The Occurrence of Groundwater in the Limpopo Province North of Latitude 23°S

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DECLARATION

I hereby declare that this dissertation submitted for the degree Masters in the Faculty of Natural and Agricultural Sciences, Department of Geohydrology, University of the Free State, Bloemfontein, South Africa, is my own work and has not been submitted to any other institution of higher education. I further declare that all sources cited or quoted are indicated and acknowledged by means of a list of references.

C.J. Sonnekus
April 2012

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ABBREVIATIONS

DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
HARMEAN	Harmonic mean
IAH	International Association of Hydrogeologists
IAHS	International Association Hydrology Sciences
GRIP	Groundwater Resource Implementation Programme
mamsl	metres above mean sea level
mbgl	metres below ground level
NGDB	National Groundwater Data Base
SANS	South African National Standard
SACS	South African Committee Stratigraphy
TWQR	Target Water Quality Range
TDS	Total dissolved salts
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VES	Vertical Electrical Soundings
VSA	VSA Geoconsultants Group
WMS	Water Management System
WRPS	Water Resource Planning Systems

SYMBOLS AND UNITS

km^2	square kilometre
ℓ/s	litres per second
m	metres
Ma	million years
Mm^3	million cubic metre
meq	milli-equivalents
mg/ℓ	milligrams per litre
mS/m	milliSiemens per metre
m^3	cubic metre
pH	logarithm of the hydrogen ion concentration in moles per litre
s	seconds
%	percentage

CHEMICAL SYMBOLS

Al	Aluminium
As	Arsenic
Cd	Cadmium
Ca	Calcium
Cl	Chloride
Cu	Copper
F	Fluoride
Fe	Iron
TH	Total hardness
Mg	Magnesium
Mn	Manganese
NO_3	Nitrate
NO_2	Nitrite
N	Nitrate (NO_3) + Nitrite (NO_2)
K	Potassium
Na	Sodium
SO_4	Sulphate
Si	Silica
Zn	Zinc

Chapter 1 : Introduction

1.1 Introduction

Water is the most precious resource on earth as everything alive depends on it. The availability of water in even the remotest area is vital to maintain this indispensable requirement for existence.

An estimated 3% of fresh water available on earth occurs on the surface and 97% occurs underground (Johnson Division, 1975). Groundwater is an important resource in South Africa as precipitation is low and irregular over a large part of the country. 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 in order to comprehend how and where groundwater occurs.

This desk study on the occurrence of groundwater north of latitude S23º was made possible by the research done in compiling the explanatory brochure for the 1:500 000 Messina hydrogeological map sheet (Messina 2127). The amassed volume of groundwater data from various sources was evaluated to compile the brochure. With the permission of the Department of Water Affairs this study was done using the same data, with the brochure as basis and the map as reference. Twenty-nine hydrogeological units based on the occurrence of water in interstices were identified within the Messina map area. The geology of the area is diverse and the volume of available data impressive. Spatial distribution is moderate to very good, especially within the former homelands where the DWA was very actively involved with water supply from groundwater. The 1:500 000 Messina hydrogeological map sheet (Messina 2127) is available from DWA but at the time of writing the brochure has not yet been published. A copy of the map sheet is included in Chapter 10, (p181): Appendix.

The primary aim of hydrogeological maps is to produce a synoptic and visual overview of the geohydrological character of an area. The Messina Hydrogeological main map thus features borehole yield, aquifer type, groundwater quality, and groundwater use, which are superimposed against a slightly subdued surface lithological background. The brochure discusses these topics in more detail, as well as issues such as geological controls on groundwater yield and quality, borehole surveying methods, groundwater management, groundwater levels and suggestions for future studies. Hydrogeological maps should be informative to both the groundwater scientist, the interested layman and to planners, especially in the role local municipality's play in the supply of groundwater. It can also play a constructive role in general groundwater education and groundwater awareness building.

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 livestock watering purposes. In areas with high yields intercepted groundwater use was found to focus on irrigation. In lower yielding areas the use is for livestock or game farming. The largest river within the map area, the Limpopo River is an important surface source. When the river is dry, users depends on groundwater.

Plate 1: The confluence of the Shashi River and the Limpopo River, also known as Crookes Corner, currently part of the Greater Mapungubwe Transfrontier Conservation Area, photo taken from the South African side, Botswana left, Zimbabwe right. The Limpopo River (foreground) is the largest river within the map area. The Shashi River joins into the Limpopo River from the north. (Photograph: J.J. Van Zyl, 2007, Wikimedia).

1.2 Background

The research for the thesis emanated from a project funded by DWA entitled: Explanation of the 1:500 000 Messina hydrogeological map sheet (Messina 2127). Permission to use the map and hydrogeological information was given by DWA with the agreement that additional findings can be used to update the as yet, unpublished brochure. The point source groundwater data and some of the maps used for this study are the same as used in this brochure (all available data up to January 2011). The geographical extend and boundaries of the hydrogeological units, the description of the geology, the presentation of yield frequencies and stiff diagrams presenting the chemistry of each unit is the same as those compiled for the brochure.

The research on the occurrence of groundwater north of latitude 23ºS in the Limpopo Province represents an area of 2 498 969ha or 24 989.69km². Three international borders frame the area, Botswana in the west to north-west, Zimbabwe in the north and Mozambique in the east (**Figure 1**).

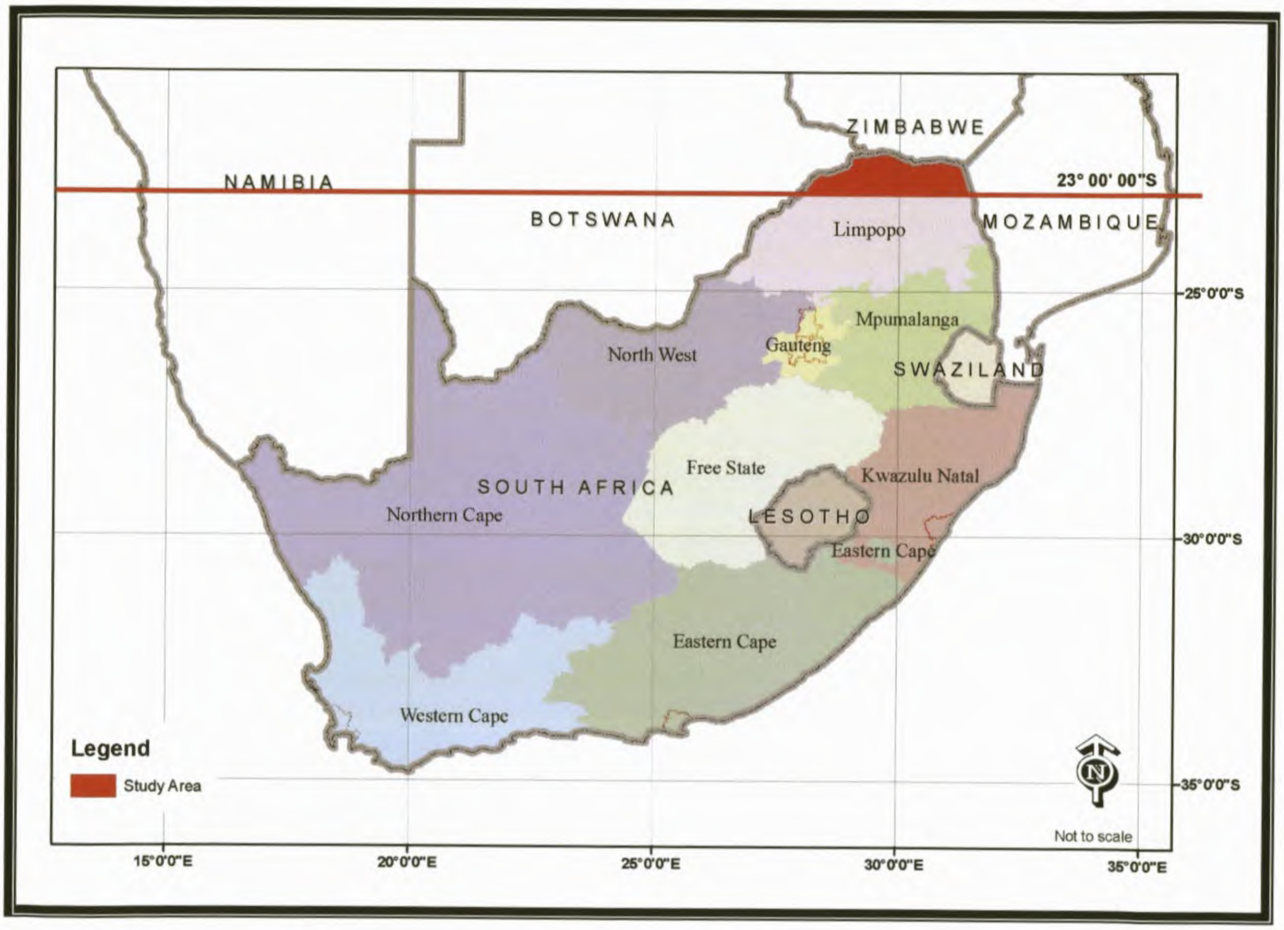


Figure 1: Locality map, depicting the area north of latitude 23ºS in the Limpopo Province.

1.2.1 Desk study and literature review

In the desk study phase hydrogeological maps were investigated and aspects such as the origin, development, purpose and objectives were researched and the findings included as part of the literature review. The UNESCO 1983 legend is an integral part of national and international hydrogeological map compilation and was therefore also researched and discussed.

The development of national groundwater maps in South Africa was investigated. Three South African maps are discussed namely; the National Groundwater Map and the accompanying published brochure (Vegter, 1995); the Groundwater Harvest Potential of The Republic of South Africa (Seward P, Baron J, Seymour A, 1996) and the 1:500 000 hydrogeological map sheet 2127 Messina (Du Toit, 1995).

Research on old hydrogeological projects relevant to the study area were done. Four were discussed as part of the literature study review. The projects include two regional and two site-specific investigations. The projects discussed are:

- Assessment of the Groundwater Resources in the proximity to Messina with particular reference to the Dowe-Tokwe Fault (Orpen and Fayazi, 1983).
- A Geohydrological Assessment of the Swartwater and Beauty Areas, N.W. Transvaal (Bush, 1989).
- Development of a water supply for Alldays from groundwater resources associated with the Taaibos Fault (Fayazi and Orpen, 1989).
- "Geohidrologie van die Nasionale Krugerwildtuin gebaseer op die Evaluering van bestaande Boorgatinligting' (Du Toit, 1998).

In the literature review, Chapter 4, (p55) is a discussion on geological concepts relevant to the study. The geology of the study area is complex and some of the processes that have an influence on the occurrence of groundwater are discussed.

1.3 Objectives

- To investigate the methods used to eliminate unwanted and poor data when working with large sets of data.
- To investigate existing hydrogeological maps as a method to present large volumes of groundwater data effectively.
- To research previous hydrogeological projects with special emphasis on field techniques used, data manipulation and presentation methods and findings that is relevant to the study area.
- To use the data and findings obtained in previous projects to assist in the characterization of the groundwater occurrence within the relevant hydrogeological units.
- To highlight the influence of large-scale geological processes related to the occurrence of groundwater. These processes influenced the regional and structural geology that in turn is influencing drainage, climate, vegetation and the quality and quantity of groundwater.
- To discuss the occurrence of groundwater using the 1:500 000 Messina hydrogeological map as reference (2127 Messina). A copy of the map is included in Chapter 10, (p181), Appendix. Permission to use the information and data of the map and the yet unpublished accompanying brochure was obtained from DWA.
- To present the data and research on the groundwater occurrence within each hydrogeological unit in such a way that it can be used by the layman and professional.

1.4 Structure of the Thesis

This thesis is structured as follows:

Chapter 1: Introduction

Background information extent of the study area, desk study background and the objectives of the thesis.

Chapter 2: Literature review hydrogeological maps

History of hydrogeological maps, investigating the techniques used in presenting vast amounts of data, UNESCO legend, existing groundwater maps including the National Groundwater Map, the Groundwater Harvest Potential of the Republic of South Africa, the Messina hydrogeological map.

Chapter 3: Literature review previous hydrogeological work done in the study area

Four case studies on previous hydrogeological work done in the area namely the Dowe Tokwe Fault, Beit Bridge Complex, Taaibos Fault and the Kruger National Park with special emphasis on data presentation methods, field methodology and findings.

Chapter 4: Literature review geological concepts

Important geological concepts that relates to the geology of the area and the discussion of the geology of each unit in the study. Aspects discussed include stratigraphy, the formation of rocks, stress, strain and the deformation of rocks, openings in rocks that lead to the occurrence of groundwater.

Chapter 5: The occurrence of groundwater north of latitude 23ºS

Study area, physical environment, regional geological settings, general hydrochemistry, characterization and detailed description of hydrogeological units divided and grouped in terms of occurrence, intergranular aquifers, fractured aquifers, karst aquifers and intergranular and fractured aquifers.

Chapter 6: springs and artesian boreholes

Description and occurrences of hot springs, cold springs and artesian boreholes within the study area.

Chapter 7: Groundwater management

In this chapter the aspects and concept of groundwater management is discussed in brief. Topics include groundwater contamination and pollution, groundwater use, current monitoring, geophysical methods used in the past and future groundwater exploration.

Chapter 8: References

The references used to obtain data and information for the research are listed. Within the document a reference is given where the relevant authors are quoted directly. Parts of the geological descriptions for some of the units could not be attributed to an author as DWA obtained the descriptions commercially from The Council of Geosciences. DWA gave permission for this data to be used in the thesis.

Chapter 9: Final summary

A short final summary in English and Afrikaans.

Chapter 10: Appendix

Appendix: CD containing data sheets, a copy of the Messina Hydrogeological map and this report.

Chapter 2 : Literature review - hydrogeological maps

2.1 Hydrogeological maps

In South Africa, a large volume of groundwater data is available on various data systems such as the DWA National Groundwater Archive. Through government-sponsored projects, such as the Groundwater Resource Information Programme, new data is added almost on a daily basis. This data must be readily available to interested parties in a format that will be understandable. Globally, hydrogeologists have the same need to present data that led to the development of hydrogeological maps. These maps envision the characteristics of aquifers on a regional basis.

Hydrogeological map sheets, internationally or locally, must use the same methodology from data interpretation to final map compilation. Individual maps usually form part of a combined hydrogeological mapping project such as the International Hydrogeological Map of Europe: scale 1:500 000. Hydrogeologists had difficulty in reaching an agreement on how to present data on a universally accepted map. This was evident in the long period it took to develop a universally usable legend. This process started in 1959 and the revised legend was finally published in 1983 (UNESCO legend, 1983).

The 1:500 000 hydrogeological map sheet 2127 Messina (Du Toit, 1995) is the first hydrogeological map produced to depict groundwater resources in the area north of latitude 23ºS in the Limpopo Province. A working group under the guidance of DWA compiled the Messina map. The National Groundwater Map (Vegter 1995) and the Harvest Potential Map (Seward et al, 1996) are national maps covering the entire South Africa. Other maps are mostly compiled to project requirements covering small to district size areas. These include feasibility studies, mining projects, regional and local groundwater source developments, as well as various investigations on extensive fault zones.

The occurrences of groundwater are more complex and heterogeneous than can be shown on any map sheet. An explanation brochure is a necessary annexure intending to enhance the map by giving additional information that cannot be included on the map within a pre-determined framework or format. In the case of the Messina map sheep the compiled brochure (not published at time of writing) discusses each of the 29 hydrogeological units in more detail. This detail includes geology, groundwater targets, structural geology, quantity and chemical diagrams and findings of other groundwater projects done in the past.

2.2 History of hydrogeological maps

From the 1940's, the first attempts to illustrate the characteristics of groundwater on maps were made in various European countries. The scales of the maps varied widely between 1:25 000 and 1:200 000 with a few maps up to 1:500 000. These maps were produced for local developments as a basis for planning due to the pressure of increasing demand on resources from the domestic and agriculture sectors (Grahmann, 1952-1957).

The International Association of Hydrogeologists (IAH) established a commission for Hydrogeological maps in 1959 to prepare a universal legend of recommended symbols, ornaments and colours and to plan a set of small-scale maps to cover the whole of Europe (Anon, 1963). A working group was set up to oversee these projects. At the time, the International Association of Hydrological Sciences (IAHS) established within their Commission for Underground Water a permanent standing committee on hydrogeological maps. Both the standing committee and working group decided to use the legend produced for the hydrogeological maps of Morocco as a starting point (Ambroggi and Margat, 1960).

The project to compile a series of maps representing the regional hydrogeological setting for Europe, irrespective of political boundaries, became a reality during 1960 at the XXI International Geological Congress in Copenhagen when the IAH commission was appointed to prepare a small-scale hydrogeological map series covering Europe. The diversity in ideas to present groundwater data on a map became apparent during a meeting of the IAHS in 1961 where approximately 200 hydrological and hydrogeological maps were displayed. A survey was initiated by the IAH, trying to determine the techniques used in preparing these maps by circulating a questionnaire to hydrogeologists from various countries. The result of the survey highlighted the diversity of opinions as most ideas were based on localized projects not considering a universal view. It became apparent that the expression of theoretical concepts on a two dimensional map had practical difficulties that were to be solved (UNESCO Legend, 1993).

International coordination and agreement was needed on the methods to present hydrogeological information and which hydrogeological features were of sufficient importance to be depicted on a map when occurring within the area covered. A draft legend for maps was only published in 1963 by UNESCO after a joint meeting held in Paris during 1962 where the IAH and IAHS reached an agreement on a draft legend (Anon, 1963).

This draft legend was partly based on theoretical considerations rather that practical experience. The IAH commission used the preparation of the European maps as a practical test and map sheet C5 Bern was used as a prototype due to a high level of geological variations and good data coverage. From 1962 to 1964, various international hydrogeologists were involved in creating four different examples on a 1:500 000 scale. The first two examples named model 1 and 2 were presented in New Deli during the 1964 international congress. Model 1 had notes in the legend depicting permeability and other hydrogeological data for each formation. Model 2 show potential source yields in each formation. Both models 1 and 2 were not accepted in general (Karrenberg, 1964). During 1965 a third model was produced depicting aquifers as good, moderate and poor (including aquitard). Due to the disagreement on what constitute a good, moderate and poor aquifer a joint meeting of the IAH working group and the IAHS committee decided in 1966 to differentiate aquifers based on fractured and intergranular flow, extensive aquifers with large, localized or discontinuous resources. Fundamentally, the change was to move away from well yields towards aquifers and groundwater resources. Model 4 was thus accepted as the prototype for the planned series (25 map sheets) of The International Hydrogeological Map of Europe scale 1:500 000. The final version of map sheet C5 Bern was published in 1970 (Karrenberg, Deutloff, Stempel, 1974). Not all the information could be shown on the map leading to the publication of explanatory notes (brochure) in 1974. The explanatory notes become standard accompaniments with the map sheets (Karrenberg et al, 1974).

During 1967 at a joint meeting of the IAH working group and the IAHS committee new symbols and ornaments for Karst areas, arid zones and for other outstanding hydrogeological aspects was considered leading to a revised draft published in 1970 in the United Kingdom under supervision of the Institute of Geological Sciences (Karrenberg et al, 1974). This draft had limitations, as some lithologies of strata depicted on hydrogeological maps were more complex, requiring additional symbols to quantify groundwater resources, illustrating groundwater flow and accommodating ideas on aquifer protection. An unpublished additional list of symbols and ornaments were prepared in 1974 for use of the editors of the European map series (Karrenberg et al, 1974). UNESCO published a final revised legend in 1983 (UNESCO Legend, 1993).

2.2.1 The international legend for hydrogeological maps

Most of the information was obtained from UNESCO 1983 (anonymous, 1983) revised edition of the international legend for hydrogeological maps. A short summary of the most important aspects follows:

Legend
The legend should be in line with the international agreed means for displaying information in map form. Maps could be local, regional, national or international and usually vary in scale from small

(1: 1000 000) to large (1:250 000). Hydrogeological maps intend to depict groundwater resources in an understandable and usable way for a variety of users, including the layman and professional.

Main map

The main map should display the hydrogeological character of an area in relation to the geology according to legend requirements. The geology should be subdued and the hydrogeological features should be prominent. The aerial extent of the study area will influence the scale of the map that will in turn influence the information detail that can be depicted. Maps can consist of any information that could lead to a better understanding of the occurrence, movement, quality and quantity of groundwater resources. Another decisive factor in the choice of scale is data coverage and quality.

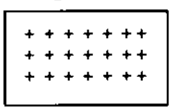
Inset maps

Due to the complexity and variation in the occurrence of groundwater and other natural factors, inset maps are the ideal way to depict data that can not be included on the main map. Good examples are rainfall, evaporation, topography, aspects of groundwater chemistry, distribution of data points used and geological cross sections. In the case of the Messina hydrogeological map sheet (2127 Messina) the working group decided to include an inset map showing the hydrogeological units of the Soutpansberg Supergroup in more detail, including some of the major fault zones. This subdivision and additional information were not allowed for inclusion on the main map due to the conformity required.

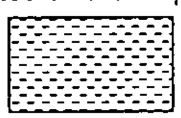
Definitions for Cartographies

Ornament a pattern of marks, lines or other symbols representing the occurrence of a particular factor over an area of ground as represented on the map.

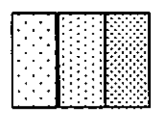
Examples:



Basic intrusive



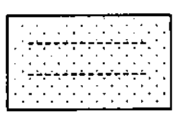
Clay, mud, silt



sands

Sands: Variation in thickness of points can distinguish different units.

Example of a combination:



Clay, mud, silt and sand combination

Symbol a single graphic representation to donate the presence of a particular factor at a point location on the map e.g. a small circle to show the location of a spring.

Example: O Non–perennial spring

Line a solid or broken line may be used to either to delimit an area such as a geological unit or to join points of equal values such as elevation (contour).

Sign a sign may consist of a line, symbol, ornament or a combination of all these.

Colour Constant tone or wash. Colour can be used for differences and can be applied for lines, symbols or ornaments. It can also be used to emphasise areas of importance.

Tone The value of the tone is expressed as a percentage of the full (100%) colour.

Background information

Background information is usually shown to give an idea of locality on the map and includes information such as roads, major towns etc not related to hydrogeological information. Grey with a type face different from the hydrogeological information is used. Grid lines such as latitude and longitude are usually printed in black.

Aquifers and non-aquifers
The boundaries of aquifers and of non-aquifers are shown in plain colour on outcrop within the map area. Productive and extensive aquifers will be coloured in increasing darker colour while poor or limited aquifers will be in a lighter tone. The UNESCO classification distinguishes the occurrence of groundwater only according to the primary or secondary nature of interstices. The layout on Page 28, (**Table 2**) shows the adapted hydrogeological classification used for the Messina map sheet according to the origin and nature of the saturated interstices combined with subdivisions based on existing known blow yields (after Orpen, 1994). Other map authors had problems with this part of the legend and with some of the terminology used that is not clearly defined. Not everyone agreed on words such as productive or extensive (Vegter 1995). The compilers of the Hydrogeological map of Australia had similar problems. The salinity/yield matrix is preferred to the aquifer/yield classification of the international legend (Vegter 1995).

Lithology
The lithology of the strata in outcrop is represented by ornament printed in grey beneath the colour. E to W orientated ornaments indicates horizontal or gently dipping strata. NS orientated ornaments show steeply inclined or folded strata.

Representation of detailed data
Detailed hydrogeological data is shown by the use of symbols, and occasionally of lines and ornaments, printed in various colours. Numerical figures printed in the same colour may be added e.g. at certain intervals on contoured data. The different sections in which data is grouped are as follows.

	Group	Colour
1.	Groundwater including springs	Violet
2.	Groundwater quality and temperature	Orange
3.	Surface water and Karst hydrography	Blue
4.	Man-made features and alterations to the natural groundwater regime	Red
5.	Horizon contours, isopachytes and limits of permafrost	Dark green
6.	Geological and stratigraphic information	Black

Stratigraphy
Stratigraphy is not an important feature on hydrogeological maps. It is advisable to use local symbols on large scale maps.

Climatology
It is advised to depict this information on an inset map as it usually obscures more pertinent data on the main map.

Vertical sections
The use of vertical cross sections included as inset maps is highly recommended. The vertical scale must not be over exaggerated as it can lead to a distorted picture. The colours, lines, symbols and ornaments used must be the same as on the main map.

Comment: The terminology used in the international legend is not always properly defined leading to different interpretations. The most problems are experience with the section on aquifers. The legend makes provision for 3 main categories namely,

- **Intergranular aquifers:** porous rock aquifer, highly to moderately productive. Intergranular porosity of secondary origin e.g. as in disintegrated granite is presumably excluded.
- **Fissured aquifers**: Fissured rock aquifer, including Karst aquifers, highly to moderately productive. Interstices are of secondary or epigenetic origin.
- Strata consisting of porous or fissured rock with local and limited or no groundwater resources (essentially aquitard).

The legend lacks clarity on words such as aquifer, productive, extensive, local and highly which leaves the legend open to different interpretations. This vagueness may be deliberate to leave the legend open to the map compiler's own interpretation to suit the hydrogeological conditions studied and the map requirements best. On the other hand, the ideal of an international, standardised way of compiling hydrogeological maps is defeated (Vegter, 1995).

2.3 Existing hydrogeological maps

Maps from other countries are not discussed further as it is not in the scope of this study. The only maps that will be further discussed are the National groundwater maps (Vegter, 1995); the Groundwater Harvest potential of the Republic of South Africa. (Seward et al, 1996) and the Messina Hydrogeological map sheet 2127 (Du Toit, 1995).

2.3.1 The national groundwater map

The information obtained for the following discussion is from the national groundwater map and the accompanying published brochure.

The national groundwater map is a set of hydrogeological maps printed on two A0 sheets with an explanatory brochure and consists of the following:

Sheet 1: Borehole prospects in colours superimposed on a background of lithostratigraphy indicated by different hachuring and letter symbols (scale 1:2.5 million).
Sheet 2: Consists of the following maps:

- •Saturated Interstices providing a qualitative indication of groundwater storage. (scale 1.4 million).
- •Depth of Groundwater Level (scale 1.7.5 million)
- •Mean Annual Groundwater Recharge (scale 1.7.5 million)
- •Groundwater Component of River Flow (Base Flow), (scale 1.7.5 million)
- •Groundwater Quality (scale 1.7.5 million)
- •Hydrochemical Types (scale 1.7.5 million)

A short discussion on the methodology followed to create each map.

2.3.1.1 Borehole prospects

The borehole prospects are depicted on the National Groundwater Map sheet 1 (Vegter, 1995). It shows the chance of drilling a successful borehole as well as the probability that the borehole will yield more than 2ℓ/s. It is accepted that most of the data used was from boreholes drilled without DWA approved scientific methods. A successful borehole from the report is drilled with a blow yield of >0.1ℓ/s. To determine the probability of obtaining a yield of more than 2ℓ/s the following calculation is used:

Example of calculation: In any area, a 40% chance exists of drilling a successful borehole with a 20% chance that the successful hole will yield more than 2ℓ/s. The probability of drilling yielding more than 2ℓ/s in this area is thus 40/100 * 20/100 =8%.

The probability of striking a yield of at least 0.1ℓ/s is termed accessibility. The probability of finding a yield of more than 2ℓ/s is termed exploitability, emulating a concept initiated by Struckmeier (1989).

The background is a simplified lithostratigraphy map created from the 1.1 million scale geological map of South Africa. Originally depicting 358 different lithostratigraphic units, it was reduced to 86 by adhering to the main lithostratigraphic units and, where possible, joining adjacent units with similar lithologies.

2.3.1.2 Types of saturated interstices

The national groundwater map sheet 2 (Vegter, 1995) gives information regarding the types of openings in which groundwater is held as well as recommended drilling depths based on a statistical analysis of water strikes in boreholes.

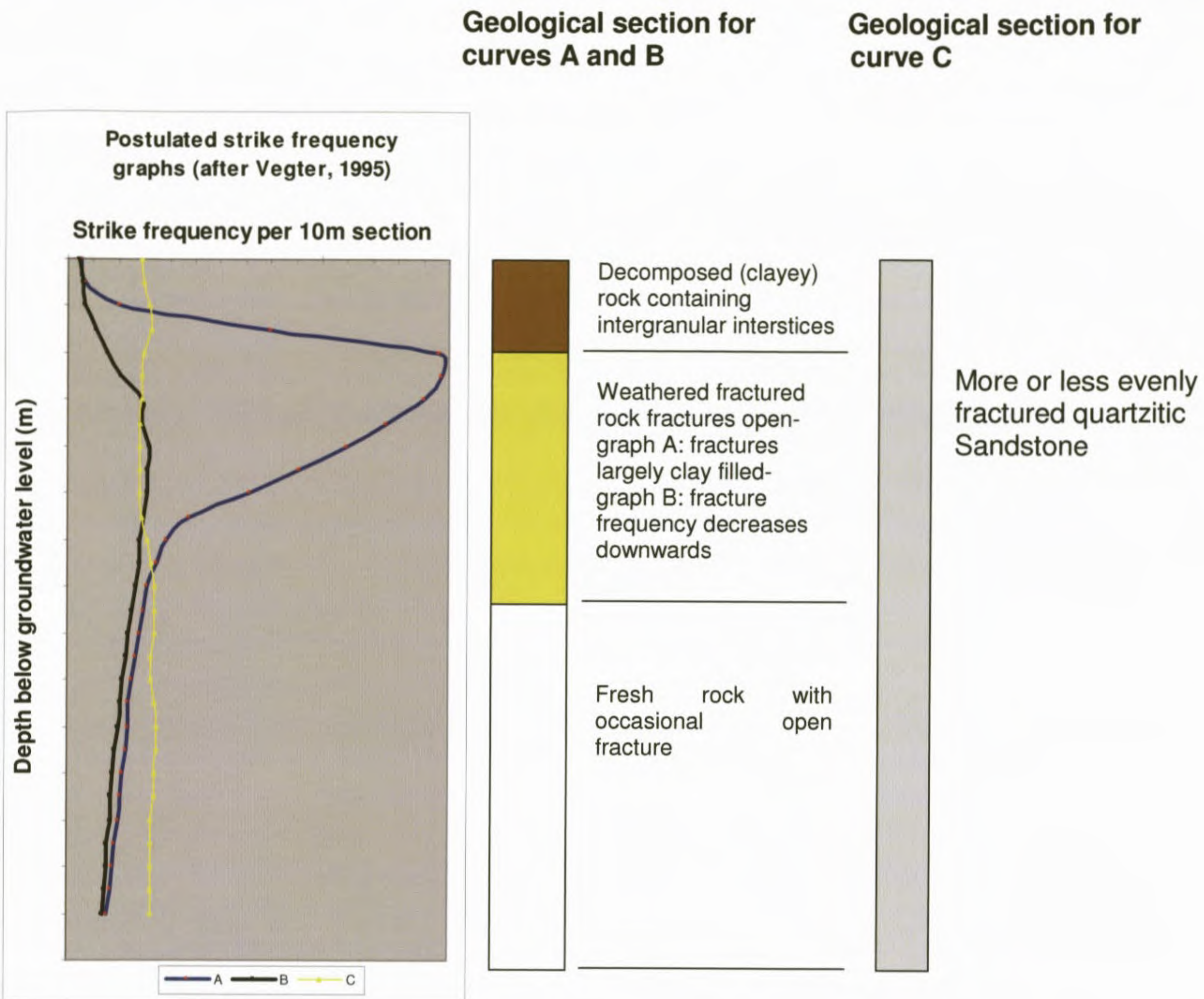


Figure 2: Postulated strike frequency graphs (after Vegter, 1995).

2.3.1.3 Groundwater storage

The national groundwater map sheet 2 (Vegter, 1995). The storage coefficients used in the legend are rough indications of the storage capacities of saturated rocks containing fractures only or fractures plus intergranular openings or pores. The pores may be primary or secondary. A storage coefficient of 0.001 means that every cubic metre of rock contains one litre of water. The mean thickness of the saturated zone can be taken as half the optimum drilling depth below the water table that contains the bulk of the accessible groundwater. The strike frequency graph was used to deduct a mean thickness of the main water-bearing zone.

If the storage coefficient is 0.001 and the well-fractured zone is 5m thick per definition there are 5 litres of water stored beneath a square metre of surface. A low success rate to strike water (<40%) in an area indicates that the real storage might be lower than in the rest of the area.

2.3.1.4 Groundwater level and drilling depth

On the national groundwater map, sheet 2 (Vegter, 1995) the static water level indicated on the map was used to obtain the drilling depth. The assumption used is that if the static water level in an area is between 20 to 30m then the mean water level will be accepted as 25m. A 15 to 25m variation in water level due to topographical differences occurs and therefore the water level can be near the surface or up to 50m deep. The recommended drilling depth is thus 20m in very shallow water level areas and 70m in areas with water levels up to 50m.

2.3.1.5 Groundwater recharge and effective rainfall

On the national groundwater map, sheet 2 (Vegter, 1995) the mean annual rainfall or precipitation (MAP) is a measure of the rainfall available for recharge. Groundwater recharge is dependant on rainfall. Effective rainfall is the part of rainfall seeping into the ground of which only a very small % will reach the saturated zone. The lost water is partly related to runoff, evaporation and transpiration. In the low rainfall areas, recharge might not be an annual occurrence as indicated on the map.

2.3.1.6 Groundwater quality

On the national groundwater map, sheet 2 (Vegter, 1995) water quality is depicted as an inset map. Water quality for domestic use must comply with certain minimum physical, chemical and bacteriological requirements. In producing a quality map for the purpose of a national groundwater map the whole spectrum can not be shown. The TDS (total dissolved salts) is a good primary indicator of suitability. Fluoride and nitrate concentrations give an indication of the ions contained in the water. Both are commonly present in groundwater with poor quality where the concentrations exceed the recommended limits (F >1.5mg/l) and (NO_2 + NO_3 as N >10mg/l). Different ornaments were used to show fluoride and nitrate in areas where more than 20% of the samples exceed the minimum allowable standard.

Nitrate can be a natural constitute of groundwater in certain areas or the result of excessive use of nitrogen fertiliser or it could be an indicator of pollution due to concentrations of animal excrement in livestock pens, sewage leakages and poor sanitation practices due to wrongly designed toilets in villages.

Fluoride is commonly, though not exclusively, associated with acidic and alkaline igneous rocks such as granite, rhyolite and foyaite.

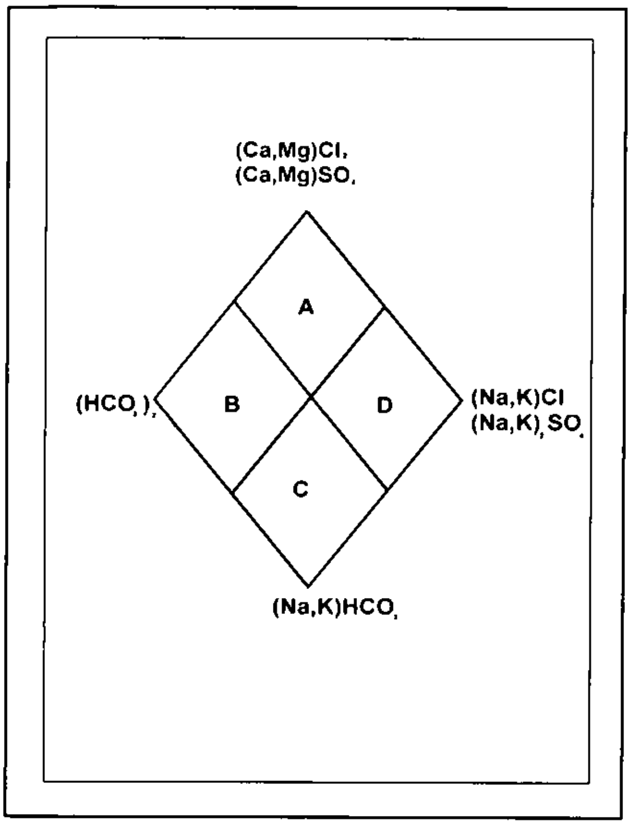
As with the Messina map, comprehensive volumes of data (52000 analysis) were available. Data was reduced (±32%) by averaging data from the same sample point and by evaluating ionic balances. EN =±5% was accepted in samples where the TDS <1000mg/l and EN =±10% in samples where the TDS is >1000mg/l.

The World Health Organisation's guideline for drinking water recommends a TDS <1000mg/l. The SANS 241-1984 (at the time of mapping it was the standard, revised in 2006) is expressed in EC (electrical conductivity) to facilitate analytical procedures and comparison of results. It was established that the ideal mapping using the recommended generally acceptable and maximum allowable limits of 70mS/m, 1000mg/l and 300mS/m could not be realised with the available data and the map scale. The aerial variability of TDS is too great and requires a considerable denser network of sampling points. The cut off points of 300, 500, 1000 and 2000mg/l were chosen for the mapping scheme.

It was found that TDS distributions in the polygons did not follow normal distributions; therefore, the values were transformed into log values in order to determine the geometric mean and variance for each polygon. The upper and lower values of the geometric standard deviation were calculated from the geometrical variance. The TDS values indicated on the map are the geometric mean concentration of TDS in mg/l. Approximately 17% of the analysed samples fell outside the upper and lower geometric standard of specified ranges within each polygon. These samples were not used for the when compiling the map. The map is an indicator of groundwater chemistry and the author states that single source analysis is still relevant when deciding on the use of a borehole within an area.

2.3.1.7 Hydrochemical Types

On The National Groundwater Map sheet 2 (Vegter, 1995), groundwater was classified in terms of the dominant anions and cations. The fourfold division of the quadrilateral Piper diagram (Hem, 1992) was used.



Field	Anions	Cations
A	Ca + Mg	$CO_3 + HCO_3$
B	Na + K	$CO_3 + HCO_3$
C	Ca + Mg	$Cl + SO_4$
D	Na + K	$Cl + SO_4$

Dominance means that the sum of the relevant two anions and the sum of the relevant two cations, in each case expressed in terms of milli-equivalents range between 50 and 100% of the total anion and cation composition. An area may be characterised in terms of the proportion of analyses that plot in the differed four fields.

Single field dominance: More than 40% of the analysis plots in one field. The balance of the analysis is divided into the other three fields with each field having less that 30%.

Two field dominance: Two fields contain more than 30% of the analysis.

Figure 3: Piper diagram showing fields A-D as shown on the National Groundwater Map (Vegter, 1995).

2.3.1.8 Groundwater component of river flow

Perennial rivers have a surface and groundwater flow component. By analysing river flow hydrographs it is possible to quantitatively separate these components. The groundwater component is also known as base flow and it is expressed in water depth i.e. the annual volume of groundwater in m^3 derived from a particular catchment divided by the surface area of the catchment in m^2 and multiplied by 1000. In the eastern Escarpment (Transvaal Drakensberg) it mostly constitutes between 10 and 25% of the annual runoff for those catchments that produces measurable base flow volumes. Approximately 95% of the National Groundwater Map, sheet 2 shows the base flow to be negligible.

2.3.1.9 Groundwater harvest potential map

The map Groundwater Harvest Potential of The Republic of South Africa is available from the DWA, first print 1996, map Authors, Seward P, Baron J and Seymour A. The map is not included in this document. The discussion under this heading was summarized from the notes on the map.

The main map to a scale of 1:1.3 million shows the maximum volumes of groundwater (m^3/km^2/annum) that may be abstracted per surface area of a aquifer system to preserve a sustainable abstraction (**Figure 107**, p166). Various inset maps are included on the map sheet presented as: factors restricting harvest potential, average borehole yield and a map on groundwater quality showing TDS as a geometric mean concentration similar as to the inset map on Sheet 2 of the National Groundwater Map. The methodology in creating the harvest potential map and the other inset maps are discussed as notes on the map sheet. In short, the harvest potential map was created by dividing the country into regions followed by the calculation of the mean annual recharge for each region using base flow studies in the eastern high rainfall part of South Africa and extrapolation of the findings of local recharge studies in the western arid parts. For each region, the groundwater storage was determined by multiplying the storage coefficient with the aquifer dimensions. The storage coefficient was assigned by using typical values for different geology. Aquifer dimensions were determined from borehole logs and extrapolating according to geology. Groundwater storage divided by mean annual recharge = "storage time" (ST). Storage time equals the time it will take to deplete an aquifer if pumped at a rate equal to the mean annual recharge. An indication of drought length and recharge viability was introduced by multiplying recharge by a precipitation variability factor. The other inset maps were compiled using the same methodology as in the National Groundwater Map by Vegter (1995).

2.3.2 The Messina Hydrogeological map

The 1:500 000 Messina hydrogeological map sheet 2127 (Du Toit, 1995) covers the area north of latitude 23ºS on a scale of 1:500 000 and it is the first map representing the regional hydrogeological character of the area. A high degree of conformity was needed in the presentation of data as the maps forms part of the National Hydrogeological map series published by the Department of Water Affairs. The methodology followed to create the hydrogeological map and explanatory brochure was therefore done to pre-determined mapping standards. The UNESCO legend published in 1983 was adapted to suit the South African situation (Orpen, 1994). A copy of the hydrogeological map and the inset map showing the Soutpansberg Supergroup is included in Chapter 10, (p181): Appendix.

Within this pre-determined deliverable environment, the hydrogeological map is expected to be a visual tool representing groundwater resources in a usable and understandable form for the public, the professional community and planners. The accompanying explanatory brochure (not yet published) written to stipulated rules is intended to explain the information depicted on the map, the methodology followed, and other important information regarding groundwater resources in the area that could not be shown on the map. It was expected to be compiled in an understandable language for the layman but also to give more information to a professional. The occurrences of groundwater are more complex and heterogeneous than can be depicted on a map sheet and brochure. The hydrogeological units in the brochure are described in relation to locality, geology, quantity and quality, preferable targets for groundwater development and findings of previous research.

The methodology followed to create the maps is discussed on the following pages.

2.3.2.1 Data sources

Various data sources were used for the compilation of the map and include:

- The National Groundwater Archive which replaced the National Groundwater Data Base (NGDB), under the custody of the Department of Water Affairs (DWA).
- Water Management System (WMS), Department of Water Affairs (DWA).
- Existing data from the former homeland Venda.
- Available geohydrological reports.
- Limpopo GRIP data base managed by GPM for DWA.
- Existing information from various consultancies stationed in the Limpopo Province.

Table 1: Number of borehole records extracted and evaluated from the NGA and WMS (Du Toit, 1995).

RECORDS EVALUATED				
NGA and GRIP - 6180		WMS and Limpopo – 4139		
Total number of borehole yields	Total number of water levels	Total number of EC measurements used	Total number of nitrates and fluorides used	Total number of complete chemical analysis used
5269	1063	2484	2484	2263

2.3.2.2 **Main map**

The lithostratigraphy of the region, based on the 1:1 000 000 Geological Map of South Africa and supplemented by the 1:250 000 geological map series, was used to sub-divide the mapped area into hydrogeologically relevant lithologic units which possess some degree of lithologic homogeneity and similarities in rock properties. These units are displayed as grey ornament on the map. An age symbol, displayed in black, has been assigned to these basic lithologies. The symbol consists of two or three letters, the first being the first letter of the lithostratigraphy (Erathem used up to the end of Namibian, thereafter System was used) as on the 1984, 1:1 000 000 Geological Map of South Africa and the second and third, where necessary, the map compiler's choice. These lithologic units were then grouped together based on the expected groundwater occurrence viz. **Intergranular (a), Fractured (b), and Intergranular and Fractured (d), Karst (c) is part of the legend for map continuity although no dolomitic rocks occur within the map area.**

Borehole yield data available on the National Data Base represents data from different populations which are non-uniformly distributed in space and which are heavily skewed in a positive direction. Because of this, the median yield was recommended as a suitable measure of centrality rather than the average. The median was also found to be a reasonable discriminator between hydrogeological regions and was easy to compute and interpret as a "typical" yield of a region. In order to provide sufficient resolution of the data to permit visual portrayal in a distinguishable manner, the borehole yield data was classified according to five groupings (borehole yield class) for each of the four classes (aquifer type) or mode of groundwater occurrence. The five 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 also 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 lithologic 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 geohydrological well-defined areas were extrapolated into areas of data scarcity.

Major groundwater abstraction points are shown on the map as solid red circles of various sizes representing the annual volume of abstraction. Springs, thermal springs and artesian conditions are shown in pink (solid circle), orange (open circle) and pink (open circle). A network of water level recorders and monitoring points was only developed since the first publication of the main map (1995). The positions of these points are shown in Figure 108, p168.

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

2.3.2.3 Inset maps

The following inset maps have been included on the Messina Hydrological map sheet 2127:

The Soutpansberg Supergroup and its sub-divisions: Due to the significant hydrogeological differences between the different formations of the Soutpansberg Supergroup which could not be displayed on the main map an inset map depicting the Soutpansberg Supergroup with all its sub-divisions was inserted on the main map. Each formation with its unique age symbol is displayed together with flow rates and temperatures of springs where available. In addition most known faults are shown as these are important targets for groundwater development in the Supergroup (inset map Chapter 10, (p181), Appendix).

Two hydrogeological cross-sections: based on limited geological information and the author's own interpretation of the available information. The cross-sections display the third dimension and regional hydrogeological relationships discussed on the map as points 1 to 8. The static water level is included to show its relationship with surface topography.

Distribution of borehole data: scale 1:2 000 000: represent borehole data points per 1-minute grid. The yellow colour represents no data points, light pink represent one data point, light blue 2 to10 data points, violet 11 to 20 data points and the purple represent more than 20 data points.

Elevation above mean sea level: scale 1:2 000 000, contour intervals relevant to the map at either 200 or 400m. The elevation in the map area varies more or less between 200 to1600mamsl (Figure 24, p68).

Mean annual precipitation: scale 1:2 000 000, contour intervals at 100 to 200mm/a. The rainfall in the area varies from approximately 300 to just over a 1000mm/a (Figure 25, p69).

Groundwater quality map: scale 1:1 500 00 representing contoured electrical conductivity data, (a measure of salinity), the position of sampling points and the distribution of problematic chemical species, namely nitrate (concentration >10mg/l) and fluoride (concentration >1.5mg/l) (Figure 34, p89). The EC intervals as well as the nitrate and fluoride values shown are based on the DWA 1996 prescribed guidelines for human and livestock water consumption.

2.3.2.4 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 than could be depicted on the map. Groundwater occurrence is very heterogeneous in South Africa while the mapping standards, legend, etc. demand a high degree of conformity. Aspects of groundwater that are important, but could not be shown on the map, will vary dramatically from region to region and the brochure provides opportunities to reflect this variability. Included in the brochure are frequency diagrams on borehole yields and stiff diagrams giving information on groundwater chemistry for various lithology. These are guideline values with the accuracy a function of availability and quality of data.

2.3.2.5 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**, (p28) depicts the adapted hydrogeological classification used for the Messina map sheet according to the origin and nature of the saturated interstices combined with subdivisions based on existing known blow yields (after Orpen, 1994).

Three modes of groundwater occurrences, based on the dominant porosity type, are depicted on the Messina map sheet namely:

- •Intergranular (a),
- •Fractured (b),
- •Intergranular and fractured (d)

The fourth, Karst (c), is included in the legend for mapping continuity although no dolomitic rocks occur within the map area.

Table 2: Adapted hydrogeological classification of the principle occurrences of groundwater within the boundaries of the Messina Hydrogeological map sheet, according to origin and nature of the saturated interstices with subdivisions based on borehole yields (After Orpen, 1994).

<table>
<tr><th colspan="4">CLASS A</th><th colspan="4">CLASS B</th><th colspan="4">CLASS C</th><th colspan="4">CLASS D</th></tr>
<tr><td colspan="4">INTERGRANULAR</td><td colspan="12">HARD, CONSOLIDATED ROCK MATERIAL</td></tr>
<tr><td colspan="4" rowspan="2">A water saturated zone, generally unconsolidated but occasionally semi-consolidated. Groundwater storage and flow through intergranular interstices in porous and permeable medium.</td><td colspan="12">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.</td></tr>
<tr><td colspan="4">Where the principal water strike is in a fracture or in the contact between two different rock types, interporosity groundwater flow can occur within the rock matrix (double-porosity matrix).</td><td colspan="4">In the case of carbonate rocks incipient fissures and fractures are enhanced through chemical dissolution. Some groundwater storage can be expected in in-situ weathered residuum.</td><td colspan="4">Fractured zone overlain by varying thicknesses of weathered saturated material. Storage and flow in both. Fractures act as conduits during abstraction, vertical recharge from intergranular zone.</td></tr>
<tr><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td></tr>
<tr><td>Range</td><td>ℓ/s</td><td>Range</td><td>ℓ/s</td><td>Range</td><td>ℓ/s</td><td>Range</td><td>ℓ/s</td></tr>
<tr><td>a1</td><td>Un-economical</td><td>0.0-0.1</td><td></td><td>b1</td><td>Un-economical</td><td>0.0-0.1</td><td></td><td>c1</td><td>Un-economical</td><td>0.0-0.1</td><td></td><td>d1</td><td>Un-economical</td><td>0.0-0.1</td><td></td></tr>
<tr><td>a2</td><td>Very low</td><td>0.1-0.5</td><td></td><td>b2</td><td>Very low</td><td>0.1-0.5</td><td></td><td>c2</td><td>Very low</td><td>0.1-0.5</td><td></td><td>d2</td><td>Very low</td><td>0.1-0.5</td><td></td></tr>
<tr><td>a3</td><td>Low</td><td>0.5-2</td><td></td><td>b3</td><td>Low</td><td>0.5-2</td><td></td><td>c3</td><td>Low</td><td>0.5-2</td><td></td><td>d3</td><td>Low</td><td>0.5-2</td><td></td></tr>
<tr><td>a4</td><td>Moderate</td><td>2-5</td><td></td><td>b4</td><td>Moderate</td><td>2-5</td><td></td><td>c4</td><td>Moderate</td><td>2-5</td><td></td><td>d4</td><td>Moderate</td><td>2-5</td><td></td></tr>
<tr><td>a5</td><td>High</td><td>>5</td><td></td><td>b5</td><td>High</td><td>>5</td><td></td><td>c5</td><td>High</td><td>>5</td><td></td><td>d5</td><td>High</td><td>>5</td><td></td></tr>
<tr><td colspan="4">Alluvial deposits of limited extent along river terraces such as sand and gravel. Weathered crystalline rock with the principle water strike in the weathered intergranular zone

Examples:
Deposits along rivers such as the Limpopo, Mutale, Luvuvhu, Nzhelele</td><td colspan="4">Sedimentary rocks of arenaceous origin. Igneous and metamorphic rocks with very limited overlying residual weathered products.

Examples:
Malvernia-, Jozini-, Bosbokpoort- and Solitude Formation, Undifferentiated Ecca Group and Clarens Formation, Ecca Group, Soutpansberg Supergroup (quartzite and sandstones).</td><td colspan="4">Carbonate rocks including dolomite, limestone of marine origin

Examples:
No dolomitic rock occurs within the map area.</td><td colspan="4">Sedimentary. Igneous and metamorphic rocks with significant thicknesses of overlying saturated residual weathering.

Examples:
Letaba and Clarens Formation, dolerite, Syenite and diabase intrusions, Soutpansberg Supergroup (basalt and lava), older Gneisses (Bulai, Sand River, Hout River, Alldays, Goudplaats), Messina Suite, Beit Bridge Complex</td></tr>
<tr><td colspan="4">INTERGRANULAR</td><td colspan="4">FRACTURED</td><td colspan="4">KARST</td><td colspan="4">INTERGRANULAR AND FRACTURED</td></tr>
</table>

The map author defined the definition of the productive yield ranges indicated on the 1:500 000 Messina hydrogeological map sheet (2127 Messina). Considering local conditions and equipment options for production boreholes, yield ranges were defined into five sub-divisions (**Figure 4**, p29). On the Messina map sheet the classes are represented by colours and the yield subdivisions by the tone of the respective colour. **Figure 4**, (p29) and **Table 2**, (p28) is representative thereof. Subsurface lithology is presented by lithologic ornaments and the chronostratigraphy by alphabetical symbols. Production ranges are defined as follows:

- High borehole yields, generally greater than 5ℓ/s, can be used for urban and rural water supply, industry or large-scale irrigation.

- Moderate borehole yields generally, 2ℓ/s to 5ℓ/s, can be used for urban and rural water supply to small towns, industry or small-scale irrigation.

- Low borehole yields generally, 0.5ℓ/s to 2ℓ/s, can be used for domestic and livestock watering supply to rural settlements, hospitals and health centres or small-scale irrigation at community vegetable gardens.

- Very low borehole yields generally, 0.1 to 0.5ℓ/s, can be used for domestic supply to single homesteads, schools, police stations, clinics, small rural villages (250 persons) or livestock watering. Boreholes in this group are mostly equipped with hand, submersible or wind pumps.

- Un-economical borehole yields generally, 0.0 to 0.1ℓ/s. Non-reticulated water supply for isolated households or for monitoring in certain cases. Suitability dependable on factors such as construction, objective of monitoring, location and geological setting.

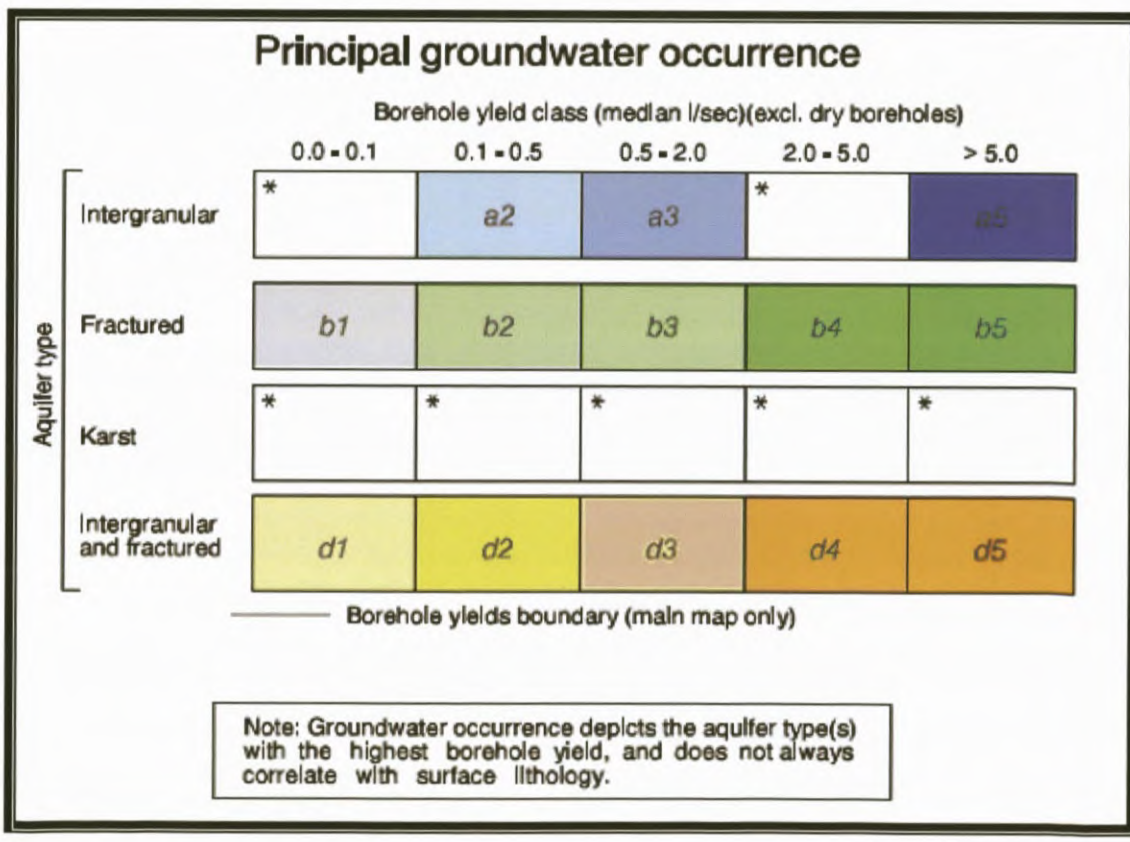


Figure 4: Principal groundwater occurrence as used in compiling the Messina Hydrogeological map sheet (after Du Toit, 2011).

2.4 Summary

History of maps

- •Hydrogeological maps are an effective visual method of presenting vast volumes of groundwater in an understandable way for the public and the professional.
- •The history of hydrogeological maps in the world closely represents the development of groundwater as a science since the early 1940's.
- •The first maps formed part of small specific and localized projects, increasingly becoming a basis for planning due to the ever increasing water demand for agriculture and domestic use.
- •The first attempt to prepare a universal legend was in 1959.
- •The diversity in ideas to present groundwater data on a map was based on hydrogeologists localized project experience. Universal concepts were not taken into account.
- •The final universal accepted legend was published in 1983 (UNESCO legend 1983).
- •The fundamental change in creating an acceptable legend was when the presentation of data moved away from well yields towards aquifers and groundwater resources.
- •Hydrogeological maps should differentiate between aquifers based on fractured and intergranular flow, extensive aquifers with large, localized or discontinuous resources.

Map compilation and the international legend

- •**The legend** is the starting point of any hydrogeological map to present groundwater resources in an understandable and usable way.
- •**The main map** is to highlight the hydrogeological character of an area with the geology subdued.
- •**Inset maps** are used to present additional data that can not be shown on the main map.
- •**The lithology** of outcrop is presented by ornaments in grey print beneath the hydrogeological unit colour.
- •**Vertical sections** are cross sections included as inset maps and are highly recommended to show the relation between different geological settings.
- •The terminology used in the international legend (UNESCO, 1983) is as follows:
    - o **Intergranular aquifers:** porous rock aquifer, highly to moderately productive. Intergranular porosity of secondary origin e.g. as in disintegrated granite is presumably excluded.
    - o **Fissured aquifers**: Fissured rock aquifer, including Karst aquifers, highly to moderately productive. Interstices are of secondary or epigenetic origin.
    - o **Strata** consisting of porous or fissured rock with local and limited or no groundwater resources (essentially aquitard).
- •The international legend (UNESCO, 1983) does not give a clear meaning on words such as aquifer, productive, extensive, local and highly, which leaves the legend open to different interpretations. Two types of maps are used.
- •**Systematic general hydrogeological maps** such as the Messina map showing geological and hydrogeological data and compiled to the UNESCO international legend for hydrogeological maps.
- •**Derived Maps** are problem orientated, differ widely in content and format and are prepared to meet the needs of well defined group of users. These maps show more detail such as groundwater exploitation potential, groundwater suitability, degree of vulnerability and required protection.

South African hydrogeological maps

Three maps were investigated namely the National Groundwater Map (Vegter, 1995); the Groundwater Harvest potential of the Republic of South Africa. (Seward et al, 1996.); the Messina Hydrogeological map sheet 2127 (Du Toit, 1995).

- The two national maps are essentially derived maps as the specifications of the UNESCO legend were not completely followed.
- The Messina map is a systematic general map as the international legend was used, except for the description of the type of aquifers where amendments were made to clarify the terminology used and to fit the South African conditions.
- The Groundwater Harvest Potential map is especially useful on GIS as it has a table where the MAP, geology, recharge etc can be referenced and used to check findings of other projects.
- The inset maps for all three maps were more or less compiled using the same methodology and depicting the same information such as rainfall, topography and distribution of groundwater data. The groundwater chemistry in all three maps used TDS as a primary indicator of suitability. Fluoride and nitrate concentrations are used on all three maps as an indicator of the ions contained in the water.
- The national groundwater map and the Messina map were compiled using large sets of existing groundwater data.
- The data preparation phase is the most important part of the map compilation.
- In areas with poor data groundwater coverage the advantage of averaging is lost – incorrect data can influence the outcome for such an area.
- Some data problems experienced:
  - huge volumes of data make for a time consuming process of deciding what to keep and what to reject
  - poor recordings of dry boreholes
  - chemistry data with only the basic chemistry recorded
  - time chemistry data for a single hole - averages data are used and are thus time consuming to calculate
  - incorrect co-ordinates
  - not enough data points on a unit to characterize it
  - double or more data point entries for the same hole especially when data was recorded using a co-ordinate and a few years later data is again recorded for the same hole but a new entry was created using a different borehole number
  - without adequate information it is almost impossible to link the entries and to combine the data on one data point as time series data recordings
  - using hand held GPS systems co-ordinate recordings is more accurate than the old method of plotting on a 1:50 000 topographic map sheet
  - as GIS systems become more powerful and the fields of groundwater become more specialized there will always be maps following the legend requirements against site specific information requirements

- The hydrogeological units for the Messina map were chosen by sub-dividing the area into relevant lithologic units that possess some degree of lithologic homogeneity and similarities in rock properties.
- These lithologic units were then grouped together based on the expected groundwater occurrence viz. **Intergranular (a), Fractured (b), and Intergranular and Fractured (d).**
- The subdividing of the units according to yield was done in a way so as to provide physical meaning to the value of the borehole both in terms of the concomitant abstraction equipment and also as a provider of water for a particular end water user.
- The brochure highlights important groundwater topics and discusses groundwater occurrences in more detail than could be depicted on the map.

Chapter 3 : Literature review - case studies

3.1 Former groundwater development and research projects

Thanks to Mr. W.H. du Toit for his facilitation and effort in obtaining reports and data used in compiling the brochure for the Messina Hydrogeological map from DWA. His support in facilitating the permission to use the data and reports for the thesis is greatly appreciated. In total 23 reports were received in either hard copy or in an electronic data format. The majority (±99%) of these project reports were compiled in the period 1967 to early 1990 covering predominantly the part of the map that falls outside the former homelands. The reports were either compiled by the former Geological Survey (Council of Geosciences) or the former Directorate of Geohydrology of DWA. At that time, the above institutions were still actively involved in the research and development of groundwater sources, hot springs investigations, drought relief projects for farmers, subsidised drilling programs, major fault investigations, research on alluvial deposits in major rivers and the development of groundwater sources for towns. The effort by the authors in presenting data within these reports is recognized as the graphs and calculations were done without the use of computers.

From the early 1990's the former Directorate of Geohydrology was more active in the former homelands, this information is not in report format but available from the National Groundwater Archive (NGA). Private firms became more active from 1997 with numerous reports available in the DWA library in Polokwane. These data reports are mostly project information reports giving the results of a development at a village, school or agricultural project. This data was and is still checked before being added to the NGA. This process started with the implementation of the Groundwater Resource Information Project 'GRIP'. This data was obtained from the NGA in electronic format.

From the available projects two were chosen as they cover major fault zones, (faults are important targets in the search for groundwater in the area), one covers the Beit Bridge Complex (not many projects available in this unit) and one covers various units within the Kruger National Park.

Information from smaller projects are summarized and referenced throughout the report.

3.1.1 Case study 1: Dowe Tokwe Fault

Assessment of the groundwater resources in proximity to Messina with particular reference to the Dowe Tokwe Fault (GH3260).

In this report compiled in November 1983 by M. Fayazi and W.R.G. Orpen the findings of an investigation into groundwater as a water supply source for Messina is presented. The project focused on two areas; the first being a 3.5km stretch along the Dove-Tokwe Fault and the second the confluence area where the Sand and Limpopo Rivers join. The geology surrounding the fault is a grey granitic-gneiss intruded in places by sub-parallel zones of amphibolitic rock and dolerite dykes. The geology on the fault is evident on the surface by the occurrence of brecciated, epidotised and chloritised gneiss. Within the fault various coloured feldspathic quartzites, hydrothermal quartz epidote and pyrite are typical. Fifteen boreholes were drilled targeting the fault zone on the results of a geophysical and geological survey. Together with geological observations the magnetic and electromagnetic methods were used successfully to locate the fault. The boreholes were drilled varying in depth from 19.6 to 82.3m (Harmonic mean =42.3m). The static water table was measured to be between 15.4 to 24.8mbgl. The water strikes were from 18 to 78m (Harmonic mean =31.4m). The shallow strikes (<32m) were related to the base of the weathered rock or breccia and the deeper strikes related to fractured zones within the feldspathic quartzite or quartz. Five boreholes were drilled in an area adjoining the confluence of the Sand and Limpopo Rivers. The boreholes were drilled on the river bank. The boreholes were drilled to a depth of 21.9 to 33.6m and the static water levels were measured to be between 4.85 and 8.16mbgl. Four of the boreholes yielded more than 5ℓ/s and one was less than 0.5ℓ/s. At the time of this report the daily demand of the municipality was 2,343m³. The water was obtained by pumping from the Limpopo River (2,030 m³/day) and the rest from 5 existing boreholes in Messina (maximum 1,000m³/day estimated).

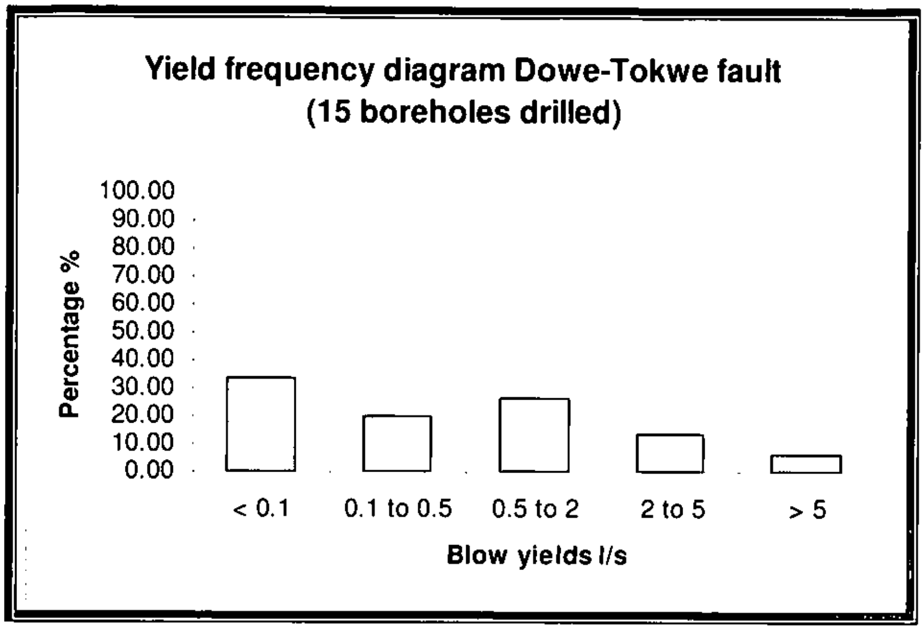


Figure 5: Yield frequency diagram; Dowe-Tokwe Fault (data source, Orpen and Fayazi, 1983).

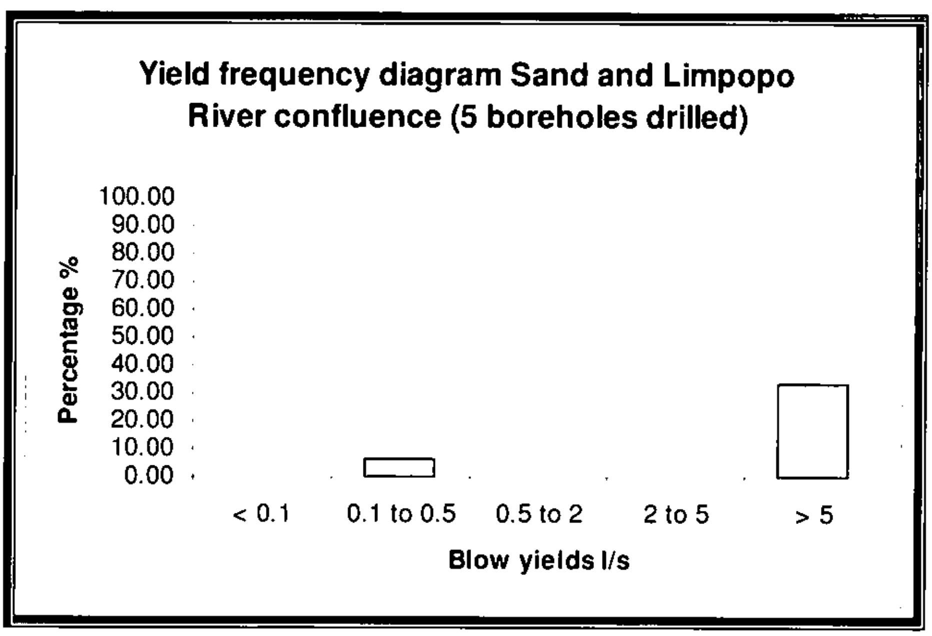


Figure 6: Yield frequency diagram; Sand and Limpopo river confluence (data source Orpen and Fayazi, 1983).

The conclusions reached in the report is that the groundwater potential of the Dowe-Tokwe Fault is 0.8 x 10^6m³/annum using a MAP of 400mm, a surface catchment area of 40km² and a 5% recharge figure. The report recommended more detailed work on the fault zone as well as to the east where the fault extends through the Sand River.

3.1.2 Case study 2: Geohydrological assessment Beit Bridge Complex

A geohydrological assessment of the Swartwater and Beauty areas, North-West Transvaal (GH3577).

The report was compiled by R.A. Bush in August 1989 presenting the findings of a major groundwater exploration project conducted by the Directorate of Geohydrology which at that stage was part of DWA. The information in the report partly covers the eastern part of the Messina hydrogeological map area underlain by the Beit Bridge Complex that is divided into the Gumbu, Malala Drift and Mount Dove Groups. Below average rainfall leading to failing surface and groundwater supplies emphasised the historic occurrence of periodic droughts that resulted in the need to investigate groundwater. The project focused on various aspects such as the assessment of the hydrogeology of the area (quality and quantity), the evaluation of geological structures by the use of different geophysical methods and the improvement of recharge. This was needed as existing information and knowledge of the area could not be used to give reliable advice and usable information to people living in the area.

The report covers two areas, the first being the Swartwater area and the second the Beauty area. The Beauty area falls under the Polokwane hydrogeological map sheet and will not be discussed. In the Swartwater area the project started with a hydrocensus covering 136 cadastral farms. Available data indicates that state assistance in the form of drilling or siting was on record since 1914 with some farms receiving up to 24 boreholes. From the results of the hydrocensus it was estimated that only 10% of the boreholes drilled in the area were found. 705 boreholes were found and evaluated. Of these 399 had some information on the yield, either from farmers or from existing data. From this data (**Figure 7**), the low number of boreholes found and the drilling results from the project it is clear that the chance of finding water is very low.

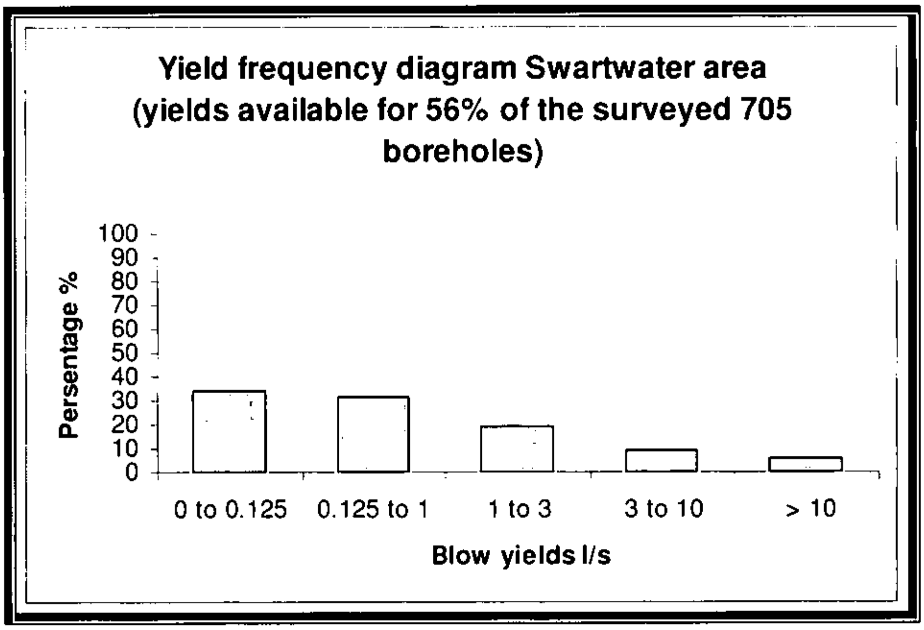


Figure 7: Yield frequency diagram; Hydro census data of the Swartwater area, (data source Bush, 1989).

The findings of 109 hydrochemical samples obtained on the project were analysed by plotting the data on a Piper diagram (**Figure 8**). The results in the report were summarized as follows: the analysis of cations indicates no dominance of any particular cation although the extension of the field towards the Na + K corner of the plot suggests that a certain amount of natural base exchange may be taken place. The plot of the anions indicates a variation in dominance from CO_3 + HCO_3 to Cl + SO_4 anions. For domestic purposes the total dissolved solids (62%, between 1,000 and 2,000mg/l), nitrate (60%; between 10 and 20mg/l) and fluoride (42%; between 1.5 to 3mg/l) is problematic. The rest of the macro elements contribute to less that 10% of the problems. For livestock watering less than 1% of the sampled boreholes proved problematic.

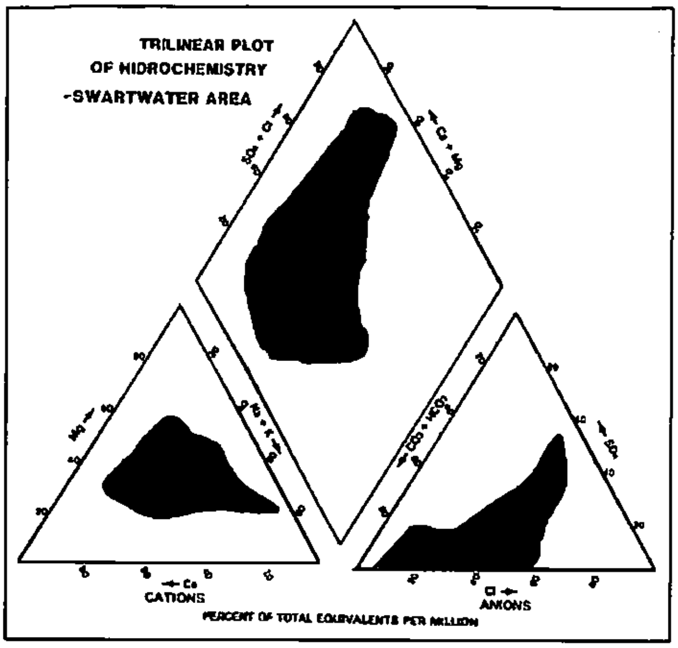


Figure 8: Chemistry from the Swartwater area plotted on a Piper Diagram (after Bush, 1989).

The drilling phase of the project included remote sensing to locate suitable geological lineaments. Techniques available at the time included Landsat images and aerial photographs. The interpreted positions of the lineaments were further investigated by geological observations and or various geophysical methods. The geophysical methods included magnetics, DC electrical resistivity, electro magnetics and seismics.

Table 3: Drilling results Swartwater area (data source, Bush, 1989).

Drilling target	Holes drilled	Successful yield >0.125ℓ/s	Unsuccessful yield <0.125ℓ/s
Diabase or dolerite	18	6	12
Faults, shears and fracturing	15	6	9
Weathered zone	9	4	5
Lithological contacts	4	0	4
Total	46	16	30

The methods used and the results of the field geophysics of the project are described in more detail in a separate report by Du Toit (1989) and the findings given in this report represent the summary reported by Bush. The magnetic method was generally successful to locate diabase and dolerite dykes with less success to locate faults and shear zones. Difficulties reported includes the apparent lack of magnetic contrasts within fault and shear zones, the presence of magnetite in the gneiss, remnant magnetism exhibited by amphibolites representing pre-metamorphic event dykes and the poor magnetic contrasts between dykes and host rock. DC resistivity soundings and profiling were done using the Chemtron G41 instrument. The Wenner vertical electric sounding method proved fast and reliable up to depths of 35m after which lateral effects influences the data to be unreliable. The Schlumberger method that is less affected was effective to depths up to 40m and the data could be interpreted to represent a layered model.

Resistivity profiling was done at the start of the project when not all the geophysical methods were available. It was not possible to explain the range of responses due to the varying nature of the weathering pattern and geological anomalies. When the apparent resistivity of the upper layers was less than 50Ωm the definition was so poor that not even dominant geological features were recognised. Apparent resistivity between 50 and 100Ωm resulted in weak trends in the anomalies that could be compared with the electromagnetic data response. Apparent resistivity above 100 and especially 200Ωm gave reasonable definition to locate weathering basins, shear, fractured and fault zones. The electromagnetic systems used included the Genie SE88, the EM34, the VLF and Time domain systems.

The Genie SE88 proved effective in areas where the upper layers have resistivity values of less that 75Ωm. Varying success was achieved in areas with values between 75 and 200Ωm and it was found to be ineffective in areas with the upper layers having a resistivity of more than 200Ωm. The EM34 was successful in confirming all anomalies found with the Genie and DC profiling. The instrument is however restricted to a theoretical 60m depth penetration. In highly conductive areas the interpretation of the depth and relevance of the anomaly is difficult.

The very low frequency method VLF was used less due to unavailability. Unreliable reception in the area may result in linear features with unfavourable strike not being detected as maximum coupling can only be obtained when signals are received. Signal decay was a problem as the source of transmission is very far. At the time the system was new with limited interpretation experience between field personnel. The data corresponded well with profiling, EM34 and Genie SE88 data. Time domain data were obtained from a mining company to apply data obtained for mineral exploration to groundwater exploration. The data was unsuitable as the method used was designed for deep mineral exploration and was insensitive to the shallow conductive layer explored in the search for groundwater. The time domain data was not available to the project in readable resistivity maps. The seismic method was used in a few locations with the results indicating shallower weathering than confirmed with drilling. Dense fault and fracturing zones were more identifiable with the seismic method than indicated by the other methods used.

Areas where dams were constructed were investigated by comparing old data with new data. It was found that improved recharge to groundwater has taken place in the majority of cases after dam construction with improved yield in marginal and even dry boreholes.

The conclusions were that the recharge is limited: by low rainfall, high evaporative losses, a dense drainage network in the Swartwater area and deep weathering and dense vegetation cover in the Beauty area. The high grade of metamorphism has largely destroyed original sedimentary and intrusive structures. The most favourable geohydrological features in the area is post-metamorphic event fault and shear zones. The secondary fractures associated with dolerite and diabase dykes intrusives does not extend to below static ground water levels except in the W of the area. The limited thickness of the saturated zone and lateral extend of aquifers resulted in dewatering during pumping tests conducted on boreholes. In the Swartwater area high TDS, nitrate and fluoride exceeds the maximum allowable limit for human consumption in 83% of the cases.

3.1.3 **Case study 3: Groundwater associated with the Taaibos Fault**

Development of a water supply for Alldays from groundwater resources associated with the Taaibos Fault (GH3664).

Fayazi and Orpen compiled the report during 1989. It represents the findings of a geohydrological research project to investigate groundwater as a source for Alldays. The town of Alldays was earmarked during the period as a potential growth point due to a planned prison complex and the development of a mine at Venetia. Water supply was the restricting factor and the Taaibos Fault zone was chosen as the preferred source to be investigated. The Limpopo and Magalakwena Rivers were deemed too far and away and water commitments were already in place for other users.

The geology along the fault are sediments and lavas of the Karoo Supergroup which lay unconformable upon older metamorphic rocks known as the Alldays Gneiss. Surface cover includes sandy soils with calcrete in places and thick black clayey soils "turf" that is a weathering product of the basalt (Letaba Formation). Rocks of the Clarens Formation usually form ridges and areas of higher topography. It consists of light green to whitish quartzitic sandstone that is resistant to weathering. In some of the boreholes drilled during the project, light to dark red argillaceous sandstone (Red beds) were intercepted. The research for groundwater focused on the geological lineaments transecting the area of which the Taaibos Fault was the primary target followed by stress related fractures related to the fault and drilling targeting secondary fractures related to dyke intrusions.

