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FACULTY OF SCIENCE
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**Geohydrologic Potential and Groundwater Management
in the Dendron Area, Limpopo Province.**

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A research report submitted to the Department of Geosciences in partial
fulfilment of the requirements for the degree of Master of Sciences in
Environmental Sciences

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DECLARATION

I declare that this is my own unaided work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree in any other University.



(Signature of Candidate)

2 day of NOVEMBER 2004

ABSTRACT

This Research has been undertaken to provide an insight and better understanding of geohydrologic potential and management of the Dendron aquifer, by determining various aspects of groundwater, such as characterisation of its availability, quality and vulnerability. It was possible to propose some approaches for ensuring the effective management of groundwater in the area.

The relationship between geological structures and groundwater parameters has been determined, for future development and management of groundwater in the area. The study has revealed that geological factors, such as geological structures should be considered for groundwater development study in the area. The interesting finding is that the boreholes drilled along lineaments were found to be the highest yielding and consequently lineaments are good targets for future development. It has been identified that the water quality of high yielding boreholes (boreholes located in high yielding lineaments) is generally of poor quality and highly mineralised in Calcium, TDS, Nitrate and Chloride.

The groundwater water type is mostly calcium-chloride-bicarbonate with sodium occasionally present in some parts of the study area, which reflects hard water. The chemical investigations indicated the water is generally in the acceptable to poor quality category for domestic and other uses. Natural contamination due to minerals and some anthropogenic signature were identified. High abstraction areas and the drawdown trends were identified. Even though rainfall does recharge the aquifer, there is still an overall decline in water levels indicating that abstraction exceeds groundwater recharge.

Recommendation in terms of sustainable groundwater management is that the WUA should be established for an effective control and management of groundwater resource in the study area. For development purpose the water quality should be considered, since water quantity and quality are inter-dependent.

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ACRONYMS

DWAF	Department of Water Affairs and Forestry
GIS	Geographical Information System
GPS	Geographical Positioning System
IWMI	International Water Management Institute
NGDB	National Groundwater Database
SAWQG	South African Water Quality Guidelines
WUA	Water User Associations

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND PROBLEM STATEMENT

In the area around Dendron, about 60km north of Polokwane in the Limpopo Province, groundwater is stored and transmitted predominantly in structural/fractured aquifers with secondary porosity. Deep down, these cracks are closed due to the weight exerted by the overlying formations. At depths below 30m, water-bearing fractures with significant yields tend to be rare (Hodgson and Krantz, 1998). Fractures often serve as major conduits for movement of water and dissolved chemicals through hard rocks in the underground.

Some of the fractures may be identified as linear features on the geological map of the study area. Highly variable yields are found in these aquifers. Initial high yields may show a marked decrease with continued pumping due to the limited storage capacity in some of the cracks. The water in the fractured aquifers does not actually penetrate the rocks, because there is no pore space between the grains of the rock. However, some of these rocks have fractures in them. Because these fractures store water and yield amounts to wells that intersect them, a systematic examination of their distribution, with the help of remote sensing and ground geological mapping should give a useful insight into the manner of groundwater occurrence and availability for use.

The Dendron aquifer is an important source of irrigation water for the commercial agricultural activities in the Dendron area. The aquifer is also a potential water source for small-scale irrigation and home/community garden activities. There are more than 200 farms in the area, of which 50 have significant irrigation activities. The remainder of the farms utilise groundwater mainly for livestock watering. The main crops that are irrigated include potatoes, wheat, maize, cotton, oats, pumpkins and vegetable. Of the 335 boreholes surveyed in the area in 1986, 69% were used for irrigation, 27% for domestic purposes, and 4% for livestock watering (Jolly, 1986). In terms of volume, irrigation accounted for 95% of all abstractions.

Several years back, the aquifer was reported to be mismanaged (Jolly, 1986), and was also considered as over-exploited, evidenced by excessive drawdowns. Commercial farmers, the main user group, implemented some water management changes which included switching to more efficient water application and more stringent moisture monitoring so as to apply water only when required. While farmers are of the opinion that the state of the aquifer has improved and the water table has been rising in recent years, the water level data from the Department of Water Affairs and Forestry (DWAF) suggest otherwise and warrant further analysis.

Although groundwater is resilient, it is ultimately very vulnerable to poor management. Some obvious and less obvious factors are its invisible nature, the often long delays before impacts of over-exploitation and pollution manifest themselves, its very limited self-purification capacity and the near impossibility to rehabilitate it, once it has become polluted. Perhaps confirming the widespread belief that groundwater is a hidden and misunderstood resource, not much is known about groundwater quality and geochemistry in the Dendron aquifer. There is need, therefore, to carry out some study into the chemistry of the groundwater, in order to determine whether groundwater quality and mineral salt content is natural, due to natural leaching of minerals to the groundwater, or anthropogenic.

Building upon these elements of integrated groundwater assessment, including the characterization of its availability, quality and vulnerability, it should then be possible to point to meaningful approaches for ensuring the effective management of groundwater in the area.

1.2 RESEARCH OBJECTIVES

In the light of the foregoing background, this study seeks to accomplish the following key objectives:

- (a) identify and delineate the dominant lineaments that play a critical role in groundwater occurrence in the rocks underlying the Dendron area, using aerial photographs, remotely sensed images and geological maps, and producing a map of the fracture systems in the area;

- (b) determine the relationship between the fracture systems and location-specific borehole parameters, especially static water level and yield, as a vital input to the formulation of an integrated approach to groundwater development;
- (c) establish, based on aqueous speciation including major anions and cations, the dominant groundwater (hydro-geochemical) types in the area, and draw attention to anomalous constituents and possible sources of contamination;
- (d) produce a series of water-level contour maps over a time sequence using both current and historic borehole data, to establish the changing nature of the piezometric surface over the years;
- (e) deduce the distribution of drawdowns over the entire area in relation to high groundwater abstraction points, and put forward reasons for possible over-exploitation; and
- (f) advise strategies for sustainable and equitable groundwater utilization in the study area.

CHAPTER 2

LITERATURE REVIEW ON GROUNDWATER STUDIES

2.1 BASEMENT ROCK AQUIFERS

Fractured Basement Complex aquifers such as underlying the Dendron area are a major source of groundwater supplies in South Africa. In over 90% of the surface area of the country, groundwater occurs in secondary openings in so-called hard rock. Generally, secondary aquifers consist of weathered rocks, fissure systems, fault zones and solution channels that were formed during geological periods after the deposition or intrusion of the formation. The secondary aquifers are generally independent of the age of the formation or its geological associations, and are very likely to be variable for a particular geological horizon along its strike or laterally (Weaver et al, 1999).

Rock fractures are caused by stress. Rocks may fold, faults may move, and rocks may expand when the overlying material is removed by erosion and the now-bare rocks are exposed to the weather. Fractures may be large or small and may extend vertically or horizontally. They may be a few millimetres to hundreds of meters long, but most are less than a millimetre wide. In addition, greater the depth, the smaller the width of these fractures. For the most part, fractures are the only way groundwater can be stored in hard rocks. The amount of water that can be obtained from hard rocks depends on the size and location of the fractures; interconnection of the fractures; and the amount of material that may be clogging the fractures (Weaver et al, 1999).

It usually happens that a geological formation or horizon may be an excellent aquifer in one area, due to the secondary development of permeability and storage, and an aquifuge in another area not necessarily far. Thus, it may form a large groundwater reservoir in some place and show continuous outcrops of solid rock on an adjoining area. The safe yield of such crystalline rock aquifers is generally limited by the storage and recharge capacity. Secondary aquifers very often consist of two parts, the one forming the storage reservoir and the other forming the high permeability conduit network, separate from the reservoir,

but linked with it hydraulically such that the water stored in the former can be abstracted from the boreholes drilled in the latter (Enslin, 1960).

Aquifers in fractured rocks are generally considered of minor importance compared to those in primary porous media, on which much attention has been focused in several regions mainly in the northern hemisphere countries. The amount of groundwater available in fractures is generally limited, at least in arid and semi arid regions. Nevertheless, this type of aquifer is a primary source of water in vast areas throughout the world, where the aquifers with primary porosity are practically non-existent and surface water is ephemeral. This applies particularly to Southern Africa.

Fractures in a geological medium can greatly influence its hydrogeological characteristics. They can increase the hydraulic conductivity of an otherwise impermeable rock or soil by orders of magnitude in the dominant fracture directions.

The geological structure normally encountered in hard rock Basement areas of South Africa is characterised by the extensive hard, mainly granitoid rocks overlain by a weathered overburden of variable thickness. Hydrogeologically, the weathered material that constitutes the overburden has high porosity and contains a significant amount of water and, at the same time, presents low permeability due to its relatively high clay content (Barker, 2001).

Over crystalline basement rocks such as underlie Dendron and environs, the weathered aquifer occurs near the ground surface and is frequently exploited because of its shallow depth and ease of access. For example it tends to be a mere 5-12 metres deep in parts of the Olifants River Basin (Hodgson & Krantz, 1998). Solid fractured rock or structural aquifers tend to form the lower boundary of such aquifers. A weathered rock aquifer is often of a perched nature, that is, it may have a more extensive aquifer beneath it. The aquifer tends to be rather low-yielding because of its limited thickness, giving a typical flow of one litre per second or less in many places. However, when existing in conjunction with a structural aquifer, yields of up to five litres per second may occur from a borehole penetrating both the weathered aquifer and a deeper aquifer beneath (DWAF, 1991).

Unaltered Basement rock is frequently fractured, presenting high permeability, but as the fractures do not constitute a significant volume of the rock, fractured basement has a low

porosity. For this reason, a good borehole providing long term yields is one which penetrates a large thickness of weathered overburden, which acts as a reservoir and which additionally intersects fractures in the underlying bedrock, where the fractures provide the rapid transport mechanism. While these types of rocks have little or no pore spaces, groundwater is accumulated and transported in interconnected fractures within the rock. Wells that are drilled into a network of fractures can yield water, whereas a nearby well that does not intersect fractures may yield no water at all.

Fracture zones may be exposed on the surface or be evident from their topographic expression, or show up as lineaments on aerial photographs and satellite images or may be located by geophysical techniques. Lineaments, however, are not exclusively ascribable to fracture zones, but may be expressions of lithological contacts, such as dykes, and ductile deformation zones (Vegter, 2001).

According to Kellgren and Sender (2000), hard rock includes metamorphic, igneous and sedimentary formations with low primary porosity. Fracturing mainly caused by deformation and weathering controls groundwater flow in hard rocks. Typically, the degree of deformation and weathering is locally highly variable and hydraulic conductivity and storativity may change significantly over a short distance. Fractures are caused by stress that commonly can be related to regional deformation, resulting in structural features such as joints and shear fractures, faults, folds, cleavage, foliation and lineation (Davis and Reynolds, 1996).

Lloyd (1999) indicated that fractures under tensile and shear conditions associated with brittle deformation in the uppermost layer of the crust, are usually the most promising for groundwater development. Other important zones of enhanced fracturing are contacts, that is, the zone between two lithological entities, and intrusive dykes. The emplacement of dykes is usually associated with fracturing, but the dykes themselves may, due to shrinkage during cooling, fracture more than the adjacent host rock. The weathered overburden is usually associated with the fractured zones and frequently targeted for borehole sites.

2.2 FRACTURE MAPPING AND SATELLITE IMAGES

Remote sensing is a recognized tool for detecting and mapping the surface indicators of potential groundwater accumulation, storage, transmission, and recharge. Thermal images acquired from both satellite and airborne platforms have been used in geological investigations since the 1970s (Morton et al, 2000). Thermal data are useful for, amongst other applications, geological mapping and groundwater detection. Observable indicators on satellite imagery and aerial photography include regional tectonic features, fractures and lineaments, drainage patterns, lithologies, soils, and vegetation anomalies.

When combined with regional geological and local hydrologic data, groundwater potential can be assessed and prospective targets ranked according to their probable suitability as aquifers. Detailed hydrogeological exploration includes assessments of flow from potential aquifers based on existing borehole data, location of created fractures and drilling. Important to the distribution of the water found and to hydrogeologic analysis is a combination of the geologic structure, lithologic, lineament (potential fractures) and chemical analysis, a study of the above should lead to the identification of specific drilling locations. All the activities mentioned above could be achieved through, amongst other techniques, the use of remote sensing data.

Satellite images can reveal the structural geology of a site, showing faults, fractures, bedding planes and many other features (Morton et al, 2000). Geologic interpretations of satellite images include the discrimination of bedrock types, lithologic mapping, mapping of areas of alteration in bedrock, and delineation of regional geologic structures. Landsat imagery is also useful for the construction of base maps and for interpretations for the planning of site investigations, particularly where topographic or geologic map coverage is unavailable or available at an inadequate scale.

O'Leary et al (1976) defined lineaments as mappable linear surface features, which differ distinctly from the patterns of adjacent features and presumably reflect subsurface phenomena. Lattman and Parizek (1964) described lineaments as features that are generally manifested by topography (including straight stream segments), vegetation, or soil tonal alignments. Lineament mapping and analyses have gained popularity with the increasing availability of satellite and high-altitude aircraft images.

The conclusion of Boyer and Mc Queen (1964) that remotely sensed linear features are largely a reflection of rock fractures, emphasized by vegetation and topography has been evidenced by successful use of lineament analysis in exploration for oil and gas traps, and to select drilling locations for maximum porosity in tight formations (Peterson, 1980; Mah et al, 1995). Recent surveys carried out in Southern Africa by Morton and Franszen (2000), utilized satellite images to determine the positions of dolomite aquifers, polluted groundwater, and seepage from slime dams, geological structures, abandoned mines, underground fires and kimberlites. Also, hydrogeologists are successfully using lineaments to locate high-yield wells and to describe more accurately, subsurface structures important for tracking recharge, migration, and discharge of groundwater (Hart, 1999).

Landsat images may be utilized in hydrogeologic studies for enhancing the understanding of geology and geomorphology, and inventorying surface waters and associated features. The quality of interpretations varies with the amount of vegetation cover in the area of interest. Interpretations are improved when carried out in conjunction with existing topographic, geologic, hydrologic, and other mapped data. Several geomorphologic interpretations of satellite imagery also contribute to the conceptualisation of regional and site hydrogeologic models. These may include definition of basin geometry; identification of flood plains; identification of modern and paleo-stream channels and shorelines; interpretation of landforms, drainage patterns and density (texture), and vegetation patterns; and delineation of land use, land cover and soil type (Fetter, 1994).

Ground truthing and follow-up efforts can be focused on imagery interpretations, thereby making the best use of time and budget. Satellite imagery is also a valuable resource for groundwater exploration, regional and site hydrogeologic characterizations, and water resource evaluation. Imagery interpretations contribute to identification of areas for water rights acquisition, screening of areas for more detailed ground geophysical investigations, drill site targeting for groundwater exploration or for monitoring wells, and for provision of input to hydrogeologic models and watershed analysis.

The advantages of satellite imagery compared to aerial photography, include the ability to use the data in digital format, ease of re-scaling, spatial accuracy (when geo-rectified), ease of use (a large area can be displayed on one print), faster acquisition, and cost savings. Satellite imagery is, therefore, best suited to sub-regional to regional scale investigations, but is a good supplement to site-specific studies.

Neumann and Sami (2000) carried out groundwater exploration in complex fractured rock in the Mapumulo district of Kwazulu-Natal, within the Natal Metamorphic Province. The main objectives were to develop an exploration methodology that maximises the success rate of boreholes in the most cost-effective and productive manner, and to identify the geological and structural controls that distinguish high yielding features from those that have low potential.

One of the techniques which was used and found to be very effective and successful, was the determination of geology and the structural features of the Natal Metamorphic Province on the basis of Landsat imagery interpretation. The interpretation was based on observing, from Landsat images, lineaments and structural features that characterise potentially water-bearing, as opposed to largely non water bearing areas. It was found that there is a relationship between the lineaments that were identified from the Landsat image and high water-bearing regions (Neumann and Sami, 2000).

The ARC/ INFO GIS software is useful in digitising and analysing the data generated from satellite imagery. The analysis carried out in GIS provides a good reference data of the positions on the ground. It enables a precise overlay of borehole parameters such as yield and depths on the geological map of the area highlighting structures and rock types (Banoeng-Yakobo and Skjerna, 2000).

Groundwater exploration over vast areas by traditional options and processes, including geological studies and geophysical investigations, may require extensive resources, both human and financial, and can consume considerable time. However, intervention such as irrigated agricultural development for poverty alleviation and the provision of potable drinking water to rural areas are often urgent tasks that require immediate identification of water resources, frequently including groundwater sources. Fortunately, data gathered from earth observation satellites integrated with traditional data using a GIS system, coupled with selected field investigations and knowledge of the area under investigation, can provide a quick and powerful tool in the search for groundwater. Basically, the correct combination of information and data, including remotely sensed data, can lead to informed and accurate decision making that can be implemented at local and regional levels.

A case study that was undertaken in the Syrian Arab Republic proved the use of remote sensing as a very effective tool in groundwater studies (Travaglia, 1998). Groundwater

moves along faults and fractures in the basaltic terrain of Southern Syria due, in large part, to the results of tectonic movement. Landsat data was used to define lineaments. The statistical analysis of these lineaments indicated two major directions of fracturing considered as being “open” and able to store and transmit groundwater. In addition, high yielding freshwater springs were located near the Syrian coastline as a result of the study (Travaglia, 1998).

In the Syrian study, potential drilling sites were identified and positively tested by georesistivity. In selecting the satellite data for the study, Landsat TM data were preferred. This was due to the availability of a large spectrum of bands, mainly in the near and medium infrared portion of the electromagnetic spectrum (the most suitable for lineament and terrain analysis) as well as in the thermal portion of the spectrum, which permitted the acquisition of a greater range of information.

Aerial photographs have been used in geologic and geohydrologic studies for decades to form databases from which the rock units (stratigraphy) can be mapped, the expression and modes of origin of landforms (geomorphology) studied, and the structural setting of disturbed strata (folds and faults) determined. In addition the dynamic changes from natural events (e.g., floods and volcanic eruptions) surface indications of subsurface mineralization, such as alteration, as well as groundwater controls can be determined (Short, 1997).

With the advent of space imagery, geoscientists now can extend that use in three important ways (Short, 1997):

- 1) the advantage of large area or synoptic coverage allows the examination, in single scenes (or in mosaics), of the geological portrayal of earth on a regional basis;
- 2) the ability to analyze multispectral bands quantitatively, in terms of numbers, permits application of special computer processing routines to distinguish and enhance certain compositional properties of earth materials;
- 3) the capability of merging different types of remote sensing products (e.g., reflectance images with radar or with thermal imagery) or combining these with topographic elevation data and with other kinds of information bases (e.g., thematic maps; geophysical

measurements and chemical sampling surveys), enabling new solutions for determining interrelations among various natural properties of earth phenomena.

These approaches have proven to be indispensable techniques for improving the geologic and hydrogeologic mapping process and carrying out practical exploration in geological and groundwater studies.

2.3. GROUNDWATER QUALITY

2.3.1 Characterisation of Groundwater Quality

Water quality is characterised in terms of the microbiological, physical and chemical properties, all of which determine its fitness for use. Many of these properties are controlled or influenced by substances which are either dissolved or suspended in the water.

Microbiological quality

Microbiological quality refers to the presence of organisms that cannot be seen by the naked eye such as bacteria, viruses and protozoa. Groundwater may contain mineral matter that gives the water an objectionable taste, but still be free from harmful bacteria and, consequently, safe for drinking. Other borehole water, good tasting and seemingly pure, may contain harmful bacteria. Water supplies obtained from wells that are properly constructed and located away from sources of pollution are almost always free of harmful bacteria. Because human and animal wastes are high in chloride and nitrogenous material, the presence of abnormal concentrations of both chloride and nitrate can be indicative of pollution from these sources (Everett, 1980). Associated with chemical pollution from human and animal waste, coliform bacteria may be introduced into groundwater. Typical sources might be surface sources, such as unsanitary, uncontrolled living conditions, informal settlements, animal concentrations (feedlots), pit latrines, septic tanks, and leaking sewers. Infiltration through the unsaturated zone may not be sufficient to liberate the carrying fluid of bacteria. The nature of aeration zone plays an important role in the effective filtering of bacteria (Davis and De Wiest, 1966).

The main purpose of bacteriological examination is the detection of recent, and potentially dangerous, faecal pollution. Several pathogens could be present in water and it is not practical to be able to test for them all. The determination is not to ascertain whether there are pathogens in water, but to confirm the presence or absence of types of bacteria that are always present in the excreta of man and animals, and whose presence indicates faecal pollution. These indicators are *Escherichia coli* (E-Coli), *Clostridium perfringens* and *Streptococcus* (Everett, 1980).

Physical quality

Physical quality refers to water quality properties that may be determined by physical methods such as conductivity, pH and turbidity measurement. The physical quality mainly affects the aesthetic quality including the taste, odour and appearance of water (WRC, 1998).

pH

This is the balance between acids and alkaline in water. A pH of 7 indicates neutral water, pH of greater than 7 indicates the water that is alkaline, and pH less than 7 indicates water that is acidic. The extremes are 0 and 14 for natural water. A pH of 6 to 8 is normal. Acid conditions generally lead to corrosive attack on metallic objects placed in groundwater. Corrosion becomes a problem when the pH is below 7, but corrosion rates for steel are minimal at a pH above 11 (WRC, 1998).

The pH of most groundwaters results from the balance between dissolved carbon dioxide gas derived from the atmosphere and biological activity, and the dissolved carbonates and bicarbonates derived from carbonate rocks (Driscoll, 1986). This balance occurs naturally in the existing geological and biologic environment at or near the earth surface. For example, water high in carbon dioxide will progressively dissolve any available carbonate rocks until the pH is generally between 7 and 9. An increase in soil alkalinity often produces greater biological activity, causing more carbon dioxide to be released to the atmosphere from respiration and decay. Those waters with pH values lower than about 4.5 probably contain free-mineral acids from mine water, volcanic gases, or contamination by certain industrial wastes.

Specific conductance

Specific conductance is a measure of the ability of water to conduct an electric current and is an indication of the ionic strength of the solution. Chemically pure water has a very low electrical conductance, indicating that it is a good insulator.

Only a minute amount of dissolved mineral matter, however, will increase the conductance of the water markedly. Because conductance is the reciprocal of resistance, the units in which specific conductance is reported are reciprocal ohms or "mhos." Natural waters have specific conductance values much less than 1 mho and, therefore, are reported in millionths of mhos or micromhos at a standard temperature of 25 deg. C (77 deg. F). For practical purposes, the relation between specific conductance and concentration of dissolved solids is linear for dilute solutions (Everett, 1980).

Taste, odour and colour

Odour is much easier and a lot safer to identify than the taste of water. However, both measurements are very subjective and would vary from person to person and lack scientific preciseness. The senses of these two are very closely related, although that of smell is much more acute than that of taste. Disagreeable taste and odour commonly resulting from decayed organic matter, sewage and living microscopic organisms. Colour refers to the appearance of water that is free from suspended sediment. Inorganic matter extracted from leaves, roots, plant remains or even sewage, usually causes yellow to brown colour of some water (WRC, 1998).

Temperature and Turbidity

A rise in temperature of water is an indication of contamination, possibly from industrial discharges. Turbidity is an optical property of water. It is normally caused by suspended material in water (Driscoll, 1986)

Chemical quality

Chemical quality refers to the nature and concentration of dissolved substances such as salts, metals and organic chemicals. Chemical analysis requires the laboratory

determination of the concentrations of common ions found in groundwater and is commonly reported in units of milligrams per litre (mg/L). Concentrations may also be expressed as equivalents per million (epm) which is the moles of solute multiplied by the valence of the solute species in 10,000,000 g of water. A list of suggested parameters for chemical analysis is given in Table 1. Additional parameters may be tested if a more detailed analysis is requested or where known or suspected sources of pollution exist (Hodge, 2002).

Table 1: List of suggested parameters for chemical analysis (Hodge, 2002).

PARAMETERS	UNITS
Total Alkanity	Mg/l
Sulphate (SO ₄)	Mg/l
Nitrate and Nitrate (NO ₂ - + NO ₃ -)	Mg/l
Total Phosphorus (P)	Mg/l
Fluoride (F)	Mg/l
Chloride (Cl ⁻)	Mg/l
Calcium (Ca ⁺⁺)	Mg/l
Magnesium (Mg ⁺⁺)	Mg/l
Sodium (Na ⁺)	Mg/l
Potassium (K ⁺)	Mg/l
Manganese (Total and dissolved) (Mn)	Mg/l
Iron (Total and dissolved) (Fe)	Mg/l
Silica (SiO ₂)	Mg/l
pH	Relative units
Total dissolved solids (TDS)	Mg/l
Total Hardness (CaCO ₃)	Mg/l
Turbidity	(J.T.U)

Iron (Fe⁺², Fe⁺³)

Iron is very common in many igneous rocks and is found in trace amounts in practically all sediments and sedimentary rocks. The iron content of water is important because small

amounts seriously affect water's usefulness for some domestic and industrial purposes. Water may dissolve iron upon contact with metal well-casings, pump parts, and piping. Thus, large amounts of iron in any distribution system may not be derived from earth materials. The more corrosive (low pH or high oxygen content) the water, the more metal it will dissolve. The specific form iron takes in water depends on the amount of oxygen in the water and the pH (Davis and De Wiest, 1966).

In natural groundwater systems where oxygen concentrations are low or absent and the pH is from 6.5 to 7.5, the iron occurs primarily as dissolved ferrous ions (Fe^{+2}). Ferrous ions are unstable when in contact with oxygen. In the presence of air, they change to ferric ion (Fe^{+3}) and precipitate as ferric oxide or oxyhydroxides. Ferric iron is almost completely insoluble in alkaline or weakly acidic waters. In concentrations as low as 0.3 mg/l, iron is undesirable, as it may stain cooking utensils, plumbing fixtures, and clothing being laundered, or give a disagreeable taste to the water. Iron causes reddish brown stains on white porcelain (Davis and De Wiest, 1966).

Manganese (Mn^{+2})

Manganese resembles iron in its chemical behavior and occurrence in groundwater, but is less abundant than iron (Kemmer, 1977). It is found less commonly in water and the concentration is generally much lower than iron. In deep wells, manganese may reach concentrations as high as 2-3 mg/l. It is objectionable in water in the same general ways as iron. It occurs as soluble manganous bicarbonate that changes to insoluble manganese hydroxide when it reacts with atmospheric oxygen. Stains caused by manganese are more objectionable and harder to remove than those caused by iron (Kemmer, 1977).

Chloride (Cl^-)

Most naturally occurring chlorides are very soluble. Chloride concentrations in groundwater are known to range from less than 1 mg/l in some shallow aquifers to many thousand milligrams per liter in some of the deep strata. Sodium and chloride are the chief dissolved constituents in the groundwater in some of the deeper aquifers. Driscoll (1986) indicates that in some basaltic and gabbroic terrains, the chloride content in groundwater averages about 12 to 13 mg/l, whereas in some granites the concentration is 6 mg/l.

Persons having a sensitive taste can detect sodium chloride water with a chloride concentration of 150 to 200 mg/l. Water with high chloride content is corrosive to many metal surfaces, and many crops may be injured by waters containing excessive quantities of chloride. Chloride in ground water may be derived from connate marine water in the sediments, from sewage and animal wastes, or from solution of minerals containing chloride. It has little effect on the suitability of water for ordinary use unless the quantity is enough to give the taste of salt (Driscoll 1986).

Nitrates (NO_3^-)

Unlike most other elements in groundwater, nitrate is not derived primarily from the minerals in rocks that make up the groundwater reservoir. It enters groundwater from part of the nitrogen cycle in the earth's hydrosphere and biosphere. Nitrate, nitrite and ammonia are found in groundwater as nitrogen compounds, and in water analyses, these species are reported as either of the complex ions (Davis and De Wiest, 1966)

Nitrate is highly soluble. Concentrations of greater than 55 mg/l of nitrate in drinking water (SAWQG) may cause cyanosis, or oxygen starvation, if used in the preparation of a baby's food (WRC, 1998). Such concentrations may indicate contamination by sewage or other organic matter. Nitrate from natural sources is attributed to the oxidation of nitrogen of the air by bacteria and to the decomposition of organic material in the soil. In general, shallow water-table aquifers having a significant range in fluctuation of the water table appear to have more nitrates attributable to natural sources than do other aquifers. Fertilizers and animal wastes may also contribute nitrates directly to water resources (Driscoll 1986).

Moreover, high nitrate content can be considered an indicator, and thus a warning, that an aquifer should be tested for harmful pathogenic bacteria that may accompany contamination from these sources. Because nitrate in groundwater originates most often from sewage waste, its presence is taken as evidence of contamination. However, sewage contamination also adds chloride to groundwater. In fact, chloride travels especially well underground and is usually the first indication of contamination. Therefore high nitrate together with high chloride is a more positive indication of sewage seepage or barnyard pollution than is nitrate alone (Everett, 1980).

