4%	
Magnesium (mg/l Mg)	5	6,10	88,80	22,98	61,72	29,54	71,30	84,36	32,34	52,4%	
Sodium (mg/l Na)	5	57,40	228,80	88,33	109,56	64,92	85,90	177,08	68,40	62,4%	
Potassium (mg/l K)	5	1,58	10,50	3,56	5,82	2,16	4,12	10,26	4,10	70,4%	
Chloride (mg/l Cl)	5	78,70	217,60	109,69	125,34	83,10	99,50	187,04	56,74	45,3%	
Sulphate (mg/l SO <sub>4</sub> )	5	7,10	849,90	13,69	179,82	8,86	12,20	517,30	374,61	208,3%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	5	33,80	523,00	129,91	369,46	185,52	417,90	497,60	192,74	52,2%	
Nitrate (mg/l N)	5	0,64	14,50	2,17	6,05	1,59	5,12	11,48	5,28	87,4%	
Fluoride (mg/l F)	5	0,64	1,81	0,90	1,02	0,68	0,90	1,49	0,46	45,2%	
Silicon as Si	5	8,03	42,74	21,95	32,87	18,57	36,47	42,74	14,38	43,7%	
Iron (Fe)	0										
Manganese (Mn)	0										
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	5	0,01	0,91	0,02	0,20	0,01	0,03	0,56	0,40	198,7%	
ZAR	5	1,08	3,63	1,68	1,96	1,25	1,78	2,90	0,98	49,8%	
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 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 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In terms of Electrical conductivity (EC), the water quality for the five available analysis is good (80%) to marginal (20%) with values ranging between 119.6 and 242.2mS/m.

The Total Dissolved Solids (TDS) is acceptable in 80% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 5 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) and Sulphate (SO<sub>4</sub> >600mg/l) in 20% or (1/5) of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive (20%), slightly scaling (40%) and balanced (40%). The ZAR index indicates that the water is of a fair quality in 80% of the samples for irrigation (ZAR < 3).

This unit includes sills and diabase dykes. Irrespective of the pre-Karoo regional geology, diabase dykes are more prevalent compared 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 user's namely, domestic, commercial, agriculture, mining etc.

In 20% of the water samples at least one element exceeds the maximum allowed limit for domestic use. In this unit the Fluoride and Sulphate are the most problematic anion. The elevated Sulphate concentration is considered as an outlier.

### 7.2.3.3 GLENOVER COMPLEX (Mgc)

The Glenover Complex forms a circular ring structure approximately 65km south-west of Lephalale (Figure 57). It covers approximately 0.45% of the total map area. It comprises a central breccia body consisting of biotite, pyroxenite and carbonatite surrounded by red and white fenite and fenitised arkose sandstone of the Aasvoëlkop Formation. The alteration zone of the sandstone is approximately 1200m around the Complex ranging from mildly fenitised sandstone to a true fenite. Excluding the latter, the intrusive body has a diameter of about 3500m. Except for the breccia body, which forms a small prominent 'breccia hill', the other lithologies of the Glenover Complex underlie flat country with only rare exposures. The name originates from one of the five farms underlain by the unit, (Brandl 1996).

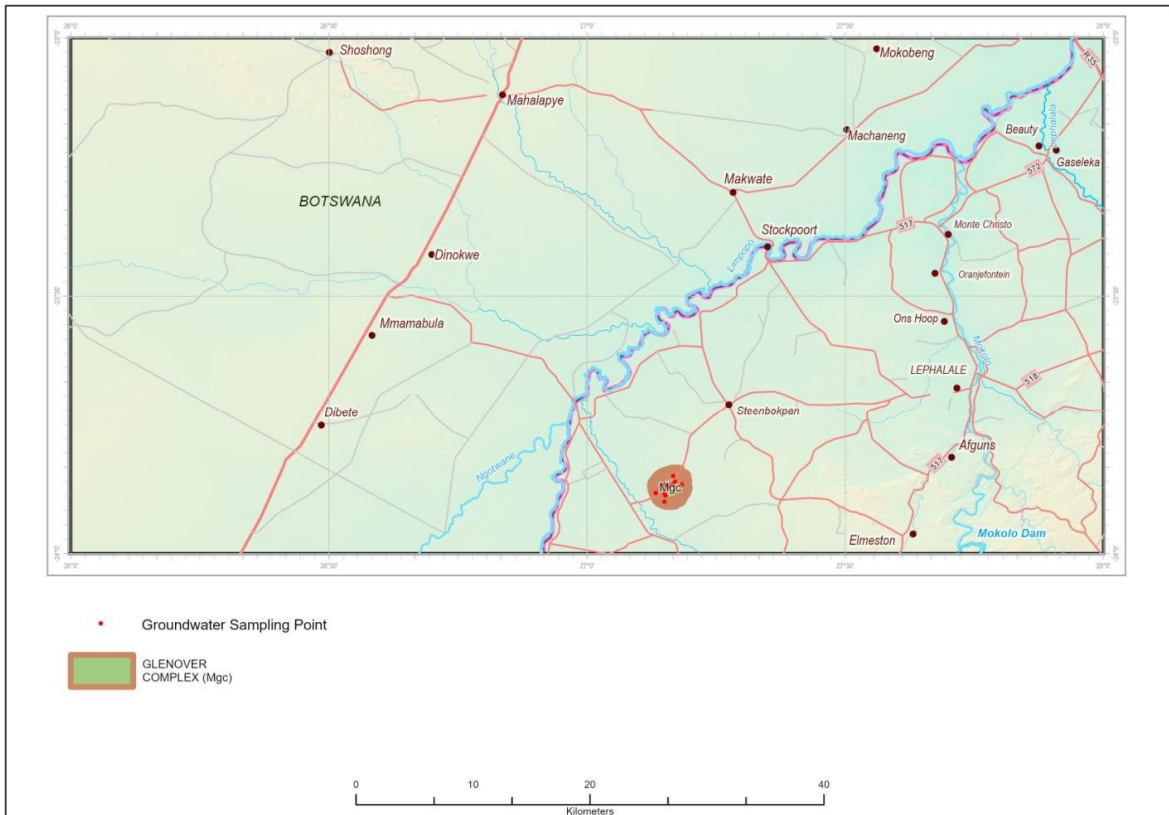


Figure 57: Geographical distribution of the Glenover Complex (Mgc) and the associated groundwater sampling points

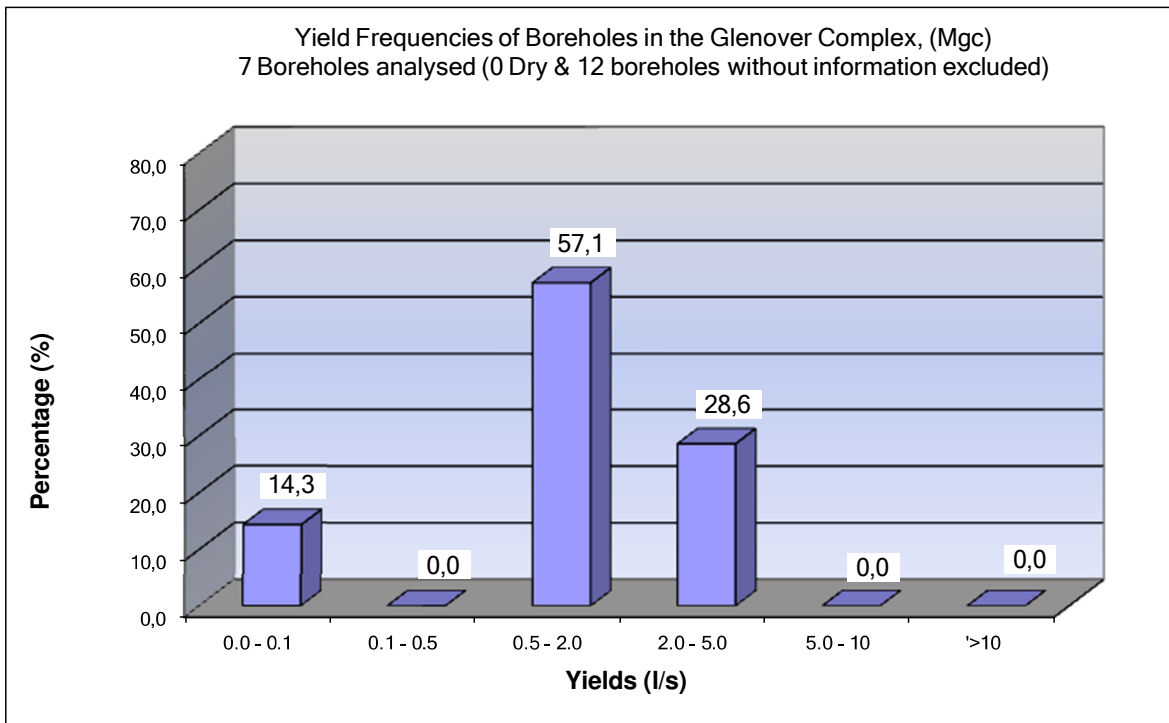


Figure 58: Yield frequency for the intergranular and fractured aquifers of the Glenover Complex, (Mgc)

Although there is not sufficient yield data for a proper conclusion, the indication is that the Glenover Complex has a reasonable groundwater potential as 28.6% of the successful boreholes yield more than 2l/s and 57.1% are between 0.5l/s and 2l/s (Figure 58). The very low yielding boreholes  $\leq 0.1$ l/s constitutes 14.3% of the boreholes with yield information.

The static water level ranges from 3.7 meters below ground level (mbgl) to 40.55mbgl, the variation is rather drastic when considering the small areal extent of the unit. The median of the static water level within the unit is 24.77mbgl and the average is 23.13mbgl, (based on 14 data points). The maximum depth recorded is 194m, with an average depth of 109m and a median depth of 143m, (7 data points). From the available information, it seems that the water strike depths are deep. No pump testing data was available for the unit.

A geohydrological study at the Glenover Phosphate Mine concluded that recharge from rainfall infiltrates a shallow, saprolitic aquifer (deep chemical weathering of rock) with a weathered, intergranular soft rock base associated with the contact of fresh bedrock and the weathering zone. The vertical hydraulic conductivity of this intergranular aquifer is between  $10^{-8}$  and  $10^{-1}$ m/day. The potential of the deeper fractured aquifer at the mine is low with yields between 0.1l/s and 2l/s and a low storage capacity. The calculated recharge percentage using the Chloride method equates to approximately 3%, (A. Huisamen, 2018).

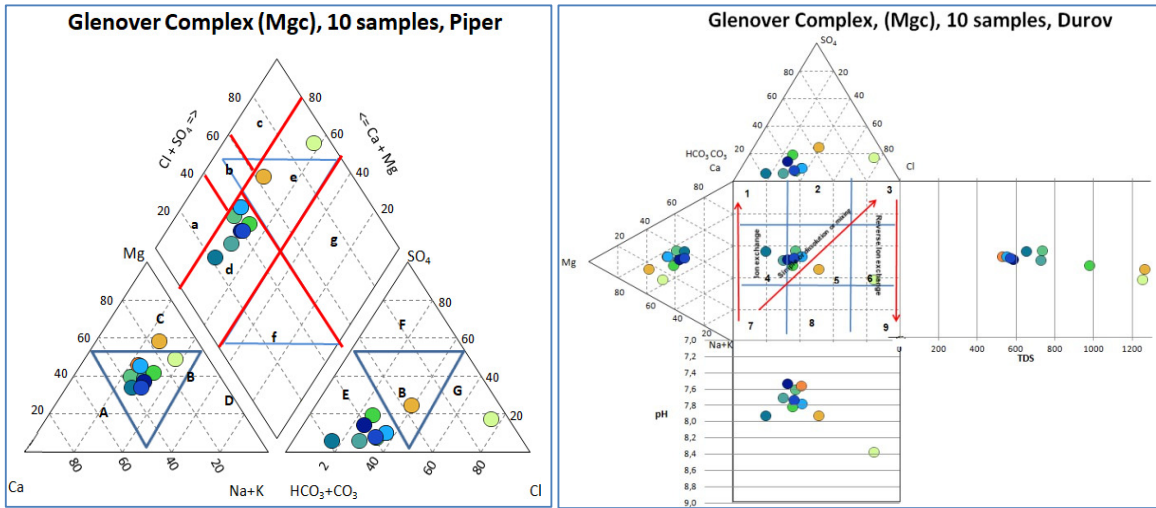


Figure 59: Trilinear diagrams, Piper and Durov for the Glenover Complex (Mgc).

The trilinear Piper diagram, (Figure 59) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (80%); Strong acids > Weak acids (20%).

The second evaluation was on the water type; the findings are as follows:

- Mixed Calcium-Magnesium-Bicarbonate type with some prevailing Sodium (80%),
- Magnesium-Bicarbonate-Chloride type (10%),
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (10%).

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 (70%), points plot along the dissolution or mixing line,
- Mixed water or water exhibiting simple dissolution or mixing (30%).

Table 39: Chemical statistics for the Glenover Complex (Mgc).

Element / Parameter	Statistics Drawn from a population of 12 data points for the Glenover Complex, (Mgc)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	12	7,53	8,39	7,79	7,79	7,56	7,76	7,93	0,23	2,9%	
Electrical Conductivity (mS/m EC)	12	76,00	200,00	102,94	115,01	81,64	92,30	179,80	44,87	39,0%	
Total Dissolved Salts (mg/l TDS)	12	529,00	1269,00	720,86	805,98	545,80	692,00	1264,80	301,97	37,5%	
Calcium (mg/l Ca)	12	43,00	171,90	63,56	71,13	47,00	62,70	74,17	33,30	46,8%	
Magnesium (mg/l Mg)	12	36,50	348,00	56,45	87,78	39,62	46,79	136,76	88,95	101,3%	
Sodium (mg/l Na)	12	32,30	450,00	64,87	105,56	36,91	66,15	162,33	114,61	108,6%	
Potassium (mg/l K)	12	4,14	61,00	8,97	14,99	4,83	9,17	24,17	15,65	104,4%	
Chloride (mg/l Cl)	12	24,60	1230,00	67,06	209,88	36,67	70,00	487,67	348,52	166,1%	
Sulphate (mg/l SO <sub>4</sub> )	12	10,20	322,00	28,55	79,59	12,78	32,50	159,43	92,52	116,2%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	12	146,6	440,6	291,6	312,0	251,6	310,4	375,8	71,2	0,2	
Nitrate (mg/l N)	12	0,03	70,35	0,16	15,74	0,07	4,26	44,68	22,80	144,9%	
Fluoride (mg/l F)	12	0,50	6,32	1,86	3,05	1,21	2,59	5,44	1,88	61,8%	
Silicon as Si	7	18,43	48,77	33,56	36,95	25,48	41,21	46,81	10,50	28,4%	
Iron (Fe)	0										
Manganese (Mn)	0										
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	12	0,01	22,40	0,02	1,89	0,02	0,03	0,05	6,46	341,4%	
ZAR	12	0,86	4,94	1,44	1,78	0,93	1,49	2,72	1,12	62,9%	
LSI	12	Langelier Saturation Index (LSI)			Slightly Scaling		50,0%		Highly Scaling		0,0%
		Highly corrosive			0,0%		Slightly corrosive		0,0%		Balanced Corrosion

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. The overall water quality in terms of the Electrical conductivity (EC) is good (75%) to marginal in 25% of the samples; the values range between 76 and 200mS/m.

The Total Dissolved Solids (TDS) is acceptable in 75% of the samples ( $TDS \leq 1200\text{mg/l}$ ). An evaluation of the major cations and anions from 12 samples show elevated concentrations of Fluoride ( $F > 1.5\text{mg/l}$ ) in 83.3%; Nitrate ( $N > 10\text{mg/l}$ ) in 33.3%; Sodium ( $Na > 400\text{mg/l}$ ) in 8.3%; Chloride ( $Cl > 600\text{mg/l}$ ) in 8.3% and Magnesium ( $Mg > 200\text{mg/l}$ ) in 8.3% of the analysis.

The analysis includes data from a Phosphate Mine, the elevated Sulphate, Fluoride, Chloride and Sodium from samples in the pit area, which was attributed to evaporative and extended fluid-rock interaction, (A. Huisamen, 2018).

The Langelier Saturation Index (LSI) indicates that the water is slightly scaling (50%) and balanced (50%). The ZAR index indicates that 91.7% is of a fair water quality for irrigation ( $ZAR < 3$ ); it ranges from 3.34 to 29.52.

The water is abstracted for livestock, game watering and domestic purposes. There are some lodges within the unit as well as mine; therefore, some of the boreholes will be used as water supply and monitoring boreholes. In 83% of the water samples at least one element exceeds the maximum allowed. For this unit the anions of concern is Fluoride followed by Nitrate that exceeds the maximum allowable concentration limit in 33.3% of the analysis.

#### **7.2.3.4 PALALA GRANITE (Mpa)**

The Palala Granite only occurs as two narrow linear bodies orientated in an east-north-east direction to the north of Villa Nora (inset map in Figure 60). The first occurrence falls within the Lephalale map sheet where it forms a narrow wedge between the Beaufort and Abbottspoort Shear Zones and extent east into the Polokwane map sheet. The second occurrence falls within the Polokwane map sheet; it occurs between the Palala Shear Zone and the Melinda Fault in the north. Both occurrences are thus fault / shear bounded.

The granite is a pinkish grey, medium to coarse-grained rock with an overall weakly developed tectonic fabric parallel to the shear zone margins, although locally well-developed fabrics are recorded. It is not regarded as a separate intrusion but rather as part of the adjacent Nebo Granite (Bushveld Complex). The rock weathered into a coarse sandy soil. The Palala Shear Belt occurs north of the Beaufort Shear Zone and south of the Melinda Fault; it is approximately 10km wide and represents the southern boundary of the Central Zone of the Limpopo Mobile Belt, (Brandl, 1996).

Within this map sheet only a small portion of the unit occurs within the boundary. The section of the unit within the Lephalale map sheet covers approximately 0.03% of the total areal extent thereof. It was decided to use all the available data within this map sheet (Lephalale) and the adjacent map sheet (Polokwane) for characterization. This is as the occurrences on both sheets are within the same hydrogeological setting, (inset map Figure 60).