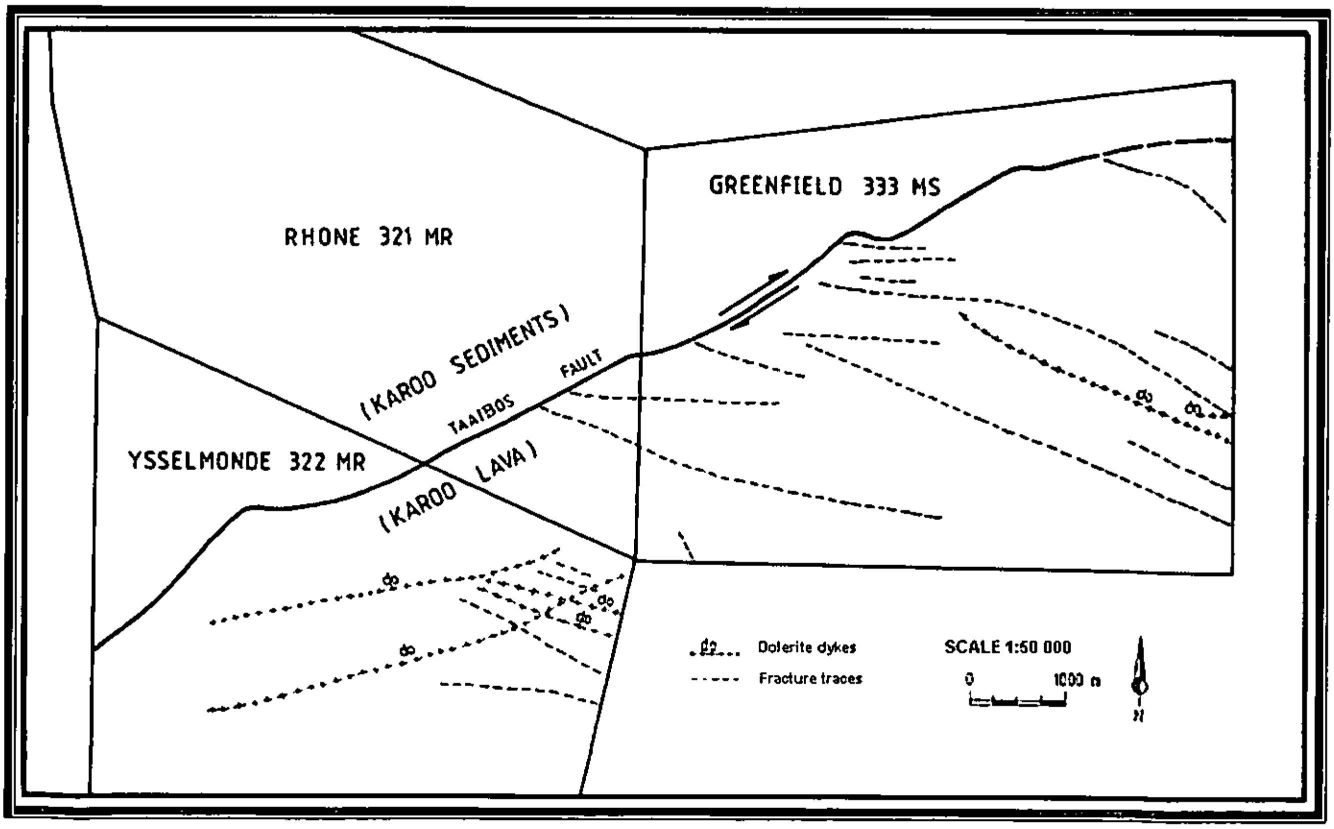


Figure 9: Taaibos Fault, dykes and stress related lineaments (after Fayazi and Orpen,1989).

The Taaibos Fault strikes south-east to north-west and the results of the exploration drilling on the farms Ysselmonde 322MR, Rhone 321MR and Greenfield 333MS showed that it appears to be a normal fault with a dip of 70 to 80º towards the south-east. Further eastwards the fault looses its clear definition as it becomes assimilated into a wide shear zone on the farms Gansvley 335MS and

Presumption 337MS. The fault also changes direction in a wide curve and eventually narrows again into the Vetfontein Fault where it strikes to south-east to north-west. A number of lineaments (fracture systems) converging on the fault at 45º seems to be stress related. Targeting these lineaments produced a number of high-yielding boreholes. Dykes were targeted to a limited extent and the findings are therefore inconclusive.

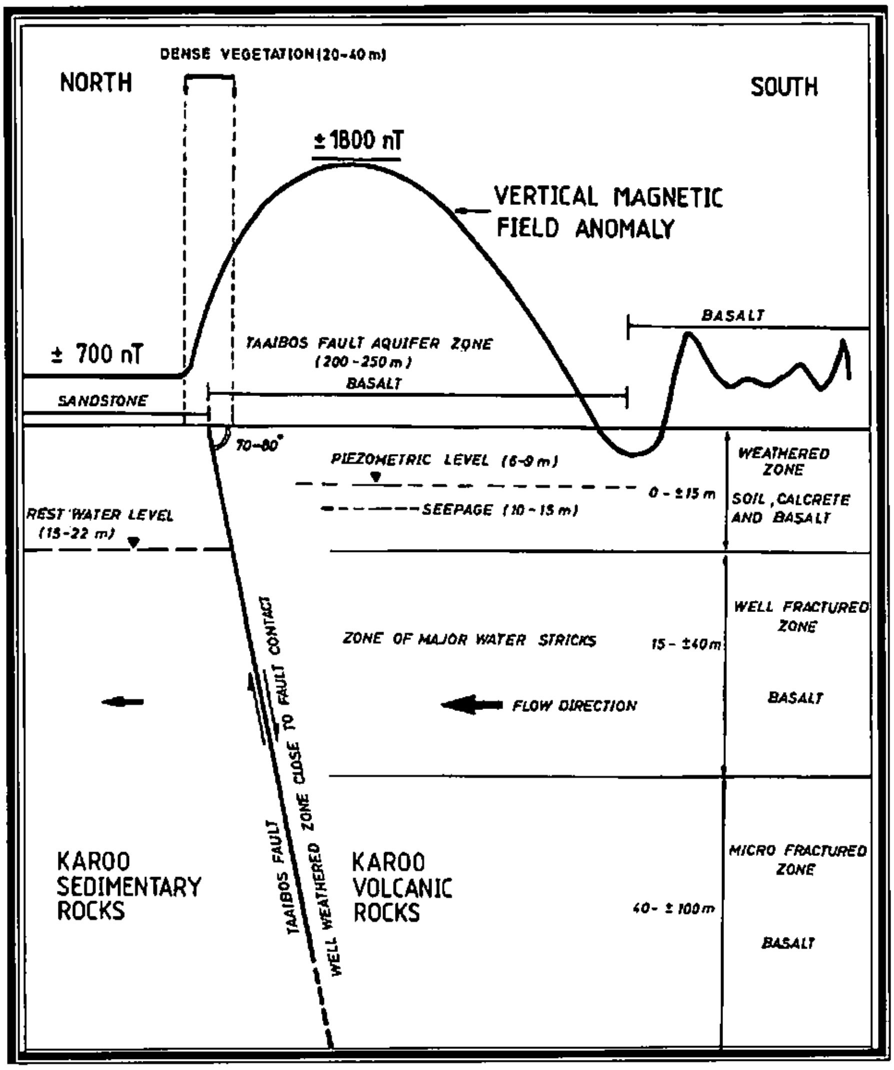


Figure 10: Typical magnetic response over the Taaibos Fault (after Fayazi and Orpen,1989).

The geophysical methods used include magnetic, electromagnetic and DC resistivity profiling. The Scintrex fluxgate magnetometer was used successfully to locate the fault zone. The anomaly followed more or less the following pattern: a flat segment of approximately 700nT on the Karoo sediments followed by a positive anomaly rising rapidly to 1300 to 1800nT related to the response of the sandstone/basalt contact. The response become less to form a small negative on the other side of the fault followed by typical erratically responses on the basalt. The Scintrex SE-88 Genie was used with coil separations of 50, 75 and 100m employed. The dip of the fault was not always determined from the data but the position of the fault could be interpreted as it had a high conductive response at the sandstone/basalt contact. DC resistivity profiling was done using the Wenner configuration employing constant electrode separations of 10, 30 and 50m. The contact and width (200-250m) of the fault zone could be interpreted from the data.

A total of 46 exploration boreholes were drilled, including two private boreholes which were re-habilitated. Ten boreholes were pump tested by doing a short calibration test of approximately 60min, followed by four steps of two hours each and a constant test of 24 to 48hrs. The recovery of the water level was measured after each pumping phase. Water level measurements were done at pre-determined time intervals during the pumping and recovery phases. The calibration test was a fast method to determine the relation between yield/drawdown for each borehole. The specific capacities were calculated for each step test using specific capacity = pumping rate/drawdown (ℓ/s/m). The data shows decreasing borehole efficiencies with increasing yield which was attributed to increased turbulence at well face at higher pumping rates. Pump test data was interpreted using curve matching techniques of Theis (non-equilibrium, confined conditions) and Boulton (gravity drainage, unconfined) and the residual drawdown method to interpret the hydraulic parameters transmissivity and storativity. The transmissivity values range from 139 to 3,481m²/d with an average of 944m²/d. Storativity values ranges from 4.8×10^{-4} to 6.7×10^{-2} and an average of 2.4×10^{-2}. All the boreholes except one exhibited radial flow which was interpreted to indicate that fracture systems in the basalt behave uniformly (isotropic aquifer).

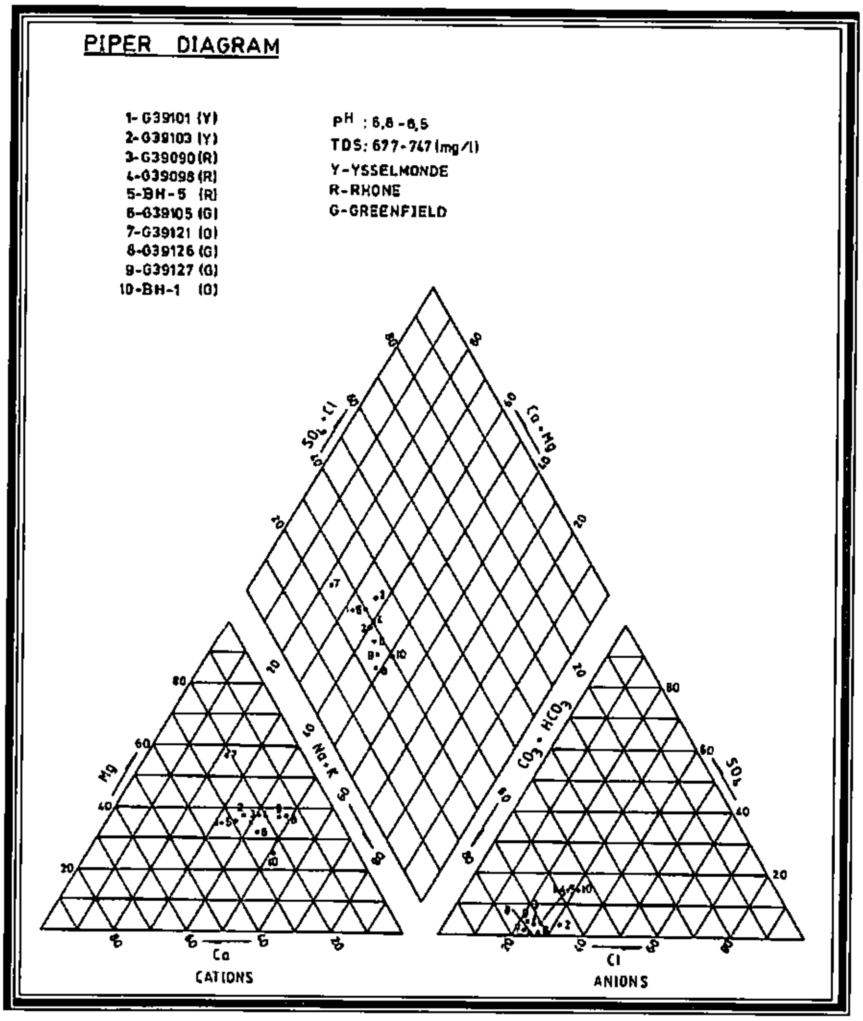


Figure 11: Chemical analysis presented on a Piper diagram (after Fayazi and Orpen,1989).

The results of the chemical analysis were plotted on Piper and Durov diagrams. The general water type can be described a calcium-magnesium bicarbonate groundwater typical associated with recent recharged water. The water is rated as hard to very hard but is still within the maximum allowable SABS limits with the exception of nitrate levels. Nitrate problems are typical of water in the basalt aquifers of the Karoo Supergroup. Two rainwater samples were collected to estimate recharge.

A regional water level contoured map at 5m intervals was produced using piezometric water levels obtained during a borehole census. The map shows fairly complicated groundwater flow directions in the area and the varying spacing of the groundwater contours reflect changes in bedrock permeability. The following observations were reported: the flow pattern mimics the topography, on the southern side of the fault (basalt) the groundwater gradient is fairly constant to the south-east and north-western direction, north of the fault (sandstone) the groundwater contours become more concentrated indicating a reduction in bedrock permeability. To the east the groundwater flow directions are less predictable, this is were the fault widens and loses its clear definition.

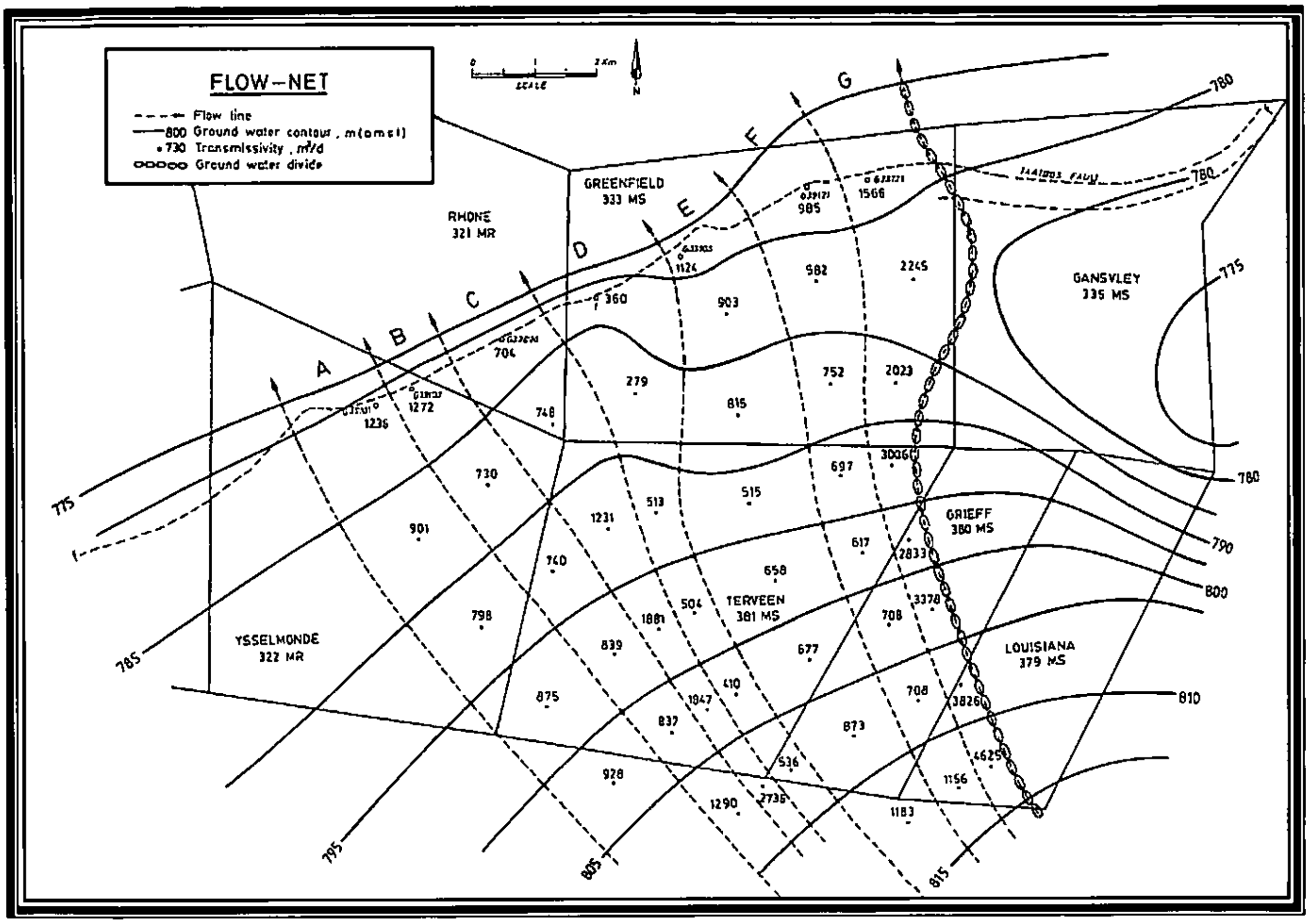


Figure 12: Flow-net showing transmissivity, piezometric water level contours and streamlines, (after Fayazi and Orpen,1989).

A flow net with transmissivity values interpreted from pumping tests data was produced. It consists of a network of equipotential lines and streamlines (**Figure 12**). From the flow net quantities of groundwater flowing through each stream tube A to G were estimated. The results show a prominent zone of high transmissivities entering the farm Greenfield from the south striking parallel and close to the groundwater divide. Caution must be exercised when interpreting groundwater behaviour as the configuration of the steam tubes depends largely on the groundwater contours. The accuracy of the contours is dependant on sufficient data points and spatial distribution. The transmissivities obtained from the pumping tests represent the values of the stream tube segment along the fault while all other transmissivities are estimated. Bedrock variations for transmissivity occur making the assumption almost invalid.

A calculation of the groundwater flow (recharge potential) towards the fault using the results of the flow net is 37,154m³/d along 11,2 km thus 37154m³/d/11,2km = 3,317 m³/d/km or 1.2 x10^{6}m^3/yr/km.

A calculation of the recharge potential was made using Darcy's equation and averages:

Recharge towards the fault/km = transmissivity x gradient x width
944m²/day x 0.0031 x 1000m = 2926m³/d/km or 1.1 x 10^6m³/yr/km

- 944m²/day is the average transmissivity obtained from the pumping tests
- 3m/km or 0.003 is the average gradient of the groundwater piezometric surface towards the Taaibos Fault
- 1000m the length of aquifer used to obtain a volume/km

Using averages to calculate the flow resulted in 1.1 x 10^6m³/yr/km compared to 1.2 x 10^6m³/yr/km from the flow net analysis.

Table 4: Total groundwater flow along each stream tube towards the Taaibos Faults (after Fayazi and Orpen, 1989).

Stream-tubes	Transmissivity (m²/day) (T)	Width of stream-tube (m)	Details of hydraulic gradients				Rate of groundwater flow (m³/d) (Q=Tiw)
			Length (m)	Between contours (m)	Head difference (m)	Gradient (i)	
A	1236	1700	8100	805 780	25	0.0031	6514
B	1272	1100	8300	810 785	25	0.0030	4198
C	704	1700	8400	810 785	25	0.0030	3590
D	360	2100	8600	810 785	25	0.0029	2192
E	1124	1500	6900	805 785	25	0.0036	6070
F	985	1500	7000	805 780	25	0.0036	5319
G	1566	1600	6800	805 780	25	0.0037	9271
Total		11200					37154

An estimate of the groundwater in storage for the main aquifer was made:

Storage = Thickness x width x length x storativity.
25m x 250m x 1000m x 0.024 = 0.15 x 10^6 m³/km

- 25m being the assumed saturated thickness of the aquifer obtained from drilling logs
- 250m is the assumed lateral extension of the aquifer southward from the fault-geophysical interpretation
- 1000m the length of aquifer used to obtain a volume/km
- 0.024 is the storativity derived from pumping tests

The study by Fayazi contributed greatly to the use of groundwater in villages along the fault. The Taaibos Fault zone is a major regional aquifer for rural villages situated along or near the fault zone between the Magalakwena River in the west and the town of Alldays in the east.

3.1.4 Case study 4: Groundwater assessment Kruger National Park

The report compiled in 1998 by W.H. Du Toit covers a study on the geohydrology of the National Kruger Park based on the evaluation of existing groundwater information (GH3806).

The report gives details on the findings of the evaluation of groundwater within the Kruger National Park. At the request of the Water Research Commission an investigation was done from 1989 to 1993 by DWA personnel. The objectives were to study the occurrence of groundwater, to determine static water levels and fluctuations. The groundwater chemistry and the so called 'dry areas' were investigated and the drainage and recharge studied

Since 1933 an estimated total of between 1000 and 2000 boreholes were drilled within the park. Drilling records of 1011 were available for evaluation. Of these drilled boreholes 339 were in use (October 1989) and the boreholes not found were mainly unsuccessful boreholes. The success rate was therefore calculated at 17% (339/2000) and 33% for (339/1011) boreholes.

Twenty-one groundwater units were identified with ten occurring within the boundaries of the Messina map sheet. Evaluated on the yield/drawdown relationship or specific capacity (ℓ/s/m) the unit with the best groundwater development potential is the Tertiary to Quaternary deposits, closely followed by the Wyllies Poort Formation. The traditional 'dry areas' were found to be mostly underlain by the Jozini Formation which had the lowest specific capacity. Groundwater levels fluctuations were found to be seasonal with a small number of boreholes showing a decline over time due to over exploitation in limited storage areas or due to below normal rainfall periods. Most of the boreholes investigated with records data showed a good relation between abstraction and recharge. The lack of abstraction figures combined with the majority of boreholes being equipped with wind pumps, made a calculation of the water balance for the park unreliable.

Groundwater drainage was found to follow the surface drainage pattern more or less in an easterly and south-easterly direction. The study suggested that based on existing data effluent flow seems to dominate (groundwater recharging rivers) along most of rivers. Exceptions seem to be where production boreholes are near rivers with sufficient abstraction to cause a local reversal in groundwater flow direction. Temporal reversals can also occur during flooding of the river where the flood plane is recharged with normality returning after days and even months. It was observed that in very dry periods water in alluvium or in river pools will flow towards a borehole where the static water level dropped. Other observations made are that boreholes drilled in elevated areas (near topographic water divides) dry up during periods of extended droughts.

The report makes use of specific capacity to evaluate the groundwater development potential of the units. It is based on a classification developed by the U.S.A. Department of Internal affairs that uses specific capacity as a measure to evaluate the groundwater development potential of different rock units (Du Toit, 1989). Specific capacity varies during a pump test; it becomes less with increased pumping time and increased drawdown due to the decrease in the saturated weathered zone during pumping. It is thus a function of the construction of the borehole as well as the hydrogeological character of the aquifer.

Information on static water levels was obtained from 1933. The water levels measured are recorded to be between 1.2 and 49.2mbgl. The largest part of the park has static water levels of less than 20m. The area falling within the Messina map sheet has static water levels seldom exceeding 10mbgl. Only eight boreholes in the park have recorded water levels exceeding 40m. It is concluded in the report that the water levels in these eight boreholes might not have been static water levels due to over pumping.

Problems mentioned in the report that were experienced during the evaluation of data.

- unreliable recording of dry boreholes
- most of the boreholes were drilled for windmills and when the first water was struck drilling was stopped thus the aquifer was not always fully penetrated
- boreholes were grouped under geological units based on position; thereafter it was referred to as a geohydrological unit and described according to groundwater characteristics. As with the Messina hydrogeological map not enough data on borehole logs is available to distinguish between the different formations of the Karoo Supergroup and therefore they were grouped together

Table 5: Summary of the characteristics of the hydrogeological units in the Kruger National Park which also occur on the Messina map sheet (after Du Toit, 1998).

Hydrogeological unit	Number dry bh	% dry bh %	% yield decreased over time %	Min bh depth (m)	Max bh depth (m)	Average bh depth (m)	Min water strike depth (m)	Max water strike depth (m)	Average water strike (m)	Max yield (ℓ/s)	Average yield (ℓ/s)	Min EC (mS/m)	Max EC (mS/m)	Min specific capacity after 100min (ℓ/s/m)	Max specific capacity after 100min (ℓ/s/m)	Average specific capacity after 100min (ℓ/s/m)	Min specific capacity after 100min (ℓ/s/m)	Max specific capacity after 100min (ℓ/s/m)	Average specific capacity After 100min (ℓ/s/m)
Goudplaats gneiss	98	19	14	4.5	65	42	5	79	25	10.33	1.82	53	372	0.004	2.137	0.291	0.003	1.736	0.236
Sibasa Formation	9	11	25	16	96	46	2	50	21	3.1	1.22	94	351			0.145			0.136
Fundudzi Formation	66	0	0	31	61	49	23	51	39	3.6	0.98	103	603						
Wyllies Poort Formation	34	39	3	12	105	50	16	100	43	22.2	2.1	21	309	0.006	1.472	0.51	0.036	1.472	0.53
Ecca Group	38	32	12	9	118	47	7	70	31	15.2	0.93	109	473	0.009	0.029	0.018	0.004	0.02	0.012
Clarens Formation	17	13	27	15	78	46	9	75	33	12.5	4.8	91	162	0.015	17.86	0.187	0.011	17.86	0.084
Letaba Formation	417	21	15	6	178	49	2	160	26	15.6	1.48	24	725	0.002	6.389	0.47	0.002	3.993	0.325
Jozini Formation	39	46	0	20	139	55	8	88	36	2	0.2	404	404						
Malvernia Formation	1	100	0	89	83	83				0	0								
Tertiary and Quaternary Deposits	24	32	6	5	69	32	3.1	56	23	18.9	2.4	93	187			0.68			0.64

Note: The table was compiled using borehole information from the entire Kruger National Park area and not just from the boreholes occurring north of latitude 23ºS.

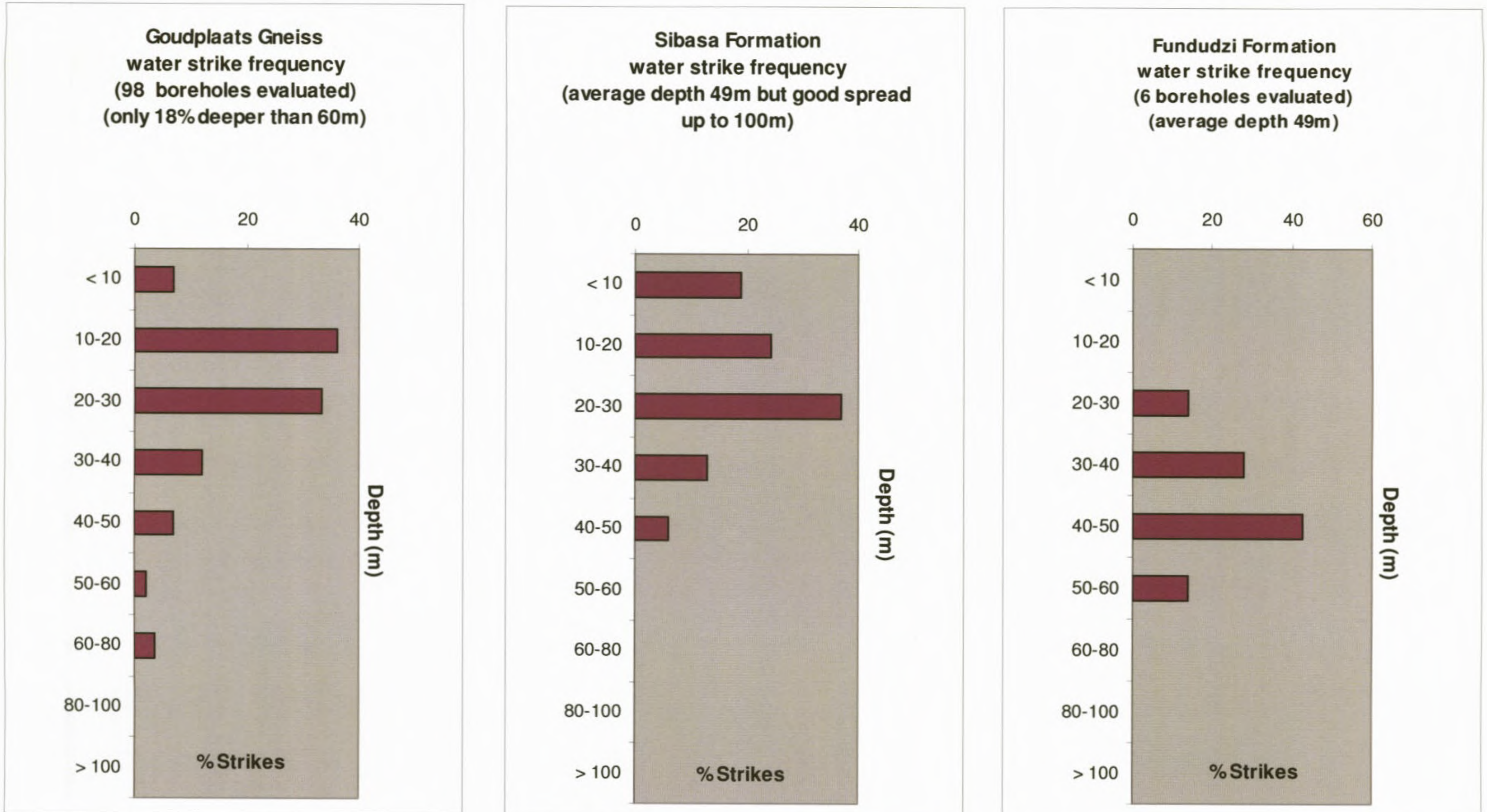


Figure 13: Water strike frequency for the Goudplaats Gneiss, Sibasa Formation and Fundudzi Formation (after Du Toit, 1998).

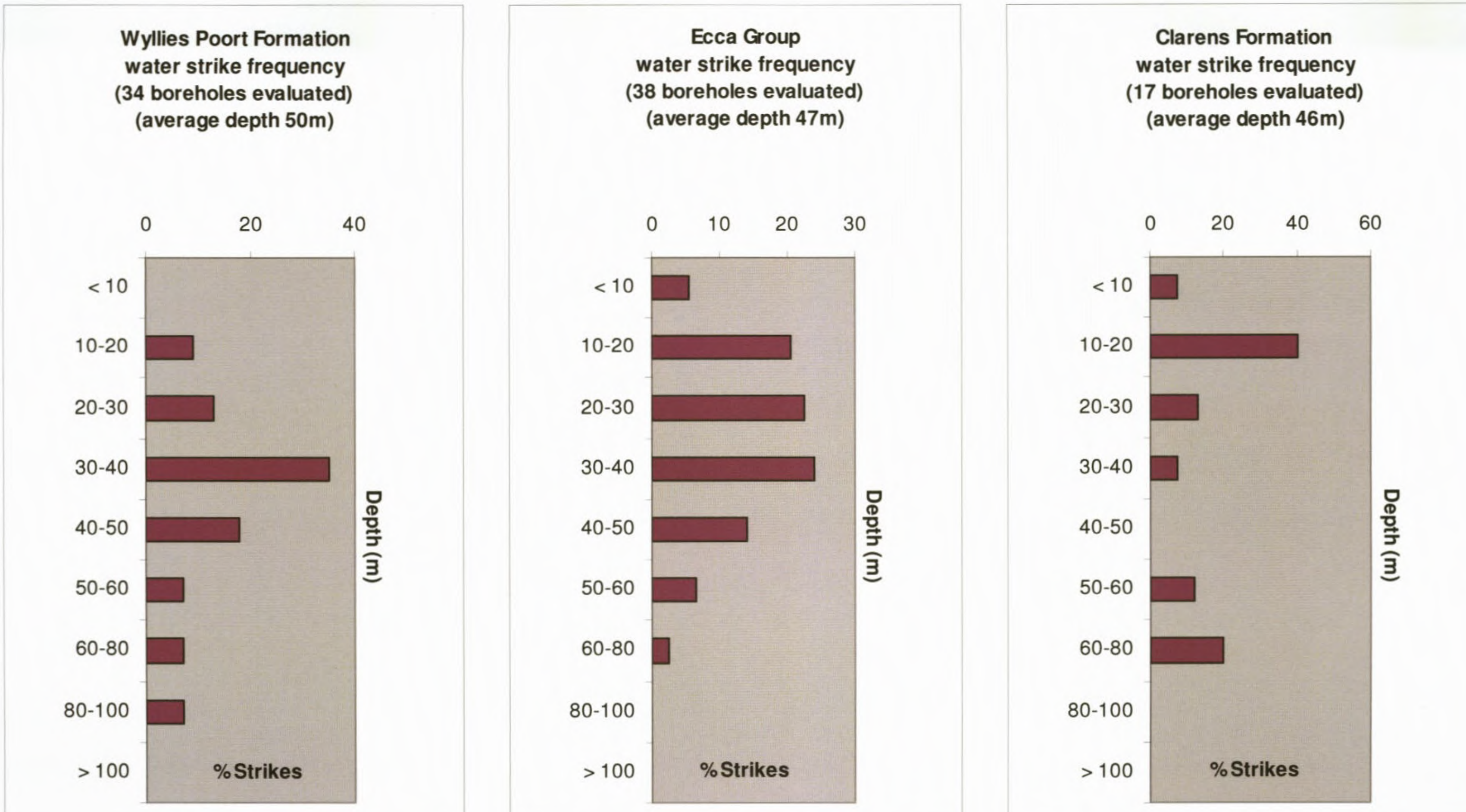


Figure 14: Water strike frequency for the Wyllies Poort Formation, Ecca Group and Clarens Formation (after Du Toit, 1998).

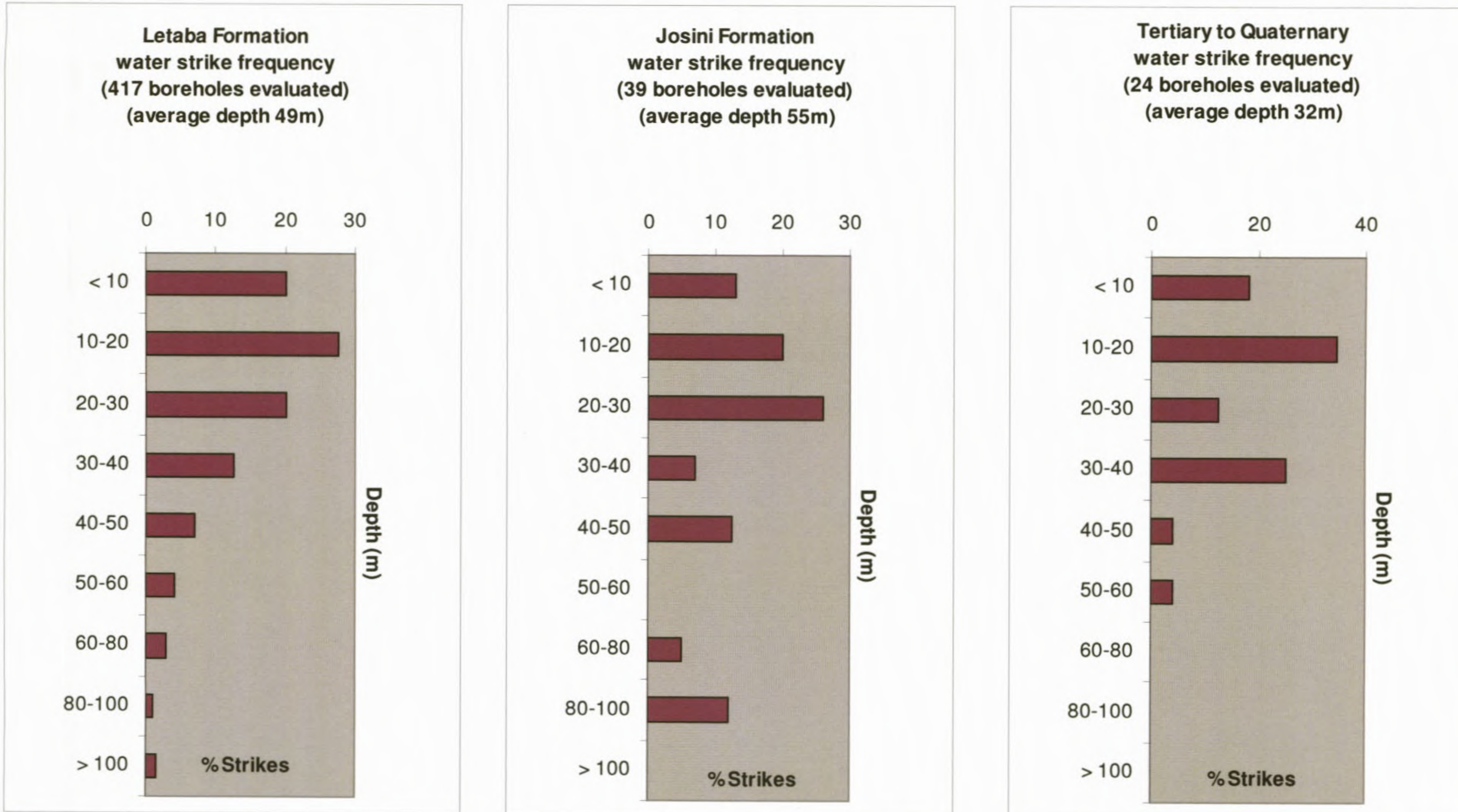


Figure 15: Water strike frequency for the Letaba Formation, Jozini Formation and Tertiary to Quaternary Deposits (after Du Toit, 1998).

Table 6: Classification of groundwater chemistry, within the geological units occurring in the Kruger National Park, which falls under the Messina map sheet (after Du Toit, 1998).

Hydrogeological unit	Classification after HEM (1970)	Classification according to dominant ionic species (Piper diagram)	Classification in regards to plot position on the Piper diagram (after Davis & DeWiest, 1966)
Goudplaats gneiss (Biotite gneiss, migmatite)	Fresh to slightly salty	1,2,3,4,5, and 6	A, B, C and E
Sibasa Formation (Basalt, quartzite)	Fresh to slightly salty	1,2 and 10	A, D and E
Fundudzi Formation (Sandstone)	Slightly salty	5 and 7	E (borders C)
Wyllies Poort Formation (Sandstone, quartzite)	Fresh to slightly salty	1,4 and 8	C and E
Ecca Group (Mudstone, shale)	Fresh to slightly salty	1,4 and 8	C and E
Clarens Formation (Sandstone, clayey sediments)	Fresh to slightly salty	1 and 3	A and B
Letaba Formation (Basalt)	Fresh to slightly salty	1,2,3,4,5,7,8,9 and10	A, B,C and E
Jozini Formation (Rhyolite)	Slightly salty	8	C
Tertiary and Quaternary Deposits (Alluvium)	Fresh to slightly salty	1,3 and 5	A and E

Explanation:

1. Sodium-magnesium-bicarbonate water
2. Sodium-magnesium-calcium bicarbonate water.
3. Sodium-bicarbonate water.
4. Sodium-chloride-bicarbonate water.
5. Sodium-magnesium-chloride-bicarbonate water.
6. Sodium-magnesium-calcium-chloride-bicarbonate water.
7. Sodium-magnesium-chloride water.
8. Sodium-chloride water.
9. Calcium-magnesium-bicarbonate water
10. Magnesium-bicarbonate water.
11. Magnesium-chloride-bicarbonate water

A. Recent recharge groundwater, rich in Ca, Mg and HCO_3.
B. Ion exchange over time. Mg, Ca exchange with Na.
C. Old water. High in Cl that build up over time.
D. Old stagnant water
E. Well mixed water, no dominant ions.

Note: The above was compiled from 363 samples collected from May to September 1991 from the entire Kruger National Park area.

In the report a broad classification of the groundwater quality was done based on total dissolved salts (TDS) as a first indication. Each hydrogeological unit of the Kruger National Park was evaluated on this basis (**Table 7**). The division after HEM (1970) was used.

Table 7: The TDS analysis was used as first indication of the groundwater quality of the National Kruger Park (after Du Toit, 1998)

Classification	Total dissolved salts (mg/l)	Approximate electrical conductivity (mS/m)
Fresh	0-1000	0-150
Brackish	1000-10000	150-1500
Salt water (see water)	10000-35000	1500-5400
Brine	>35000	>5400

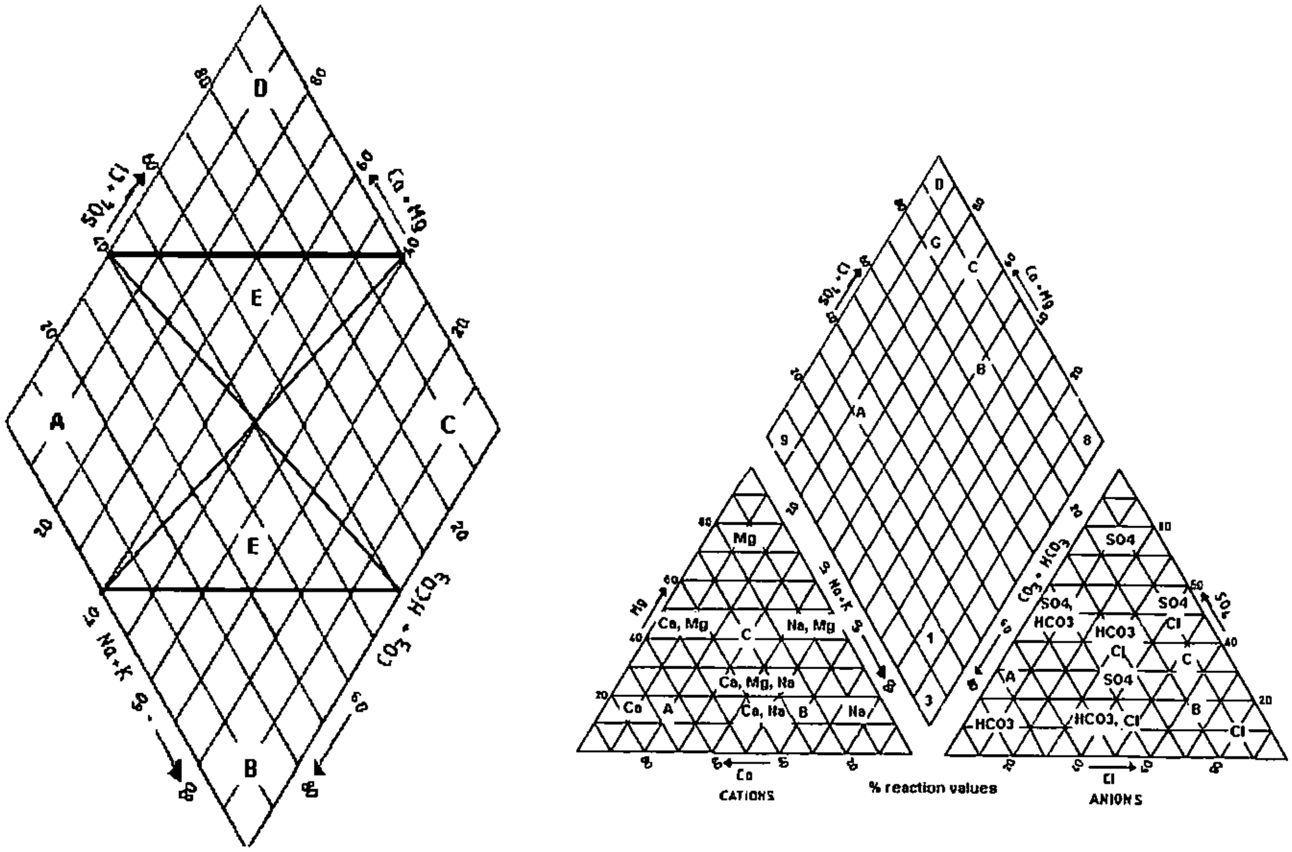


Figure 16: The Piper diagram was used in the report to classify the groundwater based on major ionic species in [% meg/ℓ] according to fields and % ions (after Du Toit, 1998).

Piper: the plot of major ionic species in [% meg/ℓ]. Five fields are divided by the Piper diagram (after Davies and DeWiest, 1966).

A – Recent recharge water rich in Ca, Mg and HCO_3 formation.
B – Over time ion exchange takes place. Mg and Ca are replaced by Na.
C – Old water, over time Cl builds up.
D – Stagnant water, high SO_4 water is not moving, moving slowly or contaminated.
E – Mixed water, no cation or anion pair exceeds 50%.

3.2 Summary

Past groundwater research and development projects

- The majority of 23 project reports received from DWA were for the period 1967 to the early 1990's.

- From the early 1990's most information was obtained digitally from the National Groundwater Archive (NGA).

Case study 1: Dowe Tokwe Fault

Report GH3260, November 1983 by M. Fayazi and W.R.G. Orpen, Directorate Geohydrology.

- The daily water demand of the Messina municipality was 2,343m³/day in 1983. The water was obtained by pumping from the Limpopo River (2,030m³/day) and the rest from 5 existing boreholes within the town (maximum 1,000m³/day estimated).

- The investigation focussed on a 3.5km stretch along the Dove-Tokwe Fault and the confluence area of the Sand and Limpopo rivers.

- The geology surrounding the fault is a granitic-gneiss intruded in places by sub-parallel zones of amphibolitic rock and dolerite dykes. The fault can be identified on the surface by the geology thereof.

- Fifteen boreholes were drilled targeting the fault zone varying in depth between 19.6 and 82.3m (Harmonic mean =42.3m).

- The static water table from boreholes near the fault zone was measured to be between 15.4 and 24.8mbgl.

- The water strikes in boreholes targeting the fault were between 18 and 78m (Harmonic mean =1.4m). Shallow strikes (<32m) relates to the base of the weathered rock or fault breccia and deeper strikes relates to fractured zones within the feldspathic quartzite or quartz.

- Five boreholes were drilled on the river bank at the confluence of the Sand and Limpopo rivers.

- These boreholes were drilled to a depth of 21.9 to 33.6m. The static water levels were measured to be between 4.85 and 8.16mbgl.

- Four of the boreholes yielded more than 5ℓ/s and the remaining one was less than 0.5ℓ/s.

- The boreholes along the Limpopo River proved to be more successful in striking high yielding groundwater than the fault zone.

- The conclusions in the report were that the ground water potential of the Dowe-Tokwe Fault is $0.8 \times 10^6 m^3$/annum using a MAP of 400mm, a surface catchment area of 40km² and a 5% recharge figure.

Case study 2: Taaibos Fault

Report GH3664, M. Fayazi and Orpen W.R.G., 1989, Directorate Geohydrology.

- This project was initiated to supply an expected increase in the water demand due to potential growth at Alldays. The growth at Alldays was restricted due to a shortage of water.
- The Taaibos Fault zone was chosen as the preferred source to be investigated as the Limpopo and Magalakwena rivers were deemed too far and commitments were already in place for other users.
- To locate and delineate the fault zone the magnetic, electromagnetic and DC resistivity profiling geophysical methods were applied with varied success.
- Forty exploration boreholes were drilled that included two private boreholes that were re-habilitated.
- Ten boreholes were subjected to pump testing.
- The calibration test was used as a fast method to determine the relation between yield/drawdown for each borehole.
- Pump test data was interpreted using curve matching techniques of Theis (non-equilibrium, confined conditions) and Boulton (gravity drainage, unconfined) and the residual drawdown method to interpret the hydraulic parameters transmissivity and storativity.
- The transmissivity values range from 139 to 3,481m^2/d with an average of 944m^2/d. Storativity values ranges from 4.8×10^{-4} to 6.7×10^{-2}. The basalt aquifer was interpreted to be isotropic.
- The general water type can be described as calcium-magnesium bicarbonate.
- The water is rated as hard to very hard but is still within the maximum allowable SABS limits with the exception of nitrate levels.
- The results of a flow net show a prominent zone of high transmissivities entering the farm Greenfield from the south striking parallel and close to the groundwater divide
- A calculation of the groundwater flow (recharge potential) towards the fault using the results of the flow net is 37,154m^3/d along 11,2km thus 37,154m^3/d/11,2km = 3,317 $m^3/d/km$ or $1.2 \times 10^6 m^3/yr/km$.
- A calculation of the recharge potential was made using the Darcy's equation and averages and the result was $1.1 \times 10^6 m^3/yr/km$ compared to $1.2 \times 10^6 m^3/yr/km$ from the flow net analysis.
- An estimate of the groundwater in storage for the main aquifer was made with the result calculated as : $0.15 \times 10^6 m^3/km$
- The study by Fayazi contributed greatly to the use of groundwater in villages along the fault.
- Today the Taaibos Fault zone is a major regional aquifer for rural villages situated along or near the fault zone between the Magalakwena River in the west and the town of Alldays in the east.

Case study 3: Beit Bridge complex – Swartwater area

Report GH3577, R.A. Bush., August 1989, Directorate Geohydrology.

- The groundwater exploration and assessment project focused around the Swartwater area.
- The report is one of the major sources of information regarding the occurrence of groundwater in areas underlain by the Beit Bridge Complex.
- The Beit Bridge Complex is divided into the Gumbu, Malala Drift and Mount Dove Groups.
- Below average rainfall, leading to failing surface and groundwater supplies emphasised the historic occurrence of periodic droughts.
- At the time of the project, the groundwater information for the area was too inadequate to give reliable advice to people living in the area.
- As with most projects of the time, an extensive hydrocensus covering 136 cadastral farms were done.
- Available data indicated that state assistance in the form of drilling or geophysical site selection was on record since 1914 with some farms receiving up to 24 boreholes.
- During the hydrocensus 705 boreholes were found and evaluated.
- From available records and other information, the estimation was made that only 10% of the boreholes drilled in the area were found.
- From this and the 399 boreholes with information, it is clear that the chance of finding water in this unit is very low.
- The findings of 109 hydrochemical samples obtained on the project were analysed by plotting the data on a Piper diagram.
- In the Swartwater area high TDS, nitrate and fluoride exceeds the maximum allowable limit for human consumption in 83% of the cases. The rest of the macro elements contribute to less than 10% of the problems. For livestock watering less than 1% of the sampled boreholes proved problematic.
- Remote sensing techniques were used to identify lineaments that were further investigated by geological observations and field geophysical methods.
- Improved groundwater recharge were found in areas with dams.
- Recharge to groundwater is limited.
- The high grade of metamorphism has largely destroyed original sedimentary and intrusive structures.
- The most favourable geohydrological features in the area is post-metamorphic event fault and shear zones. The secondary fractures associated with dolerite and diabase dykes intrusives does not extend to below static ground water levels except in the western part of the area.

- The limited thickness of the saturated zone and lateral extent of aquifers resulted in dewatering during pumping tests conducted on boreholes.

Case study 4: Kruger National Park ground water assessment

Report GH3806. W.H. Du Toit., 1998, Directorate Geohydrology.

- The project was initiated by the Water Research Commission to investigate water supply problems experienced in the Kruger National Park. DWA personnel executed the project during 1989 to 1993.

- The project was done by evaluating existing groundwater information and a field phase that included a hydrocensus, field geophysical surveys, drilling and testing. Additionally the occurrence of groundwater, recharge and the relationship between surface and groundwater levels were studied.

- Approximately 2000 boreholes were drilled in the park since 1933. During the hydrocensus 1011 boreholes were found with 339 in a working order.

- Twenty one groundwater units were identified with ten occurring within the boundaries of the Messina map sheet.

- The report makes use of specific capacity to evaluate the groundwater development potential of the units.

- Evaluated on the yield/drawdown relationship or specific capacity (ℓ/s/m) the unit with the best groundwater development potential is the Tertiary to Quaternary deposits, closely followed by the Wyllies Poort Formation. The traditional 'dry areas' were found to be mostly underlain by the Jozini Formation that also had the lowest specific capacity.

- Recorded static water levels (since 1933) are between 1.2 and 49.2mbgl. The largest part of the Kruger National Park area has static water levels of less than 20m. The water levels in the area covered by the Messina map sheet is usually less than 10mbgl.

- Groundwater level fluctuations were found to be seasonal with a small number of boreholes showing a decline over time due to over exploitation in limited storage areas or due to below normal rainfall periods

- Water strikes in the Goudplaats gneiss, Sibasa-, Letaba-, Jozini Formations and the Tertiary to Quaternary deposits is predominantly between 10 and 30m. For the Fundudzi Formation it is between 30 to 50m, the Wyllies Poort Formation is between 30 to 40 and the Ecca Group between 10 and 40m.

- Chemical evaluation of 363 samples was done using TDS values as first indicator for water quality. All the hydeogeological units except the Jozini and Fundudzi formation are fresh to slightly salty.

Problems mentioned in the report that were experienced during the evaluation of data.

- Poor recording of dry boreholes.
- Evaluation on aquifer yield and strikes was hampered by the tendency to stop the drilling process when enough water was found for a windmill; therefore the aquifers were not always fully penetrated.
- Not enough data on borehole logs is available to distinguish between the different formations of the Karoo Supergroup. They were grouped together as a single geohydrological unit.

Chapter 4 : Literature review - geological concepts

4.1 Geological Concepts

The concepts covered in this chapter deal with some of the basic geological terminology used in this thesis as well as certain processes related to the occurrence of groundwater.

4.1.1 Stratigraphy

The crust of the earth is dynamic and is in a never-ending cycle of change involving destruction (erosion) or the formation of new rocks (volcanic activity). Rocks and geological features such as mountain ranges are records of this process over geological time. By studying rocks and the processes that created them rock strata with similar properties can be grouped together to form a lithostratigraphic unit and placed in chronological order within the geological timetable. Chronostratigraphy is that element of stratigraphy which deals with the age of strata and their time relationship.

A member is the formal lithostratigraphic unit ranking below a formation. It belongs to a formation and is distinguished in lithological character from the rest of the formation making it significant as it can be used as a marker horizon. It may exhibit protrusive relationships and lenticular shapes in part and may extend from one formation to the other while retaining its name.

The fundamental formal unit in lithostratigraphic classification is the Formation. It can contain various types of rocks but is characterized by a lithological uniformity or distinctive lithological feature that can be given a formal name and listed in the stratigraphic column. There is no standard on dimension in aerial extent or thickness. The aerial extent should be large enough to be shown as a unit on a map of a scale of 1:50 000.

A group is a formal lithostratigraphic unit next in rank above a formation. It is an assemblage of two or more successive formations with significant unifying lithologic features in common.

The term Supergroup is used when there is a need to refer to several successive associated Groups and Formations with significant lithologic features in common. The term Subgroup is used to distinguish an assemblage of successive Formations from the rest of and already established Group

A Complex is characterized by a complicated structure and composed of diverse types of any class or classes of rocks, (igneous, metamorphic or even sedimentary). The terms complex, intrusive complex and metamorphic complex may be applicable in terrains characterized by extreme complexity of lithology and structure.

The fundamental rock unit recognised in intrusive igneous and high grade metamorphic terrains is the suite. In some cases the terms intrusive suite, layered suite or metamorphic suite is used. This unit is comparable with the lithostratigraphic group. (SACS. Handbook 8. 1980 pp.648-673).

4.1.2 Formation of rocks

Rocks are divided into three major groups based on the way of formation. The first group formed from a molten or partly molten state and are called **igneous rocks.** It is subdivided under intrusive igneous rocks that solidified at great depths such as granite, gabbro and extrusive igneous rock which formed from lava or volcanic ash ejected on the surface to form rocks such as basalt and andesite. The classification is primarily based on mineralogy.

Sedimentary rocks formed by the deposition of material through natural transporting agents such as water, ice or wind. The transported material originates from the weathering of igneous, metamorphic or sedimentary rocks. Sedimentary rocks are unconsolidated when formed but through various processes such as burial, compression and chemical changes become consolidated. Examples are sandstone shale and mudstone. The depositary type and the grain size are used to distinguish between rocks. When sedimentary or igneous rocks are subjected to heat, pressure and chemical change at depth, **metamorphic rocks** are formed such as amphibolites and gneisses. The process is called metamorphism and the changes are always concerned with the restoration of equilibrium in rocks subjected to a new environment. Prevailing temperature and pressure relates to the recrystallisation of certain minerals. The regional occurrence, the changes in the rock, the occurrence of certain minerals such as garnets are used to determine the source rock and to distinguish between rocks. For example sandstone changes to a quartzite when subjected to pressure and temperature over time. Quartzitic sandstone such as found in the Wyllies Poort Formation has the characteristics of sandstone and quartzite as the process has not yet been completed.

The formation of rocks is influenced by the status of the crustal region which can be stable or mobile. Crustal movements to various degrees influence the types and successions of sediments, the activities of magma and volcanism and the deep seated processes of metamorphism and plutonism. Tectonically stable continental masses (Cratons) accumulate; on balance a restricted pile of sediment and minor fluctuations in level may give rise to alternating phases of deposition and erosion. The stable cratons in Southern Africa (Kaapvaal, Rigtersveld, Rhodesian) are composed of largely granitic material with lesser metamorphosed fragments of volcanic and sedimentary rocks. The mobile belts (ancient Limpopo, relative youthful Natal) are frequently of high metamorphic grade.

The granites of the craton consist of true granites, granodiorites and quarts-diorites and even more basic rocks. Many of the rocks are gneissic and others mixed rocks or migmatites containing a metamorphic host intimately associated with granitic material. Common acid intrusions of pegmatite or aplite are common. Within the granitic rocks metamorphosed remnants in which mafic volcanics are invariably present and with which ultramafic volcanics and sediments may be associated. In the metamorphism of the widespread mafic rocks a number of green minerals are developed such as hornblende chlorite and epidote. This is the origin of the term 'greenstone' and these metamorphosed remnants are commonly referred to as the greenstone belts (Trustwell, 1977, p1-5)

The Karoo Supergroup formed by long continued deposition in the interior or a relatively stable continental mass. The sediments accumulated in a vast intracratonic basin with the maximum depth in the south and in a few satellite basins in the north. The great basins were formed by gentle deformation of the older basement rocks on which they rested (Read and Watson, 1962). It consists of a variety of sediments that reflects the environmental changes during the mitigation of the Gondwana continent over a period of 200 million years from polar to lower latitudes (Brandl, 2002). The succession is entirely continental in facies with a thickness of approximately 12000m in the Southern basin (Woodford and Chevallier, 2002). The sedimentation started with a sequence of diamictite (tillite) locally resting upon a glaciated land surface and passes into sandstone, mudstone and siltstone shale and coal seams, reptiliferous sandstones and mudstones, shales sandstones, redish mudstone and sandstone and aeolian sandstone (Read and Watson, 1962). Sedimentation was terminated by the outpouring of basaltic magma associated with the final break up of the Gondwana continent (Brandl, 2002).

The great rift valleys can be described as an example of fracture zones of limited mobility. Rift valleys are bounded by parallel faults between which tracts of land (usually 50 to 130km wide) are depressed. The depressions leads to the forming of lakes on the valley floors and is partially filled with sediment of volcanic products (Read and Watson, 1962).

4.1.3 Stress, strain and the deformation of rocks

The forces which act on the rocks within the crust are largely related to gravity and the movement of large rock masses in the crust and upper mantle. Gravitation is proportional to mass therefore the weight of an overlying column of rock constitutes a very significant force on rocks at depth in the crust. These applied forces produce a set of stresses. Strain is the geometrical expression of the amount of deformation caused by the action of a system of stresses on a body. Strain is thus the change in size and shape of a body resulting from the action of an applied stress field. Elastic strain also called temporary or recoverable, is the ability of a body to recover to its original shape with the removal of the deforming stress. Viscous strain or permanent strain results in no recovery in shape and size of a body after the removal of the deforming stress (Park, 1983, pp32-44).

In rock a combination of elastic and viscous strain exists when forces are applied. Viscoelastic behaviour is when a material under a given stress shows a basically elastic type of strain but takes time to reach its limiting value. When the stress is removed there is a delayed recovery to the pre-deformed state. Earthquake aftershocks represent continued movements as the elastic strain gradually becomes smaller after the main release of strain represented by the earthquake. Elastoviscous behaviour is when a material behaves elastically under stresses for a short period and viscous when stress is applied for a long period. Plastic behaviour is when a material behaves elastically for low values of applied stress but viscous above a critically stress value (the yield stress) (Park. 1983. pp44-45).

Ideal strain-time relationship for a typical plastic material deformed above its yield point

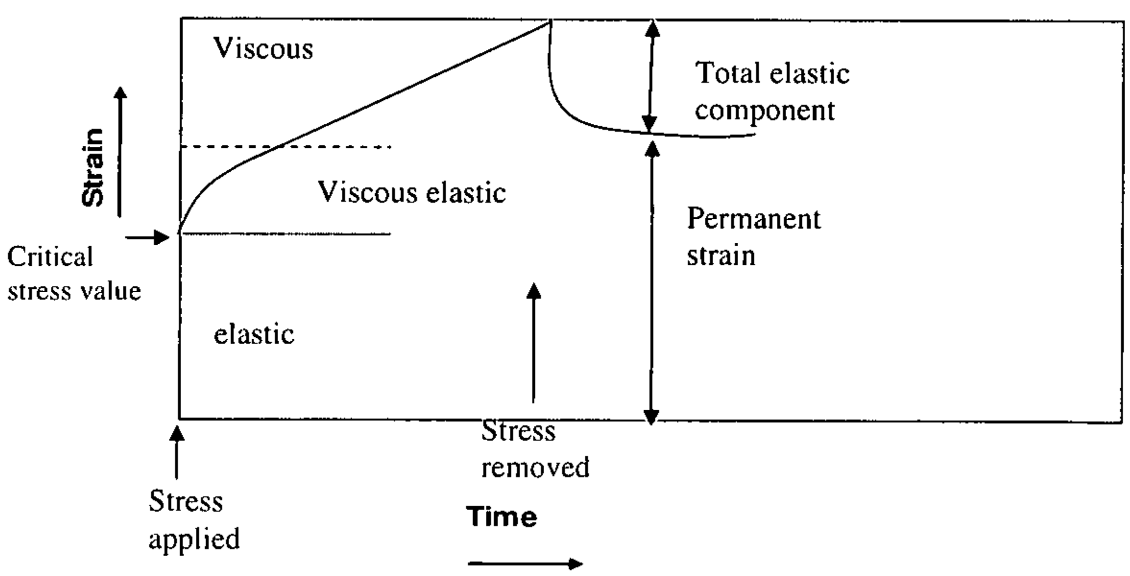


Figure 17: Ideal strain-time relationship for a typical plastic material deformed above its yield point (after Park, 1983).

When elastic deformation leads to failure, the material loses cohesion by the development of a **fracture or fractures** across which the continuity of the material is broken. It is called brittle behaviour that leads to the development of **faults and joints.** Ductile deformation is when permanent strain is produced. It exhibits smooth variation across the deformed rock without any marked discontinuities (Park. 1983, p.45).

Hydrostatic or confined stress is the lithostatic pressure subjected to rock at depth by the overlaying column of rock that will cause volume changes depending on the compressibility of the material. With increased confined pressure material exhibit a higher effective strength therefore showing more ductile behaviour at high pressure. Pore fluid in rocks can promote mineralogical reactions especially at high temperatures therefore affecting the mechanical properties of rock and the pore fluid pressure can reduce the effect of confining pressure. The length of time over which stress is applied on a material will influence the long-term strain behaviour of materials called creep. When rocks are subjected to a constant low stress for a long time, the material will exhibit a strain curve which consists of three stages: material will first behave viscoelastically (primary creep) followed by a stage of secondary creep where the material exhibits essentially viscous flow and finally a stage of tertiary creep where the material exhibits accelerated viscous strain leading ultimately to rupture. (Park, 1983, p46).

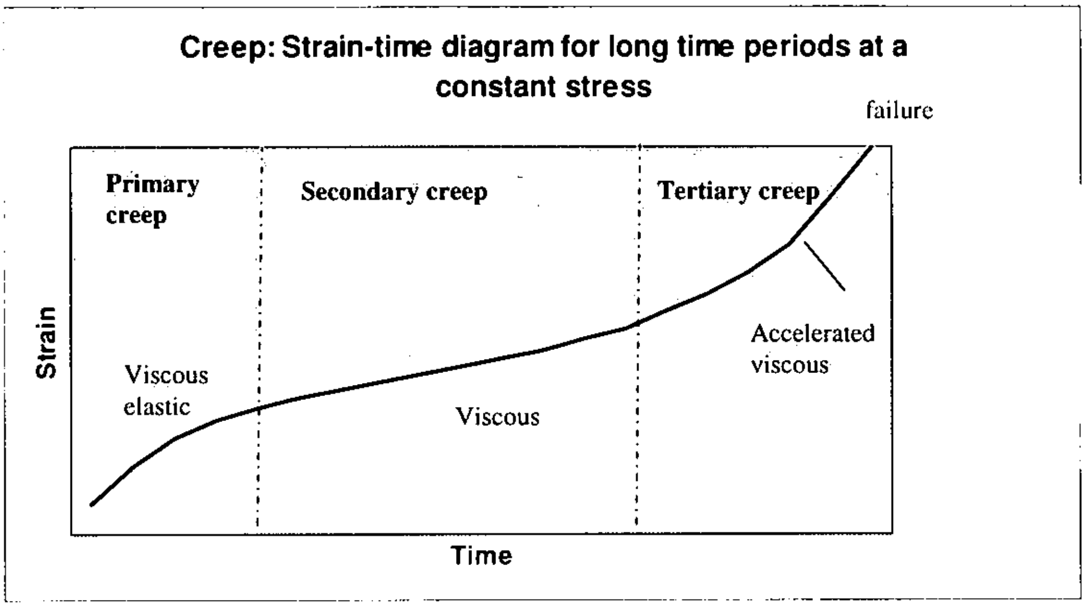


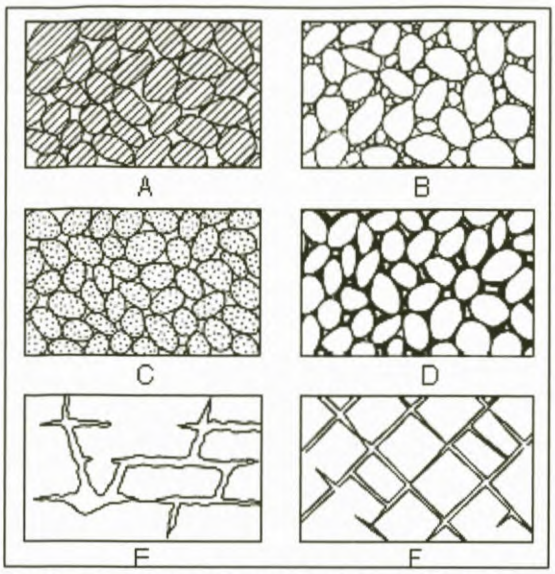
Figure 18: Creep: Strain-time diagram for long periods (after Park, 1983).

4.1.4 Openings in rocks and groundwater occurrences

Rocks occurring on the outer crust of the earth are not completely solid and have numerous openings called voids or interstices, which may contain air, natural gas, oil or water. Porosity relates to the openings in rock and can be defined as:

Porosity $n=V_v/V_T$
where V_v is the volume of the voids in a rock
and V_T the total volume of the same rock.

Porosity of a rock is the percentage of the total volume of the rock occupied by interstices. Porosity is usually expressed as a percentage or as a decimal fraction. With consolidated and hard rocks a distinction is made between **primary porosity** which is present when the rock is formed and **secondary porosity** which develops later as a result of solution or fracturing (Kruseman and De Ridder, 1994). The size of interstices may differ from microscopic to extensive solution caves formed in limestone.



A: Well-sorted sedimentary deposit with a high porosity.
B: Poorly sorted sedimentary deposit having a low porosity.
C: Well sorted sedimentary deposit consisting of pebbles and openings, resulting in the deposit as a whole to have a very high porosity.
D: Well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices.
E: Rock rendered porous by solution
F: Rock rendered porous by fracturing

Figure 19: Diagram showing various types of rock intensities and the relation of rock texture to porosity (after Meinzer 1923a).

In unconsolidated sediments, these pores are interconnected and are therefore useful for transmitting water. The interconnected pores in unconsolidated sediments are also called effective porosity (Reyneke, GHR 612, Hydrochemistry and pollution). The capability of rocks to transmit water is the hydraulic conductivity or permeability. The larger the interstices through which the water flows, be they pores or fractures, the higher the permeability of the rock. The driving force of groundwater is gravity (Vegter, 1995).

A rock is saturated when all the interstices are filled with water or other liquid. The upper zone of the saturated zone is the static water table or groundwater table. Porosity is practically the percentage of the total volume of the rock that is occupied by water. Porosity determines the amount of water held in a volume of rock but not the amount it can yield. The specific yield of a primary water bearing material is defined as the as the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume. The permeability or hydraulic conductivity of a water bearing material is defined as its capacity for transmitting water under hydraulic head, and is measured by the rate at which it will transmit water through a given cross section under a given difference of head per unit of distance (Kansas Geological survey, Pawnee and Edwards Geology and Groundwater, 2004)

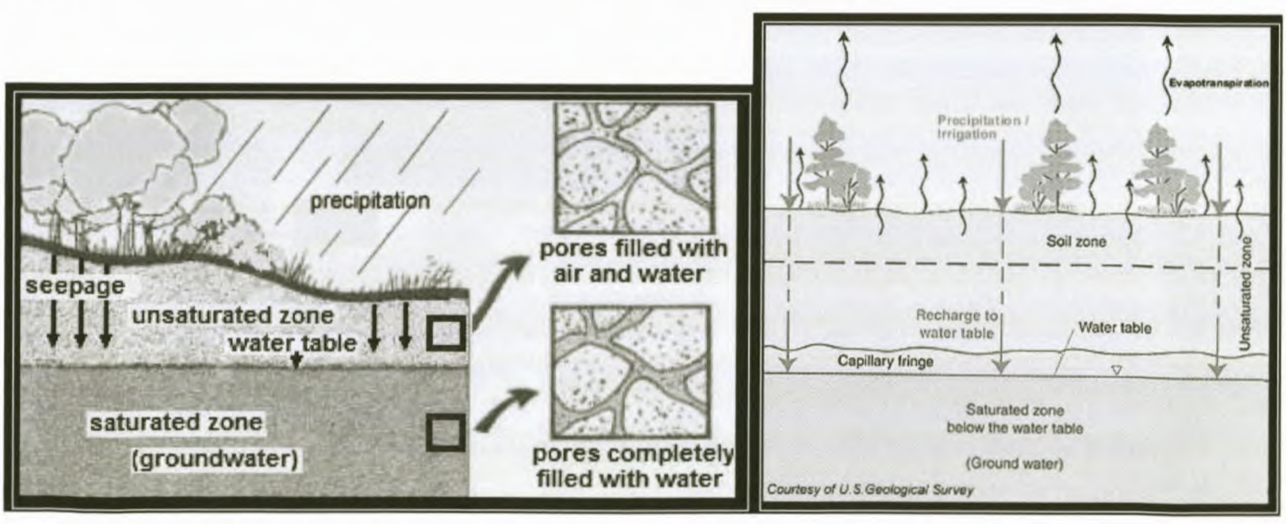
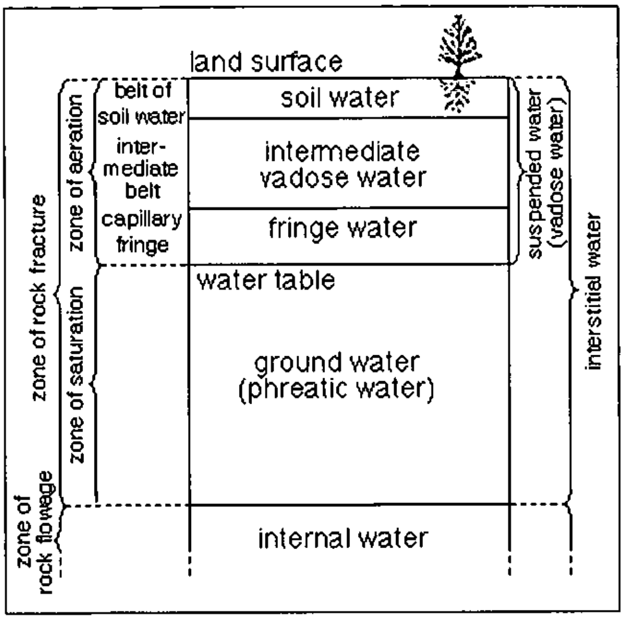


Figure 20: The saturated zone and unsaturated zone (after U.S. Geological survey, 2006).



Secondary porosity in dolomite can be as high as 20-30% but the effective porosity can be very low as the pores are not connected (Matthess, 1982). Rainwater reacts with gases in the atmosphere such as CO_2 to form weak acids such as carbonic acid that will dissolve the calcite in dolomite. The solution of the rock is especially active where there are already preferable pathways for percolating seepage such as bedding planes, fault and fracture zones, joints and folds especially in the area directly underneath a consistent water table (Davies, 1960).

Figure 21: Subsurface zones in the infiltration path from surface to groundwater (after U.S. Geological survey, 2006).

Karst is the term used to describe distinctive surface and subterranean features developed by solution of carbonate and other rocks and is characterized by closed depressions, sinking stream and cavern openings. The name was first use in the early 1900 when the solution landscape in the region of Carso in northern Italy and western Slovenia were studied (Davis, 1930). The resulting solution of rocks can form huge interstices such as the extensive Sudwala cave system in South Africa.

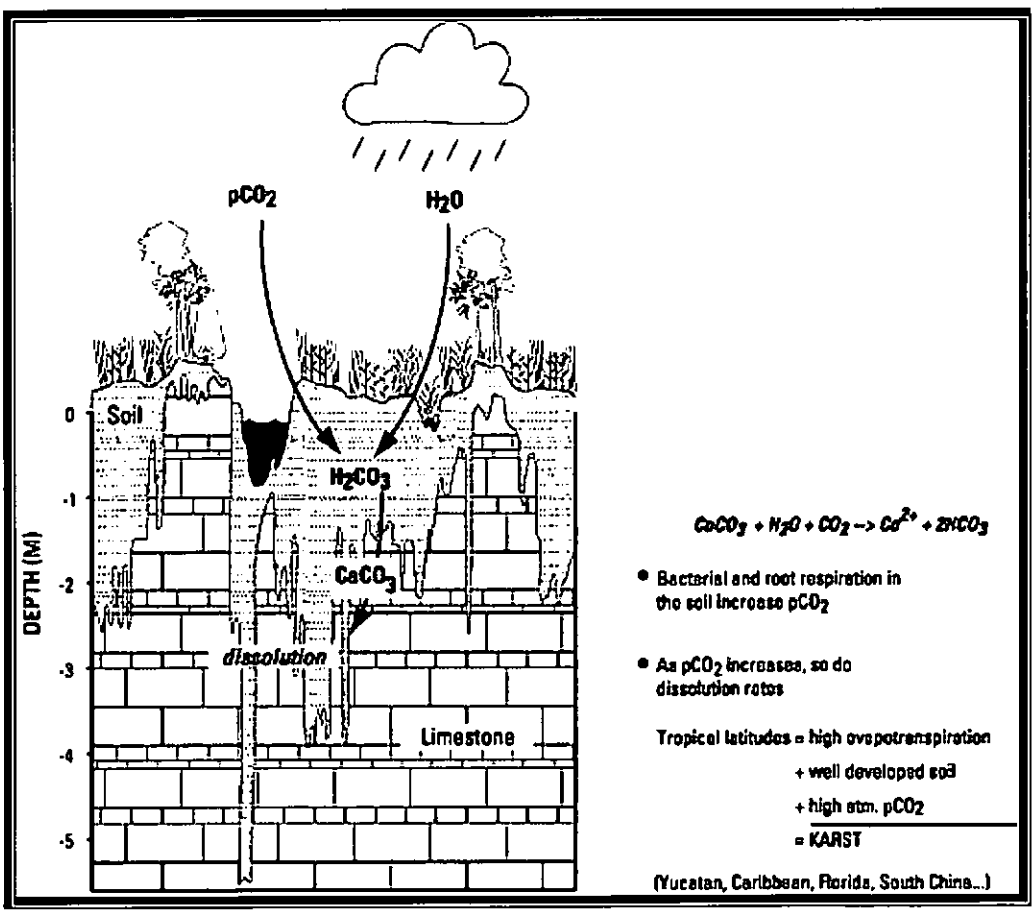


Figure 22: Carbonate dissolution process and Karst formation (after U.S. Geological Survey).

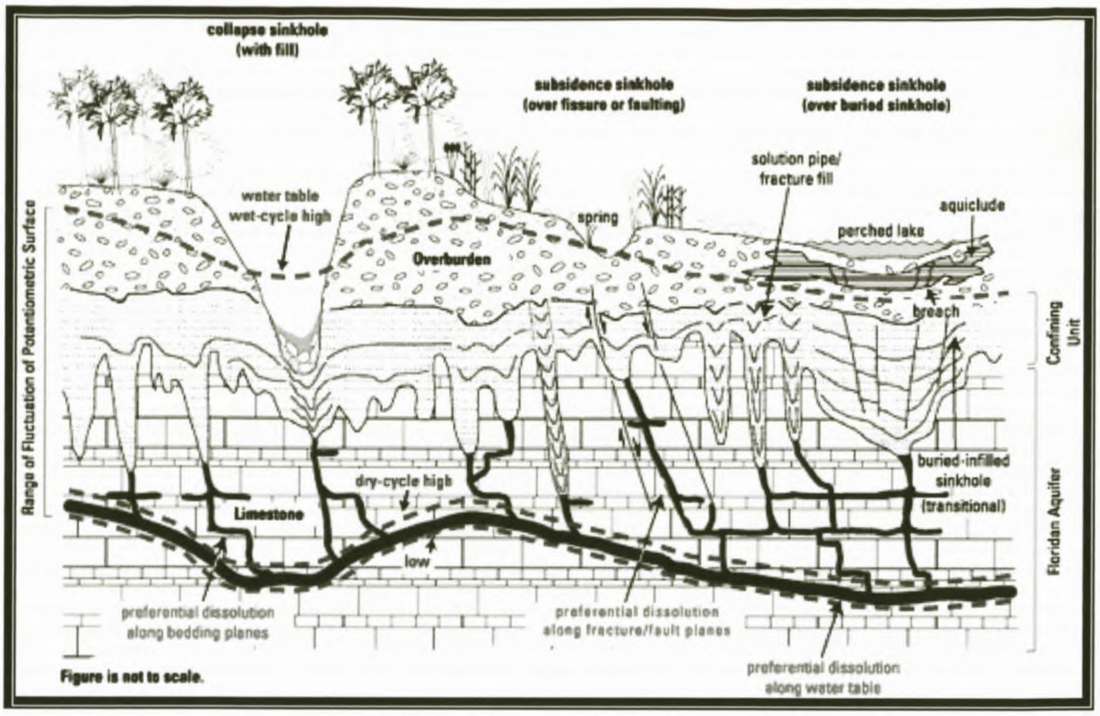


Figure 23: Solution and collapse features of Karst topography (after U.S. Geological Survey).

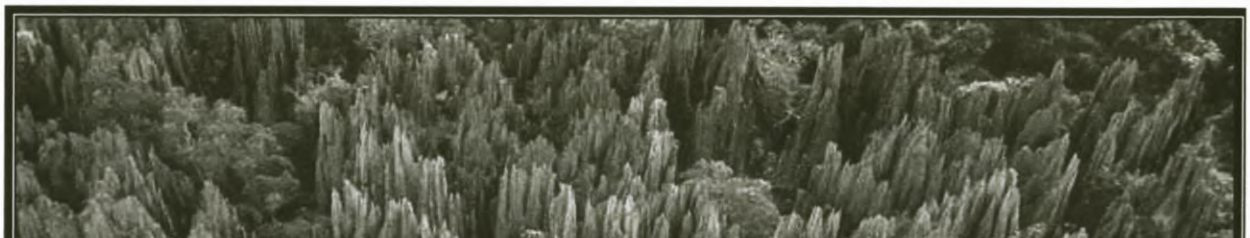


Plate 2: *Tsingy of Bemaraha, Morondava Region Madagascar (Photo by Yann Arthus Bertrand. Obtained from the internet 2011).*

Tsingy is a term used in Madagascar for this apparently inaccessible landscape with almost razor sharp pinnacles, deep channels, rock bridges and caves. The floor area is characterized by shallow overburden and rock fragments of varying sizes. This is the product of a highly jointed dolomitic rock landscape where solution started in the subsurface within the joints. The overburden was removed by weathering giving geologists a glimpse of what the subsurface conditions can look like where overburden still exists.

4.2 Summary

Stratigraphy

- Rock strata with similar properties can be grouped together to form a lithostratigraphic unit and placed in chronological order within the geological time table.

- Chronostratigraphy is that element of stratigraphy dealing with the age of strata and their time relationship.

- Chronostratigraphic classification is the organization of strata into units based on their age.

- A member is the formal lithostratigraphic unit ranking below a formation.

- The fundamental formal unit in lithostratigraphic classification is the Formation.

- A group is a formal lithostratigraphic unit next in rank above a formation and is an assemblage of two or more successive formations with significant unifying lithologic features in common.

- The term Supergroup is used when there is a need to refer to several successive associated Groups and Formations with significant lithologic features in common.

- The term Subgroup is used to distinguish an assemblage of successive Formations from the rest of and already established Group

- A Complex is characterized by a complicated structure and composed of diverse types of any class or classes of rocks, (igneous, metamorphic or even sedimentary).

- The terms complex, intrusive complex and metamorphic complex may be applicable in terrains characterized by extremely complexity of lithology and structure.

- The fundamental rock unit recognised in intrusive igneous and high grade metamorphic terrains is the suite. In some cases the terms intrusive suite, layered suite or metamorphic suite is used. This unit is comparable with the lithostratigraphic group.