Sulphate (SO_4^{-2})

Sulphate in groundwater is derived primarily from the evaporite minerals gypsum (hydrous calcium sulphate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and anhydrite (calcium sulphate, CaSO_4). It may also come from the oxidation of pyrite, which is an iron sulfide mineral. Groundwater in igneous or metamorphic rocks generally contains less than 100 mg/l sulphate (Davis and DeWiest, 1966). The concentration of sulphate is not very critical for domestic or irrigation uses or for many industrial processes. Sulphate in groundwater is derived chiefly from the solution of gypsum and the oxidization of pyrite. Sulphate concentrations in excess of about 500 mg/l may have a laxative effect on persons not accustomed to drinking such water (Davis and DeWiest, 1966).

Silica (SiO_2)

Silicon is the second most abundant element in the earth's crust, and only oxygen is more abundant. Silicon in combination with oxygen, as the oxide SiO_2 , is called silica. The common mineral quartz, in its many varieties, is essentially pure silicon dioxide. Silicon and oxygen combine readily with many other major elements such as potassium, magnesium, sodium, iron, calcium, and aluminum to create a broad range of rock forming minerals. The origin of silica in groundwater is attributed to the chemical weathering of silicate minerals. Silica is not readily dissolved by water; nevertheless, warm groundwater sometimes contains as much as 100mg/l silica and silica concentration of 20mg/l is common (Davis and DeWiest, 1966).

Fluoride (F^-)

Fluoride, derived from fluorite, the principal fluoride mineral in igneous rocks and the minerals apatite and mica, is generally present in only low concentrations in groundwater. Volcanic or fumarolic gases may contain fluoride, and in some areas, these may be the source of fluoride in groundwater. Excessive fluoride affects tooth enamel; furthermore, teeth may become brittle because fluoride affects tooth density. Fluoride, unlike chloride, is only sparingly soluble in water and usually is present in only small amounts. It is often characteristic of waters from deep strata and of salt water from oil and gas wells (Davis and DeWiest, 1966).

Calcium and Magnesium

Groundwater in contact with sedimentary rocks derives most of their calcium from solution of calcite, aragonite, dolomite, anhydrite and gypsum. Magnesium is derived from dolomite in sedimentary rocks; olivine, biotite, hornblende, and augite in igneous rocks and serpentine, talc, and tremolite in metamorphic rocks. In addition, most calcite contains some magnesium, so that solution of limestone commonly yields abundant magnesium as well as calcium. Highest concentrations of magnesium and calcium are usually found in water that has been in contact with limestone, dolomite and gypsum. Low values of magnesium and calcium are found in some waters which have undergone natural softening by cation exchange (Davis and De Weist, 1966). As water percolates through an aquifer, it may be modified and changed. Material comprising the aquifer may contain material which has a strong natural tendency to exchange one ion for another. In such an aquifer, calcium or magnesium in the water may be exchanged for sodium (Davis and De Weist, 1966).

Carbonate and Bicarbonate

Carbonate is seldom present in natural water and bicarbonate is formed when carbon dioxide in water reacts with carbonate rocks. Most water in contact with granite and similar rocks contain less the 50 mg/l of bicarbonate, and much water contains less than 25 mg/l. Carbonate and bicarbonate are reported as alkalinity, which is expressed as parts per million calcium carbonate (WRC, 1998).

2.3.2 Groundwater Constituents

Although groundwater is relatively pure in comparison to surface water, certain factors influence its constituents. Minerals, which contact water in under-ground spaces, may become dissolved in it, and some minerals dissolve more easily than others.

Naturally, groundwater contains mineral ions. These ions slowly dissolve from soil particles, sediments and rocks as the water travels along mineral surfaces in the pores or fractures of the unsaturated zone and the aquifer. They are referred to as dissolved solids. Unlike surface water, groundwater does not typically flow toward a single outlet at the

topographic bottom of the watershed, where the cumulative effect of watershed pollution and of improvements in watershed management can be directly measured.

The quality of groundwater is intrinsically linked to the chemical properties of the aquifer's geology through which it flows. As a result, its quality varies from one aquifer to another, and even within aquifers. However, artificial pollution of groundwater by human-induced means is, of course, now more and more common. Given the slow speed with which groundwater moves through the ground resulting in a very long residence time, once an aquifer is polluted it may take many generations before that aquifer can again produce unpolluted water (Hodgson and Krantz, 1998).

Groundwater is not pure water because it usually contains dissolved mineral ions. The type and concentration of the dissolved minerals can affect the usefulness of groundwater for various purposes. When certain mineral constituents are present in excessive amounts, some type of treatment may be necessary to either change or remove the dissolved mineral before the water can be used for the intended purpose. Most groundwater contains no suspended particles and practically no bacteria or organic matter. It is usually clear and odourless (Driscoll, 1986).

These characteristics contrast with those of surface waters, which generally contain suspended matter and considerable quantities of bacteria. Groundwater is normally more hygienic, although it ordinarily contains more dissolved solids than surface water (Driscoll, 1986). Although groundwater is generally less susceptible to contamination than surface waters, it is usually more highly mineralized in its natural state. As water moves slowly through the ground, it can remain for extended periods of time in contact with minerals present in the soil and bedrock and become saturated with dissolved solids from these minerals (Everett, 1980).

This dissolution process continues until chemical equilibrium is reached between the water and the minerals with which it is in contact. Important mineral constituents found in groundwater and their relative abundance are listed in Table 2. The types and relative concentrations of the chemical constituents in groundwater provide information on the evolution of groundwaters, age (residence time), solubility, and rates of movement, flow

history and sources of recharge. Older groundwaters, for example, are generally more mineralized than younger groundwaters.

Fresher groundwaters are normally associated with recharge areas whereas groundwaters in discharge areas are more mineralized. Groundwaters can be classified according to the most dominant percentage of cations and anions being present, based on concentrations in equivalents per million [epm] (e.g., a calcium-magnesium bicarbonate type).

Table 2: Classification of Dissolved Inorganic Constituents in Groundwater
(After Davis and DeWiest, 1966)

Major Constituents (1.0 – 100 mg/l)	Minor Constituents (0.01 – 10.0 mg/l)	Trace Constituents (Generally less than 0.1 mg/l)	
Sodium Calcium Magnesium Bicarbonate Sulphate Chloride Silica	Iron Strontium Potassium Carbonate Nitrate Fluoride Boron	Antimony Aluminium Arsenic Barium Bromide Cadmium Chromium Cobalt Copper Germanium Iodide Lead Lithium Manganese Molybdenum Nickel Phosphate Rubidium Selenium Titanium Uranium Vanadium Zinc	Beryllium Bismuth Cerium Gallium Gold Indium Lanthanum Niobium Platinum Radium Ruthenium Scandium Silver Thallium Thorium Tin Tungsten Ytterbium Yttrium Zirconium

The greater part of the soluble constituents in groundwater comes from soluble minerals in soils and sedimentary rocks. The more common soluble constituents include calcium, sodium, bicarbonate and sulphate ions. Another common constituent is chloride ion derived from seawater, connate water, evapotranspiration concentrating salts, and sewage wastes

for example. Nitrate can be a natural constituent, but high concentrations often suggest a source of pollution.

2.3.3 Groundwater Quality in Relation to Use

The main purpose of a water analysis is to determine the suitability of water for a proposed use. The three main classes of use are domestic (household), agricultural and industrial. A supply intended for municipal use may include all these classes and accordingly require a standard of quality that is generally higher than needed for any one class (Driscoll, 1986).

Domestic Use

All groundwaters contain various kinds of dissolved salts (minerals). Small quantities of many of these are essential to good health. Excessive concentrations however, can limit the uses of the water. The constituents originate from minute quantities dissolved in rainwater and from the chemical breakdown of rocks. Nitrate is also produced in the soil by natural biological activity. Over long periods of time evaporation concentrates them to varying degrees. In the following discussion, the maximum recommended values provided for each constituent (SABS, 1996) are guidelines rather than strict limits. The reason for this is because there are often many factors governing how a particular constituent affects the user. These can include a person's age and the total volume of water consumed.

The guidelines given below are conservatively chosen in order to cover most situations. Based on health considerations a limit of 50mg/litre of nitrate is recommended for babies less than three months old and 100mg/litre for older children and adults. This limit is based on health considerations. Excess fluoride (more than 1.5mg/litre) can be removed by treating water with aluminium sulphate. Above this limit, taste may be unacceptable but it does not pose a health problem. High iron concentrations (more than 0.3mg/litre) give water a rust brown appearance, resulting in staining of laundry, pipe encrustation and odour problems (WRC, 1998).

Hardness is a measure of the amount of calcium and magnesium in the water. Hard waters (more than 200mg/l) can cause the build-up of scale in hot water pipes and fittings. Hard water also requires more soap to obtain lather. Softening the water can reduce the hardness. Values of pH less than 6.5 indicate acidic water and can result in corrosion of pipes and fittings. When pH is more than 7.5, the water is alkaline and encrustation of pipes with

calcium carbonate can occur. pH can be adjusted to a more desirable level with the addition of either an appropriate acid or alkali (WRC, 1998).

Also of importance to drinking water quality are the following recommended limits: Total Dissolved Solids, TDS (500mg/litre), Chloride (250mg/litre), Sulphate (250mg/litre) and Sodium (180mg/litre). Above these limits, taste may be unacceptable but it does not pose a health problem. TDS and the indicated constituents can be reduced by reverse osmosis, ion exchange or distillation. People with severe hypertension or heart disease are usually advised to seek medical advice if sodium exceeds 20mg/litre in drinking water (WRC, 1998).

Industrial Use

According to Fair et al (1971), the water quality requirements for industries vary widely according to potential use. For example, saline and brackish waters are commonly used as cooling water, particularly if used only once (not recycled) and can be disposed of without polluting the environment. Industrial process waters must be of much higher quality than cooling waters. About 60% of the water used in industries must be treated to meet quality standards.

In many cases, groundwater may be desirable for particular uses because of its low, relatively constant temperature. In other cases, groundwater may be suitable because of its natural hardness, because distilleries, bakeries and breweries prefer hard water, and on the other hand, even small amounts of iron, manganese, or calcium can cause great harm in paper making processes (Driscoll, 1986).

Agricultural Use

Water quality, soil types, and cropping practises all play a role in successful irrigation. Good quality water allows maximum yields consistent with proper soil and water management. Water quality problems in irrigation include salinity and toxicity. Excessive salinity occurs when there is an accumulation of salts in topsoils. These salts can affect crop production because crop roots, especially in the upper root zone, have great difficulty in extracting enough water and nutrients from saline solutions. Groundwater, which is rich

in certain elements like boron, chlorides and sodium, are very toxic, and can preclude the growth of some plants (Driscoll, 1986).

Most sodium in groundwater originates with the release of soluble products during the weathering of plagioclase feldspars (Davis and De Wiest, 1966). When sodium rich water is applied to soil, some of the sodium is taken up by clay, the clay giving up calcium and magnesium in exchange. This reaction, called base exchange, alters the physical characteristics of soil and can even lead to growth retardation.

Soil that takes up sodium becomes sticky and slick when wet and has low permeability. Additionally, high concentrations of sodium salts can produce alkali soils in which little or no vegetation can grow. When the same soil carries excess calcium or magnesium ions, it tills easily and has good permeability. If irrigation water contains calcium and magnesium ions sufficient to equal or exceed the sodium ions, enough calcium and magnesium is retained on soil particles to maintain good tilth and permeability. This water serves well for irrigation, even though the total mineral content may be quite high.

2.4 WATER LEVEL CONTOURING

Maps of the water table for an unconfined aquifer and potentiometric surface maps of confined aquifers are basic tools for hydrologic interpretation. These maps can be shown as contour maps with lines of equal elevation. The data used to construct a water table map or potentiometric surface maps are groundwater level elevations as measured in boreholes.

However, not every borehole is useful for this purpose. Some boreholes are open borings in rocks that include both aquifer and confining beds. Others may have more than one well screen, each opposite a different aquifer. Since the water level in such wells is a reflection of the heads in several different units and not one specific unit, they are not useful in making water level maps. In order to make a groundwater level map, a number of water level readings recorded from boreholes are required. If water levels are to be measured in a borehole that is normally used for water supply, the pump is shut off long enough for the water level to recover to what is termed the static water level, or non-pumping level (Fetter, 1994).

Groundwater levels are based on approximate land-surface altitudes derived from topographic maps and/or global positioning system field measurements. Preparation of a water level map requires that only boreholes that have their well screens placed near the water table be used. If the depth-to-water is measured at a number of such wells throughout an area of study, and if those water levels are referenced to a common datum such as sea level, the data can be contoured to indicate the configuration of the water table (Fetter, 1994).

CHAPTER 3

DESCRIPTION OF THE STUDY AREA

3.1 LOCALITY

The community of Dendron, on which this study is focused (Figure 1), is situated some 60km north of Polokwane in the Limpopo Province of South Africa, and lies in the Brak and Hout river basins, both sub-catchments of the Sand river catchment (Figure 2) that drains to the northeast. The surface area covered by borehole and irrigation schemes across the vast Dendron-Bochum-Vivo communities is about 1600 square kilometres (Masiyandima et al, 2001). Of this extensive area, this study focuses on the central Dendron portion, which is about 15.689 km² in extent (Figure 1).

The main Pietersburg-Allday tar road bisects the study area. The Blouberg Mountains and the Soutpansberg to the northeast bound it to the north (Figure 1). The area is characterized by summer rainfall, the rainfall season beginning in November and lasting until March or April. The mean annual rainfall is about 400 mm. However, in years recording average rainfall amounts, a water deficit is usually present in the Sand River Basin (Jolly, 1986) (Figure 1).

3.2 TOPOGRAPHY

The Limpopo Province is characterised by its contrasting landscapes. The study area is relatively flat and shows minor landscape variations. In the Sand River catchment, general elevations decrease from 1400 mamsl in the upper reaches near Polokwane to 400 mamsl in the lower reaches near Messina at the confluence with the Limpopo River (DWAF, 2003). The most prominent hill in the catchment is the De Loskop in the southern part of the area (Figure 1) (Jolly, 1986).

3.3 CLIMATE AND RAINFALL

In the area of study, the climate is semi-arid subtropical. The summers are very hot whilst the winters are mild. The area enjoys summer rainfall that tends to be erratic (Vegter, 2001). The mean annual rainfall varies from less than 300 mm in the extreme north to 500mm in the southern portions. However, on the mountain peaks of the Soutpansberg and Blouberg range, over 900 mm of rainfall per annum is often recorded. Such high rainfall occurs during summer months, with rainfall of about 1000 mm per annum on the southern slopes of the Soutpansberg but only 415 mm per annum in the Dendron/Mara district (Figure 1).

Approximately 95% of the mean annual precipitation is lost through evaporation in the Sand River catchment. The mean annual temperatures in the study area vary between 15 °C and 23 °C (DWAF, 2003).

Figure 1: Location map of the study area

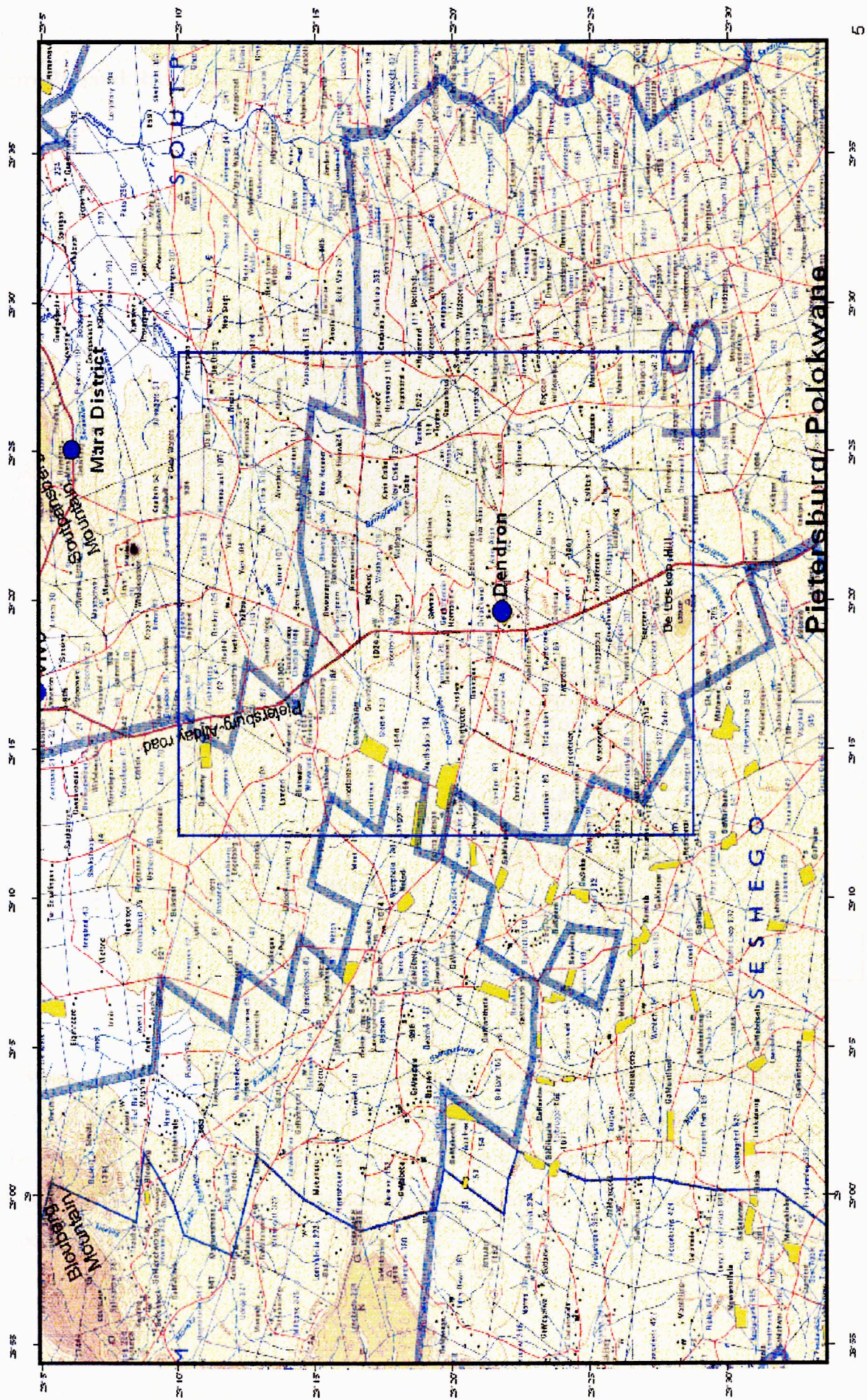
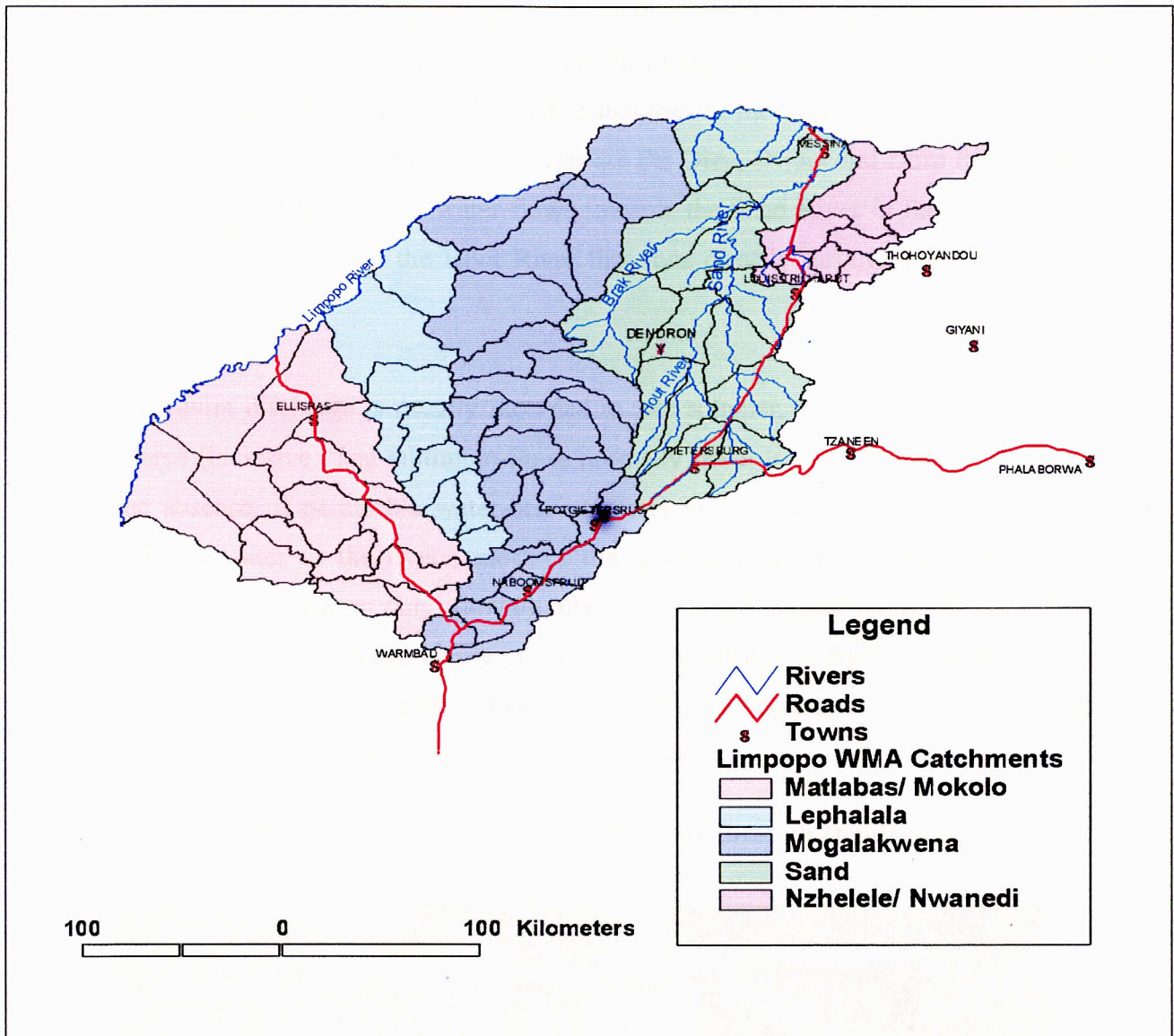


Figure 2: Sand River Catchment



The Blouberg and the Soutpansberg mountains in the north and the rural plots north of Polokwane (Pietersburg) in the south, outline the study area. General surface slope is of the order of 1%. The area has a relatively flat slope with isolated higher relief area. The Soutpansberg and Blouberg mountain ranges trend in an east-west direction immediately north of the study area.

3.4 DRAINAGE

The Sand River has its headwaters just south of Polokwane and flows to the north, cutting through the Soutpansberg mountain range and entering the Limpopo River near Musina (DWAF, 2003). The main tributaries of the Sand River are the Hout and Brak Rivers (Figure 2). Other tributaries are the Diep, Dwars and Dorp Rivers. In the study area, surface run-off water flows towards the Sand River in the east, the Brak River in the north and the Hout River that runs directly through the Dendron area (Figure 3).

Maximum discharge is usually recorded in late summer, especially from January to March (inclusive), and minimum flows normally occur in July or August. Because of the absence of permeable water-bearing strata with the capacity to store and then transmit water to the rivers, most of the water-courses are predominantly active during the wet season only, flowing after heavy local rainstorms. In the Sand River basin, due to the seasonal nature of rainfall, the discharge is highly variable, pointing to a strong need to consider groundwater as an alternative source for both domestic use and socio-economic development (IWMI, 2002).

Figure 3: Dry bed of the Hout River which flows through Dendron area



3.5 VEGETATION

The most dominant vegetation in the Limpopo area is tropical bush and savannah (Vegter, 2001; DWAF, 2003). Inland tropical forest occurs in the north-eastern portions. In the vicinity of Dendron, grassland is very common. In the western parts, the bushland occupies the lower-lying ground bordering the Limpopo River as well as the Lephhalala and Mogalakwena river valleys.

Generally in the Limpopo region, rolling bushveld, subtropical forest and highveld grassland savannah are common types. Further north of the Limpopo region, a landscape of rich deep soil covered by thorn trees is dominant.

3.6 LAND USE

Commercial irrigated agricultural activities account for the greatest land use in the Dendron area. Cattle farming is also practiced in the study area. No significant land use activities, besides agricultural farming and pockets of domestic garden, are evident in the area.

CHAPTER 4

GEOLOGY AND GEOHYDROLOGY

4.1 GEOLOGIC SETTING

4.1.1 Regional geology

The Limpopo Province is situated in the Southern Marginal Zone of the (international) Limpopo Mobile Belt. The southern marginal zone is bounded in the north by the Palala Shear Zone and in the south by the Hout River Shear zone. All the rocks of this zone have been metamorphosed to granulite grade, but have also been retrogressed to amphibolite grade within a narrow zone adjacent to the Hout River Shear zone (Brandl, 2001).

According to Brandl (2001), abundant remnants of what is thought to have been a massive greenstone belt succession are present. These remnants can be recognized as acutely attenuated slivers that are infolded in the Hout river gneiss, and range in length from a few metres to several kilometres. The remnants are made up of mainly pelitic and mafic gneisses, together with minor ultramafic rocks and magnetite quartzite (Du Toit et al, 1983).

The Limpopo region is underlain predominantly by intrusive igneous and metamorphosed rocks – mostly granite, gneiss, schists and basalts (Figure 4). NE- SW diabase dykes, dolerite dykes and faults are widespread and the main structures are related to shear zones. Faults of various ages are common (Figure 4) and some of them are intruded by older diabase and younger dolerite dykes (Figure 5). Over the Limpopo region, the general fabric is in a southwest-northeast direction. Rocks in the stratigraphic succession have experienced multiple phases of metamorphism and deformation, resulting in their fracturing and general transformation.