The groundwater data falling on both maps for the unit consisted of 68 data points. Within the Polokwane map boundary 31 had water strikes, 9 were dry and 33 data points did not have any information regarding yields. On the Lephalale map sheet 8 groundwater points occur without any data on yield

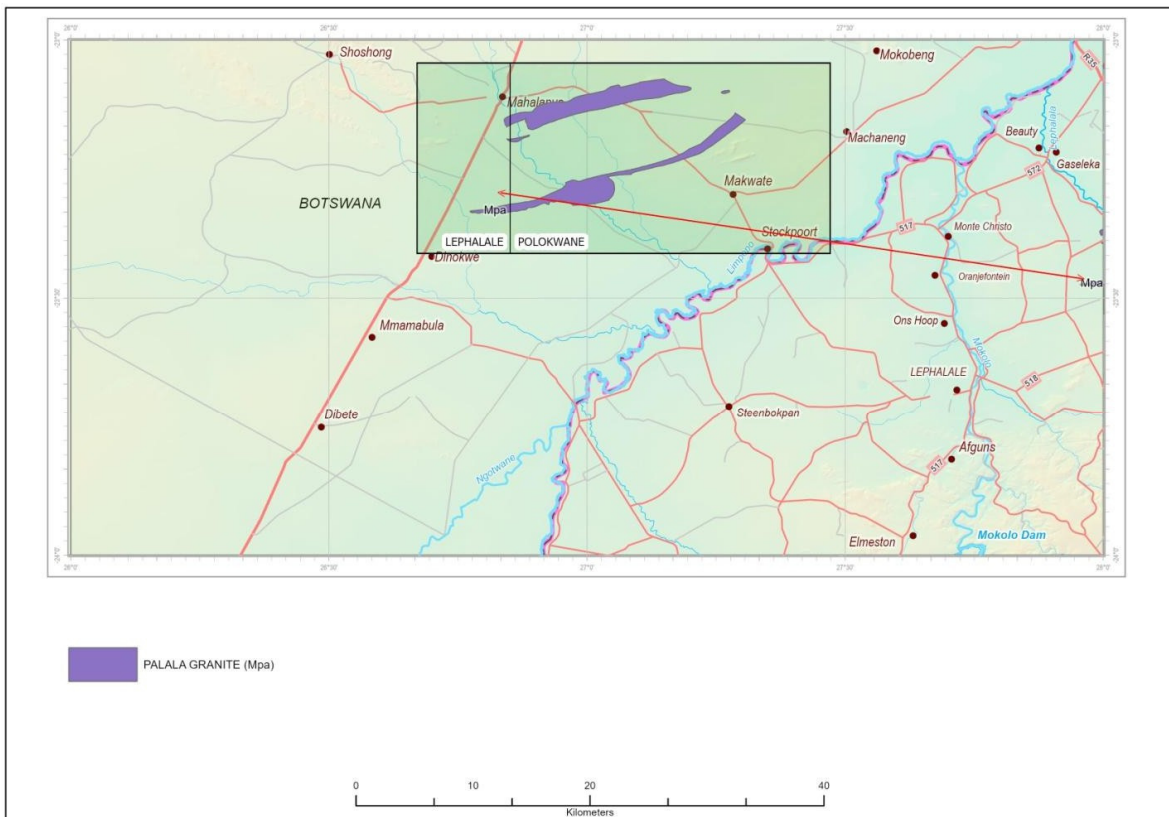


Figure 60: Geographical distribution of the Palala Granite (Mpa) and the associated groundwater sampling points.

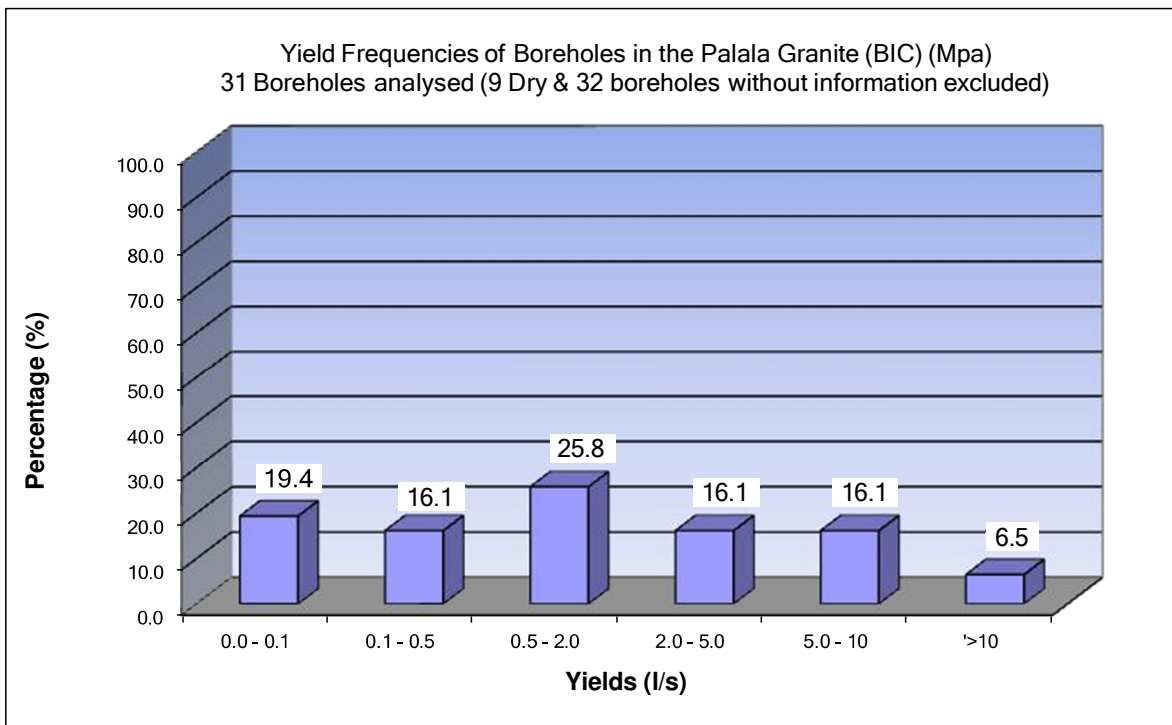


Figure 61: Yield frequency for fractured aquifers of the Palala Granite (Mpa)

The analysis of 31 borehole records indicates that 61.3% of the boreholes have maximum yields of less than 2ℓ/s, with 32.3% between 2ℓ/s and 10ℓ/s, and 6.5% of the boreholes with yields exceeding 10ℓ/s.

The static water level ranges from 0.58 meters below ground level (mbgl) to 24.07mbgl, with a median of 6.51mbgl and an average static water level of 6.87mbgl, (based on 20 data points). The maximum borehole depth recorded is 72.62m, with an average depth of 40.9m and a median of 50m, (23 data points). The maximum depth of installation is 45m; with an average of 29.9m, (8 data points). The installation depth, the average depth of the boreholes and the regional static water table gives an indication of the water strike depths.

Information is available for 15 boreholes that were subjected to pump testing within this unit. The average recommended daily abstraction is 86.72 cubic meters per day (m<sup>3</sup>/day), with the 80th percentile at 119.9m<sup>3</sup>/day and a maximum abstraction volume of 432m<sup>3</sup>/day.

The occurrence of the unit covers a small section on both the Lephalale and Polokwane map sheets and the potential of the granite itself is insignificant. The fault zones that associated with the shear zones that form the boundaries of the unit are however important for groundwater development.

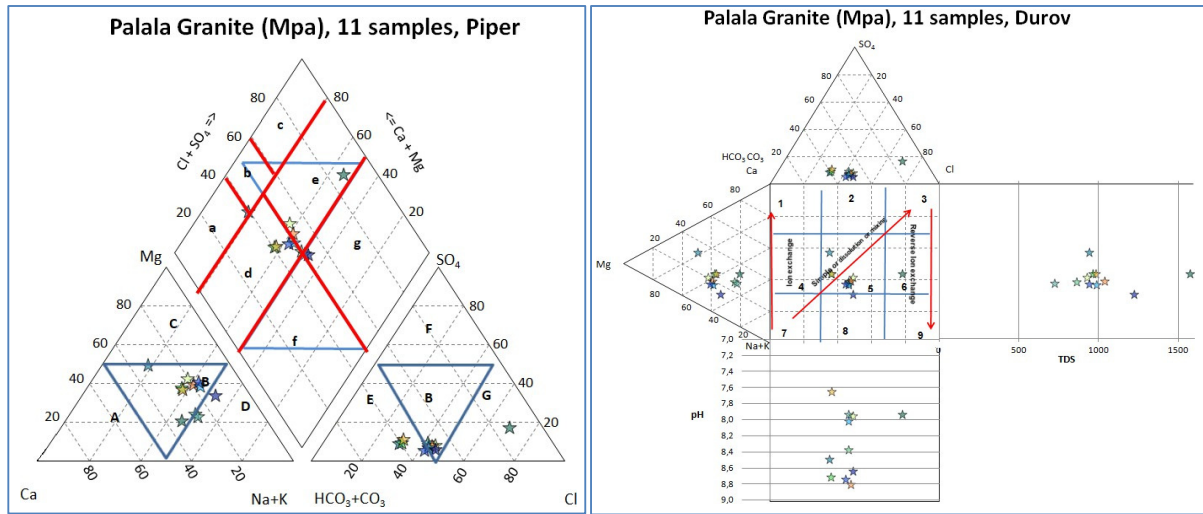


Figure 62: Trilinear diagrams, Piper, and Durov for the Palala Granite (Mpa) data points.

No chemical analyses were available within the Lephalale map sheet boundary. Within the Polokwane map sheet boundary, 26 chemical analyses were available, of which only 11 were suitable for use in the Piper and Durov diagrams. The trilinear Piper diagram, (Figure 62) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (81.8%), Weak acidic anions > Strong acidic anions (45.5%); Alkali > Alkali earths (18.2%); Strong acids > Weak acids (54.5%).

The second evaluation was on the water type; the findings are as follows:

- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with increased Sodium (36.4%),
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (27.3%),
- Sodium-Bicarbonate-Chloride type (18.1%),
- Mixed Calcium-Magnesium-Chloride type with increased Sodium (9.1%),
- Mixed Calcium-Magnesium-Bicarbonate type (9.1%).

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 (81.8%), plot along the dissolution or mixing line,
- Anion discriminate and Na dominant, indicates probable mixing or uncommon dissolution influences (9.1%),
- Cl is the dominant anion and Na the dominant cation, indicative that the groundwater is related to reverse ion exchange of Na-Cl waters (9.1%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 40: Chemical statistics for the Palala Granite (Mpa).

Element / Parameter	Statistics Drawn from a population of 26 data points for the Palala Granite (Mpa)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	26	7,00	8,89	8,10	8,13	7,43	8,17	8,71	0,50	6,1%	
Electrical Conductivity (mS/m EC)	26	99,1	1217,0	157,3	239,7	109,4	140,7	431,6	254,2	106,0%	
Total Dissolved Salts (mg/l TDS)	25	723,4	7220,0	1204,5	1740,6	889,8	1101,6	2957,5	1696,9	97,5%	
Calcium (mg/l Ca)	23	30,5	457,3	69,5	103,6	48,1	64,7	196,6	97,6	94,2%	
Magnesium (mg/l Mg)	23	30,02	121,31	66,88	74,45	55,18	70,20	108,68	22,83	30,7%	
Sodium (mg/l Na)	23	49,7	1972,6	141,7	259,3	107,9	140,5	444,1	390,9	150,8%	
Potassium (mg/l K)	23	0,54	69,72	2,91	10,10	1,02	8,74	13,37	13,65	135,1%	
Chloride (mg/l Cl)	26	52,7	2326,0	132,4	370,4	75,6	128,7	982,5	588,7	158,9%	
Sulphate (mg/l SO <sub>4</sub> )	23	22,00	2225,70	42,67	172,96	27,79	34,45	190,59	461,31	266,7%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	20	35,6	767,8	245,6	367,1	237,6	385,7	454,3	138,5	37,7%	
Nitrate (mg/l N)	25	0,61	107,09	9,60	37,90	8,88	32,08	71,33	25,86	68,2%	
Fluoride (mg/l F)	25	0,17	5,13	1,17	2,28	0,83	2,07	4,11	1,25	54,6%	
Silicon as Si	22	4,27	82,60	28,57	41,55	25,91	43,77	49,04	15,23	36,7%	
Iron (Fe)	4	0,010	0,050	0,015	0,023	0,010	0,017	0,042	0,02	81,1%	
Manganese (Mn)	8	0,001	2,070	0,002	0,267	0,001	0,006	0,642	0,73	273,5%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	21	0,009	0,247	0,019	0,038	0,013	0,021	0,029	0,06	158,6%	
ZAR	23	0,94	24,89	2,84	4,33	2,31	2,84	5,06	4,86	112,1%	
LSI	20	Langelier Saturation Index (LSI)			Slightly Scaling		95,0%		Highly Scaling		0,0%
		Highly corrosive	0,0%	Slightly corrosive		0,0%		Balanced Corrosion		5,0%	

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 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is good (58%), marginal (30.8%) and unacceptable in 11.5% of the analysis in terms of the Electrical conductivity (EC) with values ranging between 99.1 and 1217mS/m.

The Total Dissolved Solids (TDS) is acceptable in 56% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 26 samples indicates elevated concentrations of Fluoride (F > 1.5mg/l) in 80%; Nitrate (N > 10mg/l) in 76%; Chloride (Cl > 600mg/l) in 15%; Sodium (Na > 400mg/l) in 13%; Calcium (Ca > 300) in 4.3% and Sulphate (SO<sub>4</sub> > 600mg/l) in 4.3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (95%) and balanced (5%). The ZAR index indicates that 56.5% of the water is of a fair quality for irrigation (ZAR < 3).

This unit extends across both the Lephalale and Polokwane map boundaries and is geologically continuous; therefore, data from both areas were used for the characterization. None of the boreholes with available data fall within the Lephalale boundary, meaning that 100% of the chemical analysis and yield data used originate from boreholes located within the adjacent Polokwane map area.

A few rural villages are situated within this groundwater resource unit. Groundwater supplies these villages via boreholes drilled specifically to target the Melinda Fault Zone and a nearby easterly striking fault. High yields and Transmissivity values are reported for these boreholes (highest T = 292). In regard to groundwater pollution, three borehole samples show elevated E. coli counts; these boreholes are located between 360m and 1,400m from the nearest village.

Irrigation activities occur along the Palala River, and, similar to other units adjacent to rivers, surface water is likely the dominant source of water for irrigation purposes.

In 80% of the water samples, at least one element exceeds the maximum allowable limit for domestic use. For this unit, the primary anion of concern is Fluoride, followed by Nitrate, with elevated concentrations observed in 76% of the groundwater resources. Elevated Chloride concentrations are recorded in 15% of the resources.

### 7.2.3.5 NEBO GRANITE (Mn)

The Lebowa Granite Suite includes all granite rocks associated with the Bushveld Complex. Within the Lephalale map sheet, it is represented by the Nebo Granite, which occurs in the central-eastern portion of the map sheet (Figure 63) where it overlays the Villa Nora Gabbro-Anorthosite. The occurrence forms a sheet-like body of unknown thickness and is generally coarse-grained, although variations exist. The rock is typically homogeneous and pinkish, with small occurrences of a porphyritic variety (Council for Geoscience). This granite body forms part of a larger outcrop, the majority of which lies within the adjacent Polokwane map sheet (see inset map, Figure 63).

The portion of the unit within the Lephalale map sheet covers approximately 0.52% of the total area. The granite outcrop extends across both the Lephalale and Polokwane boundaries and is physically connected with the same hydrogeological setting. It was decided to combine data for this outcrop from both areas for the hydrogeological characterization of the unit. To enable comparison with other granite occurrences, specifically the second, south-to-north-trending section (Matlala-Makopane) located within the central part of the adjacent Polokwane map sheet; a separate characterization was performed using all available data from both map areas. The Polokwane brochure can be consulted for the results of this comparison, as the Lephalale brochure reports only the results for the cross-boundary outcrop.

For domestic use, elevated Fluoride and Nitrate concentration that exceeds the maximum allowable limits is of concern within the Nebo Granite groundwater resource unit.

*Table 41: 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%
Modimolle	45.5%	13.3%
Polokwane	39.2%	17.9%

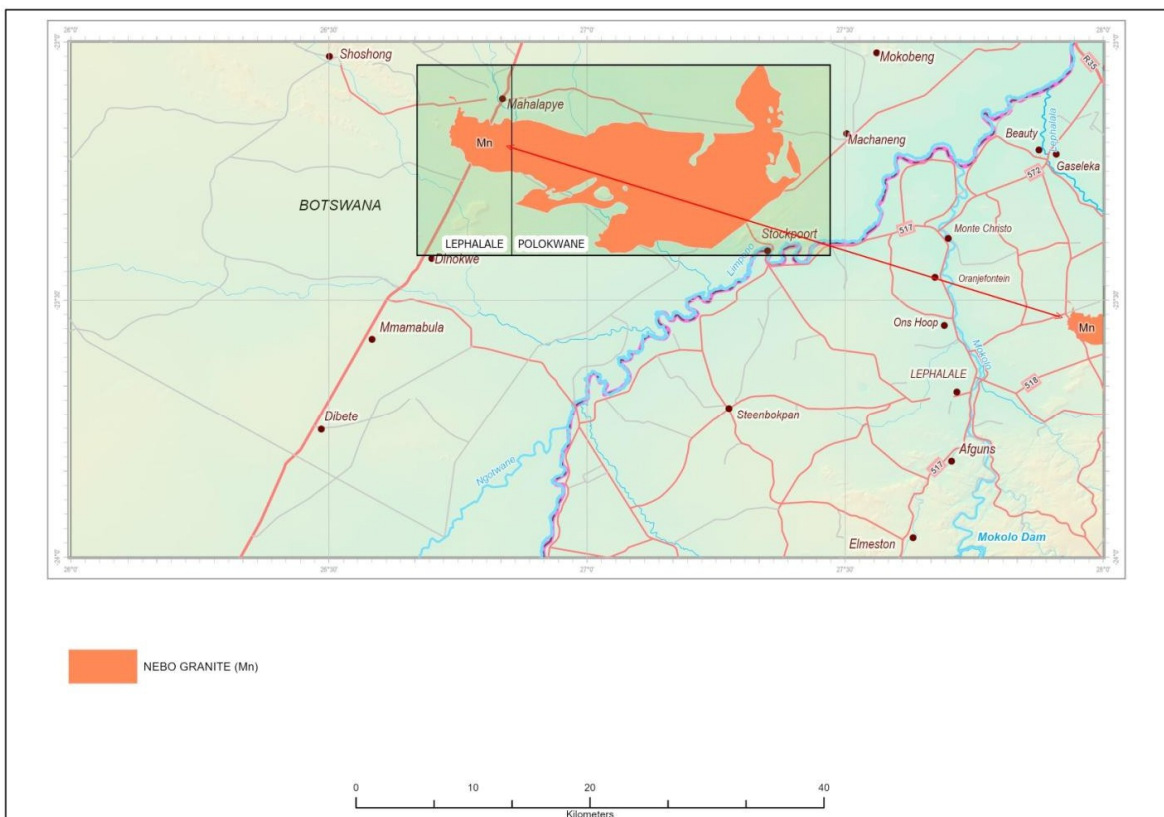


Figure 63: Geographical distribution of the Nebo Granite (Mn) and the associated groundwater sampling points.