Formation of rocks

- Rocks are divided into three major groups based on the way they were formed: sedimentary, igneous and metamorphic.

- Crustal regions can be stable or mobile and stable areas as a whole can be unstable.

- Crustal movement be it small and restricted or great and widespread control the types and successions of sediments, the activities of magma and volcanoes and the deep seated processes of metamorphism and plutonism.

- The great rift valleys can be described examples of fracture zones of limited mobility. Rift valleys are bound by parallel faults between which tracts of land (usually 50-130km wide) are depressed.

- The stable cratons in Southern Africa (Kaapvaal, Rigtersveld, Rhodesian) are composed of largely granitic material with lesser metamorphosed fragments of volcanic and sedimentary rocks. The mobile belts (ancient Limpopo, relative youthful Natal) are frequently of high metamorphic grade.

- The granites of the craton consist of true granites, granodiorites and quarts-diorites and even more basic rocks.

- The term 'greenstone' originated from the development of a number of green minerals during metamorphism of mafic rocks.

- The term greenstone belt is commonly used to refer to metamorphosed remnants within granatoid rocks.

Stress, strain and the deformation of rocks

- The forces which act on the rocks within the crust are largely related to gravity and the movement of large rock masses in the crust and upper mantle.

- Applied forces produce a set of stress. Strain is the geometrical expression of the amount of deformation caused by the action of a system of stresses on a body.

- Strain is the change in size and shape of a body resulting from the action of an applied stress field.

- Elastic strain also called temporary or recoverable, is the ability of a body to recover to its original shape with the removal of the deforming stress.

- Viscous strain or permanent strain results in no recovery in shape and size of a body after the removal of the deforming stress.

- In rock a combination of elastic and viscous strain exists when forces are applied.

- Viscoelastic behaviour is when a material under a given stress shows a basically elastic type of strain but takes time to reach its limiting value. When the stress is removed there is a delayed recovery to the pre-deformed state.

- Elastoviscous behaviour is when a material behaves elastically for stresses at short duration but behave viscous for long stress applied.

- Plastic behaviour is when a material behaves elastically for low values of applied stress but viscous above a critically stress value (the yield stress).

- When elastic deformation leads to failure the material looses cohesion by the development of a **fracture or fractures** across which the continuity of the material is broken. It is called brittle behaviour and lead to the development of **faults and joints.** Ductile deformation is when permanent strain is produced. It exhibits smooth variation across the deformed rock without any marked discontinuities

- Hydrostatic or confined stress is the lithostatic pressure subjected to rock at depth by the overlaying column of rock that will cause volume changes depending on the compressibility of the material.

Openings in rocks and groundwater occurrences

- Rocks occurring on the outer crust of the earth are not completely solid and have numerous openings called voids or interstices, which may contain air, natural gas, oil or water.

- Porosity of a rock is the percentage of the total volume of the rock that is occupied by interstices. Porosity is usually expressed as a percentage or as a decimal fraction. With consolidated and hard rocks a distinction is made between **primary porosity** which is present when the rock is formed and **secondary porosity** which develops later as a result of solution or fracturing.

- A rock is saturated when all the interstices are filled with water or another liquid. The upper zone of the saturated zone is the static water table or ground water table.

- In unconsolidated sediments these pores are interconnected and are therefore useful for transmitting water. The interconnected pores in unconsolidated sediments are also referred to as effective porosity.

- The property of rocks to transmit water is known as the hydraulic conductivity or permeability. The larger the interstices through which the water flows, be they pores or fractures, the higher the permeability of the rock. The driving force of groundwater is gravity.

- The permeability or hydraulic conductivity of a water bearing material is defined as its capacity for transmitting water under hydraulic head, and it's measured by the rate at which it will transmit water through a given cross section under a given difference of head per unit of distance.

- Karst is the term used to describe distinctive surficial and subterranean features developed by solution of carbonate and other rocks and are characterized by closed depressions, sinking streams and cavern openings.

- The term pseudokarst is used in engineering geology to designate karstlike terrain produced by processes other than the dissolution of rocks.

Chapter 5 : The occurrence of groundwater north of latitude 23ºS

5.1 Background

As discussed in the introduction at the beginning of the document the thesis covers the map area of the 1:500 000 hydrogeological map sheet 2127 Messina. The occurrence of groundwater is discussed for each of the 29 hydrogeological units depicted on this map sheet.

The discussion on each hydrogeological unit can almost become tedious when reading the whole report as each hydrogeological unit's discussion starts with a locality map, a discussion on the locality and extent, the geology, the geohydrological character followed in most cases by the frequency and stiff diagrams. The methodology followed in the discussions of the units is the easiest way to represent the vast amounts of available data as this report is essentially a desk study covering a very big area.

The intention is that the average person with limited knowledge on groundwater can find the information and discussion on the hydrogeological unit underlying his property. In most instances, the person needing a borehole for water supply will contact a drilling contractor first. The drilling contractor is in most cases the sole source of information and is therefore trusted for advice and service. The borehole is usually drilled with the survey being done by a stick or bottle and if fortunate, by a driller that has adequate experience in the area.

Source development will always be local site related and a hydrogeologist should have extensive knowledge of the character of the hydrogeological unit underlying the site.

The 'toolbox' of a hydrogeologist doing source development should include the following:

- A remote sensing technique to pre-identify possible geological lineaments that may act as groundwater conduits.
- Knowledge of the geology setting of the area.
- The correct geophysical methods and instruments.
- Knowledge of the environment (field observation) that may assist in the successful scientific site selection of a borehole such as big Mopani trees (Goudplaats gneiss).
- A good knowledge of groundwater in order to visualize the correct conceptual model of the study area. The conceptual model include the geological and groundwater characteristics, such as preferred targets, preferred strike direction of targets, depth of water level, strike depths, chemistry, yield frequencies and the probability of success.

In some areas the above methodology is adequate to obtain a good yielding borehole with a relatively short survey. In other areas one out of 10 targets drilled may lead to a successful borehole. In such a case, experience in the area is of cardinal importance. Geophysical targets must be field checked to eliminate poor choices. Poor groundwater yielding areas can be pre-determined from the national groundwater maps (Vegter, 1995) or from the hydrogeological map sheets.

5.2 Physical environment

5.2.1 General

The study area covers the northern part of South Africa flanked by three international borders, Botswana in the west and north-west, Zimbabwe in the north and Mozambique in the east. The southern boundary is latitude 23ºS (**Figure 1**, p13).

It covers an area of 24,989km² of which approximately 13.5% falls under provincial and national parks, 15% is used by scattered settlements with the rest mainly privately owned agricultural units. A small percentage is used for irrigation, livestock and game farming.

In the west and north-western part of the map sheet area, rainfall is low and irregular (**Figure 25** ,p69). Commercial irrigation farming is therefore limited to areas with surface water (along major rivers), where irrigation from dams is available (Nzhelele Dam) or where high yielding groundwater sources are available from hard rock formations (Waterpoort area) or alluvial aquifers (Weipe area). Land use is dominated by livestock farming (mostly cattle) while there is an increasing tendency towards game farming. The higher laying areas in the south formed by the Soutpansberg are the starting point for the A8, A9 and B9 secondary drainage regions (**Figure 29**, p72) and is mainly used for fruit farming and forestry. The former homelands (rural) have small scale irrigation schemes, subsistence farming and livestock farming. The eastern part of the map covers the northern area of the Kruger National Park.

Approximately 0.9 million people (2002 figures with an annual 2% increment) are resident in the area with only about 5% living in urban areas. The remaining 95% live in scattered villages and farms. Urbanization involving an estimated 10% of the population as well as an influx from Zimbabwe due to economic reasons influences current demographics (ARC, Limpopo Basin study, 2010).

5.2.2 Terrain morphology

The terrain morphology within the area is a function of the regional geology and structure. This has a direct influence on the climate, vegetation, drainage and hydrogeological conditions in the study area. A trend can be observed when comparing the relevant maps with the regional and structural maps. The most prominent elevated feature is the east-west-trending Soutpansberg Mountain consisting of a sedimentary and volcanic assemblage. Faulting is responsible for the frequent structural repetition of the Soutpansberg Supergroup. The result of this is the sequence of mountains and valleys encountered when crossing the area perpendicular to regional geological strike.

Elevations between 800 and 1600mamsl occur in areas underlay by rocks of the Soutpansberg Supergroup (**Figure 24**, p68). Areas underlain by basement gneisses and rocks of the Karoo Supergroup have elevations between 400 to 800mamsl forming undulating to irregular plains. The volcanic rocks within the Lebombo Basin have the lowest elevation of between 200 to 400mamsl trending lower towards the coastal plains of Mozambique in the east.

The area can be divided into four main terrain morphological units (Kruger, 1983), (**Table 8**, p71 and **Figure 27**, p70), viz.:

- Plains with low relief
- Plains with moderate relief
- Lowlands, hills, and mountains with moderate and high relief
- Closed hills and mountains with moderate and high relief

5.2.3 **Types of soil**

Soil types and the formation of soil profiles are generally directly related to the underlying geology, topography and climate. In the mountainous regions of the Soutpansberg shallow, soils with stones of the Mispah, Glenrosa and Hutton forms are developed especially on the steeper slopes. The wetter zones (south-facing slopes) also comprise areas of deep, red apedal and structured dystrophic and mesotrophic sandy clay to clay soils even on the steeper slopes. These soils belong to the Hutton, shortlands and occasionally Glenrosa forms.

In the north to the north-western part of the map area around Alldays and Messina, the area is characterized by plains with moderate relief and underlain by granitoid rocks. It gives rise to shallow or moderately deep, mainly reddish-brown apedal, eutrophic to calcareous sandy loams with zones of lithosols found on intruding rocky ridges and koppies. The main soil forms are Hutton and Glenrosa. In the areas underlain by basaltic rocks of the Letaba Formation the soils are moderately deep, greyish-black, structured, calcareous sandy clays of the Arcadia, Moyo and Bonheim soil forms. Lithosols are also common in this zone. These soils are very similar to soils found in the area underlain by basalt south of the Soutpansberg mountain range. Soils formed from alluvium are dark brown, weakly structured, mainly calcareous sandy clays and clays belonging to the Oakleaf and Valsriver forms. Immediately adjacent to the Limpopo River, varying in width, a zone of deep, brown, weakly structured, alluvial sandy clay loam to clay soils, silty in places and often calcareous occur. Mainly belonging to the Oakleaf form, these deposits increase generally in width to the east especially at the confluence of the Levubu and Limpopo rivers.

The south eastern part of the map area is underlain by gneiss forming plains with low relief. The soils is shallow to moderately deep, reddish-brown apedal, often gravely, eutrophic sandy loams and sandy clay loams with zones of lithosols. Hutton and Glenrosa soil forms predominate. Soils found on the quaternary sand are deep, red and yellow apedal, mesotrophic sandy loams belonging to the Clovelly and Hutton soil forms. (Memoirs Agriculture National Resources. S. Afr. No 37. pp. v to vi, 2003).

5.2.4 **Climate**

North of the Soutpansberg the mean annual precipitation (MAP), (**Figure 25**, p69) varies between 300-400mm, decreasing to 200 to 300mm along the Limpopo River and the border with Zimbabwe. In the north-east at the confluence of the Luvuvhu and Limpopo rivers, the average MAP is 260mm. MAP increases slightly north-westwards towards Messina with an average rainfall of 280mm. Further west at Pontdrif Border Post, the MAP is approximately 370mm.

In the Swartwater area towards the south-western corner of the map sheet the climate can be described as semi-arid with dry warm winters and hot summers receiving an annual rainfall of 350mm. Variability in annual rainfall from one season to the next and between successive wet and dry cycles is high and gives rise to the frequent periods of drought documented for the area. Low and variable rainfall together with high potential evaporation result in low expectation of natural recharge to groundwater.

Towards the eastern side of the map area, near and within the Kruger National park, MAP varies between 400 to 600mm. From Punda Maria (430mm) the rainfall increases towards the mountainous area in the south with an average of 800 to 1000mm/annum. Within the Kruger Park the rainy season stretches from November to March with a peak during January and February. Very little rain falls from June to August (Du Toit, 1998). Thohoyandou, with a MAP of 1053mm, is the town with the highest rainfall within the map area.

Rainfall events are usually in the form of downpours in the summer months, October-March. Cyclonic rains caused by the movement of cyclones through the Mozambique Channel also occur though infrequently. The last occurrence was in January 2000 resulting in most areas receiving more than twice their average rainfall within a two week period. Excessive damage to infrastructure resulted and a few mudslides and rock falls were reported in the southern part of the Soutpansberg. The static groundwater level was not influenced as expected. Less rain but more frequent downpours influences the static water level more (Verster, personal communication, 2010). As a result of the generally high summer temperatures and low humidity, evaporation is high (**Figure 26**, p69) over most of the area and varies from 1300mm in the Soutpansberg mountain area increasing to 2000mm towards the north and north-west. From a replenishment point of view, it seems that the area gains relatively little benefit from the rainfall, as it is concurrent with periods when evaporation is at its peak (Fayazi et al, 1981).

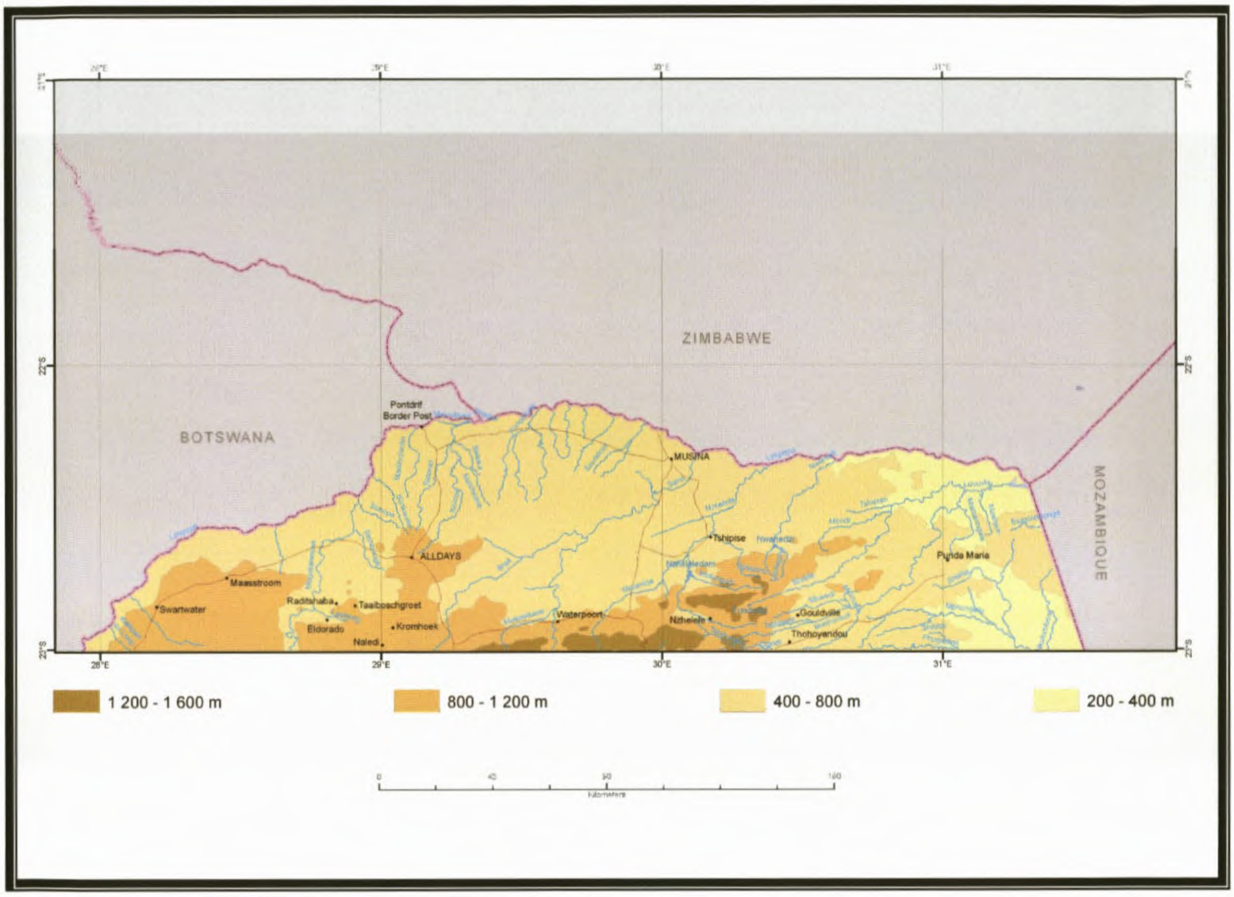


Figure 24: Elevation metre above mean sea level (after DWA, 2011).

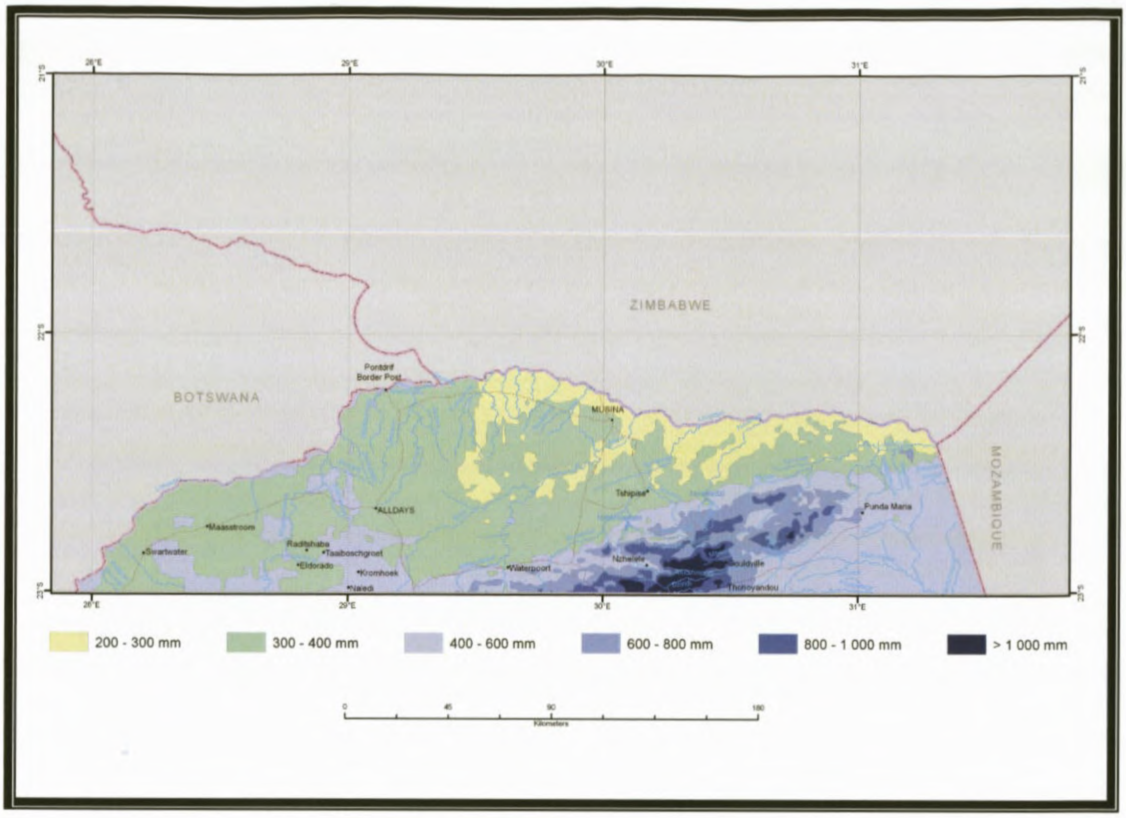


Figure 25: Mean annual precipitation (after DWA, 2011).

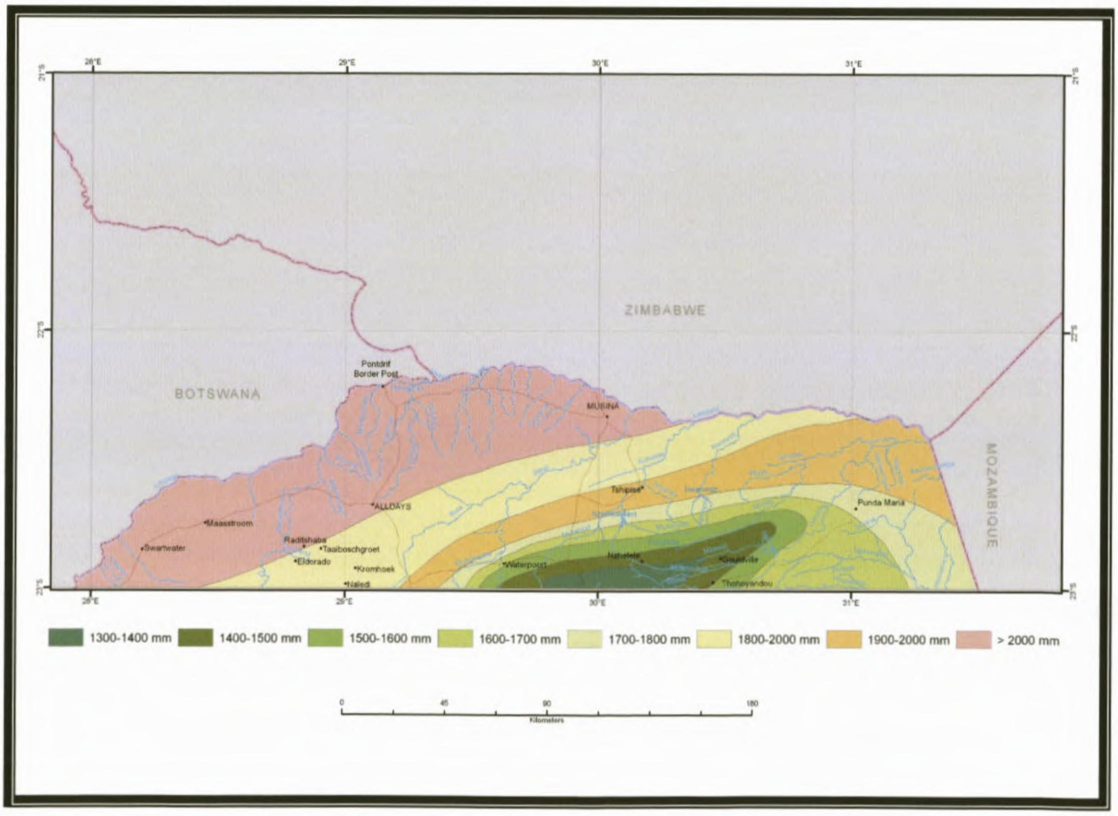


Figure 26: Mean annual evaporation (after DWA, 2011).

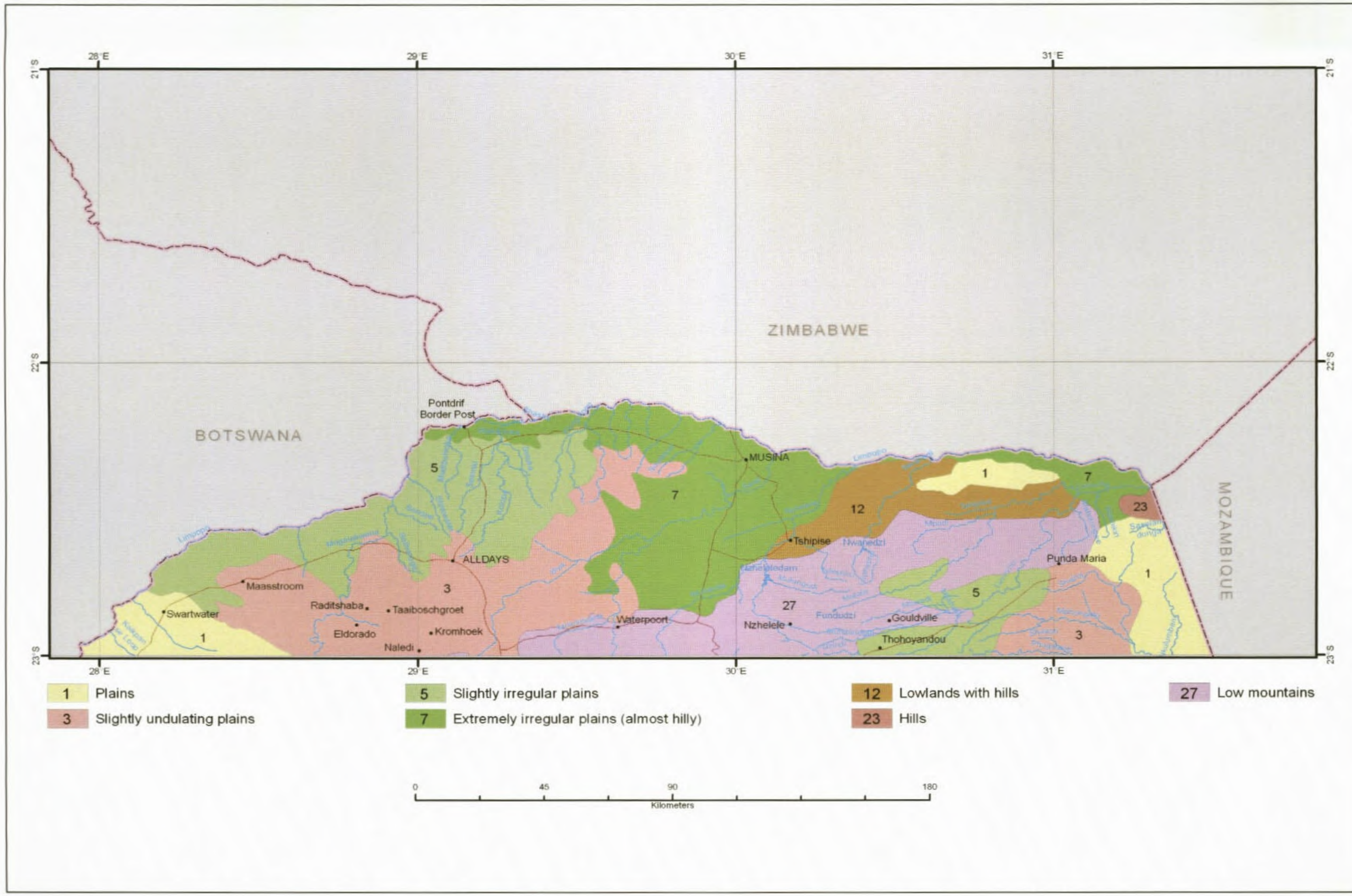


Figure 27: Terrain morphology (Kruger, 1983).

Table 8: Explanation for Figure 27, Terrain Morphology.

BROAD DIVISION	MAP SYMBOL	DESCRIPTION	DRAINAGE DENSITY* (km/km^2)	% OF AREA WITH SLOPES <5%
Plains with low relief	1	Plains	low - medium 0 to 2	>80%
	3	Slightly undulating plains		
Plains with moderate relief	5	Slightly irregular plains	low – medium 0 to 2	>80%
	7	Extremely irregular plains (almost hilly)	high 2 to 3.5	
Lowlands, hills and mountains with moderate to high relief	12	Lowlands with hills	low - medium 0.5 to 2	50 to 80%
Closed hills and mountains with moderate and high relief	23	Hills	medium 0.5 to 2	<20%
	27	Low mountains		

Note: Drainage density is calculated by dividing the *total length of drainage channels by the area in km^2*

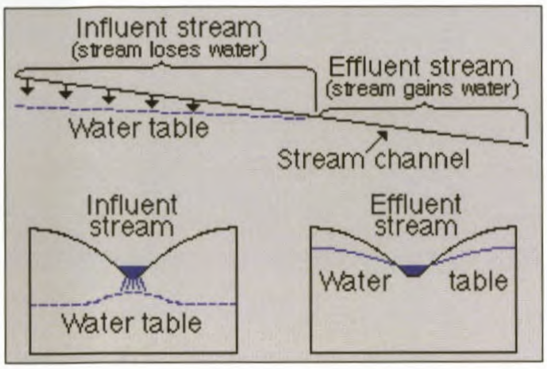
5.2.5 **Surface Hydrology**

The area is divided into **two primary drainage regions** i.e. the Limpopo system (A) which drains approximately 75% of the area, and the Luvuvhu/Letaba system (B). In the west relatively short non-perennial tributaries of the Limpopo River drain the area in a north to north-north-western direction. West of the town of Mussina, the Mogalakwena and Sandriver are the only perennial rivers. East of Mussina perennial rivers are more abundant with their headwaters in the Soutpansberg, such as the Mutamba, Nzhelele, Tshipise, Mutale, Mutshindudi and Luvuvhu rivers. These rivers flow more or less north-east towards the Limpopo River.

Plate 3: Lake Fundudzi was created by a landslide which formed a natural obstruction within the Mutale Valley. It is the only inland perennial lake in South Africa and is one of the many beautiful areas that form part of the Ivory Route. This lake is the source of the Mutale River. (Photo: Google images, 2010)

In the eastern part of the map area, the Shisha and Mphongolo are perennial rivers draining south-east to join the Shingwidzi River. Non-perennial rivers joining the Mphongolo before flowing into the Shingwidzi River are the Nkulumbeni and Phugwane rivers. **Figure 29**, (p72) displays the location of the two main surface water drainage basins as well as the major dams with their storage capacities depicted in **Table 8**, (p71).

Many of the perennial rivers within the map area, including the Limpopo River, can stop flowing in exceptionally dry years. Water used for irrigation also contributes to the reduction in flow. The mode and irregular frequency of precipitation combined with high evaporation rates results in droughts and periodical flows in most of the smaller rivers and streams. Interaction between surface and groundwater in river systems is seasonal with rivers either gaining or losing water to groundwater. Respectively this interaction is dependant on factors such as the water level of the river, depth of erosion channel and type of riverbed material, geology and structures, riparian vegetation, abstraction points near the river and the static water level in the vicinity of the river.



Influent stream: The stream looses water to groundwater.

Effluent stream: The steam gains water from groundwater.

Figure 28: Interaction between surface and groundwater in streams and rivers (after U.S. Geological Survey, 2006).

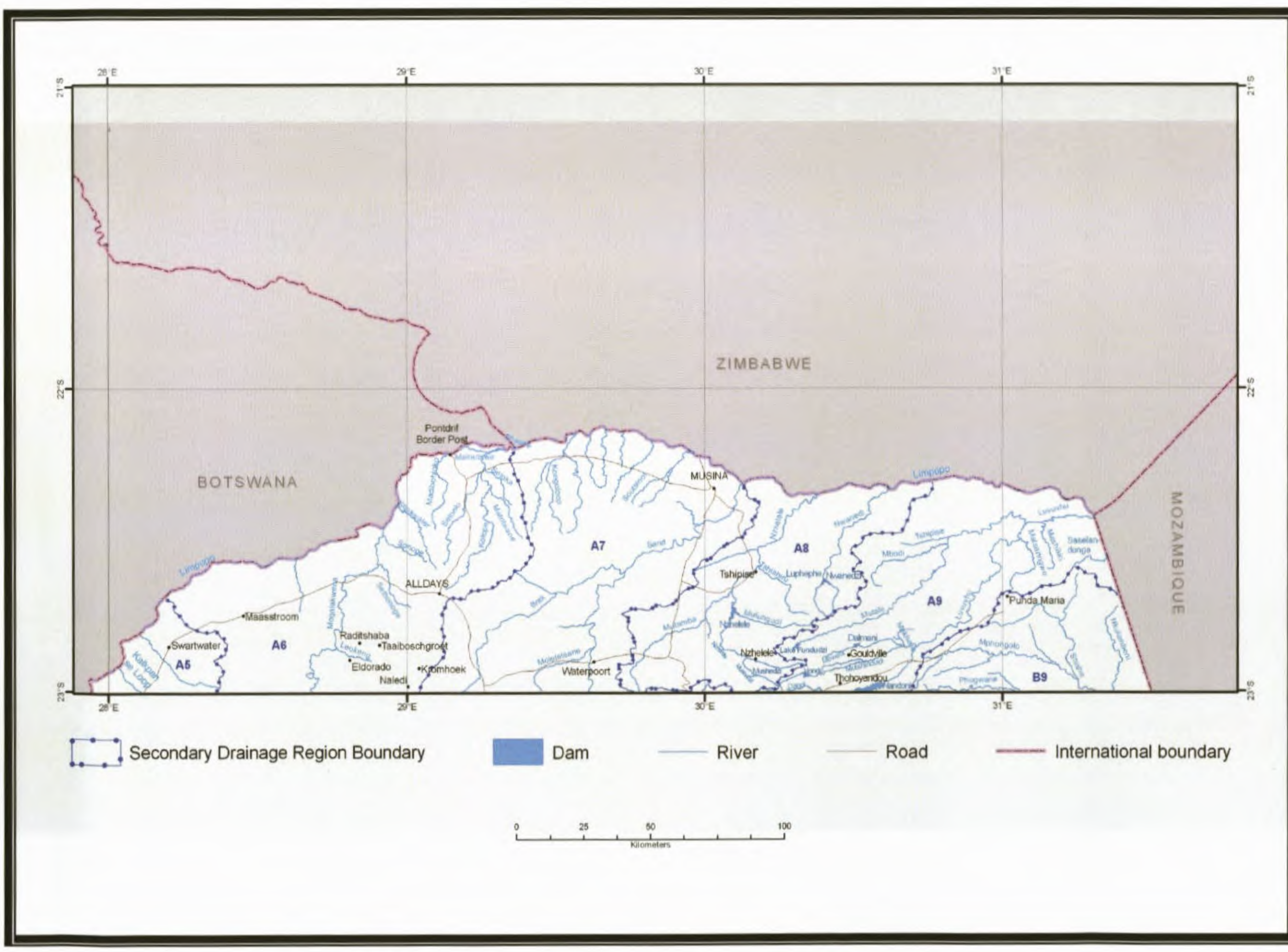


Figure 29: Drainage regions and major dams (HRU, 1981).

Table 9: Major dams, drainage basin, supplying river and storage capacity (HRU, 1981).

DAM NAME	DRAINAGE BASIN	RIVER	STORAGE CAPACITY (Mm^3)
Dalmani	A9	Luthava	12.7
Luphephe	A8	Luphephe	14
Mutshedzi	A8	Mutshedzi	2.4
Nandoni	A9	Levhuvhu	166.2
Nwanedzi	A8	Nwanedzi	5.2
Nzhelele	A8	Nzhelele	51.3
Vondo	A9	Mutshindudi	30.5

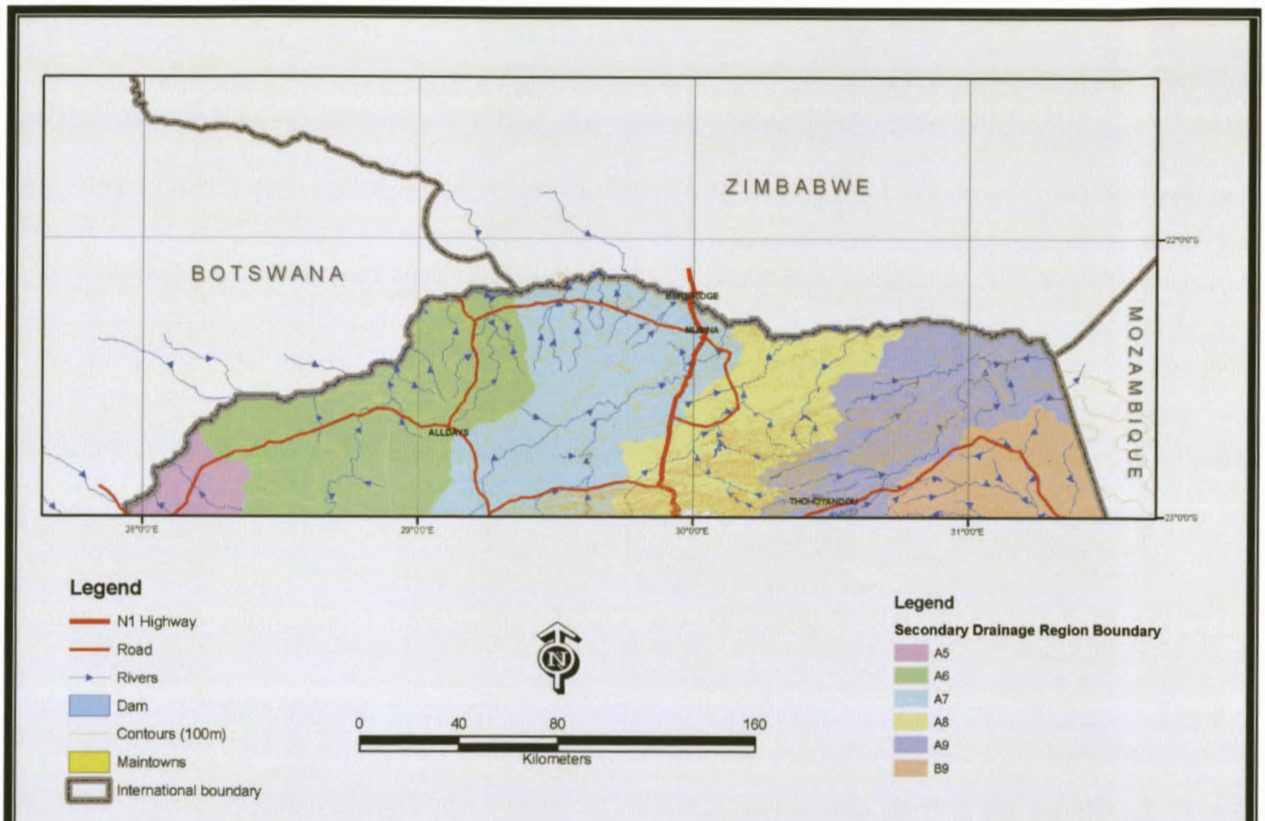


Figure 30: Drainage regions, rivers and drainage trends (after DWA, 2011).

5.3 Geology

5.3.1 Regional geology

The geology occurring within the study area spans the length of South African geological history and contains some of the major stratigraphic groups in the country. A simplified geological map (**Figure 31**, p75) was compiled from the following 1:250 000 published geological map sheets and explanatory booklets (Council for Geosciences):

- 2228 Alldays
- 2230 Messina

The major stratigraphic units formed the basis for the delineation of the hydrological units that were chosen according to geohydrological similarities. The boundaries of the hydrological units do not always follow the geological boundaries. The major stratigraphic groups in the map area are as follows:

- The Basement Complex
- Soutpansberg Group
- Diabase dykes and sills
- Karoo Supergroup
- Dolerite dykes and sills
- Cretaceous
- Quaternary

5.3.1.1 The Basement Complex

The south-eastern part of the map sheet consists essentially of leucocratic biotite gneiss, leucocratic granite and pegmatite, grey biotite gneiss and migmatite, [Goudplaats Gneiss (Zgo)]. Within this gneiss scattered enclaves occurs of the Giyani Group (Zy) consisting of amphibolite, metaquartzite, magnetite quartzite and lesser of metapelite. In the east, small enclaves consisting of metapyroxenite and serpentinite (Zym) occurs within the gneiss. North of major north-eastern-trending fault zones the Central Zone of the Limpopo Belt occurs. It is represented by the supercrustal rocks of the Beit Bridge Complex that is divided into the [Mount Dove Group (Zbo), Malaya Drift Group (Zba) and Gumbu Group (Zbg)]. The sequence was intruded by anothosite and metaleucogabbro of the Messina Suite (Zbm), the resistant metasyenite of the Madiapala Syenite (Zma), and the various varieties of the Sand River Gneiss (Zsa), the grey biotite –bearing gneisses of the Alldays Gneiss (Zal) and the large batholithic intrusion of predominantly porphyroblastic gneiss of the Bulai Gneiss (Rbu).

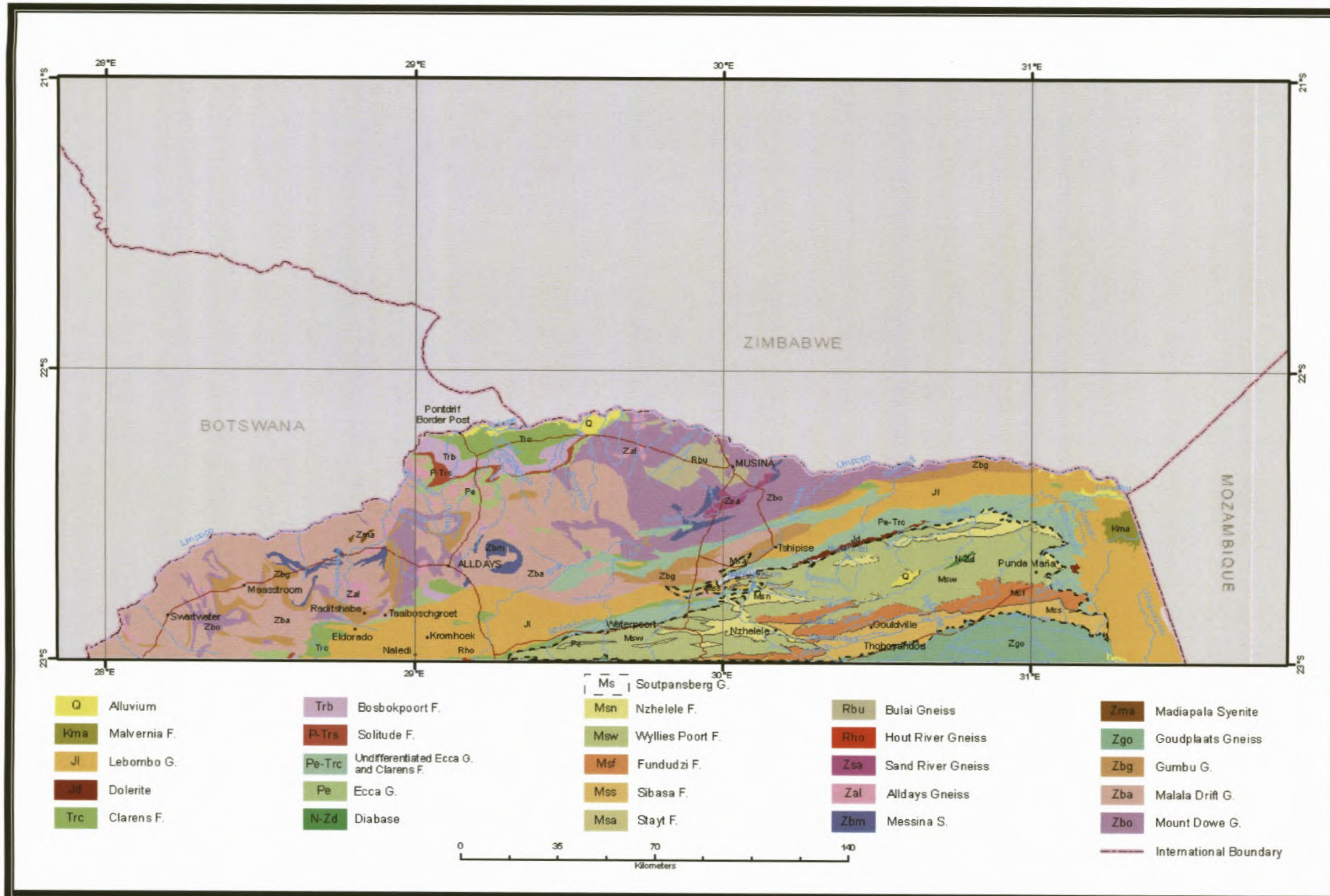


Figure 31: Simplified regional geology of the map area (after DWA, 2011).

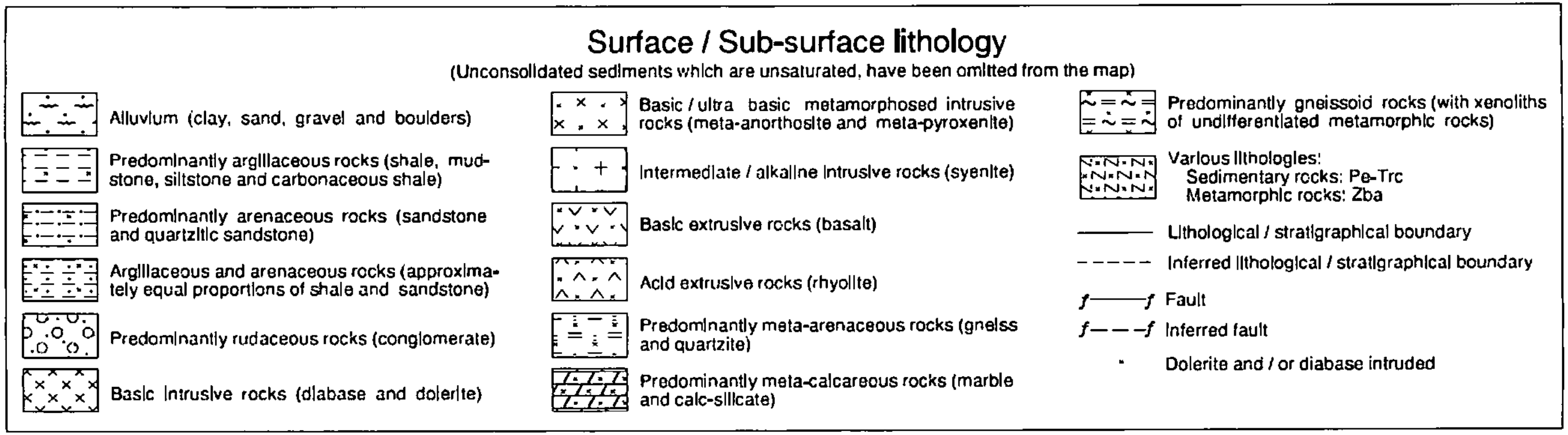


Figure 32: Ornaments used on the Messina hydrogeological map to depict the sub-surface lithology (after DWA, 2011).

5.3.1.2 **Soutpansberg Group**

The Soutpansberg Group (Ms), named after the Soutpansberg Mountain range, underlie mountainous terrain that ranges from Vivo in the east towards the border of the Kruger National Park in the west. It is a volcanic sedimentary succession with a total thickness of approximately 12km, deposited in an elongated fault bounded depression which developed by rifting along a major zone of weakness between the central and southern marginal zones of the Limpopo Mobile Belt (Jansen 1975). Various fault zones varying in geological age transect the area in two prominent directions namely east to west and north to south. The group is divided into several formations, with the following separately depicted on the map sheet. It includes the **Sibasa Formation (Mss)** unconformable overlaying basement gneisses with an estimated maximum thickness of 3300m and consisting mainly of volcanic material and thin intercalations of arenaceous sediments. The poorly exposed **Fundudzi Formation (Msf)** with a maximum thickness of 2800m consists mainly of sandstone with interbedded siltstone, sandy shale, shale and intercalated bands of lava. The **Wyllie's Poort Formation (Msw)** usually occupying high ground and has a maximum thickness of 4000m in the Thengwe and Ha-Makuya areas. This Formation consists mainly of arenaceous rocks comprising two main varieties, namely purple or reddish sandstone and a pink to white quartzite or quartzitic sandstone. The **Stayt Formation (Msa)** has a maximum thickness of approximately 1800m consisting of a lower basaltic lava overlaid by argillaceous rock predominantly shale interbedded with siltstones and sandstone with the top of the formation predominantly quartzite. The **Nzhelele Formation (Msn)** consists of a volcanic assemblage at the base followed by argillaceous and arenaceous sediments. The Tshifhefhe Formation at the base of the Soutpansberg Group and the Mabiligwe Formation that occurs as an isolated succession of sediments near the Mabiligwe village is not indicated on the map sheet as it is insignificant regarding the occurrence of groundwater. The 1:500 000 Messina hydrogeological map attached in the Appendix under Chapter 10, (p181) has a cross section of the Soutpanberg Group included as an inset map.

5.3.1.3 **Diabase dykes and sills**

Diabase (N-Zd) dykes and sills occur in almost all the pre-Karoo formations in the area. Sills within the Beit Bridge gneisses are mainly concentrated around Venetia Mine. Sills within the Soutpansberg Group are common where it preferably intruded contacts between the argillaceous and arenaceous rocks or the interface between lava and sediments. Dykes and sills within the Soutpansberg Group tend to form low laying areas while forming high, narrow ridges in the older granitoid rocks. Dykes are more common in the Soutpansberg Supergroup and Goudplaats Gneiss than in the Beit Bridge Gneisses.

5.3.1.4 **Karoo Supergroup**

The Karoo Supergroup was deposited in a vast intracratonic basin with the maximum depth in the south and in a few satellite basins to the north. It consists of a variety of sediments that reflects the environmental changes during the mitigation of the Gondwana continent over a period of 200 million years from polar to lower latitudes. Sedimentation was terminated by the outpouring of basaltic magma associated with the final break up of the Gondwana continent (Brandl, 2002). The Supergroup is divided in a few geographical areas with three well defined areas within the map sheet. In the first area occurring south of the Limpopo River in the Pontdrift area, is the east to west-trending fault bounded **Tuli basin** with a preserved width of 80km. The area is characterized by slightly irregular plains to extremely irregular plains, almost hilly in the north. The second area, north of the Soutpansberg, and south of the Tshipise Fault, is defined as the north-eastern-trending **Tshipise basin** characterized by lowlands with hills. Minor outliers consisting of the older formations occur in down-faulted blocks between these two basins. The north-south-trending **Lebombo basin** which links up with the latter two basins, is underlain by rocks of the Lebombo Group (Jl) characterized by plains grading into more hilly landscape to the north. The Lebombo Group that presents the final magmatic phase is divided into two formations within the map area with the Letaba

Basalt Formation being the dominant one. The youngest formation of the Karoo Supergroup, the Jozini rhyolite Formation occurs only on the eastern edge of this basin along the border with Mozambique.

5.3.1.5 **Dolerite dykes and sills**

The outpouring of Karoo lava was closely followed by the intrusion of numerous dolerite (Jd) dykes and sills which accompanied the fragmentation of Gondwana (Brandl, 2002). Within the argillaceous sediments in the lower part of the Karoo Supergroup thick concordant sheets (up to 200m) occur. North-north west trending dykes are developed in the north-eastern portion of the map area while dolerite dykes in the rest of the map area show no preferable orientation.

5.3.1.6 **Cretaceous**

The Malvernia Formation (Kma) is believed to be of Cretaceous age as similar lithologies in Mozambique pass laterally in a coast-wise direction into fossiliferous, marine upper Cretaceous sediments (Haughton 1969). It lies discordant on the lavas of the Karoo Supergroup along the eastern boundary of Kruger National Park. In places it has been deposited in "klowe" and narrow valleys cut deep into the underlying lavas (Venter, 1990). It dips moderately to the east with a maximum depth of about 80m (Schutte, 1986). It comprises a succession of conglomerate, sandstone, merril and limestone.

5.3.1.7 **Quaternary**

Quaternary deposits depicted on the map are limited to alluvium (Q) along rivers and palaeo flood channels. Alluvial deposits are found along most of the major rivers and vary in thickness form a few centimetres up to as much as 45m along the Levuvhu River. Extensive deposits occur along the Limpopo (Weipe area) where large scale abstraction from the alluvial aquifer is taking place for agriculture and mining purposes. The alluvium generally comprises alternating layers of clay and poor to well-sorted and gravel deposits.

5.3.2 **Structural geology**

5.3.2.1 **Dykes**

The south-eastern area of the map sheet underlain by basement gneisses is characterised by the occurrence of numerous diabase dykes with a predominant north-easterly strike. The presence of these dykes are usually indicated by boulders forming small ridges and spherical weathering patterns in road cuttings. In the search for high yielding boreholes these dykes and contacts with the host rocks are generally regarded as poor targets.

Fewer lineaments occur in the area of the map underlain by rocks of the Beit Bridge Complex (**Figure 33**, p81). The presence of these lineaments is mostly concluded from the interpretation of remote sensing data as the area is covered by overburden. These lineaments are predominantly striking north-easterly and to a lesser extend east, north and north-westwards. Work done in the Swartwater and Beauty areas identified these lineaments as granophyre-, amphibolite-, diabase-, and dolerite dykes and also fault and/or shear zones. Dominant strike directions in the Swartwater area are north-east to south-west and east to west in the Beauty area (Bush, 1989).

In the Swartwater area linear features such as dolerite and diabase dykes do not possess good hydrogeological properties for groundwater development and should rather be avoided as drilling targets. It was found that dyke/host rock contacts are usually devoid of fracturing or that those fractures which occur at the contact or within the dyke itself are in filled with calcareous or other deposits. In the Swartwater area it is concluded that zones of fracturing, shearing or faulting form favourable target zones for groundwater exploration in regions where rest water levels do not exceed 35m. At depths greater than this, the probability of intersecting open cracks and fissures is reduced despite the fact that jointing/fracturing usually extends to these levels. In some cases boreholes drilled in favourable areas had poor results due to the infilling of fractures. There is no evidence of any favourable fracturing, jointing or weathering occurring at the contacts between any of the lithological rock types in the Swartwater area. There is also no evidence of such features occurring within gneissic banding. All contacts were found to be welded or transitional in nature, a consequence of metamorphism (Bush, 1989).

In the area underlain by rocks of the Soutpansberg Supergroup diabase dykes occurs mainly in the upper formations of the Supergroup in an area bounded approximately by the Klein Tshipise Fault in the north, the Mufungudi Fault in the south-west, the Thengwe Fault in the south and the Lavhurala Fault in the south-east. The strike length of these dykes is extensive, the trend being mainly east-north-east and to a lesser extends west-north-west and north-north-west.

The diabase intrusions generally predate the main period of faulting. South of the Klein Tshipise Fault a few north-east-trending diorite dykes occurs (Brandl, 1981)

Rocks of the Karoo Supergroup are underlying three geographical areas within the map area with minor outliers consisting of the older formations occurring in down-faulted blocks between the Tuli and Tshipise basins. Dolerite dykes is most prominent in the Tuli basin striking easterly to north-north-easterly with minor north to north-westerly trends. Within the Tshipise basin dolerite dykes are less developed with no predominant strike. In the vicinity of the Taaibosch Fault, exploration drilling into and adjacent to dolerite dykes produced disappointing borehole yields with no conclusive results obtained (Fayazi, Orpen, 1989). In the north-eastern part of the Lebombo basin the dolerite dykes trend north-north-west.

5.3.2.2 **Faults and shear zones**

In the south-eastern sector of the map sheet, (**Figure 33**, p81), geological lineaments are predominantly related to dyke intrusions. Minor faults occur within the area but these are confined to a zone around the contact between the Gneiss and the Sibasa Formation. The faults are trending northerly with almost 2/3 of the strike length within the basalt and 1/3 within the gneiss. Minor shear zones occur within the gneiss dominated by a north-eastern strike and a minor southern strike with both trends having a limited extend.

The regional grain of the north-western part of the map underlain by rocks of the Beit Bridge Complex is defined by large-scale north-trending folds and large closed structures. Geological lineaments occurring in the area underlain by these rocks were predominantly concluded from the interpretation of remote sensing data and are believed to be mostly related to dyke intrusions. Regionally the trends are predominantly north-easterly and easterly and to a lesser extend southerly.

A number of brittle shear zones are developed in the map area trending east-north-east or easterly. They are generally normal faults with a downthrown to the south. The **most prominent faults are the Bosbokpoort, Tshipise and Voorburg faults** with estimated vertical displacement of approximately 500m. The Bosbokpoort Fault was investigated near Sigonde village for water supply. The fault was drilled without finding any water. The fault will be investigated further by DWA. The Tshipise Fault was successfully drilled for water supply for various villages (Lubbe personal communications 2009). The **Senotwane Fault**, just north of the Blouberg in contrast with the above mentioned fault zones has a northerly downthrow. The displacement is approximately 1500m in the west decreasing to approximately 600m near Soutpan 459MS and disappearing within the Karoo sediments further east. Near Mussina the **Dowe-Tokwe Fault and the Messina Fault** are strike-slip shear zones with a right-lateral displacement. Displacement by the Dowe-Tokwe Fault at Schoonoord 230MS is approximately 1800m as seen in the displacement of a prominent north-trending magnetite quartzite outcrop. The near vertical fault zone interpreted as a strike-slip shear forms a 200m wide breccia zone in the Limpopo River on Eersteling 138MR (Brandl 2002). The country rock adjacent to the Dowe-Tokwe Fault is referred to as a grey granitic-gneiss. The fault itself is commonly evident on the surface and recognized by the occurrence of brecciated, epidotisation and chloritic gneiss, quartz and epidote. Within the fault various coloured feldspathic quartzite, hydrothermal quartz, epidote and pyrite are typical. The fault is commonly intruded by amphibolite and dolerite and in places by younger granites (Fayazi, Orpen, 1983).

Within the Soutpansberg Group, fault zones occur more frequently. Two intersecting fault systems are described. The first is trending east-north-east, parallel to the regional strike, delineating major horst-and-graben structures and responsible for the frequent structural repetition of the Soutpansberg Formations. The **Klein Tshipise Fault** is a typical example. The second fault system is oblique to the regional strike and has faults trending west-northwest to north-west. The most prominent fault of this system is the **Siloam Fault** with an estimated vertical displacement of 1500m (Brandl, 1981). Within the Tshipise basin intense block-faulting caused the development of a series of stepped half-grabens resulting in the repeatedly occurring narrow strips of Karoo rocks.

The north-east-trending **Taaibosch Fault** is an important regional aquifer for rural villages along the Magalakwena River up to and including the town of Alldays. Exploration drilling on the farms Ysselmonde 322MR, Rhone 321MR and Greenfield 333MS showed that it appears to be a normal fault with a dip of 70 – 80° towards the south-east. Further eastwards the fault looses its clear definition as it becomes assimilated into a wide shear zone on the farms Gansvley 335MS and Presumption 337MS. The fault also changes direction in a wide curve and eventually narrows again into the **Vetfontein Fault** where it strikes north-west to south-east. The western part of the shear zone coincides with a major groundwater divide and appears to be an area unfavourable for the occurrence of groundwater. A number of lineaments in the basalt converge on the Taaibos Fault at an angle of about 45º suggesting that their occurrence is related to the lateral displacement of the fault. These lineaments are clearly discernible on aerial photographs as linear concentrations of dense vegetation. As these lineaments approach the fault a 200 to 250m wide zone south of the fault and within the basalt appears to contain a dense network of fractures creating favourable conditions for the occurrence of groundwater. A number of high-yielding boreholes have been drilled into this zone. The groundwater flow along the Taaibos Fault takes place in both an easterly and westerly direction and the dividing point is situated on the farm Rhone 321MR (Fayazi and Orpen, 1989). The **Dzundwini Fault**, an east to west striking fault within the Soutpansberg Supergroup was investigated for water supply. A single borehole with a yield of 15ℓ/s was drilled in this fault. This water was, however, very brackish, and could not be used (Burger, 1949).

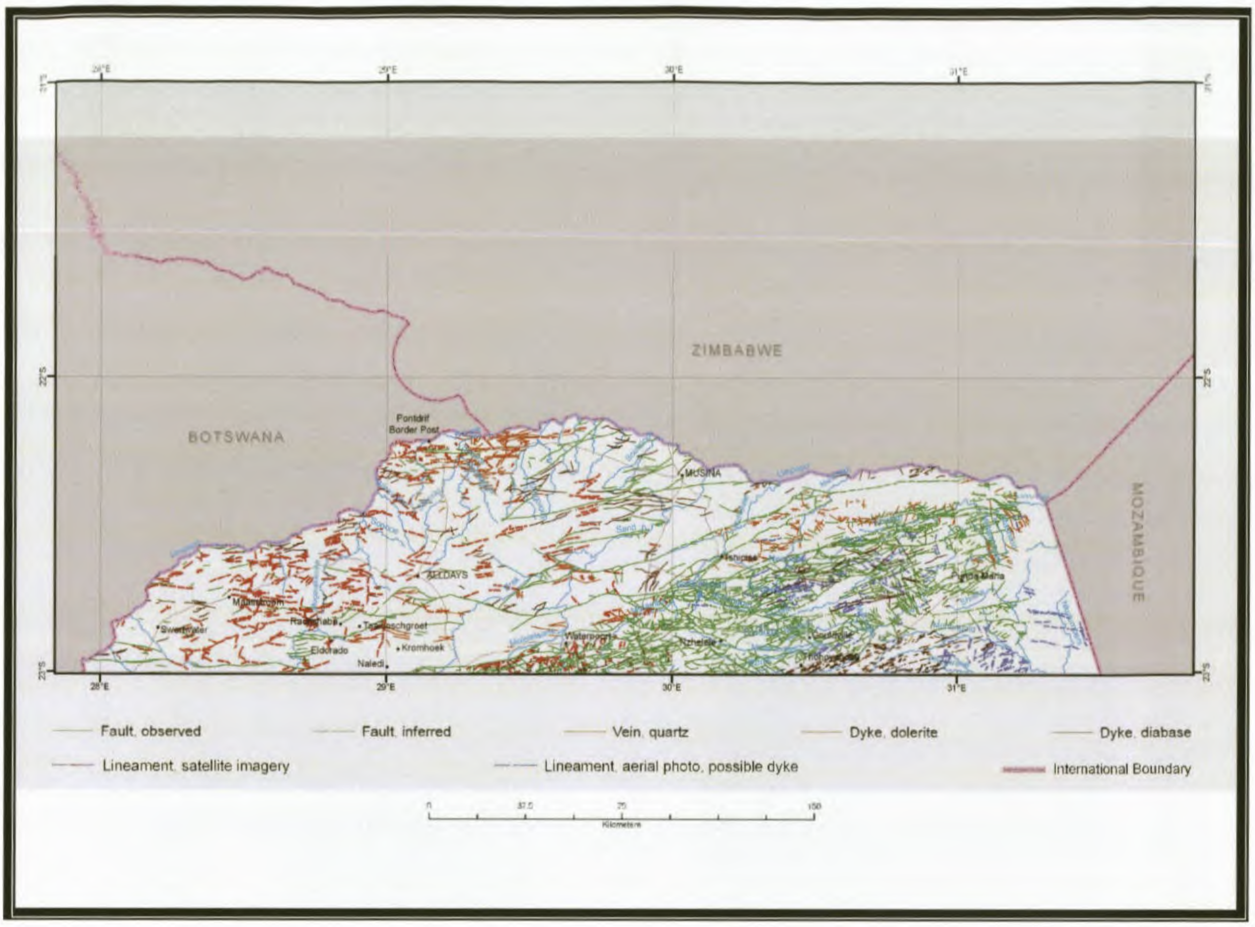


Figure 33: Inferred and observed geological lineaments (after DWA, 2011).

5.4 General Hydrochemistry

The chemical composition of groundwater reflects the result of chemical, physical and biological processes such as weathering, dissolution, evaporation, evapotranspiration, ion exchange and organic decomposition along the path (movement and time) from rainwater through various media (various soils and rock types) to the aquifer. The processes occur in the unsaturated and saturated zone with nature trying to establish chemical and biological equilibrium. As with surface water, anthropogenic activities are increasingly influencing the natural groundwater on a small to regional scale predominantly leading to a decrease in water quality.

In order to characterise and compare the chemical composition of groundwater in the various rock formations, the complete chemical results of 2263 analysed groundwater samples taken during the period from 1968 to 2008 was used. The samples were carefully chosen from a total of 4139 using the following criteria. Incomplete or questionable analysis was not used. Where sample points had more than one analysis (time series data) the harmonic mean was calculated for each parameter and the results used as a single analysis for that particular sample point which further reduced the total analysis used for the report.

The accuracy of the results for the chemical analysis was further checked by the plausibility of the electrical conductivity (EC) and the electro neutrality (E.N) of the chemical analysis. The calculation used for the EC is [$\sum$anions (meq/L) = $\sum$cations (meq/L)] = EC/100(µS/cm) and for electro neutrality it was calculated as follows: [$\sum$cations (meq/L) + $\sum$anions (meq/L)] / [$\sum$cations (meq/L) - $\sum$anions (meq/L)]*100%≤±10%. Chemical analysis is usually only accepted when the electro neutrality is ±5%. Keeping to this would have resulted in some of the units not having enough chemical data for

for each unit. Where the concentration displayed in **Table 11** exceeds the maximum allowed limit (SANS 241, 2005), it is displayed in bold red.

Table 12, 13 and 14, (pp86-88) were compiled using the percentages of samples grouped into different domestic water classes for each major element. The clasification (ideal, acceptable, maximum allowed and unacceptable) is according to the South African National Standards for domestic water use (SANS 241, 2005) document. For example, in **Table 12**, (p86), 51.1% of the samples occur within unit Q (Tertiary-quaterary alluvial deposits) for the element chlorite (Cl) falls within the ideal water class. Furthermore 13% falls within the acceptable water class and 21.7% within the maximum allowable water class. The remaining 14.1% of the chloride sample is unacceptable and can not be used for domestic water supply. The number of samples are shown in the tables to give the reader clarification on the credibility of the data presented. Further in the document, under the discussion for each unit, the hydrochemistry is presented as a stiff diagram showing the major anions and cations.

Six of the units did not have any chemistry data available for analysis. They are the Malvernia Formation (Kma), Lebombo Group (Jl) (fractured aquifers), Stayt Formation (Msa), Hout River Gneiss (Rho), Madiapala Syenite (Zma) and Sand River Gneiss (Zsa).

Table 11: Summary table - calculated harmonic mean values for various chemical parameters for each hydrogeological unit on the Messina map sheet.

Symbol	Total sampled points	Total samples	E.N. ≤ ±10%	Total samples used in analysis	pH	EC	NO_3	F	TAL as ($CaCO_3$)	Na	Mg	SO_4	Cl	K	Ca
						mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
					SANS 241:2005 Class 2. (Max. allowable for limited duration) (mg/l) except pH										
					4-10	370	20	1.5		400	100	600	600	100	300
Category A: Intergranular aquifers															
Q	96	165	157	92	8.2	60.6	0.08	0.27	96.5	37.9	19.0	13.9	40.7	1.5	19.9
Category B: Fractured aquifers															
Kma	No data														
Jl	No data														
Trb	2	2	2	2	7.5	474.1	2.8	1.5	761.8	838.9	81.7	294.0	886.9	12.9	38.9
P-Trs	1	1	1	1	8.3	97.8	5.6	0.87	455	113.9	48.3	103.2	21.5	6.4	61.3
Pe Trc	144	229	219	138	8.0	128.4	0.11	0.47	135.7	122.1	11.1	23.5	144.9	3.1	22.2
Pe	57	108	102	56	8.0	106.4	0.44	0.51	374.6	105.4	37.9	10.2	75.9	1.5	36.9
Msn	116	205	188	108	7.9	69.0	0.25	0.31	190	45.3	29.1	11.5	56.4	0.69	31.2
Msw	310	484	413	270	7.5	18.7	0.17	0.15	30.6	12.0	4.5	4.2	16.1	0.57	5.8
Msf	149	271	234	135	7.7	22.8	0.19	0.14	57.7	12.3	8.8	3.5	12.6	0.39	11.5
Category C: Intergranular and fractured aquifers															
Jl	429	744	656	395	8.2	86.1	0.41	0.42	193.2	70.5	9.02	8.1	62.3	1.5	24.7
Jd	18	27	22	15	8.0	70.9	0.17	0.29	147.3	62.9	22.9	21.0	86.2	2.7	26.5
Trc	85	114	113	84	7.9	90.0	0.15	0.42	159.5	68.2	9.06	9.9	82.5	2.0	33.1
N-Zd	6	8	8	6	7.6	51.6	010	0.39	156.8	46.3	20.9	9.6	43.7	0.62	24.3
Mss	282	455	407	242	7.9	34.8	0.27	0.17	113.8	14.8	9.1	4.1	15.8	0.32	17.4
Msa	No data														
Rbu	33	88	67	29	7.9	151.5	0.42	1.1	310.7	130.5	63.5	64.3	156.4	3.3	47.0
Rho	No data														
Zal	18	25	24	17	7.9	136.4	0.58	1.4	228.1	128.7	11.9	26.04	82.9	1.9	71.7
Zbm	6	6	4	4	7.6	165.6	0.16	1.0	109.9	116.5	41.3	30.3	156.9	1.9	102.9
Zma	No data														
Zsa	No data														
Zgo	221	443	376	196	8.0	70.8	0.23	0.31	244.4	42.7	28.5	7.7	34.0	0.9	41.3
Zbg	63	87	82	59	7.8	155.9	1.3	0.56	428.2	118.4	46.0	32.9	104.4	3.8	55.6
Zba	321	538	476	293	7.9	88.5	0.81	0.8	266.6	98.1	15.6	18.7	76.9	2.6	60.8
Zbo	126	136	129	120	7.8	130.6	0.68	0.87	146.7	105.2	53.5	35.7	92.8	3.6	54.6
Total	2484	4138	3682	2263											

Note: (Q:Tertiary-quaternary alluvial deposits), (Kma: Malvernia Formation), (Jl: Jozini Formation), (Trb: Bosbokpoort Formation), (P-Trs: Solitude Formation), (Pe: Ecca Group), (Msn: Nzhelele Formation), (Msw: Wyllies Poort Formation), (Msf: Fundudzi Formation), (Jl: Letaba Formation), (Jd: dolerite), (Trc: Clarens Sandstone Formation,) (N-ZD: diabase), (Mss: Sibasa Formation), (Msa: Stayt Formation) (Rbu: Bulai Gneiss), (Rho: Hout Rivier Gneiss), (Zal: Aldays Gneiss), (Zbm: Messina Suite), (Zma: Mediapala Syenite), (Zsa: Sand River Gneiss), (Zgo: Goudplaats Gneiss), (Zbg: Gumbu Group), (Zba: Malala Drift Group) (Zbo: Mount Dowe Group)

characterization. Another reason is that improvements in the analytical instruments of laboratories results in more accurate determination of parameters. Not all element concentrations were previously taken into account when applying electro neutrality as a basis for accuracy evaluation. There is a difference when using all the available parameters in calculation or only the major ones. The electro neutrality is more influenced in water with a good quality. The results of one inaccurate parameter can result in the whole sample being ignored when working with big volumes of data.

Due to the large number of groundwater samples a basic method of general characterisation of water composition known as the Kurlov method (Kurlov, 1928) was used. It is based on the relative concentration (meq/l) of major cations and anions. The harmonic mean was calculated for each of the parameters needed for the stiff diagrams.

Some major water types are listed below with some examples of occurrence is listed below. Most of the units are a combination of two or more of the major types dominated by a combination of calcium-magnesium-bicarbonate, sodium-bicarbonate and chloride water. Detailed hydrochemical classification of the individual units is undertaken in Chapter 5. Six of the hydrogeological units display slightly elevated sulphate concentrations namely Tertiary-quaternary alluvial deposits (Q), the Bosbokpoort Formation (Trb), Solitude Formation (P-Trs), Bulai Gneiss (Rbu), Alldays Gneiss (Zal) and Gumbu Group (Zgo).

•Calcium Magnesium bicarbonate water

Bicarbonate water is usually characterised by a high content of HCO_3^- and Ca^{2+}/Mg^{2+} such as in groundwater associated with dolomitic aquifers. Groundwater encountered in the Tertiary-quaternary alluvial deposits (Q), Ecca Group (Pe), Nzhelele Formation (Msn), Wyllies Poort and Fundudzi Formation (Msf) and the Bulai Gneiss (Rbu) show a tendency to this water type.

•Sodium bicarbonate water

This water type has predominantly been present in the geological units of the study area. It was encountered in the Lebombo Group (Jl), Ecca Group (Pe), Dolerite (Jd), Diabase (N-Zd), Solitude-(P-Trs) and Clarens Formations (Trc), Alldays Gneiss (Zal), Goudplaats Gneiss (Zgo), Gumbu Group (Zbg), Malala Drift Group (Zba) and Mount Dowe Group (Zbo). This type of water is generally related to the movement of groundwater from intensive recharge areas and normally indicates a cation exchange process. It is dominated by a high content of Na^+ and HCO_3^-.

•Sulphate water

SO_4^{2-} and Ca^{2+} or Mg^{2+} and occasionally Na^+ dominate this type of water. No SO_4^{2-} type of water was characterized in this study area.

•Chloride water

The anion chloride dominates this type of water. The cation content is variable. Where Ca^{2+} and Mg^{2+} are dominant, water is related to reverse ion exchange (replacement of Na^+ with Ca^{2+} and Mg^{2+}). These types of water are found in the Tertiary-quaternary alluvial deposits (Q), Bosbokpoort (Trb), Undifferentiated Ecca Group and Clarens formation (Pe-Trc), Ecca Group (Pe), Clarens Formation (Trc), Diabase (N-Zd), Nzhelele Formation (Msn), Wyllies Poort and Fundudzi Formation (Msf), Bulai Gneiss (Rbu), Alldays Gneiss (Zal), Messina Suite (Zbm), Goudplaats Gneiss (Zgo), Gumbu Group (Zbg), Malala Drift Group (Zba), Mount Dowe Group (Zbo). A predominance of Na^+ and Cl^- indicates an end point of discharge or stagnation of water.

For an overall picture various chemical elements were plotted on the same map. The first observation is that in certain units single sampling points with poor chemistry are distributed randomly while in other units these points are in close proximity to each other. The clusters with poor chemistry could be attributed to geological features and or possible anthropologic activities. Further investigations should be carried out if there is reason to believe that the cause may be anthropologic. A second observation is that the problematic sample points usually have more than one chemical element falling outside the acceptable water class.

Table 10 provides some guidelines on the suitability of water quality based on electrical conductivity (EC) measurements for domestic, livestock and irrigation purposes (DWA 1996). **Figure 34**, (p89) gives an overview of the area for EC values, nitrate and fluoride concentrations. The ranges in Tables 11 to 14, (pp85-88) is as per SANS 241:2005 specification.

Table 10: Guidelines for groundwater quality and suitability (DWA 1996).

ELECTRICAL CONDUCTIVITY RANGE (mS/m)	SUITABILITY		
	DOMESTIC	LIVESTOCK	IRRIGATION
<70	Suitable	Suitable	Suitable
70 to 50	Suitable - slightly salty taste	Suitable	Suitable - salt sensitive crops may show a 10% decrease in yield. Wetting of foliage should be prevented
150 to 300	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
300 to 450	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
>450	Totally unacceptable	Tolerable - may be refused by animals not accustomed to the water	Generally unacceptable

5.4.1 Aquifer Hydrochemistry

Chemical data was obtained from various sources, but predominantly from the National Water Quality Database (WMS). This was used for hydrochemical data analysis and interpretation. The data points representing the chosen chemical analysis were plotted on a base map showing the surface occurrence of the aquifer units. These data points were grouped to represent the different hydrogeological units.

The hydrochemical results were averaged by calculating the harmonic mean value for each of the major elements and groundwater parameters. These values are summarized for each aquifer unit in **Table 11**, (p85). The first column gives the symbol of each unit and the second the total sample points. The total samples in each unit can be put into perspective when compared with the unit aerial extent in relation to the map. The percentage coverage of each unit in relation to the map extent is given in column 2 of **Table 15**, (p90). For spatial distribution of the sample points the reader is referred to the unit map in the report. The total samples in column three compared with the total sample points gives an indication of the availability of time series data in each unit. In general **Table 11**, (p85) gives an overview of the expected concentrations of the major chemical elements in mg/l for each unit. Where the concentration displayed in **Table 11** exceeds the maximum allowed limit (SANS 241, 2005), it is displayed in bold red.

Table 12, 13 and 14, (pp86-88) were compiled using the percentages of samples grouped into different domestic water classes for each major element. The clasification (ideal, acceptable, maximum allowed and unacceptable) is according to the South African National Standards for domestic water use (SANS 241, 2005) document. For example, in **Table 12**, (p86), 51.1% of the samples occur within unit Q (Tertiary-quaterary alluvial deposits) for the element chlorite (Cl) falls within the ideal water class. Furthermore 13% falls within the acceptable water class and 21.7% within the maximum allowable water class. The remaining 14.1% of the chloride sample is unacceptable and can not be used for domestic water supply. The number of samples are shown in the tables to give the reader clarification on the credibility of the data presented. Further in the document, under the discussion for each unit, the hydrochemistry is presented as a stiff diagram showing the major anions and cations.

Six of the units did not have any chemistry data available for analysis. They are the Malvernia Formation (Kma), Lebombo Group (Jl) (fractured aquifers), Stayt Formation (Msa), Hout River Gneiss (Rho), Madiapala Syenite (Zma) and Sand River Gneiss (Zsa).

Table 11: Summary table - calculated harmonic mean values for various chemical parameters for each hydrogeological unit on the Messina map sheet.

Symbol	Total sampled points	Total samples	E.N. ≤ ±10%	Total samples used in analysis	pH	EC	NO_3	F	TAL as ($CaCO_3$)	Na	Mg	SO_4	Cl	K	Ca
						mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
					SANS 241:2005 Class 2. (Max. allowable for limited duration) (mg/l) except pH										
					4-10	370	20	1.5		400	100	600	600	100	300
Category A: Intergranular aquifers															
Q	96	165	157	92	8.2	60.6	0.08	0.27	96.5	37.9	19.0	13.9	40.7	1.5	19.9
Category B: Fractured aquifers															
Kma	No data														
Jl	No data														
Trb	2	2	2	2	7.5	**474.1**	2.8	**1.5**	761.8	**838.9**	81.7	294.0	**886.9**	12.9	38.9
P-Trs	1	1	1	1	8.3	97.8	5.6	0.87	455	113.9	48.3	103.2	21.5	6.4	61.3
Pe Trc	144	229	219	138	8.0	128.4	0.11	0.47	135.7	122.1	11.1	23.5	144.9	3.1	22.2
Pe	57	108	102	56	8.0	106.4	0.44	0.51	374.6	105.4	37.9	10.2	75.9	1.5	36.9
Msn	116	205	188	108	7.9	69.0	0.25	0.31	190	45.3	29.1	11.5	56.4	0.69	31.2
Msw	310	484	413	270	7.5	18.7	0.17	0.15	30.6	12.0	4.5	4.2	16.1	0.57	5.8
Msf	149	271	234	135	7.7	22.8	0.19	0.14	57.7	12.3	8.8	3.5	12.6	0.39	11.5
Category C: Intergranular and fractured aquifers															
Jl	429	744	656	395	8.2	86.1	0.41	0.42	193.2	70.5	9.02	8.1	62.3	1.5	24.7
Jd	18	27	22	15	8.0	70.9	0.17	0.29	147.3	62.9	22.9	21.0	86.2	2.7	26.5
Trc	85	114	113	84	7.9	90.0	0.15	0.42	159.5	68.2	9.06	9.9	82.5	2.0	33.1
N-Zd	6	8	8	6	7.6	51.6	010	0.39	156.8	46.3	20.9	9.6	43.7	0.62	24.3
Mss	282	455	407	242	7.9	34.8	0.27	0.17	113.8	14.8	9.1	4.1	15.8	0.32	17.4
Msa	No data														
Rbu	33	88	67	29	7.9	151.5	0.42	1.1	310.7	130.5	63.5	64.3	156.4	3.3	47.0
Rho	No data														
Zal	18	25	24	17	7.9	136.4	0.58	1.4	228.1	128.7	11.9	26.04	82.9	1.9	71.7
Zbm	6	6	4	4	7.6	165.6	0.16	1.0	109.9	116.5	41.3	30.3	156.9	1.9	102.9
Zma	No data														
Zsa	No data														
Zgo	221	443	376	196	8.0	70.8	0.23	0.31	244.4	42.7	28.5	7.7	34.0	0.9	41.3
Zbg	63	87	82	59	7.8	155.9	1.3	0.56	428.2	118.4	46.0	32.9	104.4	3.8	55.6
Zba	321	538	476	293	7.9	88.5	0.81	0.8	266.6	98.1	15.6	18.7	76.9	2.6	60.8
Zbo	126	136	129	120	7.8	130.6	0.68	0.87	146.7	105.2	53.5	35.7	92.8	3.6	54.6
Total	2484	4138	3682	2263											

Note: (Q:Tertiary-quaternary alluvial deposits), (Kma: Malvernia Formation), (Jl: Jozini Formation), (Trb: Bosbokpoort Formation), (P-Trs: Solitude Formation), (Pe: Ecca Group), (Msn: Nzhelele Formation), (Msw: Wyllies Poort Formation), (Msf: Fundudzi Formation), (Jl: Letaba Formation), (Jd: dolerite), (Trc: Clarens Sandstone Formation,) (N-ZD: diabase), (Mss: Sibasa Formation), (Msa: Stayt Formation) (Rbu: Bulai Gneiss), (Rho: Hout Rivier Gneiss), (Zal: Aldays Gneiss), (Zbm: Messina Suite), (Zma: Mediapala Syenite), (Zsa: Sand River Gneiss), (Zgo: Goudplaats Gneiss), (Zbg: Gumbu Group), (Zba: Malala Drift Group) (Zbo: Mount Dowe Group)

Table 12: Percentage samples in each unit, classed for domestic use for chloride, nitrate and sulphate concentrations.