Figure 4: Limpopo Regional Geological map with faults

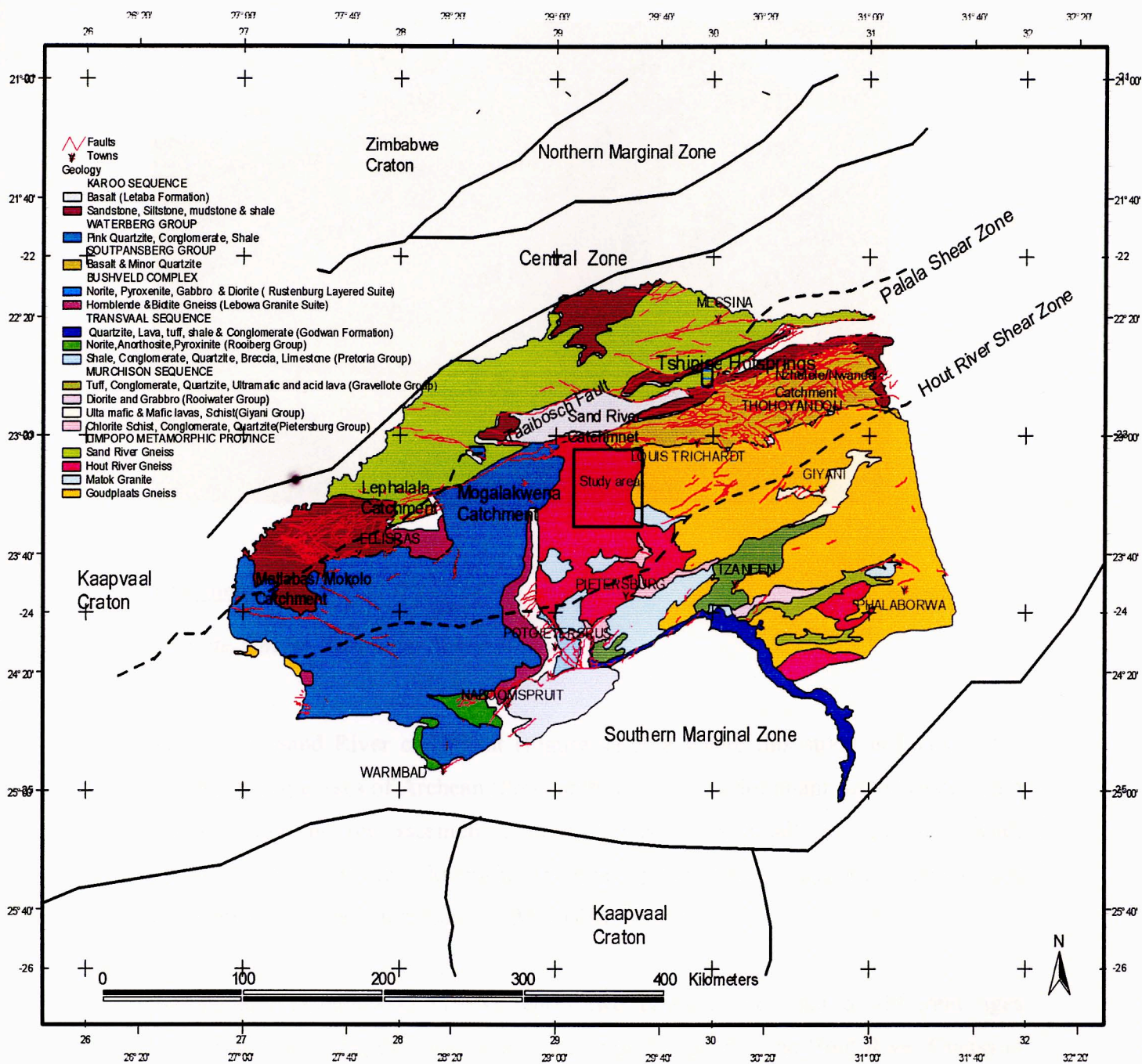


Figure 5: Dolerite dyke outcrop in the study area



Basement Rocks

Granite-Gneiss- basement Schist Rocks

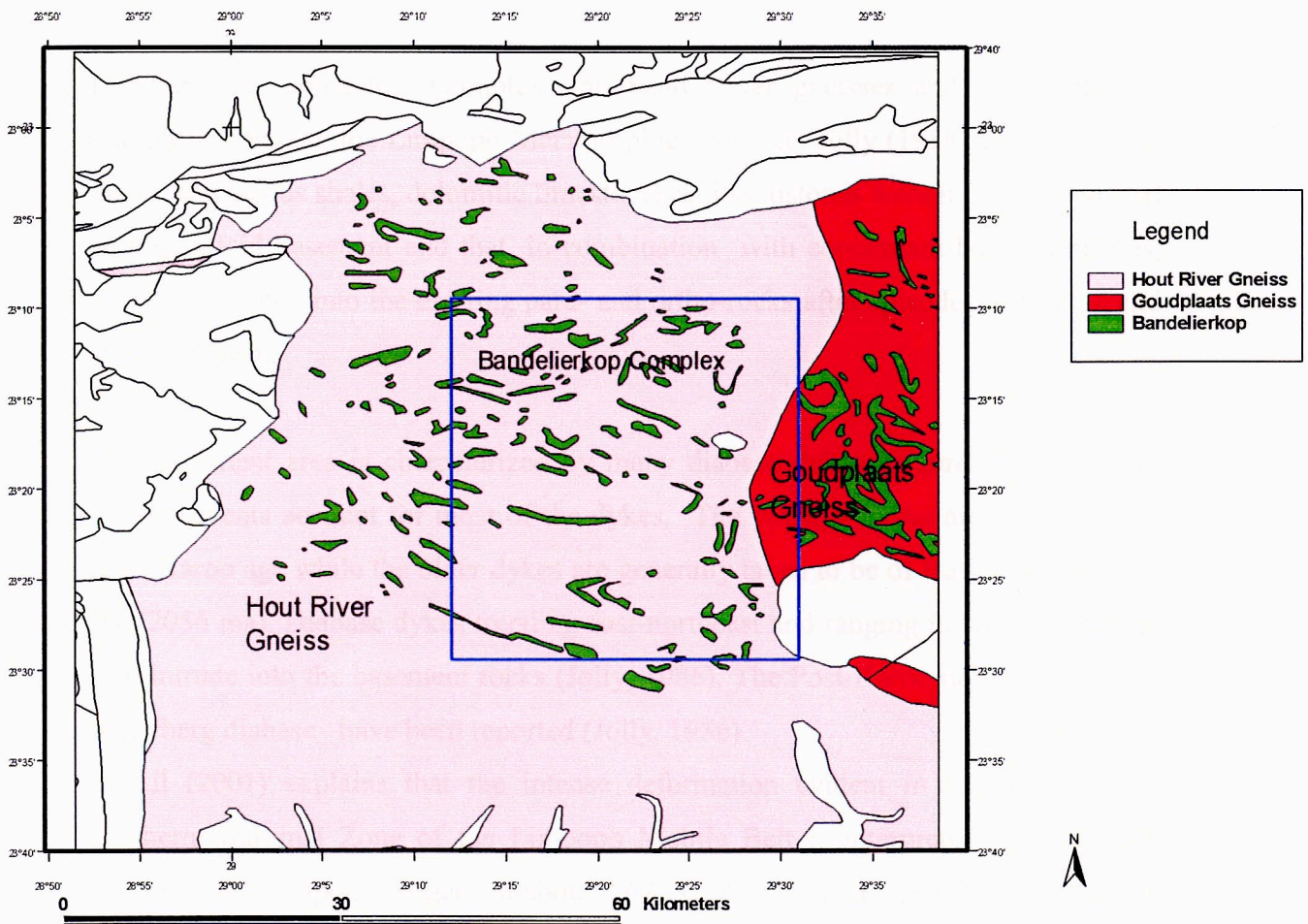
Within the Sand River catchment (Figure 4) area where this study is focused, the granites and gneisses of Archean (Pre-Cambrian) age are dominant. In the eastern and northern portions, the Basement Complex rocks are essentially granite gneiss with xenoliths of mafic to ultramafic material, greenstones, migmatite gneiss and undifferentiated metamorphics (WSM/DWAF, 1995).

Braune and Dziemowski (1998) report two types of gneisses of different ages occurring in the area; the Goudplaats Gneiss in the east and the Hout River Gneiss in the west (Figure 4 and 6). The older of the rock types is believed to be the Goudplaats gneiss, probably the basement of the Bandelierkop complex comprising mainly ultramafic, mafic and pelitic gneisses.

Goudplaats Gneiss

The Goudplaats Gneiss is thought to have formed the basement to the Bandelierkop Complex and the Pietersburg Group, on the basis that it locally exhibits much more complex deformation (Barton, 1979). The age of the Goudplaats Gneiss varies between 2652 and 3054Ma (Barton, 1979). This probably reflects metamorphic overprints (Barton, 1979). The Goudplaats Gneiss includes gneiss, banded gneiss and migmatite associated with leucocratic granite in varying proportions. Du Toit (1979) points out that the leucocratic bands are usually concordant and, cross-cutting with respect to the melanocratic bands and earlier-formed leucocratic bands. The colour of the gneiss ranges from dark to light grey. The melanocratic bands are generally consisting of biotite, hornblende, oligoclase and quartz. Chemical analysis shows that the grey-migmatitic gneiss has a tonalitic, and in places, quartz-dioritic composition, whereas the leucocratic material varies in composition between adamellite and tonalite (Du Toit, 1979).

Figure 6: Hout River and Goudplaats Basement gneisses in the study area



Hout River Gneiss

The Hout River gneiss is the dominant rock type of the Southern Marginal Zone, and encloses all the Bandelierkop complex gneisses which stretch away northwards from Polokwane to the Limpopo River and beyond, and cover the whole of the low-lying portions of the surface of the region (Figure 6) (Du Toit et al, 1983). Its inferred intrusive relationship with the Bandelierkop Complex gneisses can however not be proved, since anatectic granitoid material is always developed along the contacts. The gneiss is mostly a grey or light grey rock of tonalitic and granodioritic, locally also trondhjemitic composition, and frequently has a migmatic texture.

The rocks underlying flat country and are poorly exposed and the contact between the Hout River gneiss and the Goudplaats Gneiss is only arbitrary. In addition, there is a small remnant exposure of fine-grained, dark grey biotite gneiss similar to the Goudplaats Gneiss. In the Dendron and Blouberg areas, the common variety is a medium to coarse grained, pinkish grey and pink leucocratic gneiss composed of orthoclase and quartz with minor plagioclase, biotite and hornblende.

Together, this crystalline Complex, the Sand River gneisses and the Beitbridge Complex constitute the Limpopo Metamorphic Province. Jolly (1986) considers that shales, calcareous shales, dolomitic limestones and sandstones were initially deposited on a granitoid basement and that, in combination with concordant basic intrusions, were transformed into the existing para- and ortho-rocks after episodes of folding and metamorphism.

The catchment area is characterized by many diabase dykes (Figure 7); two major igneous events account for most of the dykes. The younger dykes are considered to be of Karoo age while the older dykes are generally taken to be of Bushveld Complex age (2056 ma). Diabase dykes trending east-northeast and ranging in width from 7 to 20m intrude into the basement rocks (Jolly, 1986). The Post-Karoo dolerite and post-Waterberg diabase –have been reported (Jolly, 1986).

Brandl (2001) explains that the intense deformation evident in the rocks of the Southern Marginal Zone of the Limpopo Mobile Belt is interpreted to have been caused by the Limpopo orogeny at about 2.67 Ga. A noticeable upright, ENE-trending

regional fabric is believed to have been superimposed on the rocks. Consequently, a number of significant east-west striking ductile shear zones were formed, in which most of the earlier formed structures were transposed or obliterated. Shear zones extending up to several kilometers in width have been reported (Brandl, 2001). Also, it is thought that, following the cessation of the Limpopo orogeny, the thickened crust was subjected to rapid uplift and the Southern Marginal Zone was backthrust along the Hout River shear Zone (Brandl, 2001). In general, it is likely that the metamorphic events alluded to were of the highest regional grade, as can be deduced from the high silimanite content of the rocks.

The granite-gneiss in the area is made up of pink to grey granites, the latter having a greater foliation with a more gneissic texture. Parts of the Nzhelele-Nwanedi catchment near the Limpopo River are underlain by the northeast-southwest trending metamorphic granite, gneiss and schist of the Limpopo Mobile Belt. Granite, gneiss and schist of the Limpopo Mobile Belt also underlie parts of the northern portions of the Mogalakwena catchment (Figure 4).

Bushveld Complex

Norite and Gabbro

In the Matlabas-Mokolo-Lephalala catchment, a small area of norite and gabbro of the Bushveld Igneous Complex occurs (Figure 4).

Waterberg Group

Sandstone and Conglomerate

Underlying the vast southwestern region, which provide an important recharge zone to the aquifers, are coarse-grained sandstone and conglomerate (Figure 4). The area is structurally complex with several significant faults and fracture zones, and is characterised by a rugged and mountainous terrain with steep sided valleys. Sandstones are also encountered in the Mogalakwena catchment area (Figure 4). Coarse-grained sandstone and conglomerate are formed in the east western part of the

Dendron area

More specifically, Archaen rocks of the Kaapvaal Craton and the leucocratic granites and gneiss rocks of the Bandelierkop Complex underlie the Dendron area of study. The Bandelierkop Complex in the study area is made up of ultramafic, mafic and pelitic gneisses occurring as deformed and metamorphosed remnants in tonalitic grey granitoids. In particular, the pelitic gneisses predominate, are commonly migmitic, and exhibit a well-developed mineral layering.

The Bandelierkop complex comprises original greenstone rocks (Figure 7) that have been subjected to at least three phases of deformation, giving rise to pelitic gneisses, mafic gneisses and metaquartzites, in addition to ultramafic rocks (Jolly, 1986). Brandl (2001) summarizes the resulting members as follows:

- **Ultramafic** rocks occur less frequently than pelitic and mafic gneisses. They are generally large massive, isolated pods up to 2 km in length. The dominant minerals of the rocks are olivine, orthopyroxene, hornblende and spinel that display a granoblastic nature. The ultramafics appear to be massive, but thin sections reveal the presence of a fabric.
- The **mafic** member consists of medium-grained gneisses, poorly to well-foliated rocks that locally show signs of incipient melting. Core constituents include plagioclase, hypersthene and augite. In the zone of retrogression, the rock is composed almost entirely of plagioclase and hornblende, with the latter having been formed mainly at the expense of clino- and ortho-pyroxene (Du Toit et al, 1983).
- As already alluded to, **pelitic** gneisses are the most widespread lithology of the Bandelierkop Complex in the area of study, and exhibit a well developed mineral layering and are frequently migmitic. The constituent minerals are mainly hypersthene, garnet, cordierite and silimanite.

- The **metapelitic** member is recognised by a foliation that varies from fine banding to a gneissic texture, enhanced by white granitic lenses and granitic segregation and resulting in a migmatized character.

The age of the Bandelierkop Complex ranges between 2 636 and 2 657 Ma. Apart from the metaquartzite, outcrops are not common, the surface consisting of a reddish-brown and sandy soil, with minor development of calcrete. The granites do not give rise to a topographic expression, and their occurrence beneath the sandy-soil layer is solely indicated by feldspar and granite fragments on the surface. Leucocratic granites are also present in the study area (Figure 8), giving rise to the development of corundum-bearing oligoclase veins separated from ultramafic material by biotite (Brandl, 2001).

Figure 8: Leucocratic Granite outcrop in the Groothoek farm, by the side of the Dendron -Vivo road.



4.1.3 Structure

As indicated previously, rocks underlying the area of study have been affected by multiphase deformation and metamorphic mineral growth occurred more than once.

The initial deformation, essentially an inferred event, was followed by another event that brought about tight co-axial folds and rocks of the Bandelierkop formation and the Baviaanskloof gneiss. As Van Reenen (1983) reports, the third deformation is expressed as open cross folding that is not always penetrative throughout the area. Commonly, the last phase of deformation may be recognized as post-metamorphic shear zones cutting across and displacing older structures.

4.2 GEOHYDROLOGIC SETTING

4.2.1 Regional geohydrology

This section (and the next) draws on the Internal Strategic Perspective document prepared by DWAF (2003) for the interim management of water resources in the Limpopo Water Management Area.

In general, groundwater resources are limited and borehole yields are frequently lower than 0.5l/s, although higher yields of 3l/s and higher are found along fault and fracture zones. Borehole depths vary from 50 to 150m, with depth to water ranging from 20 to 50mbgl. Groundwater quality is generally acceptable. The Soutpansberg Mountains constitute a recharge area of importance, and groundwater supplies substantial baseflow to surface drainage. The mostly groundwater-fed agricultural area immediately north of the Soutpansberg is underlain by Karoo basalt. The unit forms a productive aquifer with yields greater than 5l/s from major structural features where deep weathering of the basalt up to 50m is present or local faults sub-parallel the eastern extension of the Taaibosch Fault (Figure 4). In other places, aquifers are of limited areal extent, with yields of only between 0.5 and 2l/s. Water levels average 20mbgl from boreholes with depths ranging between 60 and 80m.

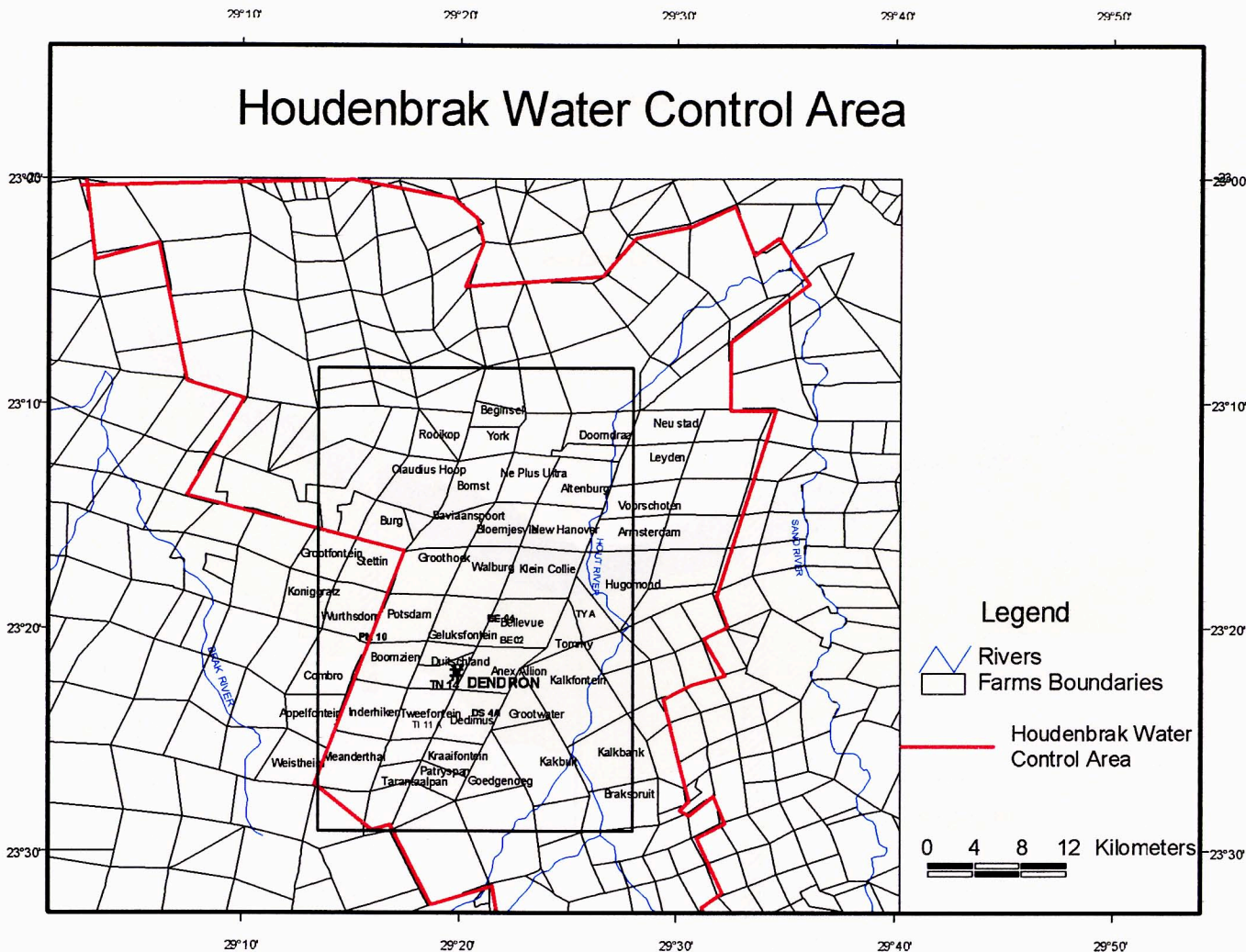
4.2.2 Local geohydrology

Geohydrology of the Sand River Catchment in the Dendron area

Four main lithologic units characterize the geohydrologic profile of the Sand River catchment where the study area is located. These units include granite, sandstone, basalt and the granite-gneiss-schist complex of the Limpopo Mobile Belt.

Granitic rocks underlie about 50% of the southern part of the catchment. This unit forms a generally flat to rolling landscape with isolated kopjes in the west and central portions. The landscape becomes hilly towards the east and the escarpment. The underlying granite is deeply weathered and borehole yields higher than 5 l/s are common. Extensive groundwater irrigation is practised over the vast western portion, stretching between Polokwane and Makhado and including Dendron where this study is centred. Groundwater quality is generally good except where irrigated agriculture has resulted in water pollution. In terms of the 1956 Water Act, the Dendron area was declared the Houdenbrak Subterranean Water Government Controlled Area (Maswuma, 2003) (Figure 9).

Figure 9: Maps showing the extent of the Houdenbrak Water control Area



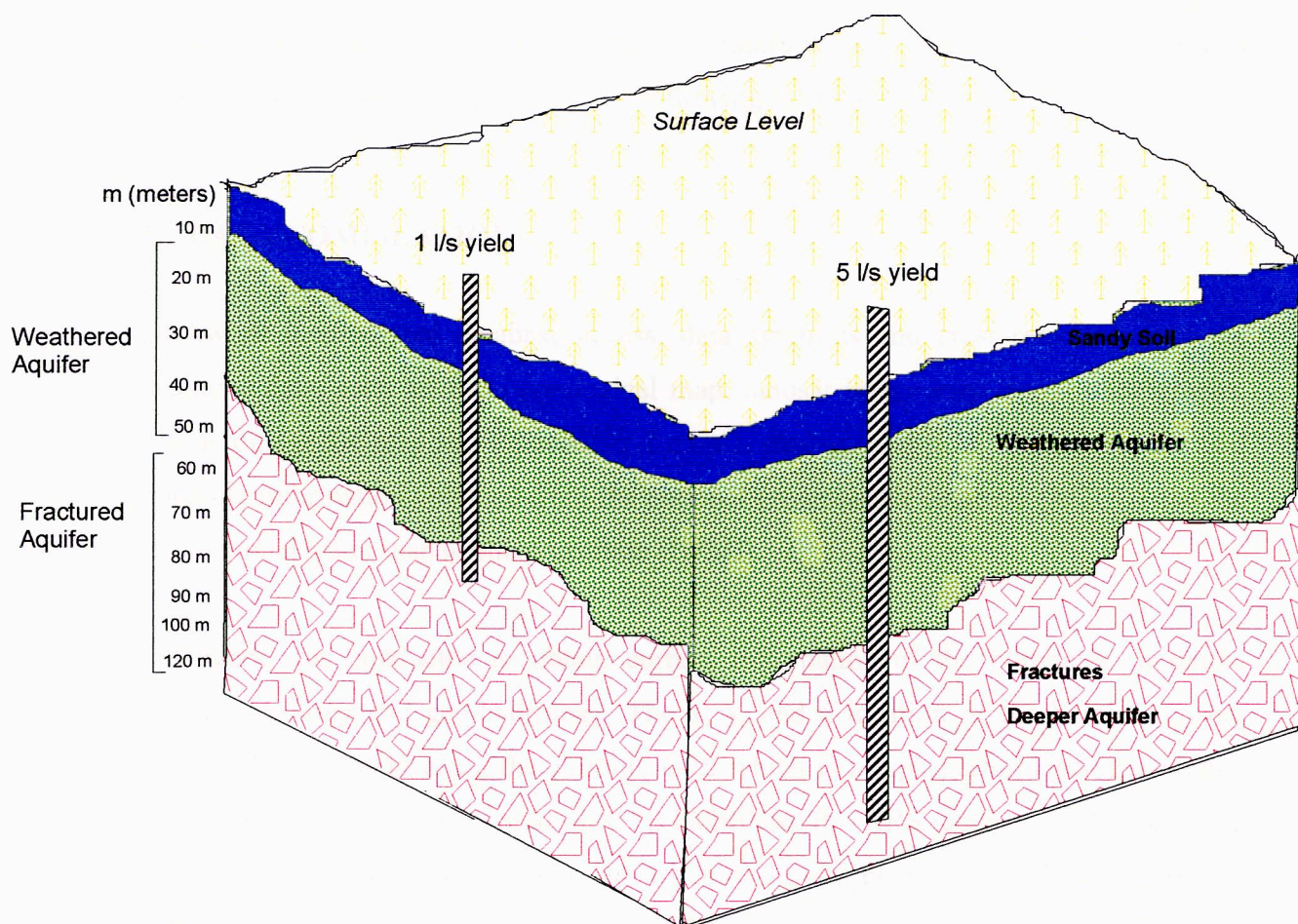
Geohydrology of Dendron

In the specific case of the Dendron study area, a description of the localized geohydrologic profile is presented by Jolly (1986). Two inter-dependent aquifers have been identified: a weathered upper aquifer and a lower fractured unit.

Throughout the area, the weathered aquifer occurs near the ground surface and is the more extensively exploited. Solid fractured rock tends to form the lower boundary of the water-bearing medium. The weathered aquifer tends to be rather low-yielding because of its limited thickness (varying from 12 to 50m), supplying a typical flow of about 1l/s (Figure 10). However, the DWAF (1991) reports that, when existing in

conjunction with a structural aquifer, yields of up to 5l/s may be available from a borehole penetrating both the weathered aquifer and a deeper aquifer unit (Figure 10).

Figure 10: Simplified aquifer system of the Dendron area



Considering that this local aquifer has been the sole source of irrigation water for commercial agriculture for more than 20 years, lowering water levels is a significant concern. Dziembowski (1976) estimated that the average recharge rate to the aquifer was 3.8% of the annual rainfall, which is in consonance with the range of 2-5% supplied by Masiyandima et al. (2001). Generally, groundwater quality around the study area is considered better in metaquartzites (often more fractured) than in gneisses, and the quality of water from boreholes could be deteriorating in portions where abstraction is high.

CHAPTER 5

METHODOLOGY

The study objectives summarized in Section 1.2 of this report were achieved through a combination of deskwork, fieldwork and laboratory work (as well as the use of various software programmes) emphasizing the following major approaches:

5.1 DATA COMPILATION

Deskwork incorporated database access, data synthesis and cross-referencing of the available data, such as maps (geological map, landsat image map, aerial photographs, and aeromagnetic map and topocadastral maps), geology and geohydrology reports and borehole information obtained from the national groundwater database (NGDB) and the international water management institute (IWMI).

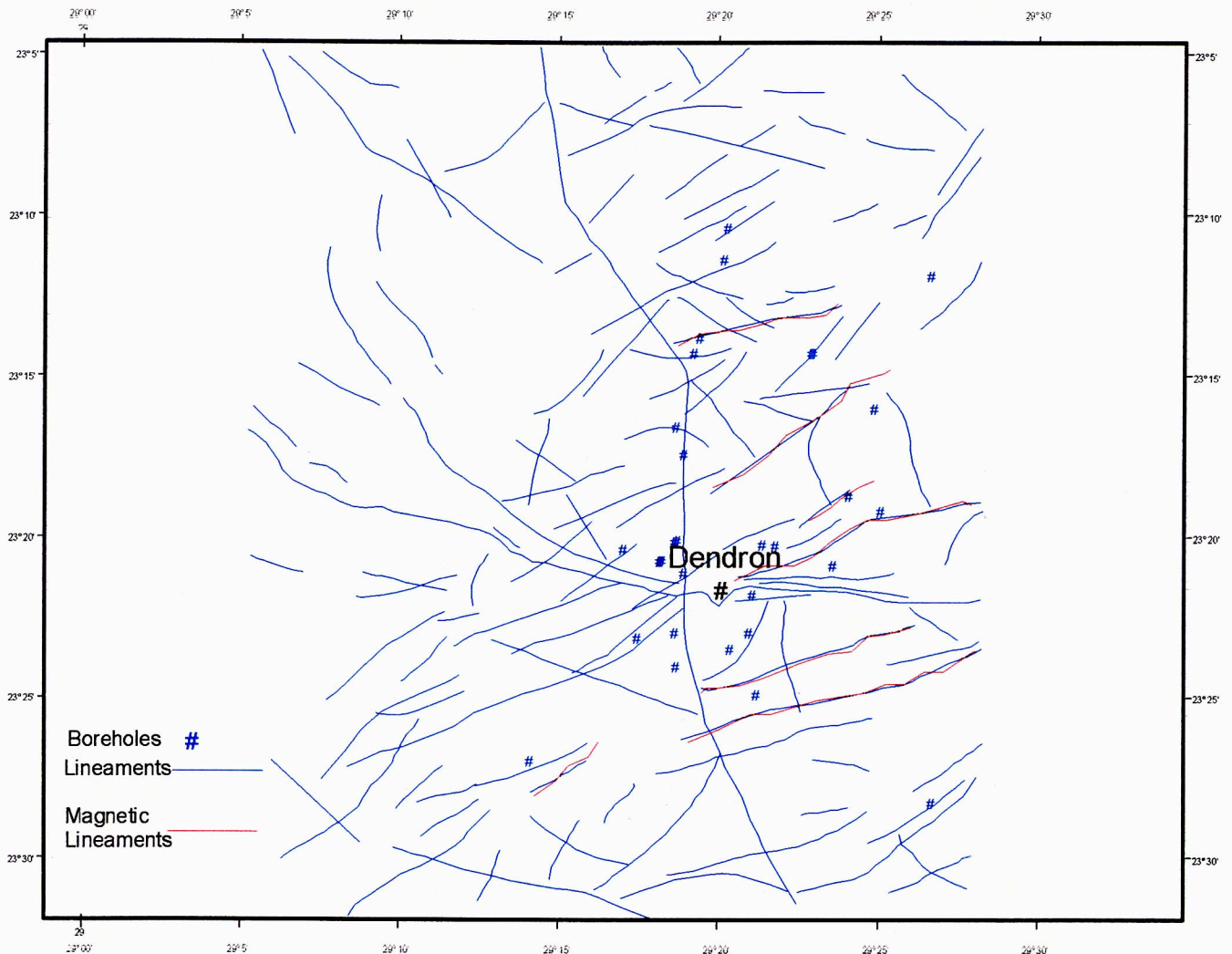
Fieldwork was conducted to obtain current information of the boreholes (borehole census), geology and geo-hydrology. The x, y, and z location of the boreholes were measured in the field using the Trimble GPS which is a high performance geographic data-acquisition tool. It is consist of: GPS Pathfinder Pro XRS receiver, TDCI field data collector with 1 MB memory (enough to store 30,000 positions), and asset surveyor software that is used with TDCI. The TDCI field data collector communicates with the GPS receiver to set specific GPS parameters and collects field coordinates and attribute data. A Pathfinder office software (running on GIS lab and desktop PCs), allows comprehensive GPS-post processing and data export functions. The accuracy of the GPS without differential correction is about 5 meters. Water levels were measured using a water level/deep meter.

5.2 MAP PLOTTING AND INTERPRETATION

An intensive literature review, coupled with limited fieldwork during this project was necessary for completion of a fracture map. The primary data sources used to produce a fracture map using existing geological maps, satellite images (Appendix A), aerial photos (Appendix B) and aeromagnetic map (Appendix C) of the area.

The study made use of 1:50 000 land satellite image map as a foundation map, to construct a fracture map of the area, and delineating the major lineaments/ geological structures that appear to be related to groundwater occurrence. Aster imagery was used as a base for fracture or lineament traces, but the 50 to 70 % cloud coverage over the study area made it ineffective for this study. The fracture traces were located by studying the linear features on hard copies of band 7, 4, 1 of landsat image accompanied by aerial photos and aeromagnetic map of the study area (Appendices A,B and C). The lineaments were mapped on a transparent overlay from a landsat image. The fracture map was also supplemented by correlating the fractures interpreted from the aeromagnetic map of the area with those derived from the images and aerial photographs which were examined by stereoscope (Figure 11).