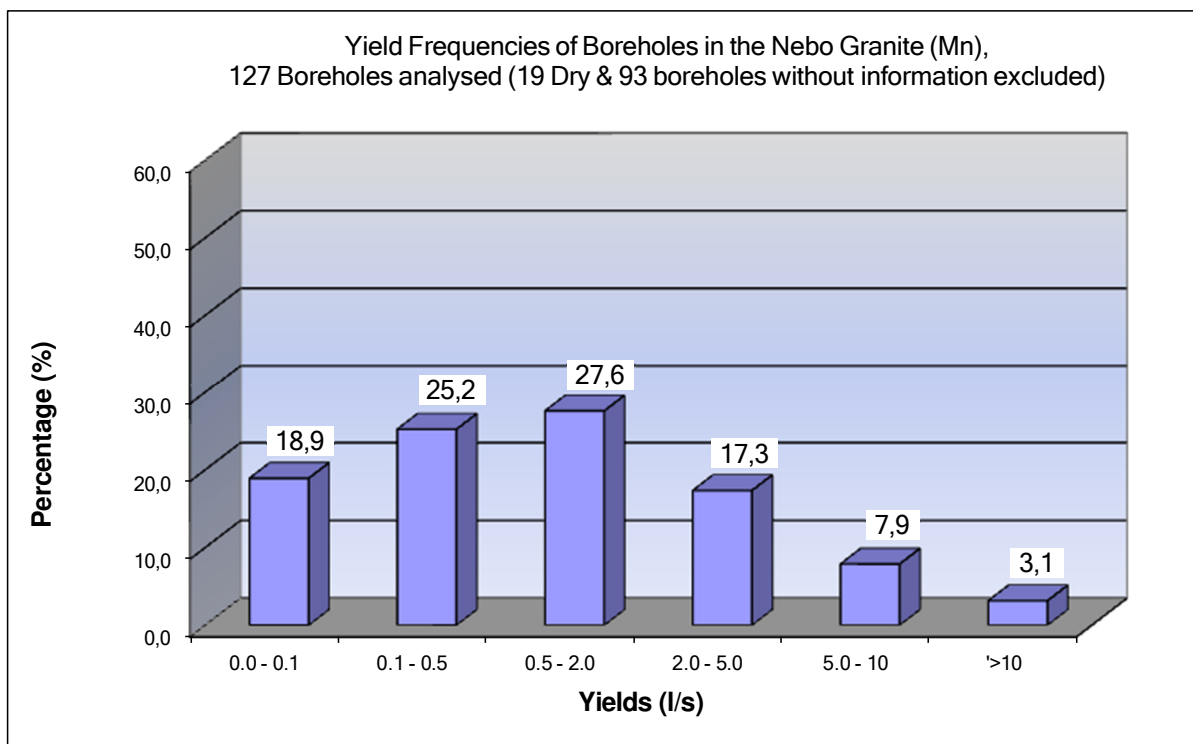


Figure 64: Yield frequency for the intergranular and fractured aquifers of the Nebo Granite (Mn), cross-boundary section.

Figure 64 illustrates the maximum yield distribution for the cross-boundary outcrop of the unit spanning the Polokwane and Lephalale map sheets. Statistics indicate that 71.7% of successful boreholes yield less than 2ℓ/s, while 17.3% of the boreholes yield between 2ℓ/s to 5ℓ/s. Only 11% of the boreholes yield more than 5ℓ/s.

For the same cross-boundary outcrop, static water levels range from 0.5 meters below ground level (mbgl) to 37.07mbgl, with a median of 5mbgl and an average static water level of 7mbgl, (based on 43 data points). The recorded maximum borehole depth is 154m, with an average depth of 58m and a median depth of 60m (63 data points). The maximum installation depth is 82.8m, and the average is 46m (33 data points). The installation depth, when compared with the average borehole depths and static water levels, provides insight into potential water strike depths.

The maximum recorded recommended daily abstraction is 256 cubic meters per day (m<sup>3</sup>/day), with an average of 50.6m<sup>3</sup>/day and a 90th percentile abstraction volume calculated as 141.4m<sup>3</sup>/day. Records indicated that 33 boreholes were subjected to pump testing within the cross-boundary outcrop.

The above statistics is for the unit that falls on the cross-boundary occurrence (thus central-east on the Lephalale map sheet and central-west on the Polokwane map sheet). Therefore, both data sets were used for the characterization; 100% of the chemical analysis and 95.3% of the yield data fell within the adjacent Polokwane map area.

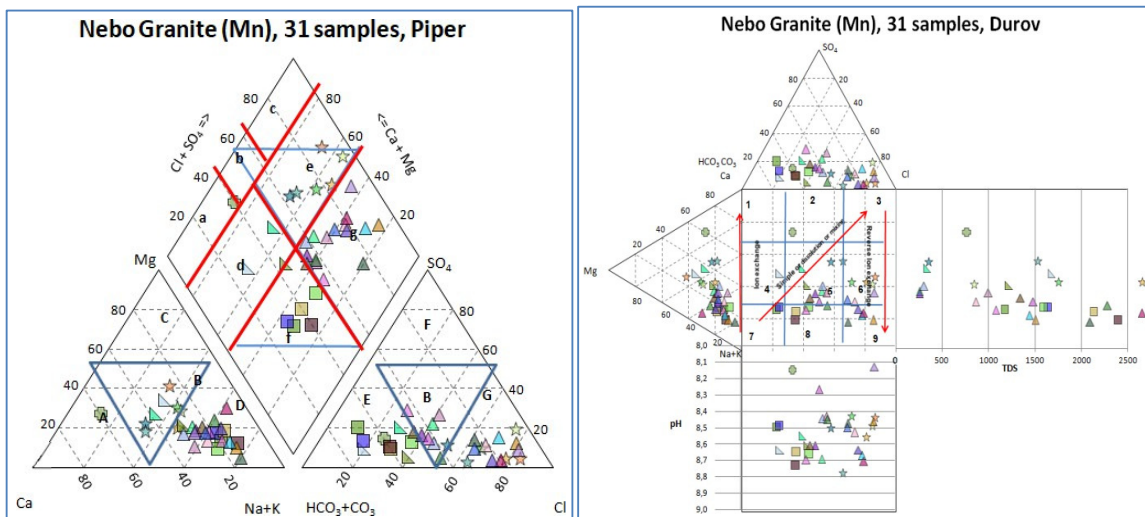


Figure 65: Trilinear diagrams, Piper, and Durov for the Nebo Granite (Mn), cross-boundary outcrop.

The trilinear Piper diagrams, (Figure 65), provide a visual representation of water chemistry by illustrating the concentrations of major cations and anions, allowing for the classification of hydrochemical facies. Figure 79 represents the cross-boundary outcrop between the Polokwane and Lephalale map sheets. The first evaluation on the chemical dominance reveals the following trends: Alkali earths > Alkali (32.3%), Weak acidic anions > Strong acidic anions (29%); Alkali > Alkali earths (67.7%); Strong acids > Weak acids (71%).

The groundwater types identified in the cross-boundary outcrop are as follows:

- Sodium-Chloride type (25.8%),
- Sodium-Mixed-Bicarbonate-Chloride type with prevailing Sulphate in some of the samples (25.8%),
- Mixed Calcium-Magnesium-Chloride type with increased Sodium (19.4%),
- Sodium-Bicarbonate type (16.1%),
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (9.7%),

➤ Calcium-Bicarbonate type (3.2%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. For the cross-boundary outcrop it is as follows:

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (32.3%), plot along the dissolution or mixing line,
- Anion discriminate and Na dominant, indicates probable mixing or uncommon dissolution influences (22.6%),
- Cl is the dominant anion and Na the dominant cation, indicative that the groundwater relates to reverse ion exchange of Na-Cl waters (16.1%),
- Cl and Na dominant, frequently indicative of end-point gradient waters through Dissolution (16.1%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (6.5%),
- The water type is dominated by Ca and HCO<sub>3</sub>, Na not significant, thus some recharge of fresh water (3.2%),
- Anion discriminant and Ca dominant, mixed water or water exhibiting simple dissolution. (3.2%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 42: Chemical statistics for the Nebo Granite (Mn) for boreholes within the cross-boundary outcrop.

Element / Parameter	Statistics Drawn from a population of 66 data points for Nebo Granite (Mn) Data used is the cross-boundary occurrence (Lephalale map west and Polokwane map east)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	66	7,00	8,57	7,92	7,94	7,29	7,99	8,33	0,39	4,9%	
Electrical Conductivity (mS/m EC)	66	13,50	480,00	71,11	130,01	24,01	109,00	228,00	87,06	67,0%	
Total Dissolved Salts (mg/l TDS)	58	102,00	2966,00	493,52	884,40	258,30	783,67	1526,23	565,85	64,0%	
Calcium (mg/l Ca)	62	6,90	270,78	33,62	63,08	17,84	52,91	120,07	51,57	81,8%	
Magnesium (mg/l Mg)	62	3,13	259,60	14,66	35,21	5,68	25,06	57,76	39,71	112,8%	
Sodium (mg/l Na)	62	11,20	389,50	63,71	155,63	19,07	140,99	298,26	100,71	64,7%	
Potassium (mg/l K)	62	0,15	45,67	1,30	4,32	0,70	1,93	7,89	8,13	188,5%	
Chloride (mg/l Cl)	66	12,13	1317,60	65,02	196,44	24,02	136,00	373,99	211,71	107,8%	
Sulphate (mg/l SO <sub>4</sub> )	62	7,10	201,18	29,25	52,18	11,75	40,82	98,27	37,76	72,4%	
Total Alkalinity (mg/l) CaCO <sub>3</sub>	58	15,20	500,00	117,74	219,64	54,70	218,25	373,30	127,09	57,9%	
Nitrate (mg/l N)	64	0,01	174,70	0,20	22,81	0,11	8,65	73,44	35,67	156,3%	
Fluoride (mg/l F)	66	0,01	10,07	0,34	2,82	0,38	2,79	5,42	2,21	78,2%	
Silicon as Si	59	2,17	48,75	13,39	22,11	7,57	23,24	39,18	12,18	55,1%	
Iron (Fe)	27	0,003	0,050	0,009	0,020	0,003	0,018	0,045	0,02	76,2%	
Manganese (Mn)	47	0,001	0,488	0,002	0,069	0,001	0,003	0,245	0,12	177,5%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	56	0,003	0,169	0,015	0,028	0,008	0,019	0,055	0,03	111,2%	
ZAR	62	0,36	12,08	2,43	4,12	1,21	3,93	7,33	2,38	57,9%	
LSI	46	Langelier Saturation Index (LSI)			Slightly Scaling		50,0%		Highly Scaling		0,0%
		Highly corrosive			0,0%		Slightly corrosive		10,9%		Balanced Corrosion

Table 42 gives a summary of the physical properties, the major anions, cations, and some of the minor elements for the cross-border occurrence between Lephalale and Polokwane map sheet.

Where the coefficient of variation listed on the summary table is above 100%, the 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality for the cross-border outcrop is ideal to good (71.2%); marginal (27.3%) and unacceptable in 1.5% of the analysis in terms of the Electrical conductivity (EC) with values ranging between 13.5 and 480mS/m.

The Total Dissolved Solids (TDS) is acceptable in 77.6% of the samples, (Acceptable TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 66 samples indicates elevated concentrations of Fluoride (F > 1.5mg/l) in 68.2%; Nitrate (N > 10mg/l) in 28%; Chloride (Cl > 600mg/l) in 4.5% and Magnesium (Mg > 200mg/l) in 1.6% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (50%), slightly corrosive (10.9%) and balanced (39.1%). The ZAR index indicates that 33.9% of the water is of a fair quality for irrigation (ZAR < 3).

Within the cross-boundary outcrop, groundwater supplies one rural village. Other uses include game and / or livestock watering and the supply to rural farmsteads. In a section of the unit (Overysse), irrigation fields were developed along the Palala River. The most likely scenario is that surface water and shallow wells within the river is used conjunctively to supply in the demand for irrigation. No groundwater sources are on record within this area or within the immediate vicinity. In other sections of the map area, 6 shallow wells are listed with a maximum depth of 9m.

Structural lineaments include diabase dykes and one major east-west fault zone that transects this unit. An evaluation based on coordinates shows four boreholes that are located near the fault zone as depicted on the geological map, these boreholes are however reported dry. Future groundwater development may target this fault using geophysical methods to determine the potential thereof.

### 7.2.3.6 VILLA NORA GABBRO-ANORTHOSITE (Vv)

The Rustenburg Layered Suite represents the mafic phase of the Bushveld Igneous Complex. On the Lephalale map sheet (central-east) and on the adjacent Polokwane map sheet (central-west the **Bushveld Complex** is thought to form a separate intrusion. The Villa Nora Compartment, not associated with the main Bushveld outcrop (north-east of Mokopane) falls within the Polokwane geological map sheet area, (Council of Geoscience).

Within the Lephalale map sheet, the outcrop accounts for approximately 20% of its total occurrence, with the remaining 80% falling within the Polokwane map sheet boundary. The section of the unit within the Lephalale map sheet covers approximately 0.551% of the total area, (Figure 66). Given that the occurrences across both sheets form part of a continuous geological unit with identical hydrogeological settings, all available groundwater data for the outcrop from both areas were combined for the characterization, (refer to the inset map Figure 66).

The yield frequency diagram, (Figure 67), provides an overview of borehole yields. For 63.4% of the successful boreholes, the maximum yield is less than 2l/s and 36.6% of the boreholes yield more than 2l/s.

Regarding water quality, 67% 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 followed by Fluoride concentrations that exceed the maximum allowable limit in 12.1% of the analysis.

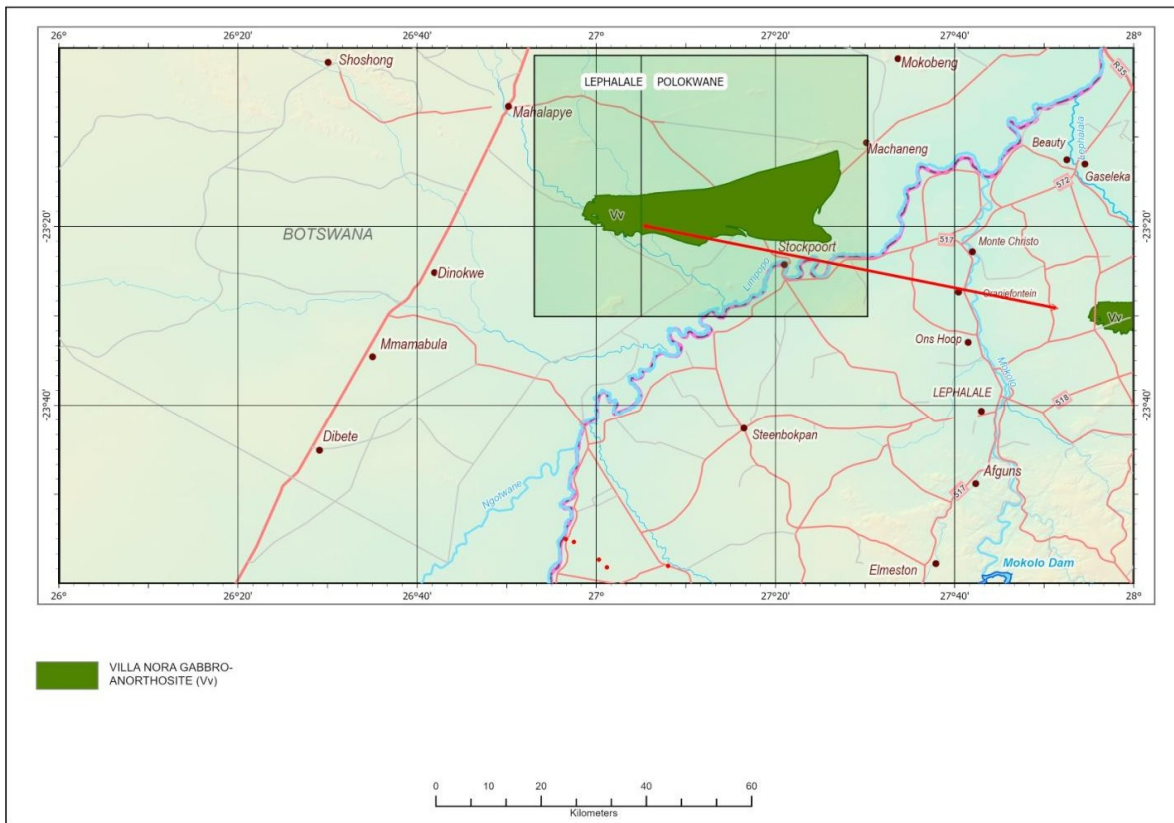


Figure 66: Geographical distribution of the Villa Nora Gabbro-Anorthosite (Vv) and the associated groundwater sampling points

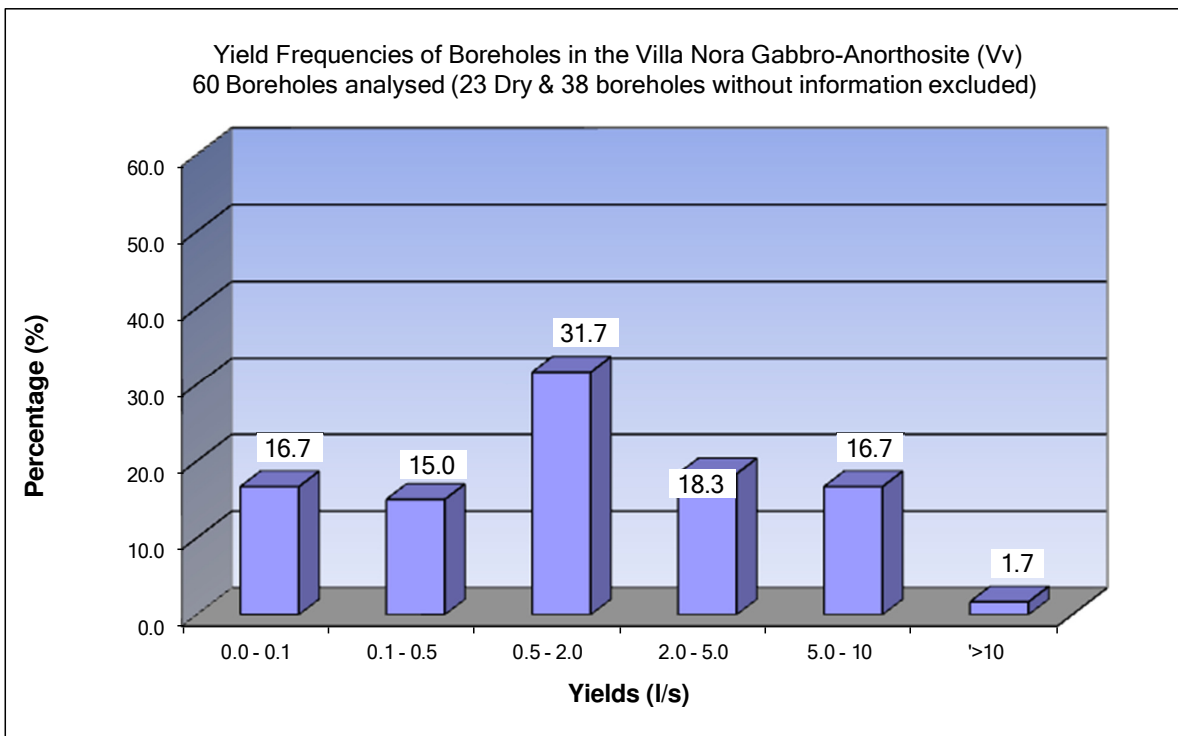


Figure 67: Yield frequency for the intergranular and fractured aquifers of the Villa Nora Gabbro-Anorthosite (Vv).