Aquifer Unit	Number of samples	Chloride Cl (mg/l)				Nitrate and nitrite (presented as N) (mg/l)				Sulphate SO4 (mg/l)			
		Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limit Ranges		100	200	600	>600	6	10	20	>20	200	400	600	>600
Category A: Intergranular aquifers													
Q	92	51.1%	13.0%	21.7%	14.1%	85.7%	6.6%	5.5%	2.2%	37.0%	31.5%	13.0%	18.5%
Category B: Fractured aquifers													
Jd	1	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Trb	2	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
P-Trs	1	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Pe Trc	138	16.7%	27.5%	31.2%	24.6%	65.6%	10.4%	9.6%	14.4%	87.0%	5.8%	2.2%	5.1%
Pe	56	60.7%	12.5%	23.2%	3.6%	53.6%	21.4%	23.2%	1.8%	98.2%	1.8%	0.0%	0.0%
Msn	108	43.5%	16.7%	24.1%	15.7%	63.1%	8.7%	12.6%	15.5%	100.0%	0.0%	0.0%	0.0%
Msw	270	85.6%	6.7%	5.6%	2.2%	91.1%	3.5%	2.7%	2.7%	99.2%	0.8%	0.0%	0.0%
Msf	135	85.2%	5.2%	8.9%	0.7%	85.4%	7.7%	4.6%	2.3%	100.0%	0.0%	0.0%	0.0%
Category C: Intergranular and Fractured aquifers													
Jl	395	59.8%	24.6%	11.1%	4.6%	39.4%	16.4%	25.1%	19.2%	98.2%	1.0%	0.5%	0.3%
Jd	15	46.7%	33.3%	13.3%	6.7%	78.6%	7.1%	0.0%	14.3%	100.0%	0.0%	0.0%	0.0%
Trc	84	42.9%	21.4%	22.6%	13.1%	59.0%	9.6%	14.5%	16.9%	92.9%	3.6%	3.6%	0.0%
N-Zd	6	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Mss	242	96.3%	2.5%	0.4%	0.83%	69.1%	12.3%	14.8%	3.8%	100.0%	0.0%	0.0%	0.0%
Rbu	29	10.3%	48.3%	24.1%	17.2%	24.1%	17.2%	37.9%	20.7%	72.4%	13.8%	3.5%	10.3%
Zal	17	47.1%	29.4%	11.8%	11.8%	41.2%	11.8%	29.4%	17.7%	88.2%	0.0%	0.0%	11.8%
Zbm	4	25.0%	25.0%	25.0%	25.0%	25.0%	0.0%	25.0%	50.0%	75.0%	0.0%	25.0%	0.0%
Zgo	197	77.2%	15.7%	6.1%	1.0%	56.9%	12.2%	12.8%	18.1%	99.5%	0.0%	0.0%	0.5%
Zbg	59	39.0%	17.0%	22.0%	22.0%	27.6%	24.1%	19.0%	29.3%	83.1%	10.2%	1.7%	5.1%
Zba	293	47.4%	27.7%	21.5%	3.4%	28.3%	22.5%	19.5%	29.7%	91.5%	3.1%	3.8%	1.7%
Zbo	120	36.7%	27.5%	29.2%	6.7%	23.3%	25.8%	24.2%	26.7%	84.2%	10.0%	4.2%	1.7%

Note: (Q:Tertiary-quaternary alluvial deposits), (Kma: Malvernia Formation), (Jl: Jozini Formation), (Trb: Bosbokpoort Formation), (P-Trs: Solitude Formation), (Pe: Ecca Group), (Msn: Nzhelele Formation), (Msw: Wyllies Poort Formation), (Msf: Fundudzi Formation), (Jl: Letaba Formation), (Jd: dolerite), (Trc: Clarens Sandstone Formation,) (N-ZD: diabase), (Mss: Sibasa Formation), (Msa: Stayt Formation) (Rbu: Bulai Gneiss), (Rho: Hout Rivier Gneiss), (Zal: Aldays Gneiss), (Zbm: Messina Suite), (Zma: Mediapala Syenite), (Zsa: Sand River Gneiss), (Zgo: Goudplaats Gneiss), (Zbg: Gumbu Group), (Zba: Malala Drift Group) (Zbo: Mount Dowe Group)

Table 13: Percentage samples in each unit, classed for domestic use for calcium, potassium, magnesium and sodium concentrations.

Aquifer Unit	Number of samples	Calcium Ca (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Sodium Na (mg/l)			
		Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able
Limit Ranges		80	150	300	>300	25	50	100	>100	30	70	100	>100	100	200	400	>400
Category A: Intergranular aquifers																	
Q	92	70.7%	17.4%	10.9%	1.1%	98.9%	1.1%	0.0%	0.0%	37.0%	31.5%	13.0%	18.5%	63.0%	14.1%	14.1%	8.7%
Category B: Fractured aquifers																	
Jl	1	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Trb	2	50.0%	50.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%	50.0%	0.0%	0.0%	0.0%	100.0%
P-Trs	1	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Pe Trc	138	73.9%	17.4%	3.6%	5.1%	95.6%	2.9%	1.5%	0.0%	18.8%	34.1%	21.0%	26.1%	30.4%	23.9%	17.4%	28.3%
Pe	56	89.3%	7.1%	3.6%	0.0%	100.0%	0.0%	0.0%	0.0%	17.9%	62.5%	14.3%	5.4%	44.6%	33.9%	16.1%	5.4%
Msn	108	59.8%	31.8%	8.4%	0.0%	100.0%	0.0%	0.0%	0.0%	26.2%	34.6%	20.6%	18.7%	50.9%	25.0%	16.7%	7.4%
Msw	270	94.4%	4.5%	1.1%	0.0%	99.6%	0.4%	0.0%	0.0%	79.6%	14.4%	2.6%	3.3%	88.5%	7.8%	2.2%	1.5%
Msf	135	91.9%	6.7%	1.5%	0.0%	100.0%	0.0%	0.0%	0.0%	73.3%	20.7%	4.4%	1.5%	91.9%	6.7%	0.7%	0.7%
Category C: Intergranular and Fractured aquifers																	
Jl	395	88.6%	8.9%	2.3%	0.3%	99.2%	0.5%	0.0%	0.3%	31.1%	40.5%	18.5%	9.9%	54.6%	33.0%	7.1%	5.3%
Jd	15	80.0%	13.3%	6.7%	0.0%	100.0%	0.0%	0.0%	0.0%	46.7%	26.7%	6.7%	20.0%	73.3%	26.7%	0.0%	0.0%
Trc	84	77.4%	16.7%	2.4%	3.6%	100.0%	0.0%	0.0%	0.0%	32.1%	50.0%	9.5%	8.3%	48.8%	23.8%	15.5%	11.9%
N-Zd	6	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Mss	242	93.4%	6.2%	0.4%	0.0%	100.0%	0.0%	0.0%	0.0%	58.3%	38%	2.5%	1.2%	98.4%	1.2%	0.0%	0.4%
Rbu	29	65.5%	20.7%	6.9%	6.9%	96.6%	3.5%	0.0%	0.0%	6.9%	44.8%	31.0%	17.2%	20.7%	55.2%	6.9%	17.2%
Zal	17	70.6%	17.7%	0.0%	11.8%	100.0%	0.0%	0.0%	0.0%	5.9%	64.7%	17.7%	11.8%	23.5%	64.7%	0.0%	11.8%
Zbm	4	25.0%	50.0%	25.0%	0.0%	100.0%	0.0%	0.0%	0.0%	25.0%	25.0%	25.0%	25.0%	25.0%	0.0%	75.0%	0.0%
Zgo	197	81.2%	16.2%	2.5%	0.0%	100.0%	0.0%	0.0%	0.0%	27.9%	62.9%	6.1%	3.1%	76.7%	20.3%	3.1%	0.0%
Zbg	59	59.3%	28.8%	8.5%	3.4%	91.5%	6.8%	1.7%	0.0%	6.8%	40.7%	13.6%	39.0%	30.5%	37.3%	13.6%	18.6%
Zba	293	67.2%	27.3%	3.8%	1.7%	97.6%	2.4%	0.0%	0.0%	10.2%	57.0%	21.5%	11.3%	41.3%	42.7%	13.0%	3.1%
Zbo	120	75.0%	19.2%	5.8%	0.0%	95.8%	4.2%	0.0%	0.0%	9.2%	43.3%	25.0%	22.5%	30.8%	37.5%	21.7%	10.0%

Note: (Q:Tertiary-quaternary alluvial deposits), (Kma: Malvernia Formation), (Jl: Jozini Formation), (Trb: Bosbokpoort Formation), (P-Trs: Solitude Formation), (Pe: Ecca Group), (Msn: Nzhelele Formation), (Msw: Wyllies Poort Formation), (Msf: Fundudzi Formation), (Jl: Letaba Formation), (Jd: dolerite), (Trc: Clarens Sandstone Formation,) (N-ZD: diabase), (Mss: Sibasa Formation), (Msa: Stayt Formation) (Rbu: Bulai Gneiss), (Rho: Hout Rivier Gneiss), (Zal: Aldays Gneiss), (Zbm: Messina Suite), (Zma: Mediapala Syenite), (Zsa: Sand River Gneiss), (Zgo: Goudplaats Gneiss), (Zbg: Gumbu Group), (Zba: Malala Drift Group) (Zbo: Mount Dowe Group)

Table 14: Percentage samples in each unit, classed for domestic use for Electrical Conductivity (EC), pH and fluoride concentration.

Aquifer Unit	Number of samples	Conductivity (mS/m)				pH (pH units)				Fluoride F (mg/l)			
		Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Acceptable to max Acidity	Ideal	Acceptable to max Alkalinity	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limit Ranges		70	150	370	>370	4.0 - 5.9	6.0 - 9.0	9.1 -to 10.0	>10 & <4	0.7	1	1.5	>1.5
Category A: Intergranular aquifers													
Q	92	35.9%	32.6%	25.0%	6.5%	0.00%	100.00%	0.00%	0.00%	81.5%	5.4%	5.4%	7.6%
Category B: Fractured aquifers													
Jd	1	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
Trb	2	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%
P-Trs	1	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Pe Trc	138	8.7%	35.5%	33.3%	22.5%	0.7%	98.5%	0.7%	0.0%	54.0%	12.7%	23.0%	10.3%
Pe	56	0.0%	67.9%	28.6%	3.6%	0.0%	100.0%	0.0%	0.0%	66.7%	11.1%	14.8%	7.4%
Msn	108	29.0%	29.9%	31.8%	9.4%	0.0%	100.0%	0.0%	0.0%	83.0%	6.0%	6.0%	5.0%
Msw	270	81.5%	11.5%	6.3%	0.74%	1.9%	98.0%	0.8%	0.0%	92.4%	1.6%	4.4%	1.6%
Msf	135	78.5%	13.3%	8.2%	0.0%	0.0%	100.0%	0.0%	0.0%	98.3%	0.9%	0.0%	0.9%
Category C: Intergranular and Fractured aquifers													
Jl	395	20.3%	60.0%	17.5%	2.3%	0.0%	95.9%	3.8%	0.3%	65.6%	17.2%	14.0%	3.2%
Jd	15	40.0%	33.3%	26.7%	0.0%	0.0%	100.0%	0.0%	0.0%	92.3%	7.7%	0.0%	0.0%
Trc	84	26.2%	41.7%	25.0%	7.1%	1.2%	98.8%	0.0%	0.0%	55.0%	18.8%	13.8%	12.5%
N-Zd	6	50.0%	50.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Mss	242	78.9%	18.6%	2.1%	0.4%	0.4%	98.0%	1.3%	0.4%	100%	0.0%	0.0%	0.0%
Rbu	29	3.5%	51.7%	27.6%	17.2%	0.0%	100.0%	0.0%	0.0%	10.3%	10.3%	41.4%	37.9%
Zal	17	0.0%	70.6%	17.6%	11.8%	0.0%	100.0%	0.0%	0.0%	5.9%	35.3%	5.9%	52.9%
Zbm	4	0.0%	25.0%	75.0%	0.0%	0.0%	100.0%	0.0%	0.0%	25.0%	25.0%	0.0%	50.0%
Zgo	197	34.5%	55.3%	10.2%	0.0%	0.0%	100.0%	0.0%	0.0%	87.5%	4.2%	7.7%	0.6%
Zbg	59	1.7%	50.9%	28.8%	18.6%	0.0%	100.0%	0.0%	0.0%	39.0%	17.0%	18.6%	25.4%
Zba	293	4.4%	63.5%	29.4%	2.7%	0.3%	99.6%	1.0%	1.0%	27.1%	24.0%	26.0%	23.0%
Zbo	120	5.0%	50.8%	39.2%	5.0%	0.8%	99.2%	0.0%	0.0%	20.8%	21.7%	25.0%	32.5%

Note: (Q:Tertiary-quaternary alluvial deposits), (Kma: Malvernia Formation), (Jl: Jozini Formation), (Trb: Bosbokpoort Formation), (P-Trs: Solitude Formation), (Pe: Ecca Group), (Msn: Nzhelele Formation), (Msw: Wyllies Poort Formation), (Msf: Fundudzi Formation), (Jl: Letaba Formation), (Jd: dolerite), (Trc: Clarens Sandstone Formation,) (N-ZD: diabase), (Mss: Sibasa Formation), (Msa: Stayt Formation) (Rbu: Bulai Gneiss), (Rho: Hout Rivier Gneiss), (Zal: Aldays Gneiss), (Zbm: Messina Suite), (Zma: Mediapala Syenite), (Zsa: Sand River Gneiss), (Zgo: Goudplaats Gneiss), (Zbg: Gumbu Group), (Zba: Malala Drift Group) (Zbo: Mount Dowe Group)

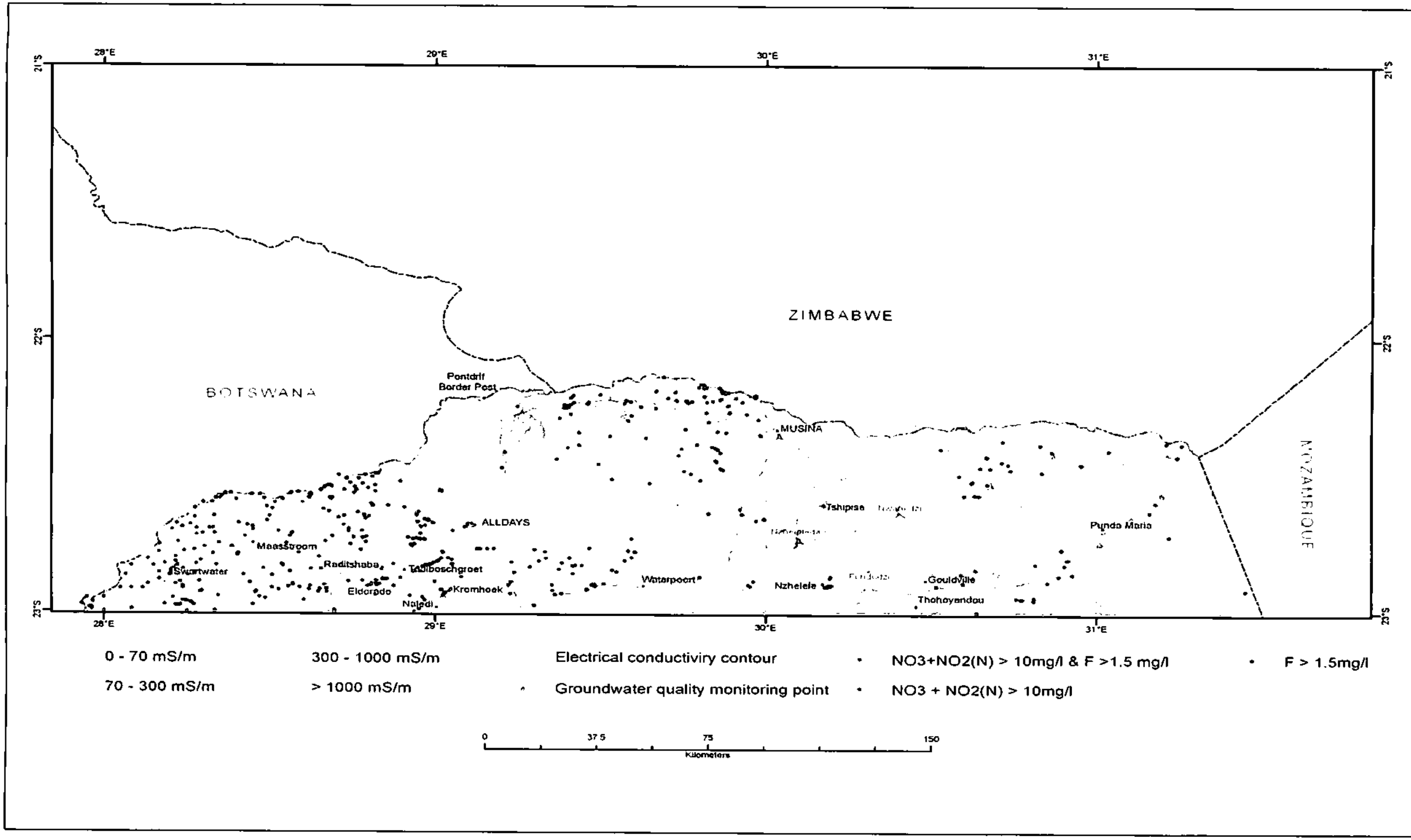


Figure 34: Electrical conductivity, (EC) with points representing boreholes with nitrate and fluoride values exceeding the acceptable levels for human consumption (DWA, 1996).

5.5 Characteristics and description of the hydrogeological units

In this chapter the characteristics of the various geohydrological units are briefly described in terms of its geographical location, lithology, general use, quality, quantity, results of previous research and its importance as groundwater aquifer. Available data for each unit was statistically analysed and presented in a pre-described format as required for the hydrogeological map series. For yield data, the results are presented as borehole yield frequency diagrams and for the hydrochemistry as stiff diagrams. **Table 15** summarizes statistics for each unit obtained from the yield frequency diagrams with yield frequency expressed as a percentage. The units are displayed on individual maps under the discussion for each unit within the report.

Table 15: Percentage of boreholes falling into five yield ranges, number of data points/wet/dry for each unit.

Aquifer Unit	Unit extent as % of map area	Total number dry boreholes	Total number wet boreholes	% dry boreholes	0-0.01 (ℓ/s)	0.1-0.5 (ℓ/s)	0.5-2 (ℓ/s)	2-5 (ℓ/s)	>5 (ℓ/s)
Category A: Intergranular aquifers									
Q	1.4%	5	63	7%	10%	11%	24%	19%	37%
Category B: Fractured aquifers									
Kma	0.48%	2	2	50%	50%	50%	0%	0%	0%
Jl									
Trb	1.52%	0	76	0%	36%	24%	24%	17%	0%
P-Trs	0.45%	0	17	0%	18%	35%	29%	18%	0%
Pe Trc	6.92%	36	231	13%	12%	17%	32%	20%	20%
Pe	1.55%	5	79	6%	11%	18%	32%	18%	22%
Msn	2.22%	31	135	19%	5%	14%	36%	31%	14%
Msw	12.2%	91	398	19%	7%	27%	31%	19%	18%
Msf	2.88%	25	193	11%	6%	12%	42%	27%	13%
Category D: Intergranular and Fractured aquifers									
Jl	16.1%	56	645	8%	6%	17%	30%	23%	24%
Jd	0.35%	11	27	29%	11%	4%	19%	26%	41%
Trc	3.01%	3	174	2%	10%	24%	30%	18%	18%
N-Zd	0.8%	3	3	50%	0%	33%	33%	0%	33%
Mss	3.61%	43	293	13%	5%	20%	36%	23%	16%
Msa	0.11%	4	11	27%	9%	27%	27%	27%	9%
Rbu	1.42%	16	42	28%	12%	17%	36%	21%	14%
Rho	0.001%	No data							
Zal	1.17%	8	66	11%	12%	29%	33%	15%	11%
Zbm	1.29%	1	79	1%	25%	38%	29%	5%	3%
Zma	0.04%	0	6	0%	50%	17%	33%	0%	0%
Zsa	0.36%	No data							
Zgo	4.22%	44	277	14%	8%	19%	35%	27%	10%
Zbg	4.63%	23	193	11%	11%	28%	36%	14%	10%
Zba	21.75%	60	1365	4%	13%	28%	36%	15%	9%
Zbo	12.15%	53	372	12%	13%	28%	33%	19%	7%
Total	100.73%	522	4747						

Note: (Q:Tertiary-quaternary alluvial deposits), (Kma: Malvernia Formation), (Jl: Jozini Formation), (Trb: Bosbokpoort Formation), (P-Trs: Solitude Formation), (Pe: Ecca Group), (Msn: Nzhelele Formation), (Msw: Wyllies Poort Formation), (Msf: Fundudzi Formation), (Jl: Letaba Formation), (Jd: dolerite), (Trc: Clarens Sandstone Formation,) (N-ZD: diabase), (Mss: Sibasa Formation), (Msa: Stayt Formation) (Rbu: Bulai Gneiss), (Rho: Hout Rivier Gneiss), (Zal: Aldays Gneiss), (Zbm: Messina Suite), (Zma: Mediapala Syenite), (Zsa: Sand River Gneiss), (Zgo: Goudplaats Gneiss), (Zbg: Gumbu Group), (Zba: Malala Drift Group) (Zbo: Mount Dowe Group)

5.5.1 Primary aquifers

Primary aquifers or unconfined aquifers, also known as water table aquifers are where the top boundary of the aquifer is the static water table and equal to atmospheric pressure. The water level is therefore free to rise and fall. It consists of unconsolidated material with the volume of water released from storage per unit surface area of aquifer per unit decline of the water table known as the drainable pore space or Specific yield (Sy) of the aquifer. It is also known as effective porosity as water can only move through pores that are interconnected.

5.5.1.1 Category A: Intergranular aquifers

5.5.1.1.1 Tertiary-quaternary alluvial deposits (Q)

Quaternary alluvial deposits of limited lateral extent and thickness occur along most river terraces in the map area. Major deposits depicted on the map include deposits along the Limpopo, Mutale, Luvuvhu, Shisha and Nzhelele rivers. The deposited material relates to the upstream regional geology and the sorting, grain size distribution and deposition is a function of the river flow. The intensity of flow in the rivers within the study area is only rapid during floods. During these times the dumping and re-working of river sediments is most active. The main river within the map area is the Limpopo River that forms the border between South Africa and Botswana in the north-west and with Zimbabwe in the north. Deposits along this river include unconsolidated high-level gravels that are mainly confined to the reaches of the river. At some prominent exposures observed on the farm Eersteling 138 MR these gravels occur 15 to 50m above the present level of the river. Rounded to semi-rounded clasts are found within these deposits. Near the deposit depicted east of Pontdrif (**Figure 35**, p93) on the farm Riedel 48, alluvial gravel occurs 5km south of the Limpopo River up to 50m above the current level of the river. Mining for alluvial diamonds revealed that the gravel deposit is up to 30m thick with well rounded clasts. Large areas flanking the major rivers are covered in thick, light grey to brownish, muddy to silty alluvium (Brandl, 2002). The most extensive deposits occur along the Limpopo, Levuvhu and lesser along the Magalakwena and Brak rivers where it forms fertile soils.

As with most alluvial deposits along rivers, the success of obtaining a high yielding source depends on various factors including the depth, extend, material and sorting of the deposit as well as the flow regime of the river. Past exploration projects along major rivers such as the Limpopo highlighted the varying groundwater potential within alluvial deposits over relative short distances. It is therefore critical to investigate the depositary character of the river to obtain the best position for a Sandpoint. Such points can be on the inner slower moving depositary side of a river bend or within horseshoe bends in matured rivers where alluvial deposits accumulated.

Plate 4: Sandpoint supplying the Pafuri Police Station and border post with water. A thick alluvial deposit formed at the confluence of the Luvuvhu and Limpopo rivers. During periods of excessive rainfall, the area is flooded. Flood markings in white from top are 9/2/2000, 9/2/77, 18/01/2000, 27/01/1972, 22/01/1958, 1/02/1981, 7/3/1977, 22/2/1975, 11/02/1996, and 28/2/1988 (Photo, C.J.Sonnekus 18/04/2008).

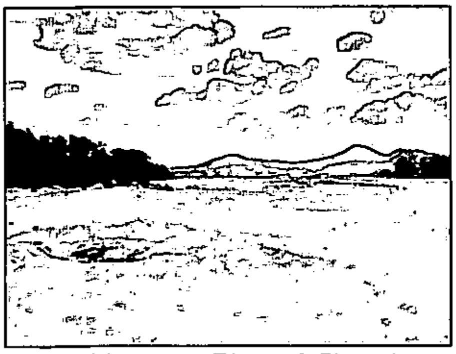


Plate 5: Boreholes in the Limpopo River supplying Beit Bridge border post. In the foreground is borehole H18-0699. Within a 100m radius, two other production boreholes exist (H18-0690 and H18-0698). These boreholes are equipped with submersible pumps with the top of the casing approximately 1m below surface. The area is about 2km east of Beit Bridge with South Africa on the left and Zimbabwe on the right. The river was in flood within 5 days after taking the photo (Photo, C.J.Sonnekus, 3/10/2010).

In the Limpopo River, 3.5km downstream of Beit Bridge up to the confluence of the Sand River, the average width of the sand bed is 300m and the average thickness of water saturated sand is 3.5m. The specific yield (Sy) is 24% by volume. The bedrock floor is extremely irregular with an average sand thickness of 4.5m. In the tributaries of the Limpopo River, such as the Sand River, the bedrock floor is more uniform in shape and considerably deeper up to 20m in places. Probing in the Sand River revealed numerous silt lenses. This was also found in other tributaries of the Limpopo like the Mogol River where the amount of silt increased markedly near the confluence with the Limpopo (Mulder, 1973).

In another study ((vd Westhuizen, 1983) using data from three investigations done over a 30 year period, including the work of (Mulder, 1973)) a 2km long section of the Limpopo River in proximity to the Soutsloot-Limpopo confluence was investigated to assess the potential of available groundwater resources contained in the sandy riverbed with the following findings:

- The sand is coarse to very coarse grained and remarkably free of any silt.
- There is very little variation in composition of the sand with increasing depth.
- Full saturation (porosity) varied from 33.6 to 36% by volume.
- Specific retention (field capacity) varied little from 9.3 to 9.9%.
- Specific yield (effective porosity) ranged from 23.7% to 25.3% by volume, averaging 24% for all samples taken.

The geohydrological parameters and conditions reveal no significant changes over the 30 year period of investigation. The average thickness of the saturated sand is 3m and the average width of the sand bed is 300m with an extremely irregular bedrock rock floor. Porosity is calculated at a value of 30% by volume, for the alluvial aquifer.

Extensive irrigation from the alluvial aquifers in the Limpopo River occurs at the confluence of the Maloutsi River and on the farm Overvlakte in the east. An estimated 60 x $10^6 m^3$/year is abstracted along the reach of the river (Du Toit, 1995).

A study by De Klerk and Wiegmans, (1990) in an area east of the confluence of the Shashi and Limpopo rivers on the farm Greefswald 37MS was done to determine the thickness and base elevation of the aquifer and the presence of clay layers in the river bed. Using geophysical methods and contouring the resulting data, the aquifer was interpreted to be within a continuous deep channel with an average saturated thickness of 20m and width of about 100 metres. The aquifer consists of interlayer gravel, sand and clay layers.

A study by Venter, (1990) in the north-eastern section of the map revealed that most major rivers have alluvial deposits formed along the stream bed changing in thickness from a few centimetres up to 45m along the Levubu River.

Numerous hand dug wells are found within ephemeral stream beds, characterized by a sandy to gravel filled streambed with a shallow perched water level. These wells are seldom protected by concrete rings as in more formal developed sand points and are usually destroyed after the first rains. These are mostly used by small scale farmers in the rural areas.

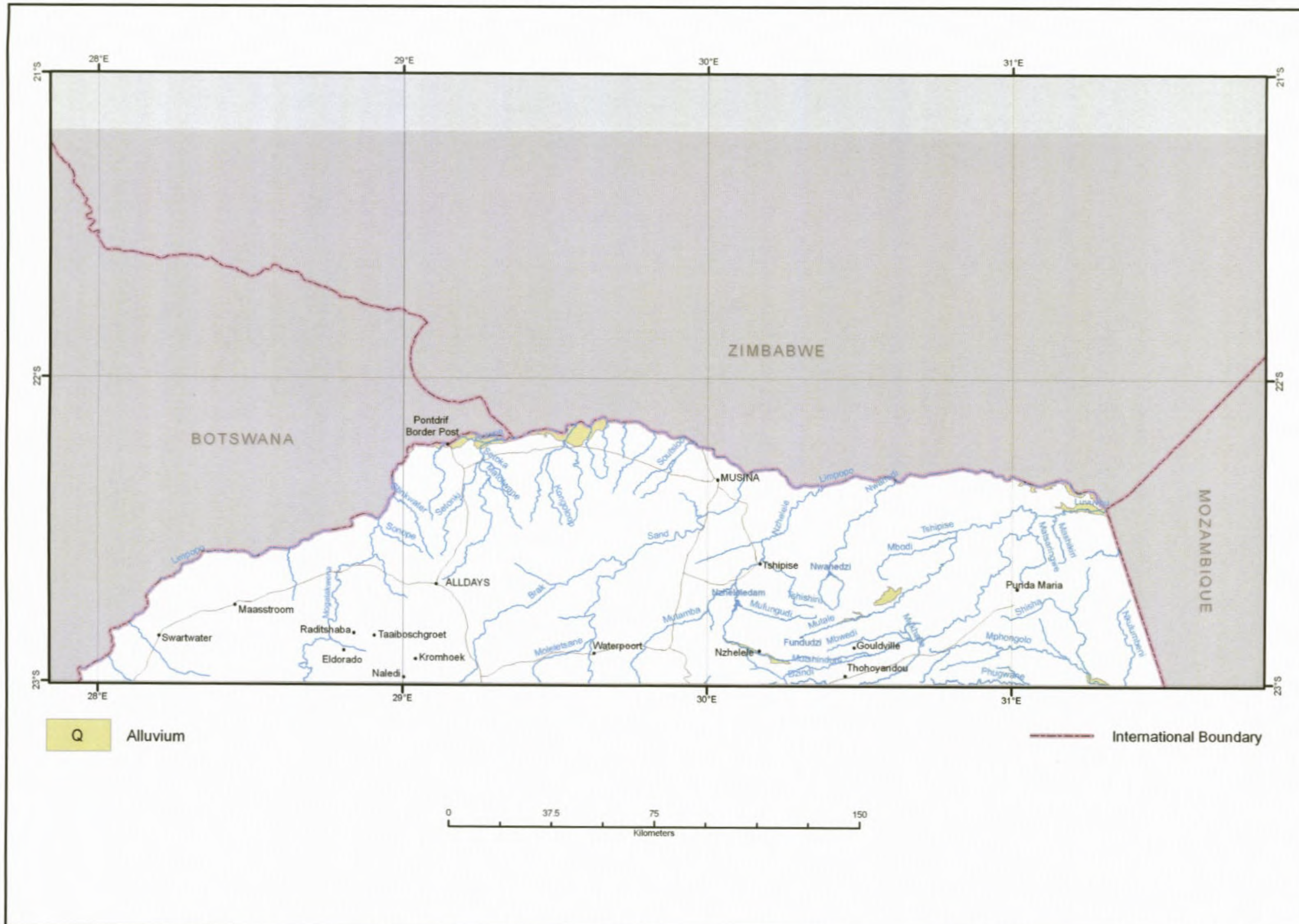


Figure 35: Geographical distribution of the intergranular aquifers (Q) (after DWA, 2011).

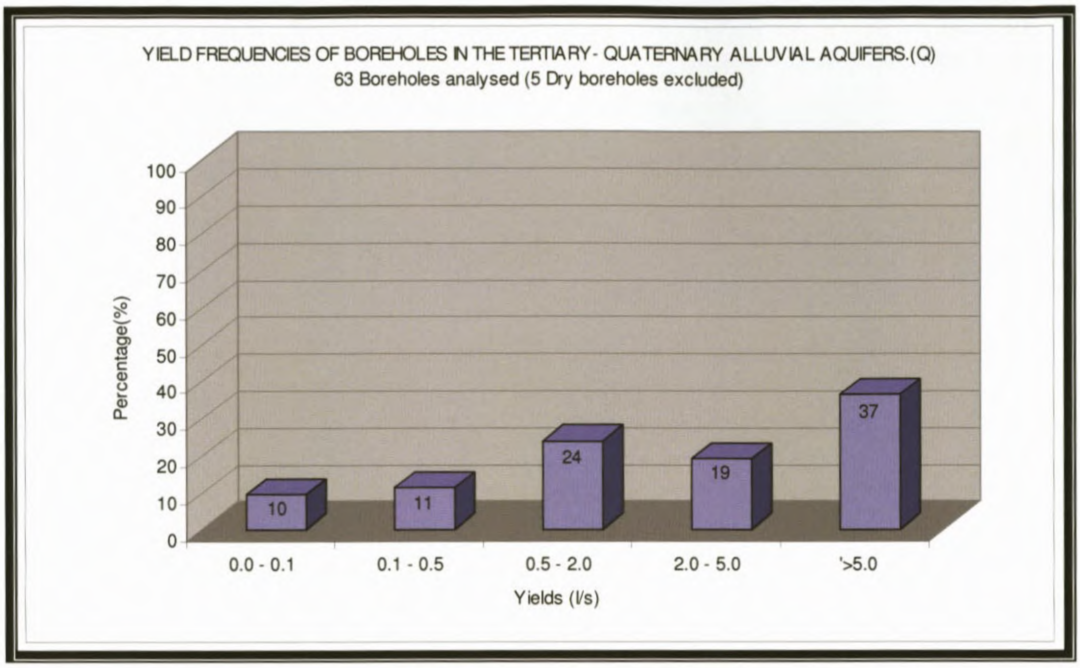


Figure 36: Yield frequency for Tertiary-Quaternary alluvial (Q) aquifers.

Figure 36 is a representative yield frequency diagram of yields within the alluvial aquifers. The diagram shows that existing borehole yields are generally high with 37% of the successful boreholes in excess of 5ℓ/s.

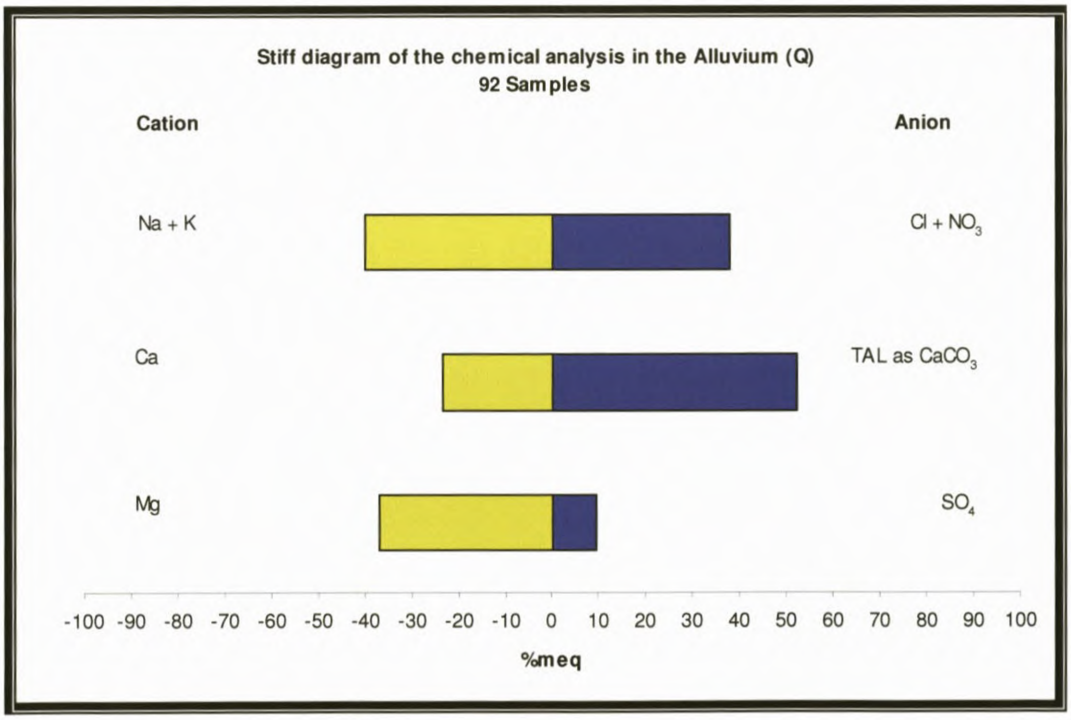


Figure 37: Stiff diagram representing chemical analysis of the alluvial deposits (Q).

The Stiff diagram (**Figure 37**) shows the broad classification according to anions and cations. From this diagram the groundwater can relate to sodium-magnesium-bicarbonate and chloride water types.

The water quality is ideal (35.9%) to unacceptable (18.5%), (Table 12, 13 and 14, pp86-88) with EC values ranging from 6 to 1570mS/m. The harmonic mean is calculated as 60.6mS/m falling comfortably within the acceptable limit (EC <150mS/m). Take note that the calculation of the harmonic mean is always giving a lower value than the arithmetic mean. Furthermore 18.5% of the magnesium, 18.5% of the sulphate and 14.1% of the chloride concentrations exceed the maximum allowable limit (Mg >100mg/l, SO_4 and Cl >600mg/l). Elevated concentrations of sodium and fluoride were reported in some of the samples. Samples from the alluvial aquifer along the Limpopo River in the Thuli Basin as well as a stretch between Pontdrift and Saamboubrug have elevated Mg, SO_4 and Cl concentrations. The quality seems to improve eastwards from Mussina as more perennials join the Limpopo River. The water quality of boreholes within the river, supplying Beit Bridge, fluctuate seasonally depending of the level of the surface flow (resident engineer at Beit Bridge, personal communication, 2011)

In terms of water resources and provision, these alluvial aquifers are playing an essential role. Recharge to these aquifers occur almost immediately after river flows and the quality within the alluvial deposits is generally of an acceptable standard. The quality of the groundwater as well as the type and character of the underlying rock will have an influence on the water chemistry of the alluvial deposits (du Toit 1998). Quality problems reported in some of the samples within the alluvial deposits of the map area might be due to the influence of the underlying Lebombo and Karoo sediments.

5.5.2 Secondary aquifers

The map area is predominantly (± 98.6%) underlain by consolidated hard rocks of sedimentary, igneous and metamorphic origin. The secondary aquifer types shown on the map includes fractured and intergranular & fractured aquifers. Karst aquifers are included in the legend for mapping continuity although no dolomitic rocks occur within the area.

5.5.2.1 Category B: Fractured aquifers

- Malvernia Formation (Kma)
- Lebombo Group (Jl)
    - Jozini Formation
- Bosbokpoort Formation (Trb)
- Solitude Formation (P-Trs)
- Undifferentiated Ecca Group and Clarens Formation (Pe-Trs)
- Ecca Group (Pe)
- Soutpansberg Group (Ms)
    - Nzhelele Formation (Msn)
    - Wyllies Poort Formation (Msw)
    - Fundudzi Formation (Msf)

The geographical distribution of the fractured rock aquifers is shown in **Figure 38**, (p96). The fractured rock aquifers cover approximately 28.2% of the total map area. Dolerite (Jd) is wrongly indicated on the main map, of the 1:500 000 Messina hydrogeological map sheet (2127 Messina), to fall under fractured aquifers. It is only part of the fractured and intergranular aquifers.

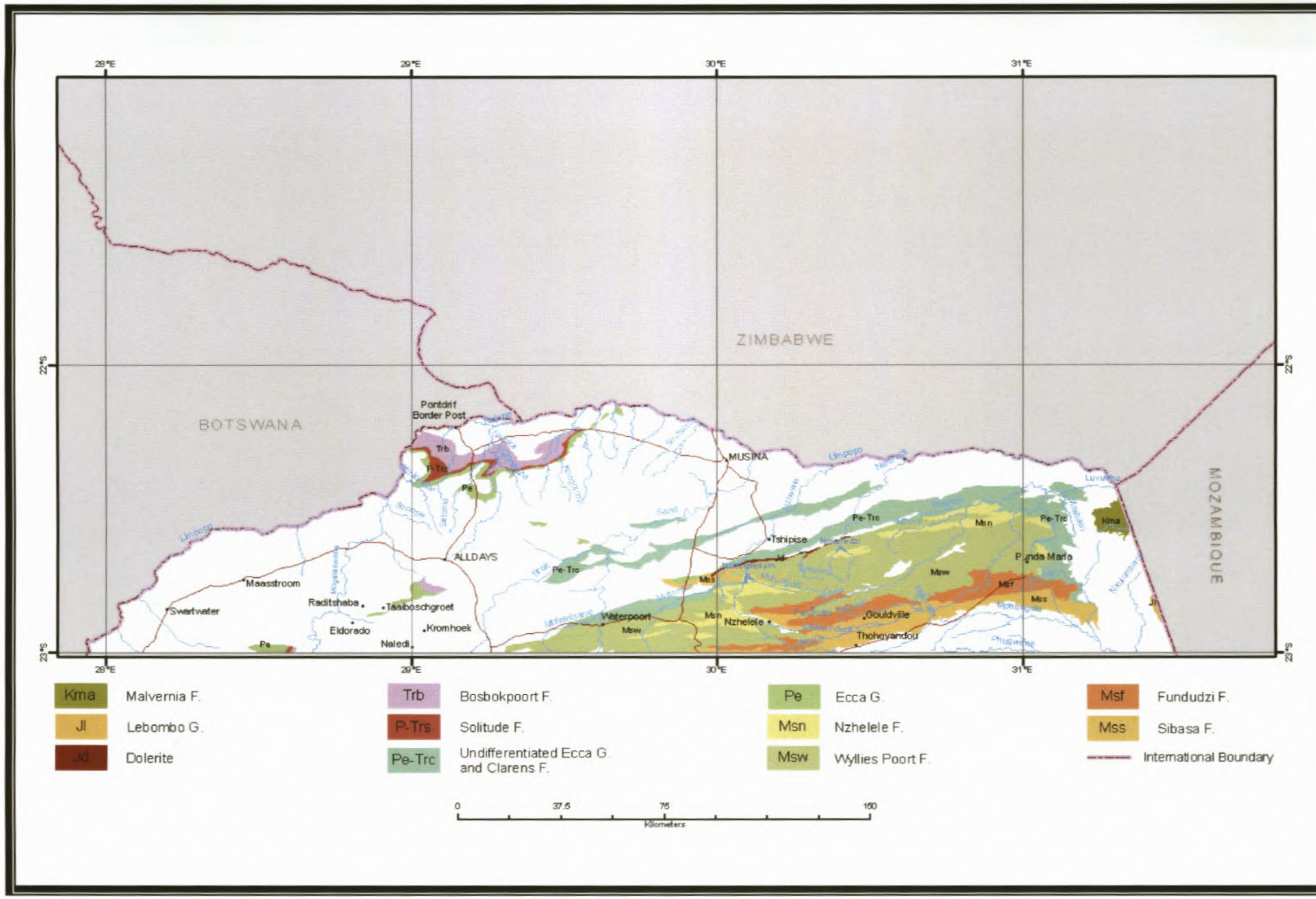


Figure 38: Geographical distribution of the fractured rock aquifers (after DWA, 2011).

5.5.2.1.1 **Malvernia Formation (Kma).**

This formation forms an extensive plateau south of Pafuri (**Figure 24**, p68 and **Figure 39**, p97) in the north-eastern sector of the map area. Minor occurrences north-east and north-west of Masisi are not indicated on the map. The formation is of Cretaceous Erathem, unconformable overlaying the basalt of the Letaba Formation. It is dipping to the east at 5 to 10 degrees to obtain a maximum thickness of approximately 80m along the eastern fence of the Kruger National Park. Whitish, coarse-grained and gritty sandstones and conglomerate with limestone and marl intercalations characterise the formation (Keyser, 1972). The pebbles of the conglomerate are rounded to sub-rounded, have a maximum diameter of 500mm and are derived partly from the Soutpansberg Supergroup and partly from granitic terrain. The matrix of the arenaceous sediments is usually calcareous.

The unit has a limited thickness (20 to 80m) and extent (0.48% of the map area). It is located within the National Kruger Park restricting its current and future development as an aquifer. The existing data from the unit shows that the aquifer is potentially low yielding. Groundwater development in this sector of the map area usually targets geological lineaments at depths >40m. Future groundwater development in this area might therefore focus on targets within the underlying basalt. The database has information on 4 boreholes of which two are dry. The remaining two have yields of 0.07ℓ/s and 0.2ℓ/s respectively with no chemical data. From the above it is likely that the yield frequency will follow the tendency as for the fractured aquifer of the Lebombo Group described in section 5.2.1.2. The chemical result might reflect higher calcium concentrations. A piezometric contoured map compiled for the Kruger National Park groundwater study revealed the Malvernia Formation to be a groundwater recharge area as groundwater drains from it (Du Toit, 1998).

Figure 39: Geographical distribution of the Malvernia Formation (Kma).

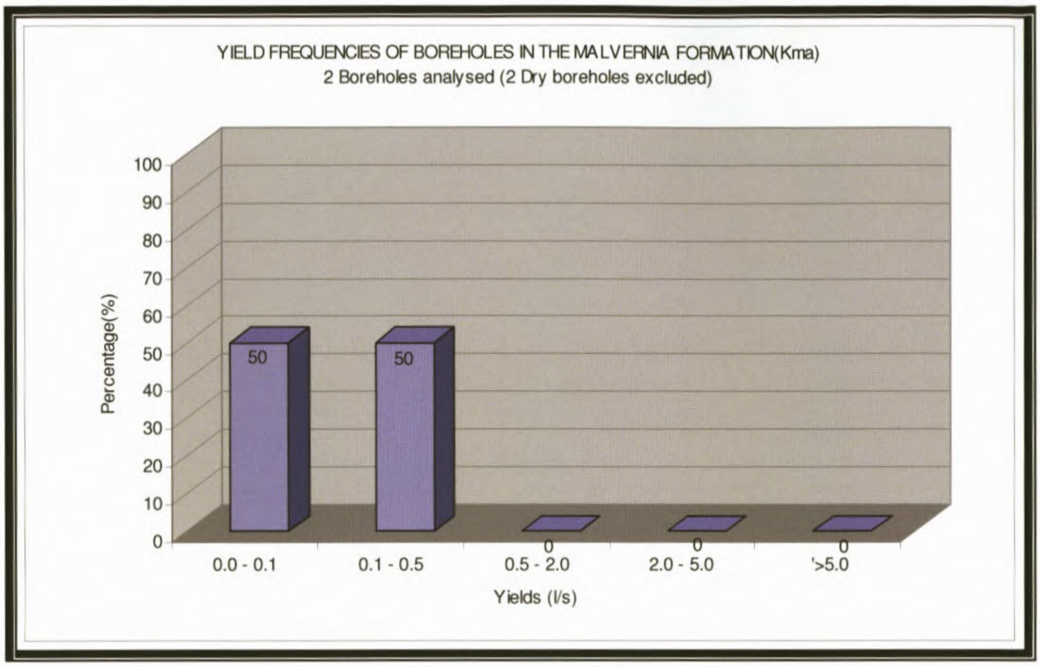


Figure 40: Yield frequency for fractured aquifers of the Malvernia Formation (Kma).

5.5.2.1.2 **Lebombo Group (Jl) –Jozini Formation.**

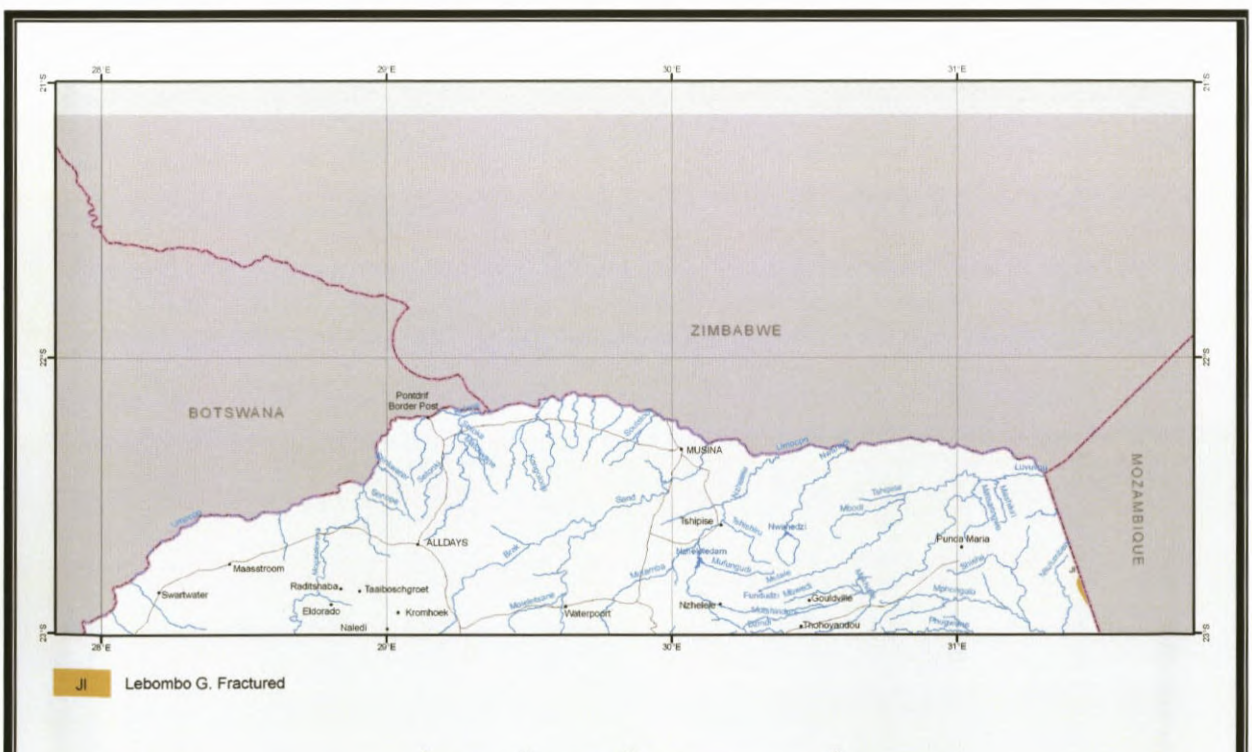


Figure 41: Geographical distribution of the fractured aquifers of the Lebombo Group (Jl).

The outpouring of lava marked the end of the sedimentary deposits of the Karoo Supergroup. Two Formations of the Lebombo Group occurs within the map sheet. The **Jozini Formation** representing the youngest Formation of the Lebombo Group within the map area occurs along the eastern border of the Kruger National Park (**Figure 41**) where it forms a conspicuous cliff. It consists of massive, resistant, red, brown, purple to green **rhyolite** with a thickness of approximately 70m. Outside the map area to the south if forms part of the Lebombo Mountain range with a thickness of approximately 8000m. The texture is porphyritic to glomeroporphyritic and the rock is flow-banded (Brandl, 1981).

No chemical or borehole yield data was available for analysis.

5.5.2.1.3 Bosbokpoort Formation (Trb).

Rocks of the Karoo Supergroup occur in three well-defined areas as described in the relevant section for the Supergroup in Chapter 5. The Bosbokpoort Formation occurs within two of the basins (Tuli and Tshipise) and within one of the outliers between the basins. The occurrence within the Tshipise basin was grouped by the map compilers, of the 1:500 000 Messina hydrogeological map (2127 Messina), under the undifferentiated Ecca and Clarens Formation as described in section 5.5.2.1.5, p103. Within the Tuli basin the Bosbokpoort Formation is up to 60m thick consisting of brick-red to purplish mudstone with subordinate white siltstone horizons developed mostly in the upper half. Calcareous nodules and concretions are often present (Brandl, 2002). The description of the hydrogeological character of the unit is for the occurrence within the Tuli basin and a single outlier as depicted in **Figure 42**, (p100).

As expected from the lithology and confirmed from yield data, the unit can be regarded as a poor to average aquifer as 60% of the existing boreholes are yielding less than 0.5ℓ/s. However, no dry boreholes were recorded. Rocks from this formation have a low to very low primary permeability with low storage potential. Water is generally obtained in fractures and joints, locally developed bedding plains, contact zones between sediments, faults and associated shear zones. Contact zones with intrusive dolerite sills and dykes where present is also targeted in the search for groundwater (Du Toit, 2011).

From the stiff diagram representing the chemical analysis of the **two sampled** boreholes (**Figure 44**, p101), the water is of poor quality. It is classed as a sodium-bicarbonate and chloride water type. The magnesium and fluoride concentration is unacceptable in 50% of the samples and the chloride and sodium is unacceptable in both the samples (Table 12, 13 and 14, pp86-88). The high Electrical Conductivity (EC) measurements are a clear indication of water quality problems. Due to limited data additional sampling should be done to determine if the above holds true for the whole of the unit as was found in the Polokwane map sheet or whether these quality problems are localized. Groundwater in this formation is abstracted for livestock watering and, where the taste permits, for domestic purposes.

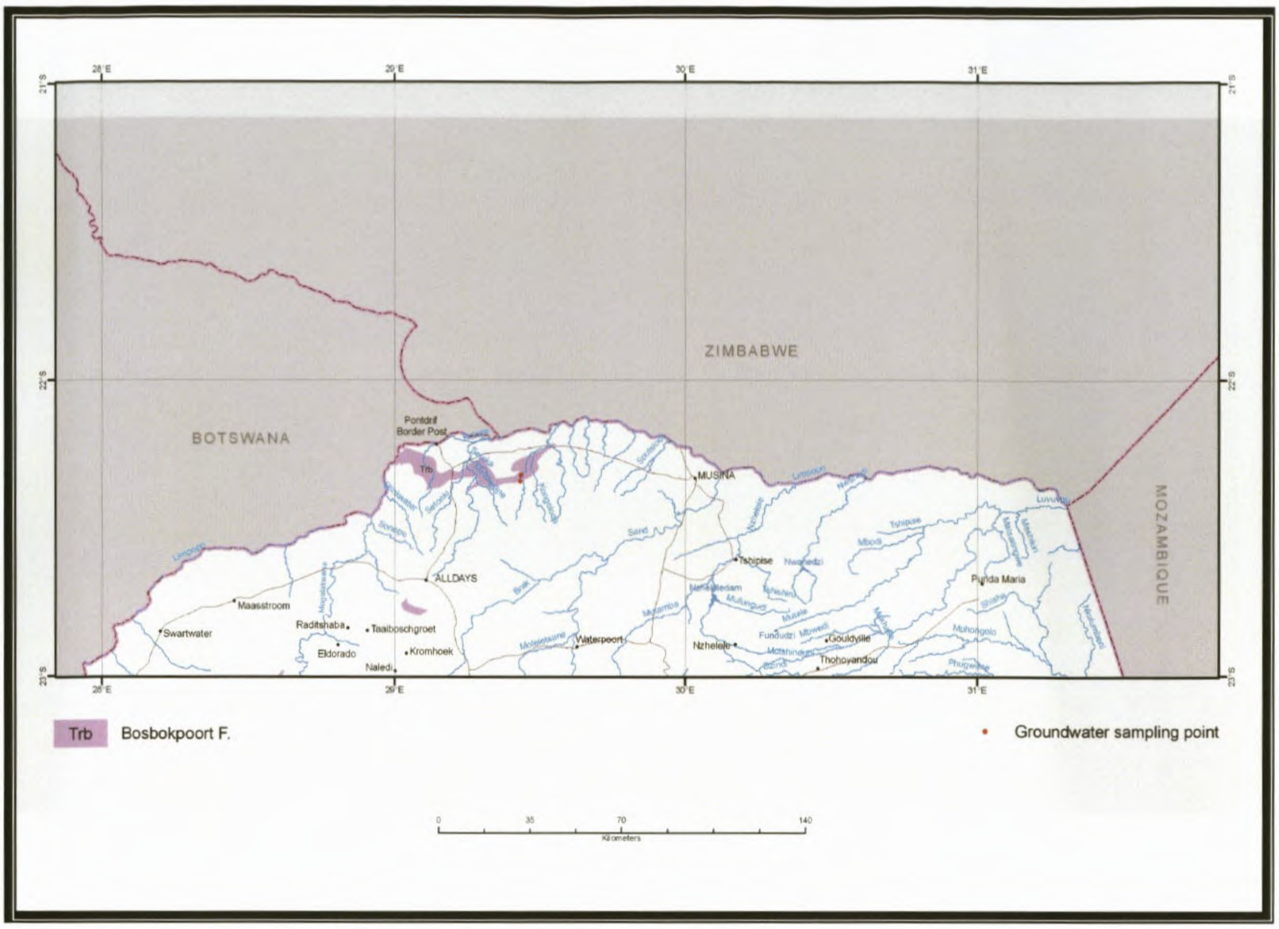


Figure 42: Geographical distribution of the Bosbokpoort Formation (Trb) and some of the associated groundwater sampling points.

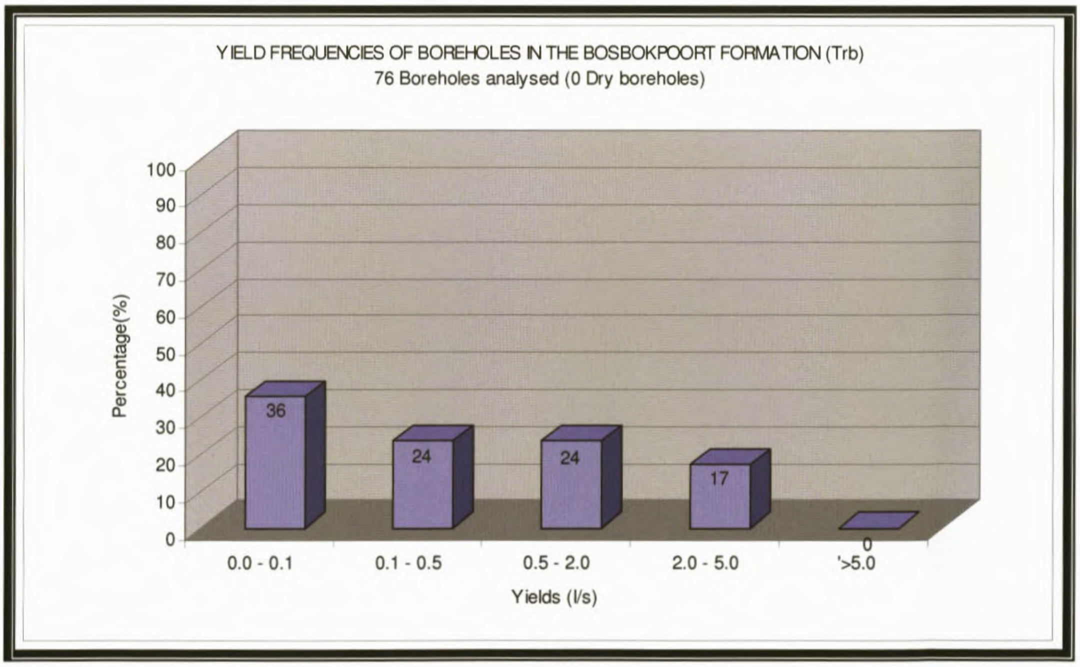


Figure 43: Yield frequency for fractured aquifers of the Bosbokpoort Formation (Trb).

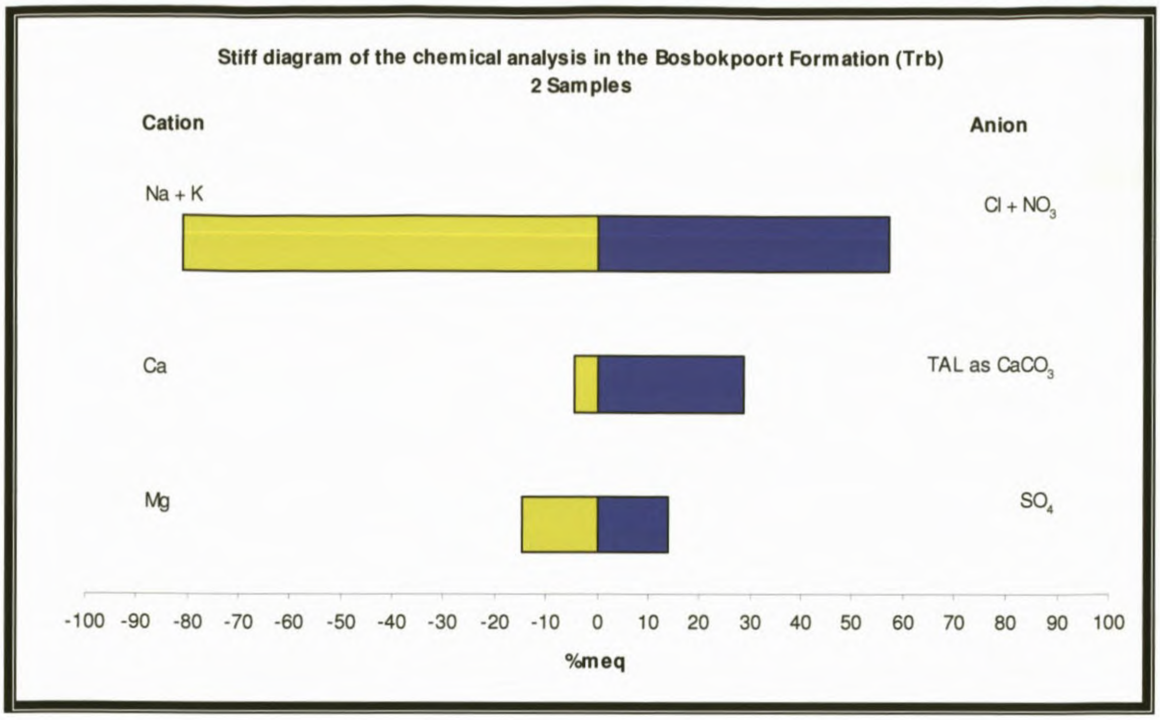


Figure 44: Stiff diagram representing chemical analysis of the Bosbokpoort Formation (Trb).

5.5.2.1.4 **Solitude Formation (P-Trs)**

The occurrence of the Solitude Formation within the Tuli basin and within minor outliers as depicted in **Figure 45**, (p102) consists of white to buff, pink, green, red and khaki siltstone and very fine-grained sandstone with subordinate grey mudstone. The contact with the upper Bosbokpoort Formation becomes arbitrary where reddish colours are developed in the upper part of the Formation (Brandl 2002). As with the Bosbokpoort Formation, the occurrences of the Solitude Formation outside the Tuli basin and outliers are discussed under undifferentiated Ecca and Clarens formations in section 5.5.2.1.5, p103.

The sedimentary rocks of the Formation have a low to a very low primary permeability and storage potential. Statistics indicate that 82% (**Figure 46**, p102) of the successful boreholes yield less than 2*ℓ/s* with the remaining 18% yielding between 2 and 5*ℓ/s*. No data of dry boreholes or with yields exceeding 5*ℓ/s* was available.

Targets in the search for groundwater will relate to secondary fracturing associated with geological lineaments such as fault zones or intrusive dykes. Joints, bedding planes and contacts between sediments may also be targeted if no lineaments occur within the area of groundwater development.

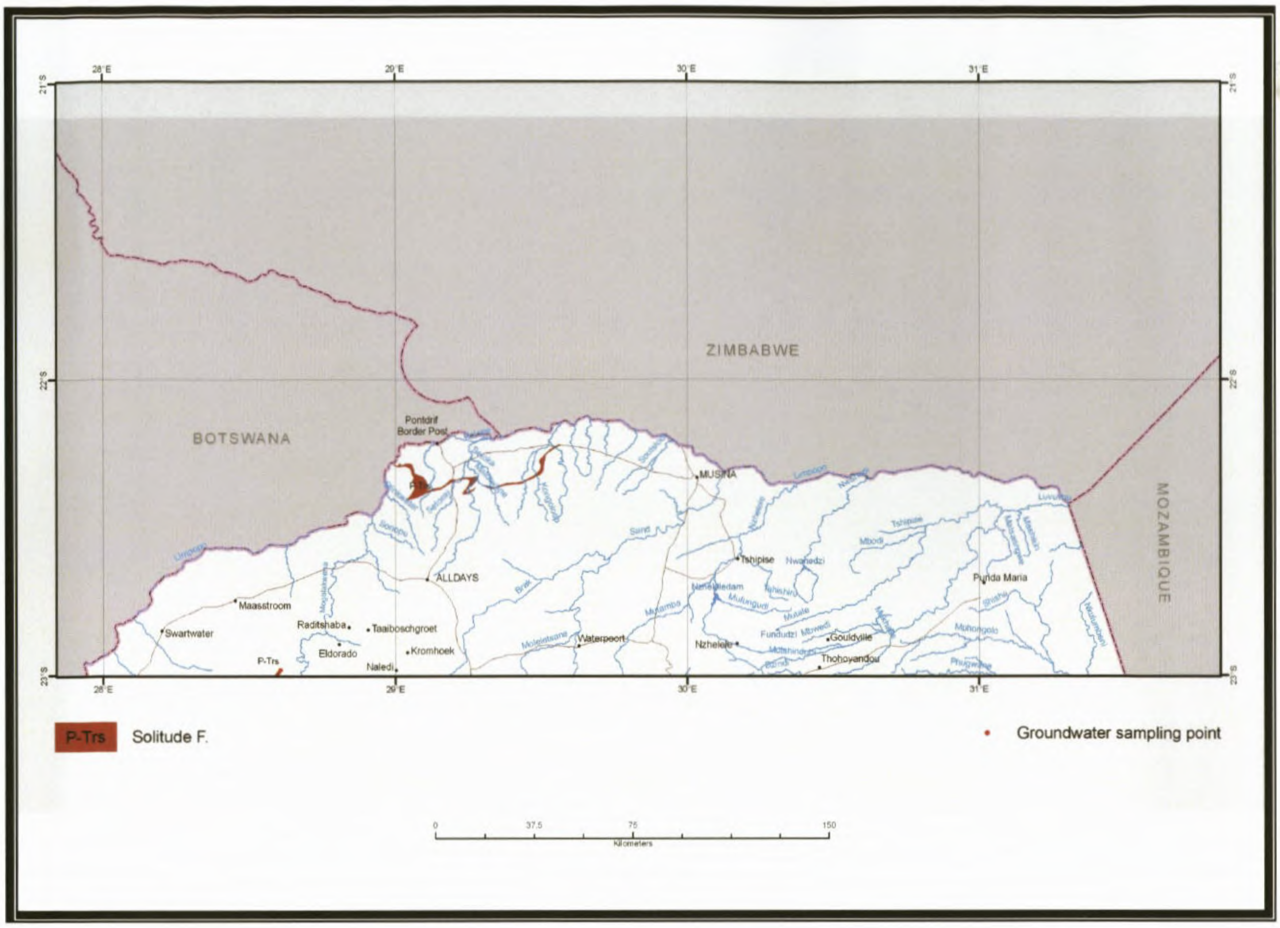


Figure 45: Geographical distribution of the Solitude Formation (P-Trs) and the associated groundwater sampling points.

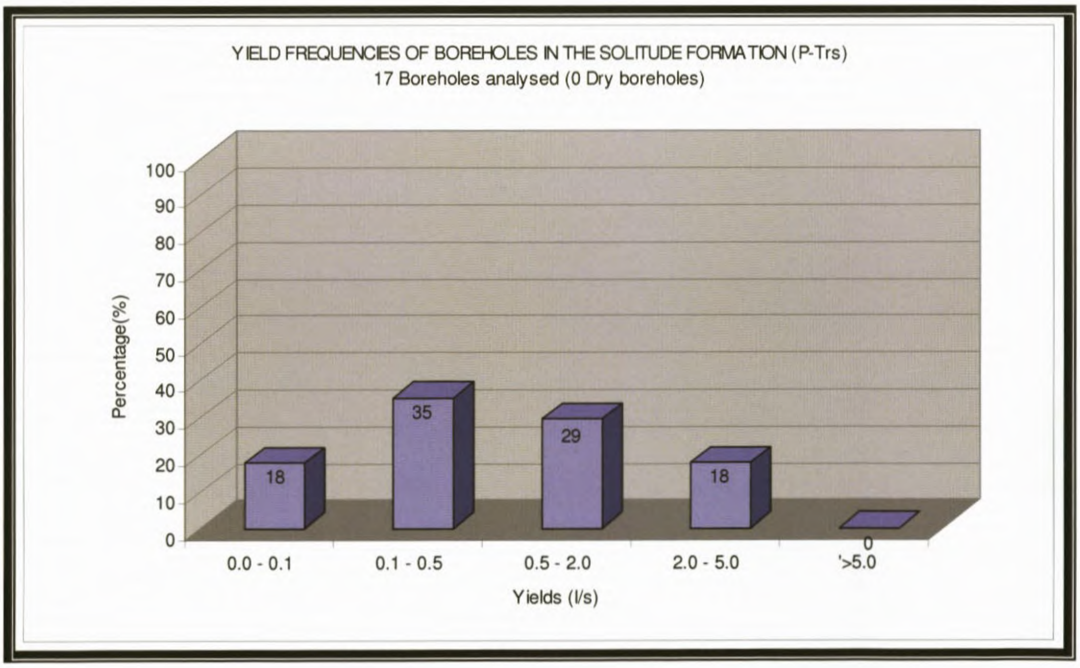


Figure 46: Yield frequency for fractured aquifers of the Solitude Formation (P-Trs).

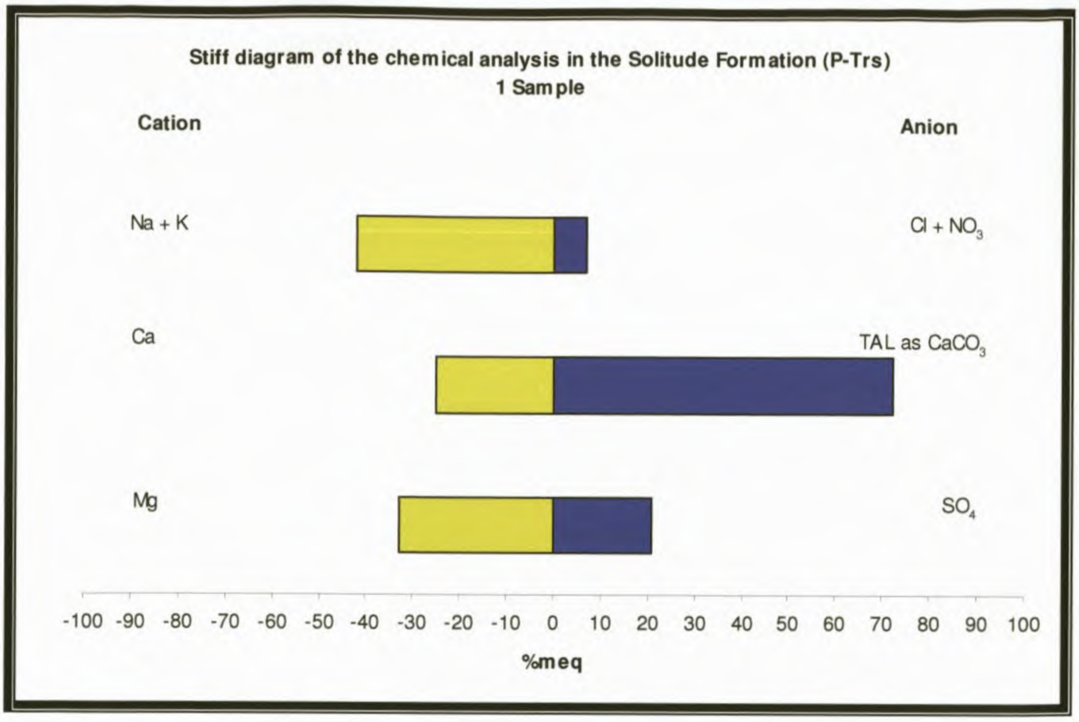


Figure 47: Stiff diagram representing chemical analysis of the Solitude Formation (P-Trs).

The stiff diagram (**Figure 47**) represents the results of one available chemical analysis that exhibits a sodium-magnesium-bicarbonate water type. The calcium and sulphate concentrations are slightly elevated but still within acceptable limits. In order to characterize and compare the chemical composition of the groundwater in this unit more chemical analysis is required to obtain a representative population for statistical analysis.

5.5.2.1.5 **Undifferentiated Ecca Group and Clarens Formation (Pe-Trc)**

Various formations of the Karoo Supergroup occurring within the Tshipise basin are grouped under this heading. The map scale and area extend of the relevant formations made it very difficult to differentiate between them. All the Karoo rocks occurring south of the Voorburg, Bosbokpoort and Tshipise faults are regarded part of the Tshipise basin (Van der Berg, 1980). The trend of the basin is north-east with the southern border more or less delineated by the Klein Tshipise Fault and rocks of the Soutpansberg Supergroup. The formations included under this heading are Clarens, Bosbokpoort, Klopperfontein, Solitude, Fripp, Mikambeni, Madzaringwe and Tshidzi formations. The combined thickness of the sedimentary succession is approximately 1000m. In contrast to the outlay of the document, the formations are described from oldest to youngest.

The **Tshidzi Formation** formed in a fluvioglacial environment and is confined to a few sporadic outcrops which probably developed in pre-Karoo depressions. The maximum thickness is 20m and it is composed of angular and rounded clasts imbedded in a sandy or bluish grey, muddy matrix.
The overlaying **Madzaringwe Formation** with a maximum thickness of 200m formed in a swamp environment. It consists of carbonaceous shale, shaly coal, coal, grey-black shale, brownish siltstone and laminate micaceous sandstone.
The **Mikambeni Formation** with a maximum thickness of approximately 150m comprises dark and pale mudstones, black shale and thin coal seams deposited in a swamp environment (Brandl, 1981)
The **Fripp Sandstone Formation** with a maximum thickness of approximately 110m forms a sharp contact with the underlying **Mikambeni Formation** and consists of white or greyish white, cross-bedded, very feldspathic medium to coarse grained sandstone. The sediments were transported from the north-east and deposition in braided streams is envisaged (Van Vuuren, 1979). Within the Tshipise basin the

Solitude Formation has a maximum thickness of 170m and is dominantly composed of alternating multi-coloured shale and mudstone. Sedimentation took place in a fluviatile environment (Brandl, 1981).

The **Klopperfontein Sandstone Formation** is lithologically similar to the Fripp Formation with a thickness between 10 and 20m. In the Tshipise area reddish colours prevail due to an abundance of red feldspar. The overlaying **Bosbokpoort Formation** is characterized by dominantly red lithologies with a maximum thickness of approximately 100m in the Tshipise area and thinning gradually towards the east. The lower part consists mainly of massive mudstone followed by siltstone which occasionally grades into (minor) very fine sandstone. Calcareous concretions are frequently scattered throughout the exposures. The clayey and silty material of the succession seems to have been deposited in a flood basin under moderately hot and arid conditions (Brandl, 1981).

The **Clarens Sandstone Formation** with a maximum thickness of 300m is divided into the **Red Rocks Sandstone Member** and the **Tshipise Sandstone Member**. Deposition of this Formation seems to have occurred mainly in an aeolian environment. In the south-eastern part of the map area the Formation unconformable overlies rocks of the Soutpansberg Group and basement gneiss. The absence of the lower Karoo formations in this area points to the existence of a pre-Karoo higher area (Brandl, 1981). Thin Letaba basalt sills and dykes are occasionally found to have intruded the sandstone, usually near the main basalt/sandstone contact. The contact zone between basalt and sandstone yields varying quantities but are usually <0.5ℓ/s. However, higher yielding water strikes is generally intercepted in the Clarens sandstone between 40 and 75m below the main basalt/sandstone contact. The EC values are lower in the sandstone than the overlaying basalt.

The groundwater potential in the argillaceous sediments is considered to be very low. The chance of finding water in strikes deeper than 80m is very low. Secondary fracturing related to geological lineaments such as the major fault zones (Klein Tshipise and Tshipise Faults) are primary targets in the search for groundwater. Other targets include secondary fracturing related to dolerite dykes and sills, bedding planes and sedimentary contacts (Du Toit, 1998). The Tshipise Sandstone member of the Clarens Formation is regarded as the best aquifer (quality and quantity) within this geohydrological unit.

The yield frequency distribution (**Figure 49**, p105) indicates that 29% of the successful boreholes yield less than 0.5ℓ/s, 32% is between 0.5 and 2ℓ/s, and 40% is more than 2ℓ/s. The higher yielding boreholes are largely attributed to secondary fractures related to faults, dykes and sills.

The chemical analyses of 138 samples, (**Figure 50**, p106) are representative of the formations grouped under this unit. The sample distribution covers more or less the whole unit (**Figure 48**, p105). It must be kept in mind that the results do not differentiate between the different formations as boreholes might have intersected more than one formation. It is known from field notes that the water quality found in the Clarens Formation is superior to the water found in the mainly argillaceous sediments of some of the other Formations.

Plate 6: The Tshipise basin, photographed from the north-east. The ridge on the left is the northern part of the Soutpansberg (Wyllies Poort Formation). The ridge on the right is formed by the Clarens Sandstone Formation of the Karoo Supergroup. The landscape is typical of the north-eastern sector of the map sheet. North of the Soutpansberg, Mopani, Matopi and Boabab trees dominate. The overburden in the foreground is reddish sand and calcrete, further to the south-west it changes to deep red sand and semi round quartzitic pebbles from the Wyllies Poort Formation (Photo, C.J. Sonnekus, 11/02/2011)

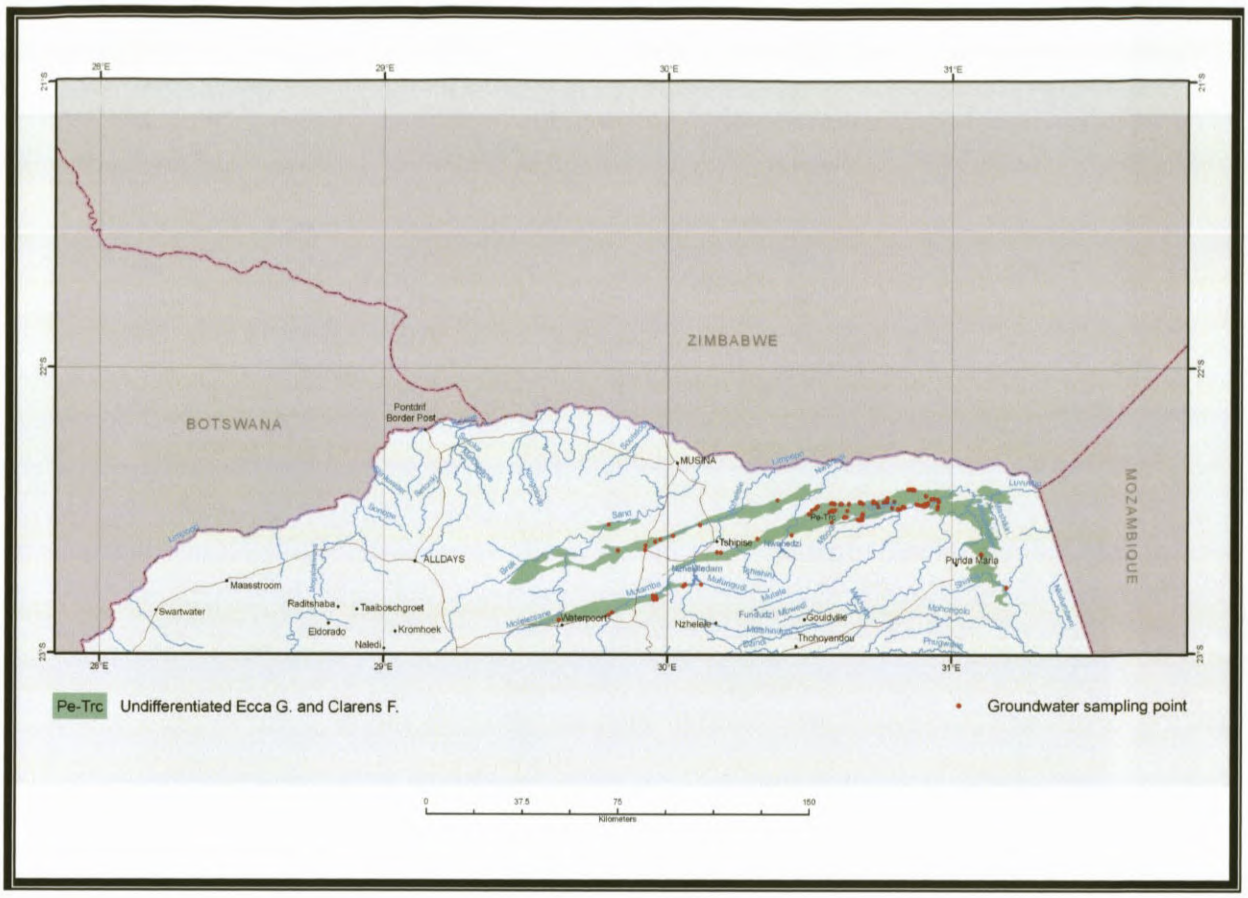


Figure 48: Geographical distribution of the Undifferentiated Ecca Group and Clarens Formation (Pe-Trc) and the associated groundwater sampling points.