Figure 11: Lineament interpretation map derived from Landsat imagery, Aeromagnetic map and Aerial photos



The overlay was then digitised and imported into ARC/INFO (GIS programme) software for editing and overlay of borehole location. The analysis carried out by GIS provided a good reference data of the positions on the ground. It enabled a good overlay of the borehole positions and geological structures and rock types. A borehole location map spread across the fracture map enabled inferences to be made; for instance, boreholes on the same fracture exhibit the same water level and yield characteristics. And finally, a field survey was undertaken to verify a number of geological structures established in the fracture map. Prior to the field investigation a number of traverse routes were planned to verify image features such as geological structures, tonal difference, drainage pattern and other morphological features of different rock units.

The field study was carried out with the aim of verifying geological structures, and assessing existing information, on geological maps, and aerial photos. Emphasis was concentrated on the differently oriented lineaments in an endeavour to establish the possible relation between the lineaments and borehole parameters, such as static water levels and yield. The study scrutinized borehole yields of fractured bedrock using the yield data set obtained by Jolly (1986) and the current static water levels. Geological structures and lineaments which have an influence on groundwater occurrence and development in the study area are oriented mainly in a NE-SW direction with some also having a NW-SE direction.

Lineament interpretation or fracture analyses in this study was based on the criteria used by Lattman and Parizek (1964), described by O'Leary et al. (1976) and recently demonstrated by Banoeng-Yakubo and Skjernaas (2000) in a study carried out in Ghana. They identified and delineated lineaments/fractures from aerial photographs, and geological maps for determining the relationship between the fracture system and borehole data.

5.3 WATER LEVEL TREND ANALYSIS AND INTERPRETATION.

In the course of fieldwork, groundwater level measurements and altitudes were recorded at 24 boreholes in order to plot potentiometric surface maps of the area. Thirty one representative monitoring boreholes in the study area were surveyed, but only data from 24 boreholes was utilised for analysis, due to the fact that historic data is only available for these and could provide a good reference over the years.

Production of the potentiometric surface maps and drawdown maps required direct measurements of static water levels in boreholes, and their elevation above sea level to obtain the hydraulic heads. The hydraulic heads were determined by subtracting the measured water level from the topographic elevation. Historical groundwater levels records from 1995 to 2001 were obtained from the IWMI and DWAF database, and the groundwater levels for 2003 were measured in the field for this study.

Potentiometric-surface maps were developed for 1995 to 2003. The data was contoured using “Surfer programme”, a contouring package, and plotted on a map base for analysis. In addition, trends in water levels over the years were established by plotting time series plots from historic records and current data, and this naturally led to a deduction of drawdown distributions over the study area. The drawdown maps were also plotted using the same programme and drawdowns were presented for 1995- 1997, 1997-1999, 1999-2001 and 2001 to 2003 periods.

5.4 GROUNDWATER SAMPLING AND ANALYSIS

Boreholes were sampled for hydrogeochemical analysis, mainly for classifying the water type and biological analysis to detect any anthropogenic contamination. Two samples were collected in each borehole (for chemical and biological analysis). Samples for biological analyses were analyzed for faecal coliforms, on the same day of sample collection. The water samples were preserved from degradation by the icing method.

Temperature, pH, electrical conductivity, total-dissolved solids (TDS) were measured in the field using a portable pH/ EC/ TDS/ Temperature meter. Chemical constituents were tested for across the spectrum of chemical parameters using standard laboratory techniques. Analysis was undertaken in the Department of Water Affairs and Forestry laboratory. Nitrates were analysed using automated determination of dissolved nitrates by cadmium reduction, sulphate (SO_4) was analysed using automated turbidimetric determination of sulphate, chloride (Cl^-) was analysed by automated determination of chloride using ferric thiocyanate.

Sodium (Na^+) and potassium (K^+) were analysed by automated determination of Na^+ and K^+ using flame emission method. Calcium (Ca^{++}) was analysed using atomic absorption method, and fluoride (F), using Ion selective method. Faecal coliforms were analysed using membrane filtration method. Magnesium (Mg^{++}) was analysed by automated determination of Mg^{++} using atomic absorption. Total alkalinity (as CaCO_3) was analysed by automated determination of alkalinity using bromphenol blue/ potentiometer determination, TDS and Total Hardness were analysed by calculations methods. Chloride, Sulphate and Nitrates were analysed using TRAACS

800 instrument. Sodium and Potassium using Flame Photometer, Magnesium and calcium using atomic absorption spectrophotometer. Total Alkalinity (as CaCO_3) using auto analyser instrument. Results were interpreted for anomalous aqueous speciation and possible sources of water contamination identified, based on the South African Bureau of Standards drinking water guidelines (Appendix D).

5.5 RESULTS OF CHEMICAL ANALYSES

Tables of data and graphical presentation are the most common ways in which the results of an analysis of water chemistry are reported. Numerous graphical methods have been devised to facilitate the interpretation and presentation of chemical analysis. In this study groundwater quality results are presented using the AquaChem Software Package which was provided by the Schonland Research Centre at Wits University. AquaChem is considered as the most comprehensive software package for aqueous geochemical analysis, plotting and modelling. Trends were examined and interpreted to characterise the hydrogeochemical complexion of the groundwater, in terms of the predominating chemical types. AquaChem's powerful graphical tools utilize different plotting techniques commonly used by hydrogeologists and geochemists for analyzing and interpreting aqueous geochemical data sets for hundreds and even thousands of different samples. The graphical methods used included:

(a) Trilinear / Piper diagram

Water quality analyses were classified by Piper plots. In a Piper diagram cations Ca-Mg-(Na + K) were plotted on the triangle as percentages. Anions $\text{HCO}_3^- - \text{SO}_4^{2-} - \text{Cl}$ were plotted on the triangle as percentages, with concentration in meq/l. Points on the anion and cation diagrams were projected upward to where they intersect on the diamond, where a common source of some ions are indicated. This plot reveals useful properties and relationships for large sample groups. The main purpose of using the piper diagram was to show clustering of data points to indicate water samples that have similar compositions and classification in the study area. The advantage of piper diagrams is that all water analyses were plotted on the same diagram, and can be used to classify and identify mixing of waters.

(b) The Durov diagram

The Durov diagram which is an alternative to the Piper diagram was also used. It plots the major ions as percentages of milli-equivalents in two base triangles. The total cations and the total anions are set equal to 100% and the data points in the two triangles are projected onto a square grid which lies perpendicular to the third axis in each triangle. This plot reveals useful properties and relationships for large sample groups. The main purpose of the Durov diagram was to show clustering of data points to indicate samples that have similar compositions.

(c) The Schoeller diagrams

Different major ion concentrations in meq/l or mg/l are plotted on vertical logarithmic scales, usually grouped in cation and anion sections. Actual sample concentrations are displayed and compared. It also demonstrates different hydrochemical water types on the same diagram. The advantage is that many analyses can be plotted and compared in terms of differing composition and concentration.

(d) Stiff diagram

Standard hydrochemical constituents were also presented graphically by stiff diagram as spatial pattern diagrams. Concentrations of cations are plotted to the left of a vertical axis and anions are plotted to the right of the axis, with all values presented in meq/l. The diagrams allow the determination of hydrochemical facies in which the dominant cation/ anion pair (s) is shown. The stiff diagrams are plotted for individual samples as a method of graphically comparing the concentration of selected anions and cations for several individual samples. The shape formed by the stiff diagrams identify samples that have similar compositions and are particularly useful when used as map symbols to show the geographic location of different water facies.

CHAPTER 6

DATA ANALYSIS, RESULTS AND DISCUSSION

6.1 FRACTURE SYSTEMS AND GROUNDWATER OCCURRENCE

Lineaments and Yields

In groundwater studies lineaments are at times associated with high yields; they play an important role for the ground water movement. The lineaments indicate secondary porosity, which is responsible for ground water reserves in the Dendron aquifer. Generally lineaments represent the fractures, faults, dykes, lithological contacts and other linear features, which are considered to be areas that yield good ground water. The main aim of fracture analysis was to understand the correlation between the borehole yields, static water levels and the lineaments, to validate if fracture assessment could be employed for groundwater development and management of the Dendron aquifer, and to establish whether groundwater potential may be increased due to fracturing in the bedrock.

Analysis of the fracture map (interpreted from maps in Appendix A, B and C) indicates a NE-SW trend to the majority of lineaments (Figure 12). With the exception of a few N-S and NW-SE trend, smaller lineaments generally trend in the same direction as the main lineaments (Figure 12). Approximately 60% of the lineaments observed on the land satellite image were also distinguished from aerial photographs and aeromagnetic map.

Relationship between lineaments and borehole parameters

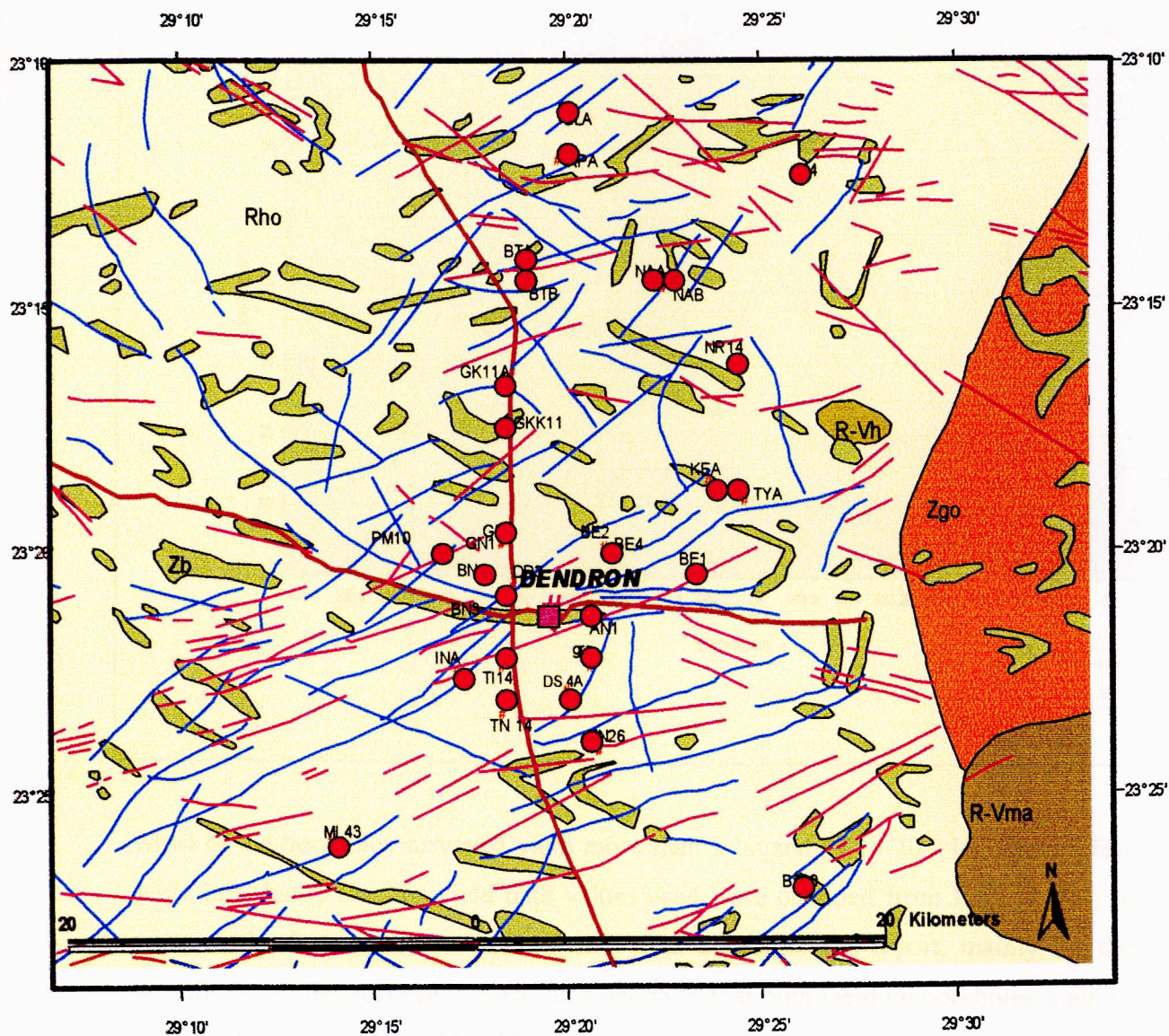
The relationship between the lineaments, static water levels and yields has been investigated for 20 boreholes in the study area. Scrutiny of the data suggests that there is a good relationship between higher yielding boreholes, high static water levels (SWL) and lineaments (Figure 13). High yields are associated with deep static water levels whilst shallow water levels are related to low yields (Table 3). Practically all

boreholes with deep SWL ranging from 40 – 70 m are associated with high yields, and boreholes with yields less than 6 l/s are associated with low SWL ranging from 13 m-30 m (Table 3), with the exception of GN 1, GN 2 and KN 26, with shallow SWL and high yield, and AN 1 borehole yielding 1.26 and is on the lineament. This indicates the consequence of magnitude and density of the fractures/ lineaments. Shallow static water levels are observed in boreholes not sited along the lineaments whereas deep static water levels are observed in boreholes sited on/ along lineaments (Figure 14). This indicates that the permeability or high porosity is along the fractures, which is allowing groundwater to move more easily toward a borehole.

Table 3: The static water levels and yields of boreholes in the study area

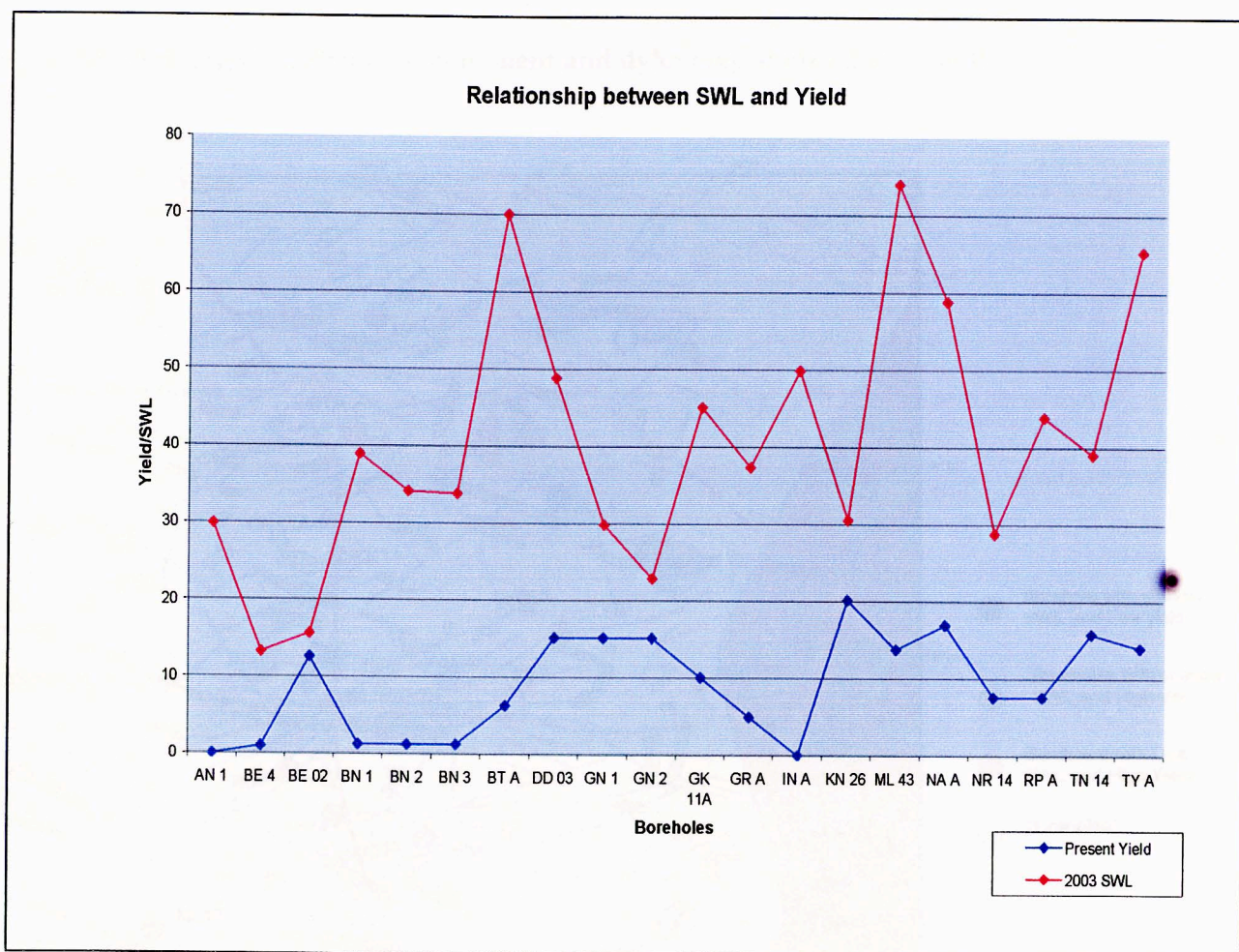
Borehole No.	Yield (l/s)	2003 SWL(m)
AN 1	1.26	29.89
BE 4	1	13.29
BE 02	2.64	15.69
BN 1	1.26	38.98
BN 2	1.26	34.15
BN 3	1.26	33.87
BT A	16.32	70.05
DD 03	15.18	48.89
GN 1	15.18	29.88
GN 2	15.18	22.9
GK 11A	10.11	45.13
GR A	5	37.38
IN A	11.89	49.95
KN 26	20.2	30.57
ML 43	13.8	74.06
NA A	17	58.87
NR 14	7.6	28.81
RP A	9.6	43.91
TN 14	15.8	40.52
TY A	14	65.289

Figure 12: Fracture/ lineaments map of the study area



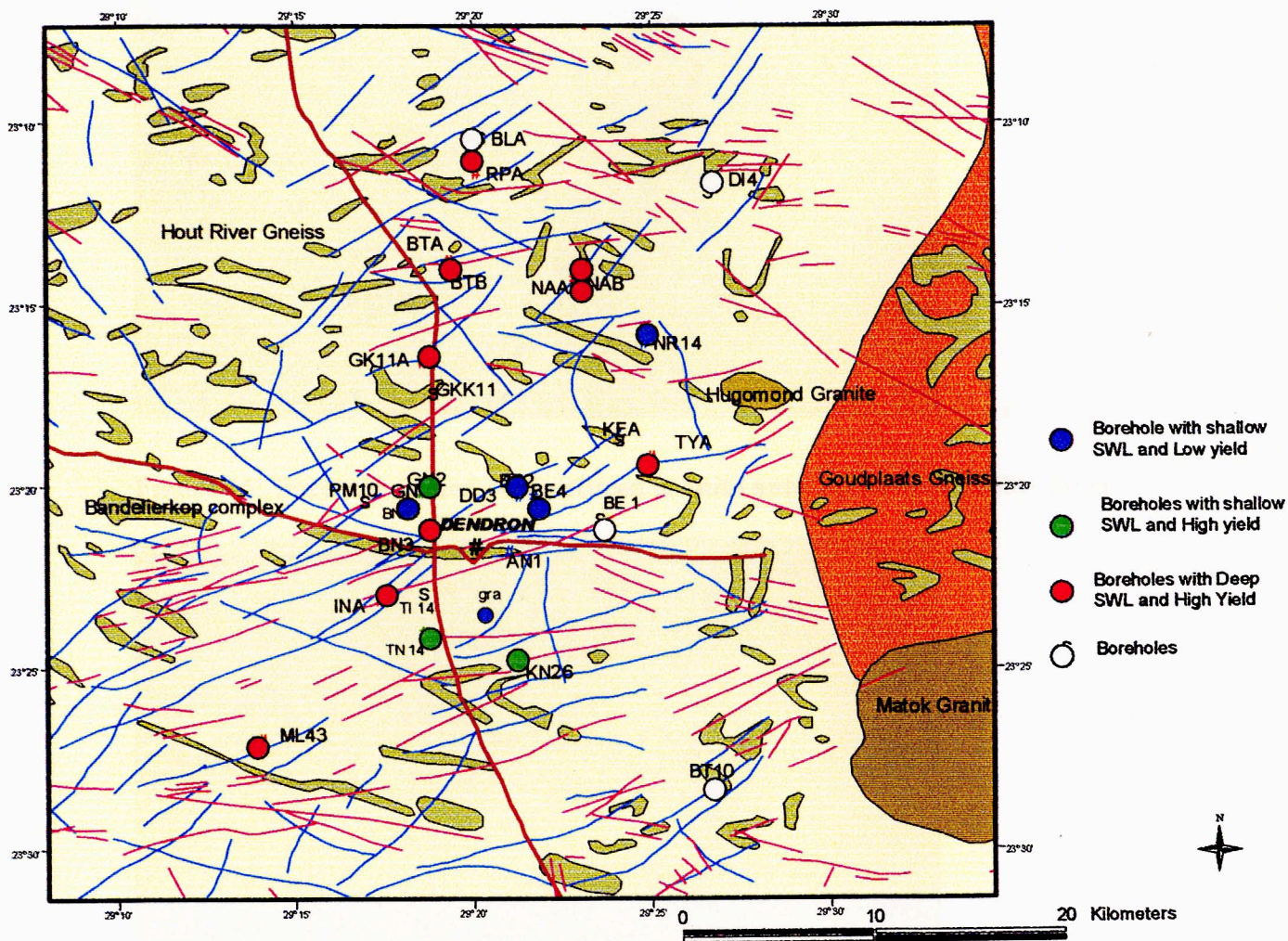
- | | | | |
|---|---------------------------|---|---------------|
|  | Hout River Gneiss (Rho) |  | Lineaments |
|  | Matok Granite (R-Vma) |  | Diabase Dykes |
|  | Bandelierkop Complex (Zb) |  | Roads |
|  | Goudplaats Gneiss (Zgo) |  | Boreholes |
|  | Hugomond Granite (R-Vh) | | |

Figure 13: Relationship between SWL and Yield



Most of the boreholes surveyed yield more than 5 l/s and up to 20.2 l/s, while a few yield less than 5 l/s. The yield data values used were obtained from Jolly (1986), in view of the fact that there was no new yield data after the report, mainly for the specific boreholes surveyed. It was also observed that high yielding boreholes such as BT A, DD 3, GK 11A, ML 43, IN A, TY A, NA A are usually related to large lineaments and consistent with structural features such as dykes (Figure 14). Boreholes drilled on or along a lineament and few metres away from the lineament have shown remarkably different borehole yields, and this is due to locally increased fracturing and permeability (Figure 14).

Figure 14: Boreholes location on a lineament and dyke map showing yield and SWL.

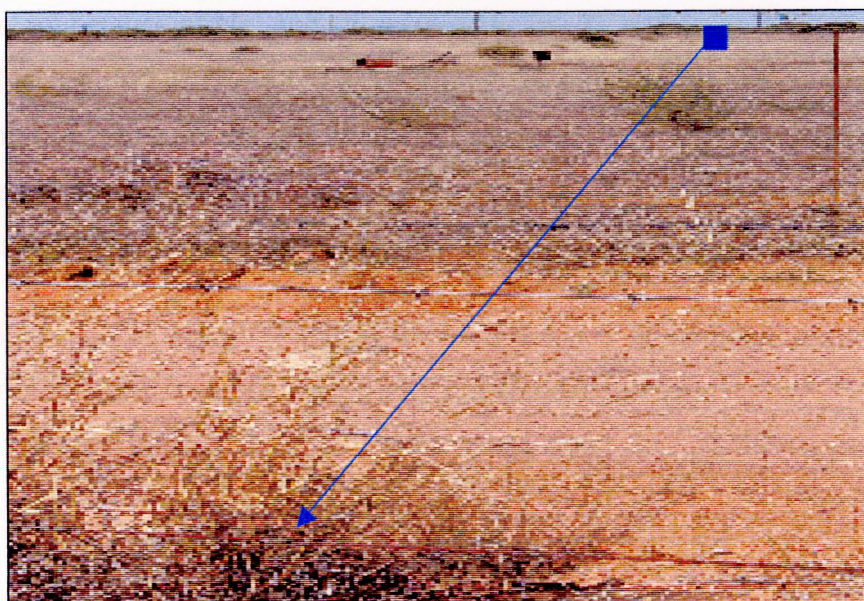


During ground-truthing of some lineaments, diabase dykes (Figure 15) were found to be responsible for many prominent lineaments in the area. Figure 16 shows a borehole drilled on a fractured granite outcrop on Klein collie farm (KEA), and is yielding about 10 l/s. This confirms the potential for groundwater development on or along the fractures, in the Dendron area.

Figure 15: Diabase dyke outcrop in Doorndraai farm



Figure 16: Borehole drilled on fractured granite outcrop on Klein collie farm



■ Borehole

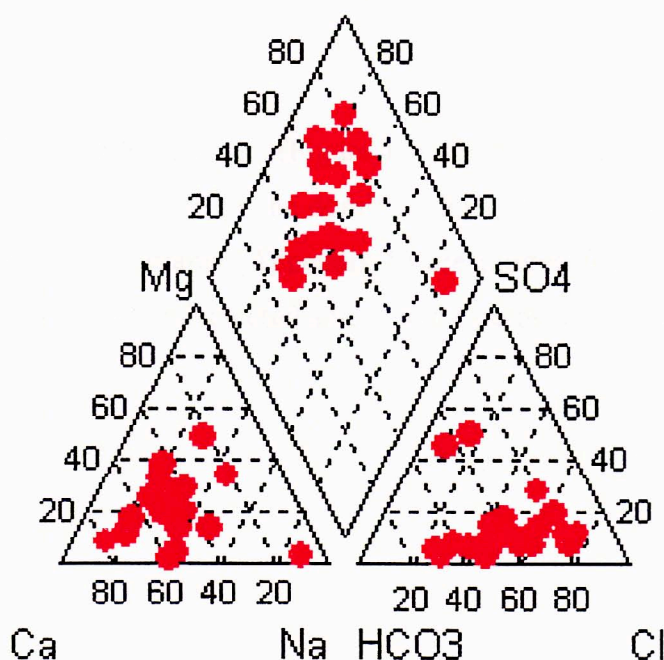
6.2 HYDROGEOCHEMISTRY AND WATER QUALITY

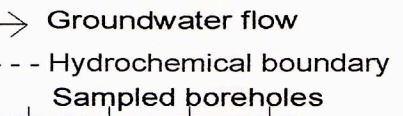
Hydrogeochemistry

The trilinear diagram (Figure 17) (and Durov diagram, Appendix E) depicts the overall chemical nature of groundwater. The diagram displays the water type as calcium, sodium, chloride, bicarbonate (Ca-Na-Cl-HCO_3). Groundwater in the study area could be typified overall as being calcium bicarbonate to the SW of the area and calcium-chloride dominated to the NE of the area (Figure 18), with two boreholes showing Na^+ and Cl^- content.

WSM/DWAF (1995) identified similar bicarbonate water type in the vicinity of the study area. Bicarbonate water indicates water which has been recharged recently. The water also shows some calcium chloride type to the NE, which is related to the reverse ion exchange (replacement of Na^+ with Ca^{2+} and Mg^{2+}) (WSM/DWAF, 1995). Preponderance of Na^+ and Cl^- water indicates an end point of discharge or stagnation of water (WSM/DWAF, 1995). Figure 18 indicates transition from bicarbonate to chloride water in the SW to the NE direction -- that is from shallow boreholes to deeper boreholes. This could be a sign of recently recharged water changing to old or stagnant water, and or contamination.