The statistical analysis of 60 borehole records, (Figure 67), reveals the following distribution of borehole yields:

- 31.7% of the successful boreholes yield between 0.001l/s and 0.5l/s, thus suitable for small households.
- 31.7% have yields between 0.5l/s and 2l/s.
- 18.3% yield between 2l/s and 5l/s.
- 18.4% have yields exceeding 5l/s, of which only 1.7% report maximum yields greater than 10l/s.

The static water level ranges from 1.25 meters below ground level (mbgl) to 23.7mbgl, with a median of 8.78mbgl and an average static water level of 9.69mbgl (based on 20 data points). The maximum depth recorded is 217m, with an average depth of 52.5m and a median depth of 41.9m (24 data points). The maximum installation depth is 55m, with an average of 32.2m (12 data points). Comparing the depth of installation to average borehole depth and static water levels can provide insights into water strike depths.

The maximum recommended daily abstraction on record is 345.6 cubic meters per day (m<sup>3</sup>/day), with an average of 100.9m<sup>3</sup>/day, the 90th percentile daily abstraction volume is 245.7m<sup>3</sup>/day, and the 80th percentile is 191.8m<sup>3</sup>/day. The total number of boreholes subjected to pump testing in this unit on record is 20.

The above statistics are for the outcrop that spans the cross-boundary occurrence, (the central-west portion of the Polokwane map sheet and the central-east portion of the Lephalale map sheet). As a result, both data sets were used for the characterization. Notably, 100% of the chemical analysis and 88.5% of the yield data fall within the Polokwane map area.

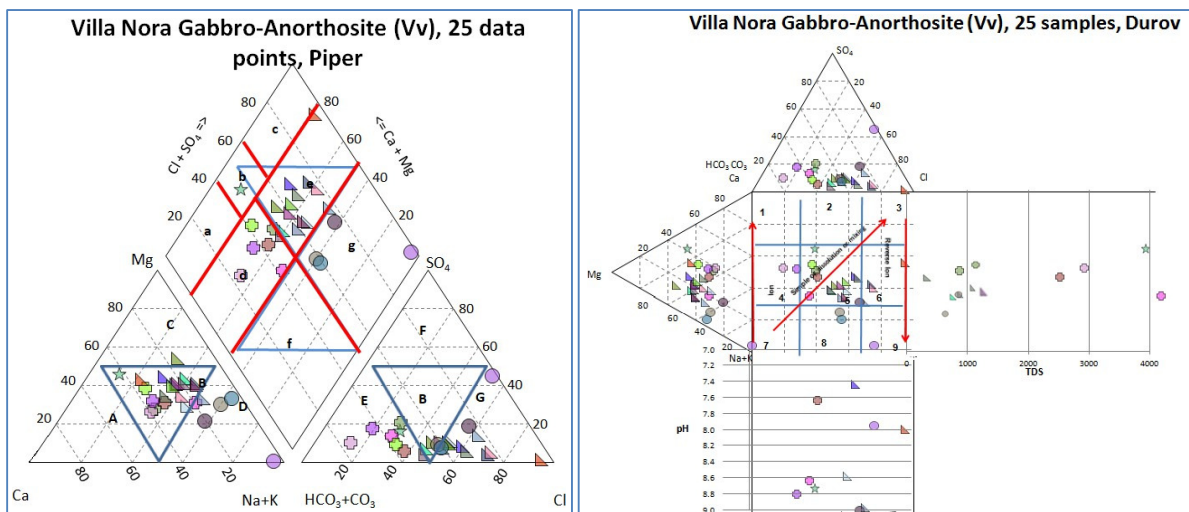


Figure 68: Trilinear diagrams, Piper and Durov for the Villa Nora Gabbro-Anorthosite (Vv).

The trilinear Piper diagram, (Figure 68), facilitates the visualization of water chemistry by representing the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (84%), Weak acidic anions > Strong acidic anions (26%); Alkali > Alkali earths (16%); Strong acids > Weak acids (74%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Chloride type (32%);
- Mixed Calcium-Magnesium-Bicarbonate type (28%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (20%);
- Sodium-Chloride type (16%);

- Magnesium-Bicarbonate-Chloride type (4%);

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 (60%), plot along the dissolution or mixing line,
- Anion discriminate and Na dominant, indicates probable mixing or uncommon dissolution influences (12%),
- Cl is the dominant anion and Na the dominant cation, indicative that the groundwater relates to reverse ion exchange of Na-Cl waters (12%),
- Anion discriminant and Ca dominant, mixed water or water exhibiting simple dissolution. (8%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (4%),
- Cl and Na dominant, frequently indicative of end-point gradient waters through Dissolution (4%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 43: Chemical statistics for the Villa Nora Gabbro-Anorthosite (Vv).

Element / Parameter	Statistics Drawn from a population of 34 data points for the Villa Nora Gabbro (Vv).										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	34	7.20	8.91	8.02	8.04	7.49	8.06	8.51	0.38	4.7%	
Electrical Conductivity (mS/m EC)	34	21.1	703.0	117.3	164.9	83.6	154.7	224.8	111.7	67.7%	
Total Dissolved Salts (mg/l TDS)	32	134.1	4072.0	829.6	1161.9	672.7	1121.0	1560.7	657.7	56.6%	
Calcium (mg/l Ca)	33	10.8	511.6	45.4	80.6	24.8	70.9	109.8	83.7	103.7%	
Magnesium (mg/l Mg)	33	1.30	388.80	21.93	74.31	24.29	62.20	105.80	65.39	88.0%	
Sodium (mg/l Na)	33	13.3	397.0	91.4	154.2	58.2	149.8	270.8	89.9	58.3%	
Potassium (mg/l K)	33	0.15	7.48	1.22	2.71	0.81	2.05	5.84	2.09	77.1%	
Chloride (mg/l Cl)	34	12.1	2226.9	85.7	256.4	42.9	165.4	445.1	377.8	147.3%	
Sulphate (mg/l SO <sub>4</sub> )	34	10.92	394.40	34.22	65.04	19.99	37.34	122.00	85.91	132.1%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	29	35.9	533.9	239.7	346.2	263.5	349.6	470.0	110.1	31.8%	
Nitrate (mg/l N)	33	0.04	95.00	1.08	27.81	1.84	25.48	48.01	20.81	74.8%	
Fluoride (mg/l F)	33	0.14	3.58	0.55	0.94	0.36	0.60	1.78	0.84	89.3%	
Silicon as Si	31	10.42	46.75	30.13	33.77	24.77	36.66	40.23	8.34	24.7%	
Iron (Fe)	11	0.005	0.266	0.014	0.049	0.006	0.023	0.050	0.07	152.9%	
Manganese (Mn)	24	0.001	0.210	0.002	0.019	0.001	0.002	0.049	0.04	230.5%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	29	0.009	0.800	0.020	0.071	0.011	0.023	0.126	0.16	221.5%	
ZAR	33	0.56	27.74	2.26	3.66	1.53	3.03	5.12	4.51	123.1%	
LSI	28	Langelier Saturation Index (LSI)			Slightly Scaling		78.6%		Highly Scaling		0.0%
		Highly corrosive			0.0%		Slightly corrosive		7.1%		Balanced Corrosion

Table 43 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 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good (47.1%), marginal (50%) and unacceptable in 2.9% of the analysis in terms of the Electrical conductivity (EC) with values ranging between 21.1 and 703mS/m. The 90<sup>th</sup> percentile is 224.8mS/m.

The Total Dissolved Solids (TDS) is acceptable in 62.5% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 34 samples indicates elevated concentrations of Nitrate (N >20mg/l) in 66.7%; Fluoride (F >1.5mg/l) in 12.1%; Chloride (Cl > 600mg/l) in 5.9%; Calcium (Ca > 300) in 3% and Magnesium (Mg > 200mg/l) in 3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (78.6%); slightly corrosive (7.1%) and balanced (14.3%). The ZAR index indicates that 45.5% of the water is of a fair quality for irrigation (ZAR < 3).

Located east of the Palala River, there are three rural villages within this groundwater unit. Water to these villages is from groundwater sources. No irrigation occurs within this unit. Water is also used to supply water for game, livestock, farm homesteads and lodges.

### **7.2.3.7 UNDIFFERENTIATED MESSINA SUITE (Zms)**

This unit comprises mainly of metapyroxenite and serpentinite which are intrusive into the Beit Bridge Complex. The meta-pyroxenite is a coarsely crystalline greyish black rock composed of large equigranular grains of pyroxene, mainly hypersthene and minor amphibole, plagioclase, spinal, and magnetite. The serpentinites, which probably represent altered peridotites, are dark green and greyish black rocks in which antigorite, antiphylite, and tremolite can be recognised. The occasional presence of chromite indicates igneous origin. Coarsely crystalline hornblendite is locally associated with serpentinite. Mylonite and various strong sheared rocks related to the Bushveld Igneous Complex (BIC) are included in the Messina Suite.

Within the Lephale map sheet the unit extent represents approximately 5% of the total occurrence, the rest falls within the Polokwane map sheet. The unit occurs within the centre-east section on the Lephale map sheet and within the centre-west section on the Polokwane map sheet. The section of the unit within the Lephale map sheet covers approximately 0.37% of the total Lephale map area (Figure 66).

It was decided to use all the available groundwater data from both map sheets for characterization. The occurrences on both sheets are within the same area and are physically connected. Therefore, the hydrogeological settings are considered the same, (see inset map, Figure 69). However, the data within the Lephale map area was limited to one borehole with no available data. Consequently, all data used for the chemical and yield diagrams falls within the Polokwane map sheet.

The groundwater potential of this unit is generally good. Figure 70 is the yield frequency diagram for the unit that show that 45.9% of the boreholes yield less than 2l/s, while 54.1% yield more than 2l/s, and 27.9% yield more than 5l/s.

In regard to water quality, in 77.5% of the water samples, at least one element exceeds the maximum allowable limits for domestic use. For this unit, the primary concern is the anion Nitrate.

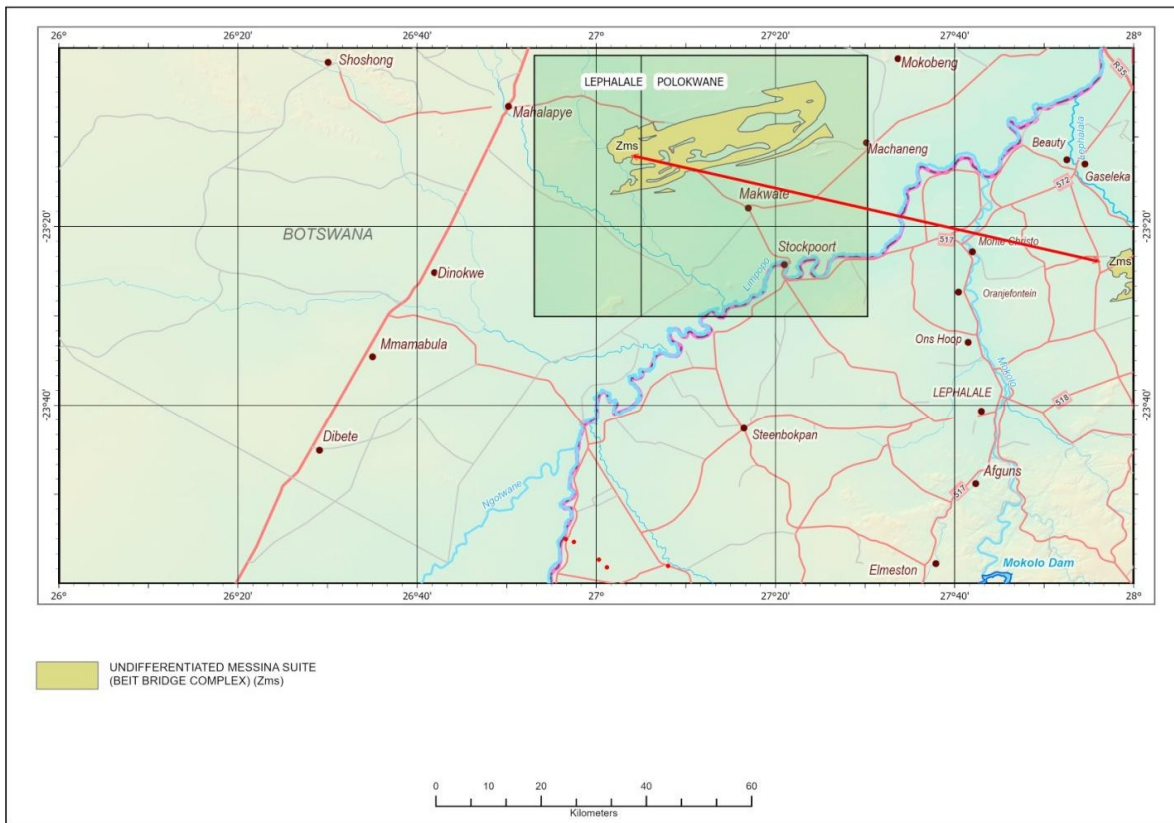


Figure 69: Geographical distribution of the Undifferentiated Messina Suite (Zms) and associated groundwater sampling points.

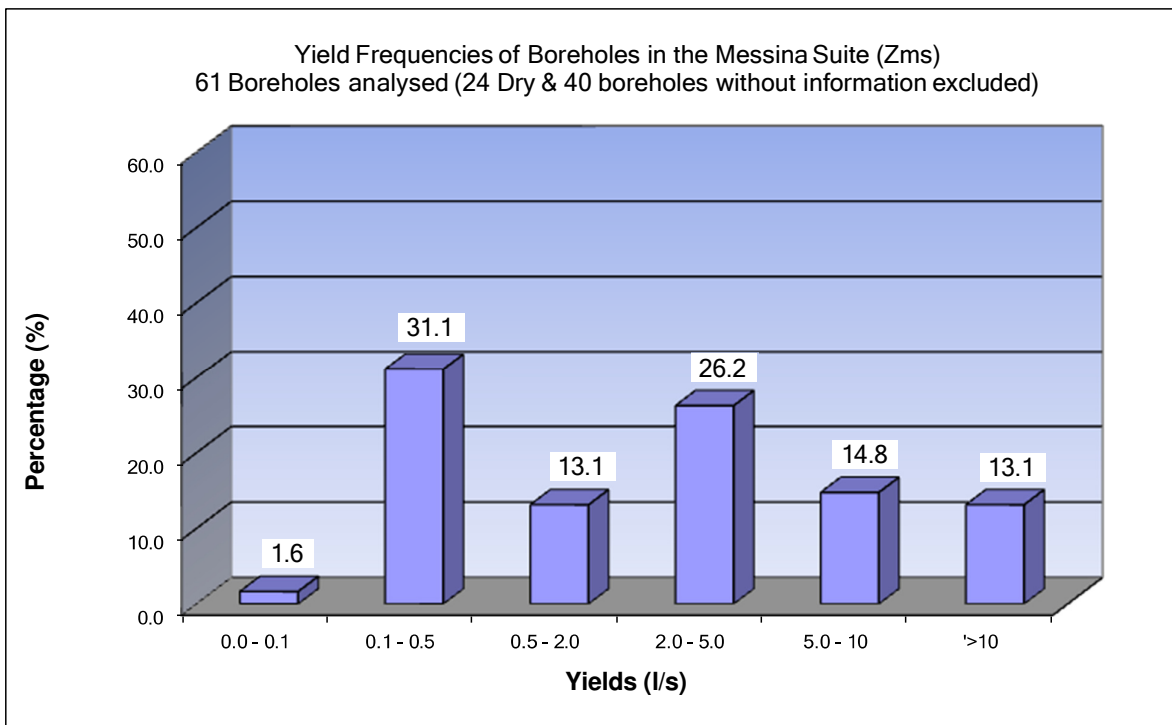


Figure 70: Yield frequency for the intergranular and fractured aquifers of the Undifferentiated Messina Suite (Zms).