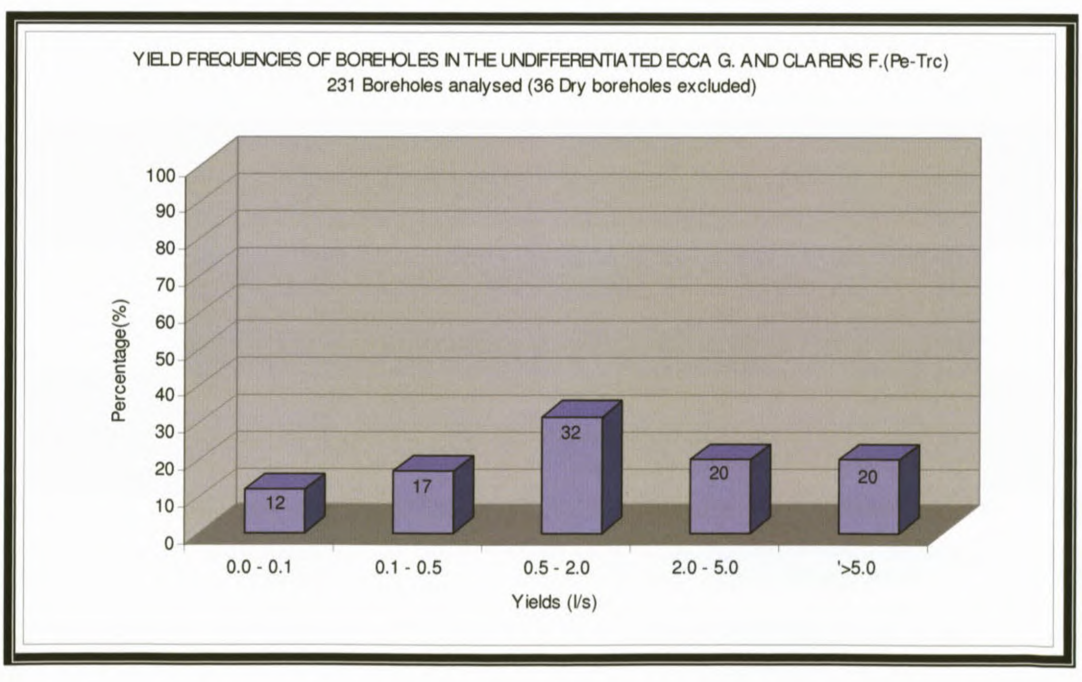


Figure 49: Yield frequency for fractured aquifers of the Undifferentiated Ecca Group and Clarens Formation (Pe-Trc).

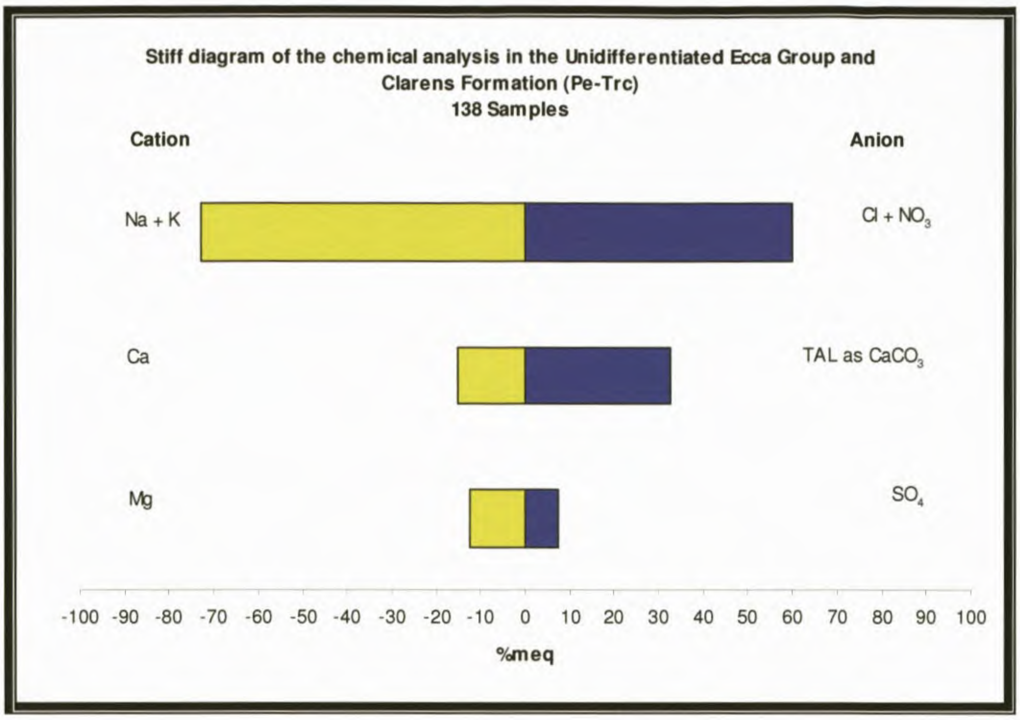


Figure 50: Stiff diagram representing chemical analysis of the Undifferentiated Ecca Group and Clarens Formation (Pe-Trc.)

The chemical analysis of 138 sampled boreholes indicates a sodium-bicarbonate and chloride water type. This is a typical classification for Karoo sedimentary rocks. The quality of the water is ideal (8.7%) to unacceptable (28.3%), (Table 12, 13 and 14, pp86-88). EC values range between 12 to 4610mS/m with the harmonic mean calculated as 128mS/m. Note that the harmonic mean gives lower values compared to the arithmetic mean. In 22.5% of the samples the EC values exceeds the maximum allowable limit (EC >370mS/m. In addition, 14.4% of the samples fall outside the acceptable limit for nitrate (N >20mg/l), 10.3% are outside the fluoride limit (F >1.5mg/l) and 24.6% are exceeding the maximum allowable limit for chloride (Cl >600mg/l). The concentration of magnesium and sodium also display problems as respectively 26.1% and 28.3% of the samples falls outside the maximum allowable limits (Mg >100mg/l, Na >400mg/l) for domestic water (Table 12, 13 and 14, pp86-88). Most of the problematic water samples occur near the Klein Tshipise Fault.

5.5.2.1.6 **Ecca Group (Pe)**

Rocks of the three lower formations of the Karoo Supergroup occur within the Tuli basin and within the down-faulted blocks between the Tuli and Tshipise basins. These formations are grouped under this heading and include the **Mikambeni, Madzaringwe and Tshidzi formations**. In contrast with the outlay of the document the succession of the unit is described from oldest to youngest.

The **Tshidzi Formation** was deposited on a markedly uneven floor of Beit Bridge gneisses and consists of local angular blocks and fragments within a matrix of coarse sand or grit. The occurrence is irregularly and infrequently. Other localised diamictite occurs as 20m thick deposits of randomly oriented blocks of the underlying metaquartzite, with a distinctive 6 to 7cm purple ferruginous band developed approximately 1m from the top. Where diamictite deposits are absent grits are found to overlay the basement gneiss. The grits pass upwards into grey to brownish weathered laminated shale of the **Madzaringwe Formation** with intermittent lenses of red and yellowish grit in the lower part and layered coal seams totalling 20m in the upper part within the shale. A purplish red mudstone occurs occasionally overlain by coarse micaceous sandstone up to 10m thick that forms the top of the formation. Mining companies are exploring for and mining coal within this formation that might lead to possible pollution of groundwater in these areas. The overlying **Mikambeni**

Formation consists generally of 15m of grey, sometimes carbonaceous, shale and siltstone with occasional coal seam lets (Brandl, 2002).

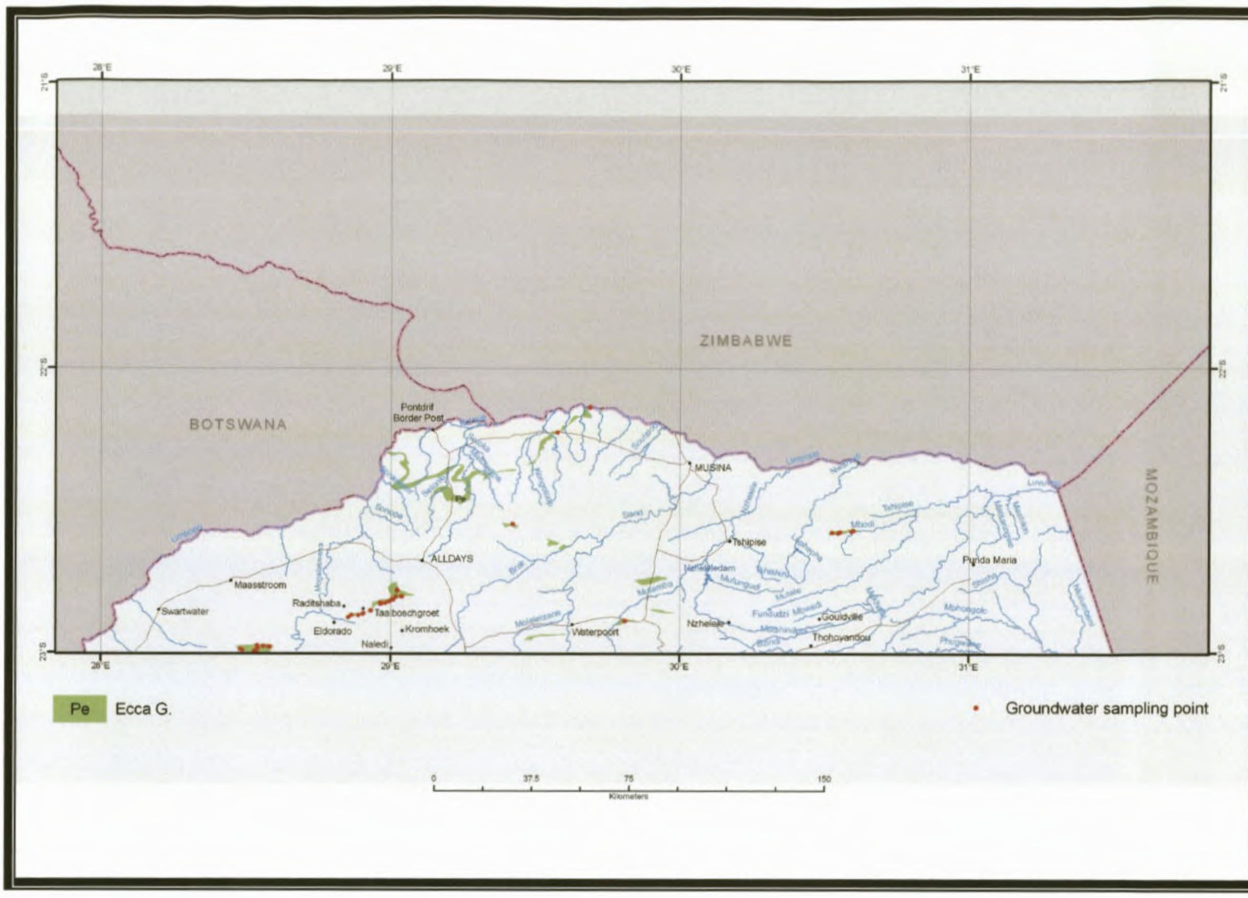


Figure 51: Geographical distribution of the Ecca Group (Pe) and the associated groundwater sampling points.

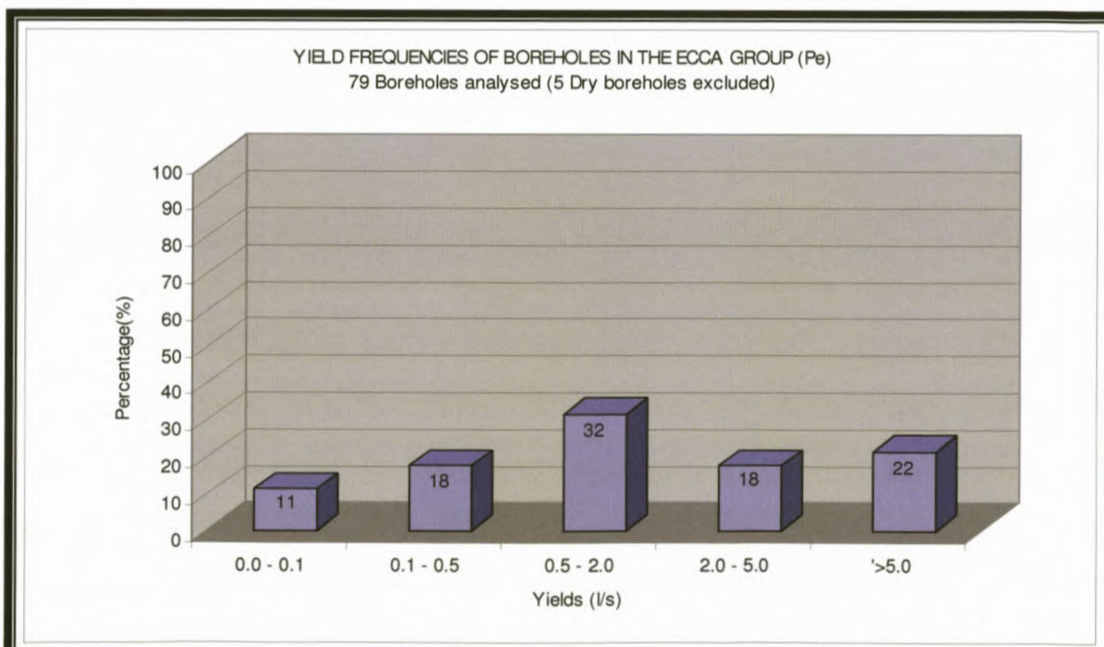


Figure 52: Yield frequency for fractured aquifers of the Ecca Group (Pe).

The analysis of 79 borehole records indicates that 32% of the yields are between 0.5 and 2ℓ/s. Another 29% are less than 0.5ℓ/s and 40% are more than 2ℓ/s (**Figure 52**).

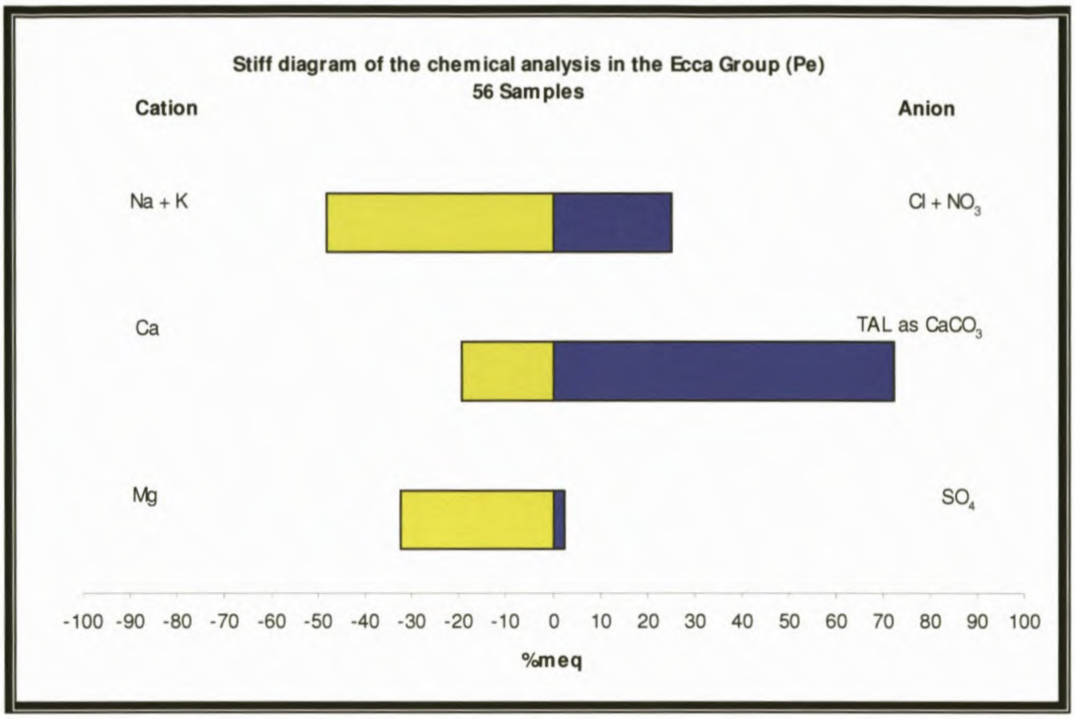


Figure 53: Stiff diagram representing chemical analysis of the Ecca Group (Pe).

Chemical data representing 56 samples is presented in the stiff diagram (**Figure 53**). The water is of a sodium-bicarbonate and chloride type with elevated magnesium and calcium concentrations most likely due to reverse ion exchange (This is a typical classification for Karoo sedimentary rocks). EC values vary between 73 to 389mS/m with a harmonic mean of 106mS/m for the unit. Note that the calculation of the harmonic mean gives lower values than the arithmetic mean.

The water quality is ideal (17.9%) to unacceptable (7.4%), (Table 12, 13 and 14, pp86-88). Fluoride is the problem in the 7.4% of the sampled sources as it exceeds the maximum allowable limit of 1.5mg/l. The water quality differs randomly throughout the unit.

5.5.2.1.7 **Soutpansberg Group (Ms)**

The Soutpansberg Group comprises a volcanic and sedimentary rock succession, laid down in an elongated, fault-bounded depression. A major centre of volcanic activity was probably located in the Sibasa area and a minor one east of Klein Tshipise. The deposition of arenaceous and argillaceous sediments within fluviatile and shallow-water conditions followed the period of volcanic activity (Brandl, 1981). The fractured hydrogeological unit of the Soutpansberg group comprises the Nzhelele, Wyllie's Poort and Fundudzi formations. Each of the formations is described separately. Groundwater data for this formation is of a high standard with a large number of boreholes scientifically selected by DWA from 1992 as part of a drought relief programme. Continuous programmes such as investigations of the Tshipise Fault zone and the Groundwater Resource Implementation Programme (GRIP) ensure good quality data up to 2007.

5.5.2.1.7.1 Nzhelele Formation (Msn)

The Nzhelele Formation has an estimated thickness of between 500 and 1000m in the west and a thickness of between 1000 and 2000m in the east (**Figure 54**). It consists of a lower volcanic assemblage approximately 400m thick at the base followed by argillaceous and arenaceous sediments. Chemically the lava is of a basaltic composition, greenish grey, slightly amygdaloidal and varies in grain size from fine to coarse. In the east lenses of white quartzite up to 25m thick, red shale, tuffaceous rocks and chert are present at various levels in the lava. The lava is overlain by shaly micaceous sandstone, fine, thinly bedded sandstone and dark-red shale. The upper portion of the formation consists of light-coloured, tabular and trough-cross-bedded sandstone and quartzite with minor thin shaly intercalations (Brandl, 1981, 2002).

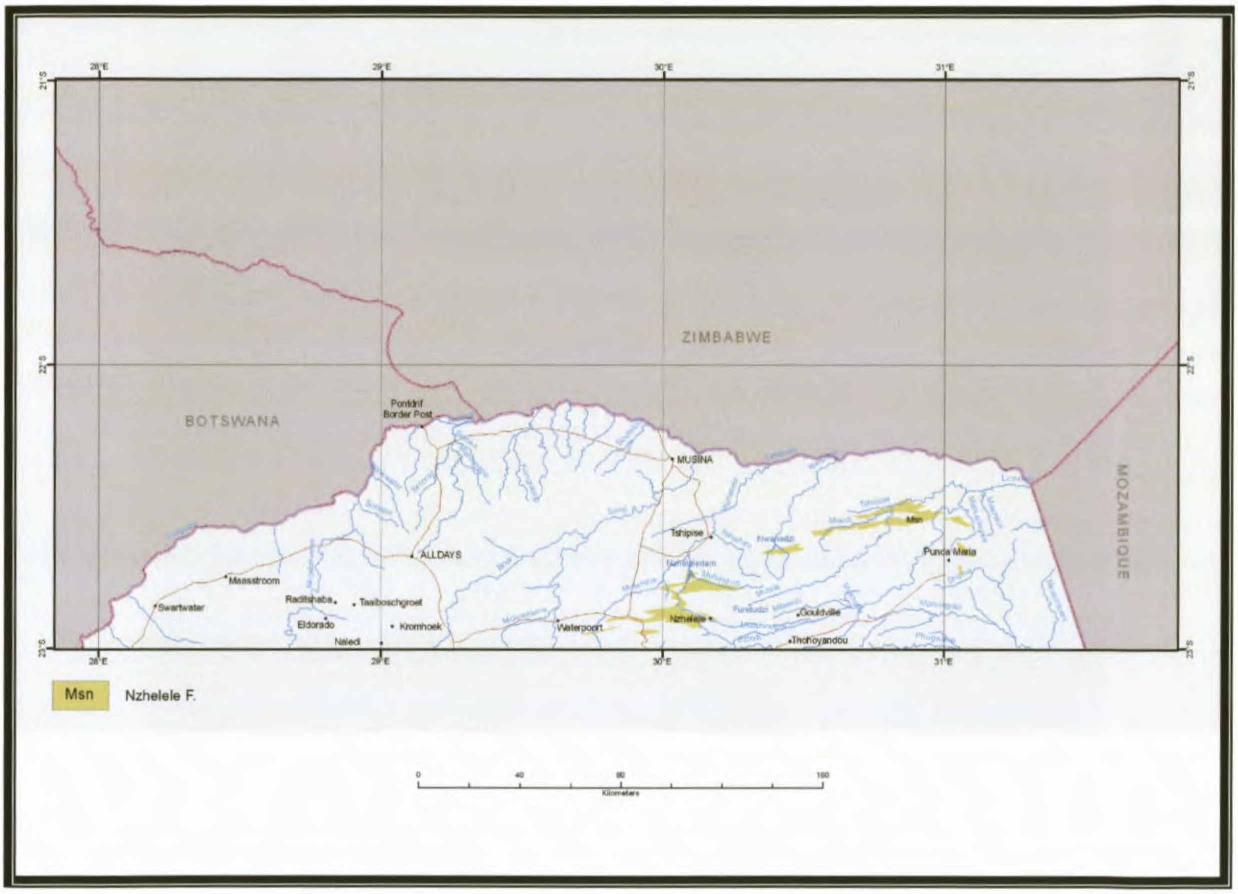


Figure 54: Geographical distribution of the Nzhelele Formation (Msn).

Figure 55 indicates the Nzhelele Formation has a good potential as 36% of the boreholes yield between 0.5 and 2*ℓ/s* and 44% more than 2*ℓ/s*. The high number of higher yielding boreholes can be attributed to secondary fracturing associated with the numerous faults that borders or cut through the unit, diabase dykes and joints. Water strikes associated with bedding planes, contact zones between sediments, and the contact with the lava are usually resulting in lower yields. Although not distinguished on the map some of the high yielding boreholes can be attributed to alluvial deposits along the Nzhelele River.

Groundwater abstraction is for the supply of small-scale irrigation, livestock and rural domestic requirements. The domestic water quality is ideal (29%) to unacceptable (18.7%), (Table 12, 13 and 14, pp86-88). EC values range between 10 to 555mS/m with 9.4% of the samples exceeding the maximum allowed limit of 370mS/m. Fluoride concentrations exceed the maximum allowable limit in

5% (F >1.5mg/l), sodium in 7.4% (Na >400mg/l), magnesium in 18.7% (Mg >100mg/l), nitrate (NO_2 + NO_3 presented as N) and chloride in 15% of the samples (N >20mg/l, Cl >600mg/l). The sample points with elevated Cl, F and Na concentrations are clustered around the village of Siloam. This might relate to a pollution source and the recommendation is to do further field investigations. The samples with elevated nitrate and magnesium concentrations and higher EC values are scattered throughout the unit. The water character is a magnesium-sodium-calcium-bicarbonate-chloride water type.

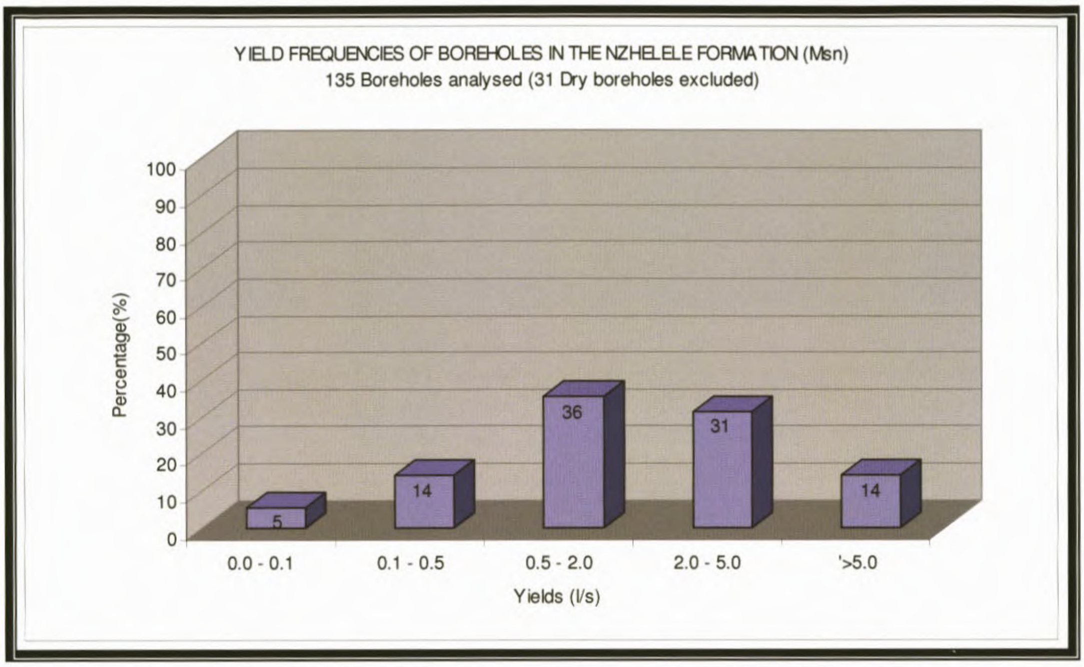


Figure 55: Yield frequency for fractured aquifers of the Nzhelele Formation (Msn).

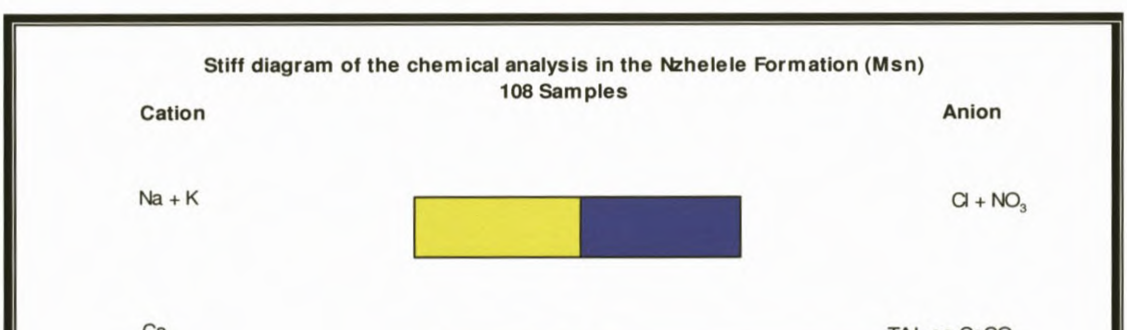


Figure 56: Stiff diagram representing chemical analysis of the Nzhelele Formation (Msn).

5.5.2.1.7.2 Wyllies Poort Formation (Msw)

The Wyllies Poort Quartzite Formation has a maximum thickness of 4000m in the Thengwe and Ha-Makuya area and decreases considerably to the east and west. It is almost entirely arenaceous and underlies the major part of the more mountainous part of the Soutpansberg. The formation consists predominantly of coarse-grained purple or reddish sandstone and a medium-to fine-grained pink or whitish quartzite or quartzitic sandstone. Locally thin lenses of grit or conglomerate occur within the sandstone. Red and brown sandy shale, shaly micaceous sandstone and minor siltstone form a few lenticular bands of limited extend nowhere exceeding a thickness of 10m (Brandl, 1981, 2002).

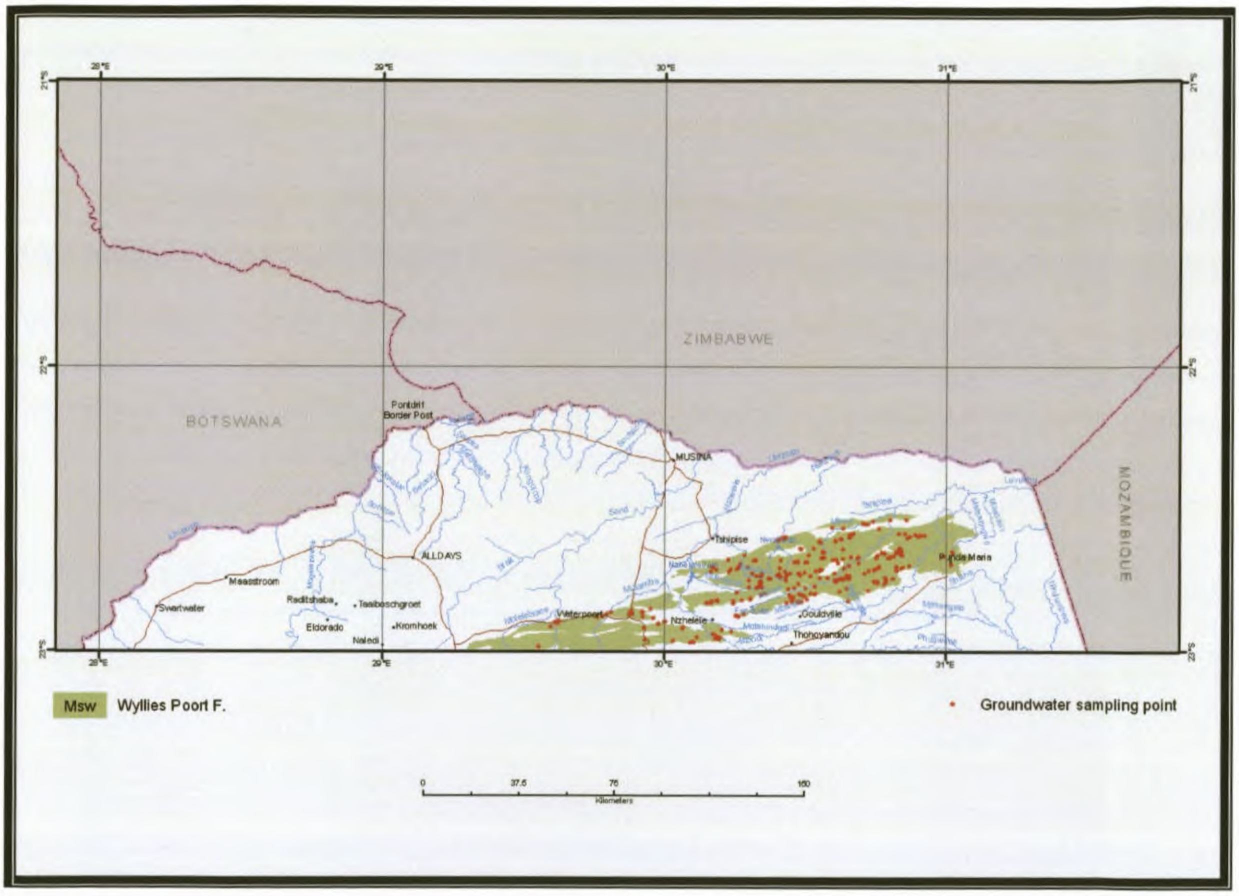


Figure 57: Geographical distribution of the Wyllies Poort Formation (Msw) and the associated groundwater sampling points.

Primary porosity is almost zero within the formation making the occurrence of secondary fractures and fissures the determining factor in finding water. Water bearing formation (weathered and fractured zones) is limited to a depth of 100m (Du Toit, 1998). The low potential of the rock mass is evident in the high number (18%) of dry boreholes drilled in the formation. Secondary fractures relate to the numerous faults transecting and bordering the formation, diabase sills and dykes and jointing. The east to west-trending fault zones are in cases associated with steep, almost polished rock faces on the southern slope of mountains. Access for drilling rigs can be a problem as the faults dip steeply and the drill rig must be positioned as near as possible to the fault plane. The faults and dykes oblique to strike give rise to narrow valleys. These are good targets to investigate in the search for groundwater. In the southern part of the map area where the average rainfall is higher small streams flows for long periods in these valleys. The first strikes can relate to deep colluvium formed in these valleys with the second strike related to the geological lineament. In the dryer northern part with less vegetation cover, white quarts crystals or recrystallisation intergrowths in the purple sandstone or quartzitic sandstone mass can indicate the presence of a fault zone.

It is advised to use scientific methods to locate drilling sites, as the groundwater potential for this formation is poor to average. Statistics indicate that 65% (**Figure 58**) of the successful boreholes yield less than 2ℓ/s with 18% of the successful boreholes yielding more than 5ℓ/s.

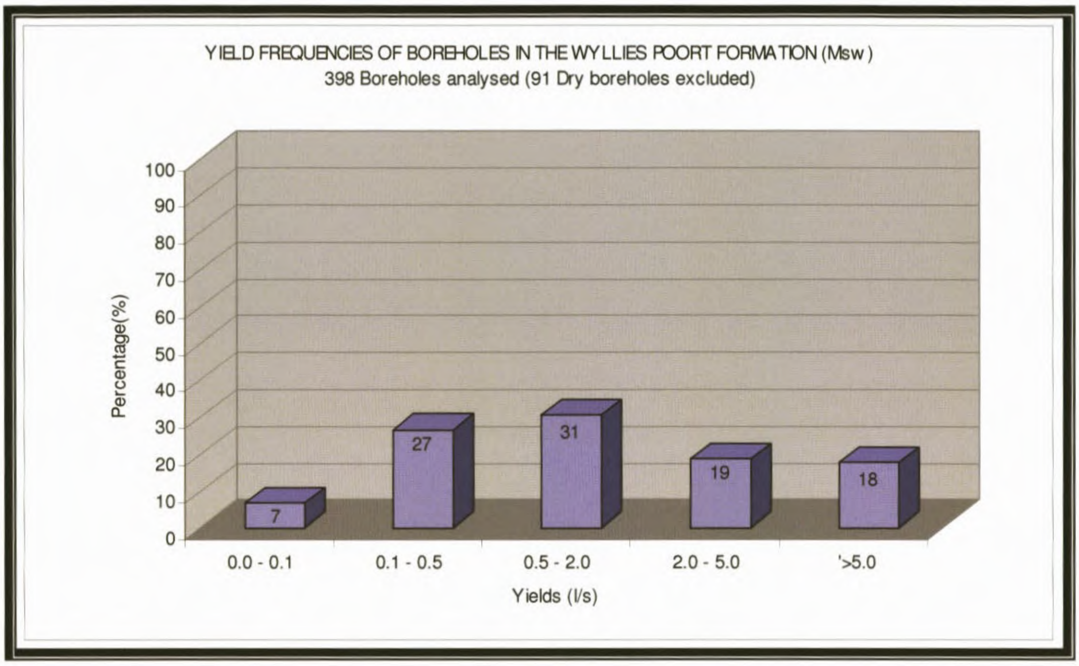


Figure 58: Yield frequency for fractured aquifers of the Wyllies Poort Formation (Msw).

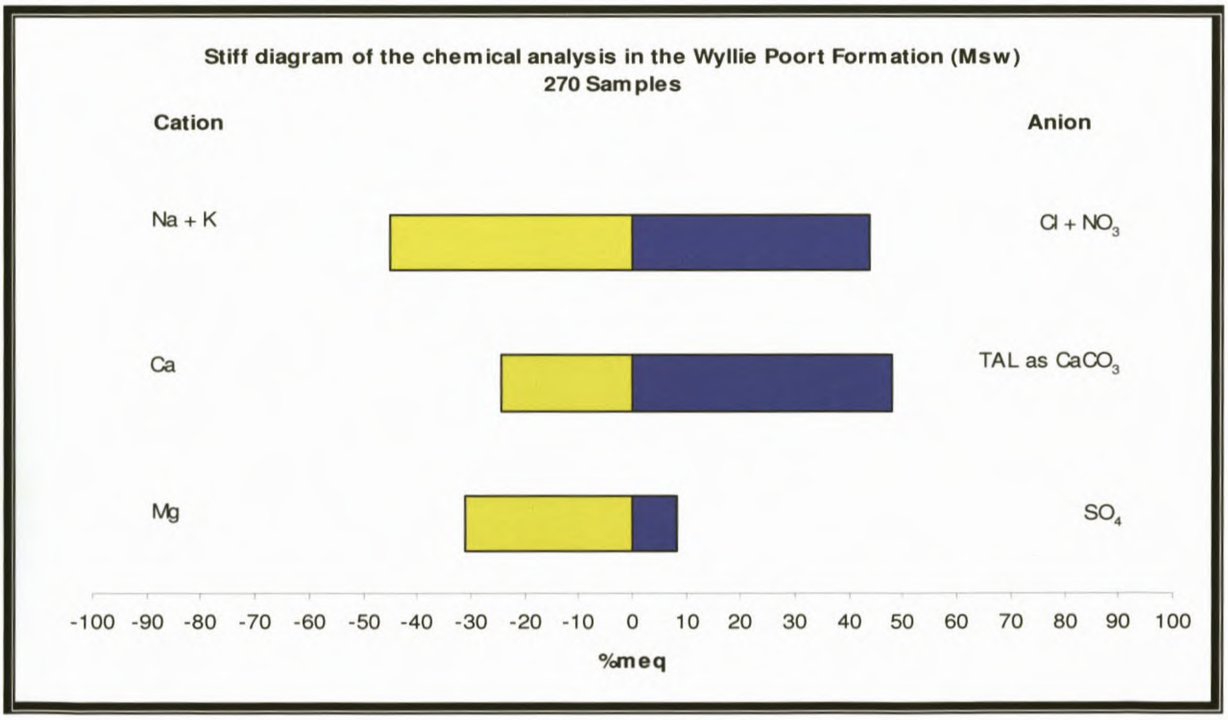


Figure 59: Stiff diagram representing chemical analysis of the Wyllies Poort Formation (Msw).

The stiff diagram (**Figure 59**, p112) shows the broad classification according to anions and cations. The water exhibits a sodium-magnesium-calcium-bicarbonate-chloride character. The bicarbonate type of water is generally associated with movement of groundwater from recently recharged areas and indicates a cation exchange process. It is difficult to explain the chloride character. The water quality is ideal to acceptable (86%) and unacceptable (3.3%), (Table 12, 13 and 14, pp86-88). EC values ranges from 3 to 912mS/m, with the harmonic mean calculated as 18mS/m. The chemical results from groundwater sampled in the unit do not show significant quality problems. In 85.6% of the sampled boreholes used in the analyses, the concentration of chloride falls within the Ideal Class (Cl < 100mg/l). In approximately 92% of the samples, nitrate and nitrite (presented as N) and fluoride (F) have concentrations within the ideal domestic water class (N <6mg/l), (F <0.7mg/l). Only 2.7% of the samples exceed the acceptable limit for nitrate (N >10mg/l), 3.3% for magnesium (Mg >100mg/l and 2.2% for chloride (Cl >600mg/l). The sample points with poor water quality are located near villages showing that incorrect sanitation practices combined with a shallow sandy overburden and open fractures in the sandstone/quartzite may contribute to the higher concentrations.

The Wyllies Poort Formation occurs mainly in moderately populated rural areas as well as the northern part of the Kruger National Park. Groundwater abstraction is to supply the domestic and agriculture demand of small to medium villages as well as for the nature reserve. In the south-western part of the formation, groundwater is utilized in periods of drought for avocado and nut orchards.

5.5.2.1.7.3 Fundudzi Formation (Msf)

The Fundudzi Formation has a maximum thickness of 2800m in the vicinity of Lake Fundudzi thereafter it decrease rapidly to the west. The formation consists of arenaceous and argillaceous rocks with intercalated bands of lava. The arenaceous rocks consist of white, pink or purple sandstones, locally quartzitic and in places well laminated. Grain size varies from fine to very coarse grading in places into conglomerate. The argillaceous sediments are interbedded within the sandstone consist of brownish or purple micaceous sandy shale, grey or dark-red shale and thinly laminated, dark-grey siltstone (Brandl 1981, 2002)

The water bearing formation (weathered and fractured zones) is limited to a depth of 60m. The groundwater exploration potential in this formation is considered low to very low. One of the conclusions reached from groundwater studies done in the Kruger National Park is that the transmissivity in the Fundudzi Formation decreases with depth. Occurrence of groundwater in this formation is limited to secondary openings associated with geological structures such as faults, shear zones, dykes and sills. It is considered a double porous medium. The water is typically stored within the rock matrix, with the fractures (if present) as the water carrying medium. Due to the low transmissivity of the formation groundwater potential is very low unless secondary fractures and fissures are present (Du Toit, 1998)

The sedimentary rocks of this formation have low to very low primary permeability with low storage potential. The results of the yield frequency diagram show a positive tendency to the higher yields that is contradictive to studies done. This can be attributed to the use of scientific approved methods in the search for groundwater over the past years that specifically targeted geological lineaments. The statistics indicate that 40% (**Figure 61**, p114) of the successful boreholes yield more than 2ℓ/s, 42% yield between 0.5 and 2ℓ/s and 18% less than 0.5ℓ/s. Records show that 11% of the boreholes were drilled dry.

The stiff diagram (**Figure 62**, p115) represents 135 groundwater samples. The water exhibits a magnesium-calcium-sodium-bicarbonate-chloride character. Water abstraction is for rural domestic supply, livestock watering and in the Kruger National Park for game watering and domestic use. The quality of the water is generally very good with 92% of the samples having EC values less than 150mS/m. (Harmonic mean for unit =22.8mS/m). Take note that the calculation of the harmonic mean gives a lower value than using the arithmetic mean. The water quality is ideal to acceptable in approximately 90% of the sampled sources with 2.3% unacceptable mainly due to elevated concentrations of nitrate that might relate to human settlements.

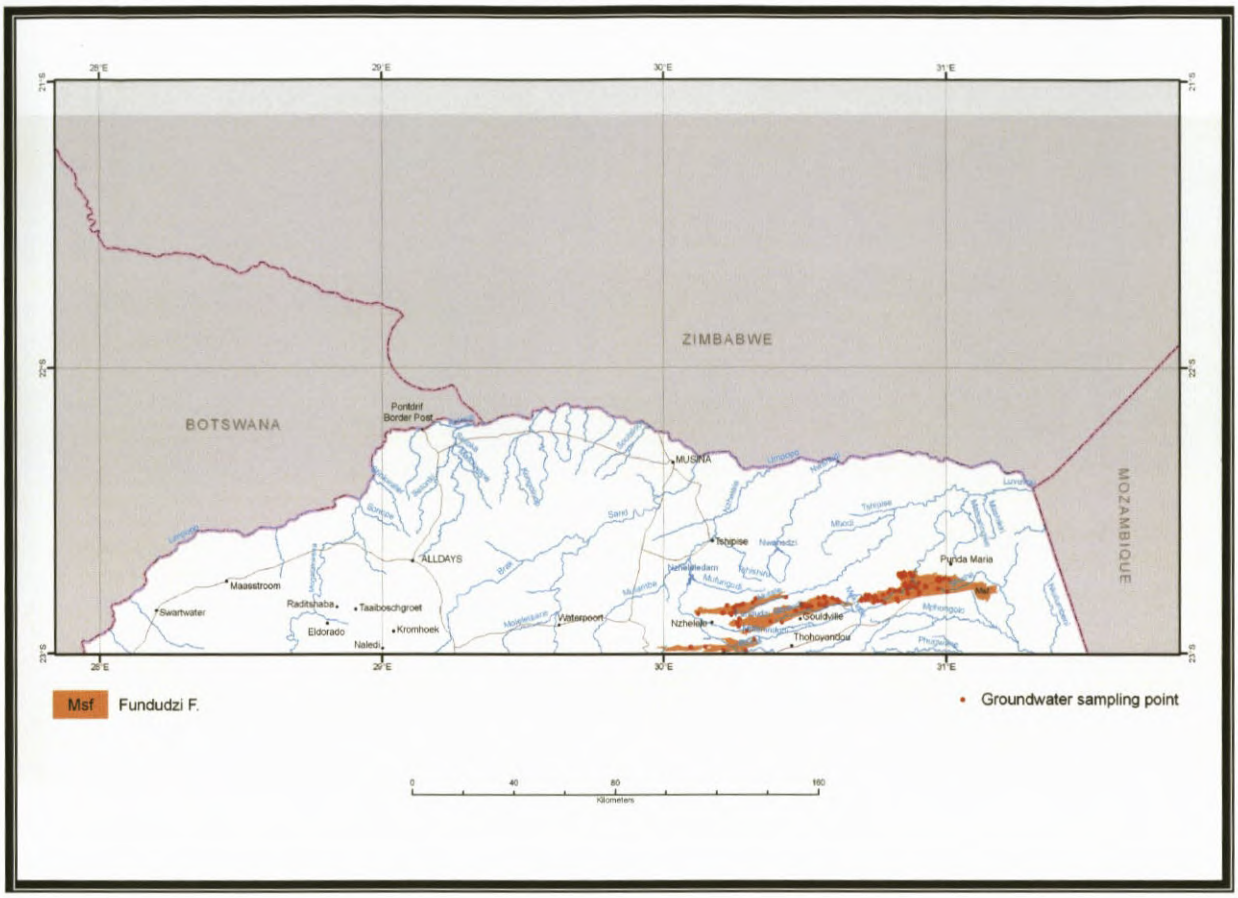


Figure 60: Geographical distribution of the Fundudzi Formation (Msf) and the associated groundwater sampling points.

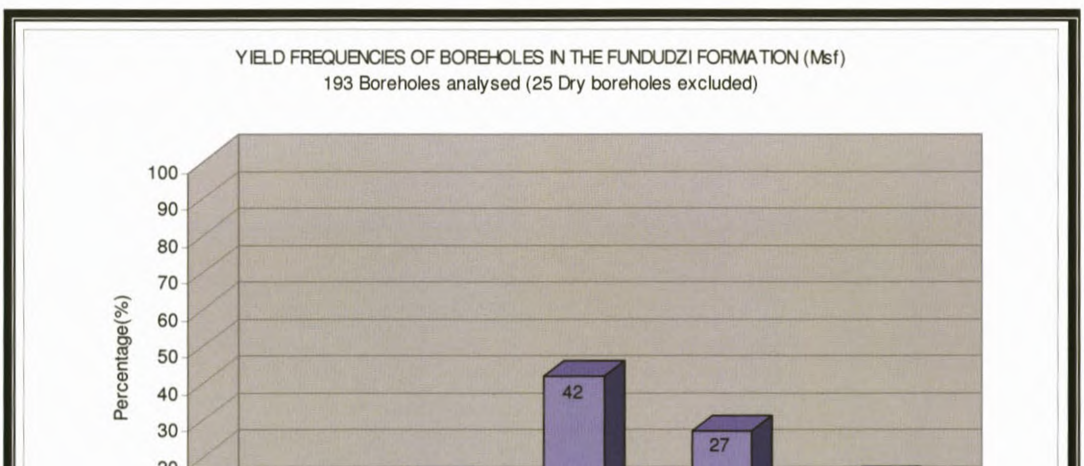


Figure 61: Yield frequency for fractured aquifers of the Fundudzi Formation (Msf).

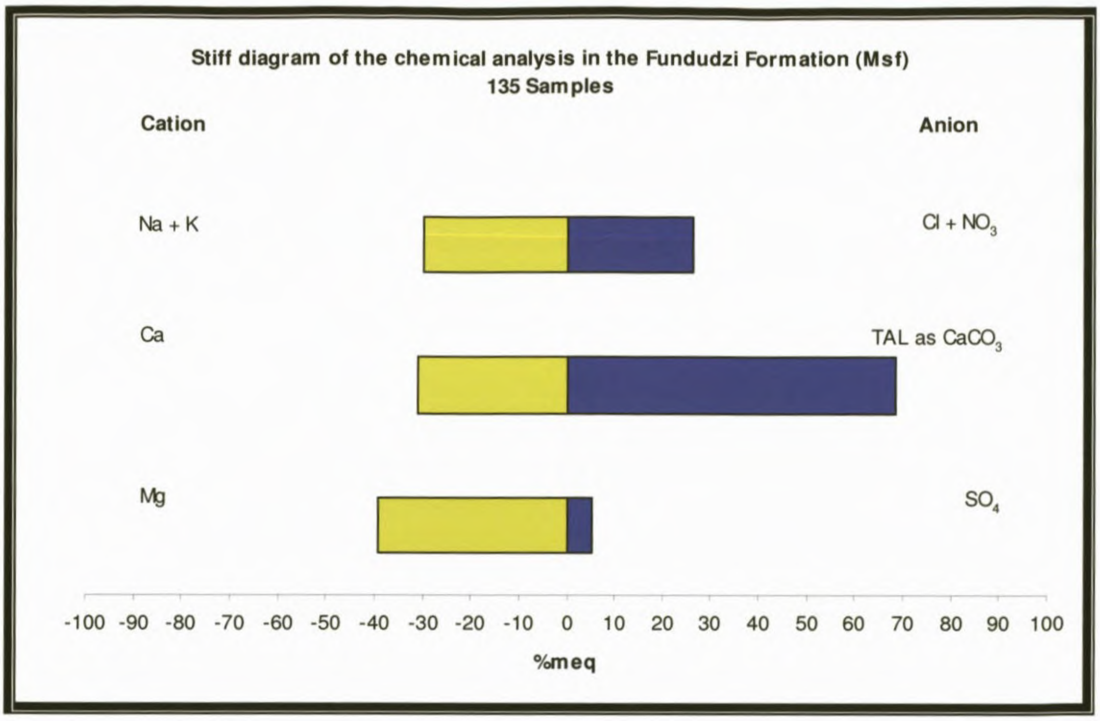


Figure 62: Stiff diagram representing chemical analysis of the Fundudzi Formation (Msf).

5.5.2.2 **Category C: Karst Aquifers**

No dolomitic rocks occur within the map area that could be grouped under the heading, Karst aquifers. The heading forms part of the standardized hydrogeological map layout that was used for all the other maps in the series.

5.5.2.3 **Category D: Intergranular and Fractured Aquifers.**

- Lebombo Group (Jl)
    - Letaba Formation
- Dolerite (Jd)
- Clarens Formation (Trc)
- Diabase (N-Zd)
- Soutpansberg Group (basalt) (Ms)
    - Sibasa Formation (Mss)
    - Stayt Formation (Msa)
- Bulai Gneiss (Rbu)
- Hout River Gneiss (Rho)
- Sand River Gneiss (Zsa)
- Alldays Gneiss (Zal)
- Messina Suite (Zbm)
- Madiapala Syenite (Zma)
- Goudplaats Gneiss (Zgo)
- Beit Bridge Complex (Z)
    - Gumbu Group (Zbg)
    - Malala Drift (Zba)
    - Mount Dowe Group (Zbo)

Intergranular and fractured aquifers cover approximately 70.29% of the total map area. **Figure 63**, (p116) shows the geographical distribution of the intergranular and fractured aquifers.

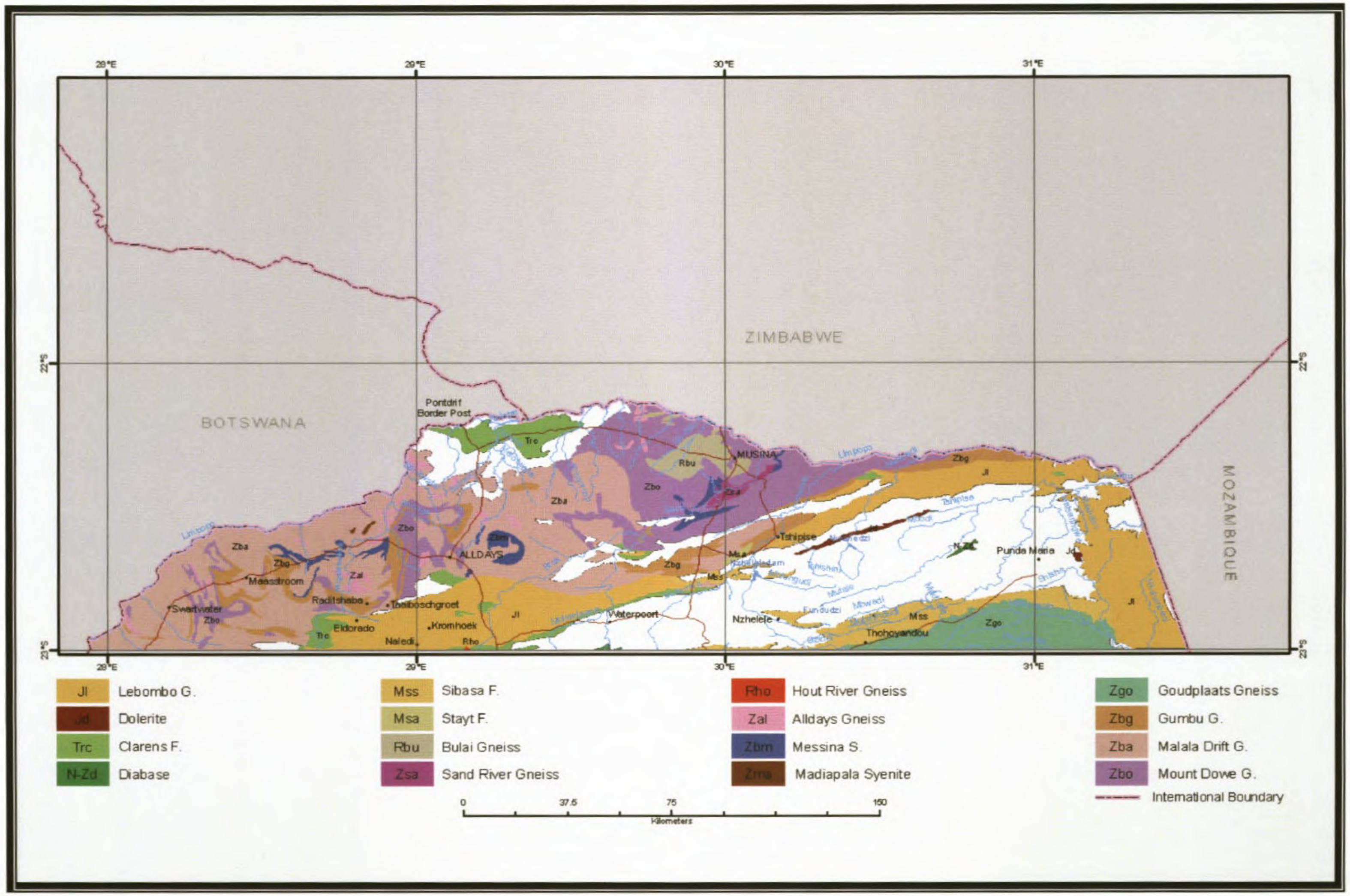


Figure 63: Geographical distribution of the intergranular and fractured aquifers (after DWA, 2011).

5.5.2.3.1 Lebombo Group (Jl)-Letaba Formation

The outpouring of lava marked the end of the sedimentary deposits of the Karoo Supergroup. Two formations of the Lebombo Group occurs within the map sheet. The youngest, the Jozini Formation occurs in a very small area in the eastern part of the map sheet and is discussed in section 5.5.2.1.2, pp98-99. It overlays the Letaba Formation a name applied to all basaltic lava of Karoo age in the Limpopo Province. In the Tuli basin the unit is represented by isolated remnants (not shown) while it is more representative and wide spread in the Tshipise and Lebombo basins (**Figure 64**, p118). It covers approximately 16.1% of the map area and is an important aquifer in the Tshipise basin in the sense that groundwater is abstracted for irrigation and regional supply from fault zones delineating the northern (Tshipise fault progressing into the Taaibos Fault) and the southern boundary (Bulkop, Senotwane and Phareng faults) of the basin respectively. Deep boreholes (100-300m) targeting deep secondary fracturing within the basalt and sandstone of the underlying Clarens Formation also yielded good success. The Clarens Formation is conformably overlain except south of Punda Milia where the Letaba Formation directly overlays rocks of the Soutpansberg Supergroup or basement gneisses (Schutte, 1986). Areas underlain by this formation characteristically consists of flat terrain with poor outcrop and a black clayey soil "turf" overburden. The basalt is massive, fine-grained, dark-grey with minor amygdales (pine-like cavities of gas chambers) of zeolite, quarts, calcite and chalcedony or chert that occurs in thin intercalated flows. In the Tuli basin the absence of pyroclastic material and the lack of evidence of violent eruptions indicate that the lava was of the non explosive, fissure-flow type (Brandl, 2002).

The potential of the formation itself is considered low to average. Studies done in the Lebombo basin found that in the absence of geological lineaments and where the formation is too thick to encounter the underlying Clarens Formation, the recommended targets for groundwater strikes relate to weathered and fractures zones within the Basalt. With a decreasing transmissivity with depth within this formation borehole yields decreases with depth. It is recommended that a maximum of 80m to 90m should be drilled for groundwater exploration purposes (Du Toit, 1998). An interesting phenomenon was found in some holes drilled near Sigonde, a village within the Tshipise basin where the underlying Clarens formation is considered too deep to explore with low budget groundwater projects. It was found that some boreholes encountered highly fractured basalt but were dry or almost dry (muddy) during drilling. Pumping tests during the DWA GRIP project were done on these boreholes with constant tests up to 8ℓ/s completed (Lubbe, personal communication, 2011).

In a study carried out on the farm Kromhoek 438MS to determine the groundwater potential of the **Tshipise sandstone underlying the Letaba Basalts.** It was determined that the basalt has no primary permeability, but when fracturing/jointing occurs as a result of localised stress releases or minor faulting followed by hydro-chemical weathering (in varying phases) a high degree of secondary permeability of several orders higher than the primary basalt rock can develop. The effect of the hydro-chemical weathering process of the basalt tends to go through different phases (from a slightly fractured to blocky, jointed and finally to a soft decomposed clayey residue/soil). The most promising phase in terms of permeability and storage is where the basalt portrays a blocky and jointed (micro-fractured) appearance. Once the hydro-chemical weathering process has commenced, the basalt tends to weather as deep as between 15 to 25m from surface. Where secondary structures and probably the most recently larger fracture and fault zones are present weathering may develop as deep as 95 m below surface. Differential weathering of the basalt, however, has resulted in secondary mineralization and subsequent sealing of many of the secondary fractures/joints. The thickness of the basalt in the Kromhoek study area varies from 99m to 202m. The hydrochemistry of the basalt is influenced by a natural built-up of nitrate either due to nitrification enhanced by the Acacia trees and/or the heavy decomposition of the basalt. Nitrate (NO_2 + NO_3 as N) concentrations in the order of 15 to 21mg/l have been recorded in the Kromhoek 438MS study area during sampling (IAEA study, 1999-2003).

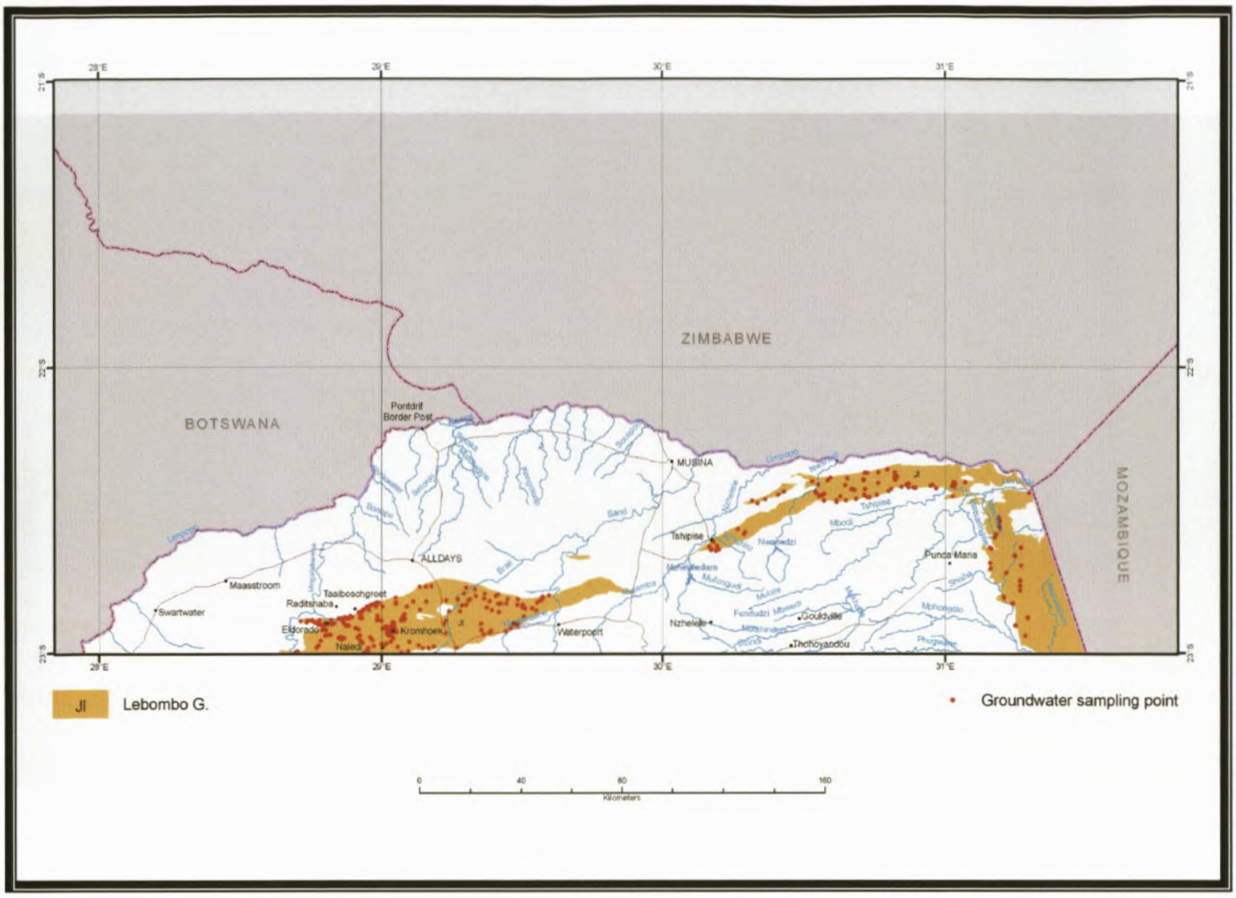


Figure 64: Geographical distribution for the intergranular and fractured aquifers of the Lebombo Group (Jl) and associated groundwater sampling points.

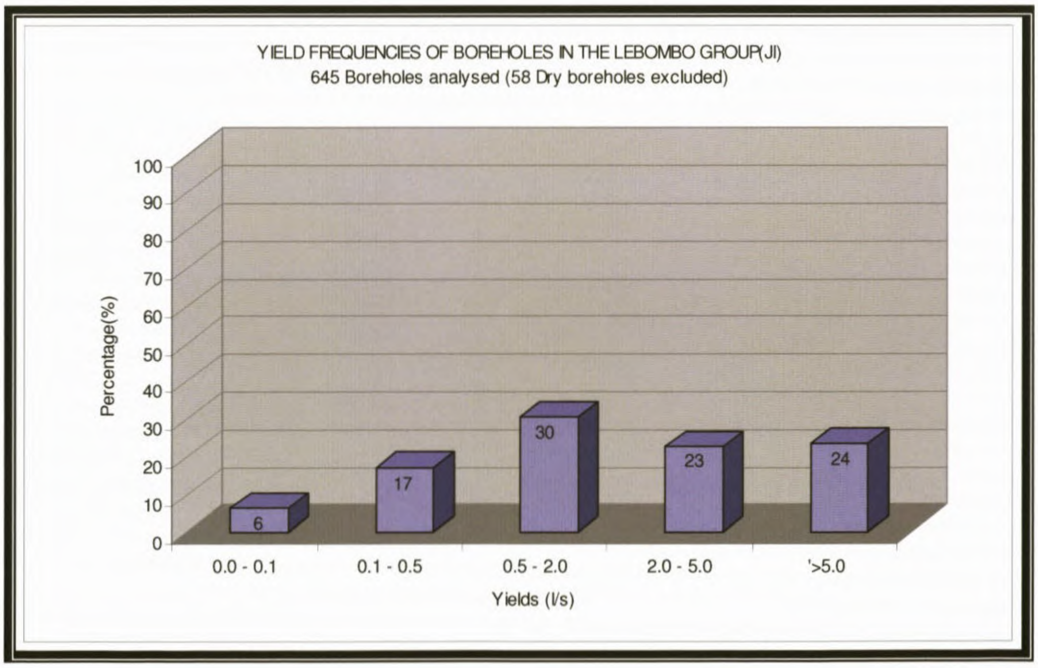


Figure 65: Yield frequency for the intergranular and fractured aquifers of the Lebombo Group (Jl).

Statistics revealed that 30% (**Figure 65**, p118) of the successful boreholes yield between 0.5 and 2ℓ/s with 47% yielding more than 2ℓ/s. Low yielding boreholes less than 0.5ℓ/s is 23% with 8% recorded as dry. The depth to groundwater level varies between 10 and 40mbgl.

Groundwater abstraction includes agriculture use, (livestock and irrigation), single village and regional village domestic water supply as well as for conservation purposes in the Kruger National Park. In many places, it is the only source of water despite the elevated nitrate (N) concentration that is evenly distributed throughout the unit.

In 97.8% of the samples the reported EC values (EC <150mS/m) falls within the ideal to maximum allowable limits (EC <370mS/m) for domestic use. The chemical analysis available for nitrate and nitrite concentrations (reported as N), shows that 55.8% falls within the ideal to acceptable range (N <10mg/l) and 19.2% outside the maximum allowed limit (N >20mg/l), (Table 12, 13 and 14, pp86-88). The concentration for (N) varies between 0.02 to 108mg/l with a harmonic mean of 0.41mg/l and an arithmetic mean of 12mg/l for the unit. The general water type can be described as a sodium-bicarbonate and chloride water with elevated calcium concentrations possibly related to reverse ion exchange (replacement of Na^+ with Ca^{2+} and Mg^{2+}). Elevated fluoride, chloride and sodium concentrations occur in samples near the Tshipise hot water spring. Sources with elevated fluoride are also more dominant in the Lebombo Basin while sources with elevated magnesium concentrations are randomly occurring. Although the groundwater is rated as hard to very hard it is considered good potable quality (most constituent levels within the maximum allowable limits) with the exception of the nitrate levels. This is typical of groundwater contained in basalt aquifers.

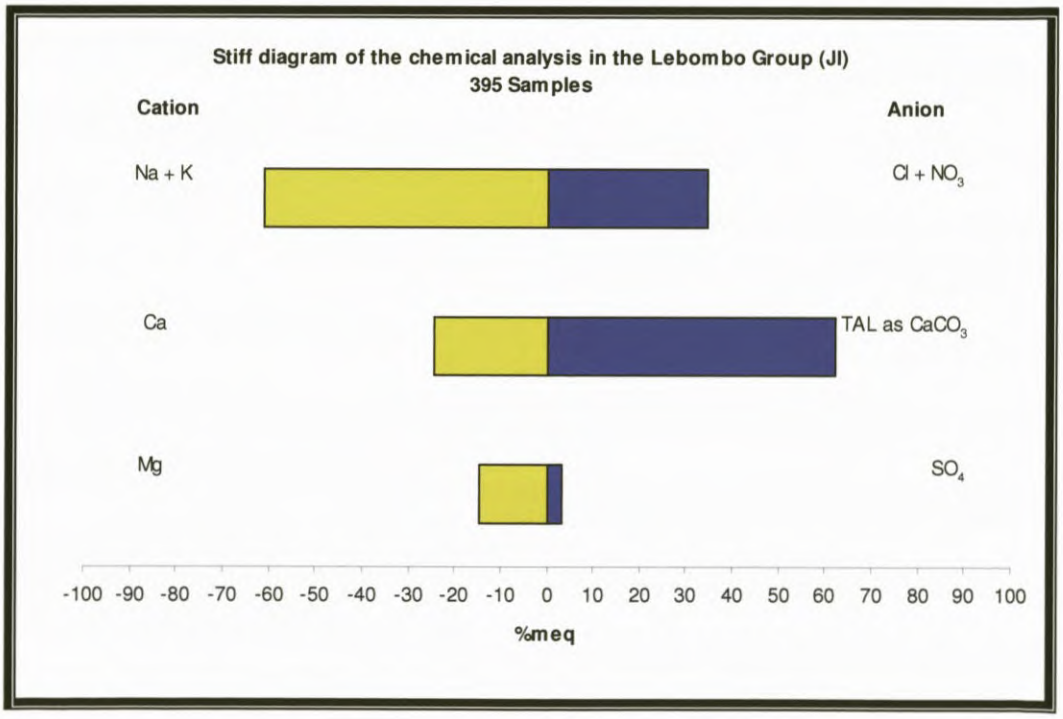


Figure 66: Stiff diagram representing chemical analysis for the fractured and intergranular aquifers of the Lebombo Group (Jl).

5.5.2.3.2 **Dolerite (Jd)**

The most widespread intrusive rock of post-Karoo age is dolerite occurring as sills and dykes. The scale of the maps prohibits the inclusion of all dyke intrusions and only the prominent sills are shown on the map (**Figure 67**, p120).

Within the Tshipise basin dolerite intrusions generally form thick semi-concordant to concordant sheets (up to 200m) in the argillaceous sediments beneath the Solitude Formation in the area north of the Klein Tshipise Fault. The rock is generally fine grained to aphanitic of lustrous black colour (Brandl, 1981). Outcrop is usually easily identified within the soft sediments. The occurrence of these sills are indicated by a perpendicular cross section to regional strike of the geology on an inset map included on the 1:250 000 geological map sheet, 2230 Messina (copy included in Chapter 10, p181: Appendix). The sills are shown as parallel intrusions between the lower formations of the Karoo Supergroup dipping moderately to the north. In the south-western part of the basin dolerite sills overlay all the sedimentary formations of the Karoo Supergroup. Dolerite dykes in the south-western part of the Tshipise basin trend easterly and some slightly more north or southerly. Within the north-eastern part of the basin the dykes do not exhibit a dominant trend as it strikes in almost all the directions.

Within the Lebombo basin one prominent sill is depicted on the map near the border with the Kruger National Park in the east (**Figure 67**). In the southern part of the basin fewer dykes are indicated on the 1:250 000 geological map sheet, 2230 Messina, although east to west-trending geological lineaments occur that are most probably related to dolerite intrusions. Towards the northern part of the basin dykes with a more dominant north-north-west trend were observed.

In the Tuli basin, dykes are abundant in the area close to the confluence of the Limpopo and Shashe rivers and may be classed as a dyke swarm (Chidley, 1985). The major trend of dykes is easterly with a subordinate north-eastern trend.

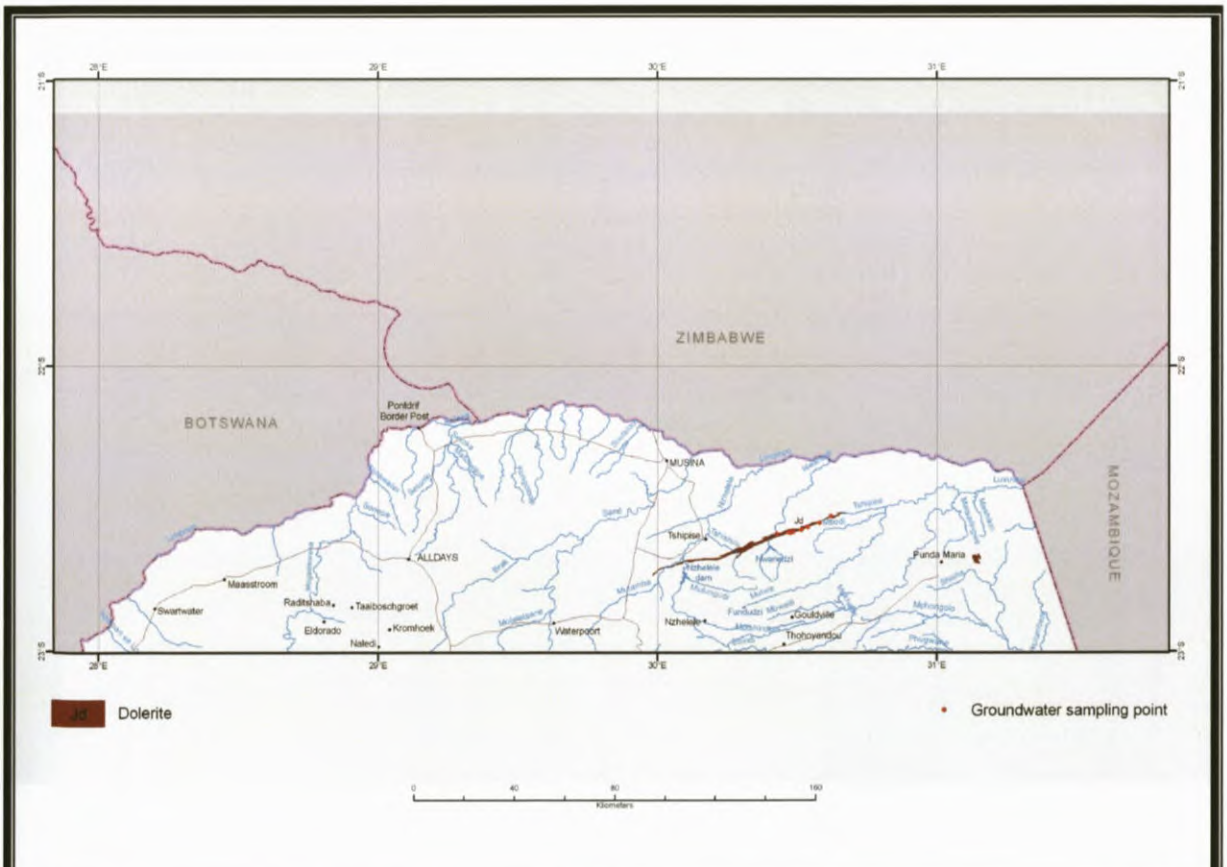


Figure 67: Geographical distribution for the intergranular and fractured aquifers of the Dolerite (Jd) and associated groundwater sampling points.

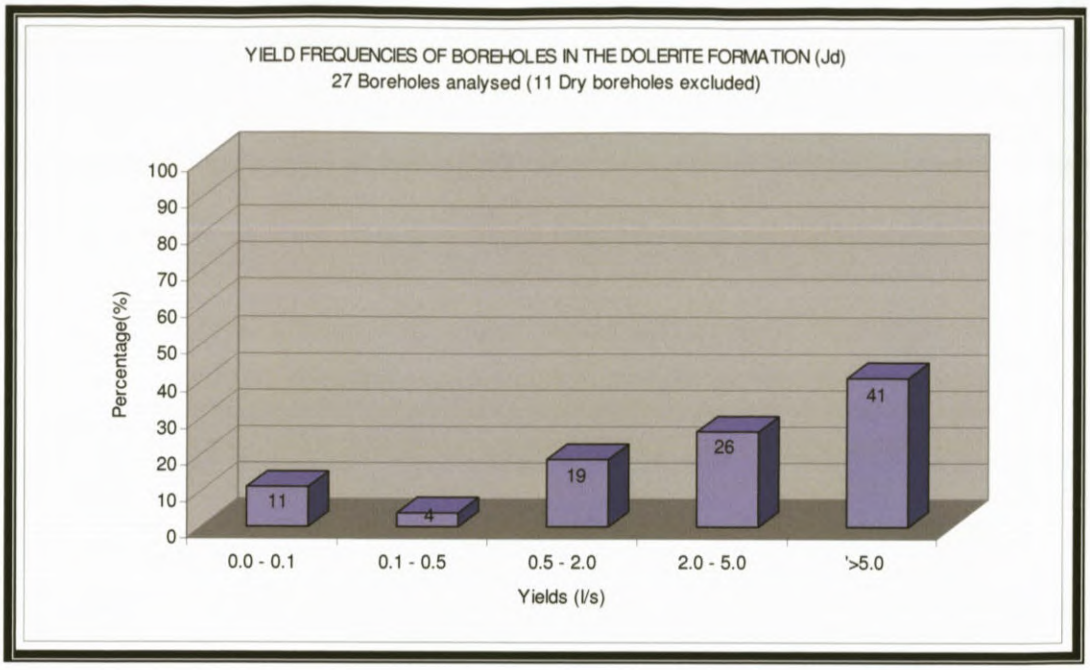


Figure 68: Yield frequency for the intergranular and fractured aquifers of the Dolerite Formation (Jd).

Statistics indicate that 41% of the successful boreholes yield more than 5ℓ/s with 45% yielding between 0.5 and 5ℓ/s. It appears from the yield frequency that the groundwater potential is good within this unit with a more than average chance of striking a borehole with a high yield. Available data show that 29% of the holes are dry. It is advised to use scientific methods to locate drilling sites.

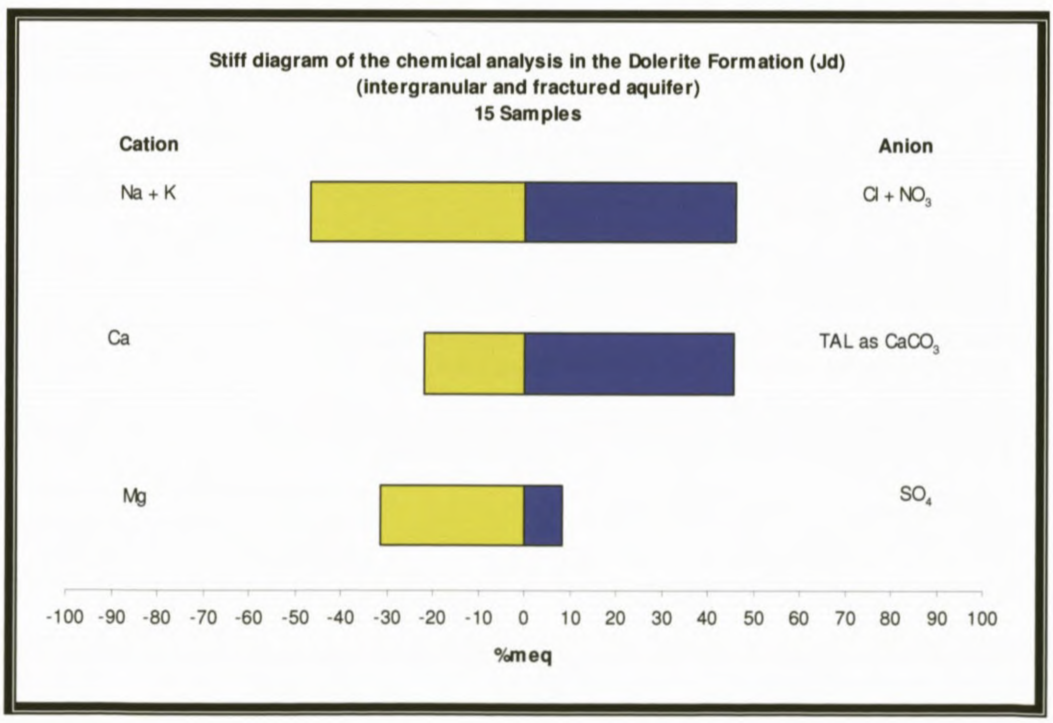


Figure 69: Stiff diagram representing chemical analysis for the fractured and intergranular aquifer of intrusive Dolerite (Jd).

Figure 69 shows the broad classification according to anions and cations of the unit. The water displays a sodium-magnesium-calcium-bicarbonate-chloride character. The quality of the water is generally good to moderate as all the EC values falls under the maximum allowable limit (EC <370mg/l) with 73.3% within the ideal to acceptable range (EC <150mS/m). No fluoride, sodium, potassium, sulphate and calcium concentrations exceed the maximum allowable limits for drinking water. Unacceptable high concentrations of magnesium occur in 20% of the samples (Mg >100mg/l), Nitrate (N >20mg/l) in 14.3% of the samples and Chloride (Cl >600mg/l) in 6.7% of the samples (Table 12, 13 and 14, pp86-88). Slightly higher than ideal fluoride concentrations occur in sources near the contact with Letaba Basalt, the other elevated elements randomly occur throughout the unit.