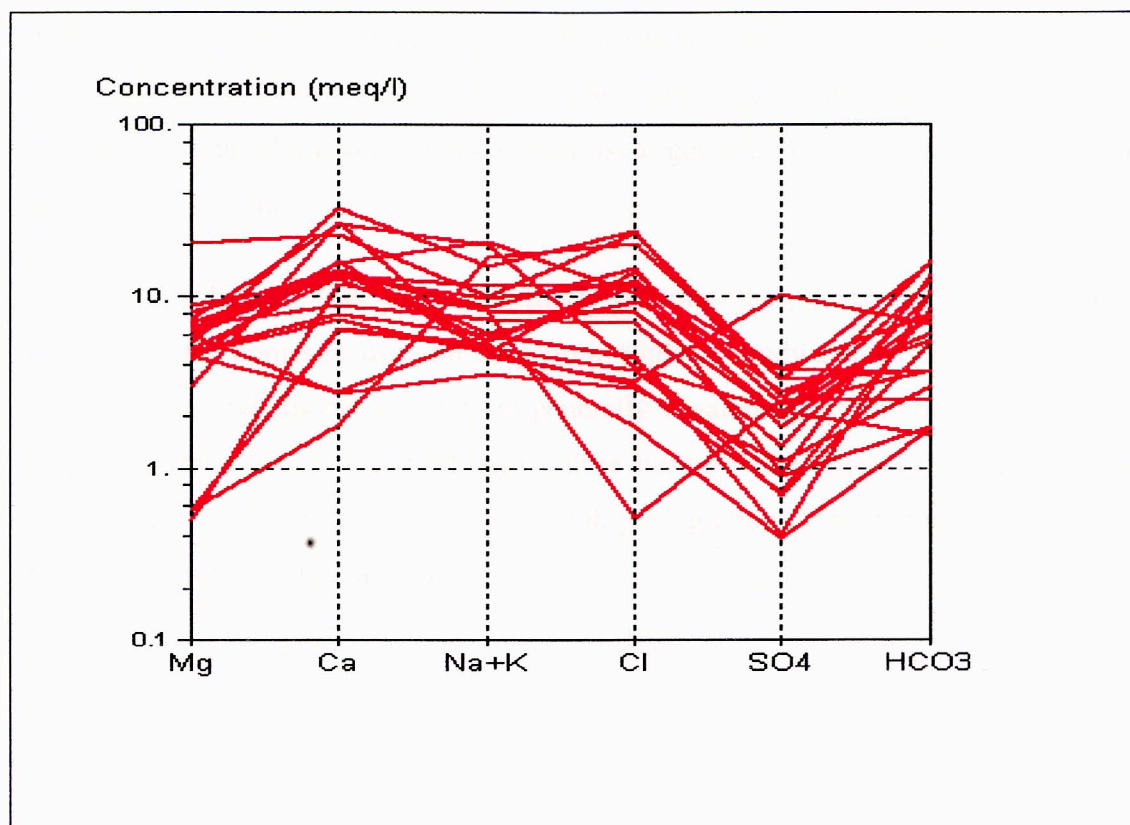
Figure 17: Trilinear Diagram showing the overall chemical nature of groundwater from 22 boreholes from Dendron area





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Figure 19: Schoeller diagram showing the concentration of major ions for all the boreholes



Groundwater varies greatly in the minerals it contains. These minerals are dissolved from the rocks of the aquifer. Generally, the longer water has been underground, the more natural minerals it contains. In excess, natural minerals can be a nuisance. The high concentration of calcium and sodium is influenced by the geology of the area, which is largely granite. Granite is associated with plagioclase feldspar, which is known to be very rich in calcium and sodium or a combination of the two. Calcium and sodium contributes to hardness of water and dissolved solids, and this is evidenced by the high levels of TDS (Table 4).

The dominant aqueous species include sodium, calcium, chloride, bicarbonate and nitrate. Calcium is the most dominant among the cations ranging from 36-656 mg/l with an average of 269 mg/l, whilst bicarbonate is the dominant anion, varying from 93.88-993.67 mg/l with an average of 453.34 mg/l, and high Total Dissolved Solids (TDS) ranging from 327-1760 mg/l; with an average of 908.9 mg/l (Table 4).

Groundwater in the Dendron could be typified as very hard water, due to the high concentration of TDS. Hard water is a problem caused by excess quantities of calcium carbonate and magnesium from soil. In Dendron hardness of water originates from calcium concentrations, perhaps in part from calcrete since there is no indication of magnesium in the water. It causes "hard water" and leaves chalky white deposits. The measure of total dissolved solids (TDS) is a good indicator of the mineralized character of the water.

Groundwater having less than 450 mg/L of total dissolved solids is generally satisfactory for domestic use and irrigation, while groundwater having greater than 500 mg/L of total dissolved solids is generally unsatisfactory for these uses. Other deep subsurface waters can be highly saline because they were originally trapped seawater that has been further altered through geologic time. The water does not show high concentrations of potassium.

Table 4: Analytical results (chemical analyses by L.A Tshesane at DWAF laboratory, 14-17 July 2003)

Site	Temperature	pH	EC (ms/m)	TDS (mg/l)	Total hardness (mg/l)	Ca ²⁺ (mg/l)	Mg ²⁺ (mg/l)	Na ⁺ (mg/l)	K ⁺ (mg/l)	HCO ₃ ⁻ (mg/l)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	F ⁻ (mg/l)	Nitrate (mg/l)	Faecal Coli (per 100ml)
AN 1	24.4	7.37	141	699	516	264	61	163.2	10.9	223.12	430	185	0.3	8.8	0
BE 02	15.4	8.07	104	518	382	150	56	101.3	13	518.17	110	35		20	1
BL A	17.1	7.98	360	856	650	55.4	72.2	77.1	7.88	185.32	104.3	51.7	0.2	20.39	0
BN 1	17.8	7.83	192	958	614	320	71.4	462	41.3	463.3	375	100	0.37	21	3
BT 10	15.8	7.7	221	1110	588	270	77	259.3	17.1	755.91	427	95	0.94	69	0
BT A	16.6	7.85	140	703	540	326	52	101.5	13.3	225.55	500	115	0.3	14	0
DD 03	23.1	7.44	171	861	548	240	6	179.3	21.6	151.18	18	120		0.11	0
DS 4A	14.7	7.82	117	588	400	160	58.3	129.6	14.1	658.37	159	20	0.31	9.6	2
GK 11A	10.5	7.22	450	1760	1500	464	251.7	223.5	10.1	963.18	843	160	0.25	78	0
GN 1	16.9	7.58	184	915	610	280	80.2	177.9	20.4	993.67	290	100	0.89	74	6
GR A	23.3	7.16	194	975	616	282	81	119.6	17	810.78	415	45	0.23	48	0
IN A	25.1	7.28	178	895	642	290	85	130.3	20.5	487.68	335	185	0.29	20	0
KE A	15	7.86	250	1411	64	36	7	366.9	35.2	227.99	720	160	0.4	9.8	0
KN 26	12.9	7.8	190	949	700	254	108	119.3	17.4	343.81	440	135	0.29	60	2.7
ML 43	17.5	7.41	65	327	282	132	7	112.9	16.6	104.85	62	19	0.33	0.1	0
NA A	16.5	7.56	181	905	694	290	98	193.5	15.7	481.58	520	85	0.2	13	99
NR 14	20.9	7.73	304	1480	930	656	67	194.5	266	377.96	870	125	0.1	53	0
PM 10	28.8	7.21	253	765	516	180	81.7	160.4	17.8	652.28	248	65	0.35	21	0
RP A	17.1	7.22	168	844	906	550	86.5	98.3	10.9	421.18	115	500	0.1	7.5	7
TI 11A	13.14	7.65	110	585.3	750	56.4	54.7	130.5	16.4	330.4	156.9	33.3	0.35	13	0
TN 14	28.8	7.53	108	542	350	128	7	106.1	18.6	107.29	133	43	0.35	0.1	3
TY A	25	7.25	275	1350	910	534	91	447.5	32.5	93.88	140	105	0.5	18	0

Water quality in relation to use

The main groundwater use sectors in the Dendron area is irrigation for agriculture, (the primary groundwater use sector) domestic use that includes human consumption, bathing, food preparation etc and cattle farming. The discussion of impacts/ contamination will focus on domestic use and agricultural use as the two main groundwater users in the area. Concentration will be discussed based on South African Water Quality guidelines and standards.

The analytical results (Table 5), indicates that the average concentration (for all sampled boreholes listed in Table 4) of TDS, calcium, magnesium, sodium, chloride, nitrate and faecal coliforms are extremely high and substantially higher than the target water quality ranges (TWQR) given in the South African Water quality guidelines and Standards (SAWQG) for water quality (Table 5).

Table 5: Summary of water chemistry from 24 boreholes in Dendron

CHEMICAL ANALYSES RESULTS FROM DENDRON			SAWQG ACCEPTABLE STANDARDS		
PARAMETERS	RANGE	MEAN	DOMESTIC	AGRICULTURE	
				Irrigation	Livestock watering
pH	7.16 – 8.07	7. 56	6 – 9	6.5 – 8.0	N/A
TDS	327 – 1760	908. 92	0 – 450	< 40	0 – 2000
Total Hardness	64 – 1500	623. 09	N/A	< 0.2	N/A
Ca ²⁺	55.4 – 656	283. 7	0 – 32	N/A	0 – 1000
Mg ²⁺	6 – 251.7	70. 89	0 – 30	N/A	0 – 500
Na ⁺	77.1 – 462	184. 29	0 – 100	< 70	0 – 2000
K ⁺	7.88 – 266	34. 2	0 – 50	N/A	N/A
Cl ²⁻	18 – 870	336. 87	0 – 100	0 – 1.00	0 – 1500 (1) 0 – 3000 (2)
SO ₄ ²⁻	19 – 185	112. 81	0 – 200	N/A	0 – 1000
NO ₆	0.1 – 78	26. 29	0 – 6	0 – 0.5	0 – 0.05
F	0.1 – 0.94	0. 35	0 – 1	0 – 2	0 - 2 (2)
Faecal Coliforms	0 – 99	5. 62	0	< 1	0- 6 (4)
EC	65 – 1080	241. 77			
HCO ₃ ⁻	93.88– 993.67	435. 34			

N/A Not available (1) Monogastrics and Poultry (2) Other Livestock

Nitrate and Faecal coliforms

Although igneous rocks contains small amounts of soluble nitrate, most nitrate is introduced into groundwater through widespread or diffuse sources, commonly called non-point sources, which can be hard to detect. These sources can include leaching of chemical fertilizers, animal manure and groundwater pollution from septic and sewage discharges. In this case considering that Dendron is highly populated by irrigation activity, the high nitrate content could be due to infiltration or leaching of excessive fertilizers applied to plants, so a surplus is always available for leaching.

Of all the samples analysed for nitrate concentration, 20.83% had unacceptable nitrate levels above the South African drinking water guideline of 45 mg/L. This was observed in the Brakspriut (BT 10), Groothoek (GK 11A), and Tommy (TYA) boreholes (Figure 21A). Irrigation is very active in the Brakspriut farm as well as in the Groothoek and Tommy farm areas; where high nitrate could be from fertilizers (Figure 20 and 21A). 58.33 % of samples had concentrations of nitrate greater than 6 mg/L, indicative of human impacts (mainly agriculture). Concentrations of nitrate above the drinking water guideline were observed on almost all farms, except in some areas where the nitrate level is in the ideal (<6 mg/l), good (5-10 mg/l) or marginal categories (10 -20 mg/l) (Figure 21A). The high nitrate concentration in groundwater rises to a very high value throughout the study area (Table 4). The source of NO₃ in groundwater is the inorganic fertilizer.

Figure 20: Land use map of the study area

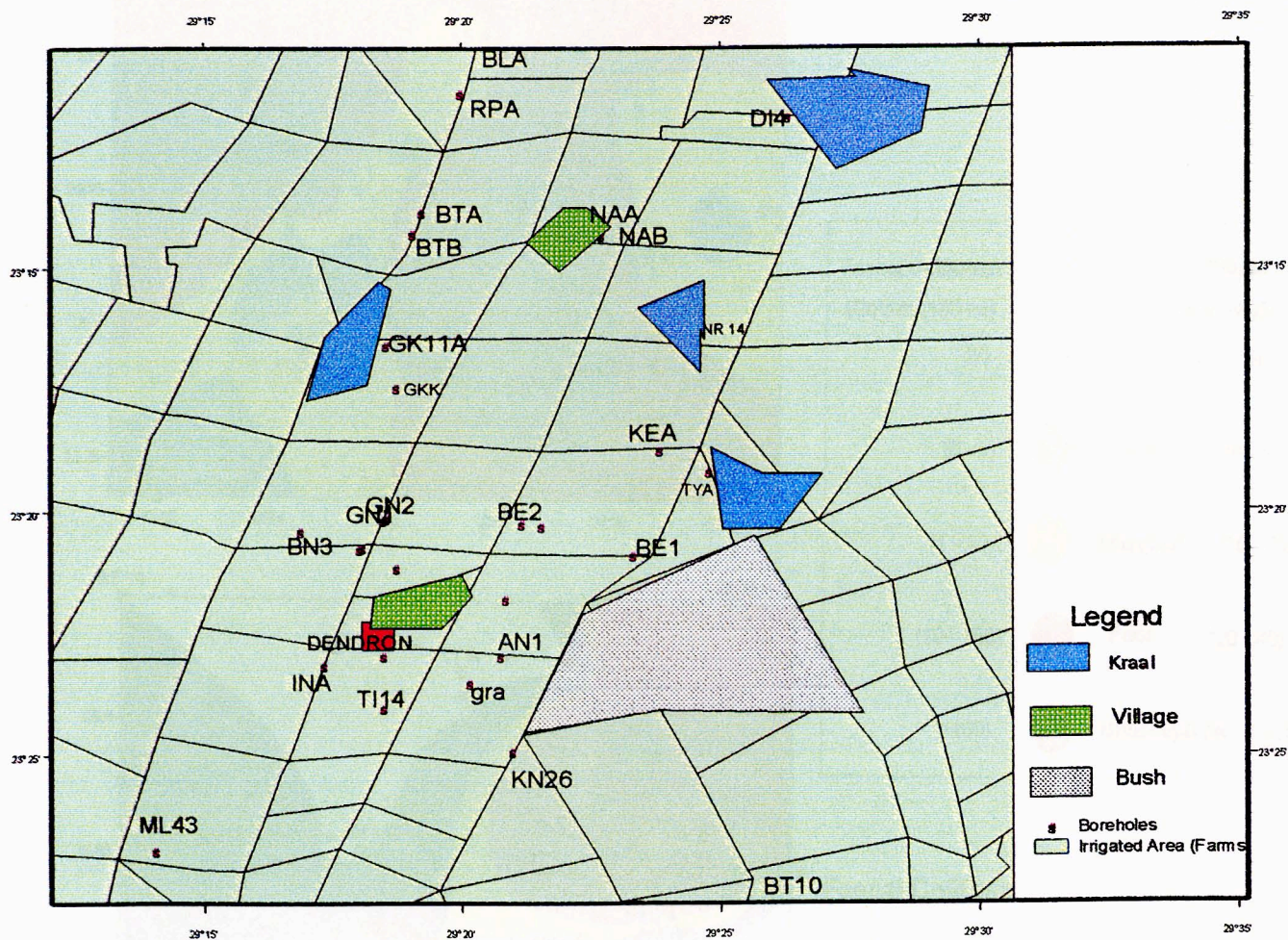
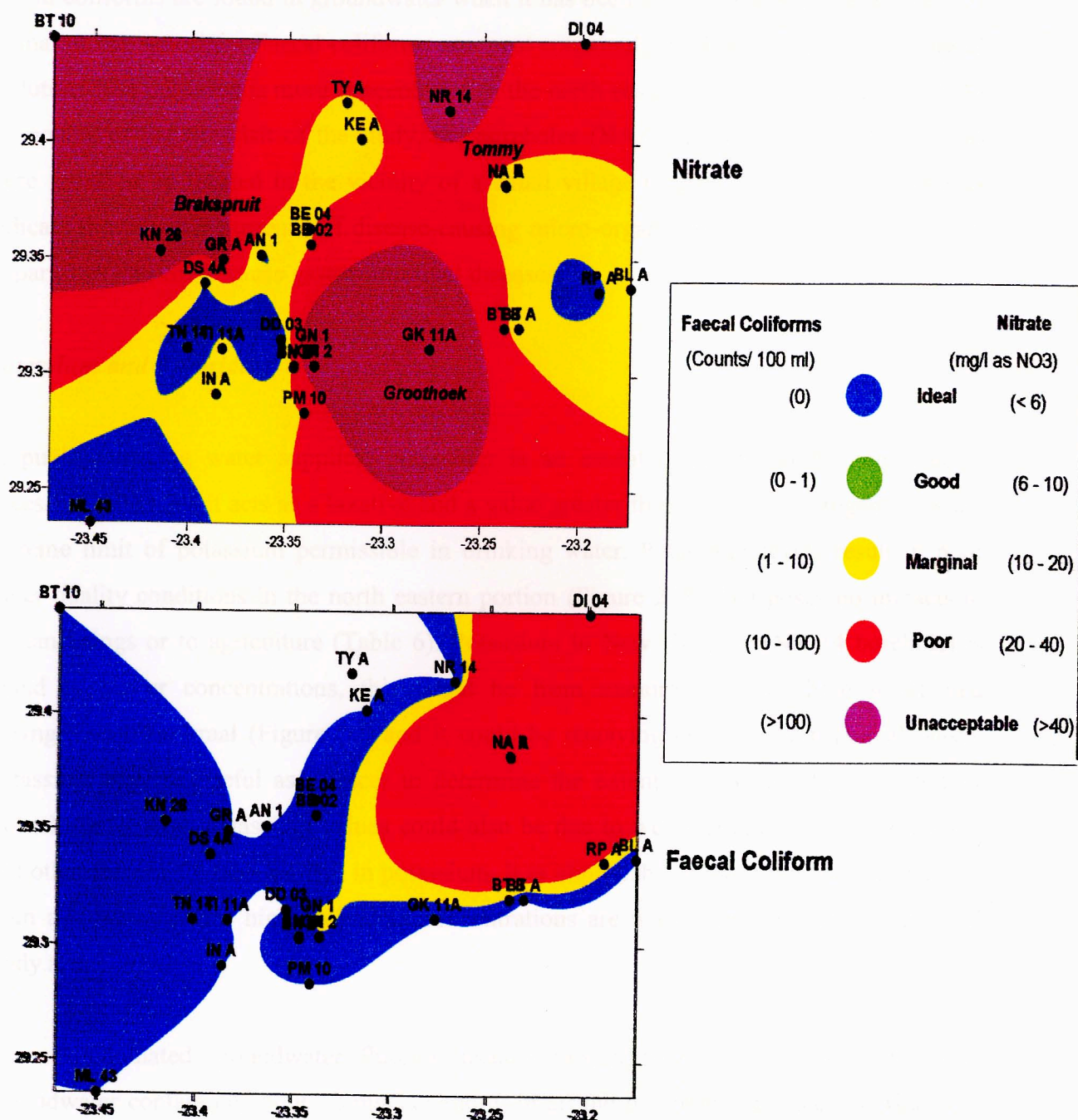


Figure 21A: Nitrate and Faecal coliforms distribution in groundwater



Although nitrate is considered relatively non-toxic, a high nitrate concentration in drinking water is an environmental health concern because it can harm infants by reducing the ability of blood to transport oxygen. In babies, especially those under six months old, *methaemoglobinaemia*, commonly called “blue-baby syndrome,” can result from oxygen deprivation caused by drinking water high in nitrate.

Faecal coliforms are found in groundwater when it has been contaminated by faecal waste of animal or human origin. Faecal coliforms are most commonly used as an indicative of faecal pollution. The pollution is more concentrated in the north easterly direction (Figure 21A). In the course of the site-visit of the study, the boreholes (NAA and NAB in Neu Plus Ultra) were found to be located in the vicinity of a small village (Figure 21A). Faecal coliforms indicate the possible presence of disease-causing micro-organisms such as bacteria, viruses or parasites that could cause gastro-intestinal diseases.

Potassium and Fluoride

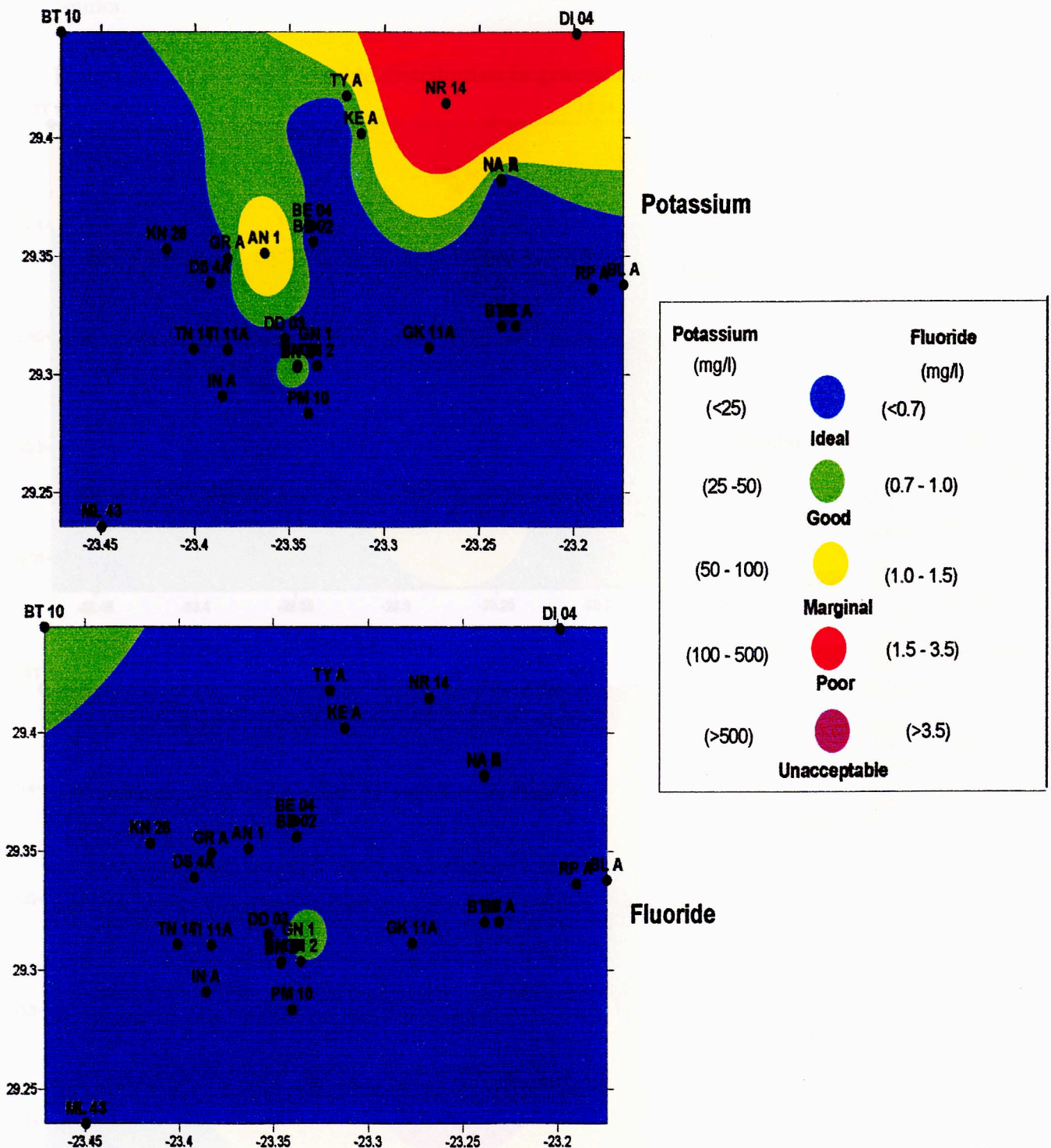
In public drinking water supplies, potassium is an essential nutritional element, but in excessive quantities it acts as a laxative and a value greater than 500 mg/L is regarded as the extreme limit of potassium permissible in drinking water. Potassium levels result in poor water quality conditions in the north eastern portion (Figure 21B), but poses no impacts to human beings or to agriculture (Table 6). Potassium in New Hanover (NR 14 borehole) is found in higher concentrations, this could be from manure. The borehole is situated downgradient the kraal (Figure 20) and it could be receiving leachate from animal waste. Potassium may be useful as a tracer to determine the extent of groundwater impacted by animal waste. High potassium values could also be due to weathering of biotite, orthoclase and other minerals which are rich in potassium. It is improbable to presume that the origin is from agriculture, since high potassium concentrations are not spread all over the irrigated study area.

In uncontaminated groundwater fluoride usually ranges from 0 – 3 mg/l with some groundwater containing about 12 mg/l or more. In all the boreholes sampled, fluoride is at low levels, showing good and ideal water quality (Figure 21B) which does not cause any hazard, either to human use or irrigation. High fluoride concentrations are associated with igneous and metamorphic rocks such as granites and gneisses, which could be the origin of fluoride concentrations in the study area.

Fluoride is common in nature and is therefore a common component of drinking water. At certain concentrations, fluoride is beneficial by reducing dental cavities significantly (WRC, 1998). Higher levels of fluoride in water (above 4.0 mg/l) can cause mottled or stained teeth

in children drinking the water for long periods before their permanent teeth are in place. This mottling can cause the teeth to be more fragile and sometimes lead to increased cavities. Osteoporosis (leaching of calcium from the bones) can also be caused by high levels of fluoride in drinking water (WRC, 1998).

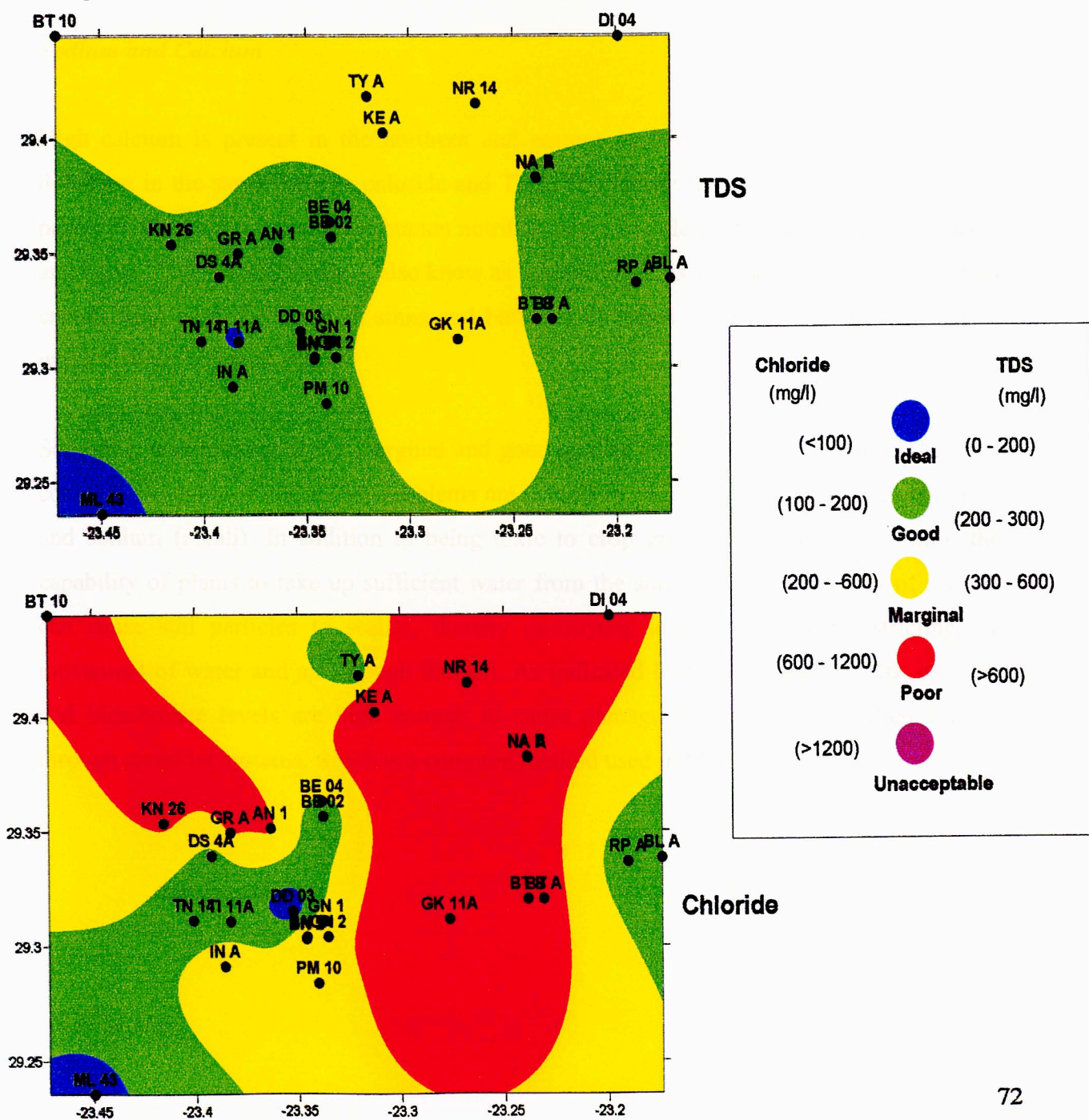
Figure 21B: Potassium and fluoride distribution in groundwater



TDS and Chloride

Salinity can be measured using total dissolved solids (TDS) or electrical conductivity (EC). Salinity is merely a measure of the amount of salt dissolved in the water. Salts are substances such as common table salt (NaCl), limestone (CaCO_3) and many others. When groundwater passes through the rocks, salts are taken up by the groundwater and soils that make up the aquifer.