The statistical analysis of 61 borehole records indicates that 32.7% of the successful boreholes have yields that can only be used for small households (>0.001ℓ/s to 0.5ℓ/s). A further 13.1% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, with 26.2% of the boreholes yielding between 2ℓ/s and 5ℓ/s and 27.9% yielding more that 5ℓ/s, (Figure 70).

The static water level ranges from 2.51 meters below ground level (mbgl) to 25.82mbgl, with a median of 10.14mbgl and an average static water level of 11.06mbgl, (based on 41 data points). The maximum depth recorded is 130m, with an average of 54m and a median depth of 52.5m, (50 data points). The maximum installation depth is 95m with an average of 36.3m, (9 data points). The depth of installation can be indicative of water strike depths if compared to the average depth and static water levels of the boreholes.

The maximum recommended daily abstraction on record is 691.2 cubic meters per day (m<sup>3</sup>/day) and the average is 137.1m<sup>3</sup>/day. The 90th percentile of the daily abstraction is 393.6m<sup>3</sup>/day and the 80th percentile is 200.4m<sup>3</sup>/day. The total number of boreholes tested in this unit on record is 35.

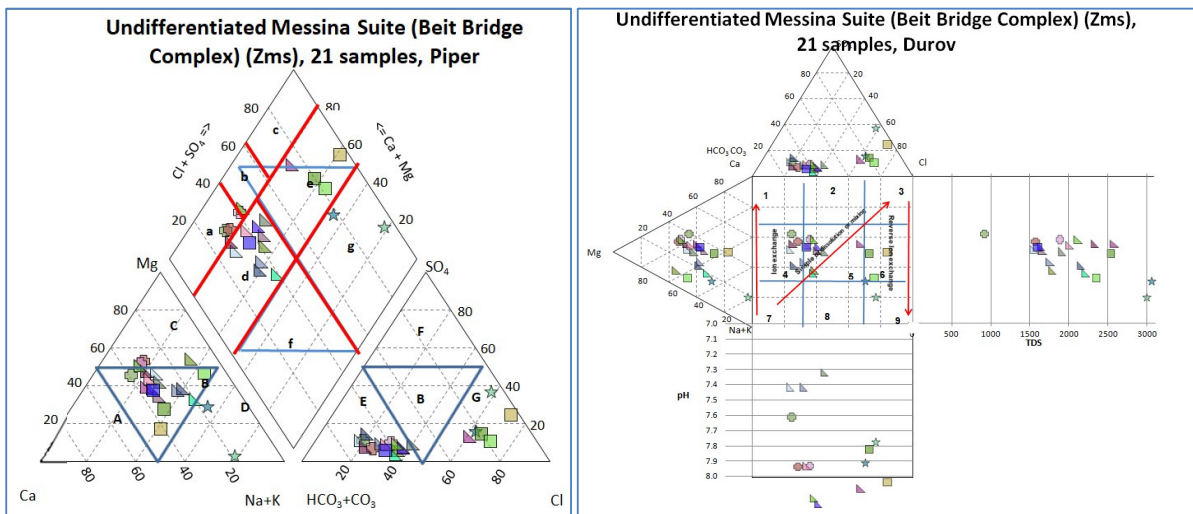


Figure 71: Trilinear diagrams, Piper, and Durov for the Undifferentiated Messina Suite (Beit Bridge Complex), (Zms).

The trilinear Piper diagram, (Figure 71) 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 (90.5%), Weak acidic anions > Strong acidic anions (71.4%); Alkali > Alkali earths (9.5%); Strong acids > Weak acids (28.6%).

The groundwater in this unit classifies as:

- Mixed-Calcium-Magnesium-Bicarbonate type (61.9%),
- Mixed-Calcium-Magnesium-Chloride type with increasing Sodium (14.3%),
- Sodium-Chloride type (9.5%),
- Magnesium-Bicarbonate type (9.5%),
- Mixed-Calcium-Magnesium-Bicarbonate type with increased Sodium (4.8%).

The high TDS is some of the samples that may be indicative of long residence times in the aquifer allowing reactions to be fairly complete.

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 (47.6%), plot along the dissolution or mixing line,
- SO<sub>4</sub> dominates, or anion discriminant and Ca dominant, Ca and SO<sub>4</sub> dominates, frequently indicates recharge in gypsiferous deposits, otherwise mixed water or water exhibiting simple dissolution may be indicated. (28.6%)
- Anion discriminant and Na dominant, indicates probable mixing or uncommon dissolution influences (14.3%),
- Cl and Na dominant, frequently indicative of end-point gradient waters through Dissolution (9.5%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 44: Chemical statistics for the Undifferentiated Messina Suite (Beit Bridge Complex), (Zms).

Element / Parameter	Statistics Drawn from a population of 66 data points for Undifferentiated Messina Suite (Beit Bridge Complex) (Zms).										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	65	6.57	8.95	8.00	8.03	7.30	8.03	8.72	0.52	6.5%	
Electrical Conductivity (mS/m EC)	65	41.20	679.00	114.85	135.31	91.10	113.70	189.88	89.03	65.8%	
Total Dissolved Salts (mg/l TDS)	63	415.40	4198.00	863.77	978.62	659.26	881.00	1253.76	539.67	55.1%	
Calcium (mg/l Ca)	63	12.60	417.20	57.96	80.15	40.05	70.20	97.67	62.94	78.5%	
Magnesium (mg/l Mg)	63	8.88	380.50	55.97	71.38	44.90	61.56	93.80	45.75	64.1%	
Sodium (mg/l Na)	63	11.66	477.70	67.69	101.90	37.16	88.68	150.08	76.26	74.8%	
Potassium (mg/l K)	63	1.75	19.90	4.85	5.75	2.84	5.52	7.95	2.58	44.9%	
Chloride (mg/l Cl)	65	15.10	1276.60	62.96	123.22	35.06	68.05	286.10	176.97	143.6%	
Sulphate (mg/l SO <sub>4</sub> )	63	11.98	595.10	28.52	56.88	17.28	28.70	74.51	103.18	181.4%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	54	100.88	567.90	317.27	347.17	236.49	347.70	439.01	86.79	25.0%	
Nitrate (mg/l N)	63	1.01	157.10	12.73	31.13	12.52	27.42	44.66	23.53	75.6%	
Fluoride (mg/l F)	63	0.14	4.50	0.60	0.84	0.37	0.77	1.20	0.58	68.8%	
Silicon as Si	57	11.58	92.90	35.64	40.45	33.82	41.75	45.22	11.57	28.6%	
Iron (Fe)	14	0.010	0.431	0.014	0.049	0.010	0.011	0.070	0.112	227.3%	
Manganese (Mn)	14	0.005	0.440	0.015	0.068	0.010	0.016	0.136	0.116	172.0%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	46	0.009	0.104	0.019	0.025	0.012	0.018	0.043	0.019	75.9%	
ZAR	63	0.38	10.85	1.41	2.09	0.73	1.89	3.48	1.54	73.9%	
LSI	53	Langelier Saturation Index (LSI)			Slightly Scaling		71.7%		Highly Scaling		0.0%
		Highly corrosive			0.0%		Slightly corrosive		0.0%		Balanced Corrosion

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 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good 81.5%; marginal in 15.4% and unacceptable, (EC > 370mS/m), in 3.1% of the analysis in terms of the Electrical conductivity (EC) with values between 41.20 and 679mS/m. The 90<sup>th</sup> percentile is 189.88mS/m.

The Total Dissolved Solids (TDS) is acceptable in 87.3% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 66 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 77.8%; Fluoride (F >1.5mg/l) in 6.3%; Calcium (Ca > 300) in 3.2%; Magnesium (Mg > 200mg/l) in 1.6%; Sodium (Na > 400mg/l) in 1.6% and Chloride (Cl > 600mg/l) in 1.5% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (71.7%) and balanced (28.3%). The ZAR index indicates that 84.1% of the water is of a fair quality for irrigation (ZAR < 3).

East of the Palala River there are some rural villages within this groundwater unit. Water supply is from the Mokuruanyane Water Scheme. Water to these villages is from groundwater and surface water from shallow wells within the river. Irrigation occurs west of the Palala River, the water

source is most likely surface water and shallow wells within the river. Water is also used to supply water for Game, livestock, and farm homesteads.

### **7.2.3.8 UNDIFFERENTIATED BEIT BRIDGE COMPLEX (Zbc)**

The Beit Bridge Complex is part of the Limpopo Metamorphic Belt which is subdivided into three domains, a Central Zone and two flanking Marginal Zones. They are separated from each other, and from the neighboring Kaapvaal and Zimbabwe Cratons (Rhodesian Craton), by major shear zones.

The Beit Bridge Complex is restricted to the Central Zone and is a succession of supracrustal gneisses into which mafic and ultramafic rocks (Messina Suite) and granitoid rocks (Alldays Gneiss) were emplaced, (Council of Geoscience).

It is broadly subdivided into the Mount Dowe, Malala Drift and Gumbu Groups. The supracrustal gneisses of the complex which include metaquartzite, amphibolite, marble, and calc-silicate rocks are interpreted to represent mainly a shelf-type sequence.

Due to the lack of outcrop as the area is extensively covered by sandy soils the delineation between the Groups is not always possible. The groundwater units are thus divided into the Undifferentiated Beit Bridge Complex, Undifferentiated Malala Drift and Mount Dowe Groups. The Gumbu Group do not have any outcrops within the map area. The quaternary sediments as indicated on the 1:250 000 geological map sheet 2328 do not have aquifer characteristics and were ignored.

The undifferentiated Beit Bridge Complex aquifer unit consists of the rocks of all three groups (Mount Dowe, Malala Drift and Gumbu Groups), except where outcrop occurs, that is assigned to one of the groups, as indicated on the geological map sheet. This unit underlay approximately 6.95% of the total map area.

Although the unit cross over to the Polokwane map sheet area, the characterization for each map was done separately as sufficient data was available on both map sheets for proper characterization. The findings are that the maximum yield and chemical characteristics are similar for the unit in both map sheets, (see inset map Figure 72).

Statistics indicate that 67.9% of the successful borehole yields less than 2l/s, while 28.3% of the boreholes yield between 2l/s to 10l/s. Only 3.8% of the boreholes have yields exceeding 10l/s, (Figure 73). This can be compared to the 76.3% of boreholes yielding less than 2l/s that falls within the Polokwane map sheet.

In 51.6% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit, the anions of concern are nitrate, followed by elevated concentrations of Fluoride and Chloride in 22.2% and 18.7% of the analyses, respectively. Within the Polokwane map sheet, 52% of the water samples contain nitrate concentrations that exceed the maximum allowable limit for human consumption. Fluoride and Chloride concentrations within the Polokwane map sheet that exceeds the maximum allowable concentration limits for human consumption are 4.8% and 10.1% of the analyses.

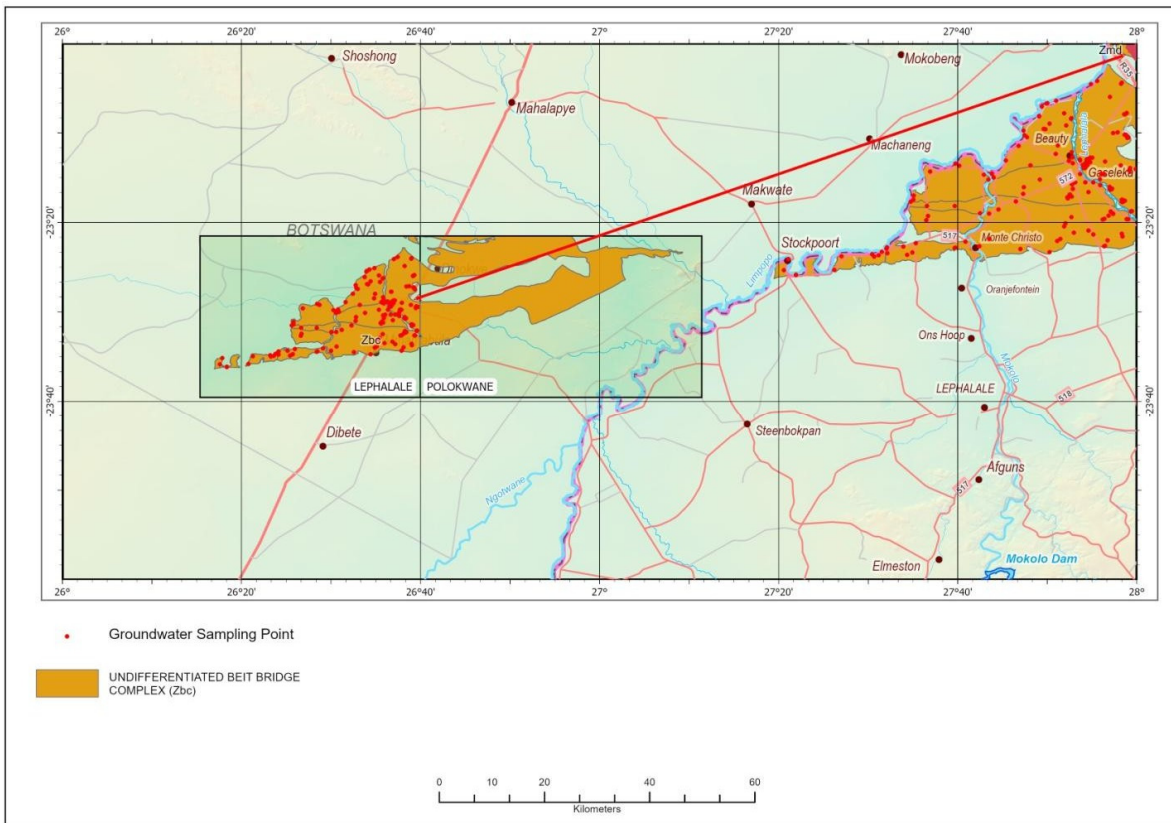


Figure 72: Geographical distribution of the Undifferentiated Beit Bridge Complex (Zbc) and associated groundwater sampling points

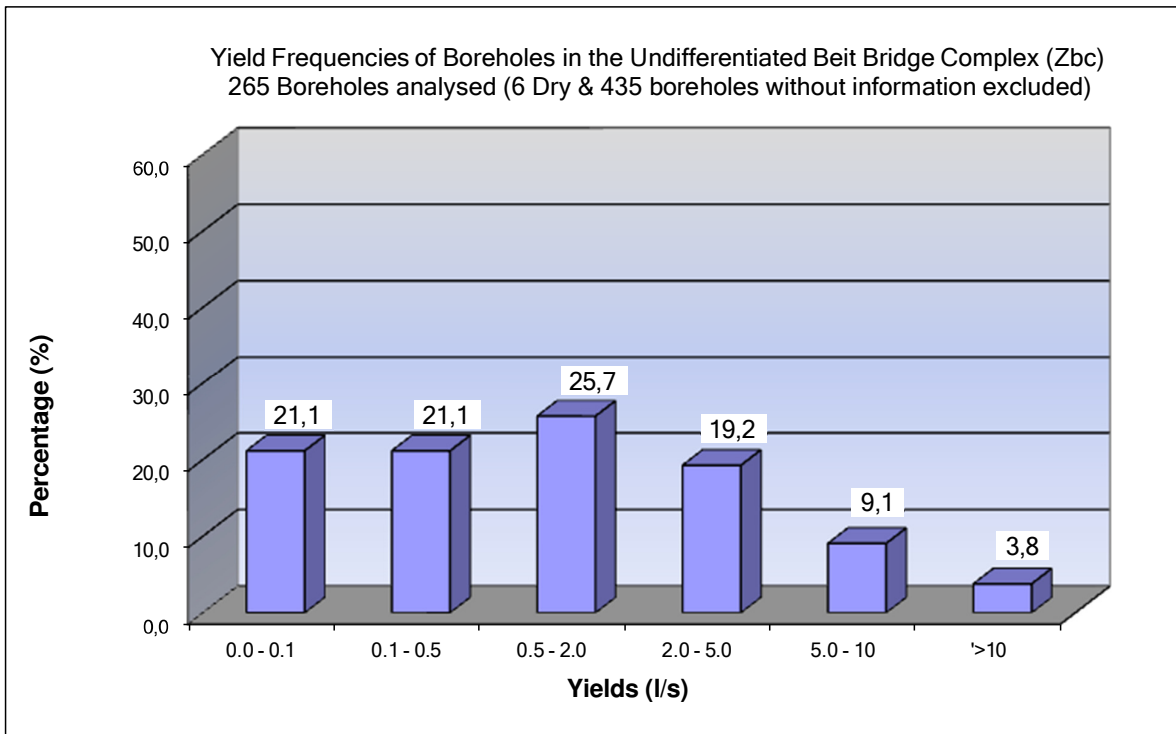


Figure 73: Yield frequency for the intergranular and fractured aquifers of the Undifferentiated Beit Bridge Complex (Zbc).

The static water level ranges from 0.65 meters below ground level (mbgl) to 86.95mbgl, with a median of 10.77mbgl and an average static water level of 16.05mbgl; (based on 72 data points). The maximum depth recorded is 180m, with an average depth of 62m and a median depth of 54m; (81 data points). The installation depths can give an indication of water strike depths. The maximum installation depth is 96m and with an average of 30.7m (44 data points).

In total 44 pumping test data sets were available. The maximum daily abstraction is 432 cubic meters per day ( $m^3/day$ ) and the average is  $90.6m^3/day$ . The 90<sup>th</sup> percentile is  $205.9m^3/day$  and the 50<sup>th</sup> percentile (median) for daily abstraction is  $122m^3/day$ .

Groundwater occurs mainly in faults and associated shear zones as well as fractured contact zones between mafic and acidic rocks as well as dyke contact zones. The Complex in general has a low groundwater potential. Higher yielding boreholes (yield > 2l/s) occurs throughout the whole unit and could therefore not be correlated with any fault zones or diabase dykes as depicted on the geological map sheet for the area.