5.5.2.3.3 **Clarens Formation (Trc)**

The Formation is divided into two members, the **Red Rocks Member** and the overlying **Tshipise Member** that together attain a thickness of approximately 200m in the Tuli and Tshipise Basins.

The Red Rocks Member is generally a very fine-grained to fine-grained, white and pinkish to red, argillaceous **sandstone** with a characteristic mottled appearance. In the Tuli Basin the thickness is more or less 40m and in the Tshipise Basin it has a fairly constant thickness of approximately 100m with a maximum thickness of 150m reported near Tshipise. The thickness of the overlaying Tshipise Member is extremely variable in the Tuli Basin, the contact often sudden, consisting of pinkish sandstone near the base but otherwise homogenous whitish fine-grained sandstone. Outcrop forms flat-topped 'koppies' underlain by Red Rock lithologies forming concave slopes with caves often developed immediately below the contact. In the Tshipise basin the thickness of the Tshipise Member is more constant with thicknesses reported as 100m in the east and 130m in the south-west. It often forms local spectacular topographic features with steep cliffs and rugged hills. It is composed essentially of fine-grained whitish to cream coloured matured sandstone (Brandl, 2002).

In a study carried out on the farm Kromhoek 438MS to determine the groundwater potential of the Tshipise sandstone underlying the Letaba Basalt, it was found that the sandstone aquifer is by far superior in quantity and quality compared to the overlying basalt aquifer. Blow yields of up to 40*ℓ/s* were obtained in the sandstone in the vicinity of Kromhoek 438MS and Terveen 381MS. The boreholes that penetrated the Karoo sandstone below the basalt gave increasing blow yields of good quality water from the first strike down to final depth. The hydraulic conductivity is determined mainly by fracturing of the sandstone but a progressive increase in yield was observed also in a section of sandstone in which no fractures were observed. The aquifer therefore appears to have significant primary porosity. In contrast to the high nitrate concentrations of water in the basalt aquifer several samples taken from the much deeper seated and probably wider recharged Tshipise Sandstone show a much better water quality (N <5mg/l), (IAEA study, 1999-2003). The above characteristics were also found in groundwater development projects for various farmers and villages in the rest of the Tshipise basin from north of Vivo to the far north-eastern Vhembe District.

Plate 7: Mapungubwe Hill, a world famous archaeological site. Artifacts found here include a golden rhinoceros. The hill consists of sandstone of the Clarens Formation. The locality is within the Thuli Basin near the confluence of the Shashi and Limpopo rivers. (Photo: Google images, 2011)

Plate 8: The Tshipise hot spring at Aventura Holiday Resort. The photo is taken from the north-east. The mountain on the horizon is the northern slope of the Soutpansberg Mountain range (Wyllies Poort Formation), the low area is the Tshipise basin underlain by rocks of the Karoo Supergroup with the first small ridge north of the Soutpansberg formed by outcrop of the Clarens Formation, and the next low area is underlain by basalt of the Letaba Formation. The high ridge in the foreground at the resort is sandstone of the Clarens Formation and north of the road is granatoid rocks of the Gumbu Group. The Tshipise Fault cuts oblique through the road following the northern escarpment of the high ridge in the foreground. (Photo: Aventura Resort website obtained, 2009).

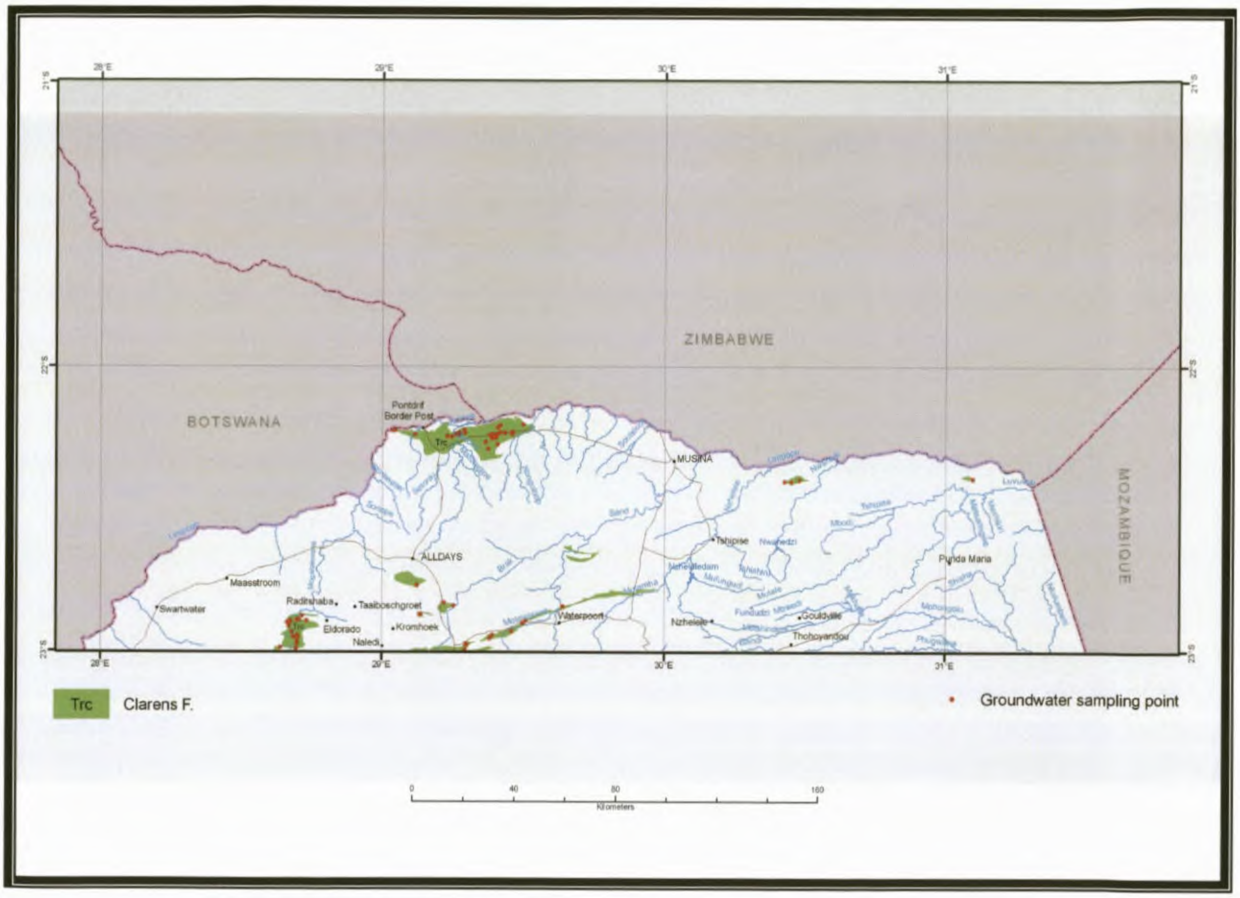


Figure 70: Geographical distribution of the Clarens Formation (Trc) and the associated groundwater sampling points.

The contact zone between basalt and sandstone yields varying quantities but are usually <0.5ℓ/s. Higher yielding water strikes are generally intercepted in the sandstone between 40 and 75m below the main basalt/sandstone contact. The harmonic mean of the reported EC values in **Table 11**, (p85) does not show that the sandstone (EC =90mg/l) has a better quality than the overlaying basalt (EC =86.1mg/l), field research established that the quality improve if water strikes are encountered in the underlying sandstone.

The groundwater potential in the Clarens Formation is considered moderate to good, although the primary permeability and storage potential is low. It seems that the depth of the weathered and fractured zones within the formation is playing an essential role in the potential yield of the borehole. The formation bears a residual primary water bearing character as in progressively increasing yield with depth of weathering. Geological structures such as faults and dolerite intrusions are also good targets for ground water exploration within this Formation (Du Toit, 1998). The unit covers approximately 3% of the total map area.

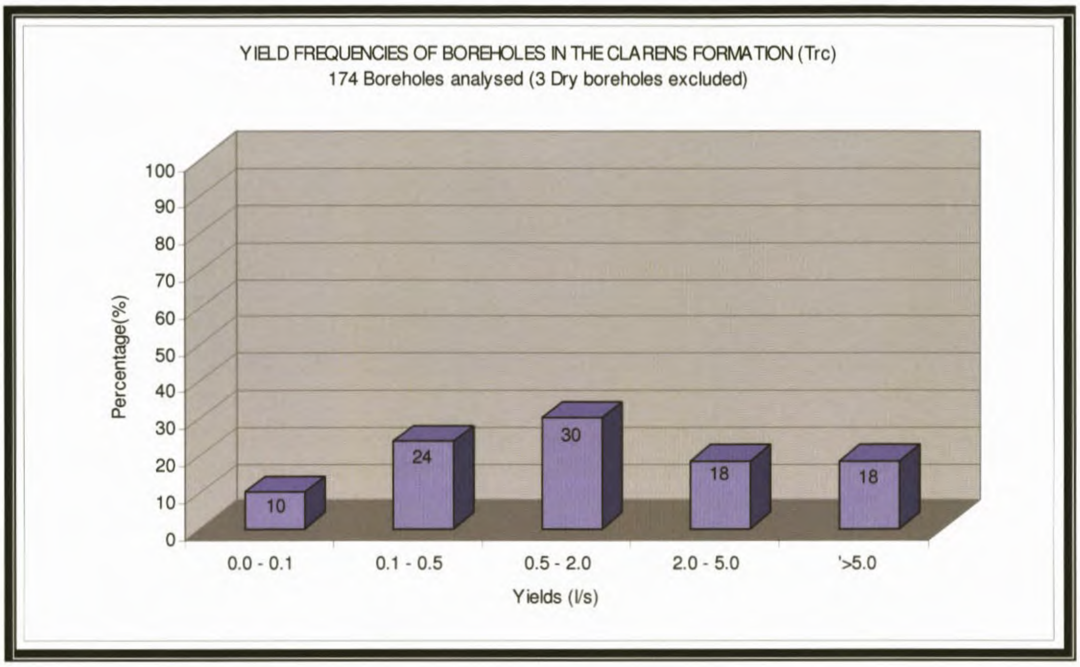


Figure 71: Yield frequency for the intergranular and fractured aquifers of the Clarens Formation (Trc).

Statistics reveal that 64% (**Figure 71**) of the successful boreholes yield less than 2ℓ/s. The contact zone with the overlaying basaltic rock yield water of varying quantity. Dolerite intrusions in the form of dykes and sills are targeted as it created secondary fractures and joints at the contact with the host rock. High yielding boreholes occurs in fault and deep fracture zones. The static water level varies between 10 and 30mbgl.

Water is abstracted from this unit for domestic use, nature conservation and livestock watering in the central and eastern part of the Tshipise basin with abstraction for irrigation more to the south-western part of the basin. Results show that in 67.9% of the samples the EC values is less than 150mS/m (harmonic mean for the unit is 90mS/m) with 7% exceeding the maximum allowable limit (EC >370mS/m). The domestic water quality is ideal (32.1%) to unacceptable (16.9%). In 12.5% of the samples concentrations exceeds the limits for fluoride (F >1.5mg/l), 13.1% for chloride (Cl >600mg/l), 8.3% for magnesium (Mg >100mg/l), 11.9% for sodium and 16.9% for nitrate and nitrite (reported as N), (N >20mg/l), (Table 12, 13 and 14, pp86-88). The sources of problematic chemistry occurring mainly in clusters, one of which is in the Thuli Basin between Weipe and the farm Cerberus where intensive irrigation occurs. The groundwater in the unit is a sodium-calcium-bicarbonate-chloride water type (**Figure 72**, p125).

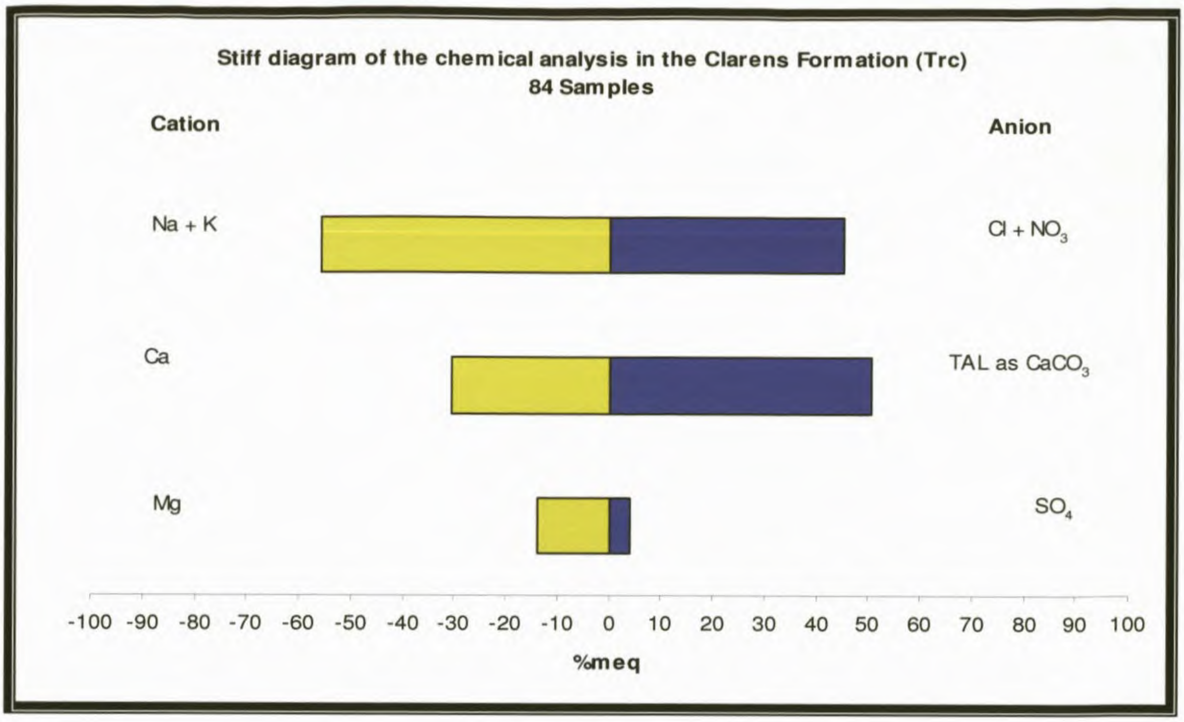


Figure 72: Stiff diagram representing chemical analysis for the fractured and intergranular aquifers of the Clarens Formation (Trc).

5.5.2.3.4 **Diabase (N-Zd)**

This unit consists of diabase intrusions that includes sills and dykes that occur in almost all the pre-Karoo formations in the area. The scale of maps prohibits the inclusion of all dyke intrusions (**Figure 73**, p126).

Within the Beit Bridge gneisses the dominant strike of dykes is east-north-east, with less prominent north-east and easterly trends. Within the Goudplaats gneiss the dominant strike is east-north-east. Dykes tend to give rise to high narrow ridges in all the older rocks. Sills within the older gneisses are concentrated more or less north-east of Alldays around Venetia Mine. The outcrops form almost continuous semicircular morphological structures consisting of at least two concentric inward-dipping rigs (Brandl, 2002).

Within the Soutpansberg Group dykes form negative features. Preferred orientation is east-north-east and less prominent west-north-west. The sills may be several hundred metres thick and are usually found at the interface of lava and sediment or between shale and sandstone. The diabase is generally medium-to coarse-grained dark grey to black rock with greenish to grey colours restricted to diabase within the Soutpansberg strata.

Figure 74, (p127) is a poor reflection on actual field conditions due to inadequate sample representation. The samples grouped under this unit only reflect data from a sill in the Soutpansberg Supergroup as the scale and the GIS method of choosing sample points representing the unit cannot identify boreholes drilled along dykes. Evaluation of borehole logs is the only accurate method to show if dykes were struck during drilling. In this study geological drilling records were not evaluated. Six boreholes were available for analysis, of which three were dry, thus making an analysis of the unit from this data meaningless. Secondary fractures associated with diabase dykes are good groundwater targets in rocks of the Soutpansberg Supergroup. Dykes occurring within the rocks of the Goudplaats gneiss and Beit Bridge Complex are not the first priority when exploring for groundwater. South of the map sheet in the Giyani area dykes and contact zones are better targets for groundwater development because they are usually more fractured. Where dykes outcrop there is a better chance of making a good decision on where to drill. This is because the results of the geophysical investigation can be field checked to the actual conditions and therefore eliminating the non-fractured dykes or contact zones. Anomalies caused by rocks not related to liniaments such as amphibolite or greenstone remnants can also be eliminated as possible drilling targets. Within most of the areas secondary fracturing related to faults or joints are the preferred target followed by deep weathering, pegmatite zones and sedimentary transition/contact zones. If the above targets are not found within the area earmarked for a groundwater source the final drilling position usually relates to a dyke intrusion.

Important details to consider when choosing a drilling site in the vicinity of a dyke intrusion is width, geological setting, strike, dip and lateral extent thereof. Drilling positions in thin dykes (less than 7m) are positioned with the expectancy of finding water within the dyke. With wider dykes (7 to15m), the most successful zone is usually within 2m of the contact zone. Very wide dykes are usually not good targets. Yields can differ on each side of the dyke as well as along the strike. When using aerial magnetic data and maps, dykes are usually targeted on the ground in areas along the strike where there is possible weathering (magnetic background data lower) or where joints or fracture zones transect the dyke (bends, discontinuous data). Sills are usually more difficult to drill successfully as the thickness is not always known. Targets associated with sills is the contact with the host rock, deeper than average weathered and fractured zones within the sill, younger intrusions within the sill or the lower contact zone if the sill is not too thick. The above is a general approach and depends on the geological, hydrogeological and physiographical settings of the target area.

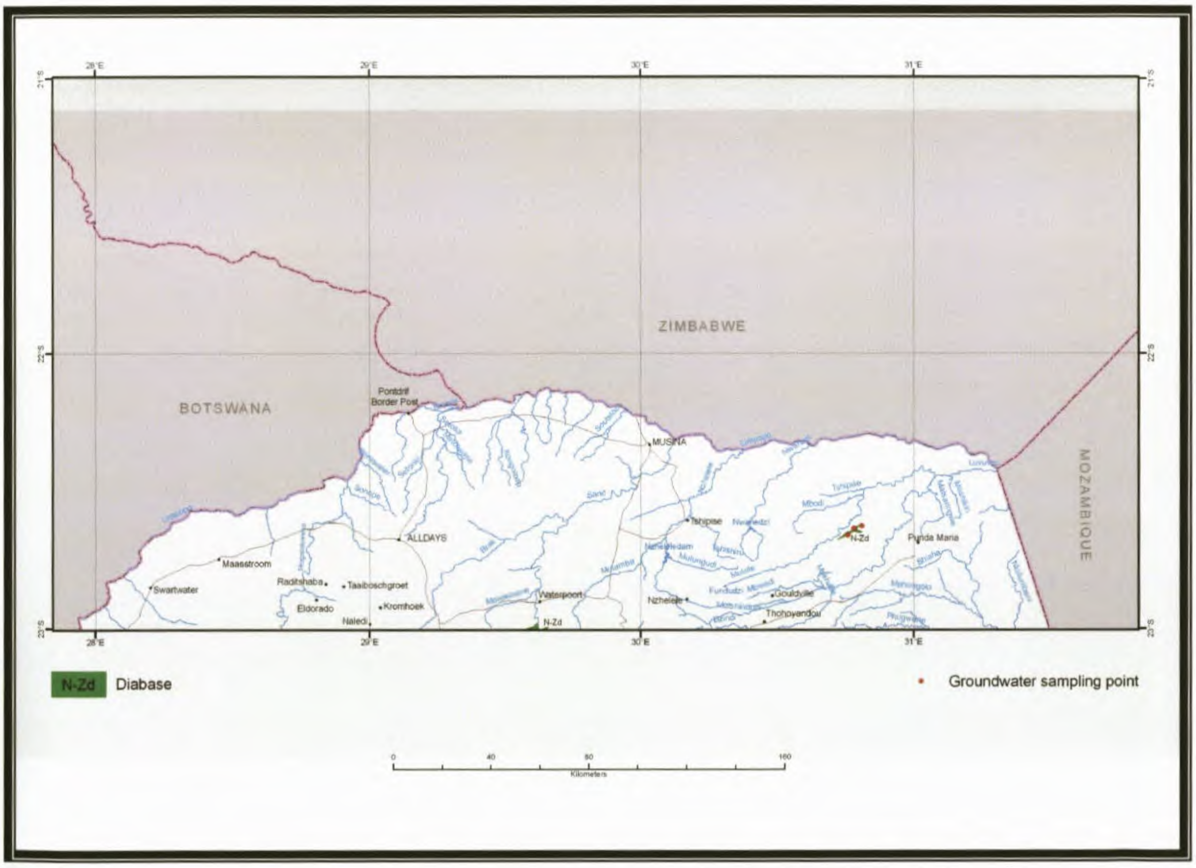


Figure 73: Geographical distribution of the Diabase Intrusions (N-Zd) and the associated groundwater sampling points.

Six groundwater samples were available and included samples from the 'dry' boreholes. The quality of the water is generally very good. No chemical element exceeded the maximum allowable value in the 6 available samples. EC values range from 32 to 100mS/m with a harmonic mean value of

51.6mS/m. **Figure 75**, (p128) shows the dominant anions/cations present. The water exhibits a sodium-magnesium-bicarbonate-chloride water type. With more representative samples covering the whole of the map area the analysis might differ due to geological and hydrogeological conditions.

Plate 9: Younger dyke (possible dolerite) intrusion into a very wide diabase dyke in the Pontdrift area. The diabase exhibits typical spheroidal weathering, caused by water promoting chemical weathering within cooling joints. The younger dyke exhibits typical closely spaced jointing, most likely cooling joints where the joints are formed perpendicular to the cooling surface by thermal contraction. If this jointing results in the rock breaking into small 'cube like' fragments it is locally called "blokkiesklip". It can be difficult to drill but the chance of finding a higher than average yielding borehole makes the effort worthwhile (Photo, H. Verster, 2010).

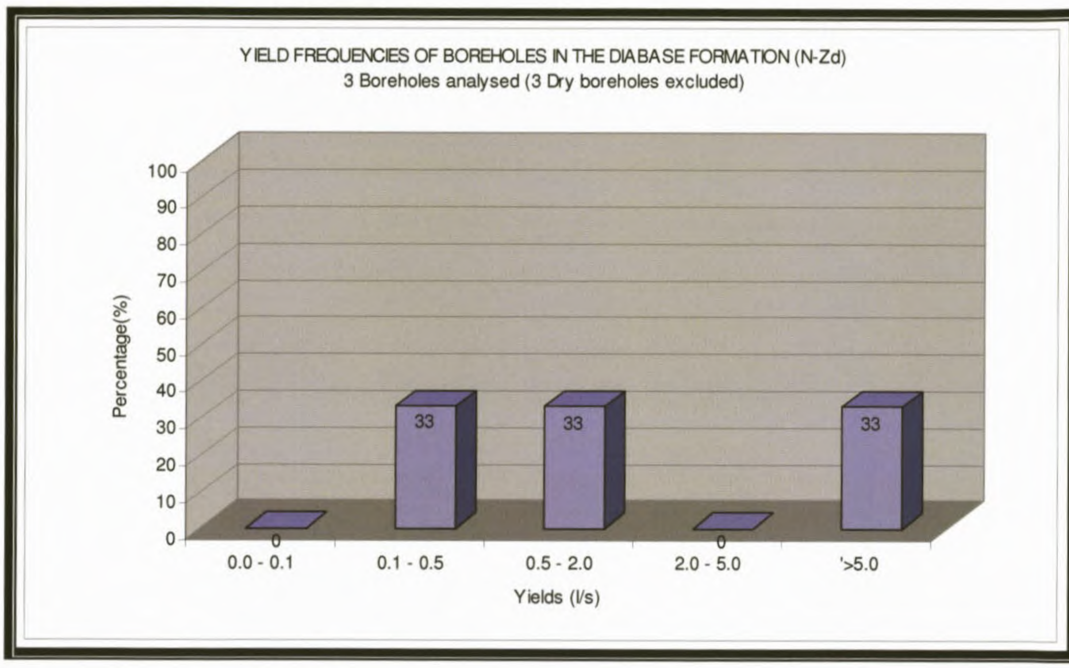


Figure 74: Yield frequency for the intergranular and fractured aquifers of the Diabase Formation (N-Zd).

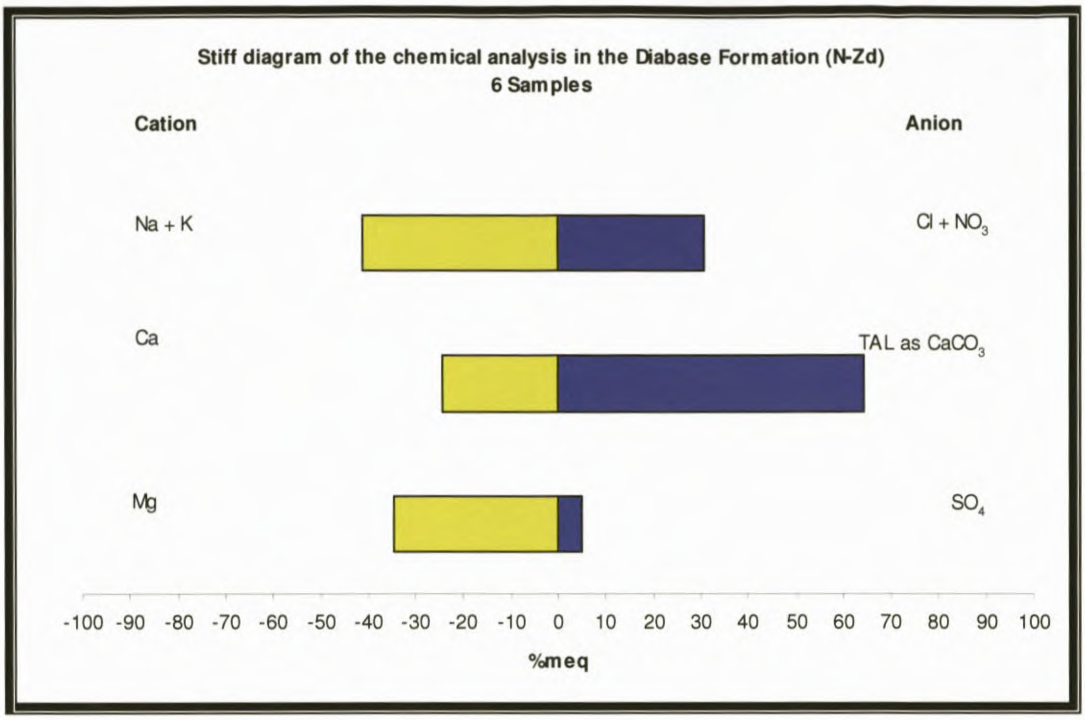


Figure 75: Stiff diagram representing chemical analysis of the diabase intrusions (N-Zd).

5.5.2.3.5 Soutpansberg Group (Ms)

The Soutpansberg Group comprises a volcanic and sedimentary rock succession, laid down in an elongated fault-bounded depression. A major centre of volcanic activity was probably located in the Sibasa area and a minor one east of Klein Tshipise. The fractured and intergranular hydrogeological unit of the Soutpansberg group comprises the Sibasa and Stayt Formations.

5.5.2.3.5.1 Sibasa Formation (Mss)

The Sibasa Formation has a maximum thickness of 3300m in the Sibasa area but decreases to the east, west and north-west. The formation consists predominantly of lava flows with minor intercalations of sedimentary and tuffaceous rocks. The lava is generally aphanitic to fine grained with medium-coarse grained varieties occurring occasionally. The colour varies from blackish to light green. The upper part of the formation can consist of amygdaloidal varieties with the vesicles filled with quartz, chalcedony, agate or chloride. Lenticular layers and lenses of tuff and in places agglomerate up to 200m thick occur. The sedimentary rocks tend to be more persistent along strike in the upper part of the succession. The arenaceous rocks reach a maximum thickness of 400m consisting of white, greenish, grey or pink quartzitic sandstone, quartzite, gritty quartzite and conglomerate. The argillaceous sediments do not exceed a thickness of 30m and consist of red and purple micaceous shales grading locally into whitish sandy shale and minor greyish siltstone (Brandl, 1981).

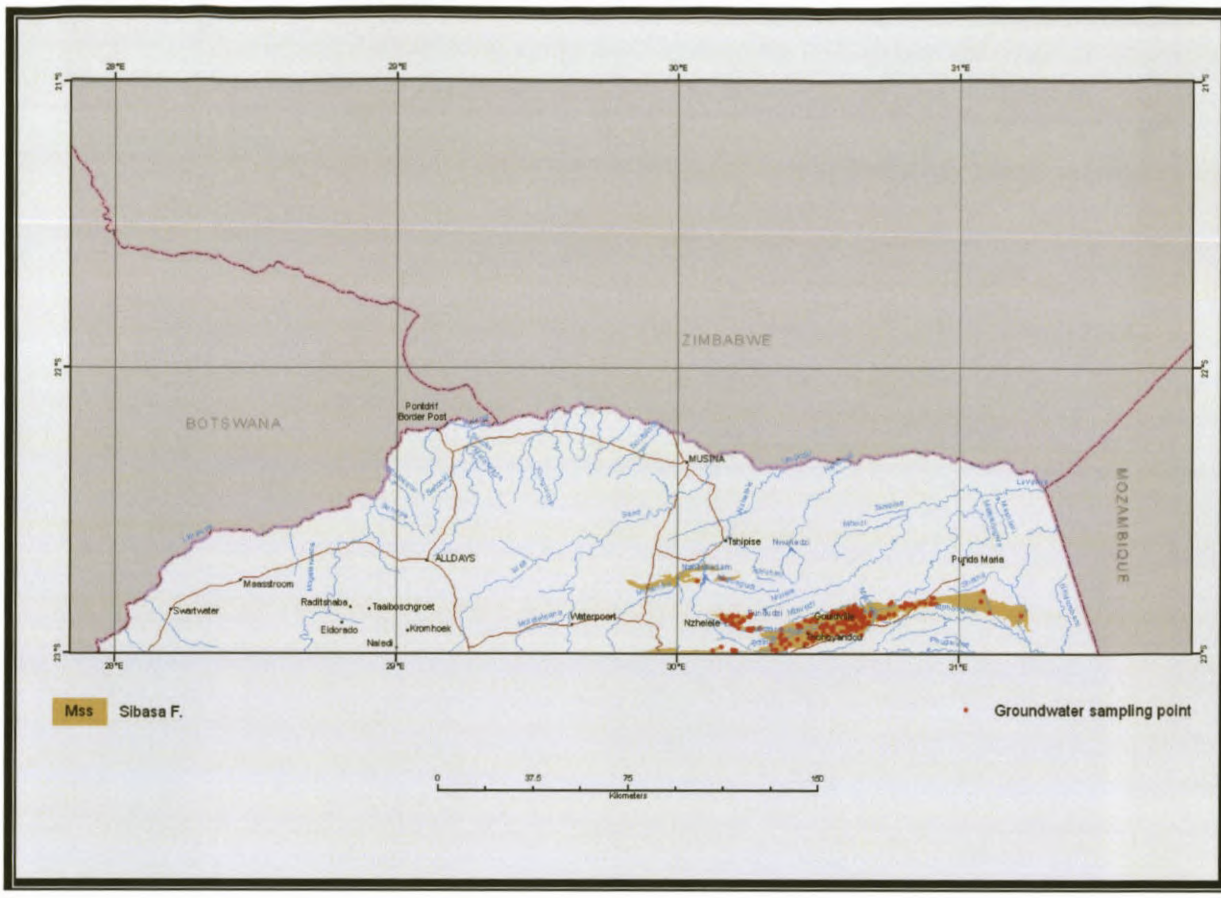


Figure 76: Geographical distribution for the intergranular and fractured aquifers of the Sibasa Formation (Mss) and the associated groundwater sampling points.

Numerous faults cut through the formation which is also the main target for sustainable groundwater development. Other targets include deep weathered and fractured basins where groundwater is usually intercepted in the transitional zone between the weathered and fresh basalt. The latter is fed from the overlying weathered zone in which the water is stored. The unit occurs in a high rainfall area with chemical weathering the dominating process. Where weathering is intensive clay is produced reducing the permeability and subsequent yielding potential significantly. Water is also obtained on the contact between the basalt and the overlaying sandstone, due to the mountainous topography, however this option is not always feasible (Du Toit, 1998). The depth to groundwater level is generally <25m.

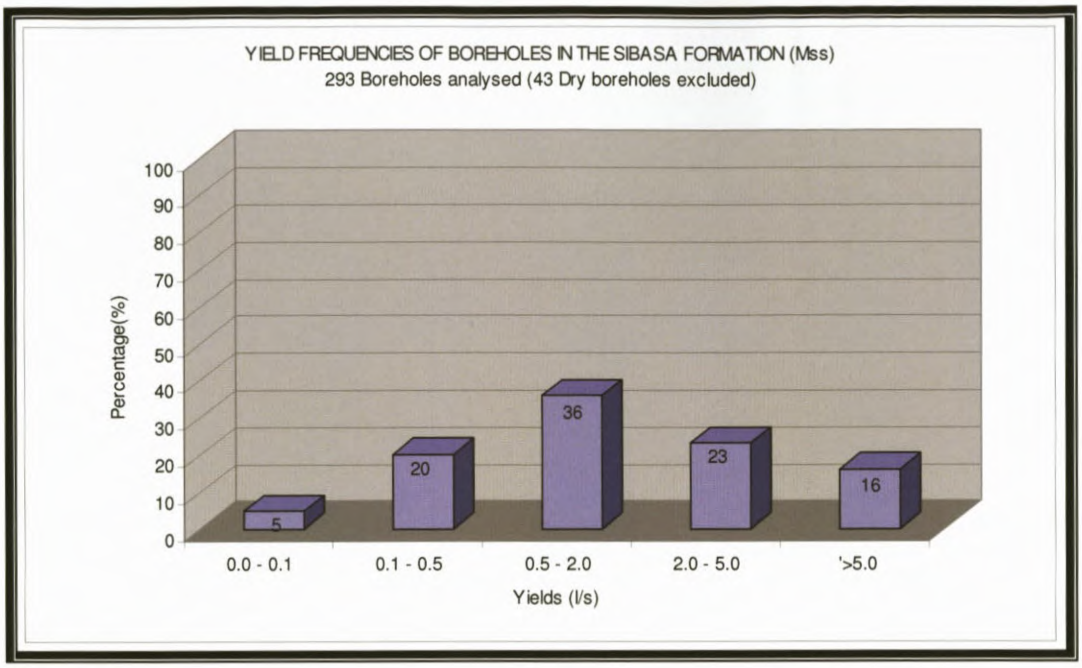


Figure 77: Yield frequency for the intergranular and fractured aquifers of the Sibasa Formation (Mss).

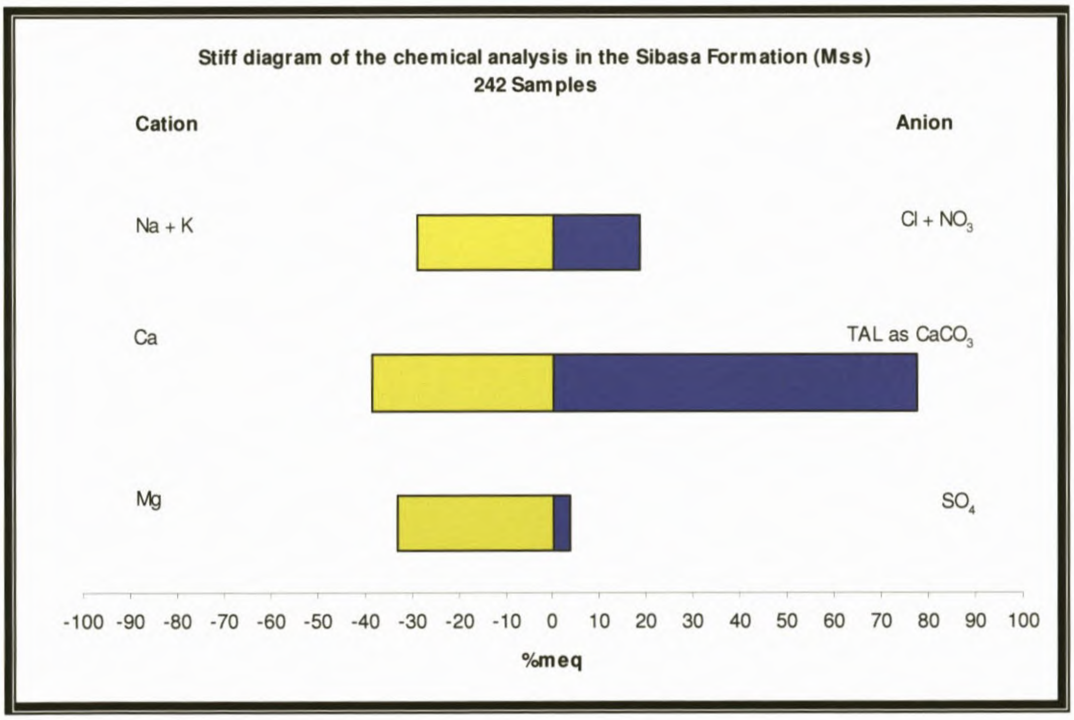


Figure 78: Stiff diagram representing chemical analysis of the Sibasa Formation (Mss).

Figure 77 shows the yield frequency of the Sibasa Formation. The unit occurs in a high rainfall zone that contributes to the 39% boreholes with a yield exceeding 2ℓ/s. Distribution of data points is moderate to good over the unit aerial extend (**Figure 76**, p129). Data shows that 18% of the boreholes are dry with 61% of the successful boreholes yielding less than 2ℓ/s. This indicates that the selection of drilling sites can be difficult. It is advised to use scientifically approved methods. Groundwater supplies the domestic, livestock and irrigation needs of small to medium size villages.

Chemical data for the unit is presented in a stiff diagram (**Figure 78**). The water exhibits a calcium-magnesium-sodium-bicarbonate water type with elevated chloride concentrations. EC values range between 3mS/m and 150mS/m. The calculated Harmonic mean is 34.8mS/m and the arithmetic mean is 56mS/m. The water is dominantly of an ideal water quality as 100% of the fluoride and sulphate, 96.3% of the chloride and 69.1% of the nitrate and nitrite (reported as N) concentrations fall within the ideal class. Only 3.8% or 9 sampled boreholes exceed the maximum allowed concentration for nitrate (N >20mg/l) when evaluated for domestic use (Table 12, 13 and 14, pp86-88). These sources occur within or near villages. In one sample, the pH value exceeded the maximum acceptable alkalinity (pH >10). In another three samples, the pH values were inside the acceptable parameters, but still very high in alkalinity (pH 9.1 to10).

5.5.2.3.5.2 Stayt Formation (Msa)

The Stayt Formation forms a small occurrence between the Xmas and Tshipise faults. The maximum thickness is estimated at 1800m (Brandl, 1981). The contact with the underlying Beit Bridge Complex is unconformable. At the base a thin conglomerate is generally developed followed by greenish grey amygdaloidal lava with a thickness of 1000m followed by argillaceous and arenaceous sediments (Meinster, 1974; Sohnge, 1945, Vitry, 1976).

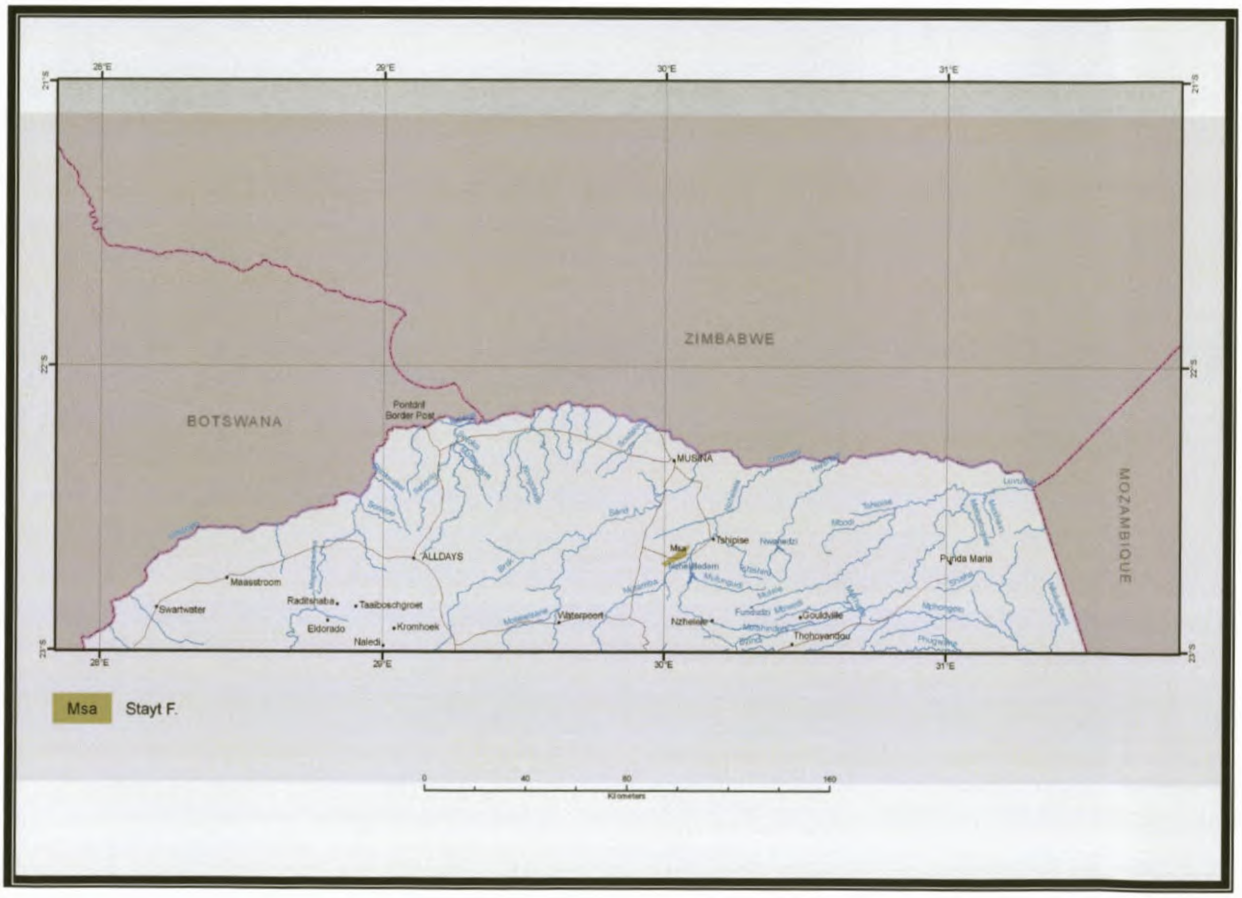


Figure 79: Geographical distribution for the Stayt Formation (Msa) and the associated groundwater sampling points.

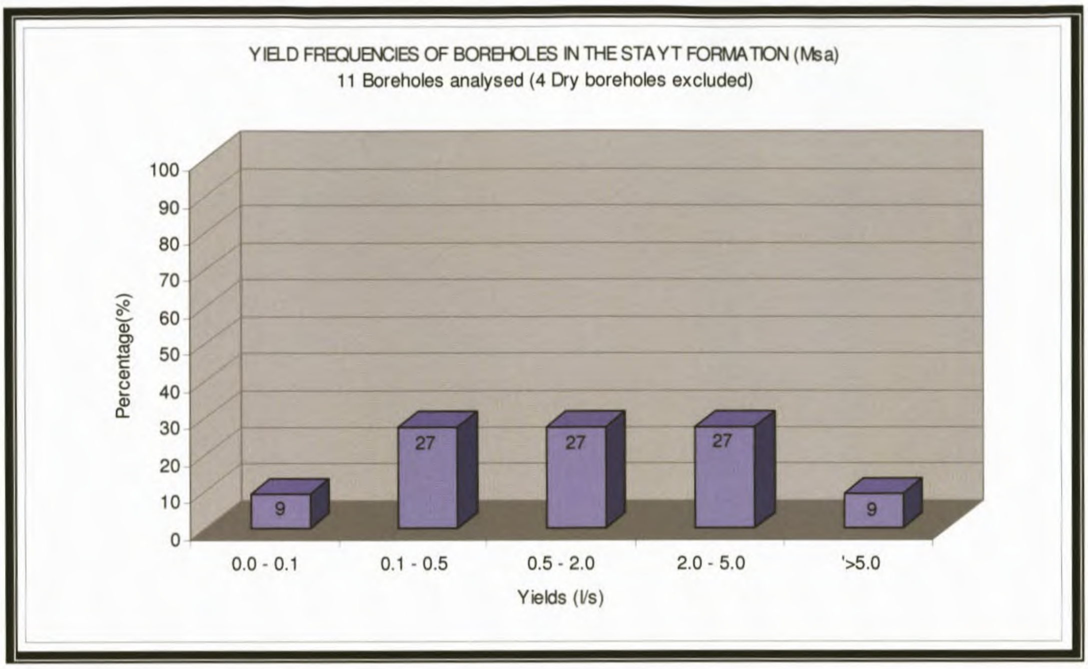


Figure 80: Yield frequency for the intergranular and fractured aquifers of the Stayt Formation (Msa).

The data of 11 successful boreholes was plotted in **Figure 80**. The groundwater potential within this Formation is considered moderate to poor with 63% yielding less than 2ℓ/s. Data shows that 26% of the boreholes were dry. No chemical analyses were available to give an indication of the water quality of unit.

5.5.2.3.6 **Bulai Gneiss (Rbu)**

The Bulai Gneiss, a large probably syntectonic batholith intrusion is confined to the northern part of the map occurring just north-west of Mussina (**Figure 81**, p133). Morphologically it is characterised by the development of large flat pavements, barren exfoliation domes and whaleback "koppies". A number of varieties have been recognised within the batholith, with grey to pinkish porphyroblastic gneiss being the most widespread and best exposed variety. It has a monolithic composition and is composed of porphyroblasts of microcline in a groundmass of plagioclase, quartz and biotite. The intrusive nature of the unit is noticeable on a local and regional scale and is further supported by the ubiquitous presence of supracrustal enclaves. Two types of intrusive contacts have been observed; the first exhibits a cross-cutting relationship with no or little structural disturbance of the intruded rocks while the second displays a major deformation of the enclosing gneisses (Watkeys, 1984).

A prominent feature of the gneiss is the presence of fresh meso- to melanocratic lamprophyric dykes with a frequent width of 30cm, although it can be up to 150cm. They cut across the regional fabric of the host rock. In low-strain areas the dykes are slightly sinuous, trending in northerly or north-easterly direction, but where the strain was more intense they are complexly folded or boudinaged (Brandl, 2002).

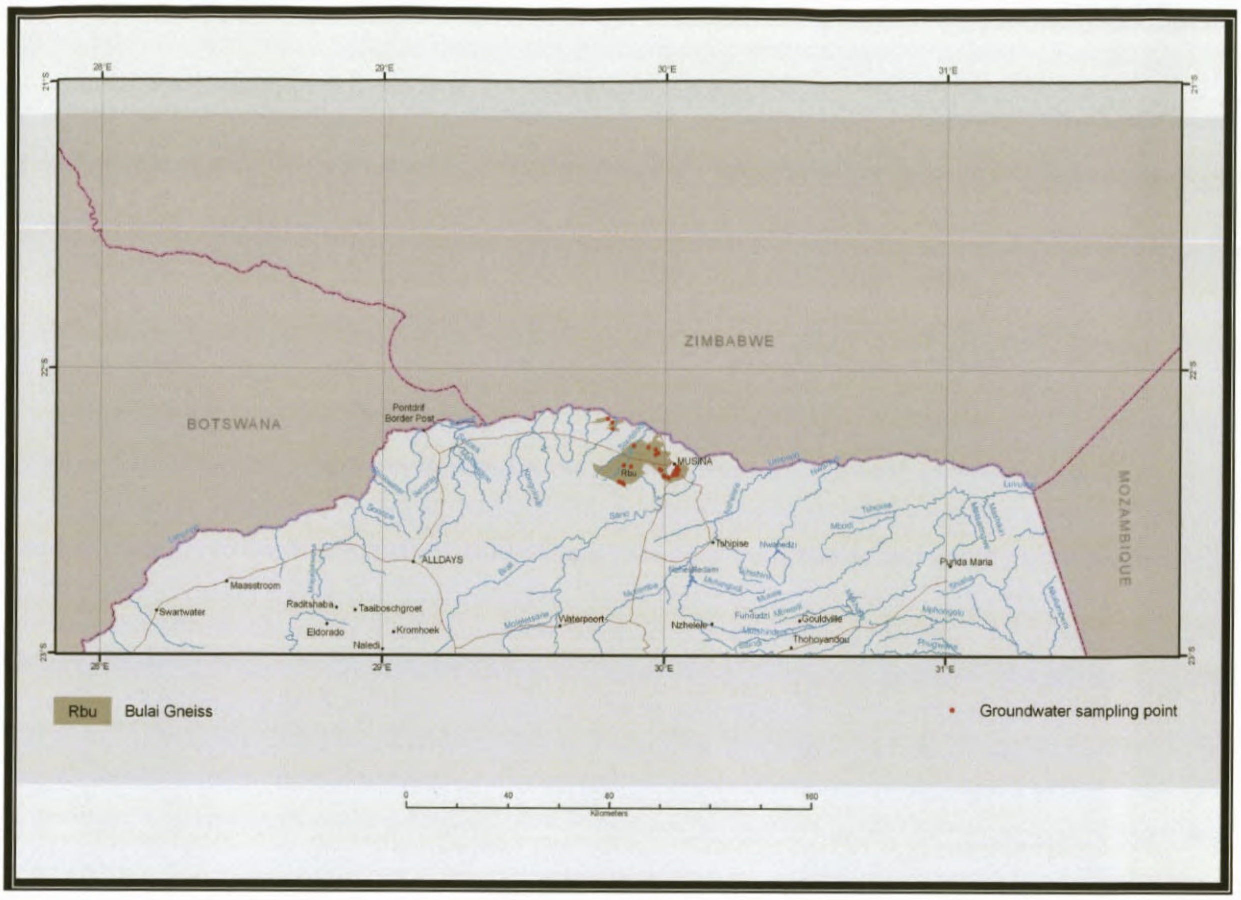


Figure 81: Geographical distribution for the Bulai Gneiss (Rbu) and the associated groundwater sampling points.

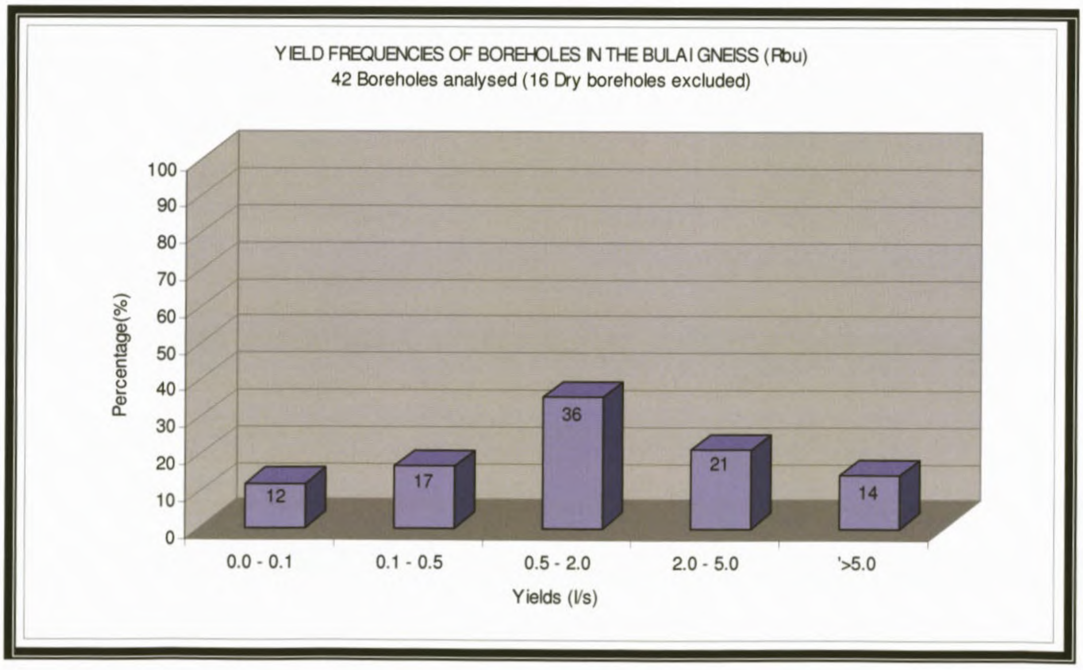


Figure 82: Yield frequency for the intergranular and fractured aquifers of the Bulai Gneiss (Rbu).

The yield frequency distribution diagram in **Figure 82**, (p133) gives a very good indication of the expected groundwater potential. 65% of the successful boreholes are yielding less than 2ℓ/s, 21% between 2 and 5ℓ/s and 14% yields more than 5ℓ/s. Data shows that 28% of the boreholes were dry.

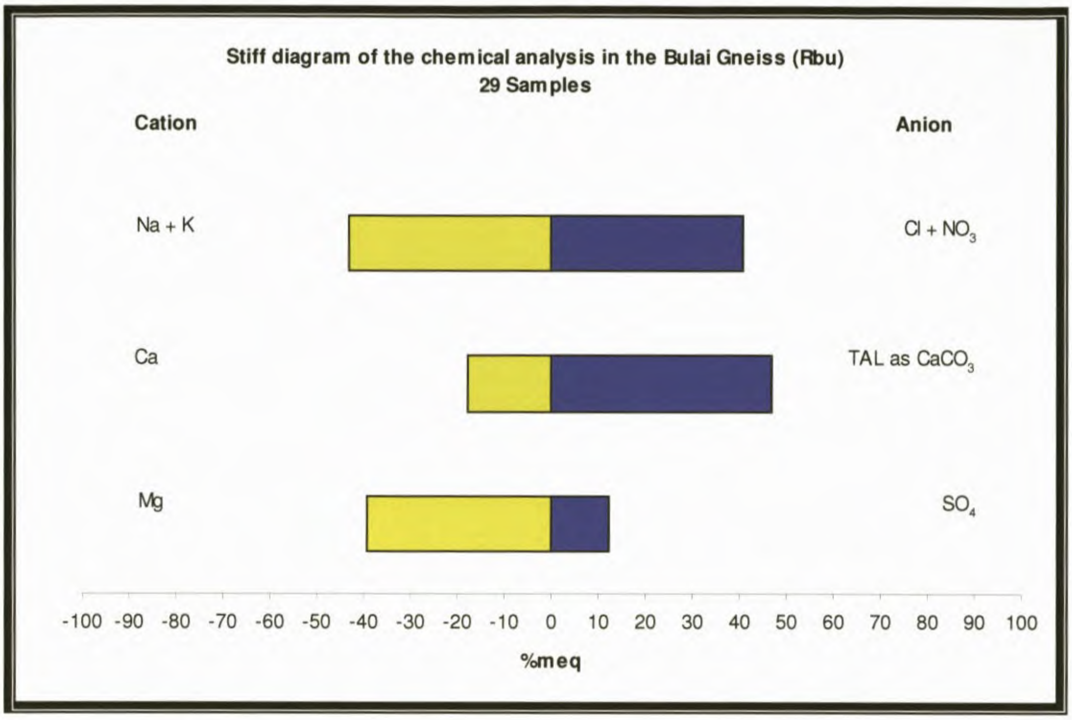


Figure 83: Stiff diagram representing chemical analysis of the Bulai Gneiss (Rbu).

The stiff diagram (**Figure 83**) shows the broad classification according to anions and cations. The water displays a sodium-magnesium-bicarbonate-chloride character. The water quality is moderate to poor with elevated magnesium, sodium and calcium concentrations. EC values range between 48mS/m and 1139mS/m. The harmonic mean is 151.5mS/m with the arithmetic mean 246mS/m. For domestic purposes (3.5%) is of an ideal water quality with (37.9%) exceeding the maximum allowed limit. In 17.2% of the samples the EC values fall outside the maximum allowed limit (EC >370mS/m). Nitrate and nitrite (N) problems are reported in 20.7% of the analysis with concentrations exceeding the maximum allowable limit (N >20mg/l), compared with 24% classed as ideal (N <6mg/l). Fluoride values exceed maximum allowed limits in 37.9% of the groundwater samples evaluated (F >1.5mg/l). Only 10% of the samples are falling within the Ideal Class (F <0.7mg/l). Unacceptable elevated chloride concentrations are reported in 17.2% of the samples and sulphate in 10.3% (Cl and SO_4 >600mg/l), (Table 12, 13 and 14, pp86-88). The water sources with problematic chemistry occur randomly throughout the unit.

5.5.2.3.7 **Hout River Gneiss (Rho)**

The Hout River Gneiss is an important unit on the adjacent Polokwane hydrogeological map sheet but on the Messina map the unit does not outcrop and only occurs on depth in the southern part of the map near Kromhoek. The unit was included on the map sheet as the contact between this unit and the overlaying rocks of the Karoo Supergroup was investigated in various groundwater projects. A wide variety of granitoid rocks have been grouped under this unit. It includes leucocratic migmatite and gneiss, grey and pink hornblende-biotite gneiss, grey biotite gneiss and pegmatite rocks (Brandl. 1986).

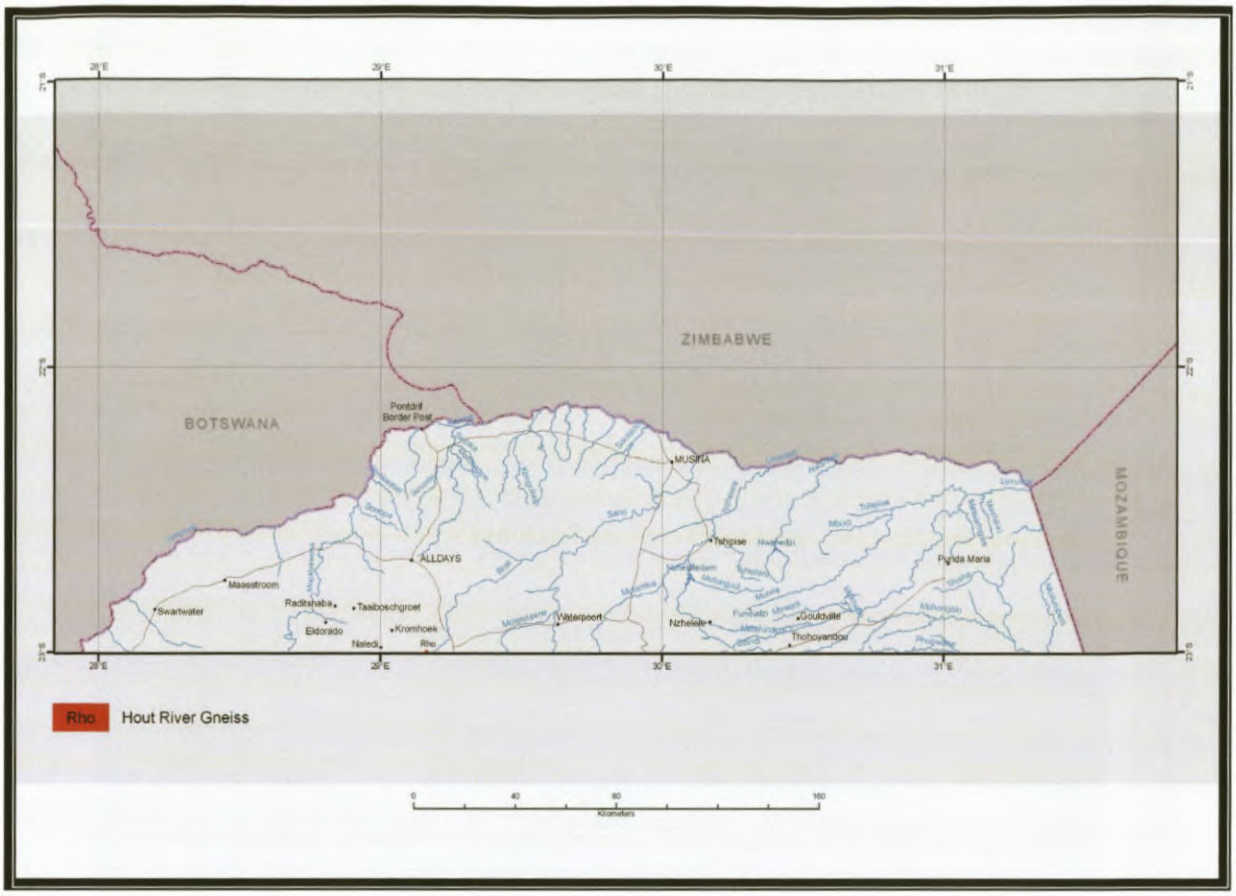


Figure 84: Geographical distribution for the Hout River Gneiss (Rho.)

Although no chemical samples are available in this unit of the study area the characterization of the Hout River Gneiss in the adjacent Polokwane study area can be assumed. The quality of the water is generally good and within acceptable limits for domestic use. Groundwater in this unit is classified as a sodium-magnesium-bicarbonate-chloride water type. The groundwater potential is good (Du Toit, 2011).

5.5.2.3.8 **Alldays Gneiss (Zal)**

In the central and western parts of the Central Zone (**Figure 85**, p136), a homogeneous tonalitic gneiss, younger than the supracrustal rocks of the Beit Bridge Complex are well developed (Brandl, 1990). The unit underlies 1.17% of the map sheet.

All greyish, biotite-bearing gneisses occurring in this area have been grouped under the term Alldays Gneiss, except the Sand River Gneiss. The Alldays gneiss occurs in the map area as either large elongate or oval-shaped bodies up to several km across, or more often as concordant sheets which can vary in width from as little as 20 cm to several hundred metres. Characteristic forms of weathering are isolated boulder-strewn hills, large whaleback exposures or smooth pavements near rivers. It consists of medium rarely coarse-grained rock varying from leucocratic, light to dark grey, pinkish grey or pink. Its gneissose structure is defined by the orientation of ferromagnesian minerals (Brandl, 1990).

The presence of remnants of supracrustal gneisses at a number of localities demonstrates that the Alldays Gneiss is an orthogneiss which has an intrusive relationship with the country rocks. Local occurrences of xenoliths (2-5m) of anorthositic gneiss of the Messina Suite in the Alldays Gneiss strongly indicate that the latter postdates the emplacement of the Messina Suite rocks. Mineralogically the Alldays Gneiss is composed of plagioclase, quartz, K-feldspar, biotite, hornblende and opaque phases, with cummingtonite, pyroxene and garnet occurring only locally. Apatite, zircon and epidote are present as accessories (Brandl, 2002).

Within the Swartwater area the Alldays gneiss appears in two outcrop forms, a homogeneous granular textured type which forms small hills of rounded boulders, and a widespread form which exhibits clear gneissic banding and extensive flat outcrops (Pretorius, 1986).

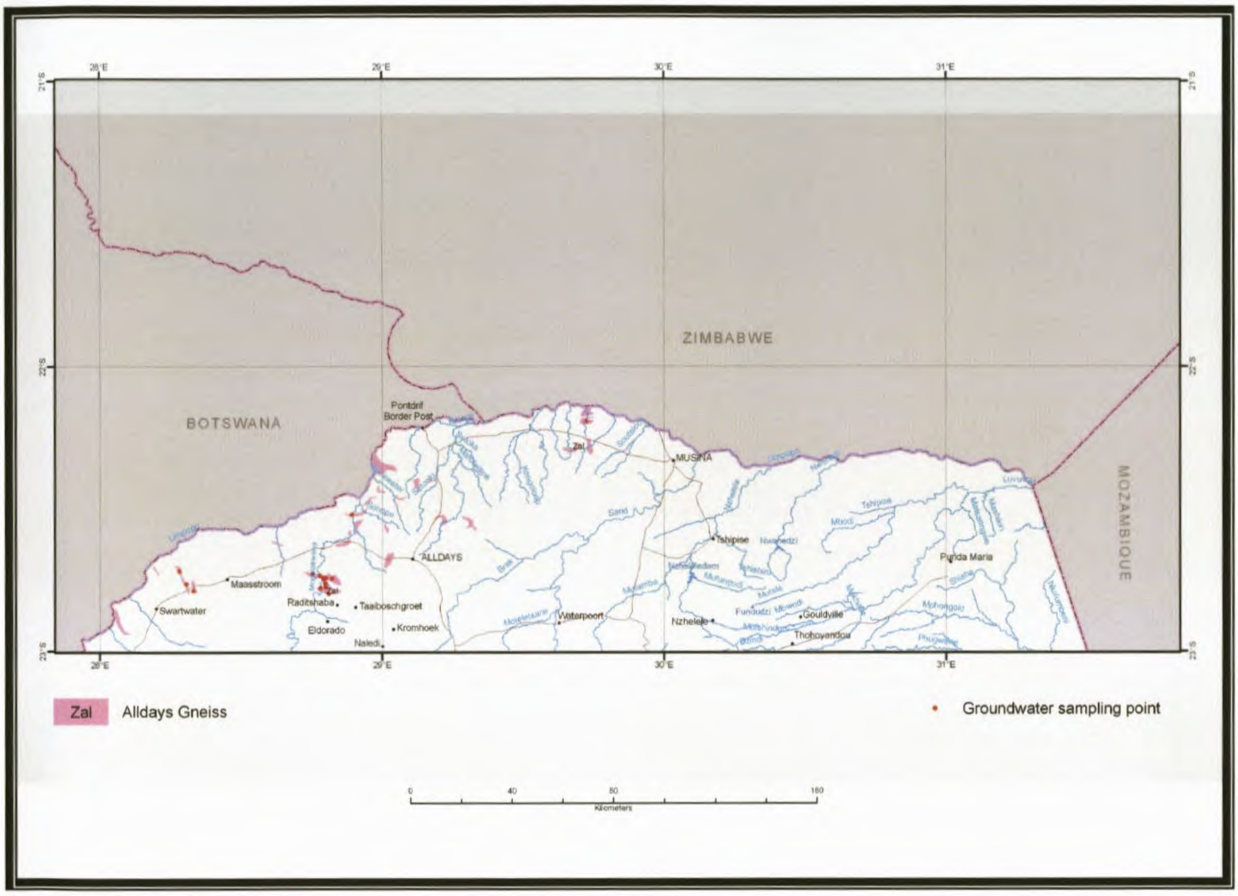


Figure 85: Geographical distribution for the Alldays Gneiss (Zal) and the associated groundwater sampling points.

The groundwater potential of the gneisses is moderate to poor with 74% (**Figure 86**, p137) of the boreholes yielding less than 2ℓ/s and 26% yielding >2ℓ/s. A total of 74 boreholes plot within the unit with a small percentage (5%) reported as dry. Statistically the chances of finding a wet borehole within this unit are very good. It is, however, possible that dry yielding boreholes are not well documented on the data base.

Seventeen groundwater samples were available for chemical analysis. Two of these samples have EC values greater than 600mS/m. This exceeds the maximum allowed limit (EC >370mS/m). These same 2 samples differ completely from the rest of the samples in the unit, as the concentrations of all the chemical elements are 2 to 5 times higher, except for the fluoride values. When plotting these two boreholes no explanation can be interpreted. These 2 samples however do not change the character of the water. **Figure 87**, (p137) shows the broad classification according to anions and cations. Groundwater in this unit has a sodium-calcium-bicarbonate-chloride character. The groundwater is of an ideal (5.9%) to unacceptable (52.9%) water class. The available samples indicate that 17.7% of the nitrate and nitrite (reported as N >20mg/l), 11.8% of the sulphate, chloride, magnesium and sodium (Cl and SO_4 >600mg/l, Mg >100mg/l, Na >400mg/l) and 52.9% of the fluoride (F >1.5mg/l) concentrations exceed the maximum allowed limit for domestic use.

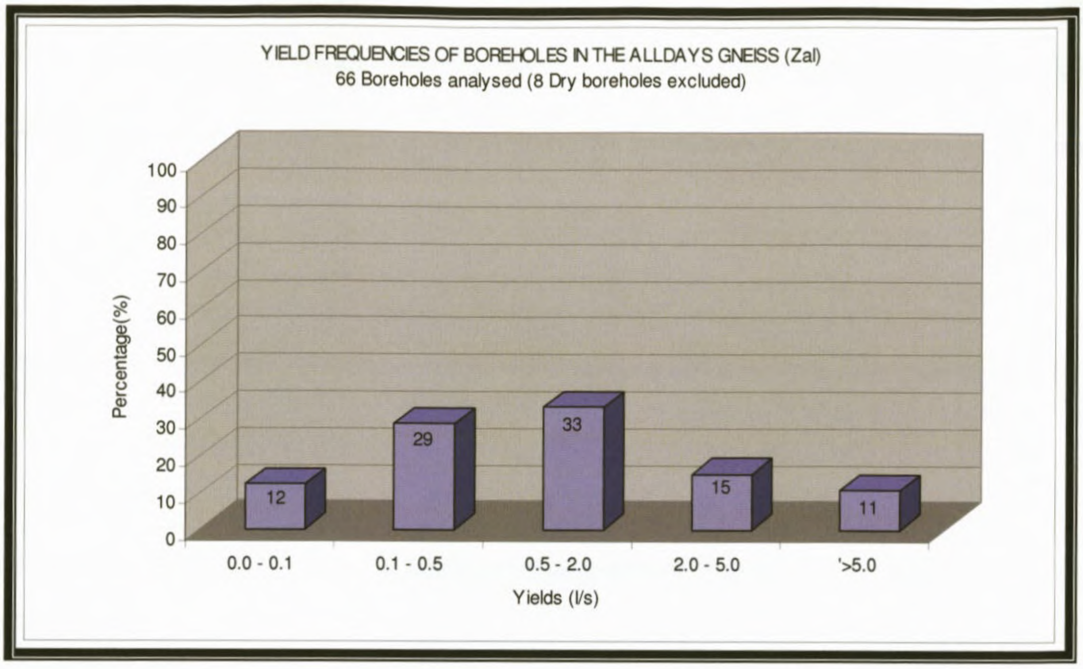


Figure 86: Yield frequency for the intergranular and fractured aquifers of the Alldays Gneiss (Zal).

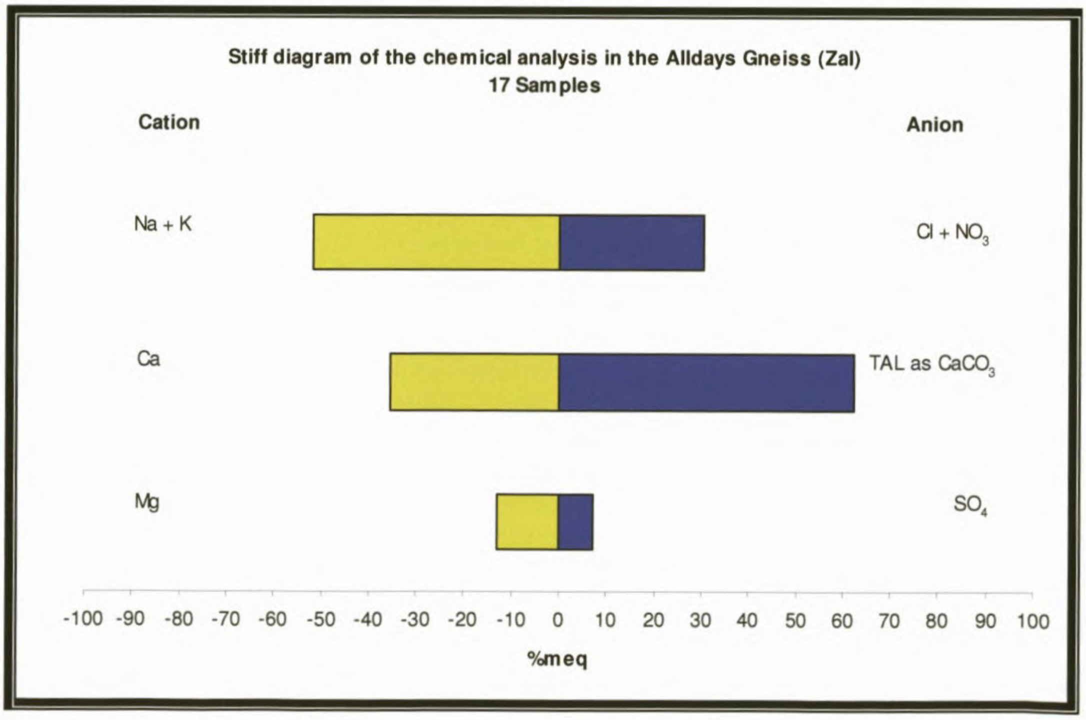


Figure 87: Stiff diagram representing chemical analysis of the Alldays Gneiss (Zal).

5.5.2.3.9 **Messina Suite (Zbm)**

The Messina Suite is interpreted as having been emplaced as a sill-like layered igneous body into the supracrustal gneisses of the Beit Bridge Complex, probably at a depth of less than 12km (Barton, et al. 1979). Frequent remnants of supracrustal gneisses in particular metaquartzite and calc-silicate rocks are evidence of the intrusive nature of the Suite. Outcrop generally occurs as elongate layers of considerable outcrop width, which can extend along strike continuously for tens of kilometres (**Figure 88**, p139). The Messina Suite rocks in the eastern occurrences are mainly associated with metaquartzite, while in the Mogalakwena River area they are adjacent carbonate rocks (Van der Walt, 1977, Pienaar, 1985).

Rocks of the Messina Suite consist of meta-anorthosite and metaleucogabbro (anorthositic gneiss) together with very subordinate ultramafic rocks. The majority of the anorthositic gneisses seem to be derived from leucogabbro. On occasion as in the domal structure approximately 10km in diameter near Alldays, metaleucogabbro is seen to grade into thin horizons of metagabbro, now represented by layered hornblende gneiss. This intrusion is surrounded by a characteristic coarse garnetiferous leucogneiss.

The anorthositic gneiss characteristic weathers to large blocks or slabs having a greyish or light-brown skin through which ferromagnesian minerals, and sometimes quartz grains, protrude. Where the rock has the composition of an anorthosite it is fairly massive and slightly speckled, and with an increase of the dark minerals, it becomes streaky or has a banded appearance. In hand specimens the rock, which is medium-grained, is commonly greyish white to bluish grey and only rarely has a greenish tint. The anorthosite is composed principally of plagioclase, together with very subordinate hornblende, pyroxene, quartz and biotite. Accessories include sphene, apatite, epidote, allanite and opaque.

The ultramafic rock is quite rare in the map area and therefore not indicated on the 1:250 000 geological map sheet for the area (2228 Alldays). It includes metaperidotite, metapyroxenite, hornbendite and serpentinite (Brandl, 2002).

The results of four chemical analyses were available for analysis. The stiff diagram representing the chemistry of the unit (**Figure 89**, p139) shows the broad classification according to anions and cations. With the results of only four boreholes, it is not possible to perform a valid assessment of expected yield and chemistry. The diagram shows the water to exhibit a sodium-calcium-magnesium-chloride-bicarbonate character. High fluoride (F >1.5mg/l) and nitrate and nitrite (reported as N >20mg/l), concentrations are found in 50% of the samples. High chloride (Cl >600mg/l) and magnesium (Mg >100mg/l), concentrations is found in 25% of the samples. More samples are required to validate the interpretation.

The yield frequency diagram (**Figure 90**, p140) was compiled using the data of 79 successful boreholes plotting within the Messina Suite. Only 1 borehole is reported as dry on the data base. This is an understatement as work done for farmers in the Alldays area underlain by this unit give a picture of a high percentage of dry boreholes. From the graph and field notes the groundwater potential is generally low as approximately 93% of the successful boreholes yield less than 2ℓ/s.

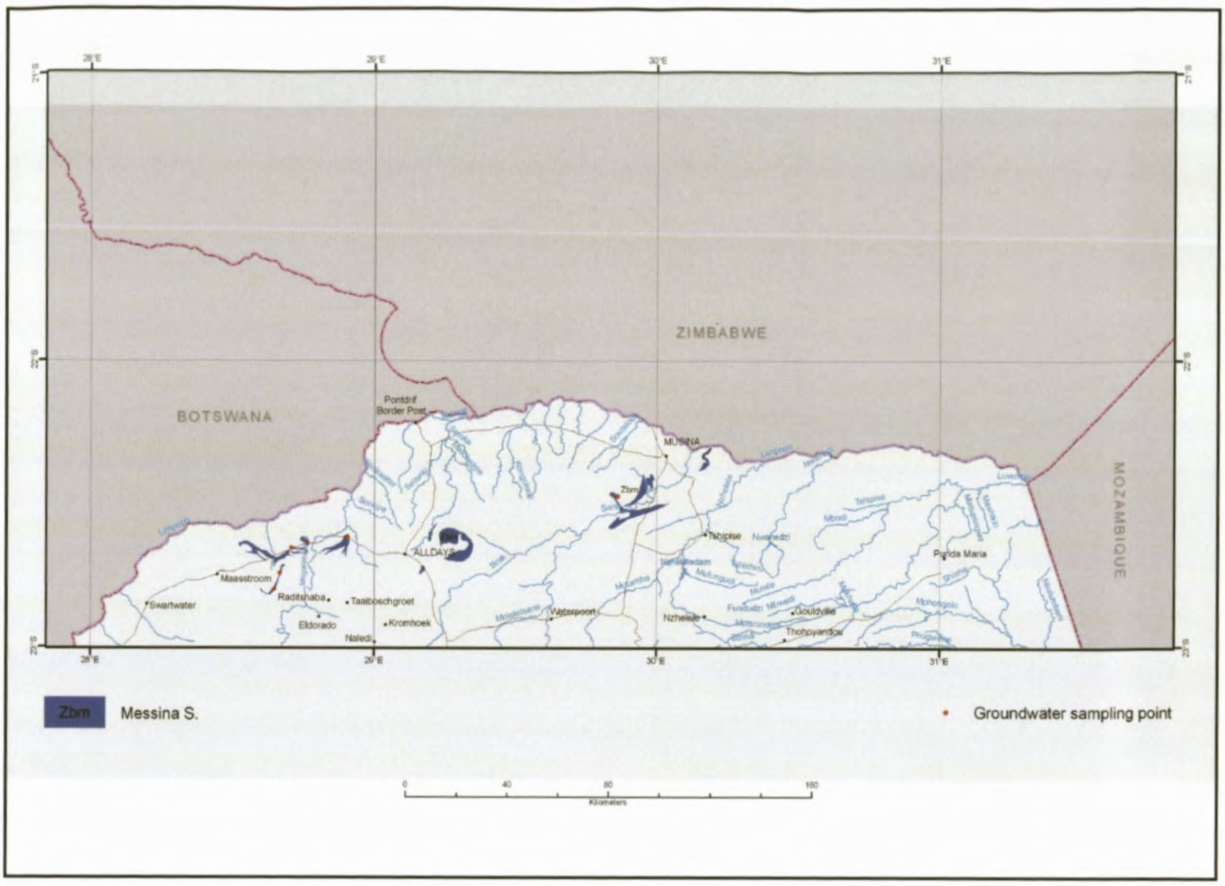


Figure 88: Geographical distribution of the Messina Suite (Zbm) and associated groundwater sampling points.