Figure 21C: TDS and Chloride distribution in groundwater



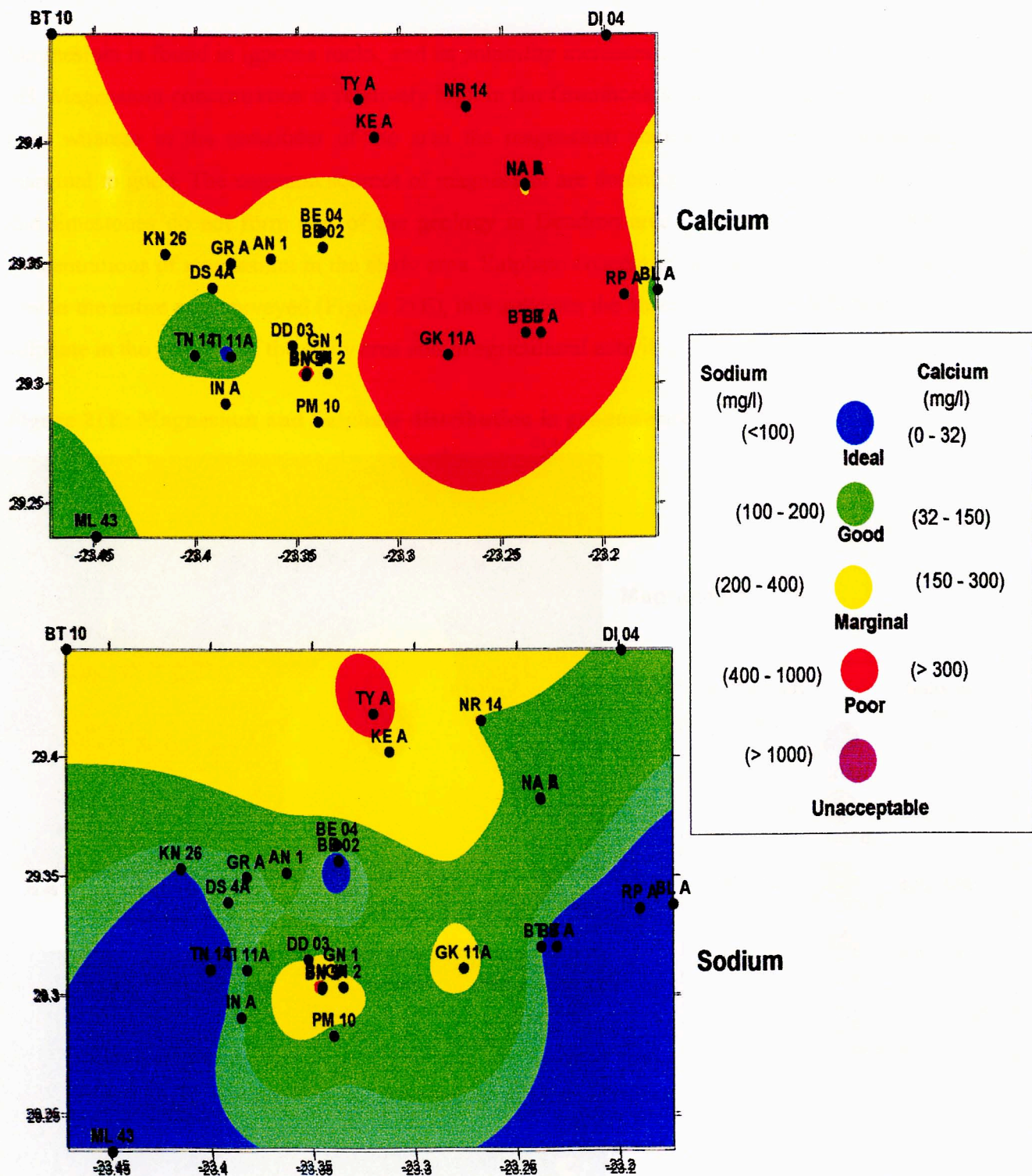
High levels can cause problems for human uses, such as for potable water and crop irrigation, although low levels of these salts are vital to the growth of aquatic plants and animals. Figure 21C shows the water quality for TDS as being good and marginal and of a type which will only cause risk in sensitive groups. A zone of high chloride water extends through the eastern part of the area and places the groundwater into the poor category. The reason for this build up in chlorine is either from dissolution of chloride type mineral accumulated either in the soil or geological formation in the study area. The highest concentration was recorded for boreholes located in agricultural areas, and the increase in chloride concentration probably results from infiltration of minerals applied in irrigation water.

Sodium and Calcium

High calcium is present in the northern and eastern parts of the area and appears to be dominant in the same areas as chloride and TDS. The reason for this could be high calcrete presence. Calcium is essential to human nutrition and a key element in the formation of teeth and bones. Calcium carbonate is also known as limestone and is a cause of water hardness that creates soap curd and scum in sinks and bathtubs. It forms scale deposits in water pipes, water heaters, and tea kettles.

Sodium concentrations depict marginal and good quality for human consumption. The most common irrigation water quality problems are caused by excessive amounts of salt (salinity) and sodium (alkali). In addition to being toxic to crop growth, excess salt can limit the capability of plants to take up sufficient water from the soil. Excessive amounts of sodium can cause soil particles to scatter, thereby destroying soil structure and restricting the movement of water and air through the soil. As indicated by the analytical results, chloride and bicarbonate levels are high enough to cause damage to certain crops when applied through sprinkler systems, which is a common method used in the Dendron area.

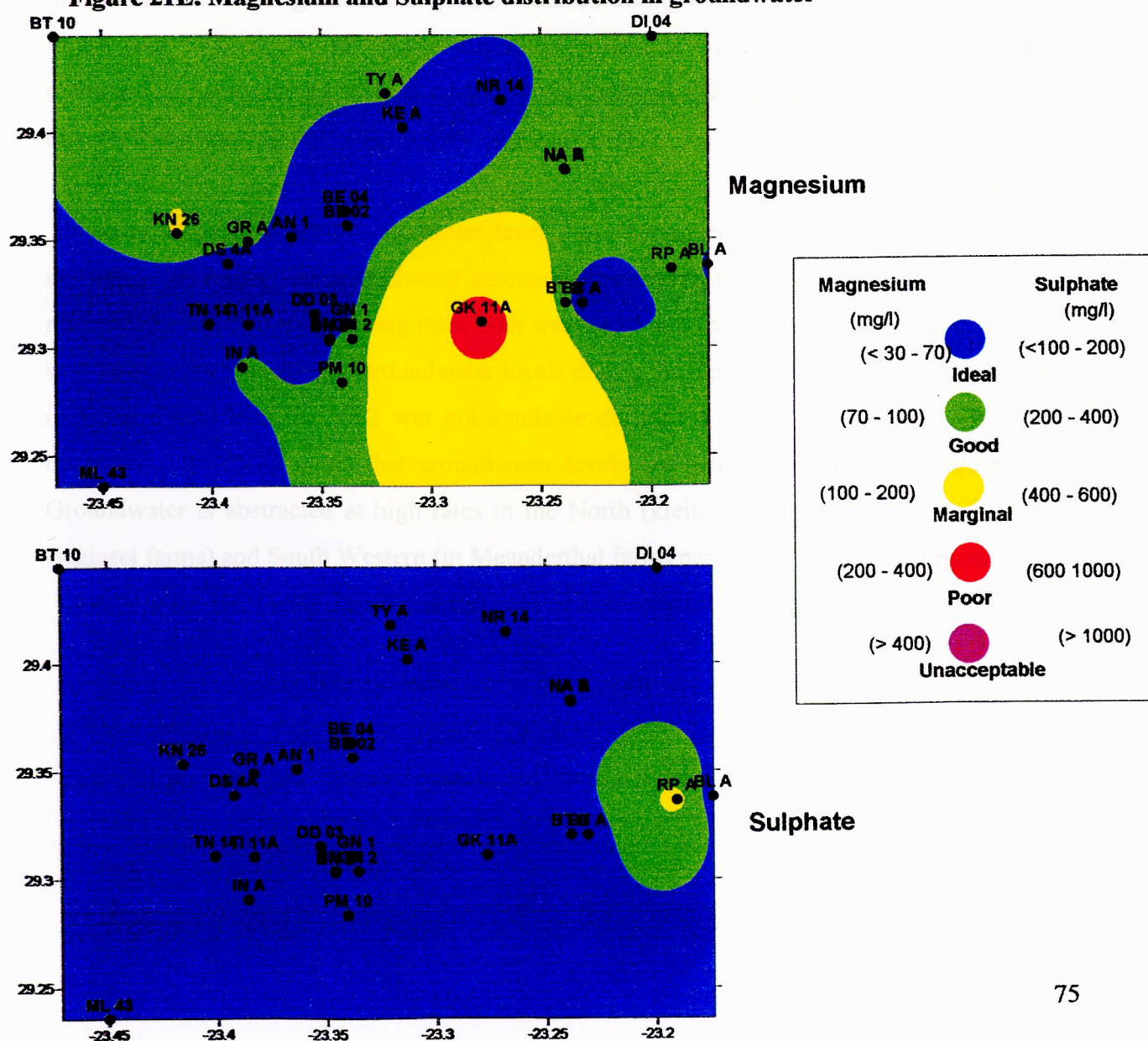
Figure 21D: Calcium and Sodium map distribution in groundwater



Magnesium and Sulphate

Magnesium is found in igneous rocks, and its solubility increases with increased CO₂ or lower pH. Magnesium concentration is relatively high in the Groothoek area classifying the water as poor whereas in the remainder of the area the magnesium content classifies the water as marginal to good. The common sources of magnesium are dolomite and limestones. Dolomite and limestones do not form part of the geology in Dendron area. This account for the low concentrations of magnesium in the study area. Sulphate concentrations were found to be very low in the entire area surveyed (Figure 21E), this indicates the absence or low concentration of sulphate in the geology of the study area and in agricultural activity.

Figure 21E: Magnesium and Sulphate distribution in groundwater



6.3 GROUNDWATER LEVELS AND DRAWDOWN TRENDS

As from 1995 to 1997, depth to water dropped about 2.3 meters, with boreholes in the Beginsel region (eastern part of the study area) decreasing by 10 meters (Figure 22A). Between 1997 to 1999 period (Figure 22B) the levels decreased by 2.30 metres. Deepening of boreholes by 11 metres took place in the North (Klein collie farm) and South (Potsdam farm) areas in 1997 – 1999 periods (Figure 22B). In the 1999 to 2001 period, groundwater levels increased by 1.41 metres overall, with increase at Neu Plus Ultra farm, Deutschland farm and Tweefontein farm, with borehole in Klein Collie farm increasing by 6.5 m. In 2001 to 2003 (Figure 22D) groundwater levels appeared to be decreasing again. The average decrease in water levels from 1995 to 2003 is about 11 metres, though various boreholes exhibit different trends of decrease (Appendix G shows the boreholes time series plots over the years). Increase in groundwater levels occurred during the wet season (January to April) of the year 2000, due to the heavy rainfall (Appendix H). The impact of rainfall in 2000 recharged groundwater by up to 6 metres in the study area (Figure 22C). This indicates the direct effect of the rainfall in the aquifer (Appendix H).

However, in 2001 to 2003 groundwater levels have continued to decline, and this indicates the impact of rainfall on groundwater resource. The overall trend of declining water levels may well be affected by pumping from both weathered and fractured aquifers (Figure 10), as well as changes in recharge. Groundwater levels during the period of 1995 to 2003 are shown in Table 6, and data for 2002 was not available during the period of this study. By mere observation it can be noted that groundwater levels are generally decreasing (Figure 26). Groundwater is abstracted at high rates in the North (klein Collie farm), East (Bronst and Beginsel farms) and South Western (in Meanderthal farm) part of the study area (Figure 23).

Table 6: The average groundwater levels from 1995 – 2003

Boreholes	Farm Names	1995	1996	1997	1998	1999	2000	2001	2003
AN 1	Annex Allion	27.53	27.81	27.83	27.83	28.86	27.68	27.88	29.89
BE 02	Bellevue	13.36	13.61	13.76	14.71	14.74	13.04	13.94	15.69
BE 04	Bellevue	12.47	12.51	12.81	13	13.02	12.01	12.13	13.29
BL A	Beginsel	71.17	80.43	81.07	82.65	83.5	82.62	85.75	90.77
BN 1	Boomzien	29.73	33.65	34.61	36.24	36.55	36.38	36.98	38.98
BN 2	Boomzien	30.53	31.14	31.78	32.14	32.77	30.31	33.11	34.15
BN 3	Boomzien	31.11	31.31	31.37	32.32	32.84	30.09	32.93	33.87
BT A	Bornst	65.88	66.21	67.33	68.65	68.65	67.5	68.29	70.05
DD 03	Duitschland	39.53	44.61	46.16	46.16	46.16	46.16	46.16	48.89
DI 04	Doordraai	21.2	21.21	22.22	23.23	24.11	18.98	21.84	26.6
DS 4A	Didemus	49.5	49.56	50.12	50.88	51.33	50.36	51.28	54.25
GK 11A	Groothoek	39.72	40.44	41.37	42.01	42.34	39.84	40.16	45.13
GN 1	Geluksfontein	24.66	26.71	27.02	28	28.5	26.21	26.89	29.88
GN 2	Geluksfontein	19.98	20.08	20.83	21.08	21.86	15.66	16.63	22.9
IN A	Inderhiken	45	45.01	45.03	45.87	46.22	42.17	43.22	49.95
KE A	Klein Collie	80.23	80.51	81.03	88.54	88.65	82.04	83.77	89.97
KN 26	Kraaifontein	22.44	25.81	26.49	27.71	28.11	20.22	22.24	30.57
ML 43	Meanderthal	65.21	70.83	71	72.17	72.26	72.05	72.9	74.06
NA A	Ne plus Ultra	45.13	45.38	45.46	46.69	47.69	46.11	50.64	58.87
NR 14	New Hanover	19.31	20.51	21.09	23.07	26.48	18.01	21.54	28.81
PM 10	Potsdam	30.32	30.41	31.52	33.29	42.11	37.14	39.77	49.83
TI 11A	Tweefontein	30.71	34.99	35.2	36.01	37.37	37.41	38.76	40.52
TN 14	Tweefontein	33.52	35.15	36.15	38.05	38.23	31.08	33.21	39.05
Average		36.88	38.603	39.18	40.448	41.407	38.39	40.001	44.17

Figure 22A: 1995 – 1997 Drawdown map

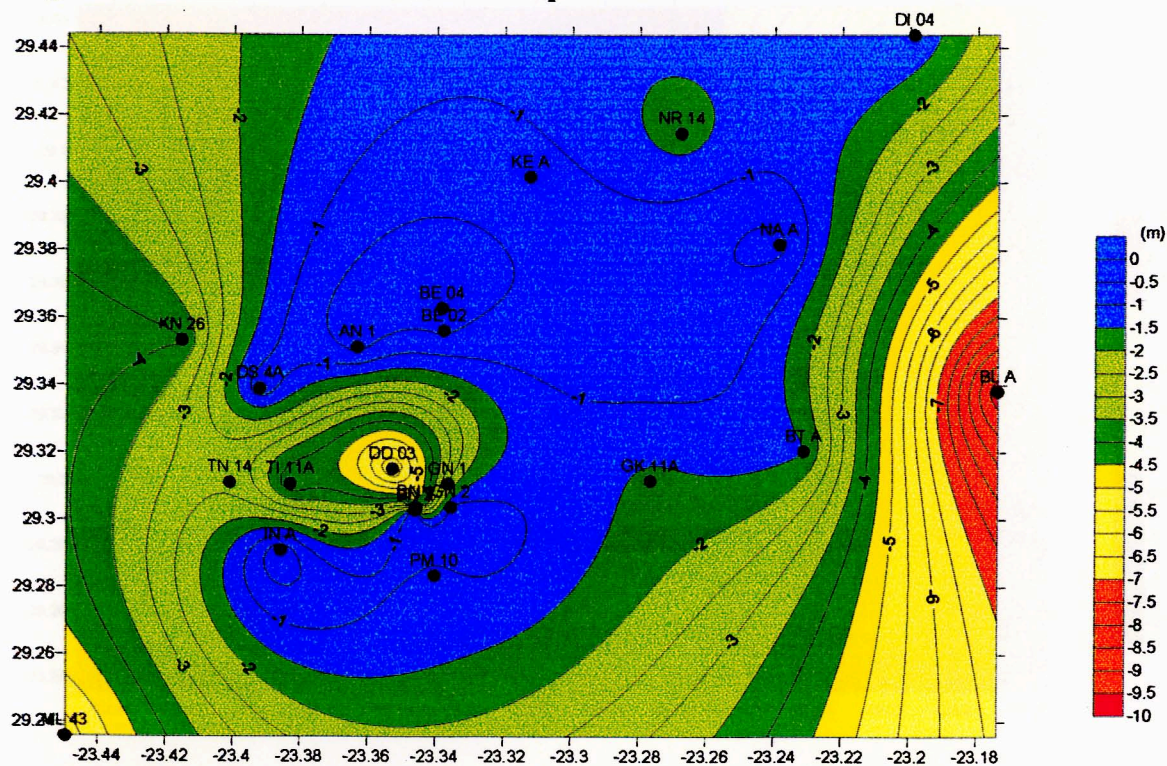


Figure 22B: 1997 – 1999 Drawdown map

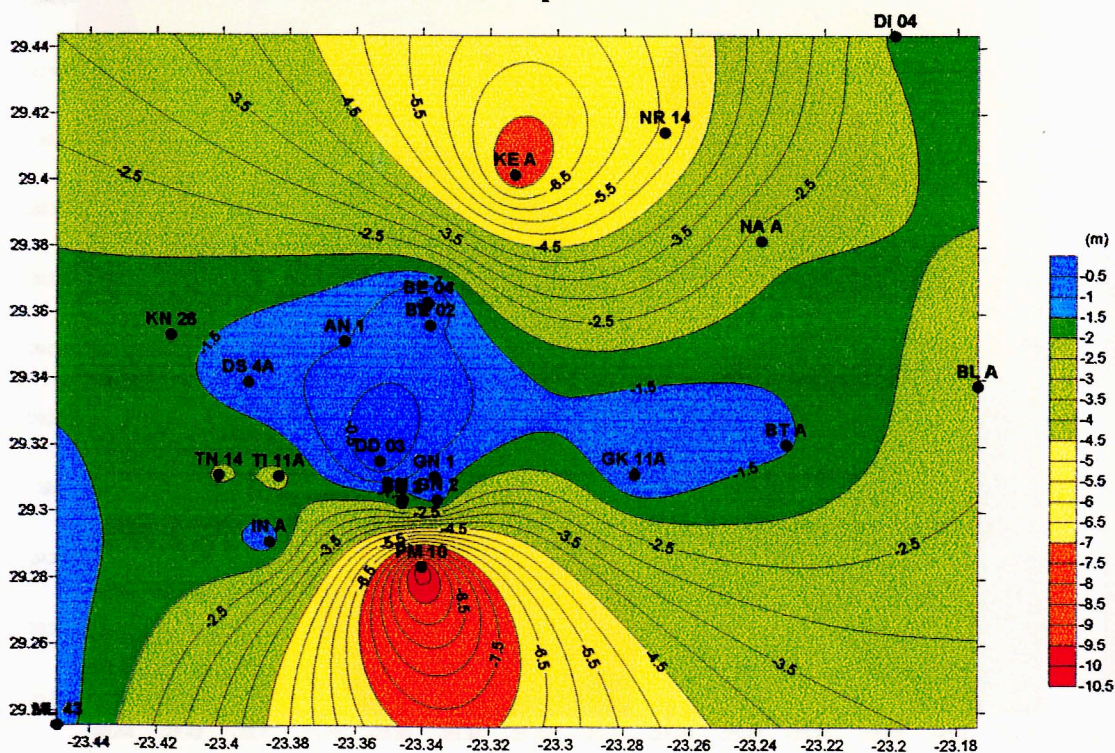


Figure 22C: 1999 – 2001 Drawdown map

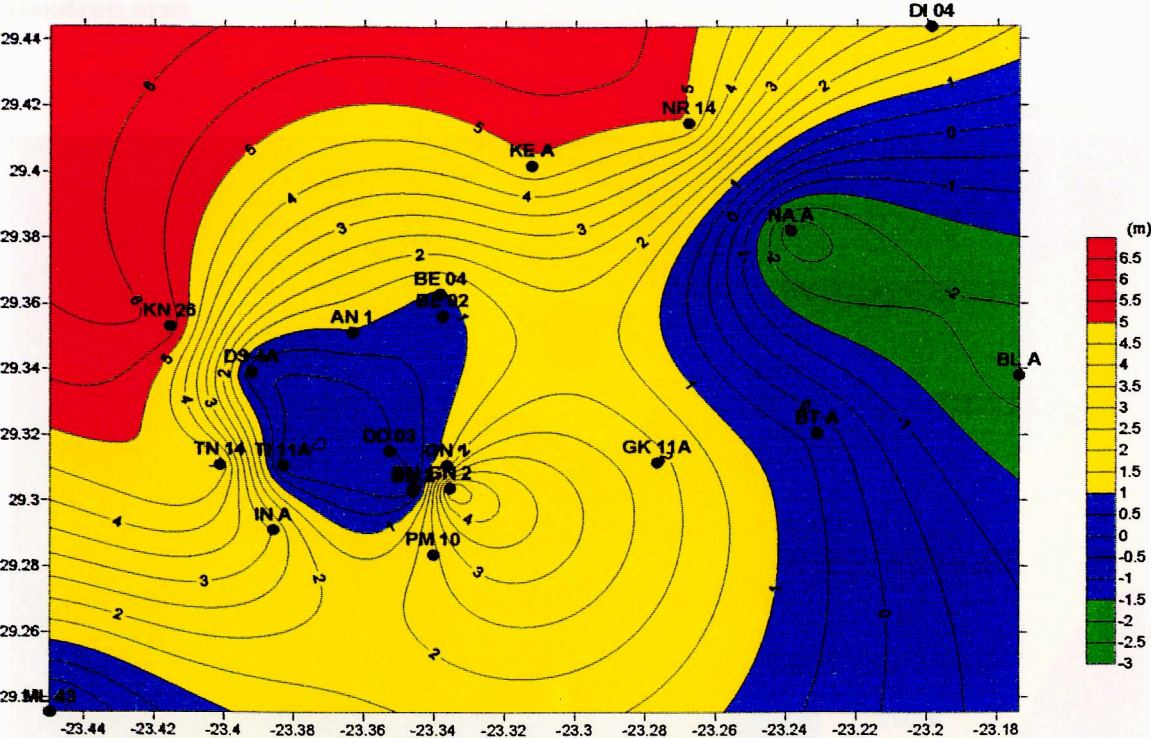


Figure 22D: 2001 – 2003 Drawdown map

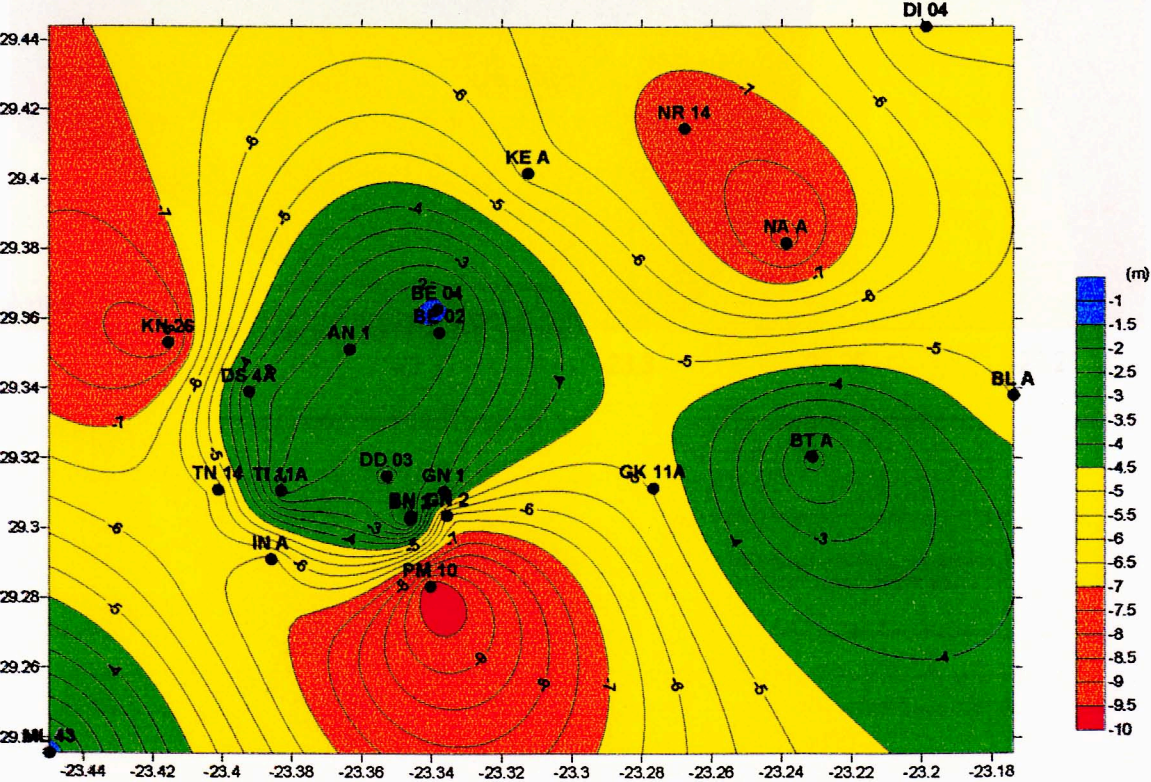
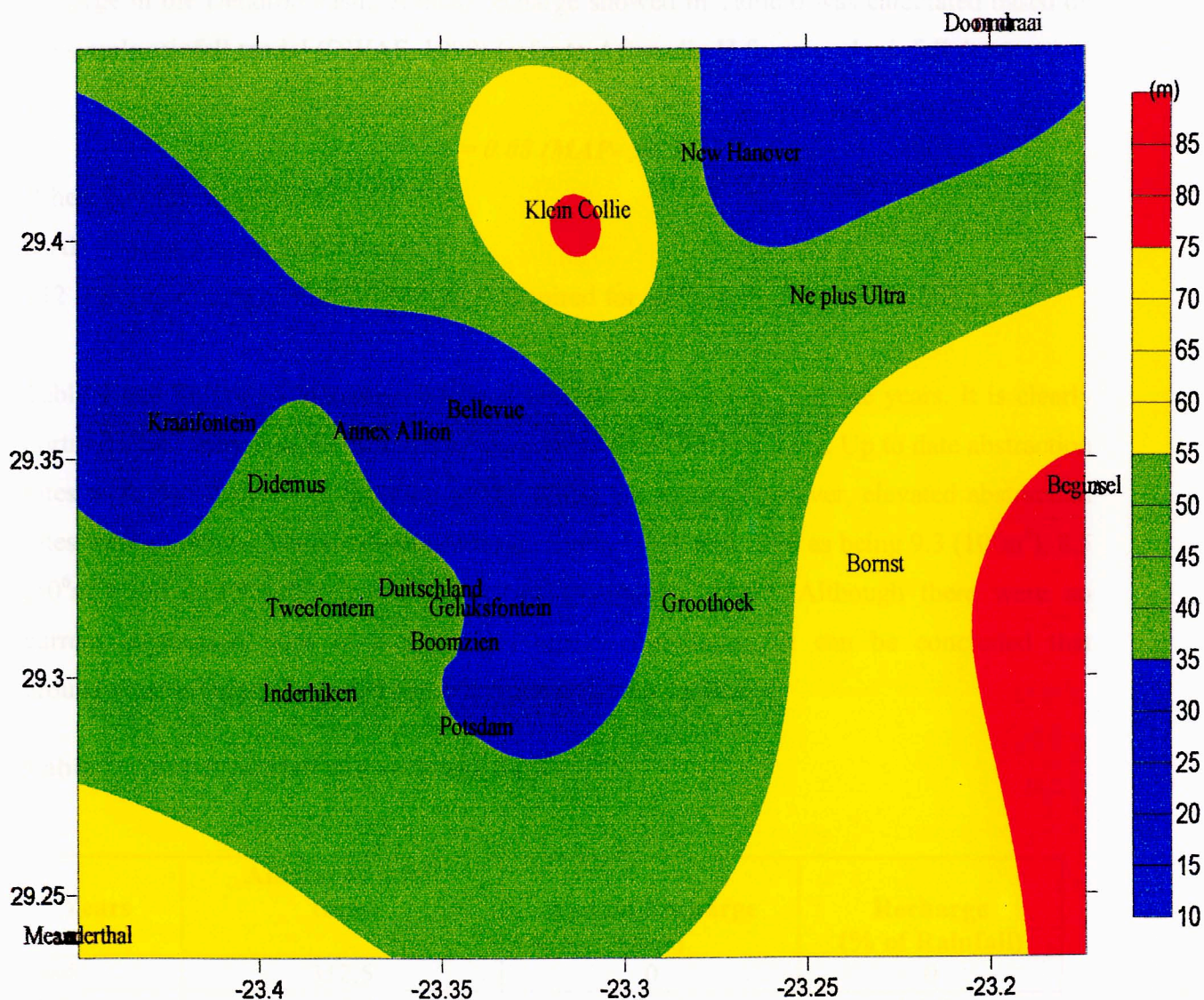


Figure 23: Map showing general trend for groundwater levels for 2003 in the Dendron area



6.4 GROUNDWATER RECHARGE AND RAINFALL PATTERNS

Previous studies by Jolly (1986), Dziembowski (1976) and Masiyandima (2001) demonstrated that rainfall below 342 mm/ annum does not effectively contribute to aquifer recharge in the Dendron basin. Annual recharge showed in Table 6 was calculated based on the simple rainfall model (DWAF, 1990) (refer to Appendix H for annual rainfall data):

$$R = 0.08 (MAP - 342)$$

Where R = Recharge (mm)

MAP = Mean Annual Precipitation

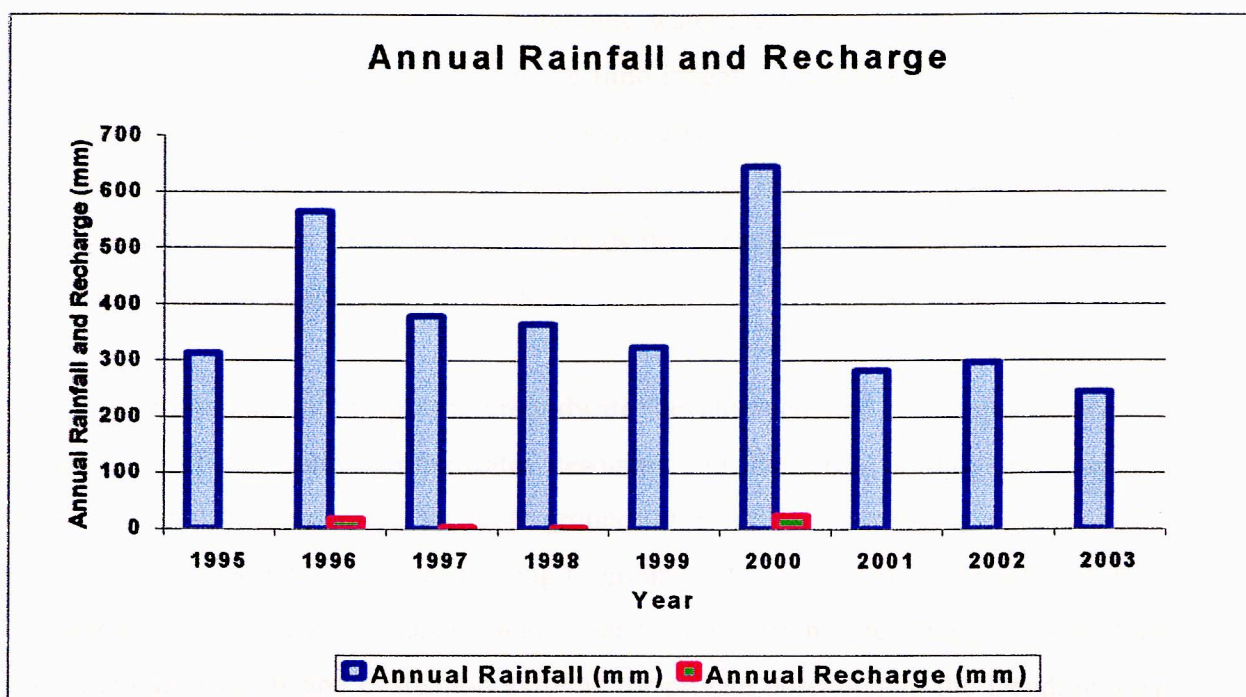
342 is the minimum annual rainfall (mm) required for recharge to occur in the basin.