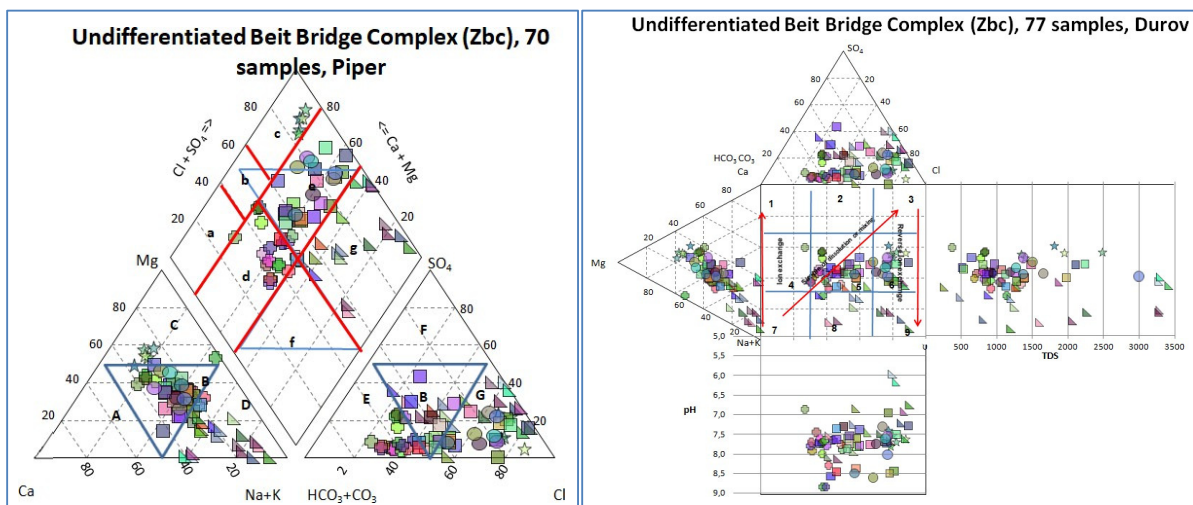


Figure 74: Trilinear diagrams, Piper, and Durov for the Undifferentiated Beit Bridge Complex (Zbc).

The trilinear Piper diagram, (Figure 74) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (72.9%), Weak acidic anions > Strong acidic anions (25.7%); Alkali > Alkali earths (27.1%); Strong acids > Weak acids (74.3%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with prevailing Sodium and Sulphate (27.2%),
- Sodium-Chloride type (27.1%),
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (25.7%),
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium and Sulphate (12.9%),
- Magnesium-Chloride type with prevailing Sulphate (7.1%).

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 (51%), plot along the dissolution or mixing line,
- Anion discriminant and Na dominate indicative of possible mixing or uncommon dissolution influences (30%),

- Cl dominant anion and Na dominant cation, indicative of reverse ion exchange of Na-Cl waters (10%),
- Cl and Na dominate; frequently indicate endpoint down gradient waters through dissolution (7%),
- SO<sub>4</sub> dominates, or anion discriminant and Ca dominant, frequently indicates recharged water in gypsiferous deposits or mixed water or water exhibiting simple dissolution (1%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 45: Chemical statistics for the Undifferentiated Beit Bridge Complex (Zbc)

Element / Parameter	Statistics Drawn from a population of 185 data points for the Undifferentiated Beit Bridge Complex (Zbc)										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	185	5,90	10,21	7,67	7,71	7,10	7,65	8,37	0,54	7,0%	
Electrical Conductivity (mS/m EC)	185	10,60	7069,00	144,82	282,15	94,20	166,00	459,22	559,58	198,3%	
Total Dissolved Salts (mg/l TDS)	179	210,00	5981,48	1068,09	1505,03	685,00	1136,96	2856,44	1046,86	69,6%	
Calcium (mg/l Ca)	176	5,10	964,30	68,61	134,01	40,42	88,32	287,60	135,88	101,4%	
Magnesium (mg/l Mg)	176	0,50	693,65	23,82	98,96	28,60	67,89	181,50	105,14	106,2%	
Sodium (mg/l Na)	176	2,86	1012,71	94,57	190,27	62,07	137,59	423,90	161,59	84,9%	
Potassium (mg/l K)	174	0,94	33,44	4,92	8,39	2,24	8,15	14,93	5,11	60,8%	
Chloride (mg/l Cl)	182	5,09	3721,49	113,64	401,30	54,28	191,15	944,92	557,00	138,8%	
Sulphate (mg/l SO <sub>4</sub> )	178	1,00	1421,27	30,33	140,07	17,31	65,90	352,02	201,21	143,6%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	154	2,00	1227,20	81,99	286,07	164,30	289,05	399,93	127,91	44,7%	
Nitrate (mg/l N)	182	0,02	395,14	0,74	36,83	0,68	21,63	84,38	51,43	139,7%	
Fluoride (mg/l F)	180	0,10	5,85	0,75	1,23	0,39	1,04	2,17	0,87	70,9%	
Silicon as Si	166	0,59	48,97	23,62	35,51	22,05	37,41	44,94	9,77	27,5%	
Iron (Fe)	37	0,003	0,224	0,006	0,025	0,003	0,005	0,061	0,05	179,7%	
Manganese (Mn)	34	0,001	0,090	0,002	0,011	0,001	0,002	0,043	0,02	188,1%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	162	0,003	0,800	0,013	0,025	0,008	0,016	0,033	0,06	253,5%	
ZAR	176	0,17	20,05	2,15	3,36	1,28	2,65	6,01	2,90	86,4%	
LSI	150	Langelier Saturation Index (LSI)			Slightly Scaling		52,7%		Highly Scaling		0,0%
		Highly corrosive		2,7%	Slightly corrosive		4,7%	Balanced Corrosion		40,0%	

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 90<sup>th</sup> percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good (41.6%), marginal in (40%) and unacceptable in 18.4% of the analysis in terms of the Electrical conductivity (EC) with values ranging between 10.6 and 7067mS/m. The Total Dissolved Solids (TDS) is acceptable in 53.3% of the samples, (TDS ≤ 1200mg/l).

An evaluation of the major cations and anions from 185 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 51.6%; Fluoride (F >1.5mg/l) in 22.2%; Chloride (Cl > 600mg/l) in 18.7%; Sodium (Na > 400mg/l) in 10.8%; Calcium (Ca > 300) in 10.2%; Magnesium (Mg > 200mg/l) in 8% and Sulphate (SO<sub>4</sub> >600mg/l) in 4.5%. The pH value exceeds the maximum allowable limit in one sample; it is alkaline.

The Langelier Saturation Index (LSI) indicates that the water is corrosive (7.4%); predominantly slightly scaling (52.7%) and balanced (40%). The ZAR index indicates that 63.1% of the water is of a fair quality for irrigation (ZAR < 3).

The water abstracted supply people in rural farmsteads and lodges; the water is also abstracted for livestock and game watering. Large scale irrigation is along the Limpopo, Mokolo and Palala Rivers. Various rural villages are predominantly along, and east of the Palala River except Mothlasedi settlement that is located on the western side of the river. These villages obtain water from the Mmaletswai Regional Water Scheme that uses a combination of groundwater from boreholes and surface water from shallow wells and abstraction points within the Palala River.

### 7.2.3.9 UNDIFFERENTIATED MALALA DRIFT GROUP (Zma).

The Undifferentiated Malala Drift Group underlies extensive parts of the Central Zone of the Limpopo Mobile Belt and consists predominantly of leucocratic quartz-feldspathic gneisses (leuco-gneiss), metaquartzite, pink granitoid hornblende gneiss, felsic granulite, metapelite, amphibolite or mafic granulite, and marble or calc-silicate rocks, which occur as subordinate intercalations. Leucocratic quartz-feldspathic gneiss is the most abundant rock type in the Central Zone and estimated to comprise approximately 50% of the gneisses present, (Brandl, 1996).

The gneiss consists of quartz, K-feldspar, and sodic plagioclase, with minor amounts of garnet, biotite, and sphene. The garnet, which is reddish-brown in colour, may be locally absent. Due to extensive soil and sandy overburden, exposures are poor, leading to part of the unit being included in the Undifferentiated Beit Bridge Complex.

Within the Lephalale map sheet the unit extent represents approximately 10% of its total occurrence, with the remaining portion falling within the Polokwane map sheet boundary. The unit occurs north-east on the Lephalale map sheet and north-west on the Polokwane map sheet. The section of the unit within the Lephalale map sheet covers  $\pm 6.1\%$  of the total areal extent thereof (Figure 75).

It was decided to use all the available groundwater data within this map sheet and the adjacent map sheet for characterization. This is as the occurrences on both sheets are within the same area and it is connected, thus the hydrogeological settings are the same, (inset map Figure 75).

The groundwater potential of the groundwater resource unit is poor to moderate with 60.7% of boreholes yielding less than 2ℓ/s and 39.3% yielding more than 2ℓ/s, (Figure 76). In 41.3% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit, the primary concern is the anion Nitrate.

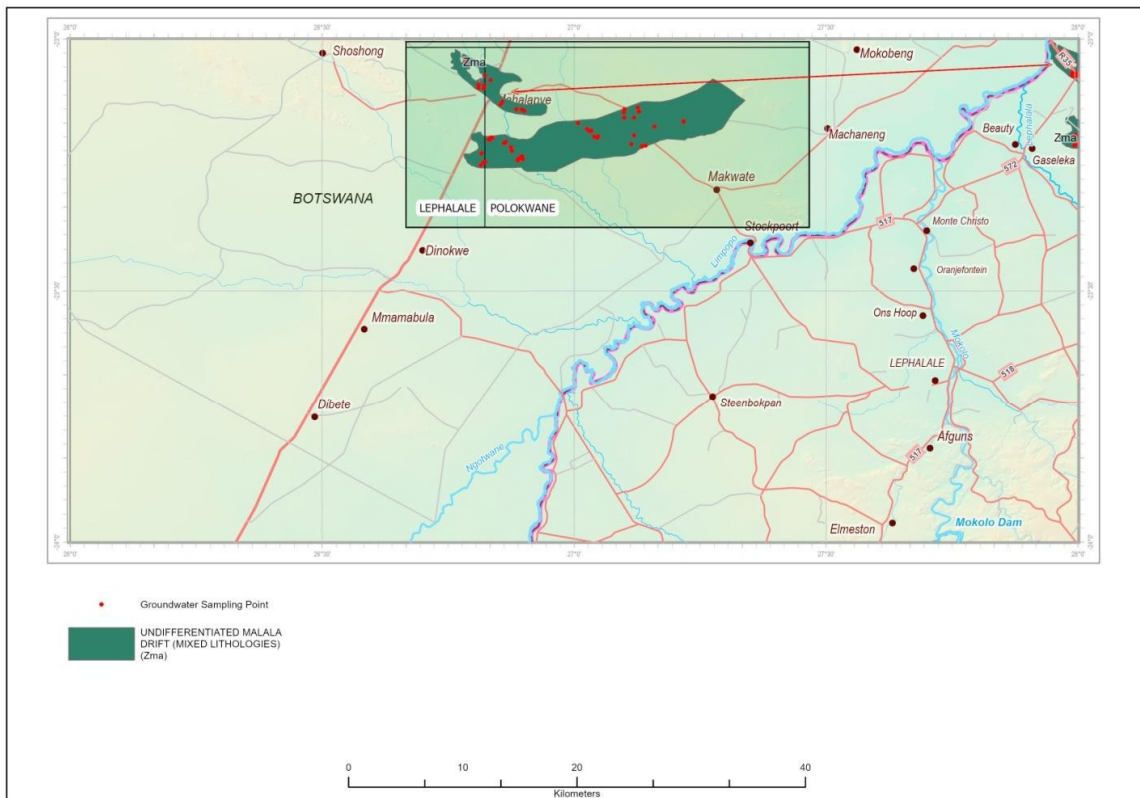


Figure 75: Geographical distribution of the Undifferentiated Malala Drift Group (Zma) and associated groundwater sampling points.

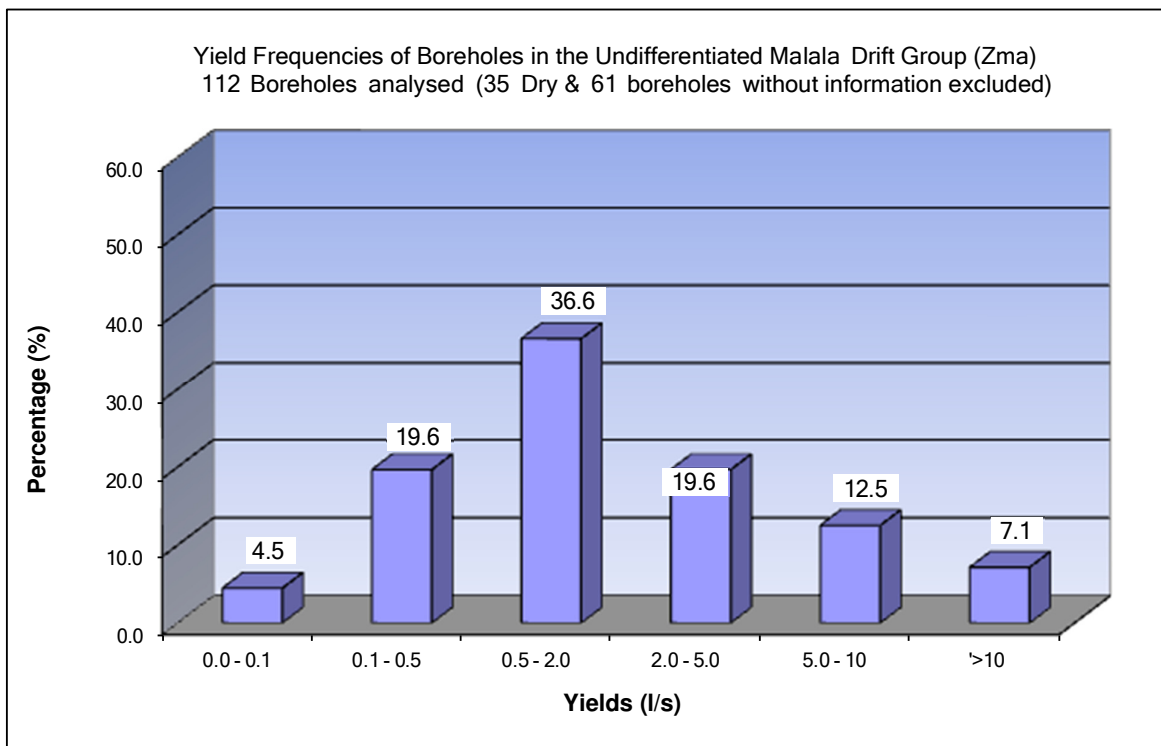


Figure 76: Yield frequency for the intergranular and fractured aquifers of the Undifferentiated Malala Drift Group (Zma).

Statistics indicate that 36.6%, (Figure 76) of the successful borehole yields between 0.5l/s to 2l/s. A further 21.1% of the boreholes yield less than 0.5l/s, with 19.6% yielding between 2l/s to 5l/s and 19.6% of the boreholes have yields exceeding 5l/s.

The static water level ranges from 2.46 meters below ground level (mbgl) to 49.13mbgl, with a median of 15.16mbgl and an average static water level of 16.89mbgl (based on 48 data points). The maximum depth recorded is 179.70m, with an average depth of 74.76m and a median depth of 63.0m (70 data points). The maximum installation depth is 100m and with an average installation depth of 36.37m (45 data points).

The maximum recommended daily abstraction on record is 561.6 cubic meters per day (m<sup>3</sup>/day). The 80<sup>th</sup> percentile for the recommended daily abstraction is 198.7m<sup>3</sup>/day and the average daily abstraction volume is 107.9m<sup>3</sup>/day. The total number of boreholes subjected to pump testing within this unit on record is 45.

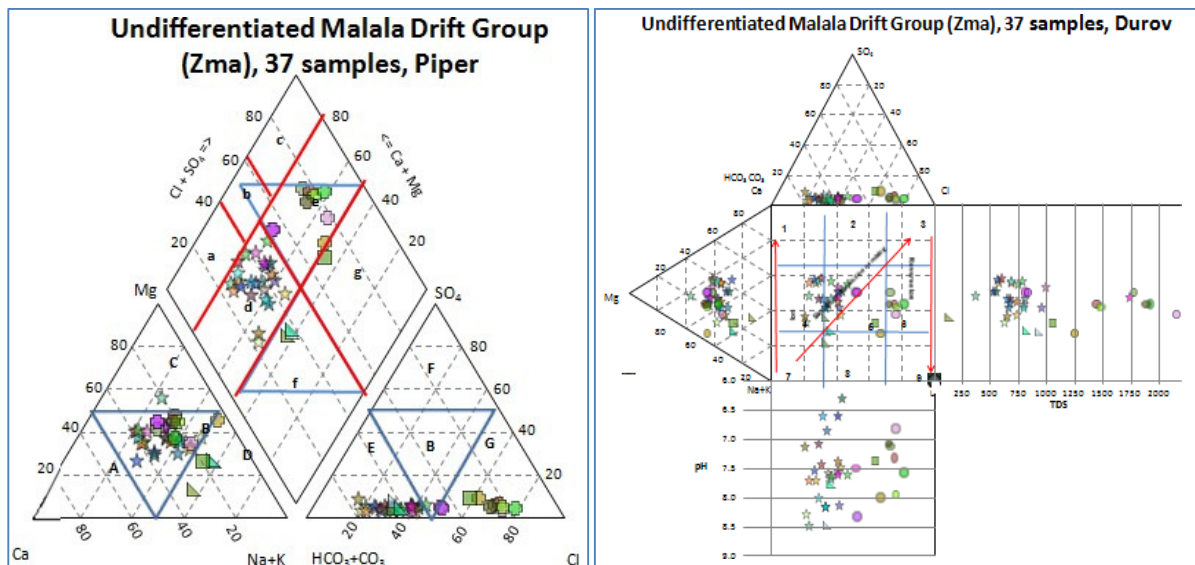


Figure 77: Trilinear diagrams, Piper and Durov for the Undifferentiated Malala Drift Group (Zma), 37 data points.

The trilinear Piper diagram, (Figure 77) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (89.2%), Weak acidic anions > Strong acidic anions (73%); Alkali > Alkali earths (10.8%); Strong acids > Weak acids (27%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type with increasing Sodium (62.2%),
- Mixed Calcium-Magnesium-Chloride type with increasing Sodium (24.3%),
- Sodium-Bicarbonate type (8.1%),
- Magnesium-Bicarbonate-Chloride type (2.7%),
- Sodium-Chloride type with (2.7%).