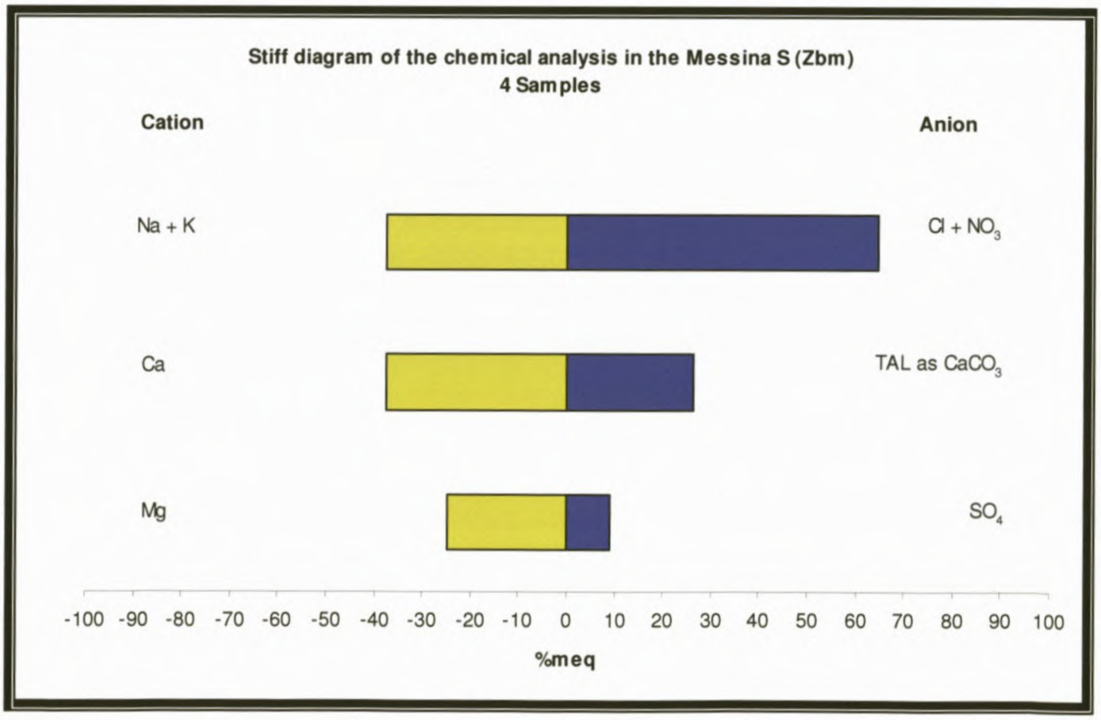


Figure 89: Stiff diagram representing chemical analysis of the Messina Suite (Zbm).

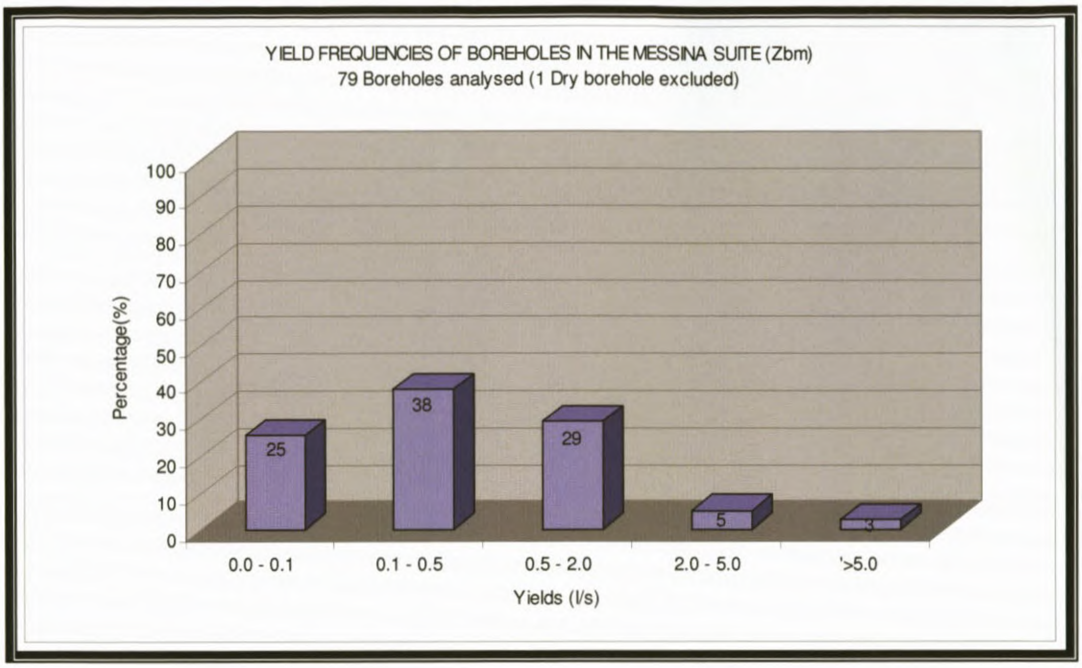


Figure 90: Yield frequency for the intergranular and fractured aquifers of the Messina Suite (Zbm).

5.5.2.3.10 **Madiapala Syenite (Zma)**

The Madiapala metasyenite occurs as a seemingly closed elongate structure in the north-western part of the map sheet (**Figure 91**, p141). Small nearby satellite bodies are not indicated. The metasyenite is resistant to weathering giving rise to a prominent steep-sided ridge. It appears that two main varieties of metasyenite are present. The first is pinkish grey and homogeneous and the second is irregular dark-grey and pink bands. The rock exhibits strong fabric, although in places cross-cutting veins of a pinkish material have also been observed (Brandl, 2002).

The yield frequency distribution diagram in **Figure 92**, (p141) gives an indication of the expected groundwater potential although only 6 data points were available. All of the successful boreholes are yielding less than 2ℓ/s. No dry boreholes were reported and no chemical data was available to determine the nature of the groundwater chemistry for this unit.

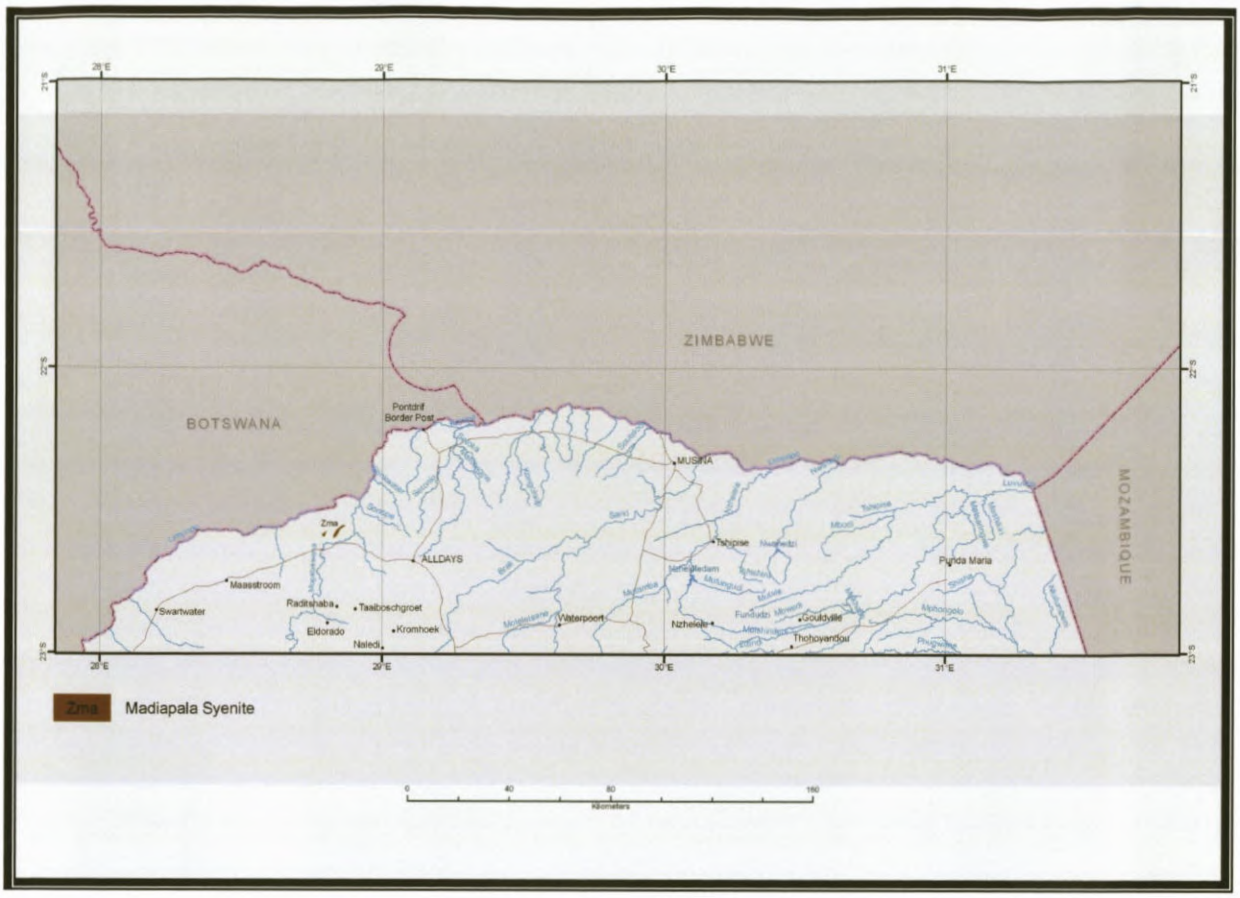


Figure 91: Geographical distribution of the Madiapala Syenite (Zma).

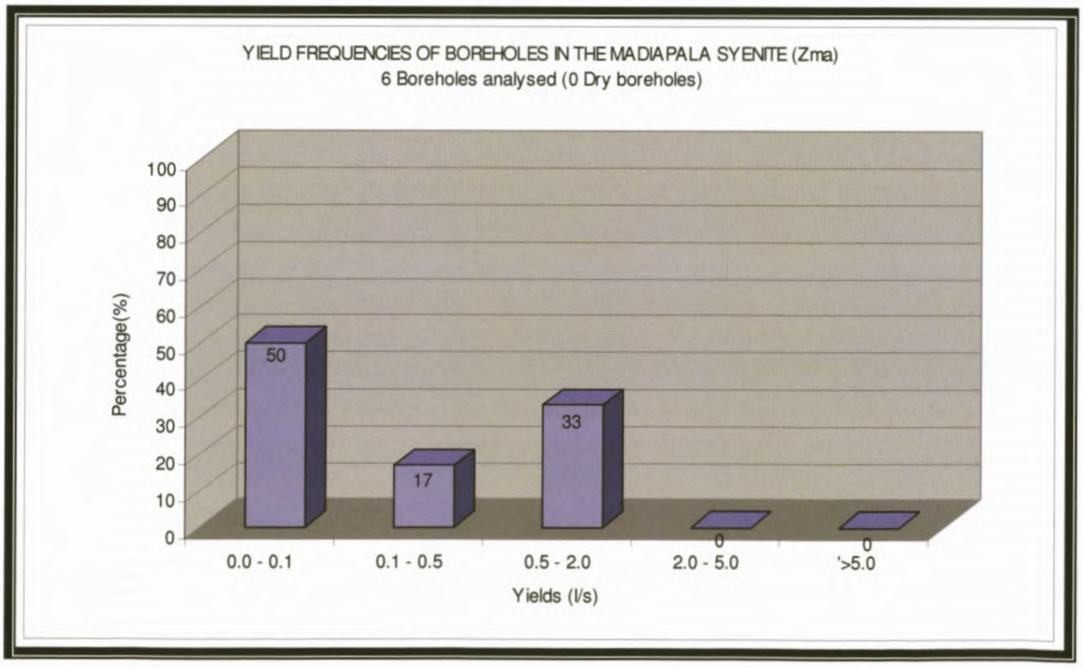


Figure 92: Yield frequency for the intergranular and fractured aquifers of the Madiapala Syenite (Zma).

5.5.2.3.11 **Sand River Gneiss (Zsa)**

The Sand River Gneiss occupies a large area south-east of Messina where it forms spectacular outcrops on rock pavements in the bed of the Sand River (**Figure 93**).

The Sand River Gneiss consists of alternating layered bands of grey, leucocratic and magmatic gneiss. The varieties occur intimately intermingled with each other and are strongly folded together. The grey layered gneiss variety seems to be the oldest, as it forms rotated boulders within the leucocratic gneiss. The youngest phase appears to be the dark grey variety (Brandl, 1981, 2002).

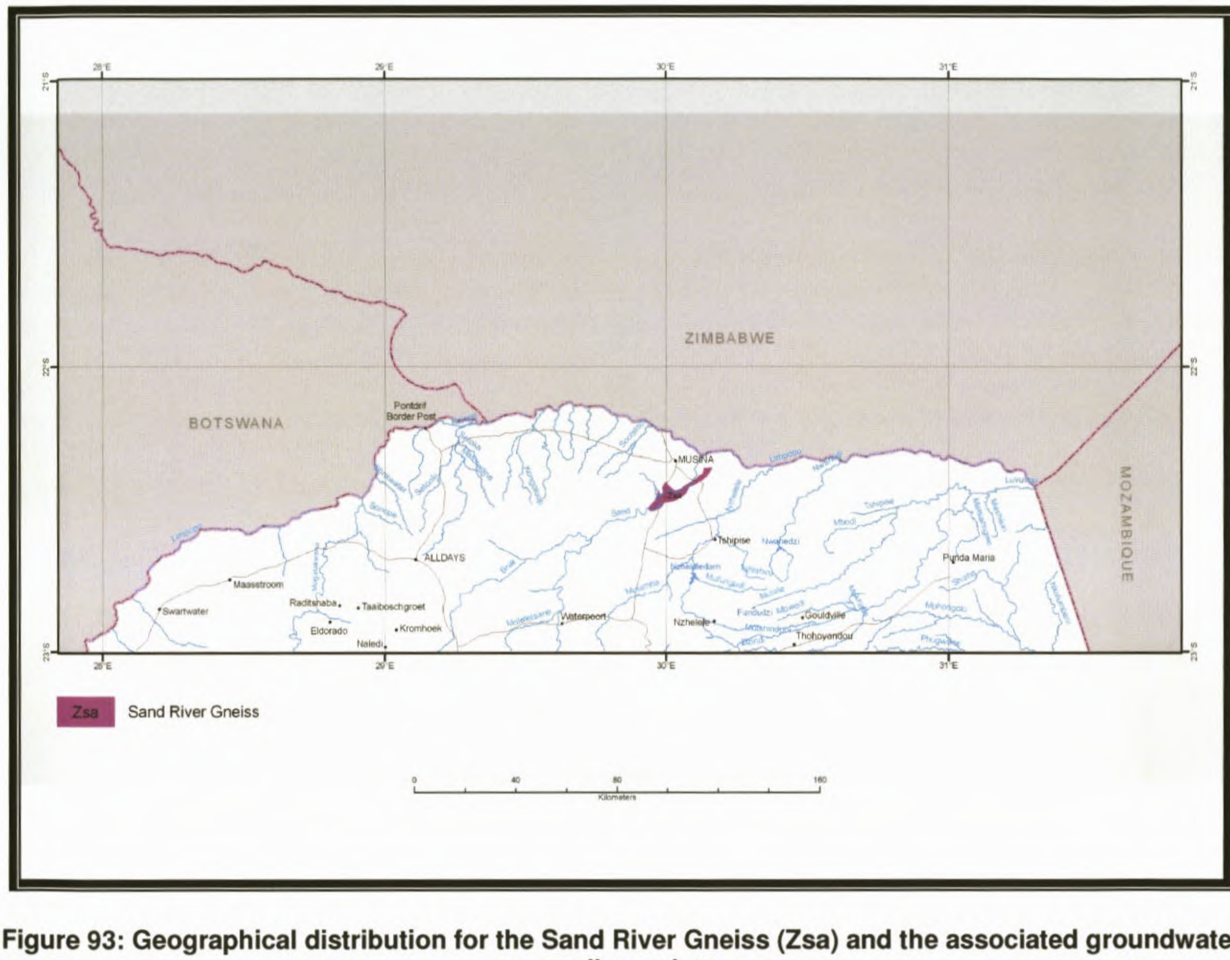


Figure 93: Geographical distribution for the Sand River Gneiss (Zsa) and the associated groundwater sampling points.

Due to a lack of data no quality and quantity assessment could be done. The unit underlies 0.36% of the total map area.

5.5.2.3.12 Goudplaats Gneiss (Zgo)

Goudplaats Gneiss underlies the south-western part of the map sheet (**Figure 94**, p144) and 4.2% of the total map area. It consists of leucocratic biotite gneiss, leucocratic granite and pegmatite, grey biotite gneiss and migmatite. Outcrop can be seen throughout the area in ephemeral stream beds and road cuttings. The gneiss can be large unfoliated masses or exhibit alternating bands of melanocratic and leucocratic material.

Small scattered enclaves of the Giyani Group are found throughout the gneisses. They include amphibolite, metaquartzite, metapelite and ultramafic rocks. The ultramafic rocks are presented by massive, greyish green serpentinite and greenish black coarsely crystalline metapyroxenite. The amphibolites generally occur as small rafts within the gneiss. Metapelite forms only one outcrop on the map area in contrast with the occurrence within the gneisses on the Polokwane map sheet. The Jerome Granite outcrops within the gneiss clearly show the intrusive nature thereof. It is fine-to medium-grained greyish, pink or reddish granite (Brandl, 1981). The above xenoliths and intrusions are not seen as good groundwater targets.

Other intrusives included numerous diabase dykes and lesser sills. Dykes predominantly strike north-east to south-west. Although these dykes are targeted in the search for groundwater it is generally not expected to be associated with high yielding boreholes. The occasional 'blokkiesklip' dykes are usually higher yielding. A field approach in the search for high yielding boreholes that must still be statistically verified is to target areas where the gneiss exhibits strong gneissose with frequent alternating bands of leucocratic and mesocratic material. Another field observation that has proved on various occasions to lead to high yielding boreholes is to look for areas with big Mopani and Leadwood trees. Additionally the possibility of recharge for the source is important. Water strikes in the area are usually between 20 and 40m relating to deep weathering and fracturing. Drilling using air percussion is usually done without any problems. On occasion highly fractured gneiss or diabase will lead to drill and drive methods. Steel casing is usually installed to depths between 24 and 48m to prevent boreholes from collapsing.

The groundwater potential of the Goudplaats Gneiss is moderate. Due to its location entirely within southern Venda and Malemulele the groundwater within this unit is widely used for rural village supply, small irrigation and livestock watering purposes. The depth to groundwater level is generally situated between 10 to 30mbgl. Water strikes are dependant on the depth of the weathered and fractured zone. Limited storage capacity makes the aquifer vulnerable to dewatering. Management in terms of the balance between abstraction and recharge must be controlled to prevent dewatering of the aquifer (Du Toit, 1998).

The yield frequency distribution diagram in **Figure 95**, (p144) gives a very good indication of the expected groundwater potential. It shows that 62% of the successful boreholes are yielding less than 2ℓ/s, 27% between 2 and 5ℓ/s and 10% yields more than 5ℓ/s. Approximately 14% of the reported boreholes were dry. Geophysical methods have been successfully employed in the search for groundwater within this unit. Groundwater targets usually include deep weathering and fracturing, faults, pegmatite zones and secondary fracturing associated with dyke intrusions. The success rate increases in areas where the gneiss exhibits strong banding and pegmatitisation.

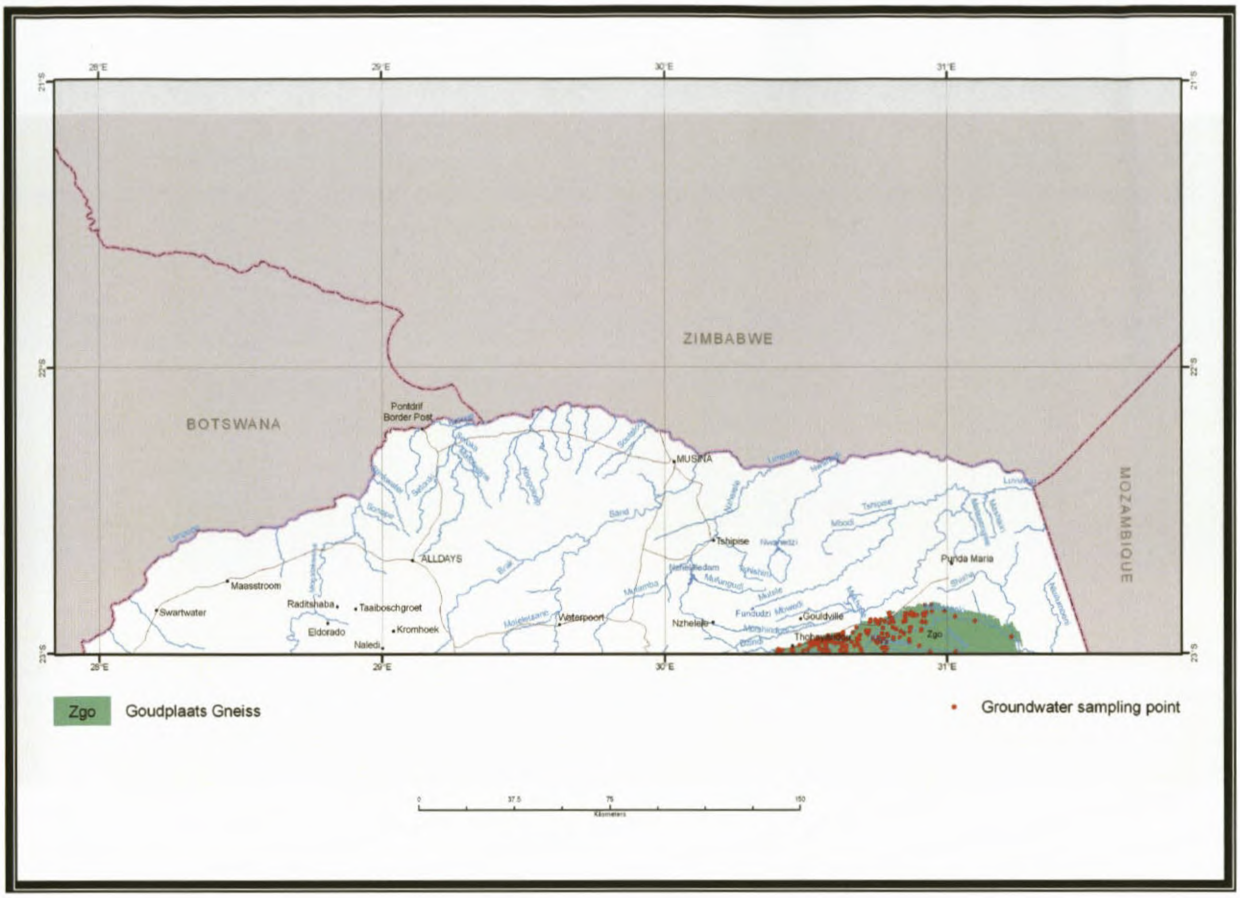


Figure 94: Geographical distribution of the Goudplaats Gneiss (Zgo) and associated groundwater sampling points.

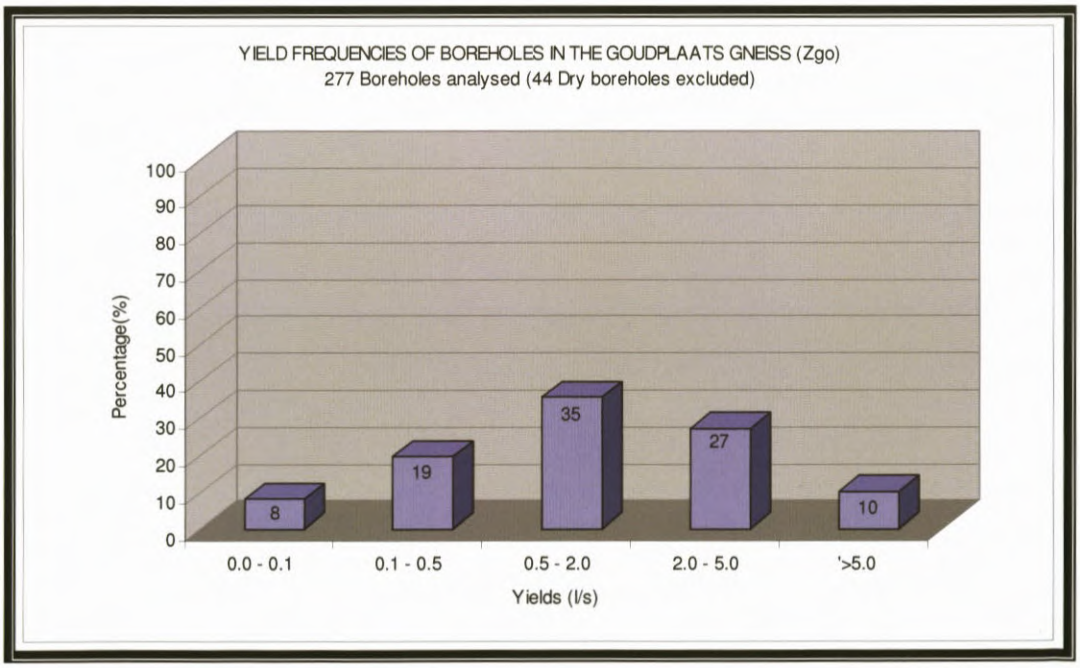


Figure 95: Yield frequency for the intergranular and fractured aquifers of the Goudplaats Gneiss (Zgo).

The quality of the water is generally good with a harmonic mean of 70.8mS/m for the EC of the unit. The EC values varies from 12 to 300mS/m, with 89.9% of the samples with values varying between ideal water quality and the acceptable limit for domestic use (EC <150mS/m). Fluoride concentrations are not a concern as it varies between 0.03 and 3mg/l with only 0.6% of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary from 0.02 to 71mg/l with 18.1% exceeding the maximum allowed limit (N >20mg/l). Overall, the water is of an ideal (27.9%) to unacceptable (18.1%) domestic water quality. The elevated nitrate concentrations can be attributed to sanitation problems as the sources plots within or near villages. The local laboratory confirmed an increase in quality problems in the area for nitrate (Andrin, personal communications, 2010). **Figure 96** shows the dominant anions and cations present. The groundwater displays a magnesium-calcium-sodium-bicarbonate character with slightly elevated chloride concentrations.

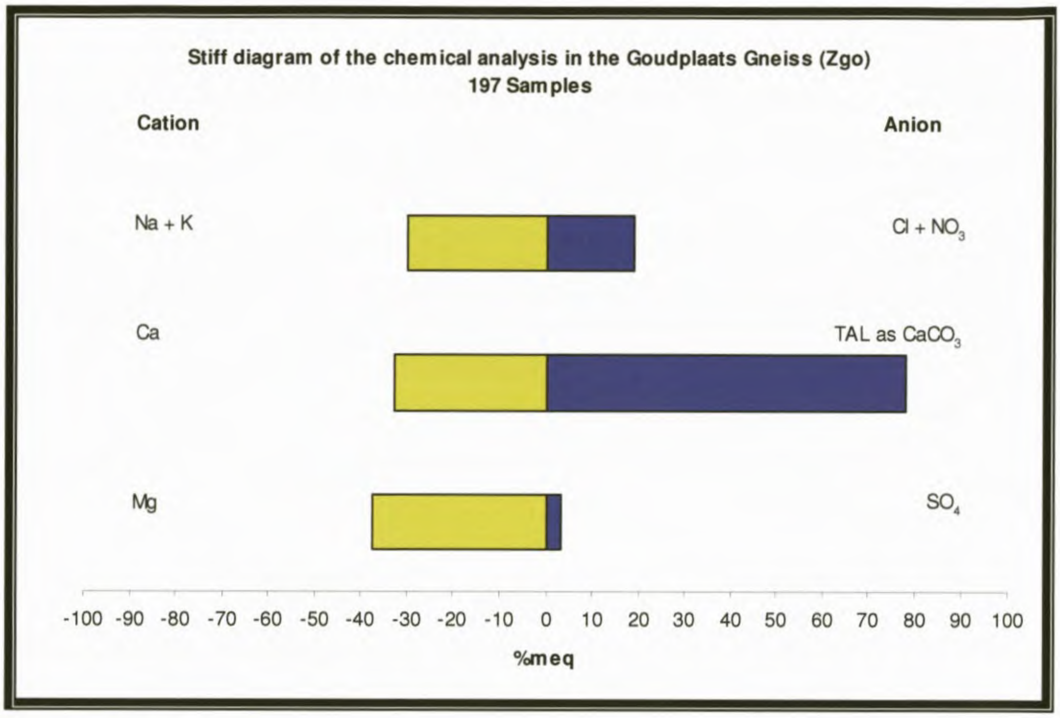


Figure 96: Stiff diagram representing chemical analysis of the Goudplaats Gneiss (Zgo).

5.5.2.3.13 The Beit Bridge Complex (Z)

The Beit Bridge Complex forms part of the central zone of the Limpopo Metamorphic Belt and is broadly subdivided into the ***Mount Dowe***, ***Malala Drift*** and ***Gumbu Groups*** *(Brandl, 1981)*. It underlay 38.53% of the map area. The data available is believed to underestimate the total of dry and low yielding boreholes drilled in the area.

The complex geology of the Beit Bridge Complex around Mussina is best seen south of the town in the Messina Nature Reserve which is an area well known for its many spectacular ancient baobab trees. Here the high-grade metamorphic gneisses of the complex show incredible patterns of ductile deformation and are best seen in the bed of the usually dry Sand River. This world-famous and accessible geosite is located close to the road bridge along the R508 to Tshipise approximately some 8km south-east of Mussina.

In the south-western sector of the map sheet and more specifically in the Swartwater and Beauty areas various geological lineaments namely granophyre dykes, amphibolite dykes, diabase dykes, dolerite dykes and fault and/or shear zones were observed. This area is located within the central part of the Limpopo Mobile Belt. Dominant strike directions in the Swartwater area are north-east to south-west and east to west in the Beauty area (Bush, 1989).

From a study done in the Swartwater area linear features such as dolerite and diabase dykes do not possess favourable geohydrological properties and should not be considered target zones for drilling. It was found that dyke/host rock contacts are usually devoid of fracturing, that those fractures that occur at the contact or within the dyke itself are in filled with calcareous or other deposits. In some cases the infilling of fractures is associated with poor yielding boreholes in favourable hydrogeological areas. It was concluded that zones of fracturing, shearing or faulting form favourable target zones for groundwater exploration in regions where rest water levels do not exceed 35m. At depths greater than this the probability of intersecting open cracks and fissures is reduced despite the fact that jointing/fracturing usually extends to these levels. From a hydro census done in the area followed by a geophysical survey undertaken across 147 boreholes indications are that the deepest weathering in the area extends to 43m, although the semi-weathered or transitional zone may extend to 54m. On average the depth of weathering ranges from 18 to 30m. There is no evidence of any favourable fracturing, jointing or weathering occurring at the contacts between any of the lithological rock types in the Swartwater area. There is also no evidence of such features occurring within gneissic banding. All contacts were found to be welded or transitional in nature, a consequence of metamorphism (Bush, 1989).

5.5.2.3.13.1 Gumbu Group (Zbg)

The **Gumbu Group** consists of marble and calc-silicate rocks with minor metaquartzite, quartzo-feldspathic gneiss, metapelite and amphibolite. The Marble and calc-silicate rocks are intimately associated, and are often seen to give rise to a number of prominent horizons. They form positive features due to the relatively dry climate of the area. Whereas the calc-silicate rocks generally give rise to narrow steep features, the marbles form rather wide, low ridges that are often covered by calcrete. The group occupies the smallest area within the Beit Bridge Complex but is still underlying 4.22% of the map area.

The *marble* is a medium-to coarse-grained, often massive re-crystallized rock which weathers to a blackish grey or dark brown skin on which the more resistant accessory minerals stand out as small protuberances. The colour of fresh specimens can range from milky white through light grey to bluish grey and locally an attractive pink colour is developed. Colour generally depends on the amount of the accessory minerals present and where these accessories are more abundant the marble attains a rather banded appearance showing gradations into a calc-silicate rock. Maximum thickness of individual marble horizons is at least 20m. The marble consists mainly of interlocking grains of calcite/dolomite which average 0.5 to 3mm in size but can range up to 20mm. The accessory minerals can reach up to about one third of the rock and consist mainly of olivine, pyroxene, biotite, spinel and amphibole. Pure white marble is rare, the most common marble type being an olivine marble in which the olivine (forsterite) is variously altered to antigorite. Grain size of the olivine is generally much smaller than that of calcite/dolomite, but occasionally grains can be up to 6.0mm. Geochemical analyses indicate that the precursors of the marbles were pure to slightly impure carbonates. Some carbonate horizons are almost entirely calcite whereas others can be entirely dolomite (Counsil for Geoscience, 2009).

Calc-silicate rocks generally intimately associated with marble, where they occur as narrow discontinuous horizons. The horizons rarely exceed a width of 10m. The rocks regularly exhibit a strong lineation with an unusual gradation along strike into amphibolite at places. The calc-silicate rock is dark to pale grey or greenish when fresh, but weathers into a light brown, pitted or grooved surface which is caused by the differentiated weathering of the silicate- and carbonate-rich bands. Regionally the calc-silicate rocks within the map area consist of a great variety of mineral phases. They generally include clinopyroxene, quartz, microcline, scapolite, calcite/dolomite, plagioclase and minor opaques. Grains sizes up to 6mm in length were observed. The origin of the carbonates is not clear but might be due to organically induced carbonate precipitation most probably in the form of aragonite. The relatively high MgO content of some marbles was probably caused by later selective dolomitisation. Protolith of the calc-silicate rocks was calcareous shale with variable carbonate content (Counsil for Geoscience, 2009).

Groundwater occurs mainly in faults and associated shear zones as well as fractured contact zones between mafic and acidic rocks and dyke contacts. The Complex has, in general, a low groundwater potential. The yield frequency diagram (**Figure 98**, p148) shows that 75% of the successful boreholes yield less than 2ℓ/s.

Due to the low and erratic rainfall (350 to 450mm/a) in this area, together with periodical droughts and the dense vegetation in places, recharge events are very irregular. These factors, together with abstraction contributed significantly to the generally deep water levels (30 to 60m) occurring in the area (Bush, 1989).

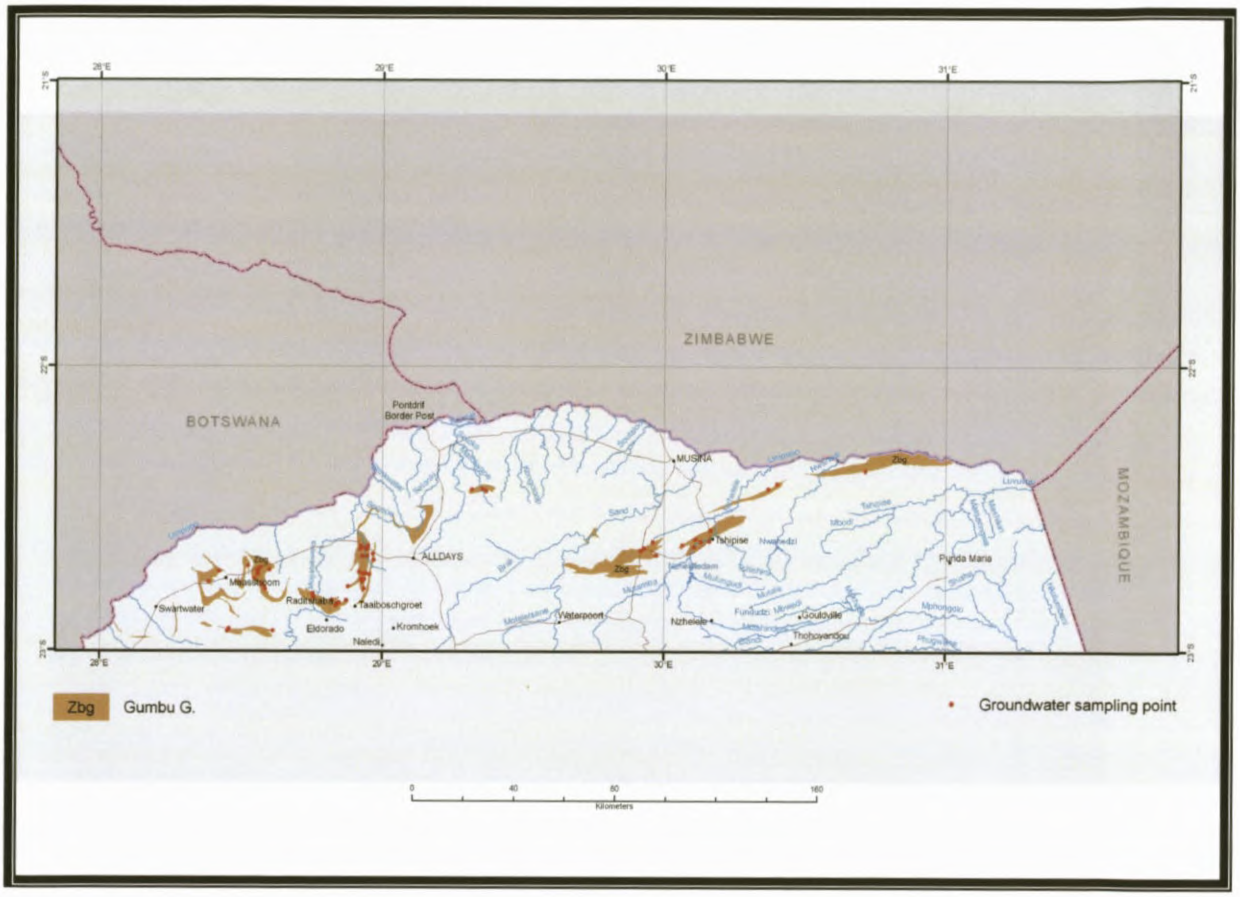


Figure 97: Geographical distribution of the Gumbu Group (Zbg) and associated groundwater sampling points.

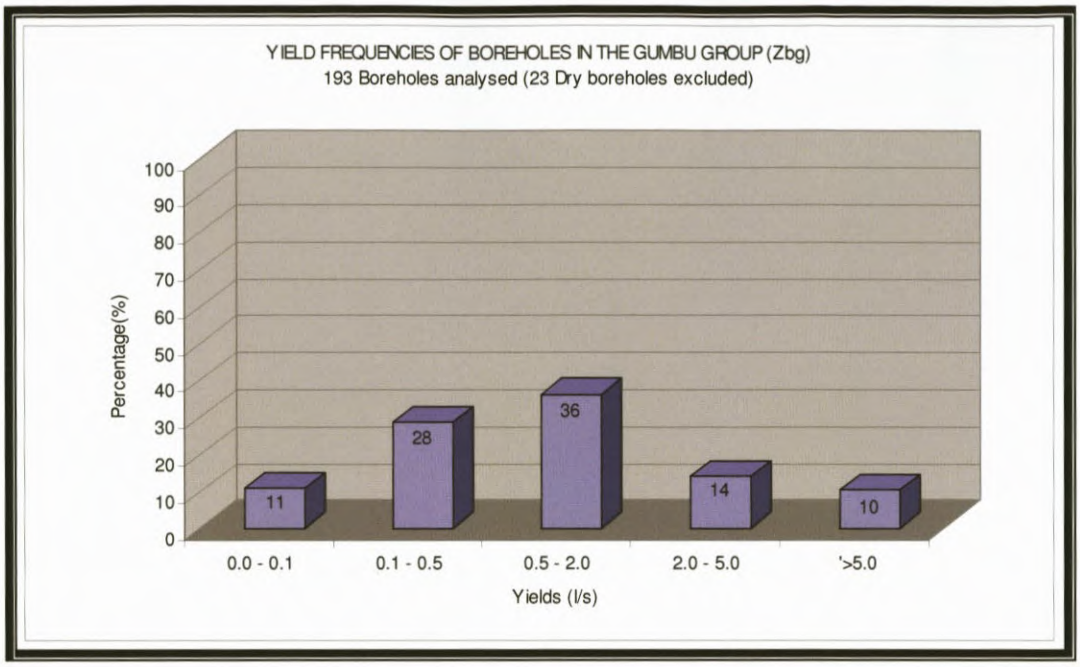


Figure 98: Yield frequency for the intergranular and fractured aquifers of the Gumbu Group (Zbg).

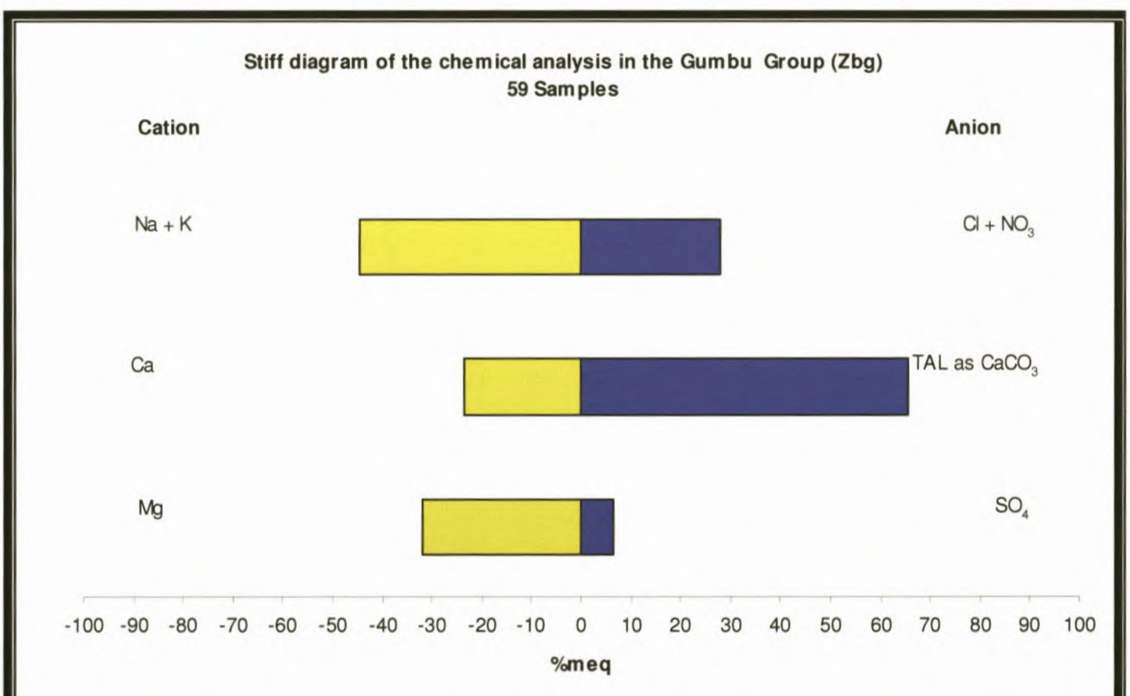


Figure 99: Stiff diagram representing chemical analysis of the Gumbu Group (Zbg).

Chemical data for the unit is represented in a stiff diagram (**Figure 99**). The water exhibits a sodium-magnesium-bicarbonate water type with elevated calcium and chloride concentrations. Magnesium concentrations vary between 22 to 1016mg/l, with 39% exceeding the maximum allowed limit (Mg >100mg/l). EC values vary between 80 and 1560mS/m with a harmonic mean of 156mS/m. Note that the harmonic mean gives lower values compared to the arithmetic mean. In 18.6% of the analysis the EC values exceeds the maximum allowed limit (EC >370mS/m) for domestic use. Fluoride concentrations vary between 0.05 to 4mg/l with 25.4% of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary between

0.04 to 105mg/l with 29.3% exceeding the maximum allowed limit (N >20mg/l). In 18.6% of the samples sodium (Na >400mg/l) concentrations, 39% of the magnesium (Mg >100mg/l) and 22% of the chloride (Cl >600mg/l) concentration exceed maximum allowable limits for domestic use. The domestic water quality is ideal (1.7%) to unacceptable (39%), (Table 12, 13 and 14, pp86-88). The water is mainly used for livestock watering and domestic purposes with limited irrigation.

5.5.2.3.13.2 Malala Drift (Zba)

The ***Malala Drift Group*** underlies extensive parts of the Central to western zone of the map (**Figure 100**, p150) and consists predominantly of leucocratic quartz-feldspathic gneisses (leucogneiss), metaquartzite, pink granitoid hornblende gneiss, felsic granulite, metapelite, amphibolite or mafic granulite and marble or calc-silicate rocks occur as subordinate intercalations. The most extensive of the Beit Bridge Complex and all the units in the map sheet underlay 21.75% of the map area.

The *quartz-feldspathic gneiss* is by volume the most common rock-type of the Central Zone, estimated to constitute ±50% of the gneisses. However, exposures are in general poor. Overburden is often consisting of thin immature soil containing abundant quartz and feldspar. The gneiss is medium to coarse-grained, in places pegmatitic, whitish, whitish-grey, or locally pinkish. Where no ferromagnesian minerals are developed, the rock is massive and may form prominent scattered outcrop. In places the rock is well foliated with fabric defined by the parallel orientation of the platy minerals or the dimensional orientation of quartz "ribbons". The dominant minerals in the gneiss is quartz and feldspar (80 to 90%) occurring more or less equally. The feldspars include orthoclase, microcline and plagioclase with the proportions of K-feldspar and plagioclase varying widely. Minor minerals include garnet, biotite, hornblende and sillimanite representing different phases of metamorphism. Most of the quartz-feldspathic gneisses are presently interpreted to represent intrusive granitoid rocks (Counsil for Geoscience, 2009).

Layers of *amphibolite* are rarely developed and generally not wider than 100m. In hand specimens the amphibolite is bluish black or brownish depending on the percentage pyroxene. Amphibolite can exhibit a typically speckled appearance. Texturally, two main varieties can be distinguished: a fine to medium-grained type and a coarse-grained one. The latter forms massive outcrops generally with no intercalations of other supracrustal gneisses. The major constituents of the amphibolite are plagioclase, hornblende, clinopyroxene, hypersthene, quartz and biotite. Garnet is a major constituent restricted to a few units and is often associated with thin felsic bands. Major units of garnetiferous amphibolite are rarely developed. Hornblende can be up to 6mm in length, is greenish or olive brown, and occasionally overgrown by hypersthene or partially replacing pyroxene. Plagioclase is mainly andesine and generally shows zoning and partial alteration to sericite and epidote. Biotite occurs either as relatively large subidioblastic grains or as an alteration product along fractures in hornblende. Garnet that can measure up to 20mm across is poikiloblastic displaying numerous inclusions of generally quartz and plagioclase. The supracrustal amphibolites with a relatively small grain size can be of igneous extrusive (basaltic lava) or sedimentary (marly sediment). The amphibolites of sedimentary origin are probably those forming thin bands and which are intimately interlayered with clastic and calcareous rocks. Amphibolites forming layers of considerable thickness with a consistent appearance are interpreted to represent mainly basaltic lavas. The coarse-grained amphibolites are thought to have derived from gabbroic sills or stocks (Counsil for Geoscience, 2009).

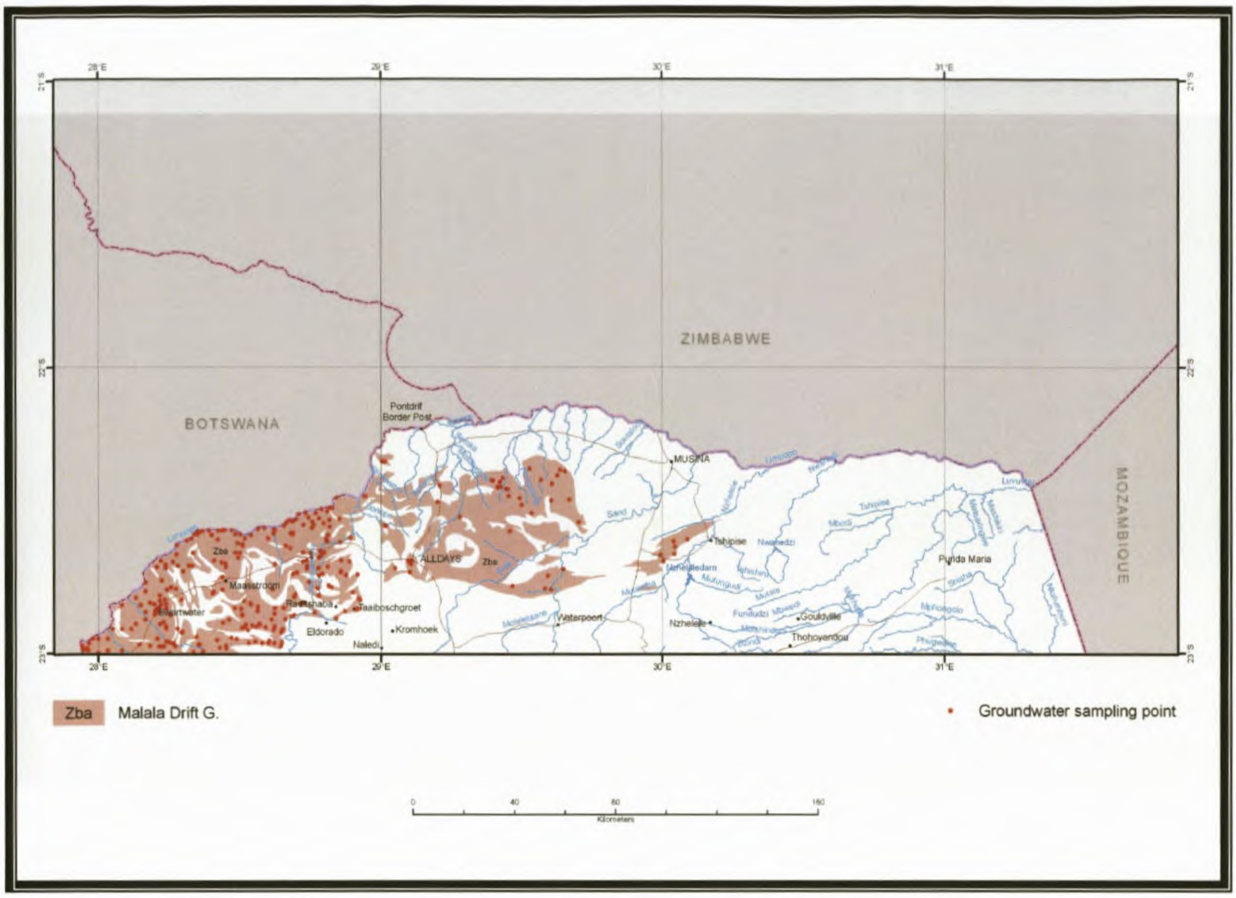


Figure 100: Geographical distribution of the Malala Drift Group (Zba) and associated groundwater sampling points.

In the Swartwater area a study found that groundwater levels are between 6 to 24mbmg. The deepest groundwater levels are located at major surface water divides or at high lying areas. The depth to weathering varies within the area but it is mostly less than 30m as was observed in new boreholes drilled for the project. In some areas however, weathering extends to a depth of 43m although semi-weathered or transitional zone material may extend to 54m. Where groundwater levels extend to below the base of the weathered zone, groundwater is obtained from deeper fractured horizons (Bush, 1998).

Another study done in the Swartwater area determined that it is unlikely to have any significant lateral groundwater flow (Vegter, 1988). The regional groundwater levels largely mimic the surface water flow pattern.

The groundwater potential of these gneisses and amphibolites is generally low. Approximately 77% of the successful boreholes yield less than 2ℓ/s (**Figure 101**, p151) although only 4% of the recorded boreholes were dry. It was concluded by Bush (1998) that the low yielding and dry boreholes were not always reported when drilled and that the total number of dry boreholes are more than recorded on the database. From the available data the average static water level for the unit is shallow (<9mbgl). Groundwater is mainly used for livestock and domestic purposes although some irrigation takes place using boreholes. Surface water is used for irrigation along the Limpopo and Magalakwena rivers.

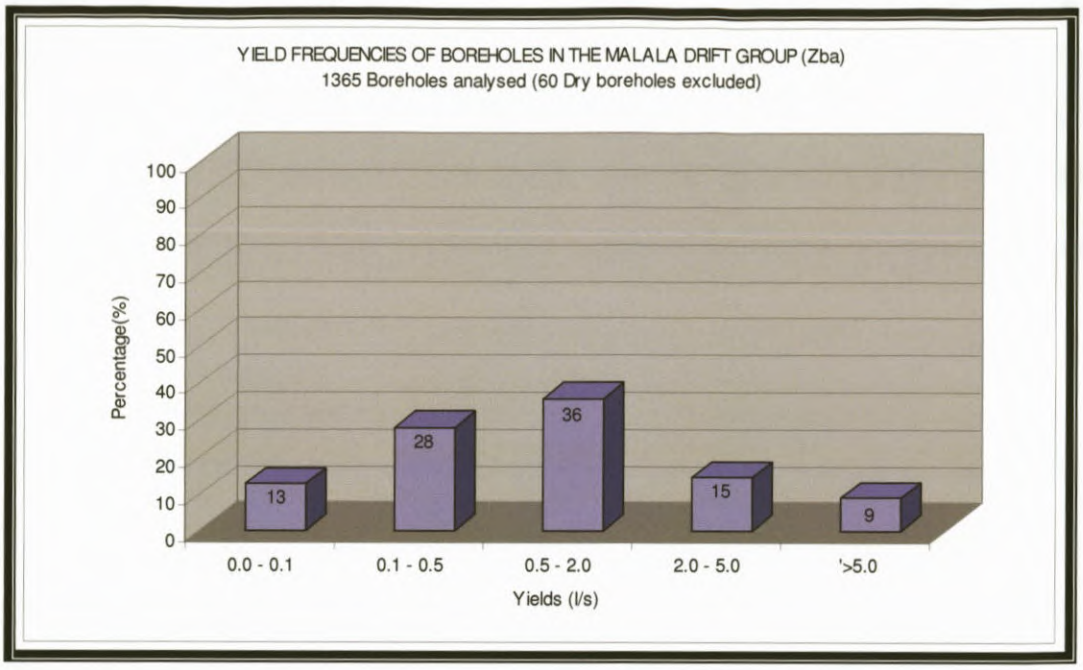


Figure 101: Yield frequency for the intergranular and fractured aquifers of the Malala Drift Group (Zba).

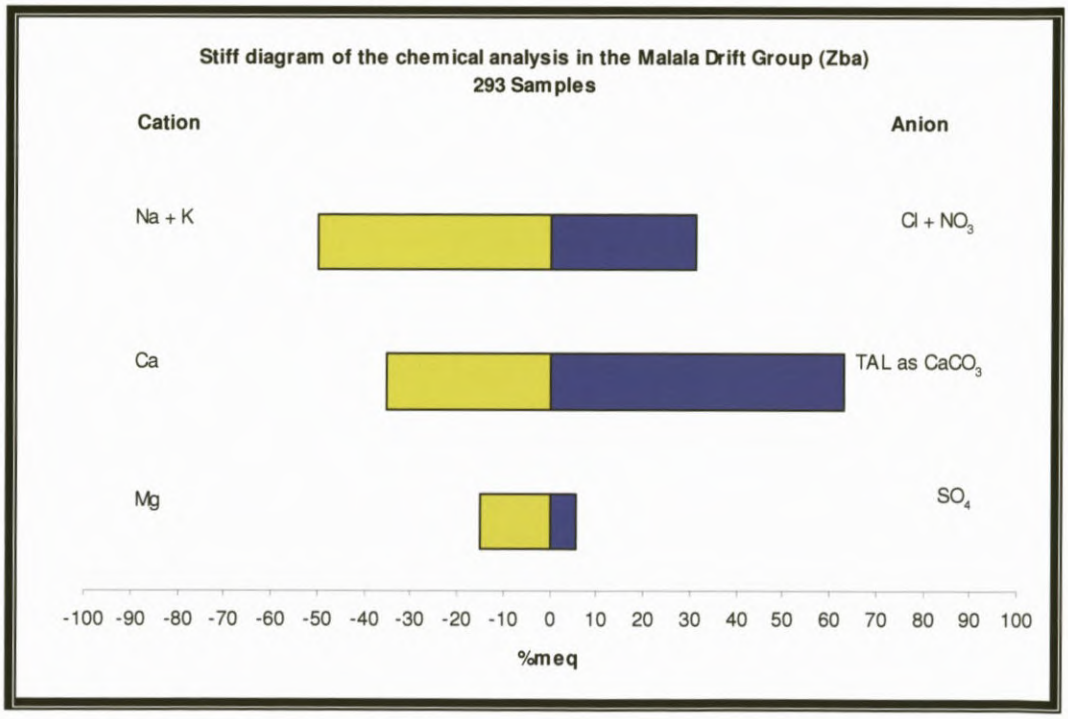


Figure 102: Stiff diagram representing chemical analysis of the Malala Drift Group (Zba).

The stiff diagram (**Figure 102**) shows the broad classification according to anions and cations. The water exhibits a sodium-calcium-bicarbonate water type with high chloride concentrations. The analysis of cations indicates no dominance of any particular cation although the extension of the field towards the Na and K suggest that a certain amount of natural base exchange may be taking place. The plot of anions indicates a variation in dominance from CO3 + HCO3 to Cl + SO4 anions. The above trends are best explained by natural variability in the hydrochemistry of the water due to differing residence times in the case of cations and sulphate reduction in the case of anions. Nitrate and nitrite concentrations (reported as N) are exceeding the maximum allowed limit in 29.7% of the samples (N >20mg/l). Fluoride concentrations exceed the maximum allowed limit in 23% (F >1.5mg/l) and magnesium in 11.3% (Mg >100mg/l) of the samples. The water quality is moderate with EC values ranging from 2.3 to 760mS/m and the harmonic mean calculated as 88mS/m. This is well within the acceptable limit (EC <150mS/m) for domestic use. Note that the harmonic mean gives lower values compared to the arithmetic mean. Overall the groundwater quality is ideal in only 3.4% and unacceptable in 29.7% of the samples.

5.5.2.3.13.3 Mount Dowe Group (Zbo)

The ***Mount Dowe Group*** 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. It underlies 12.15% of the map area.

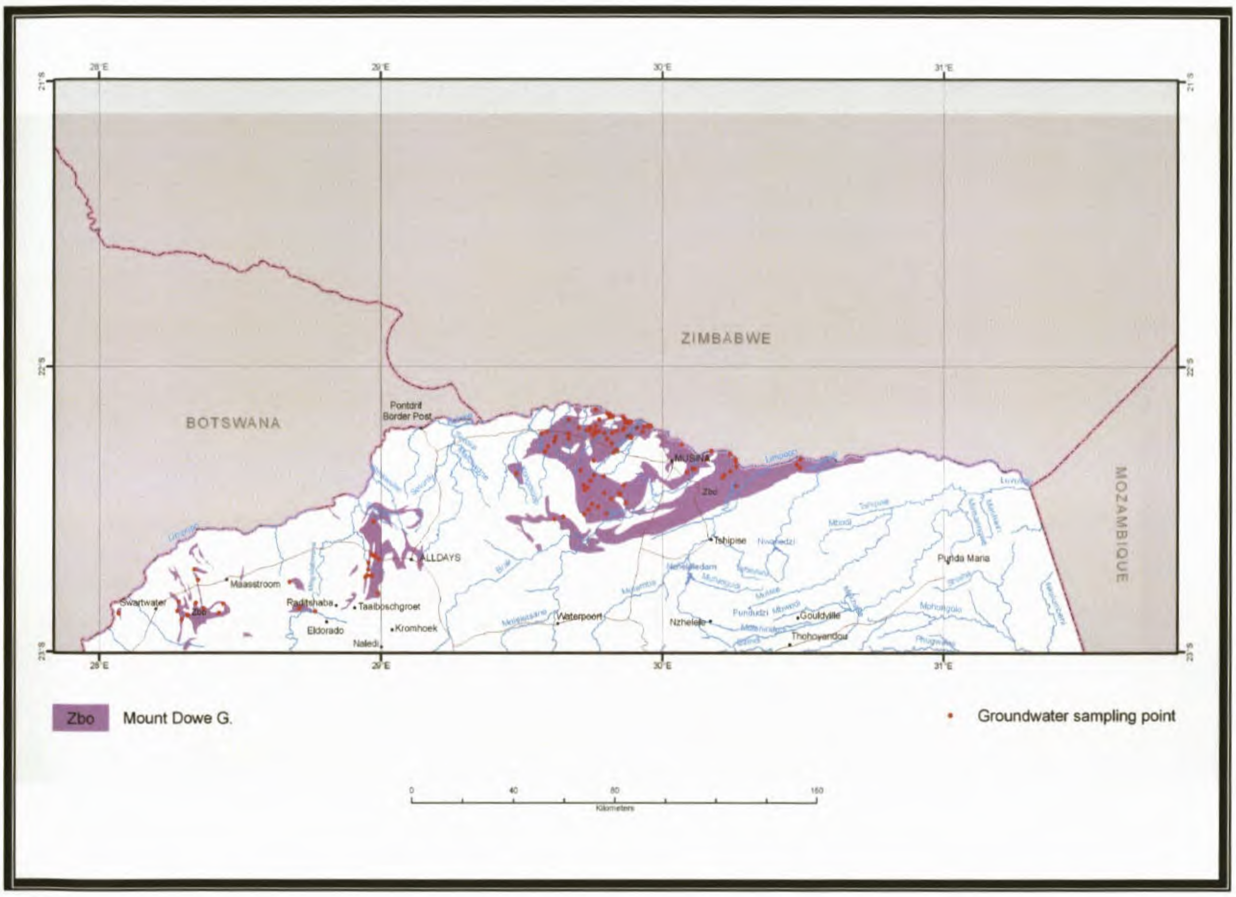


Figure 103: Geographical distribution of the Mount Dowe Group (Zbo) and associated groundwater sampling points.

Owing to its highly resistant nature, *metaquartzite* forms the main topographic features in the map area underlain by rocks of the Beit Bridge Complex. These features can be followed for many kilometres across the area and the steep slopes are often littered by large blocks and scree. The width of individual horizons probably does not exceed 50m. The rock is generally massive, medium- to coarse-grained, and where fresh it is predominantly of a milky to greyish white colour but pinkish, greenish or brownish varieties do occasionally occur. As the metaquartzite is in general largely recrystallized it frequently assumes the appearance of vein quartz. Well developed joint systems can often be seen in the competent rock. The metaquartzite is entirely recrystallized and consists of an interlocking mosaic of mainly quartz grains which show undulose extinction or extinction bands. Grain boundaries are often strongly sutured. Individual grains can be up to 5mm in length but are generally around 3mm. Minor constituents of the massive variety include plagioclase, K-feldspar, pyroxene, grunerite and garnet. In addition to the common massive metaquartzite, foliated varieties can locally be developed in which the fabric is accentuated by biotite, muscovite, fuchsite or sillimanite. Foliation planes, spaced from a few millimetres to several centimetres, may represent original bedding planes. Biotite-bearing metaquartzite is the most common foliated variety and is mostly observed where metaquartzite grades into metapelitic rocks. Most of the metaquartzite, at least the fairly thick layers are interpreted to be of sedimentary (quartz arenite) rather than of chemical (chert) origin. The complete lack of coarse material and the often observed association with marble may indicate that the metaquartzite represents mainly a marine shelf deposit with the adjacent hinterland having been a low lying stable land surface (Counsil for Geoscience, 2009).

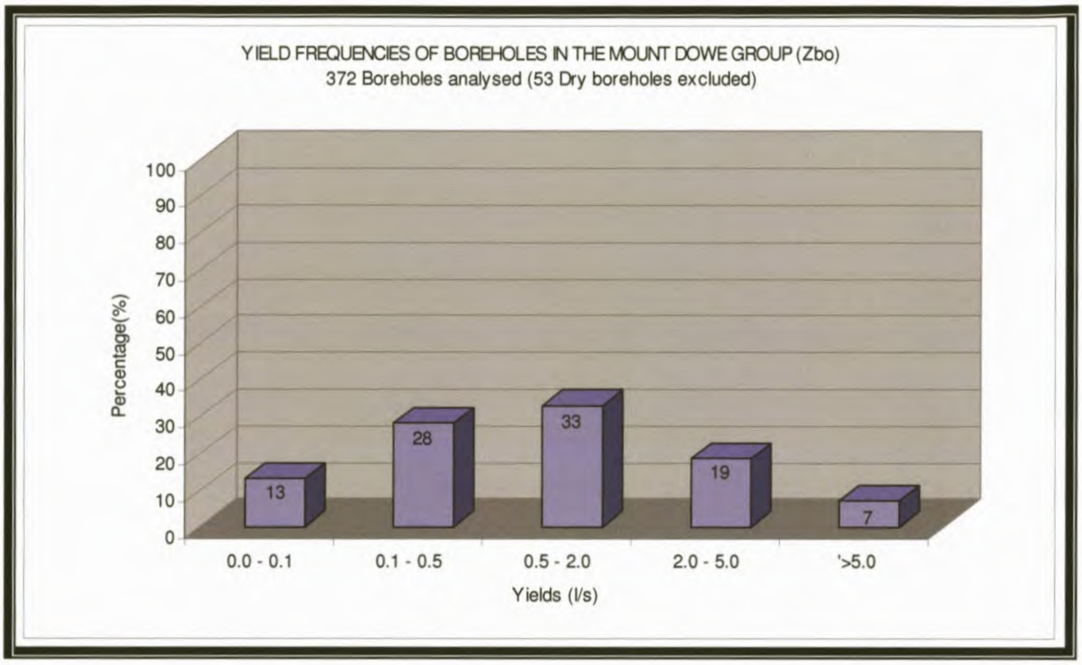


Figure 104: Yield frequency for the intergranular and fractured aquifers of the Mount Dowe Group (Zbo).

Analysis of the yield frequency diagram (**Figure 104**) shows that 74% of the sources yielding less than 2ℓ/s, 7% yields more than 5ℓ/s and 12% are reported as dry.

The water quality is moderate to poor with EC values ranging from 38 to 1140mS/m with the harmonic mean calculated as 130.6mS/m. Take note that the calculation of the harmonic mean results in a lower value as when using the arithmetic mean. Nitrate and nitrite (reported as N) concentrations ranges from 0.02 to 71mg/l. In 26.7% of the samples nitrate exceeds the maximum allowable limit (N >20mg/l). Fluoride concentrations range from 0.22 to 4.2mg/l. In 32.5% of the samples fluoride (F >1.5mg/l) exceeding the maximum allowed limit. In 22.5% of the samples magnesium (Mg >100mg/l) and in 10% sodium (Na >400mg/l) exceeds the maximum allowable limits. Overall, the domestic water is of ideal quality in only 5% and unacceptable in 32.5% of the samples. The groundwater exhibits a sodium-magnesium-bicarbonate-chloride character. Groundwater from this Group is mainly abstracted for livestock watering, game farming and domestic purposes and, to a limited extent, for irrigation.

Groundwater occurs in faults and associated shear zones, fractures related to quartz veins, deep weathered zones and pegmatites. Secondary fractures related to intrusive dykes are targeted with varying success (Bush, 1998).

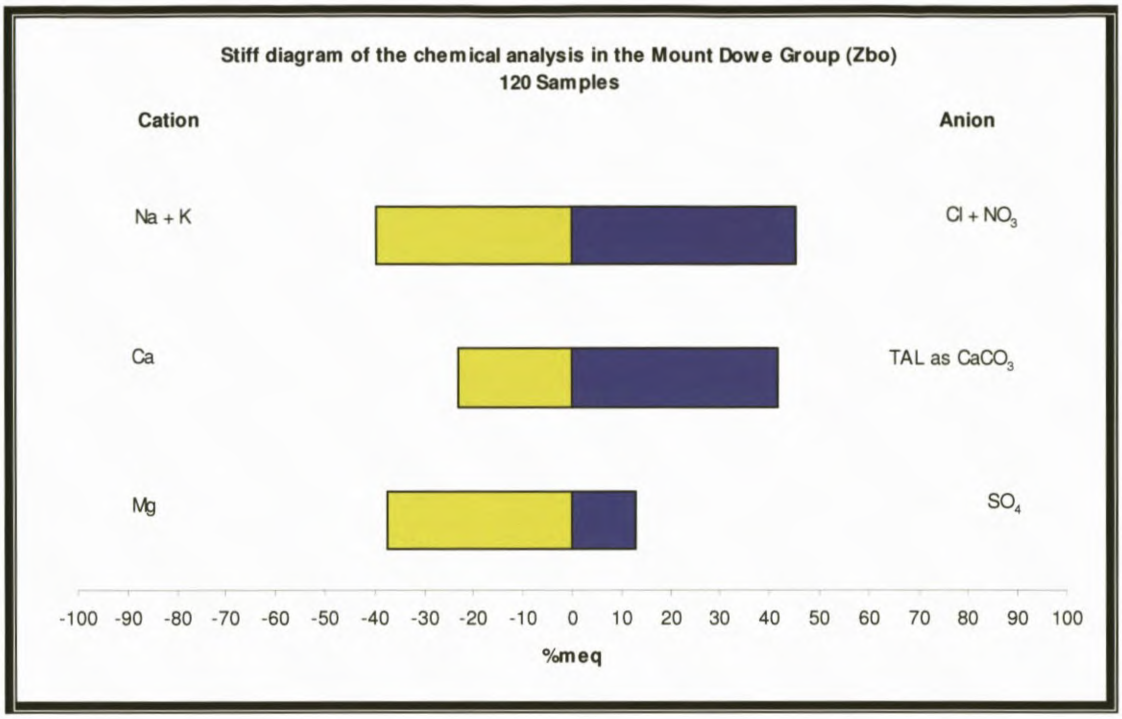


Figure 105: Stiff diagram representing chemical analysis of the Mount Dowe Group (Zbo).

5.6 Summary

- This document represents the findings and research done on the occurrence of groundwater within the Limpopo Province, north of latitude 23ºS. It is essentially a desk study.
- The aerial extent of the study area covers a surface area of 24,989km². Based on some degree of lithologic homogeneity and similarities in rock properties the area was sub-divided into 29 hydrogeological units.
- Based on the occurrence of groundwater in interstices (intergranular, fractured, intergranular and fractured) the hydrogeological units were grouped together and discussed individually, regarding locality, extent, geology, quality and quantity.
- The Terrain Morphology within the area is a direct function of the regional geology and structural history of the area.
- The most prominent elevated feature is the east-west-trending Soutpansberg Mountain. Faulting is responsible for the structural repetition of the Soutpansberg Supergroup giving rise to consecutive mountains and valleys.
- Areas underlain by basement gneisses and rocks of the Karoo Supergroup are characterized by undulating to irregular plains.
- Surface drainage is a function of the rainfall and topography. The highest precipitation occurs within the Soutpansberg and immediate surroundings. North of the Soutpansberg mountain range drainage is north-easterly towards the Limpopo River. South of the mountain range drainage is south-easterly towards the Shingwidzi River.

- The mean annual evaporation follows the rainfall pattern to some extent, with the lowest evaporation within the Soutpansberg (1300 to 1400mm) increasing almost in concentric rings towards the north and west to reach a maximum of >2000mm/a.

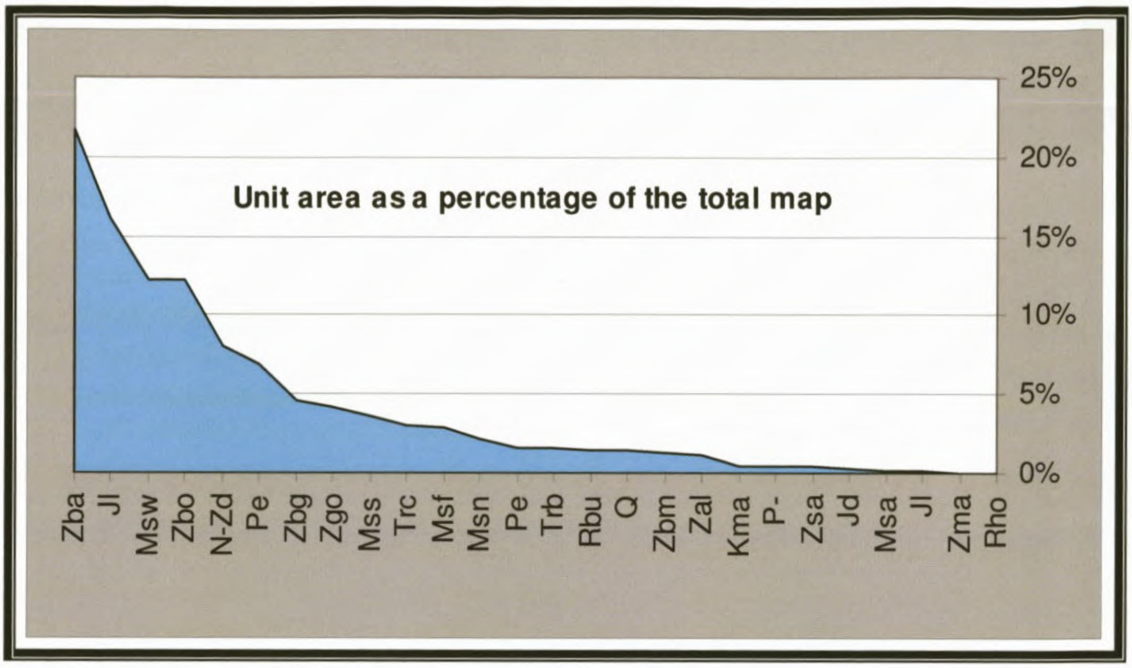
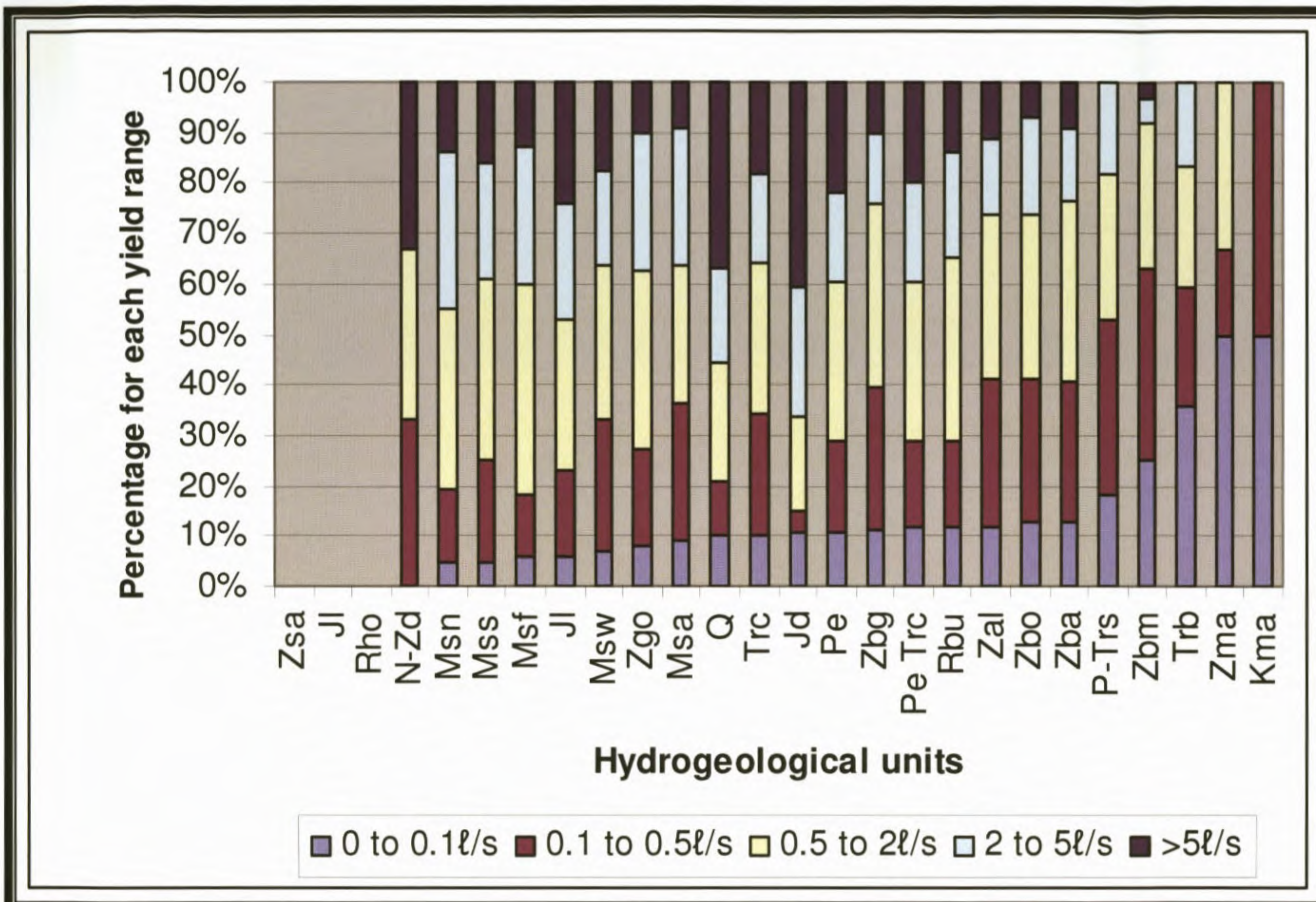


Diagram 1: Hydrogeological unit area as a percentage of the total map.

The hydrogeological unit covering the largest area within the study area is the Malala Drift Group (Zba); Houtriver Gneiss is almost irrelevant to the area.

Diagram 2: Total number of dry and wet boreholes in the study area.

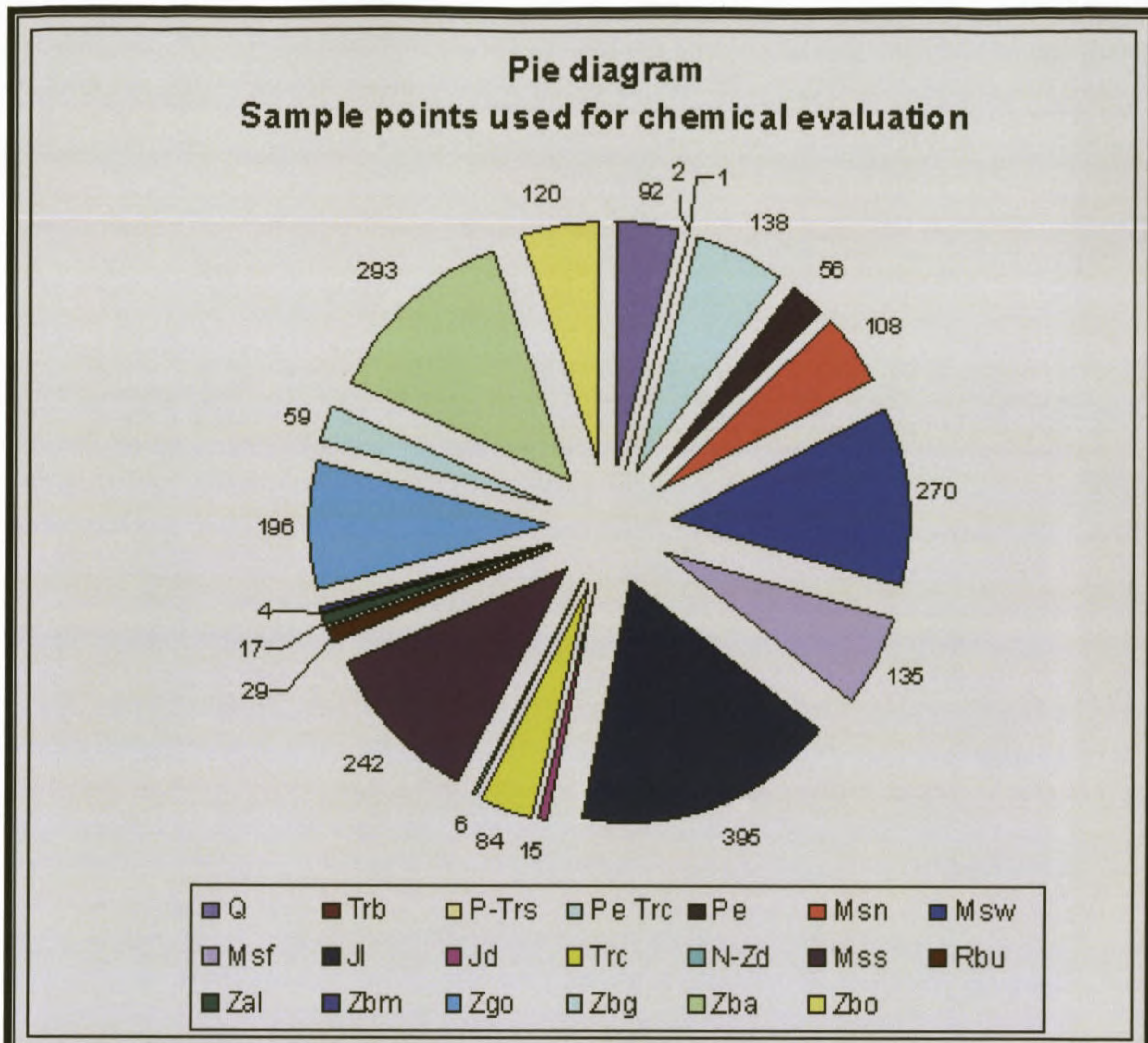
The highest number of boreholes recorded occurs within the Malala Drift Group (Zba). During the research phase of the study it became apparent that a high number of unsuccessful or low yielding boreholes drilled were not recorded on the National Groundwater Archive. Only 10% of the boreholes drilled in the Swartwater and Beauty (underlain by rocks of the Beit Bridge Complex) areas were found. The above diagram is a reflection of available data.