Table 7 and Figure 24 indicate the annual rainfall and recharge over the years. It is clearly portrayed that there was no recharge to the aquifer from 2001 to 2003. Up to date abstraction rates were not available at the time of compiling the report. However, elevated abstraction rates were shown by Masiyandima (2001) for 1968, 1974, and 1986 as being $9.3 (10^6 m^3)$, $8.5 (10^6 m^3)$ and $21.09 (10^6 m^3)$ respectively (Masiyandima, 2001). Although there were no current abstraction rates at the time of report compilation, it can be concluded that groundwater is being abstracted without recharge to the aquifer.

Table 7: Annual rainfall and recharge data

Years	Annual Rainfall (mm)	Annual Recharge (mm)	Recharge (% of Rainfall)
1995	312.5	0	0
1996	564.8	17.82	3.16%
1997	377.8	2.86	0.75%
1998	364.3	1.76	0.48%
1999	323.8	0	0
2000	643.8	24.14	3.74%
2001	281.6	0	0
2002	297	0	0
2003	244.5	0	0

Figure 24: Rainfall and estimated recharge for the Dendron basin



6.5 SUSTAINABLE GROUNDWATER MANAGEMENT

In contrast to surface water resources, groundwater resources are more difficult to quantify accurately, mostly because the data required to do so hardly ever exists. It is a well-recognized fact that groundwater in the Dendron area has, through the ages, and continues to be an essential commodity for irrigation, stock farming and domestic use. Taking into account the importance of groundwater and recognizing its role in the Dendron area, future sustainability is the key management for this resource and must be addressed properly.

Therefore, the most serious groundwater challenge facing the Dendron area is not in developing the resource but in its integrated management and long-term sustainable use. One of the problems identified that hinders proper management in Dendron area is lack of data, which is insufficient for hydrogeologists to assess the nature of groundwater occurrence, quantify aquifer resources or make decision of aquifer sustainability with any level of accuracy. Lack of data is due to the previous legal framework, where groundwater was classified as private, with the available data being scattered between different institutions, leading to difficulties in collation and accessing the information.

The only effective way to collect and compile the necessary data for management is by users themselves. Each borehole owner can benefit from keeping the record of his borehole. To ensure a continuous supply of water from boreholes, water level measurements, daily rainfall recording, and volume of water pumped or the time irrigated should be recorded regularly. Analysing such information helps in assessing the necessary remedial action to be taken at an early stage, and more highly developed methods such as mathematical modeling for an aquifer could be employed. By using such methods the behaviour of the water levels can be simulated for various pumping conditions etc.

There is no coordination with respect to groundwater development and consumption between different users of the same groundwater resource in the area. Improvement of all groundwater users' cooperation to facilitate groundwater management strategies and jointly develop methods of addressing issues relating to groundwater management is another option for sustainable groundwater management. Verification from the study shows that groundwater data records and evaluation systems for private boreholes in the Dendron area are not properly documented. Interaction between groundwater developers, government and users/ farmers are very important, for a common management programme.

The Department of Water Affairs and Forestry has initiated a new management system, whereby groundwater resources can be managed by users through the water users associations (WUA). Although the WUA is being established in Dendron, awareness of sustained groundwater management must be promoted and facilitated. It is apparent that in the absence of experienced personnel, any data gathering and evaluation systems that may be in existence, or may be proposed cannot function to the level that will be necessary to develop groundwater management tools. Institutions co-ordinating the use of groundwater should be backed up by a clear legal framework. Restrictions on groundwater access, use, withdrawal rights, ownership rights and obligations should be clearly defined and accepted by all interested and affected parties.

A common data base for all private boreholes covering all aspects of groundwater for more accurate and rational understanding of the agricultural and socio-ecological value of groundwater should be developed. There must be a reliable and comprehensive data on aquifer conditions and trends, and on abstraction and pollution. Investigating the extent and nature of the consequences of unsustainable groundwater uses is very crucial. The

development and promotion of guidelines and strategies for integrated and sustainable management of groundwater is a priority.

Groundwater monitoring is essential to sustainability. The frequency of hydrogeological monitoring of private boreholes in the Dendron area is however inadequate. Although the farmers have appointed an individual to take the water level measurements, the extent and frequency of monitoring is still insufficient. Then again, groundwater is not fully monitored, since monitoring entails measurements of all elements of the hydrological cycle, including meteorological, hydrological, water level data, measurement of water quality data, measurement of human activity (abstraction, land use) and measurement of abstraction point performance.

It is also imperative for farmers to have the records of how much water is being abstracted, and to prevent irrigating low-income crops. The farmers should also improvise ways of recharging groundwater in the area, for instance artificial recharge measures.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION

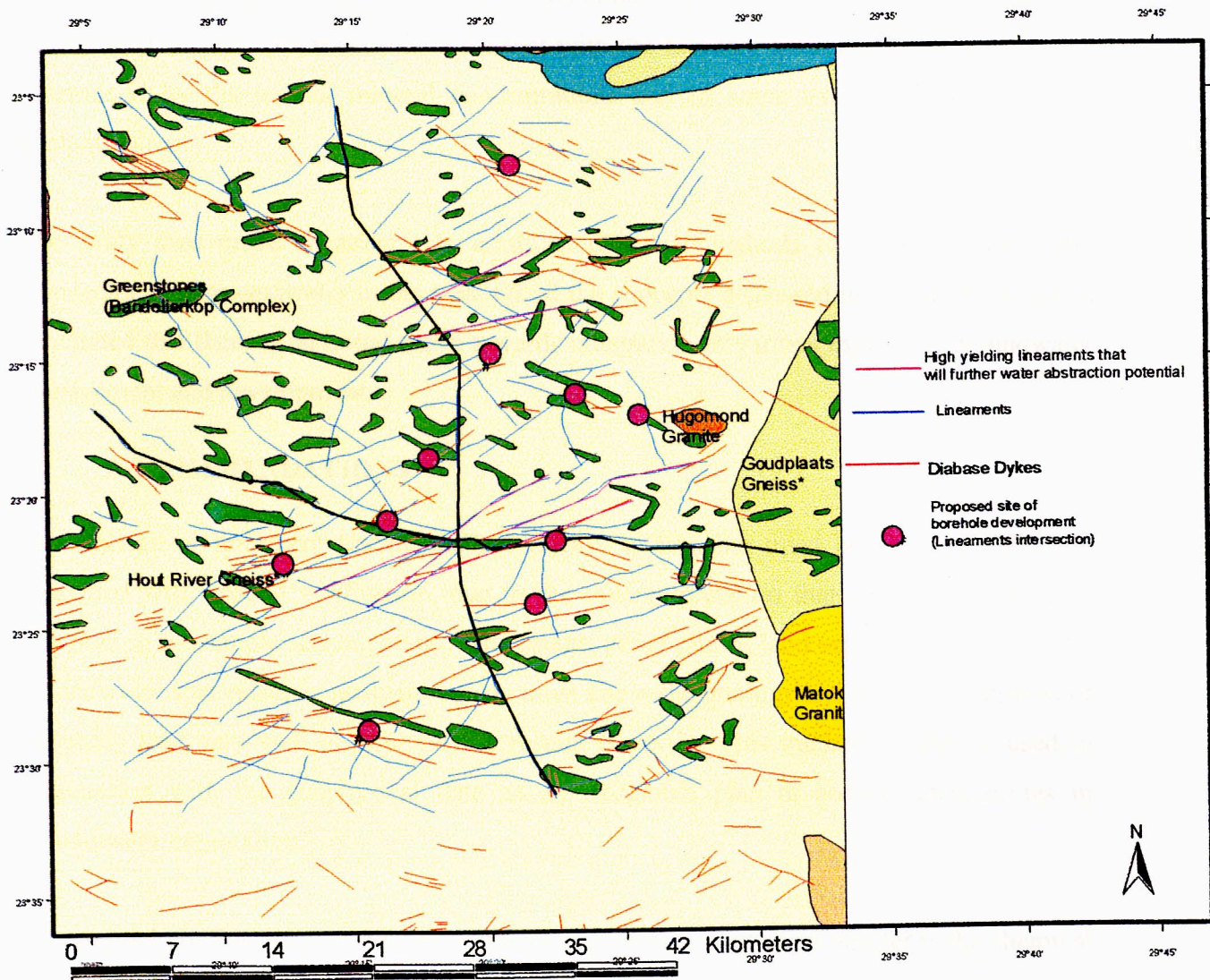
Misuse of the groundwater resource and poor water management practices have resulted in falling water tables in the Dendron area, with excessive drawdowns recorded in places. In view of the increasing demands of commercial farms, small-holder agriculture and community households on groundwater sources in the area, the groundwater source, groundwater quality and drawdown trends were studied to develop management methods for the aquifer.

A key focus of the project was to determine the geohydrologic potential and management of the Dendron aquifer, by determining various aspects of groundwater, such as characterisation of its availability, quality and vulnerability. By studying the availability, as part of integrated water resource management, it was possible to propose some approaches for ensuring the effective management of groundwater in the area.

The relationship between geological structures and groundwater parameters has been determined, for future development and management of groundwater in the area. The results indicate the aquifer's potential of being a good source of groundwater if development could be targeted on studying the geological structures of the area. The study has shown that a clear knowledge of geology and structures should be considered for groundwater development in the area. As evidenced by this study, the boreholes drilled along lineaments and certain lineaments in particular were found to be the highest yielding and therefore fractures are good targets for future development (Figure 25). Poor groundwater quality high in TDS, calcium, chloride and nitrate content are associated with areas of high yielding lineaments (boreholes GK 11A, NAA, BTA), located in the northern part of the study area (Figure 14).

A critical review of the study indicates that high yielding boreholes are located where lineaments intersect with previously mapped lineaments and diabase dykes, for instance borehole DD3, IN A and BTA (Figure 14). However, it is important to note that further geophysical studies should be undertaken to improve in determining the intensity and density of fractures.

Figure 25: Map showing proposed sites for borehole development



Areas of high abstraction and the general drawdown trends were identified. Although rainfall recharges the aquifer, there is still an overall decline in water levels indicating that

abstraction exceeds groundwater recharge. It has been envisaged that there was no effective recharge to the aquifer for some years (2001-2003).

The main objective for the hydrochemical analysis of groundwater was to determine its suitability for different uses and to classify the water type. The chemical investigations indicated the water is generally in the acceptable to poor quality category for domestic and other uses, and it is very hard. Natural contamination due to minerals and some anthropogenic signature were identified. Hydrogeochemical analysis showed primarily calcium-chloride-bicarbonate water type, with sodium occasionally present in some parts of the study area. This observation is consistent with the fact that groundwater type is usually determined by the natural mineral concentrations and to some extent by anthropogenic contamination.

The study then made an attempt to establish effective methods of ensuring sustainable management of groundwater in the area. Of all the concepts discussed in this study, it can be concluded that there is an initial move towards integration of various aspects in groundwater management and development.

7.2 RECOMMENDATIONS

The fracture or lineament tracing method is easy to use, but must be used carefully and supported with ground verification, due to the misinterpretation that could be made from interpreting the remote sensing maps (aster image, aerial photos land sat image etc) only. The groundwater specialists or geohydrologists must know the geology and structural settings of the study area very well to interpret the results correctly. This method should be used in conjunction with the geophysical data as an integrated plan to reduce uncertainties in groundwater exploration.

An essential consideration in the development and management of an aquifer is the chemical quality of water produced, as the quality can limit its use. Groundwater movement induced by pumping may change the groundwater chemistry, so it is recommended that continuous monitoring should include collection of water samples to ensure that the water is suitable for either irrigation or domestic use. There is a good relation between the water quality and water

levels drawdowns. Limitations on groundwater level drawdown can be reduced to prevent poor water quality inflow.

For consistent groundwater level data, the users themselves need to measure their water levels and keep the records of water levels every month. It is also recommended that, though these are private boreholes, a water allocation limit must be established for sustainable abstraction, and water usage monitored and reported (to the Department of Water affairs and Forestry) on a periodic basis. It is also recommended that data such as storativity, yield and transmissivity of the aquifer be rationalized and updated. Therefore the groundwater potential of the area could be determined effectively. A database for all private boreholes should be created.

It is also recommended that farmers record how much water is being abstracted, prevent irrigating low-income crops and improvising ways of recharging groundwater in the area. All these could be achieved through the establishment of the WUA, and close co- operation with the regional office. The main purpose of the WUA is to operate at restricted localised level. WUA are comprised of a co-operative association of the individual water users who are engaged in water related activities for their mutual benefit. The association operates within the framework of the national policy/ guidelines and standards. Presently, the Dendron- Vivo water control board is being transformed to WUA. The proposal has been handed in for approval by DWAF. Establishment of the WUA will enable groundwater management and utilization between competing users to be achieved proficiently.

CHAPTER 8

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APPENDICES

Appendix A Land sat. Image of Dendron area

Appendix B One of the aerial photographs for the study area

Appendix C Aeromagnetic interpretation for the Dendron- Vivo

Appendix D SABS Water Quality Guidelines and Standards

Appendix E Durov diagram

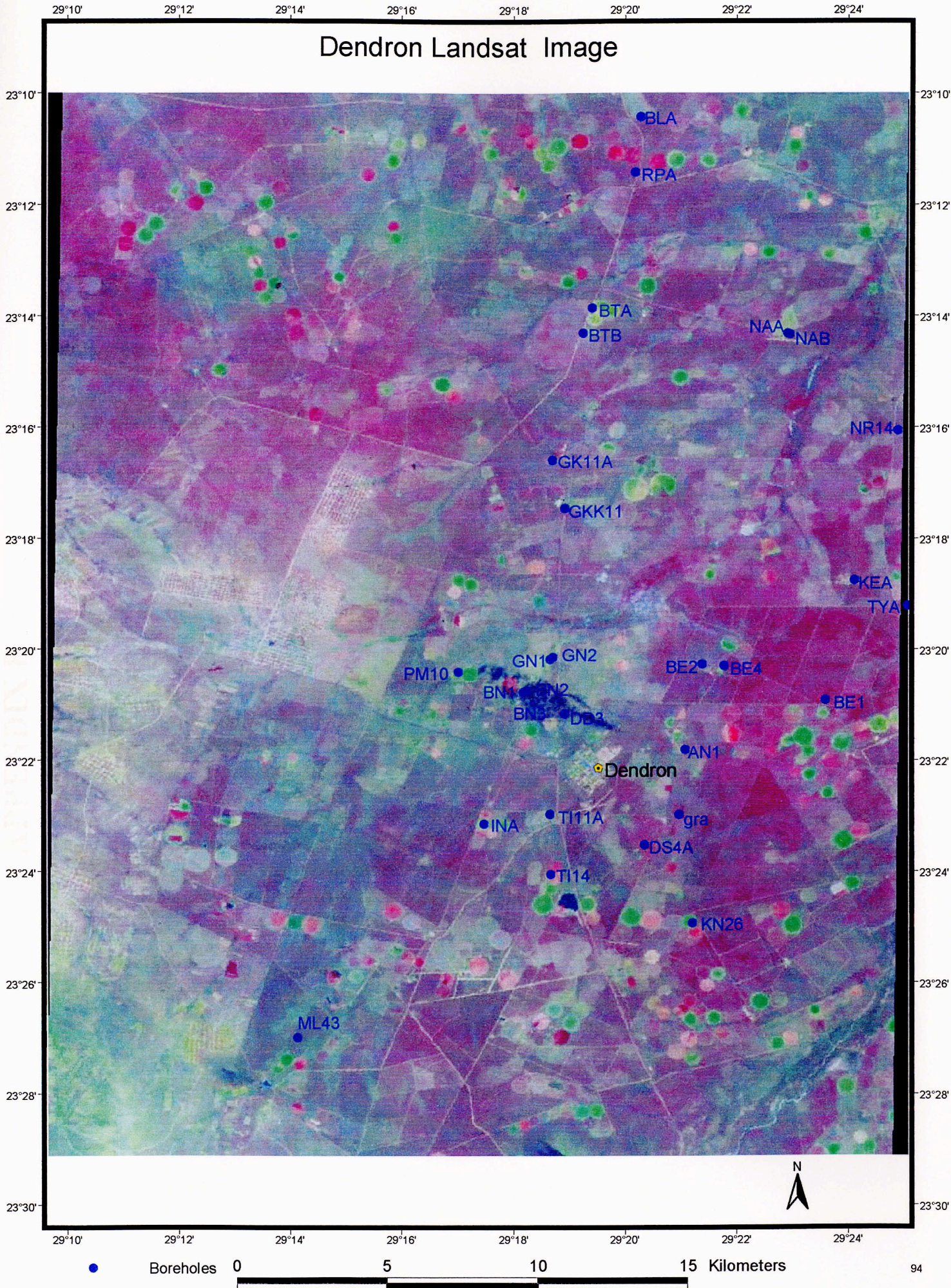
Appendix F Stiff diagrams

Appendix G Time series plots of borehole water levels

Appendix H Dendron rainfall data for the 1995- 2004 period

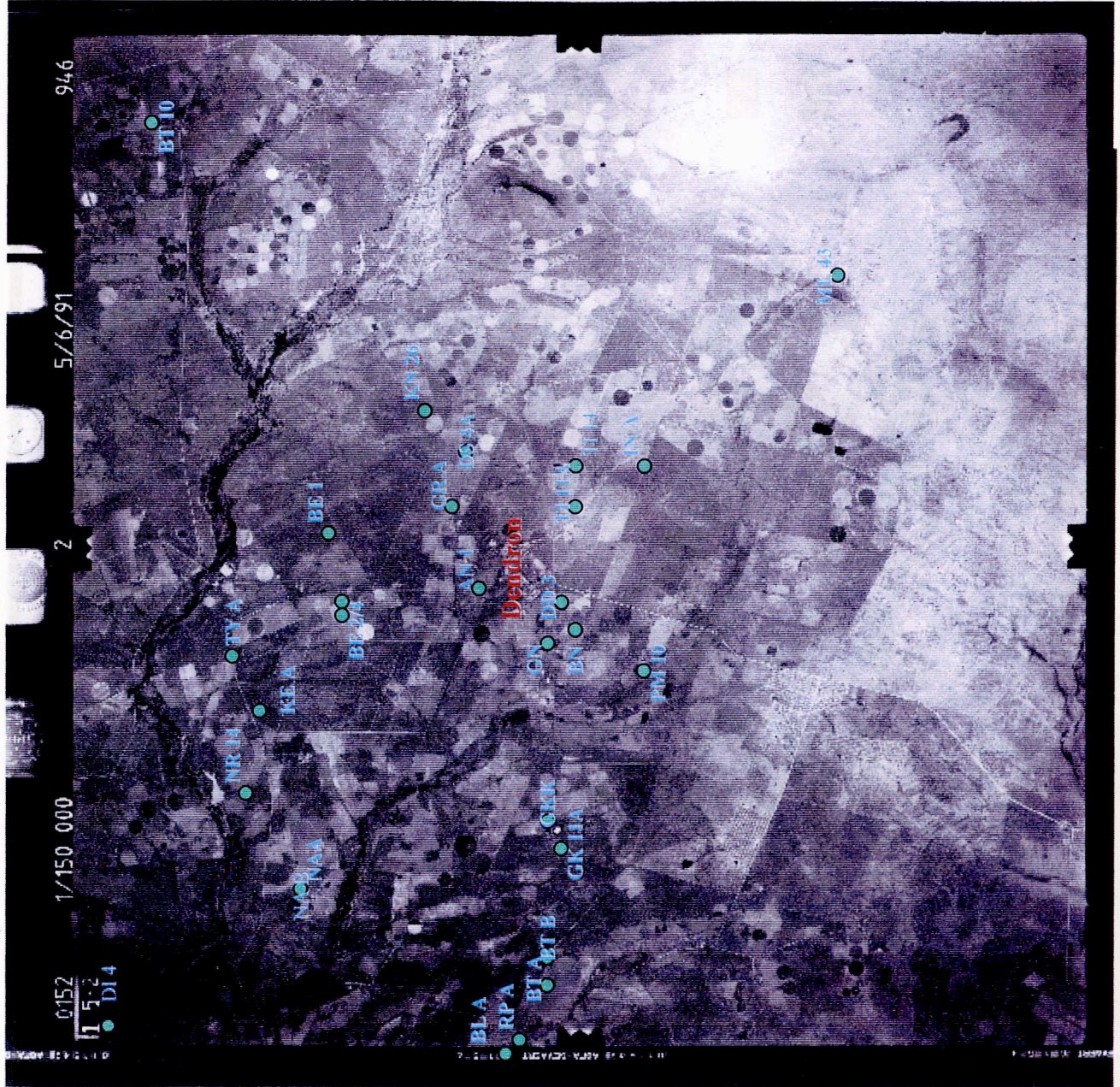
APPENDIX A

Dendron Landsat Image

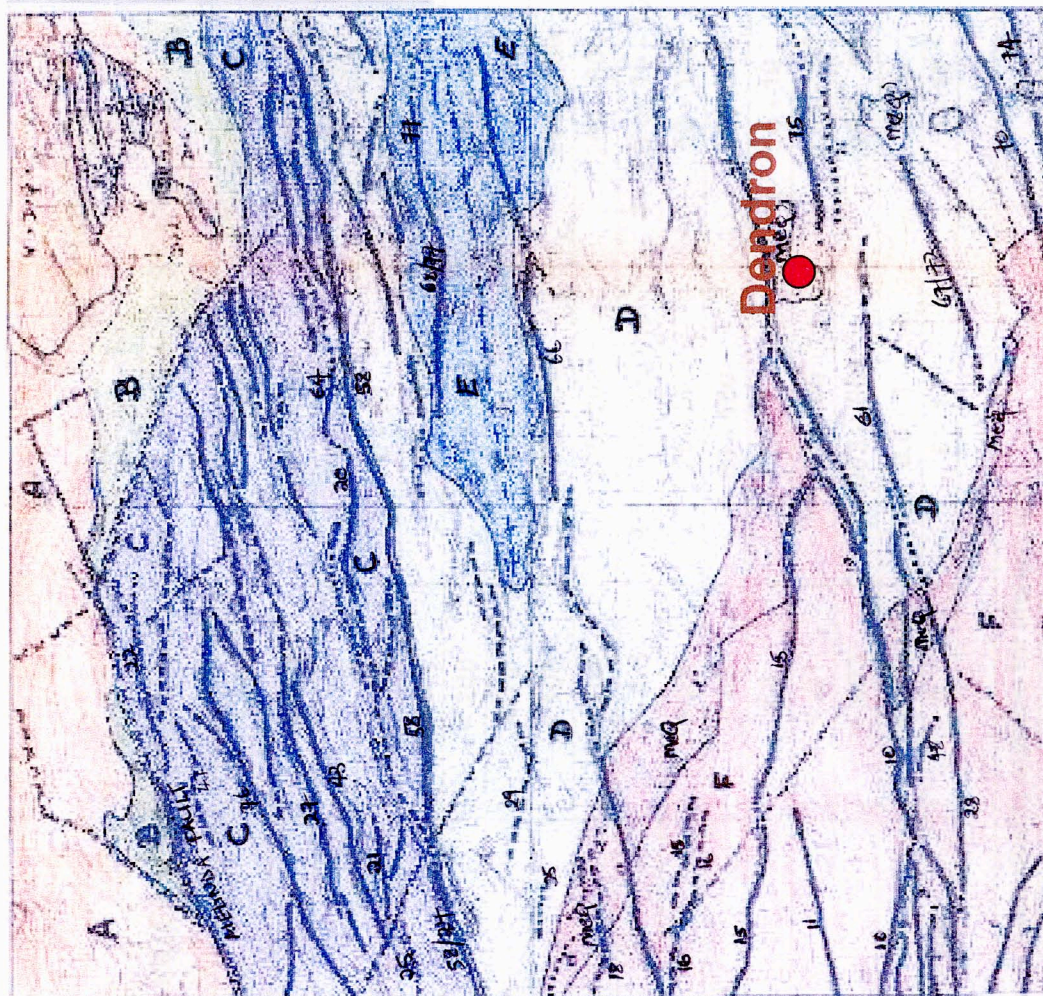


APPENDIX B

One of the
Aerial
Photographs
for the study
area



APPENDIX C

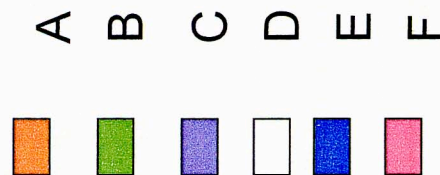


SKETCH MAP OF THE GEOPHYSICAL INTERPRETATION

LEGEND

Dykes	Probable	Uncertain
Faults	-----	-----
Geological boundaries	-----	-----
Structural Axes	-----	-----

Aeromagnetic interpretation for the Dendron - Vivo area.