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

- No dominant anion or cation indicates fresh recent recharged water exhibiting simple dissolution or mixing (51.4%), plot along the dissolution or mixing line,
- SO<sub>4</sub> dominates, or anion discriminant and Ca dominant, frequently indicates recharged water in gypsiferous deposits or mixed water or water exhibiting simple dissolution (24.3%),

- Anion discriminant and Na dominate indicative of possible mixing or uncommon dissolution influences (16.2%),
- Cl dominant anion and Na dominant cation, indicative of reverse ion exchange of Na-Cl waters (8.1%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 46: Chemical statistics for the Undifferentiated Malala Drift Group (Zma).

Element / Parameter	Statistics Drawn from a population of 83 data points for the Undifferentiated Malala Drift Group (Zma).										
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 <sup>th</sup> percentile	50 <sup>th</sup> percentile (median)	90 <sup>th</sup> percentile	Standard Deviation	Coefficient of Variation	
pH	82	6.36	8.65	7.81	7.84	7.21	7.98	8.40	0.49	6.2%	
Electrical Conductivity (mS/m EC)	81	17.3	360.8	110.2	154.6	77.2	114.9	305.0	85.7	55.4%	
Total Dissolved Salts (mg/l TDS)	81	114.0	2557.2	787.8	1090.4	582.0	874.3	1927.0	538.3	49.4%	
Calcium (mg/l Ca)	75	11.46	228.32	60.85	86.89	38.36	75.10	147.28	44.47	51.2%	
Magnesium (mg/l Mg)	76	3.26	178.30	47.44	79.69	34.70	56.97	148.05	46.42	58.3%	
Sodium (mg/l Na)	77	21.40	373.80	84.68	116.41	51.28	93.83	233.59	72.37	62.2%	
Potassium (mg/l K)	76	0.23	24.01	1.98	6.39	0.82	5.34	12.30	5.32	83.3%	
Chloride (mg/l Cl)	82	13.80	789.09	73.71	182.06	32.11	91.53	471.82	199.74	109.7%	
Sulphate (mg/l SO <sub>4</sub> )	77	1.40	149.00	15.23	34.59	8.82	20.29	74.44	31.13	90.0%	
Total Alkalinity (mg/l CaCO <sub>3</sub> )	67	79.48	818.00	326.85	369.07	242.61	350.10	462.16	130.39	35.3%	
Nitrate (mg/l N)	80	0.02	233.63	1.32	32.28	3.13	18.43	92.88	40.43	125.3%	
Fluoride (mg/l F)	80	0.04	1.65	0.43	0.70	0.27	0.69	1.17	0.35	50.3%	
Silicon as Si	74	18.66	53.92	35.84	37.26	28.86	37.09	45.34	6.81	18.3%	
Iron (Fe)	34	0.002	0.881	0.007	0.040	0.003	0.010	0.050	0.149	374.0%	
Manganese (Mn)	33	0.001	0.590	0.002	0.038	0.001	0.004	0.058	0.112	296.0%	
Ortho Phosphate as Phosphorus as PO <sub>4</sub>	72	0.003	0.800	0.016	0.056	0.008	0.025	0.077	0.132	237.4%	
ZAR	76	0.66	5.17	1.83	2.19	1.21	1.91	4.03	1.00	45.4%	
LSI	67	Langelier Saturation Index (LSI)			Slightly Scaling		77.6%		Highly Scaling		0.0%
		Highly corrosive		0.0%	Slightly corrosive		1.5%	Balanced Corrosion		20.9%	

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 90<sup>th</sup> 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, (61.7%) and marginal is 38.3 of the analysis with Electrical conductivity (EC) values varying between 17.3 and 360.8mS/m. The 90<sup>th</sup> percentile is 305mS/m.

The Total Dissolved Solids (TDS) is acceptable in 65.4% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 83 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 41.3%; Chloride (Cl > 600mg/l) in 6.1% and Fluoride (F >1.5mg/l) in 2.5% and of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive (1.5%); predominantly slightly scaling (77.6%) and balanced (20.9%). The ZAR index indicates that 80.3% of the water is of a fair quality for irrigation (ZAR < 3).

Water supplied by groundwater sources are used for farmsteads, livestock, and game watering. No irrigation takes place on the farms underlain by this unit. Regionally large-scale irrigation is along the Limpopo, Mokolo and Palala Rivers.

### 7.2.3.10 MOUNT DOWE GROUP (Zmd)

This Group, probably at the base of the Beit Bridge Complex, is characterised by the presence of thick layers of metaquartzite containing minor interlayered horizons of magnetite quartzite, leucocratic quartz-feldspathic gneiss, metapelite, amphibolite or mafic granulite, and marble or calc-silicate rocks. Due to its resistance to weathering metaquartzite forms topographic features, exposures are however limited. The unit covers  $\pm 1.8\%$  of the map area and occurs in the north-eastern section of the map sheet, (Figure 78).

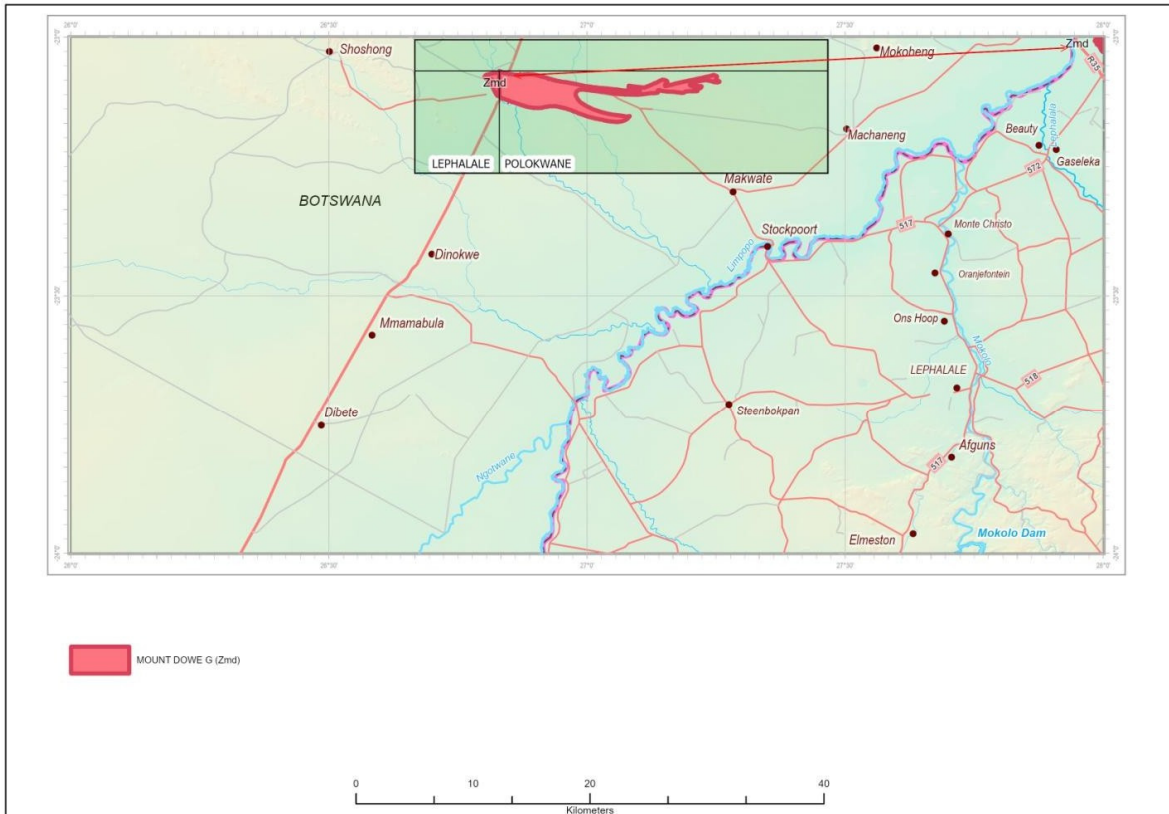


Figure 78: Geographical distribution of the Mount Dowe Group (Zmd) and associated groundwater sampling points.

No chemical or yield data is available within the map sheet area to characterize the unit. Within the adjacent 1:250 000 Polokwane hydrogeological map sheet more detailed information can be obtained in regard to the potential and water quality of the unit.

## 8. SPRINGS AND ARTESIAN BOREHOLES

### 8.1 Hot Springs

Of the 90 (Kent, 1968) known hot springs in the Republic of South Africa, none occurs on the Lephale Hydrogeological map sheet.

### 8.2 Cold Springs

No cold springs are listed on the Lephale Hydrogeological map sheet.

### 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. The groundwater is confined and 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).

From the evaluation of static water levels available for the map sheet a total of 6 Artesian boreholes were identified. Information regarding other artesian boreholes was obtained from old reports. A list of artesian boreholes is as follows:

- Werkendam 474 LQ, just north of Lephalale (Ellisras). Identified by Meyer 1976
- Zeekoevley, approximately 42km west-north-west of Lephalale and approximately 2.5km east of the Limpopo River. In total two boreholes occur within a distance of 1.2km from each other. Various other boreholes in a 2.5km radius on record are not artesian with recorded water levels ranging from 7.86mbgl to 22.2mbgl.
- Leeufontein, approximately 19km north of Lephalale.
- Waterkloof, within Lephalale.
- Vogelstruisfontein, approximately 5km north of Lephalale.

Another 2 places were identified by Meyer in 1976.

- Schaapplaas 524 LQ
- Afguns 562 LQ

The hydrogeological conditions at each of the areas are as follows, that may explain the phenomenon.

At **Werkendam** various artesian boreholes were reported in 1976. In this area impervious Karoo sediments overlie the water-bearing Waterberg sandstones. It is believed that these confined sandstone layers are recharged through fractures and along bedding planes at the higher mountainous areas where it outcrops. Due to the height differences between recharge and abstraction areas, the hydraulic pressure at the point of abstraction is higher than atmospheric pressure resulting in the surface outflow of groundwater where the impervious layer is punctured by drilling. The reported flow rates vary from less than 1l/s to a few liters per second. Not all the boreholes are artesian as the report lists a few boreholes with depths between 44 and 144m of which some were artesian but others not. In one of the boreholes drilled on the farm at the time, it was reported that the contact between Karoo sediments (black shale) and Waterberg sandstone was found at 137m. The borehole was not artesian as some of the others where the sandstone was found at shallower or deeper depths.

Numerous artesian boreholes were drilled in later years by DWS just south of Lephalale (Ellisras) encountering the same geological setting. This water has elevated Fluoride concentrations (DWA, 2009). This corresponds to the elevated Fluoride in 31.3% of the chemical analysis from boreholes in the Kransberg Subgroup Unit that underline the Karoo Formations in this area.

The hydrogeological setting that resulted in artesian conditions at the boreholes at **Waterkloof** (180m deep) and **Vogelstruisfontein** (291m deep) may be similar as reported at **Werkendam**. This area is also underlain by Waterberg Sediments at depth.

The artesian boreholes at **Zeekoevley** are underlain by the Swartrant Formation; the conditions may be the same as with the above. The reported blow yields at both boreholes are high (20 and 6.6ℓ/s) and depths of 88m and 100m. In a 3km radius 3 other boreholes have reported yields that is 2.8ℓ/s, 10ℓ/s and 20ℓ/s but with deeper static water (14-15mbgl). The depths of these boreholes are, however, not known. The hydrogeological setting at **Leeufontein** is not known; the area is underlain by Clarens sandstone, and the depth of the borehole is 100m. It is near (±500m) from the Mokolo River.

The occurrence of two artesian boreholes on the farms Schaapplaas and Afguns was investigated in 1976 by P.S. Meyer. It was reported that the actual positions were not known but that both boreholes were drilled in Waterberg sandstone. The borehole at Schaapplaas was drilled to a depth of 150m with the water strike at 148m resulting in a blow yield of 2.25ℓ/s; at the time of reporting the borehole overflowed at a yield of 0.25ℓ/s. The borehole at Afguns was drilled to a depth of 126m with the water strike at 122m resulting in a blow yield of 3ℓ/s. At the time of reporting, the borehole overflowed at a yield of 2.69ℓ/s.

## 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 a 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). To some extent, the CWS 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 CMAs 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 of water use is compulsory reserving the right to the minister of DWS 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, non-commercial small gardens, livestock watering for subsistence use, (not feeding pens), storing and using run-off water from a roof, emergencies e.g., firefighting, 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. An 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 DWS of their usage and DWS 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 on 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 water 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-period and 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 25 liters/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 impacts 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” (DWA 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.

Each resource unit is assigned a class that represents the required level of protection for the water resource, as well as the extent to which it can be used. This classification serves two key purposes: it defines the current status of the resource unit and outlines the desired future state for sustainable management. The classification process involves active stakeholder participation and consultation. It is essential for users to understand the current condition of the resource and to collaboratively determine the desired future condition, ensuring that development and usage are balanced with the need to prevent environmental degradation.

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 liters/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 quality and quantity, 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. According to DWS' records there are currently 20 monitoring stations falling within the Lephalale map of which 6 are equipped with electrical data loggers, 4 with Autographic recorders, and the rest with no monitoring equipment, (Figure 79). The DWS is responsible for setting 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 DWS 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.

Table 47: Active and inactive DWS monitoring boreholes.

Location	Station Number	Borehole number	Latitude	Longitude	Status	Monitoring	Date start	Date end	Installation date	Monitoring Equipment
Van Wyksfontein Ptn. Tom Burke	A5N0012	M03-3759	-23.063970	28.011200	In use	Active	20080220		20080220	Electrical Data Logger
Haakdoomkuil Ptn. Kitty	A5N0009	M21-0592	-23.354990	28.127960	In use	Active	20060628		20061013	Electrical Data Logger
Kildare	A5N0018	M03-3975	-23.094290	28.231850	In use	Active	20120523		20120523	Electrical Data Logger
Bonteberg	A6N0580	M03-3709	-23.195790	28.400440	In use	Active	20071120		20070619	Electrical Data Logger
Goedgelegen	A6N0598	M03-3767	-23.445556	28.408611	In use	Active	20080206		20080221	Electrical Data Logger
Duren	A6N0578	M03-2545	-23.376240	28.658350	In use	Active	19960711		20060317	Electrical Data Logger
Les Fontains Ptn. Sekhung	A6N0582	M11-2355	-23.149530	28.773870	Inaccessible	Not Active	20070125	20220922	20220922	Electrical Data Logger
Tuskow	A6N0571	H11-1745	-23.023611	28.873611	Unused	Not Active	20011121	20050503	20050503	(Not set)
Norma Portion Setlaole Village	A6N0569	H04-1461	-23.381944	28.938333	Unused	Not Active	20010124	20020117	20010124	Autographic Recorder
Udney Ptn. Sekiding	A7N0648	M11-2100	-23.191890	28.958890	In use	Active	20050118		20050118	Electrical Data Logger
Bugnufuran Ptn. Sekiding	A7N0640	M11-2101	-23.190556	28.959722	Unused	Not Active	20050118	20070201	20070201	No equipment
Beauley	A7N0634	M11-1223	-23.121500	28.987200	In use	Active	20041201		20041201	Electrical Data Logger

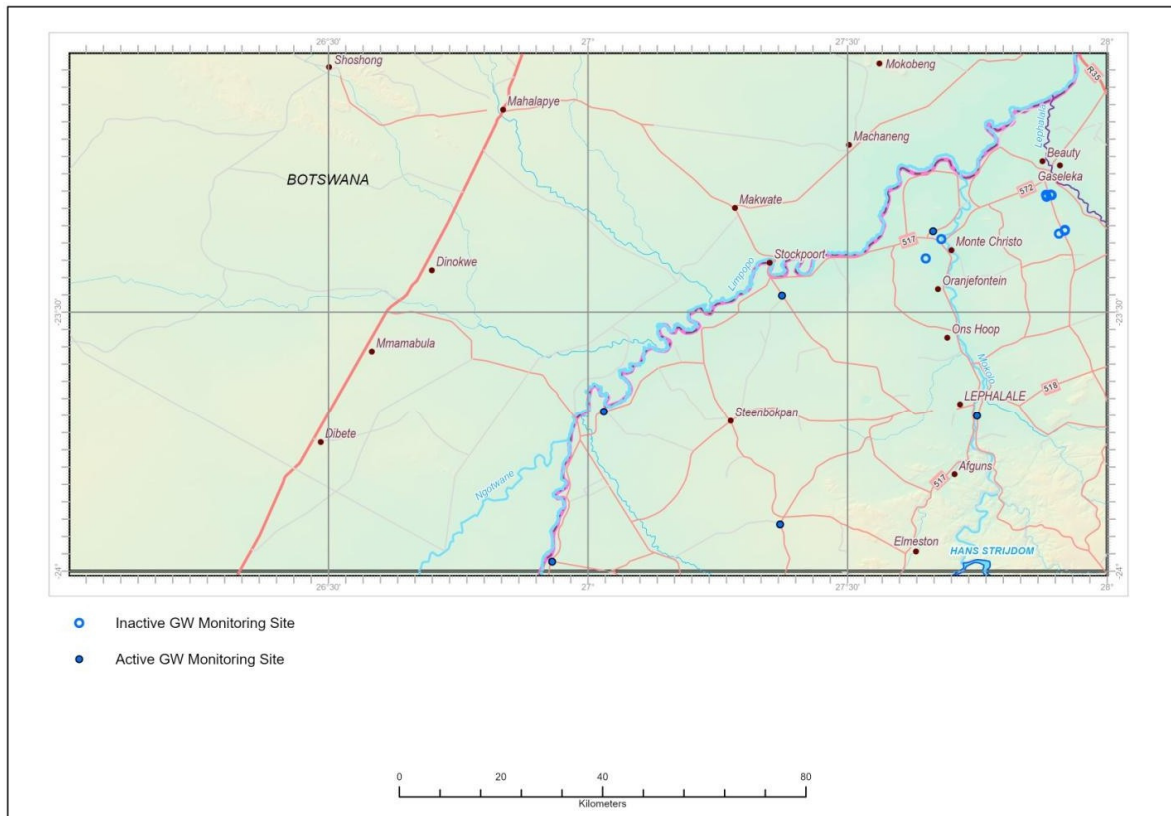


Figure 79: DWS monitoring boreholes.

## 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 Lephalale 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. The major rivers are the Limpopo River and tributaries namely the Matlabas, Mokolo and Palala. The Mokolo River is fed by various tributaries namely the Bulspruit, Rietspruit, Sandloop, Poer se Loop and Tambotie Rivers. The tributaries arise in the Waterberg Plateau in the south-western section of the map area.