Note: (Q:Tertiary-quaternary alluvial deposits), (Kma: Malvernia F), (Jl: Jozini Fe), (Trb: Bosbokpoort F), (P-Trs: Solitude F), (Pe: Ecca Group), (Msn: Nzhelele F), (Msw: Wyllies Poort F), (Msf: Fundudzi F), (Jl: Letaba F), (Jd: dolerite), (Trc: Clarens F,) (N-ZD: diabase), (Mss: Sibasa F), (Msa: Stayt F) (Rbu: Bulai Gneiss), (Rho: Hout Rivier Gneiss), (Zal: Aldays Gneiss), (Zbm: Messina Suite), (Zma: Mediapala Syenite), (Zsa: Sand River Gneiss), (Zgo: Goudplaats Gneiss), (Zbg: Gumbu Group), (Zba: Malala Drift Group) (Zbo: Mount Dowe Group)

Diagram 3: Yield distribution (ℓ/s), in hydrogeological units based on five yield ranges. Dry boreholes not included.

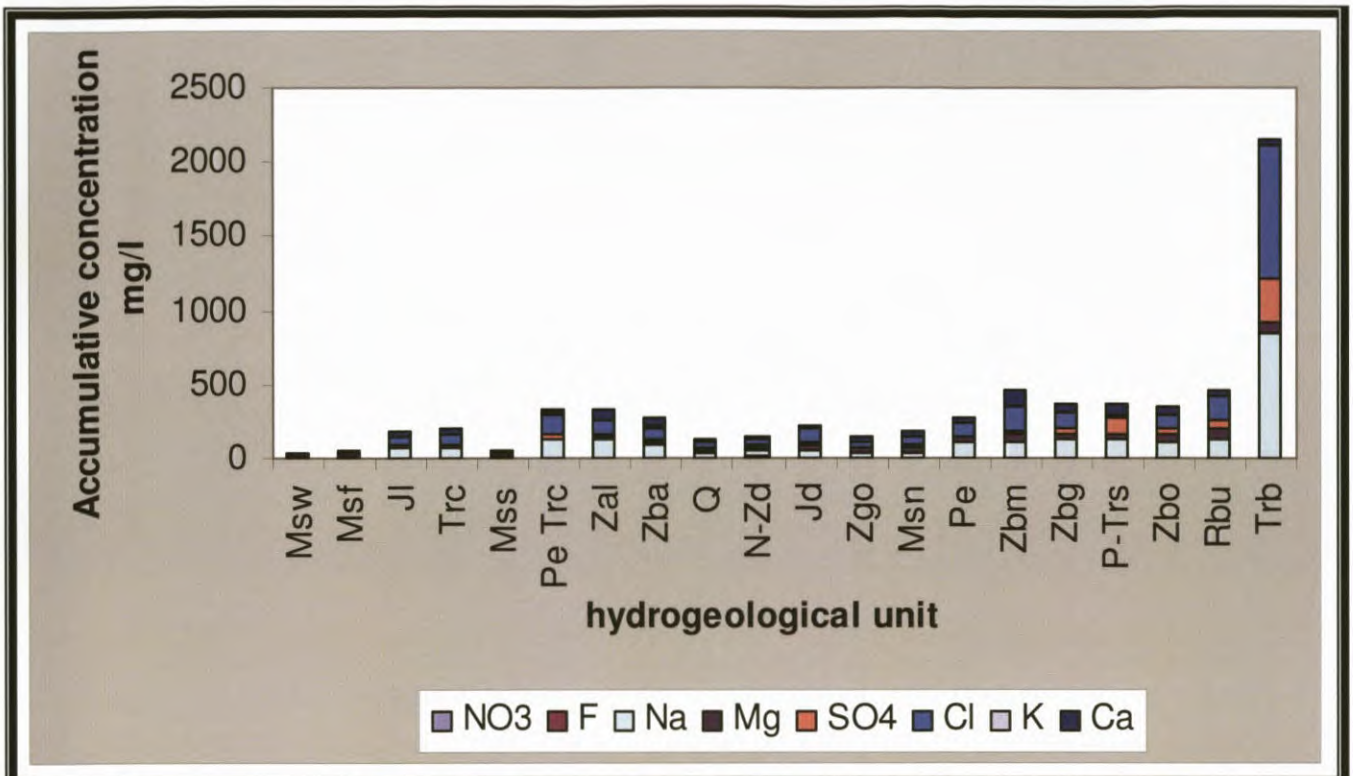
Diagram 3 shows the relation between the five productivity ranges for each hydrogeological unit. The ranges is <0.1ℓ/s, 0.1-0.5l/s, 0.5-2l/s, 2-5l/s and >5ℓ/s. Not enough data points were available for the Malvernia Formation (Kma) to give an accurate representation of possible yield distribution.



Note: (Q:Tertiary-quaternary alluvial deposits), (Kma: Malvernia F), (Jl: Jozini Fe), (Trb: Bosbokpoort F), (P-Trs: Solitude F), (Pe: Ecca Group), (Msn: Nzhelele F), (Msw: Wyllies Poort F), (Msf: Fundudzi F), (Jl: Letaba F), (Jd: dolerite), (Trc: Clarens F,) (N-ZD: diabase), (Mss: Sibasa F), (Msa: Stayt F) (Rbu: Bulai Gneiss), (Rho: Hout Rivier Gneiss), (Zal: Aldays Gneiss), (Zbm: Messina Suite), (Zma: Mediapala Syenite), (Zsa: Sand River Gneiss), (Zgo: Goudplaats Gneiss), (Zbg: Gumbu Group), (Zba: Malala Drift Group) (Zbo: Mount Dowe Group)

Diagram 4: Pie diagram showing the total sample points in each unit that were available for chemical evaluation.

Diagram 4 gives an indication of the number of chemical analysis available for evaluation in each hydrogeological unit. In some of the hydrogeological units not enough chemical analysis are available to accurately characterize the groundwater chemistry.



Note: (Q:Tertiary-quaternary alluvial deposits), (Kma: Malvernia F), (Jl: Jozini Fe), (Trb: Bosbokpoort F), (P-Trs: Solitude F), (Pe: Ecca Group), (Msn: Nzhelele F), (Msw: Wyllies Poort F), (Msf: Fundudzi F), (Jl: Letaba F), (Jd: dolerite), (Trc: Clarens F,) (N-ZD: diabase), (Mss: Sibasa F), (Msa: Stayt F) (Rbu: Bulai Gneiss), (Rho: Hout Rivier Gneiss), (Zal: Aldays Gneiss), (Zbm: Messina Suite), (Zma: Mediapala Syenite), (Zsa: Sand River Gneiss), (Zgo: Goudplaats Gneiss), (Zbg: Gumbu Group), (Zba: Malala Drift Group) (Zbo: Mount Dowe Group)

Diagram 5: Plot of the harmonic mean value of various element concentrations in mg/l.

Diagram 5 gives an indication of the element concentrations in mg/l for the hydrogeological units in the study area. From this, the Bosbokpoort Formation (Trb) has the highest accumulative element concentrations (poor quality) and the Wyllies Poort Formation (Msw) the lowest. Quaternary (Q) deposits especially those from the Limpopo River is affected by seasonal changes. When the river is flowing, the quality improves and during dry (non flowing) periods the quality is poorer.

Diagram 6 and 7 shows the calculated harmonic mean value for various chemical element concentrations in each hydrogeological unit (depicted as short colour lines on the graph). The long solid lines using the same colour scheme are the maximum allowable concentration limit for each element. From **Table 6**, (p48), the Bosbokpoort Formation (Trb) exceeds the maximum allowable concentration for chloride (Cl) and sodium (Na). TAL as ($CaCo_3$) depicted in the graph must not be mistaken for total hardness (T.H.). T.H. is the sum of calcium and magnesium concentrations expressed in mg/l calcium carbonate ($CaCO_3$). TAL is the total alkalinity as captured in the DWA chemical quality database (WMS). The laboratories analyses for P (Phenolphthalein) alkalinity and M (Methyl-Orange) and report both as $CaCo_3$. P alkalinity is the CO_3 (Carbonate alkalinity) and is only found in samples where the pH is above ±8.3. M alkalinity is the HCO_3 (bicarbonate alkalinity). Below 8.3 the P alkalinity is 0 and the M alkalinity is then the total alkalinity. TAL or total alkalinity is in theory the sum of bicarbonate alkalinity and carbonate alkalinity. The harmonic mean of the fluoride (F) concentration exceeds the maximum allowable limit for the hydrogeological units Bosbokpoort Formation (Trb) and the Alldays Gneiss (Zal), (Diagram 7).

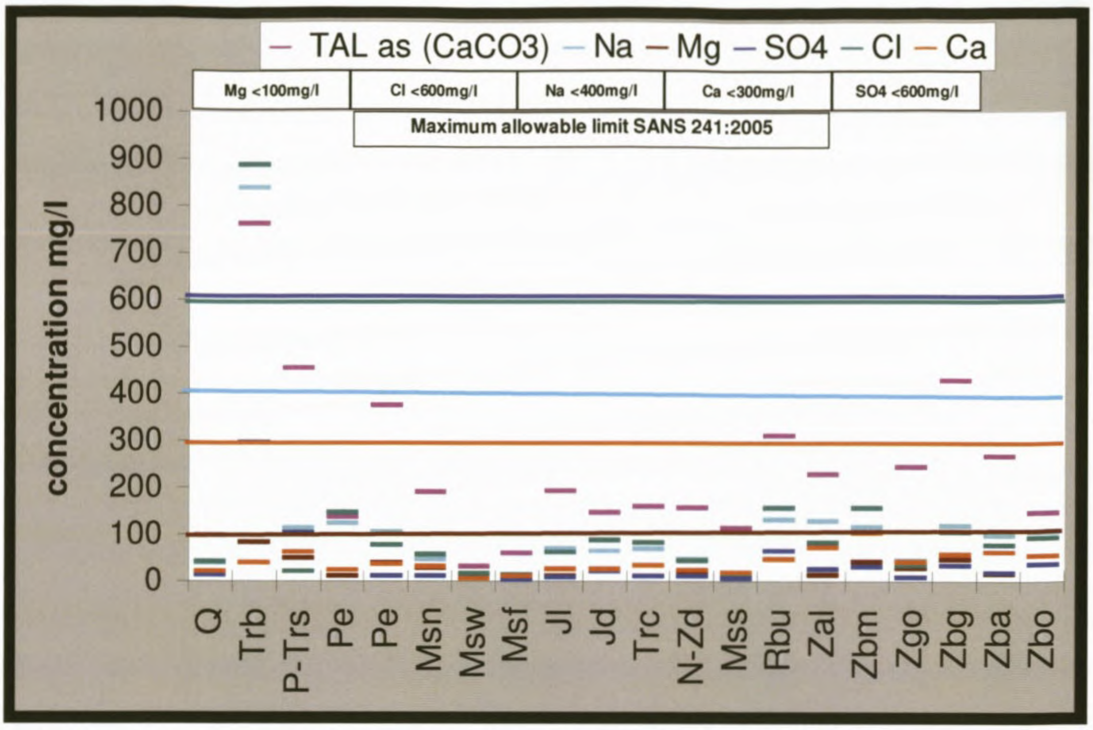


Diagram 6: Chemical concentrations, harmonic mean calculated for (TAL as $CaCO_3$), Na, Mg, SO4, Cl and Ca from available analysis for each hydrogeological unit.

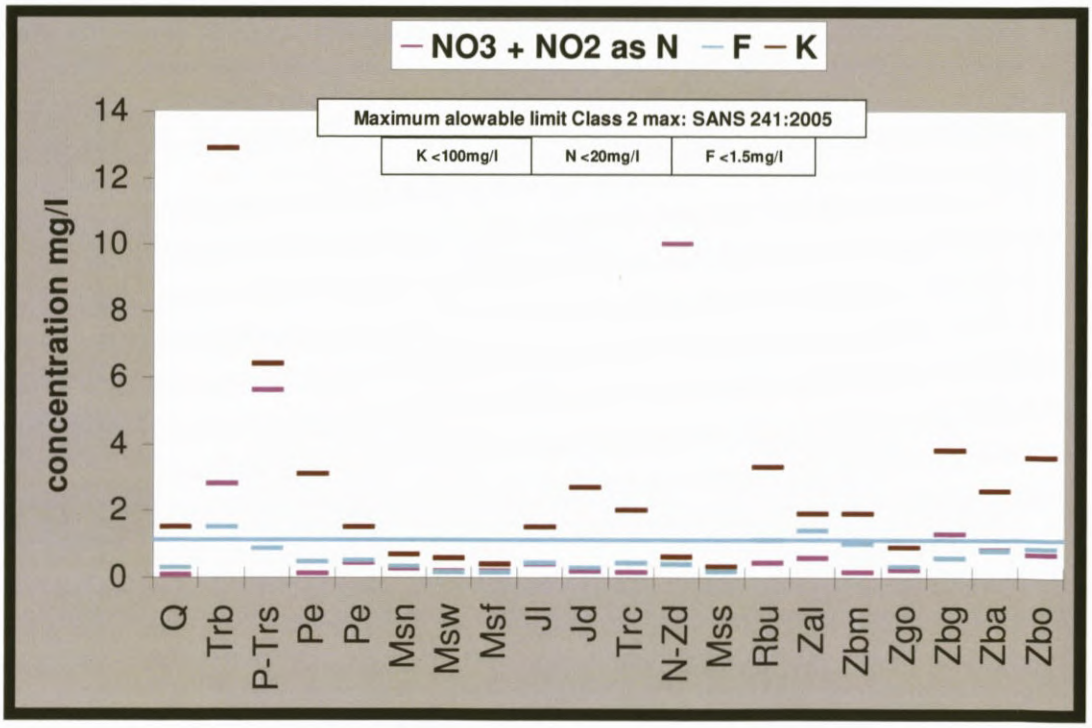


Diagram 7: Chemical concentrations, harmonic mean calculated for (NO_2 + NO_3 as N), F, and K from available analysis for each hydrogeological unit.

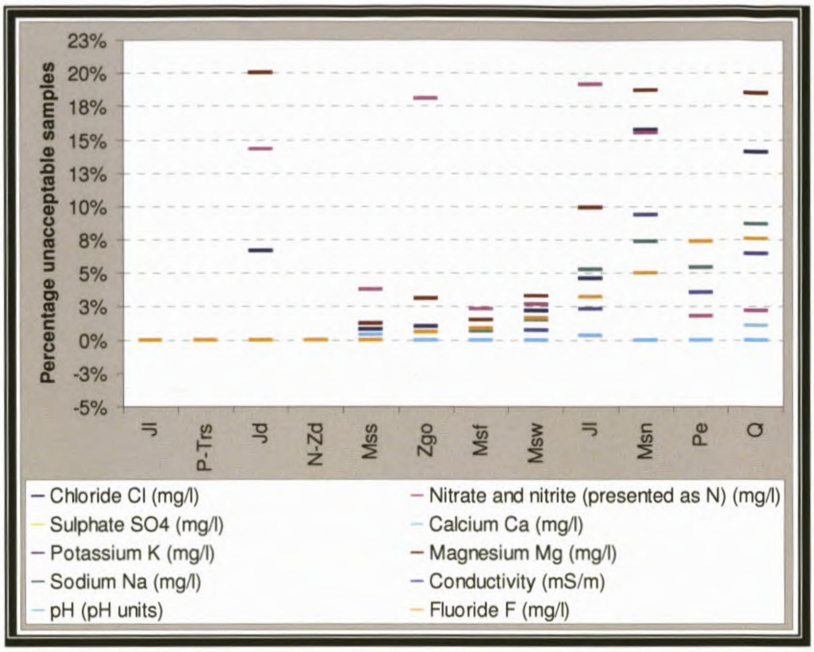


Diagram 8: Domestic water quality, percentage of samples where the concentration exceeds the maximum allowable concentration for the hydrogeological units with the least chemical problems in the study area, (SANS 241:2005).

Diagram 8 shows the hydrogeological units with the best domestic water quality. In this units less than 10% of the samples have analysed chemical elements that exceeds the maximum allowed concentration for domestic use (SANS:241, 2005). In diagram 9 approximately 5-40% of the samples have elements exceeds the maximum allowed concentration for domestic use (SANS:241, 2005).

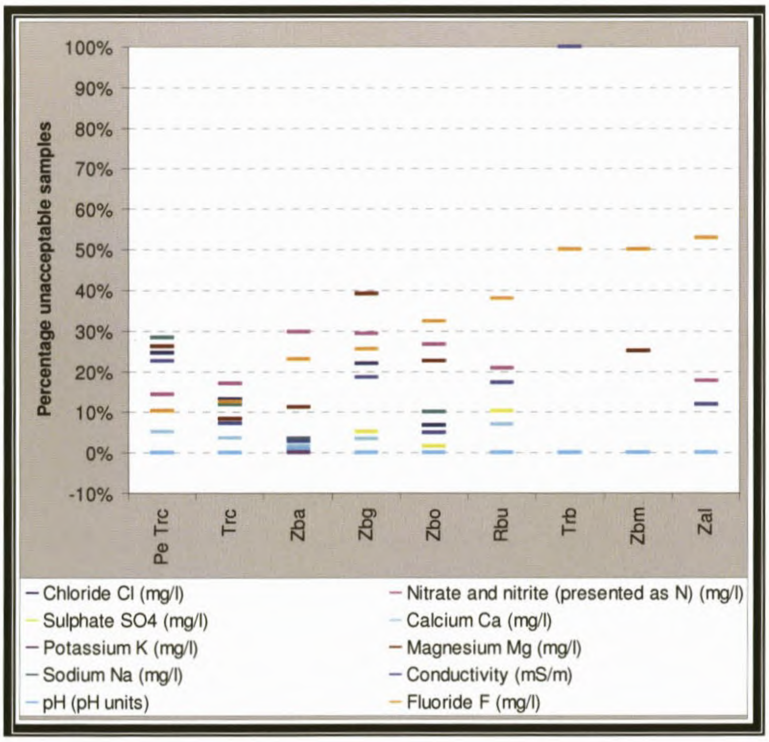


Diagram 9: Domestic water quality, percentage of samples where the concentration exceeds the maximum allowable concentration for the hydrogeological units with the most chemical problems in the study area, (SANS 241:2005).

Chapter 6 : SPRINGS AND ARTESIAN BOREHOLES

6.1 Hot springs

At least 33 thermal springs and boreholes are located in the Limpopo Province. They occur in two main regions or 'belts', namely the Waterberg area in the south-west and the Soutpansberg area in the north-east of the Province. The Soutpansberg area falls within the Messina map sheet with 8 thermal springs (depicted in **Figure 106**) and listed in **Table 16**, (p162).

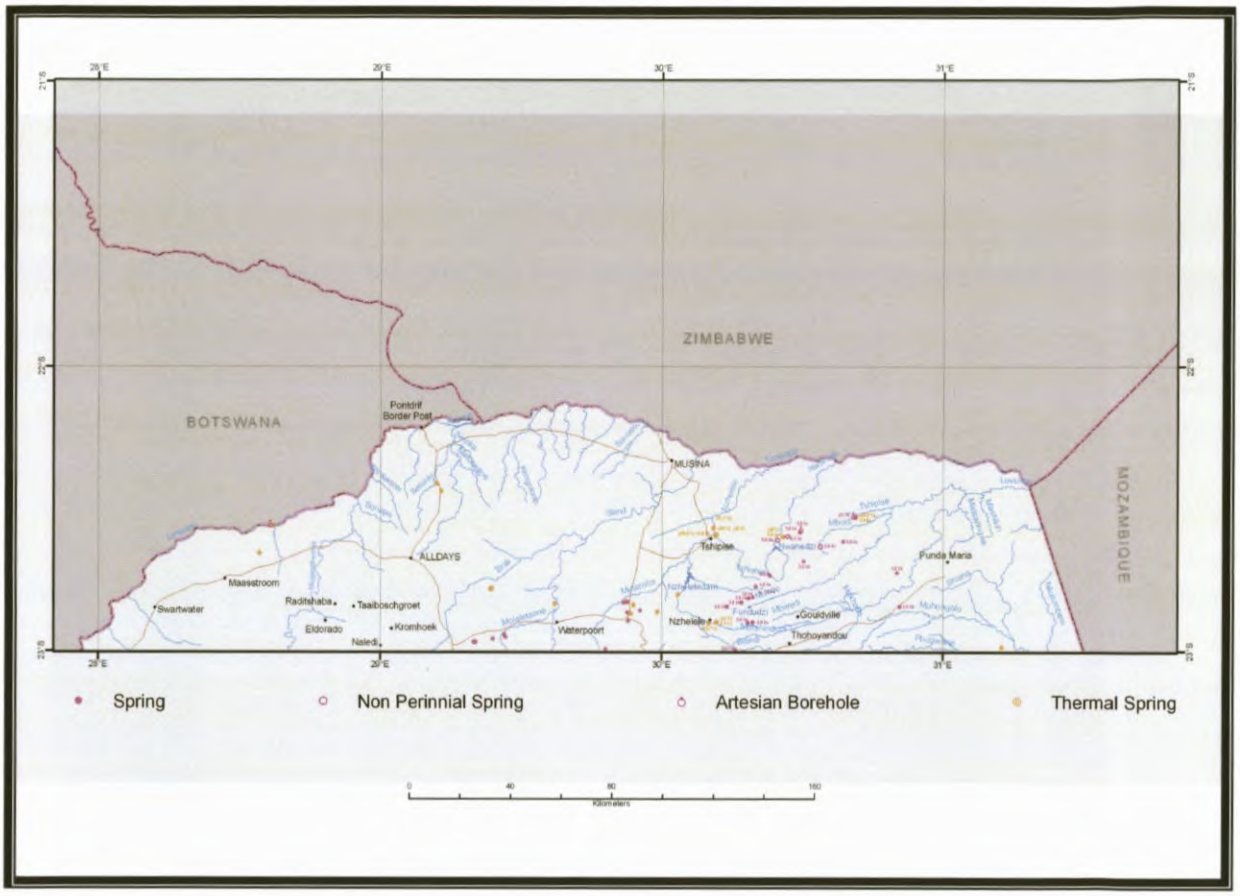


Figure 106: Springs and artesian boreholes in the study area.

Since active volcanic regions are non-existent in South Africa, magmatic water cannot play a role with regard to the origin (source) of the hot water or as a source of heat (Visser, 1989). The source of the water must therefore be meteoric. According to Kent (1949, 1968) the catchment areas are in the adjoining more elevated terrains from where rainwater filters along joint and fracture planes and eventually into narrow conduits. Along these conduits the water descends to such depths where the internal heat of the earth causes local convection cells to develop and the water is heated. The descending of cold water and subsequent ascending of heated water is a very lengthy process.

The research indicates that most thermal springs (exceeding temperatures of 25˚C) in Limpopo are associated with major faults in the Waterberg and Soutpansberg regions of the country. Geological studies have also shown conclusively that the origin of each individual thermal spring can be attributed to the local presence of deep geological structures such as folds, fractures, faults and dykes that provide a means for the circulation to depth and the return of the heated waters to the surface. The rocks generally possess no primary permeability, the aquifers are secondary, the effective porosity and permeability being due to fracturing by faulting, shearing or jointing.

The main geological features underlying the northern thermal springs are volcanic and sedimentary rocks of the Soutpansberg Group (e.g. Siloam), as well as volcanic and sedimentary rocks of the Karoo Supergroup (e.g. Sagole and Tshipise). **Table 16** is a summary of the geological structures associated with the thermal springs on the Messina Map Sheet.

Table 16: Geological structures associated with the thermal springs on the Messina map sheet (Adapted from Bond, 1947; Kent 1946, 1949, 1952, 1969; Kent and Russell, 1950; Hoffman, 1979; Ashton and Schoeman, 1986).

Name	Geological Structure
Evangelina	Diabase dyke in Archaean gneiss
Moreson	Fault in Archaean gneiss
Mphephu	Pre-Karoo fault
Sagole	Klein Tshipise Fault (1:250 000 Messina sheet) in mudstone, shale
Siloam	Siloam Fault (1:250 000 Messina sheet) in basalt
Tshipise	Intersection of two post-Permian faults in Upper Karoo
Tugela	Fault in Archaean gneiss
Vetfontein	Post Karoo fault

Boreholes have been drilled at some of the thermal springs to augment water supply for the development of resorts. At Tugela 171MR for example, a 20m deep borehole flows at 70m^3/d. The water has a temperature of 48.9°C compared with 42.8°C for the natural spring. The temperature recorded in the 2228 geological map sheet explanatory booklet gives the temperature of the spring as 60°C. The springs at Icon 95MS and nearby Evangelina 71MS is given as 45°C. Vetfontein 360MS and Sulphur Springs 653 MS is 35°C with a high H_2S concentration. Other springs mentioned include Windhoek 649MS, M'Pefu 202MT, Crimea 747MS and Kalkvlakte 670MS. All the springs are associated with post-Karoo brittle shear zones (Brandl, 2002).

All thermal springs in the study area are of meteoric origin and have temperatures ranging from 25°C to 67.5°C. The mineral composition of the thermal waters reflects the geological formations found at the depth of origin of the thermal spring water rather than the surface formations. This indicates that the spatial distribution of the thermal springs does not dictate the physical and chemical characteristics of the springs and that two or more springs located in close proximity to each other may differ markedly from one another with respect to their temperatures, flow rates and chemical composition and may not share the same development potential. Thermal springs very close to each other where the temperature differs significantly are at Tshipise (58°C) and Moreson (40°C). A difference of 28°C also occurs between Mphephu (43°C) and Siloam (67°C), less than 2km apart.

The Tshipise spring (Plate 8, p123) is the second hottest spring in South Africa. It occurs where the Tshipise Fault joins up with another minor fault. The water of Tshipise has an appreciable HCO_3 content although it is essentially moderate saline water. It is of mixed origin as various rock types including leucocratic quartz-feldspathic gneiss, marble and calc-silicate rocks of the Gumbu Group are brought together by the Tshipise Fault with sediments of the upper Karoo Supergroup including the basalt of the Letaba Formation and the sandstone of the Clarens Formation in close proximity of a dolerite sill.

The fluoride and bromine concentrations of waters from the majority of springs in the study area do not conform to domestic water quality guidelines and make the water unfit for human consumption. Unacceptably high values of trace elements such as antimony, mercury, selenium and arsenic were found at some springs.

6.2 Cold springs

Nine cold springs (temperature <25˚), all occurring within the Soutpansberg Supergroup are listed in the map area. The highest recorded yield is 3ℓ/s at H20F0534. The data plot shows that 50% occur near diabase sills and 40% might be associated with fault zones. The springs are also underlain by the Wyllies Poort, Nzhelele and Fundudzi Formations. Two of the springs formed in a narrow valley where a mudslide filled part of the valley. The streams flowing in these valleys disappear to re-surface as a spring lower down the valley. The springs occur within the southern part of the Soutpansberg Mountain range. The high rainfall combined with the sedimentary regional geology as well as the numerous fault zones, intrusive diabase sills and mountainous topography gives possible reasons for the incidence of springs. Interflow especially along the southern escarpment of this mountain range is related to rainfall events. Small plants growing on seemingly solid outcrops act as sponges resulting in minor water flow long after a rainfall event. In the area underlain by the Beit Bridge Complex no functional springs are recorded although some farm names have fountain as part of the name. This might be associated with the historic drop in static water levels investigated by Fayazi and Bush.

6.3 Artesian boreholes

Thirteen boreholes, all occurring within the Soutpansberg Supergroup are listed in the map area with artesian static water level conditions of which nine (69%) are associated with the Klein Tshipise Fault. Two are associated with the Tshipise hot water spring, one to the east to west fault zone within the Sibasa Formation also reported as warm water and the last with a south-east to north-west-trending fault within the Wyllies Poort Formation. No information is available regarding the temperature of this borehole. The highest overflow yield was measured as 3.6ℓ/s at H19-0352 after drilling 19/03/2009. The flow was recorded as 2.3ℓ/s on the 25/03/2009 after pump testing of the borehole. The average overflow rate differs during wet and dry seasons. Some of the holes are used for communal water supply with the static level dropping during pumping. Within varying recovery times after pumping, artesian conditions return. In certain villages this water is used to irrigate small areas. In other areas the community does not allow drilling of additional boreholes as they fear that their current production boreholes will dry up (Sagole). Some of the artesian boreholes not in use were sealed by DWA during 2009 to 2010. The water quality of the boreholes drilled in the Tshipise Fault have acceptable domestic water qualities except in one borehole, H20-1519, which has a high fluoride concentration (F =2.6mg/l). No chemical analysis is available for the two boreholes at the Tshipise hot spring. The remaining borehole reported as hot, H27-0138, has a fluoride concentration of 4.6mg/l.

Plate 10: The drilling of a borehole at Folovhodwe village targeting the Klein Tshipise Fault. The borehole is artesian (Photo, P.J. Lubbe, 2008).

Chapter 7 : GROUNDWATER MANAGEMENT

7.1 Background

The National Water Act (Act 108 of 1998) appointed the Minister of the DWA as 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 as a whole. This must be managed in an integrated manner according to the principles of the Act (sustainability, equity and efficiency).

To manage water resources on a local level, Catchment Managing Agencies (CMAs) and Water User Associations (WUAs) must be established to operate under the framework of the NWS and DWA guidelines. The CMA is responsible for a water allocation plan within their catchments and a Catchment Water Strategy (CWS) that is similar to the NWS. The WUA is responsible for a few functions such as the protection of water resources and prevention of water wastage.

At present the DWA is responsible for administering all aspects of the Act on the Minister's behalf as no CMA's or WUA are yet in operation within the map area.

Over-exploitation of groundwater resources is a general problem. Mining of coal within the map sheet is increasingly occurring, often without the proper licences. Through the media these mines are brought into public awareness. One of the mines is near the Mapungubwe Conservation area. The balance between conservation and economic growth will always be an issue. An issue that should be debated, with all the mines, is that the short-term economic gain will not become the pollution problem of future generations with an economic burden that is bigger than the current gain. The environmental and groundwater laws should be applied and managed very strictly. This was one of the reasons for DWA integrating with the Department of Environmental Affairs to ensure a combined effort to close loopholes in inter-government legislation.

Part of water usage licence requirements can be that water users must monitor abstraction and quality at all levels from local authorities such as the Messina municipality, mines and down to individual farmers. During the period or at the renewal date of the water user licence DWA can request monitoring data from licence holders. As licensing is compulsory holders should familiarized themselves with the licence requirements as the licence 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 in order 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 can be obtained from the Institute for Resource Quality Studies of the Department of Water Affairs at Roodeplaat Dam.

In the licence application no distinction is made between surface water or groundwater use as it is all part of the hydrological cycle. From a hydrogeological view the 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 used 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 should be drilled, 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 DWA has a large number of monitoring boreholes equipped with electronic data loggers within the map sheet area (**Figure 108**, p168). Most of them monitor ambient water level fluctuations and trends on a regional scale. There are number of specific purpose monitoring stations that are monitoring water level fluctuations in existing well fields. The data is available on request from the DWA's National Groundwater Archive (NGA) in Pretoria.

7.2 Groundwater contamination and pollution

Groundwater contamination, defined as the introduction of any substance into groundwater by the action of man. Pollution is defined as 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 reasonable expected to be use.
b) Harmful or potentially harmful to-
   - the welfare, health of safety human beings,
   - any aquatic or non-aquatic organisms,
   - the resource quality, or to property,

(Source: National water Act, Act No 36 of 1998)

Pollution is one of the greatest threats of our time. Groundwater is, like surface water, very vulnerable to pollution. It is very difficult and expensive to rehabilitate an aquifer once it is polluted. In the environmental Act the principle of "polluter pays for the rehabilitation" is followed. Managers of companies responsible for the degradation of the environment can be held responsible even after a long time.

In the modelling of pollution mitigation sources, pollution sources are classified at first according to their geometry. Point sources are sources such as waste disposal, underground storage tanks, septic tanks and sewage works. Groundwater pollution specialists should select these sites with utmost care. The sites must be regularly monitored and the status reported. The establishment or closure of such sites is strictly controlled by DWA in order to protect the water resources of the country. Selling and storage points of petrol, diesel, chemicals and fertilizers are widespread with waste disposal and sewerage works mostly confined to the bigger towns and cities within the map area. In the rural areas of the map a common problem is high concentrations of nitrates which have been introduced into the water through pit-latrines and cattle-kraals. Other occurrences are displayed on the map sheet.

Line sources are possible pollution sites such as sewage pipelines and railway lines (use of weed killing chemicals). Other sources are industrial, mining and irrigation areas that discharge contaminants over a large area. These sources are also widespread throughout the area. Mining activities such as Venetia Mine, mining along the Limpopo River for alluvial diamonds, Tshikondeni coal mine, the new coal mines along the southern boundary of the Tshipise basin, and in the Tuli basin near the Mapungubwe Conservation area are all potential sources of pollution if not properly managed.

7.3 Groundwater utilization

The Kruger National Park is situated in the eastern part of the map area, therefore groundwater use is restricted to game watering and domestic use for camps. The rural areas of Venda and northern Malamulele are located west of the park. Groundwater abstraction in these areas is for rural village supply, small scale irrigation and livestock watering. Well documented groundwater data is available for these areas. Irrigation in the Tshipise area towards Nzhelele Dam is predominantly from surface water, although boreholes are also used. In the Waterpoort area towards Vivo excessive use is made of groundwater occurring in faults, minor alluvium, and deep boreholes utilizing water from the Letaba and Clarens formations. Along major rivers such as the Limpopo (Weipe area) and Sand rivers, water is abstracted from alluvium. The Glen Alpine Dam in the Mogalakwena River supplies surface water for irrigation. In the rest of the area irrigation is from high yielding groundwater sources. Where sources are low yielding, livestock or game farming is practiced. On the main map sheet major abstraction areas are indicated as solid red circles.

The harvest potential map (**Figure 107**) gives a quantitative depiction of sustainable volumes of groundwater potentially available for abstraction. The Malvernia Formation is indicated as a high potential area. The Formation has a limited thickness and there is not enough borehole data to confirm the potential. More investigations are recommended. A piezometric contour map compiled for the Kruger National Park revealed the Malvernia Formation as a groundwater recharge area (Du Toit, 1998).

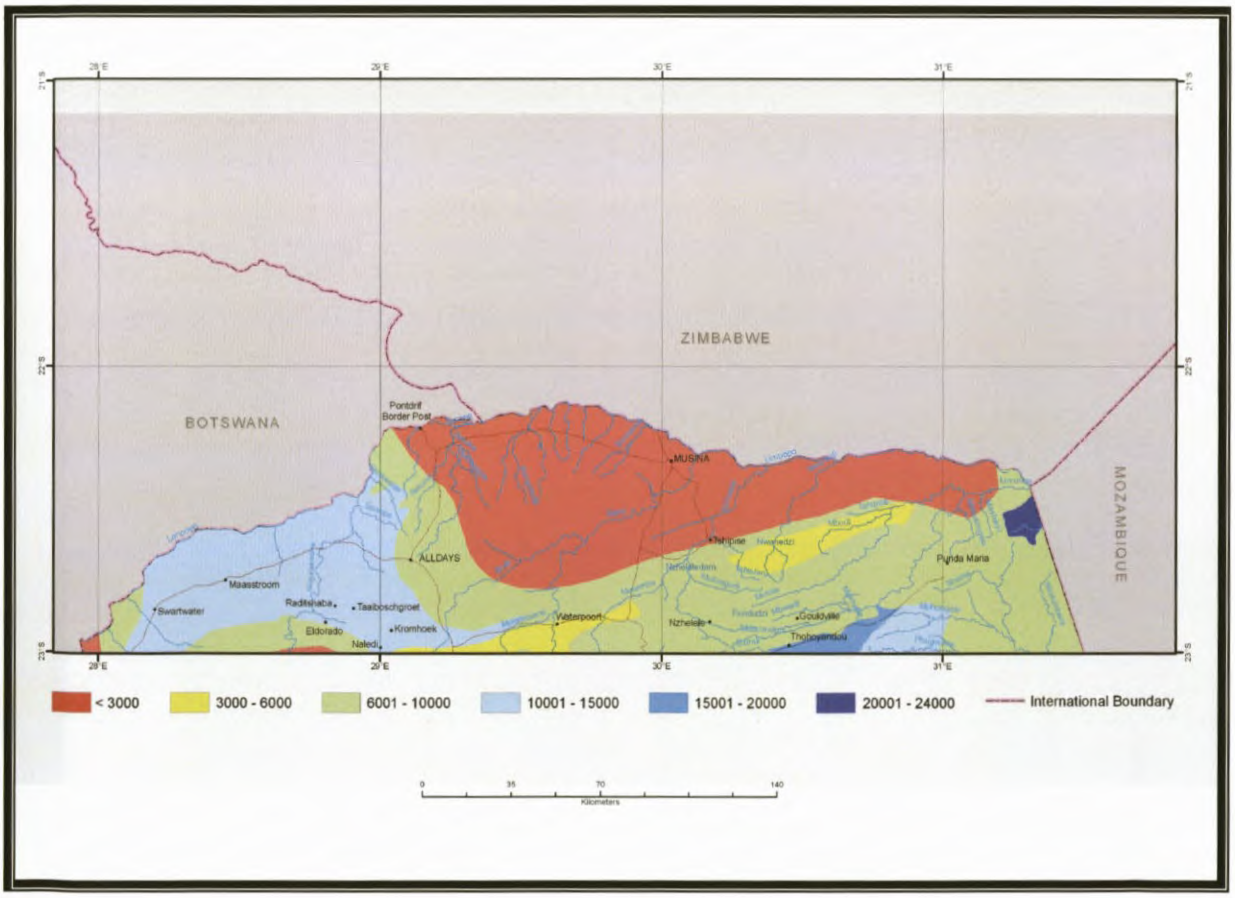


Figure 107: Harvest potential (Seward, et al, 1996)

Table 17: Localities where large-scale groundwater abstraction (>400 000 M^3/a) are taking place.

LOCALITY/AREA	COMMENT OR RESOURCE
Alldays	From various boreholes drilled in the Taaibos Fault (Tshipise Fault)
Beit Bridge border post	Boreholes drilled in the Limpopo River
Kromhoek area	Agriculture, basalt aquifer
Messina	Boreholes drilled in the Limpopo River. Water is pumped for storage in the old Messina copper mine in wet times. In times when the river is dry and the yield of the sand decreases water is pumped from the mine for the town
Regional supply scheme Taaibos Fault	Pump water for various villages from the fault
Small village supplies Vhembe district	Small village or regional schemes from groundwater sources
Venetia Mine-	Boreholes drilled in the Limpopo River. More water abstraction is allowed when the river is flowing. In dry periods the abstraction is limited.
Weipe	Boreholes drilled in the Limpopo River

Note: Exact figures could not be obtained from the DWA.

7.4 Groundwater monitoring

Monitoring, recording, assessing and dissemination of information on water resources are critically important for achieving the objectives of the National Water Act (Act 108 of 1998). The DWA is responsible for setting up national water monitoring systems that will facilitate the continued and co-ordinated monitoring of various aspects of water resources by collection relevant information and data through established procedure and mechanisms, from a variety of sources including organs of state, water management institutions and water users. Monitoring of factors such as quantity, quality, the use and rehabilitation are some of the aspects. As part of the water user licence, users can be required to supply information on abstraction, water levels and quality on a time frequency negotiated between DWA and the licence 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. In a geo-hydrological study done between Mopani and Tshipise the analysis of available borehole data showed a general drop in water levels throughout the area over the years. This drop seems to be greatest in the granite-gneiss, where a drop of up to 25m has been recorded in the time frame 1928 to 1980. In the Ecca Formation a drop of 10m was recorded during the same period. The cause is not certain, but it is unlikely that the cause was the fairly limited and moderate abstraction rates used for livestock watering. Severe continuous drought in this area and possible overgrazing caused changes in vegetation cover thereby increasing run-off resulting in the decrease of water available for infiltration to the water table. This began the cycle of water level lowering. The effect of building dams to aid replenishment at sites and to control run-off near boreholes to improve the infiltration has shown to be very effective (Fayazi, et al, 1981). The positions of monitoring points are indicated in **Figure 108**, (p168). The Messina 2127 map sheet was produced in 1995. At the time no monitoring network existed within the map area.

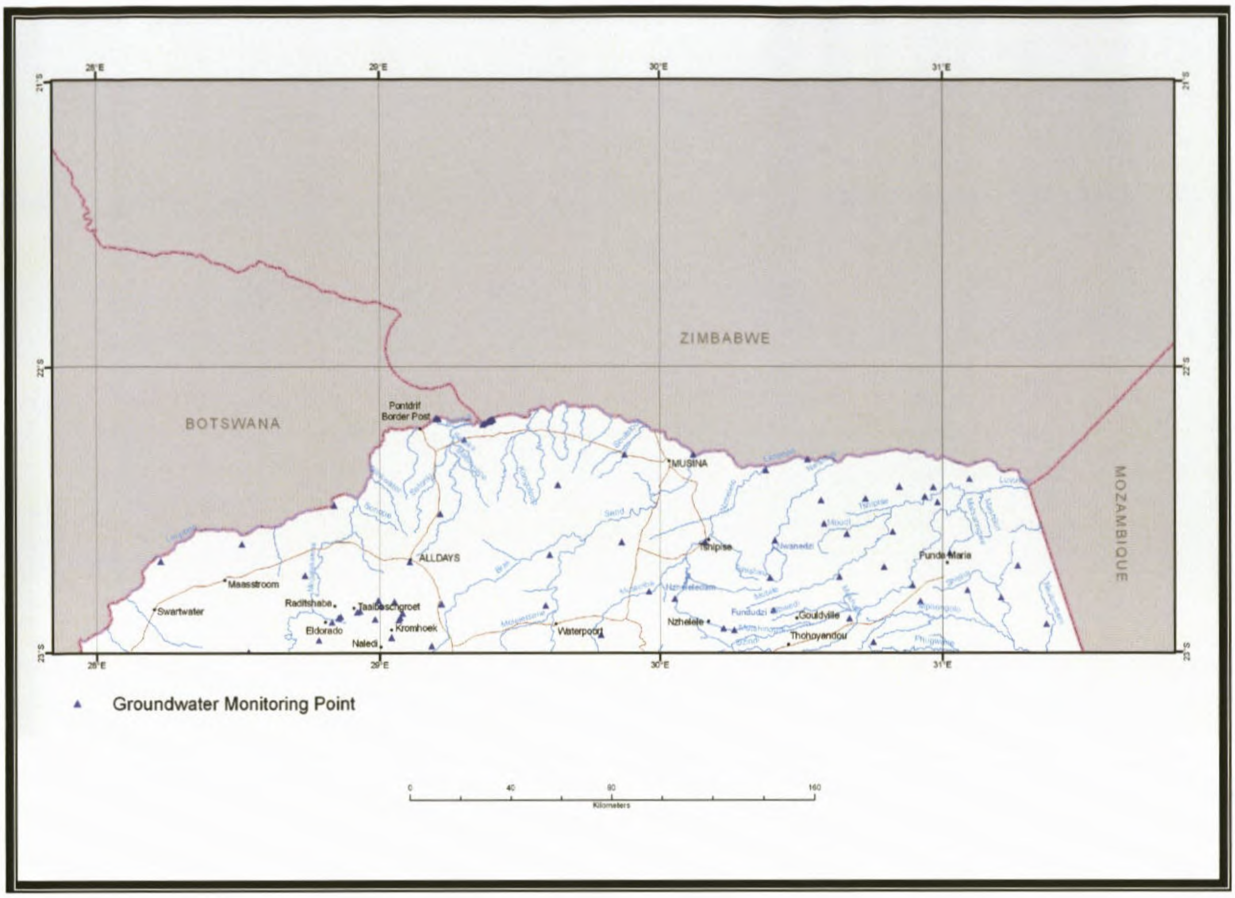


Figure 108: DWA monitoring boreholes in the map area.

7.5 Borehole positioning

Table 18, (p169) depicts the different geophysical survey techniques that can be employed in the search for geological features that might relate to the occurrence of groundwater. The choice of technique for each of the different hydrogeological resource units is based:

- on current available techniques
- proven track records in the application of the technique in each unit
- knowledge of targets and geology in each unit
- the designed application of each technique
- naturally occurring parameters that can be measured and the expected response that can be obtained from the geological setting within the resource unit.

Table 18: Recommended geophysical survey techniques to employ in each resource unit.

GROUP/FORMATION	HYDRO-GEOLOGICAL UNIT	MODE OF OCCURRENCE	1a	1b	2a	2b	3	4	5
Tertiary - Quaternary alluvial deposits	Q	A	***	***	**			**	**
Malvernia Formation	Kma	B	**	**	**	**	***	**	*
Lebombo group-Jozini and Letaba Formation	Jl	B,D	**	***	***	*	***	*	*
Bosbokpoort-, Solitude Formations, Undifferentiated Ecca Group and Clarens formation, Ecca Group	Trb, P-Trs, Pe-Trc, Pe	B	**	**	**	**	***	*	*
Dolerite and Diabase intrusions,	Jd, N-Zd	D	**	**	***	***	***	*	*
Soutpansberg Supergroup, Nzhelele -, Wyllies Poort-, and Fundudzi Formation	Msn, Msw, Msf	B	**	***	***	**	***	*	*
Soutpansberg Supergroup, Sibasa-, Stayt Formation.	Mss, Msa	D	**	**	***	**	***	*	*
Bulai-,Alldays-,Hout River-, Sand River-,Goudplaats Gneiss,	Rbu, Zal, Rho, Zsa, Zgo	D	***	***	***	***	***	*	*
Messina Suite, Madiapala Syenite, Beit Bridge Complex (Gumbu-, Malala Drift-,Mount Dowe Group)	Zbm, Zma, Zbg, Zba, Zbo	D	**	**	***	**	***	*	*

The geophysical method is listed as follows:

1a Electrical Resistivity –
1b Electrical Resistivity – profiling
2a Electromagnetic - EM-34
2b Electromagnetic - Genie SE
3 Magnetic
4 Gravity
5 Seismic

The successful application rating is as follows:

*** Essential
** Useful
* Not essential

Geological targets that can be related to the occurrence of groundwater are described for most of the hydrogeological units in chapter 5.5, pp90-154. The success of the application is enhanced by using other available scientific aids such as aerial photographs, LANDSAT images, Terra Aster satellite imagery, geological maps, existing information for the area and aeromagnetic data. An experienced geo-hydrologist will also take vegetation, topographical setting, soil changes, possible recharge zones and other visible signs into consideration during the survey. The position and direction of geophysical traverses is very important and the data interpretation should be checked in the field to validate the expected target with the anomaly as the choice of drilling position depends greatly on the type of lineament. As an example, the drilling position on a geophysical anomaly will most likely be different for a dyke than a fault zone.

Additional comments from reports on geophysical methods used:

Electrical Resistivity Soundings: Schlumberger and Wenner vertical electrical soundings (VES) were extensively and successfully used in the past in granatoid, gneissic and sedimentary environments. Cost and time implications limit the current use in groundwater development. The Wenner configuration was used with moderate success in areas where shallow weathering occurs i.e. <36 metres. Although the empirical method of interpretation is a quick method the estimated depth to bedrock can be grossly erroneous because of the higher than normal susceptibility to lateral effects. Despite being costly the accuracy and high resolution of data obtained with the Schlumberger configuration makes this a highly recommended method. The interpretation of the data has to be done by qualified and experienced personnel.

Electrical Resistivity Profiling: These older instruments limit the user to a single theoretical depth of investigation making the method time consuming and expensive. The geological environments investigated are the same as with the resistivity soundings. This method was usually used as a relatively fast way to cover vast distances before doing soundings. The development of electromagnetic methods replaced the single spacing profiling method in groundwater surveys. The development of resistivity profiling instruments that can measure apparent resistivity at multiple theoretical depths (such as the Lund) reinstated the resistivity method as a highly recommended tool. The method should be used in a combination with other instruments and, as with all methods, the surveyor should have an understanding of hydrogeological conditions.

Electromagnetic EM: Can be successfully used in most of the units to locate geological lineaments related to dykes and faults as well as deep weathered and fracture zones. Shallow highly conductive layers must be taken in consideration during interpretation. In various studies it was successfully used to locate fault zones where the magnetic response was limited such as the Tshipise and Xmas fault zones. The theoretical depth of applicability is approximately 60m, reducing use in deep water table environments. The interpreted dip and width of structures is usually extrapolated in such cases.

Electromagnetic Genie: An electromagnetic system developed to obtain data at depths up to 150m. The Stratagem is similar but much more advanced. The Genie has distinguished itself as a reliable and useful instrument in detecting water bearing zones located in a conductive environment. Its effectiveness, from a groundwater exploration point of view diminishes tremendously in higher resistive environments (Du Toit, 1998). As with the Stratagem, interpretation of data should be done by an experienced geophysicist. Due to time and cost implications, the use of the Genie is limited. Surveys with the Stratagem are expensive and are mainly used for mine exploration.

Magnetic: Still the most widely used method due to cost and time effectiveness. It is a highly recommended method to use in combination with all the other available methods in all the units on the map sheet. In the Tertiary - Quaternary alluvial deposits the use will be to locate secondary targets associated with lineaments overlain by the deposits while in the other units it will be used to locate lineaments such as dykes when using it as a single geophysical method or to confirm and to identify the type of lineament when using the method in conjunction with other methods. Certain fault zones did not have a noticeable magnetic response but when using it with other methods the smaller anomalies can be interpreted. When interpreting data one should be aware of responses related to amphibolite, or the presence of magnetite in the gneisses and magnetite quartzite when working in areas underlain by rocks of the Beit Bridge Complex. In the Goudplaats and Hout River gneiss the presence of greenstone xenoliths must be taken into account. The magnetic response over lavas especially the Letaba basalt is very erratic, making the identification of anomalies associated with intrusive dykes difficult.

Gravity: Due to its cost and use in mainly dolomitic rocks the method is not widely used in the map area. It is known from verbal conversations with various surveyors that the method can be successfully applied to locate drilling targets in schist, gneiss and granatoids. In dolomitic environments the use of this method together with the magnetic method is highly effective. Reports where the gravity method was used on other geological environments were not available for the map area. The viability of this method should be investigated within the units where the success rate is low in developing high yielding boreholes.

Seismic: Due to cost, time and logistical implication this method is not widely used in the map area. The method was applied with limited success in the Swartwater area.

7.6 Future groundwater exploration

Groundwater is, and will in future, still be used on a large scale for mining, scattered, semi urban and urban village and town supplies as well as a supplement for bulk surface regional water supply, irrigation, livestock watering and game farming. The mining environment is a potentially big polluter rather than a big user of groundwater. This will be one of the biggest challenges for groundwater in the Tuli and Tshipise basins. Within the map area particularly where game and livestock farming is practiced, in the National Park and scattered rural settlements, the groundwater is not yet over exploited. The groundwater challenge at this stage is the protection against pollution from the increasing nitrate concentrations in groundwater within or near villages as well as from pollution from irrigation practices and mining activities.

Future development of geophysical equipment combined with increasing knowledge of the hydrogeological characteristics of the map area will ensure the means to develop groundwater to its full potential. Regional surface supply projects will ensure bulk water to major users such as the Nondoni dam, (just south of the map area) that will supply parts of northern Malamulele and areas around Thohoyandou. Groundwater should be integrated in these bulk systems on the basis that only the high yielding boreholes be used to keep maintenance cost low. This will also ensure that well fields can be developed far from villages as most groundwater development projects concentrates in the immediate area in and around communities. The cost of regional pipelines makes groundwater as supply for small villages the most viable.

From a study on the Taaibos Fault (now also referred as Tshipise Fault) the following recommendations were made (IAEA study, 1999-2003).

- In view of the widespread occurrence of high nitrate concentrations in groundwater in Limpopo Province, the investigation into their origins, and their mitigation, should continue to be an important component in this ongoing study
- As there is now a unique body of geo-hydrological and other data, the Tshipise Fault area should continue to be the central focus of this study
- As nitrogen isotopes constitute a potentially powerful tool in examining the nitrogen cycle in groundwater it should form an integral part of this ongoing study
- As indications are at present that the basalt and sandstone aquifers may at least in some areas be hydraulically continuous, extreme caution is required in the exploitation of the latter in order to control possible contamination by drawing in water from the former

The growing population and development in South Africa is bound to put the country's scarce water resources under tremendous pressure in years to come. To be able to absorb this anticipated pressure the country should invest in groundwater exploration in order to maintain and manage existing resources and develop new resources. The following additional points should be addressed:

- Recharge from earth dams.
- Hydro census and updating of information in neglected areas

- The enforcement of the use of public money when municipalities develop groundwater sources to ensure the use of groundwater experts to update information on the National Groundwater Archive. Currently there are major problems as boreholes are drilled in the vicinity of production holes or possible pollution sources.

- The enforcement of environmental and groundwater laws to minimize possible pollution from mines, sewerage works, landfill sites, burial sites, petrol stations and large scale farming.

- Environmentally friendly sanitation methods should used to prevent high concentrations of nitrates

- Geophysical exploration techniques should be used to detect deep aquifers in hard rock formations.

- Application of remote sensing techniques (LANDSAT imagery, satellite imagery such as Terra Aster, aerial photography, etc) for early identification of potential groundwater target areas.

- Determination of recharge to the different hydrogeological units and techniques to improve it.

- Exploration into the occurrence and utilization of deeply (>200m) seated aquifers.

- Prevention of erosion, storm water control in rural villages, protection of waterways and riparian vegetation.

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Chapter 9 : Abstract/Summary

- The history of hydrogeological maps in the world closely represents the development of groundwater as a science since the early 1940's.
- Hydrogeological maps are the ideal tool to present vast volumes of groundwater data logically.
- The use of inset maps and explanatory brochures enables the inclusion of additional information that cannot be depicted on the main map as the format is specifically stipulated (legend).
- The legend for the presentation of hydrogeological data on a national and international map scale was achieved when the emphasis changed from well yields towards the description of aquifers.
- In the compilation of maps and brochures, data verification is time consuming and practical problems include poor recordings (dry boreholes), incomplete and double entries (chemical data) and the time/money/quality factor to rectify or filter data to an acceptable level.
- The characterization of a unit becomes inconclusive with inadequate sample representation and spatial distribution.
- Hydrogeological units were chosen by sub-dividing the area in relevant lithologic units which possess some degree of lithologic homogeneity and similarities in rock properties.
- These lithologic units were then grouped together based on the expected groundwater occurrence viz. **Intergranular (a), Fractured (b), and Intergranular and Fractured (d),**
- The subdividing of the units according to yield was done in a way as to provide physical meaning to the value of the borehole both in terms of the concomitant abstraction equipment and also as a provider of water for a particular end water user.
- Hydrogeological units are described regarding location, aerial extend, geology, water quality and quantity as to explore the significance and potential of the aquifer for current and future use.
- Within the study area, the regional and structural geology influenced the topography, vegetation, climate and hydrogeological character.
- The structural history of the area significantly controlled the development of the current underlying geology. The regional and structural geology influenced the topography, vegetation, climate (high rainfall along the Soutpansberg mountain range), surface runoff and groundwater quality and quantity.
- The objectives of the thesis were achieved as it can be used as an additional tool for a hydrogeologist working in the area.

- Die geskiedenis van hidrologiese kaarte volg die ontwikkeling van die vakgebied as n wetenskaplike veld slaafs na sedert die vroeë 1940's.
- Hidrogeologiese kaarte is n efektiewe manier of groot hoeveelhede data in logiese formaat voor te stel.
- Die gebruik van kleiner kaarte en verklarende brosjures maak dit moontlik om aanvullende inligting oor te dra aangesien die voorstelling van data op die hoofkaart volgens n spesifieke vasgestelde legende moet wees.
- Die aanvaarding van n legende vir die opstel van nasionale en internasionale kaarte het eers plaasgevind met die verandering in fokus vanaf enkel lewerings na die karakterisering van regionale waterdraers.
- .Die data voorbereidings fase is tydrowend maar uiters belangrik wanneer daar met groot hoeveelhede data gewerk word. Die gewone verwagte probleme is swak rekords veral met die aanduiding van droë gate, onvolledige data veral met ouer chemiese data, verdubbelings van gate weens swak koördinate en die tyd/koste/kwaliteit faktor om data tot n aanvaarde vlak van gehalte te kry.
- Die gevolgtrekkings wat uit data gemaak word ten opsigte van die geohidrologiese einskappe van n eenheid hang van die hoeveelheid en verspreiding van datapunte.
- Die geohidrologiese eenhede is gekies deur die gebied te verdeel in litologiese eenhede wat dieselfde eienskappe het.

- Die eenhede is gegroepeer volgens die verwagte groundwater voorkoms naamlik interkorrelrig **(a), frakture (b) en interkorrelrig en frakture (c).**
- Die afbakening van lewerings is gedoen om voorsiening te maak vir die fisiese betekenis van die bron ten opsigte van die tipe toerusting vir ontrekking en as water bron vir n spesifieke eindgebruiker.
- Die geohidrologiese eenhede word beskryf ten opsigte van voorkoms, verspreiding, geologie, water gehalte en hoeveelheid. Daarvolgens word die bron ge-evalueer ten opsigte van huidige gebruik asook toekomstige gebruik.
- Die geskiedenis van die struktuur geologie van die area het gelei tot die ontwikkeling van die streeksgeologie van die area. Tesame beinvloed dit, die topografie, klimaat (hoë reenval of die randsone van die Soutpansberg-bergreeks), oppervlak dreinering en die groundwater kwaliteit en kwantiteit.
- Die Tesis het geslaag in die doelstelling om deel te word van die geohidroloog se beskikbare arsenaal hulpmiddels wat in die area gebruik kan word om meer suksesvol te kan wees.

Chapter 10 APPENDIX

Sheet 2127

1:500 000

Hydrogeological map series of the Republic of South Africa

MESSINA

2002

10 0 10 20 30 40 50 60 km

Lambert's conformal conic projection. Standard parallels 17 °30' & 23°30'. Central meridian 30 °. Spheroid Clarke 1880.

Map Author - W.H. du Toit

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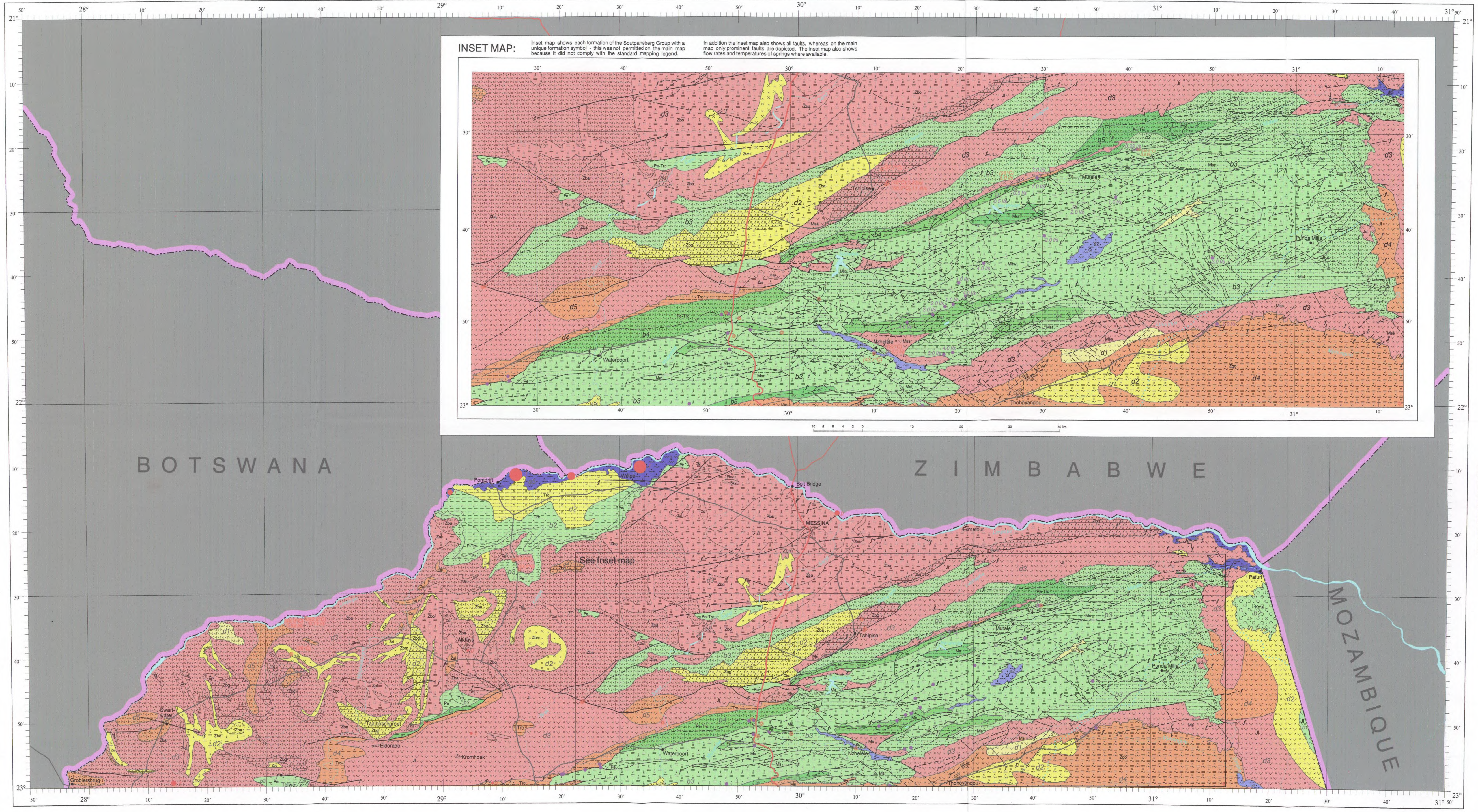
E. Braune, J. Girman, P. Seward and Z.M. Dziembowski (Consultant)

This map was approved by the Director-General of the Department: Water Affairs and Forestry.

The groundwater occurrence and groundwater quality maps, and the schematic cross-sections were compiled by W.H. du Toit. The lithology was adapted by W.H. du Toit from the 1:250 000 scale Messina 2230 (1981) and Beitbrug 2228 (1957) and 1:1 000 000 scale (1984 and 1997) maps. All these geological maps were published by the Council for Geoscience. A.J.I. du Toit was responsible for the compilation of the borehole distribution map. Precipitation and elevation data were obtained from the Computing Centre for Water Research, University of Natal, and compiled by H. Mullin.

Information on roads, rivers, towns and international boundary were obtained from the Chief Directorate: Surveys and Mapping, Department: Land Affairs, and edited by the Department: Water Affairs and Forestry. Permission from these respective institutions to make use of their information is gratefully acknowledged. Borehole data were obtained from the National Groundwater Data Base (NGDB) and the Northern Province Regional Groundwater Database. Acknowledgement is also accorded to: Groundwater Projects Management Consultants (GPM), Water Systems Management (WSM), Geocon and Van der Walt, Serfontein & Ahrends (VSA) for supplying groundwater data from the former homelands of Lebowa and Gazankulu and the former Republic of Venda.



Principal groundwater occurrence

Borehole yield class (median l/sec)(excl. dry boreholes)

Aquifer type	0.0 - 0.1	0.1 - 0.5	0.5 - 2.0	2.0 - 5.0	> 5.0
Intergranular	*	a2	a3	*	a5
Fractured	b1	b2	b3	b4	b5
Karst	*	*	*	*	*
Intergranular and fractured	d1	d2	d3	d4	d5

Borehole yields boundary (main map only)

Note: Groundwater occurrence depicts the aquifer type(s) with the highest borehole yield, and does not always correlate with surface lithology.

Surface / Sub-surface lithology

(Unconsolidated sediments which are unsaturated, have been omitted from the map)

- Alluvium (clay, sand, gravel and boulders)
- Predominantly argillaceous rocks (shale, mudstone, siltstone and carbonaceous shale)
- Predominantly arenaceous rocks (sandstone and quartzitic sandstone)
- Argillaceous and arenaceous rocks (approximately equal proportions of shale and sandstone)
- Predominantly rudaceous rocks (conglomerate)
- Basic intrusive rocks (diabase and dolerite)
- Basic / ultra basic metamorphosed intrusive rocks (meta-anorthosite and meta-pyroxenite)
- Intermediate / alkaline intrusive rocks (syenite)
- Basic extrusive rocks (basalt)
- Acid extrusive rocks (rhyolite)
- Predominantly meta-arenaceous rocks (gneiss and quartzite)
- Predominantly meta-calcareous rocks (marble and calc-silicate)
- Predominantly gneissoid rocks (with xenoliths of undifferentiated metamorphic rocks)
- Various lithologies: Sedimentary rocks: Pe-Trc; Metamorphic rocks: Zba
- Lithological / stratigraphical boundary
- Inferred lithological / stratigraphical boundary
- f——f Fault
- f— — –f Inferred fault
- × Dolerite and / or diabase intruded

Large scale groundwater abstraction

- >10 million m^3/a
- 2 - 5 million m^3/a
- 1 - 2 million m^3/a
- 0.1 - 1 million m^3/a
- I Irrigation
- D Domestic
- Mining

- Spring (flow in l/s shown on inset map only)
- Non-perennial spring
- Thermal spring (temperature in °C and / or flow in l/s where known)
- Artesian borehole (flow in l/s)
- Primary drainage region boundary
- Water course
- Perennial river
- Secondary perennial river
- Non-perennial river
- Dam
- City / town area
- Village
- Reference point
- National road
- Main road; Inset map: National road
- Inset map: Main road
- Other road (shown for orientation purpose)
- International boundary
- * Not applicable to this map

Chronostratigraphy

1	2	3	4	5	6
	PHANEROZOIC	Cenozoic	Quaternary	Q	Alluvium (Q)
1.8			Tertiary	T	
65		Mesozoic	Cretaceous	K	Malvernia F. (Kma)
142			Jurassic	J	Lebombo G. (Jl); Dolerite (Jd)
205			Triassic	Tr	Clarens F. (Trc); Bosbokpoort F. (Trb); Solitude F. (P-Trs); Undifferentiated Ecca G. and Clarens F. (Pe-Trc)
248		Palaeozoic	Permian	P	Ecca G. (Pe)
290			Carboniferous	C	
354			Devonian	D	
417			Silurian	S	
443			Ordovician	O	
495			Cambrian	Є	
545	PROTEROZOIC	Namibian		N	Diabase (N-Zd)
900		Mokolian		M	Main map: Soutpansberg G. (Ms); Inset map: Nzhelele F. (Msn); Wyllies Poort F. (Msw); Fundudzi F. (Msf); Sibasa F. (Mss); Stayt F. (Msa)
2050		Vaalian		V	
2650	ARCHAEOZOIC	Randian		R	Bulai gneiss (Rbu); Hout River gneiss (Rho)
3100		Swazian		Z	Sand River gneiss (Zsa); Alldays gneiss (Zal); Messina S. (Zbm); Madiapala syenite (Zma); Goudplaats gneiss (Zgo); Gumbu G. (Zbg); Malala Drift G. (Zba); Mount Dowe G. (Zbo)

1 = Million years before present (Council for Geoscience, 1997)
2 = Eonothem (Eon)
3 = Erathem (Era)
4 = System (Period)
5 = Symbol
6 = Complex (C), Suite (S), Group (G), Formation (F) (with symbol)

Schematic cross-sections to illustrate typical groundwater occurrence

Not to scale

Groundwater preferentially occurs in:

1. Saturated unconsolidated alluvial deposits along some of the river systems
2. The fractured transitional zone occurring between weathered and unweathered crystalline and metamorphic bedrock. This is a general characteristic of these rocks
3. Fractures that occur along the contact zone between dykes / sills and the host rocks with an average yield expectancy of about 3 l/s. The fractures developed due to the heating and cooling of the rocks involved in these intrusions
4. Contact zones between sedimentary rocks of different types, and between sedimentary and crystalline or metamorphic rocks. Contacts, which may be open, enlarged and loosened by weathering, and where discontinuity is formed by fracturing, are due to:
   - stratigraphic unconformities
   - tectonic forces
   - heating and subsequent cooling related to large extrusion / intrusion events
5. Weathered zones especially in the crystalline rocks
6. Fractures related to tensional and decompressional stresses due to off-loading of overlying material
7. Fault zones which are preferential targets for groundwater development, especially those occurring in the rocks of the Karoo Supergroup and the Soutpansberg Group. Some faults intruded by dolerite / diabase are usually favourable for groundwater development
8. Tensional fractures in lenses of folded Swazian-age inclusions which occur the Goudplaats Gneiss (Zgo).

Weathered zone

Groundwater level

Note: For additional information concerning groundwater occurrence refer to accompanying brochure.

This general hydrogeological map is part of the 1:500 000 Hydrogeological map series of the Republic of South Africa.

This map is not to be used for the purpose of local borehole siting. Simplified lithology may be considered as guidelines only. Further geological information can be obtained from the Council for Geoscience. The map series is produced with Arc/Info software.

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Private Bag X313
Pretoria
0001

Web site:
http://www-dwaf.pwv.gov.za
/geohydrology/index.htm

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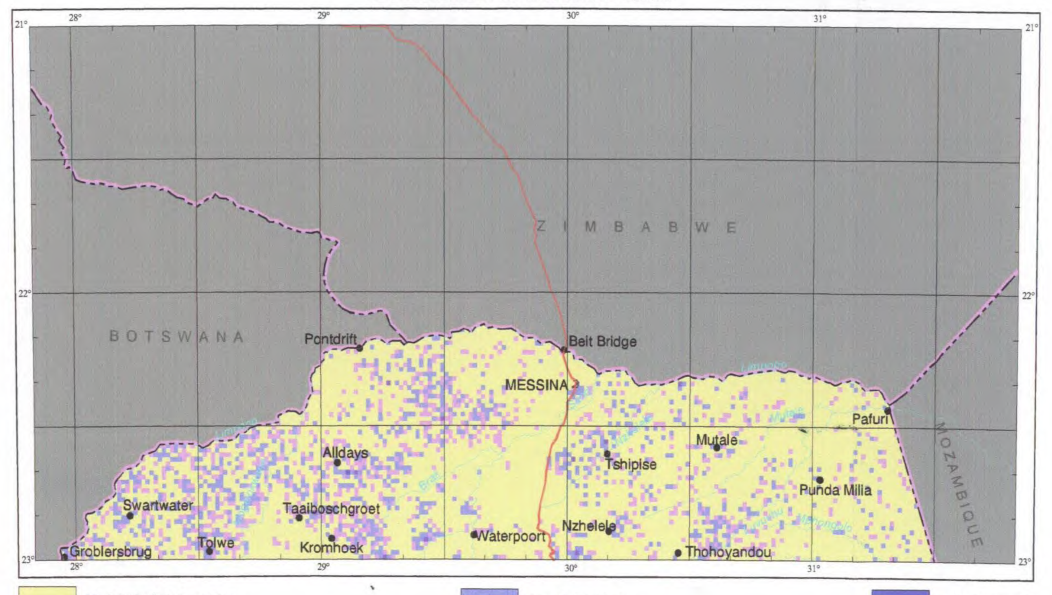
Distribution of borehole data

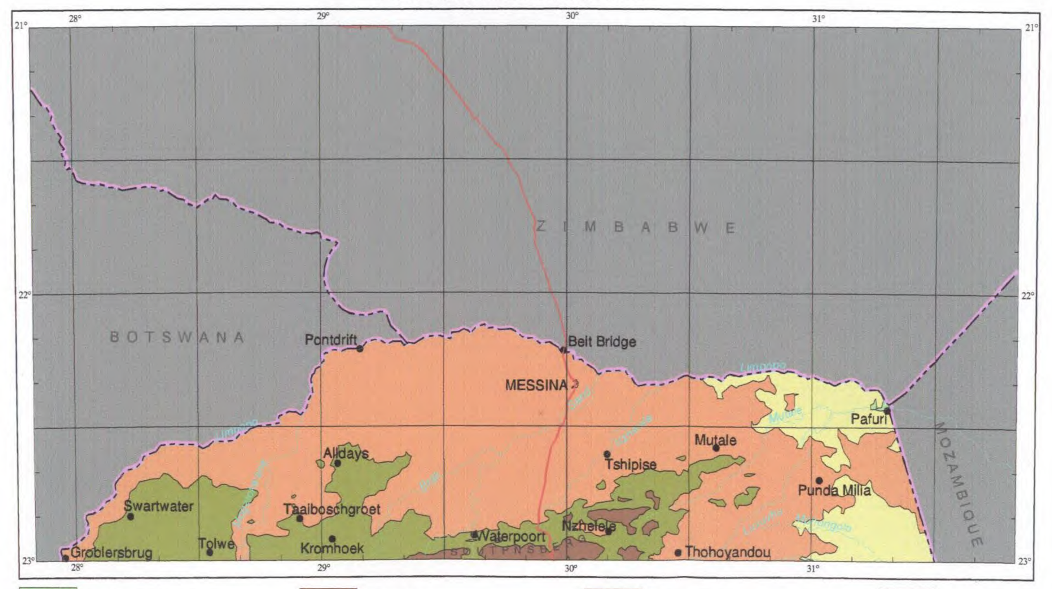


- No borehole information
- 1 Borehole
- 2 - 10 Boreholes
- 11 - 20 Boreholes
- > 20 Boreholes

Borehole data points per 1 minute grid

1 : 2 000 000

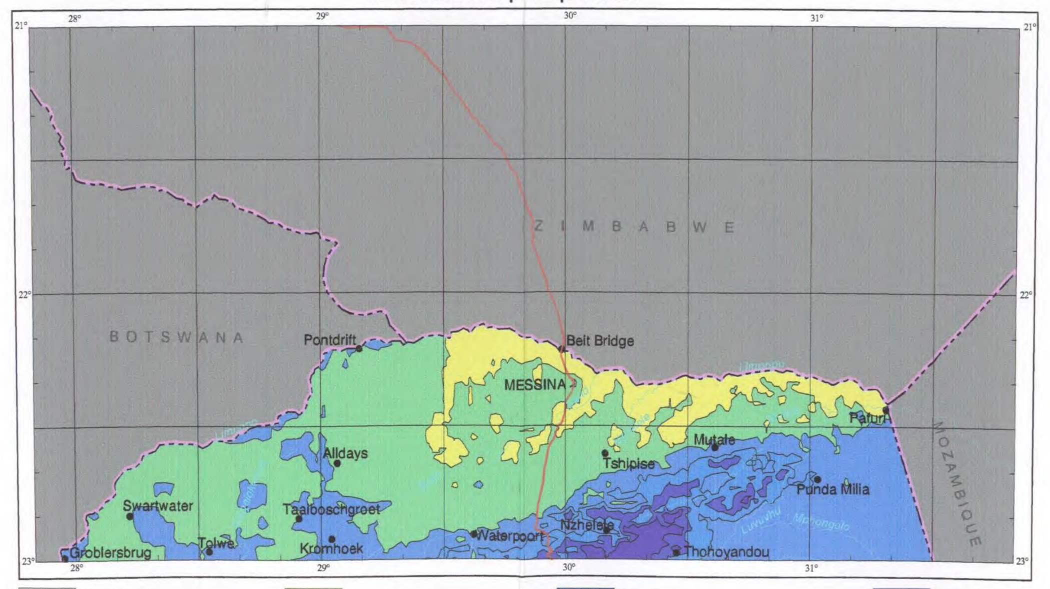
Elevation above sea level



- sea level - 200 m
- 200 - 400 m
- 400 - 800 m
- 800 - 1200 m
- 1200 - 1600 m
- 1600 - 2000 m
- 2000 - 2500 m
- > 2500 m

1:2 000 000

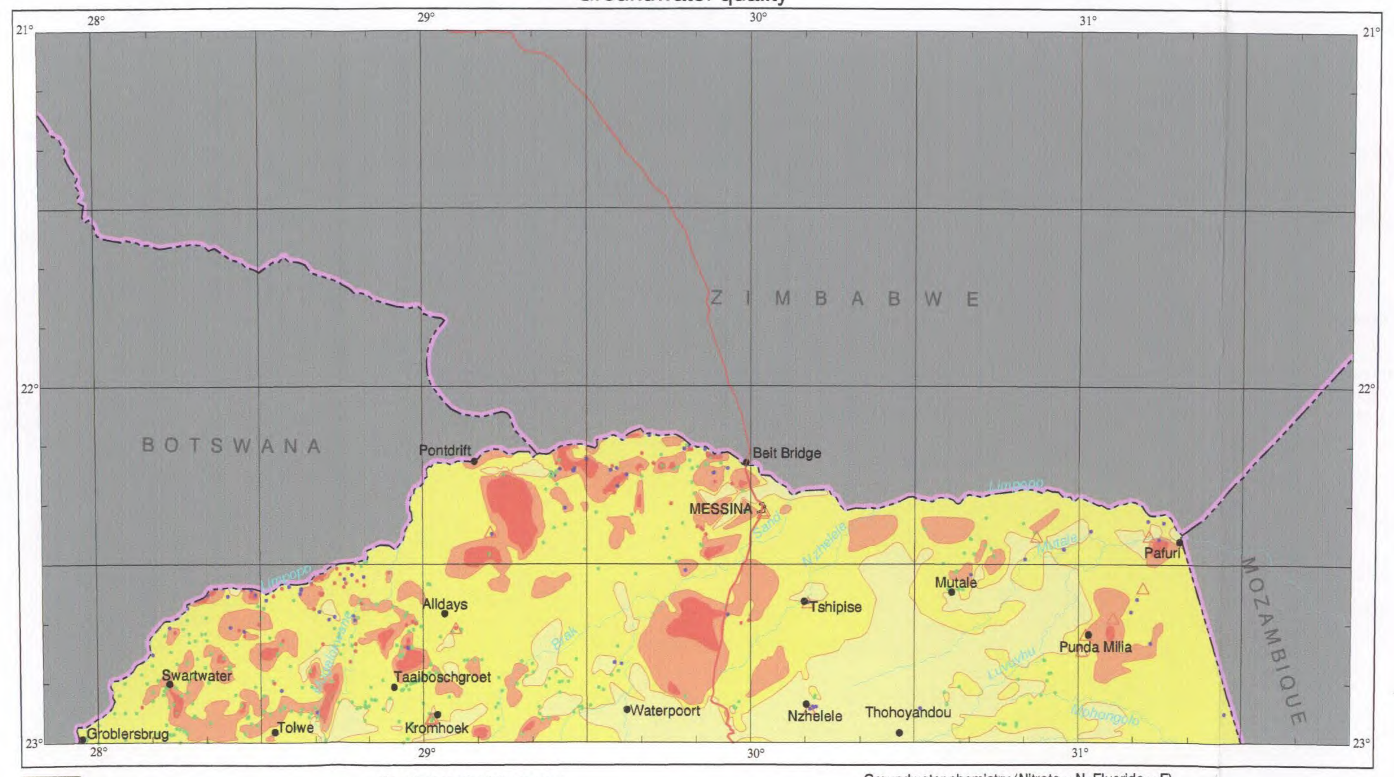
Mean annual precipitation



- 0 - 100 mm
- 100 - 200 mm
- 200 - 300 mm
- 300 - 400 mm
- 400 - 600 mm
- 600 - 800 mm
- 800 - 1000 mm
- > 1000 mm

1:2 000 000

Groundwater quality



- 0 - 70 mS/m
- 70 - 300 mS/m
- 300 - 1000 mS/m
- > 1000 mS/m
- Electrical conductivity contour
- Groundwater quality monitoring point

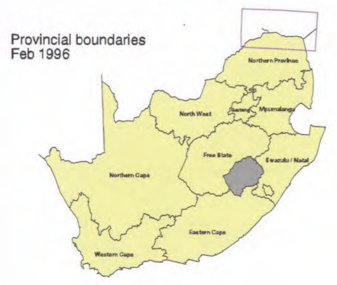
Groundwater chemistry (Nitrate = N, Fluoride = F)

- $NO_3 + NO_2$ (as N) > 10mg/l
- $NO_3 + NO_2$ (as N) > 10mg/l & F > 1.5 mg/l
- F > 1.5mg/l

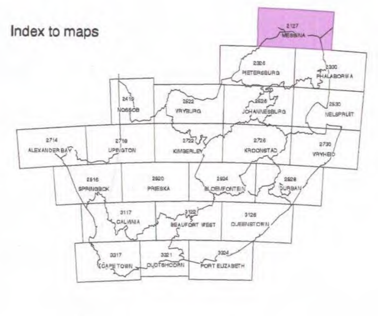
Note:
Nitrate and fluoride concentrations are shown only where the maximum allowable limits are exceeded and data are available. There may be other localities where concentrations of flouride and nitrate exceed the above limits. Unfortunately no groundwater analysis are available to prove or disprove this.
For additional information concerning groundwater chemistry refer to accompanying brochure.

1:1 500 000

Provincial boundaries
Feb 1996



Index to maps



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