West of the Limpopo River and within Botswana the tributaries are the Ngotwane, Bonwapitse, Mhalatswe and Taupye Rivers

Recharge must be seen as a seasonal occurrence mostly when the rivers flow during the rainy season. In some cases, groundwater is "lost" to rivers through seepage and springs thus contributing to base flow. However, depending on the circumstances it has been observed that dams, especially earth dams, are major local contributors to groundwater recharge. Water level responses to rainfall events sometimes show a time lapse, as the percolation of water through the unsaturated zone to the saturated zone takes time.

Some irrigation farmers along the Limpopo River dug trenches along the river that act as earth dams. This may contribute to recharge along the river. Where artificial recharge from earth dams is planned, various favorable conditions must be present such as, that sufficient sub-surface storage must be available. 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 considered 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.

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.

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 decreases 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 within the Lephalale map sheet 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 a cone 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 into this document, (Figure 80). The recharge-related numbers obtained on the Vegter map for Lephalale, was used to determine the estimated mean annual recharge for the Lephalale map sheet.

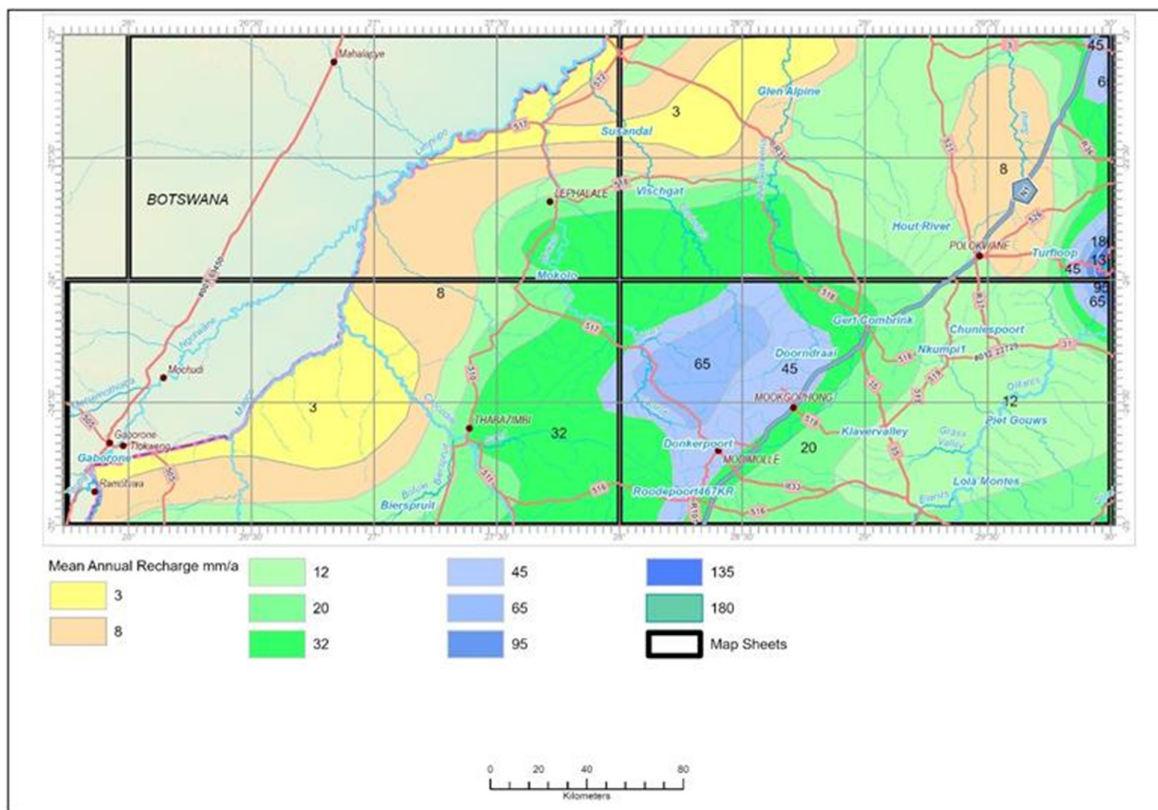


Figure 80: Mean annual recharge in mm for the four, 1:250 000 maps that is the upgrade for the 1:500 000 Polokwane hydrogeological map (after Vegter, 1995). Lephalale map area is at the top left.

Table 48: 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 in zone	Mean annual Recharge in zone
mm/annum	m/annum	km <sup>2</sup>	m <sup>2</sup>	m <sup>3</sup>	Mm <sup>3</sup> /annum
12	0,012	803,149	803149000	9637788	9,64
20	0,02	795,84	795840000	15916800	15,92
32	0,032	1088,02	1088020000	34816640	34,82
8	0,008	3759,38	3759380000	30075040	30,07
3	0,003	1220,74	1220740000	3662220	3,66
		<b>7667,129</b>			<b>94,11</b>

Vegter divided the Lephalale map into 5 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 Lephalale map, which amounts to 94.11 million cubic meters per annum (94.11Mm<sup>3</sup>/annum), (Table 48).

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.

Specialist hydrogeological reports accompanying e-WULAAS in the Lephalale area were made available by DWS. The groundwater data were abstracted from these 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). Similar to Vegter's method, the Lephalale map area was divided into several safe abstraction zones. These zones have a minimum and a maximum volume (similar to the GRAII set that refers to the minimum and maximum volume as 'dry' and 'wet' to take into consideration seasonal fluctuations in rainfall). Table 51 represent the minimum and maximum volume (m<sup>3</sup>/km<sup>2</sup>/annum) that can be safely abstracted without depleting the aquifer. In practice the average volume is mostly used.

### 9.3 Borehole siting

Table 49 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 are 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 49: Geophysical survey techniques that can be employed 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	*	**	**	**	***		**
Lisbon Formation	Trl	B	*	**	**	**	***		**
Greenwich Formation	Trg	D	*	**	**	**	***		**
Eendragtpan Formation	Tre	B	*	**	**	**	***		**
Grootegeluk Formation	Pgr	B	*	**	**	**	***		**
Goedgedacht Formation	Pgo	B	*	**	**	**	***		**
Swartrant Formation	Psr	B	*	**	**	**	***		**
Wellington Formation	C-Pwe	B	*	**	**	**	***		**
Cleremont Formation	Mcl	B	*	**	**	**	***		**
Kransberg Sub-Group (Mogalakwena Formation)	Mkr	B	*	**	**	**	***		**
Aasvoëlkop Formation	Mas	B	*	**	**	**	***		**
Diabase	N-Za	D	**	**	***	**	***		** sill
Glenover Complex	Msc	D	**	**	***	**	***		
Palala Granite	Mpa	D	**	**	***	**	***		
Nebo Granite	Mn	D	**	**	***	**	***		
Villa Nora Gabbro- Anorthosite	Vv	D	**	**	***	**	***		
<i>Messina Suite</i>	<i>Zms</i>	D	**	**	***	**	***		
<i>Undifferentiated Beit Bridge Complex, Malala Drift, Mount Dowe Groups</i>	Zbc, Zma, Zmd	D	**	**	***	**	***		

**The geophysical methods are 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 associated with groundwater occurrence are described for most hydrogeological units in Chapter 7. The success of identifying these targets is enhanced by incorporating additional scientific tools such as aerial photographs, LANDSAT images, Terra ASTER satellite imagery, geological and hydrogeological maps, existing data for the area, and aeromagnetic surveys. 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, when targeting a diabase dyke, differences in magnetic susceptibility between the host rock and the dyke can often produce a detectable anomaly. However, if the contact zone is fused together without secondary fracturing, the borehole may yield no water despite the correct identification of the geological target.

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 Groundwater management**

The new Water Act states that 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 at a local level Catchment Managing Agencies (CMAs) and Water User Associations (WUAs) must be established that operate under the framework of the NWS and DWS guidelines. The CMA is responsible for a water allocation plan within their catchments and a Catchment Water Strategy (CWS) that is like 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 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 that include local authorities, such as the Lephalale (Ellisras) and Thabazimbi Local Municipalities; Mining, such as Grootegeluk Coal Mine and Glenover Phosphate Mine; Power Generation, such as the Medupi Power Station; farming. Throughout the map area large scale farming occurs, many of these are legal water users or in the process to apply.

During the period or at the renewal date of the water user license, DWS 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 Resource Quality Services (formerly the Institute for Water Quality Studies).

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 manage 16 monitoring boreholes in the map area of which some are equipped with electronic data loggers within the map sheet area (Figure 79). The data are available on request from the Department's National Groundwater Archive (NGA) in Pretoria.

#### **9.4.1 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 to groundwater resources. Like surface water, groundwater is highly vulnerable to contamination, and rehabilitating an aquifer once polluted is difficult and costly.

The Environmental Act follows the "polluter pays" principle, holding companies responsible for rehabilitation costs. Managers of companies that degrade the environment can be held accountable even after many years.

In the modelling of pollution mitigation sources, pollution sources are classified at first according to its 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 Lephalale town and some of the smaller settlements 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 occur in the Matlabas areas. The occurrences are displayed on the inset map sheet (Figure 8, page 47).

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 Lephalale (Grootegeluk Coal Mine) and at the Glenover Complex are all potential sources of pollution if not properly managed.

#### 9.4.2 Groundwater utilization

Groundwater over a large section of the map sheet is in many cases the only source of supply, especially for rural farms. Water in these areas are predominantly used for game, livestock, homesteads and some lodges.

Along the major rivers, Limpopo and its tributaries large sections of irrigation fields can be seen using Google Earth. The source of water for irrigation is from surface water in the wet periods when the rivers are flowing. In dry periods water is abstracted from the alluvial sands. The underlying geology and especially the transported sediments is one of the controlling factors in the potential of the alluvium. Along the Limpopo River a notable difference increase can be seen in irrigation along the river north to north-west of the underlying finer grained Karoo Sediments. The areas where basement gneisses or intrusive granites occur, more irrigation fields can be observed. This is as these rocks are the source of coarser grained sands to gravel for the alluvial aquifer. The coarser grained alluvium is one of the factors for increasing in the potential of the alluvial aquifers in those areas.

Irrigation along the Mokolo River is highly dependable on surface water releases from the Mokolo Dam (Hans Strijdom Dam). The storage within the alluvial is not sufficient to sustain abstraction along the river for extended periods.

For irrigation along the **Matlabas River** the finding was that the alluvium associated with the river is of little significance as an aquifer. Strong boreholes in these areas relate to structural geology.

Irrigation along the **Palala River** was obtained from a report that stated that water for irrigation was mostly from surface water. Although there are boreholes and shallow wells along and within the river the contribution was less than surface water. Structural geology can play a role in high yielding boreholes due to shear and fault zones in the region.

Around the Grootegeluk mine registered water dewatering, production (657kl/day) and monitoring boreholes occur; the water is primarily abstracted from the Clarens Formation north of the impermeable Daarby Fault zone. It also includes boreholes drilled through the basalt into the sandstone as well as boreholes within the Ecca Group located in the mine pit.

The water allocation from Mokolo Dam to Grootegeluk mine including Lephale is 10.1 Mm<sup>3</sup>/annum and for Matimba Power Station, it is 7.1 Mm<sup>3</sup>/annum. Water from the dam is also used for irrigation purposes.

The water catchment management areas with relevance to the Lephale Local Municipality (occupies 95% of the Map area) are the Matlabas, Mokolo, Lephale, Mogalakwena and Crocodile catchment. The existing raw water supply to the Lephale urban node is mainly the Mokolo dam whilst the rural node is supplied via groundwater sources. Due to water shortages in the Mokolo catchment, the Mokolo Crocodile Water Augmentation Project (MCWAP 2A) project was initiated to transfer water from the Crocodile catchment to the Mokolo catchment. The available surface water to the urban node (Lephale Local Municipality) with the completion of MCWAP 2A will be 13.88M<sup>3</sup>/year in 2040 or 38.03MI/d. The available groundwater in the Lephale catchment where the rural node is located is estimated at 99.4MI/d (available to all users in the catchment). In terms of the DWS MCWAP feasibility study, 3 groundwater studies were initiated in the Lephale area. From the results the sustainable delivery from the boreholes drilled in the rural settlements is 1.7Mm<sup>3</sup>/annum or 4.65MI/d. This equates to approximately 45 liters per person per day, (l/p/d), (IDP 2024-2025 Lephale Local Municipality).

Table 50: Localities where large-scale groundwater abstraction (>400 000 M<sup>3</sup>/a) are taking place.

LOCALITY/AREA	APPROXIMATE ABSTRACTION (10 <sup>6</sup> m <sup>3</sup> /a)	
	DOMESTIC	AGRICULTURAL
No large-scale abstraction areas/localities occur on the Lephale map		

#### 9.4.2.1 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 section of the map the harvest potential is between 5 000 and 10000m<sup>3</sup>/km<sup>2</sup>/annum. Within the Lephale map sheet, 3 harvest potential zones are depicted in Figure 81. Using the values and the aerial extent of each zone the harvest potential for the Polokwane map sheet was calculated. The safe abstraction is 34.921 million cubic meters per annum (Mm<sup>3</sup>/annum) that represent the low volume to 70.505Mm<sup>3</sup>/annum that represent the high volume. The average is 52.713Mm<sup>3</sup>/annum

Table 51: Harvest potential within the Lephalale map sheet.

Zone m <sup>3</sup> /km <sup>2</sup> /annum	Zone Areal extent km <sup>2</sup>	Minimum safe abstraction m <sup>3</sup>	Maximum safe abstraction m <sup>3</sup>	Minimum safe abstraction Mm <sup>3</sup>	Maximum safe abstraction Mm <sup>3</sup>
2 000 - 5 000	1213	2426000	6065000	2.426	6.065
5 000 - 10 000	6279	31395000	62790000	31.395	62.790
10 000 - 15 000	110	1100000	1650000	1.100	1.650
<b>Totals</b>	<b>7602</b>	<b>34921000</b>	<b>70505000</b>	<b>34.921</b>	<b>70.505</b>
				<b>Average:</b>	<b>52.713</b>

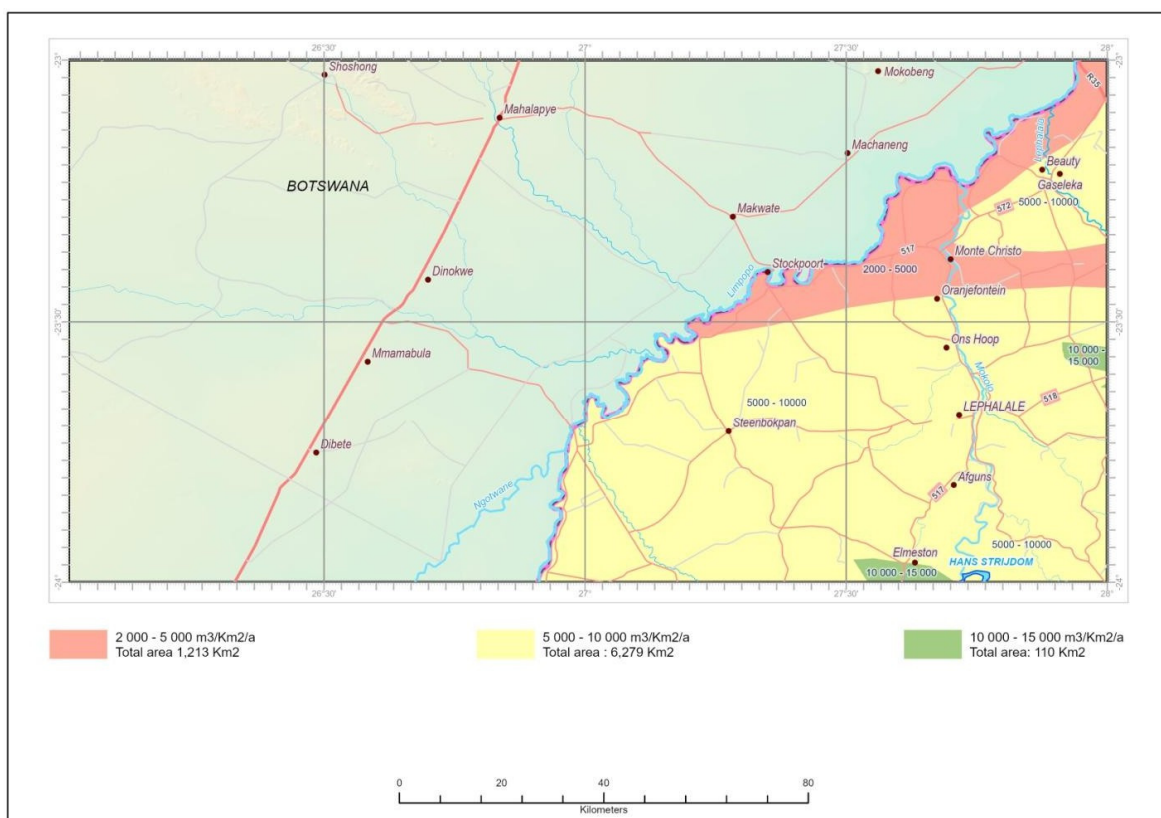


Figure 81: Harvest potential (A. Seymour and P. Seward, 1995)

### 9.5 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 accomplished by a strong groundwater database, monitoring of rainfall and water levels, updating 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, 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. Information shows that e-coli occurred in an analysis of a borehole that was more than 1km from the nearest village. The borehole is located on the Melinda Fault.

### **Groundwater Recharge and Artificial Recharge**

- Investigate the feasibility of artificial recharge interventions in areas experiencing high abstraction rates. This will be limited in the map area as the only major economic hub is Lephalale. Surface water is the major supply source to the area
- 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 hydro census 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.

### **Groundwater research project**

- Application of remote sensing techniques (LANDSAT imagery, etc.) for early identification of potential groundwater target areas,
- Further investigations in the Ellisras Karoo basin using 'available' aerial magnetic data. The objective will be to investigate the numerous subtle magnetic structures within the Karoo Sediments as potential water resources. This can be combined with exploration into the occurrence and utilization of possible deeply (>200m) seated aquifers,
- The above project may include investigations where the underlying non-Karoo Formations are expected to be less than 300m from the surface to investigate pre-Karoo erosion zones in the upper sections of the Waterberg Sedimentary rock or the Basement Granitoids or Gneissic rock.

### **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 website.

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