APPENDIX D

SOUTH AFRICAN WATER QUALITY GUIDELINES AND STANDARDS

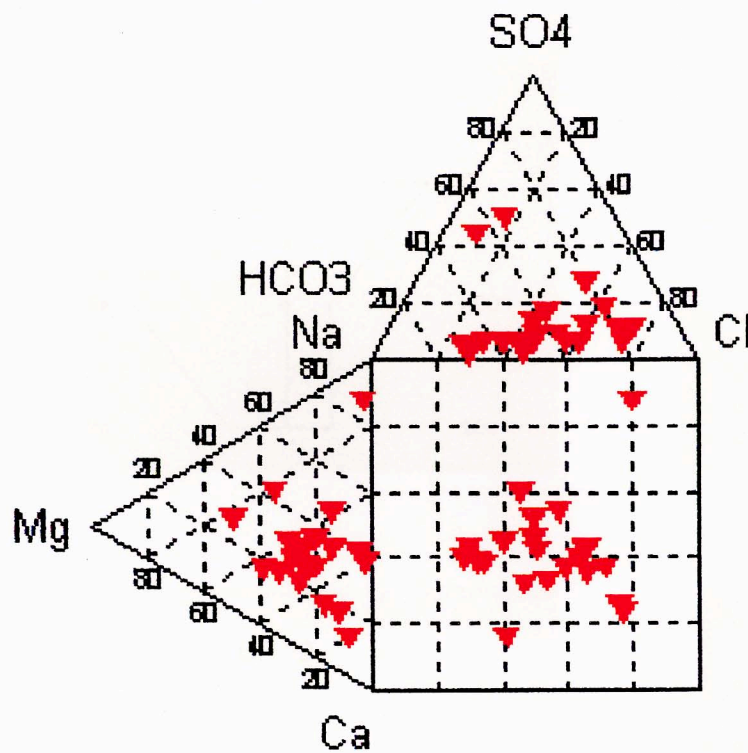
Constituents		Class 0	Class 1	Class 2	Class 3	Class 4
TDS		< 450	450 - 1000	1000 - 2400	2400 - 3400	> 3400
EC (mS/m)		< 70	70 -150	150 - 370	370 - 520	> 520
Nitrate (as N)		< 6	6 - 10	10 - 20	20 - 40	> 40
Fluoride		< 0.7	0.7 - 1	1 - 1.5	1.5 - 3.5	< 3.5
Sulphate		< 200	200 - 400	400 - 600	600 - 1000	> 1000
Magnesium		< 70	70 - 100	100 - 200	200 - 400	> 400
Sodium		< 100	100 - 200	200 - 400	400 - 1000	> 1000
Chloride		< 100	100 - 200	200 - 600	600 - 1200	> 1200
pH		5 - 9.5	4.5 - 5 or 9.5 - 10	4 - 4.5 or 10 - 10.5	3 - 4 or 10.5 - 11	< 3 or > 11
Potassium		< 25	25 - 50	50 - 100	100 - 500	> 500
Calcium		< 80	60 - 150	150 - 300	> 300	
Zinc		< 3	3 - 5	5 - 10	10 - 20	> 20
Arsenic		< .01	.01 - .05	0.05 - 0.2	0.2 - 2	> 2
Cadmium		< .003	.003 - .005	.005 - .02	.02 - .05	> .05
Iron		< .01	0.5 - 1	1 - 5	5 - 10	> 10
Faecal coliforms		0	0 - 1	1 - 10	10 - 100	> 100

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

APPENDIX E

DUROV DIAGRAM

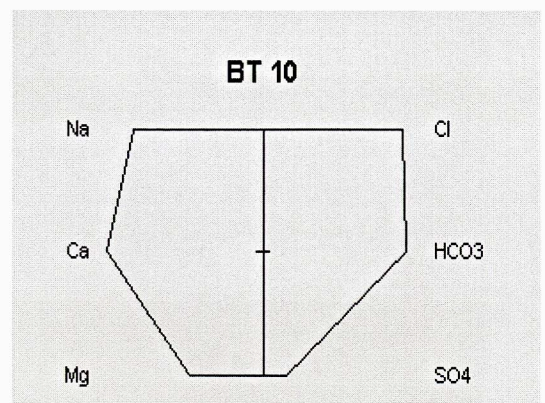
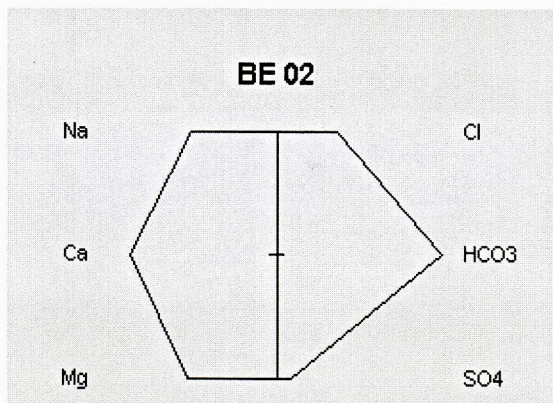
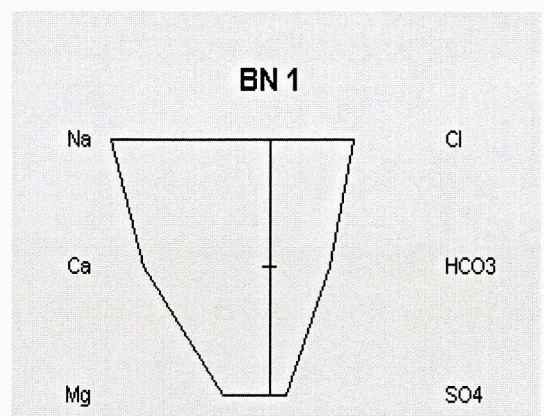
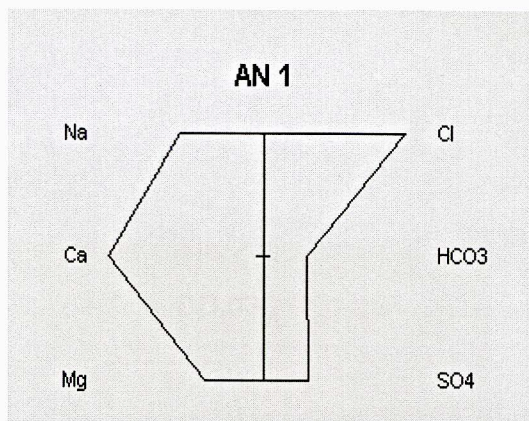
Durov diagram shows clustering of data points to indicate samples that have similar compositions.

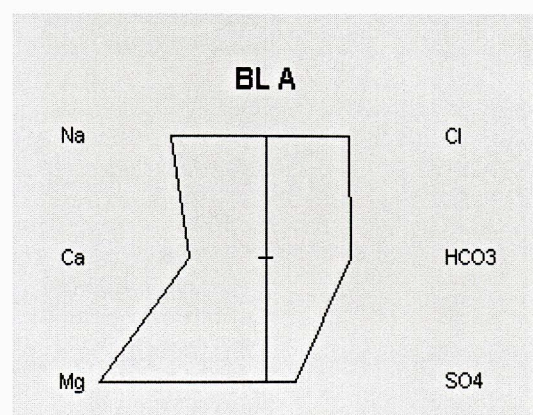
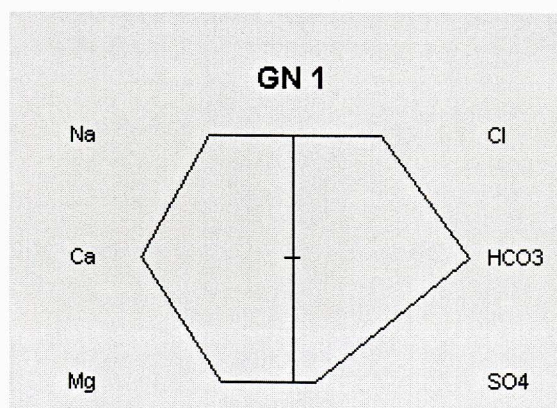
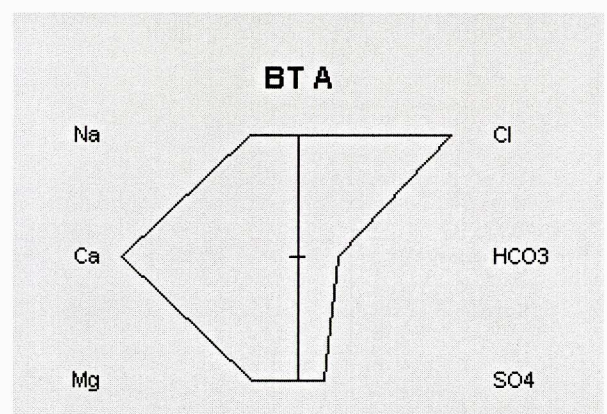
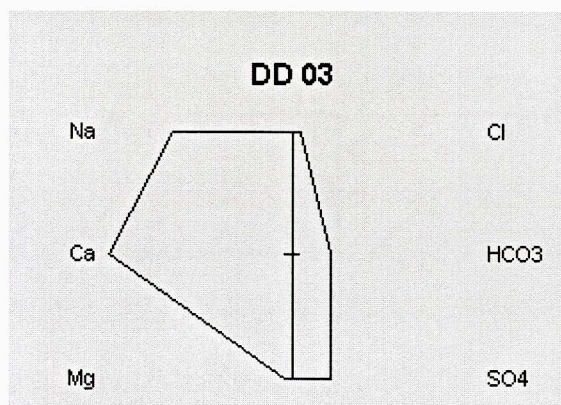
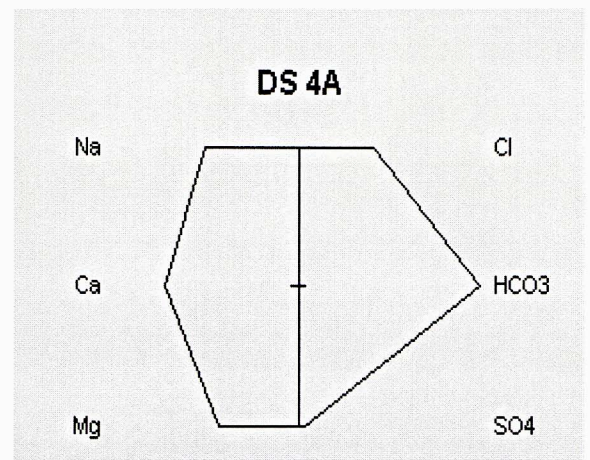
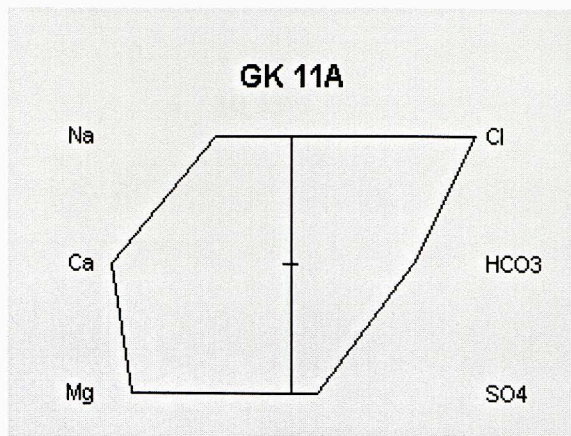


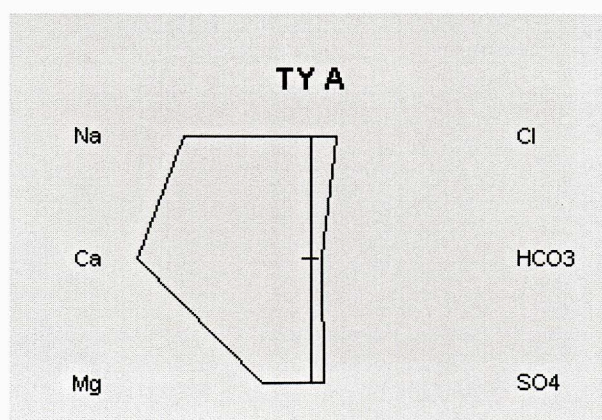
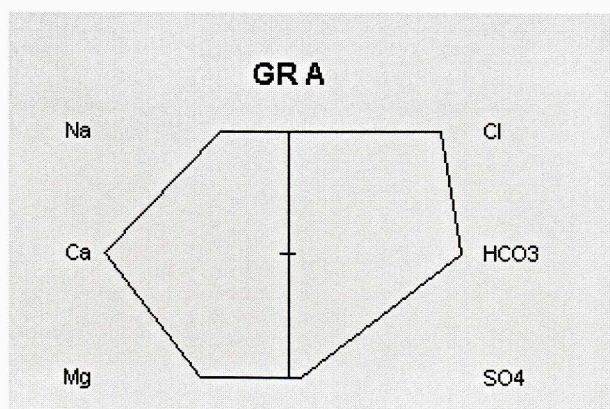
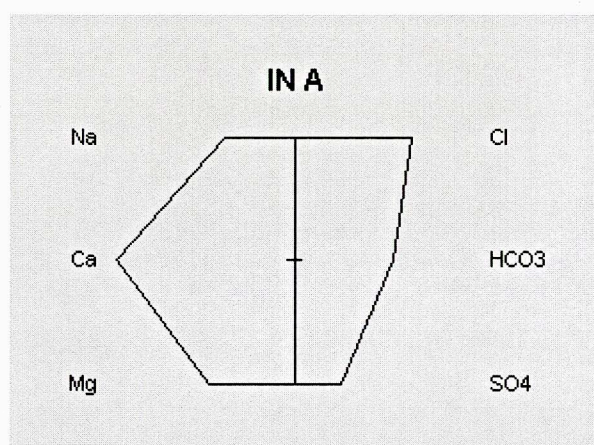
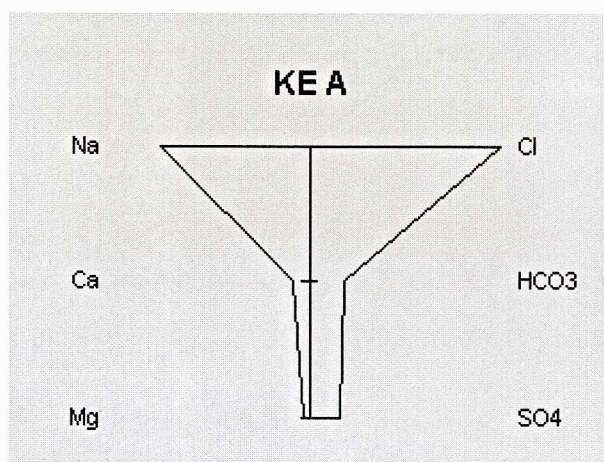
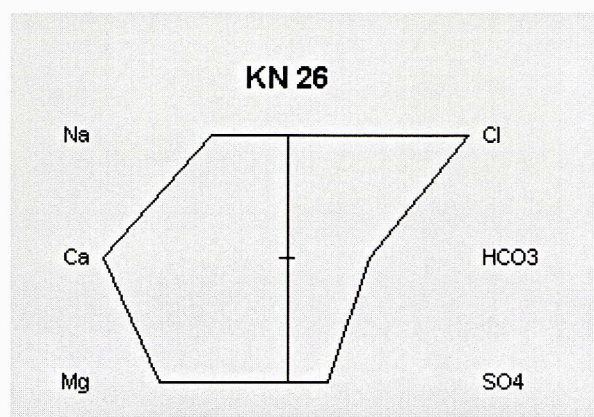
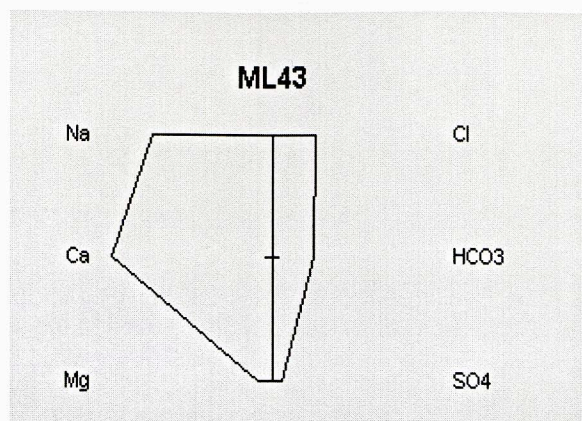
APPENDIX F

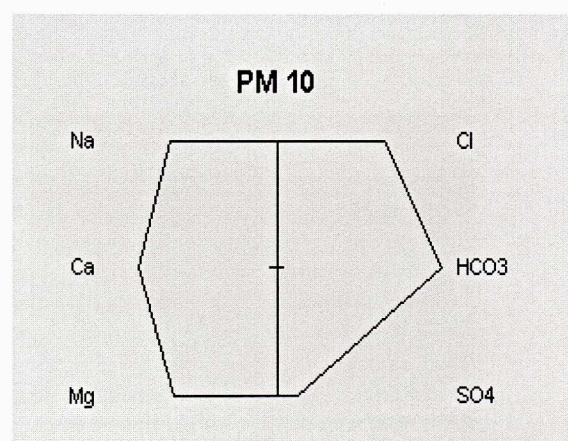
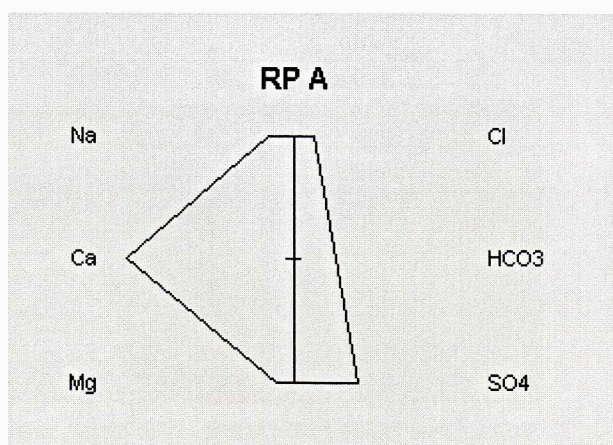
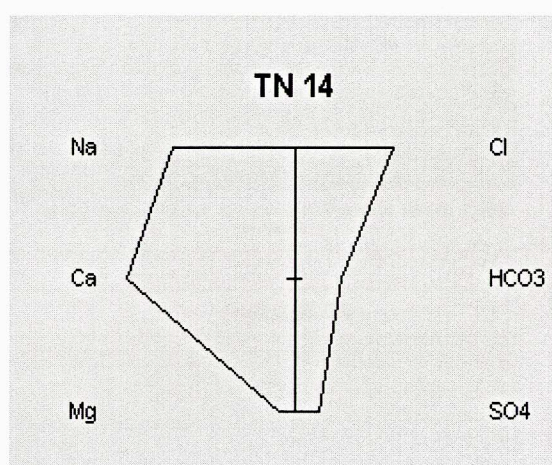
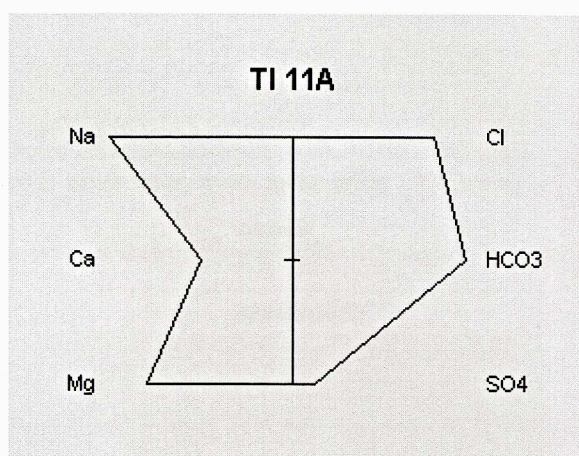
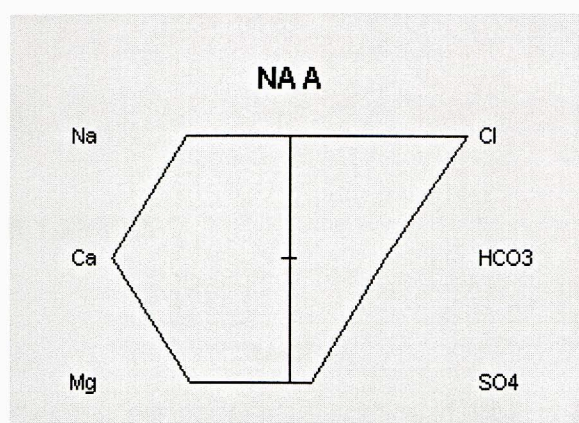
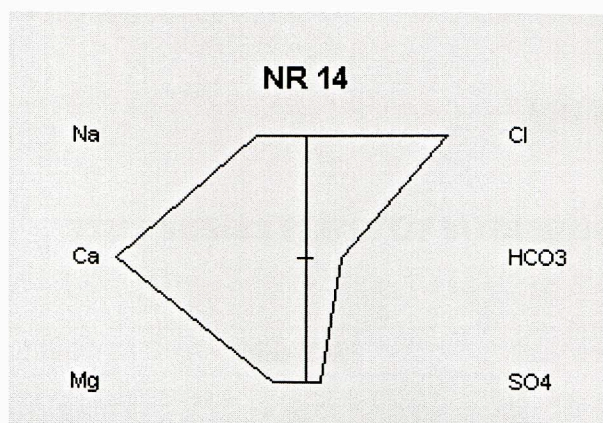
STIFF DIAGRAMMES

Stiff diagrams are good for making rapid visual comparison between water from different sources. They are plotted for individual samples to compare the concentration of selected anions and cations for several individual samples. The larger the area of the polygon shapes the greater the concentration of ions.



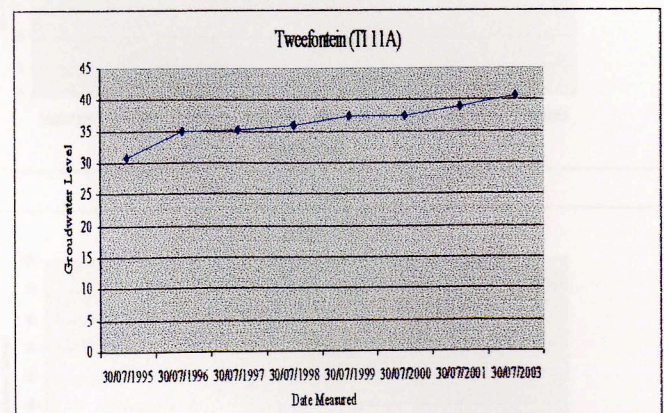
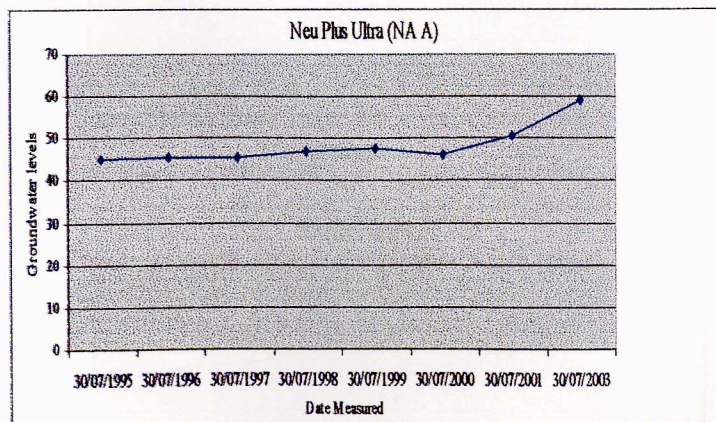
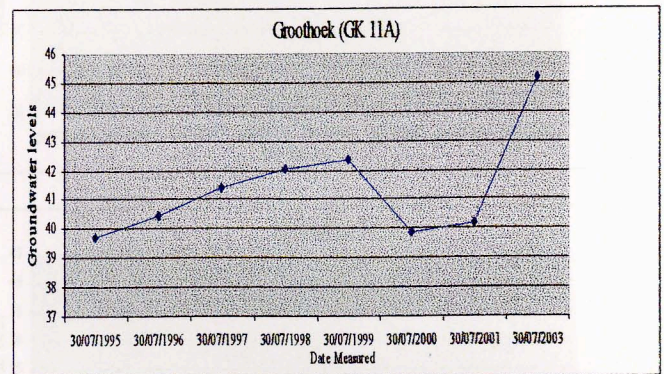
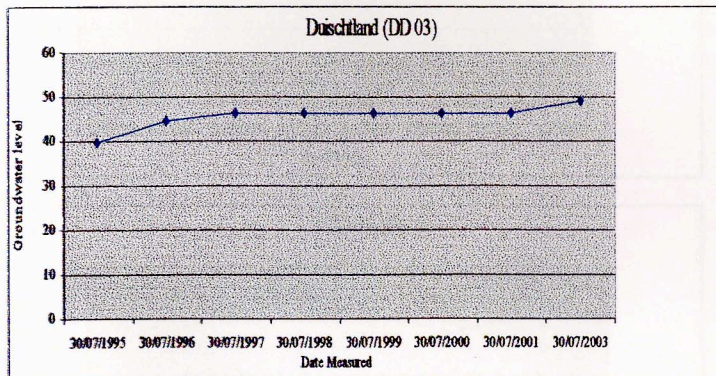
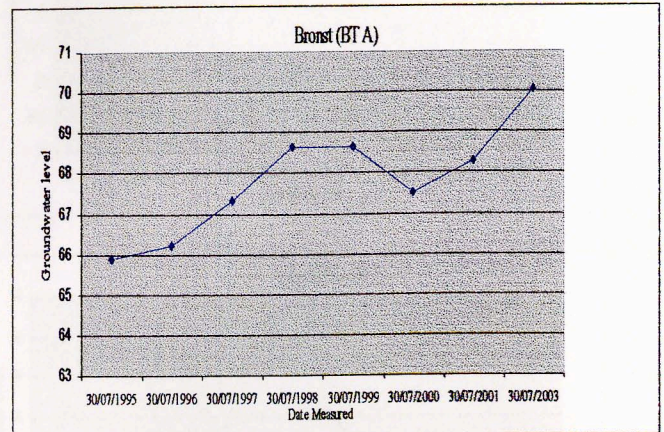
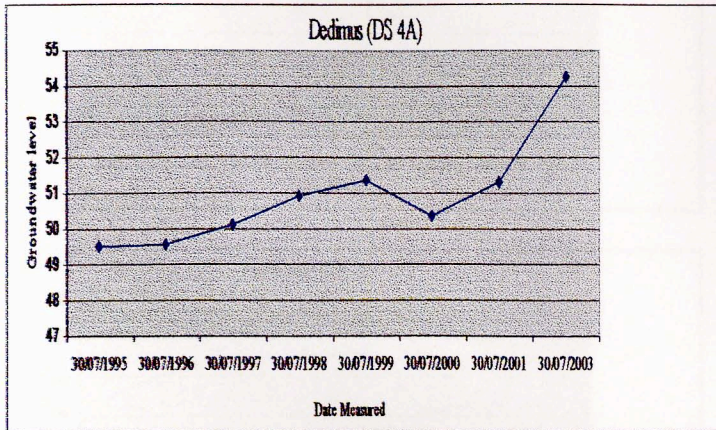


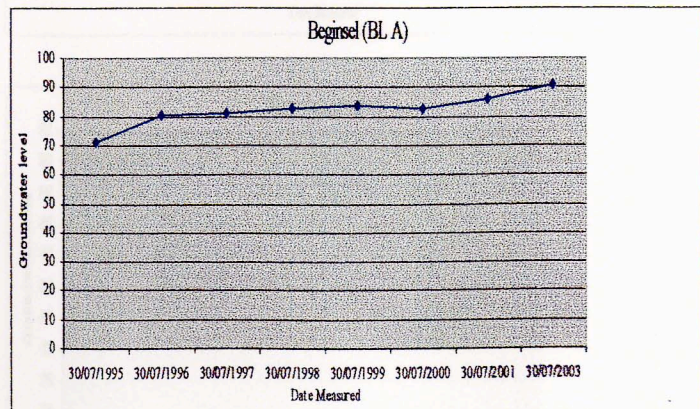
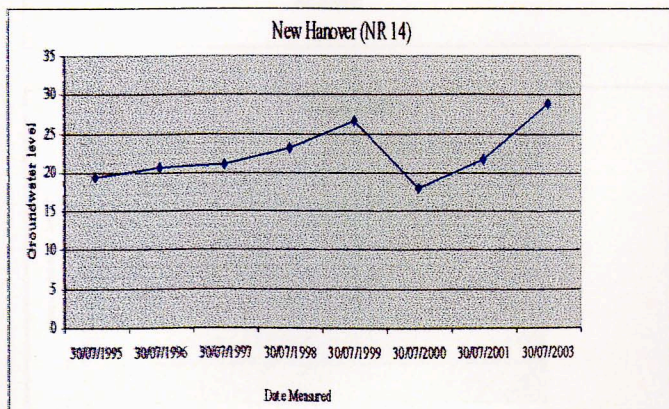
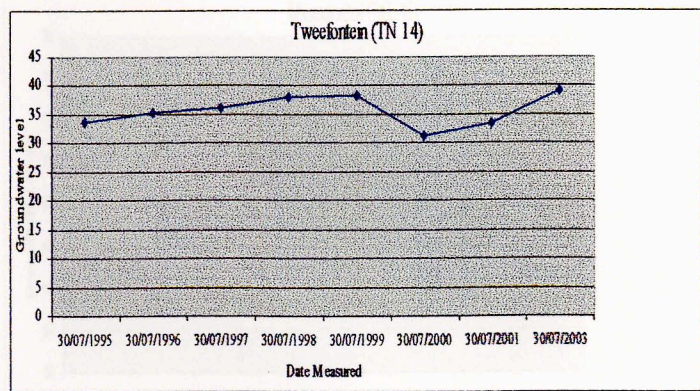
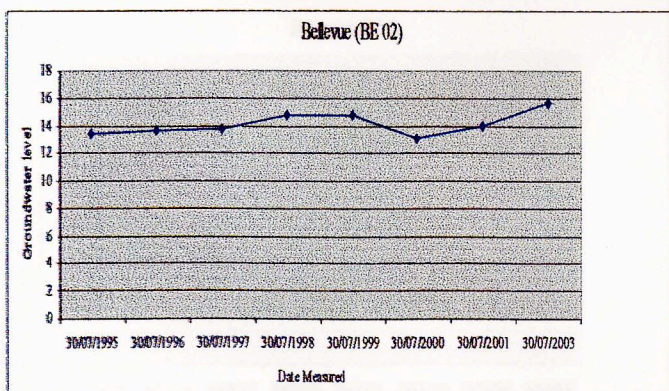
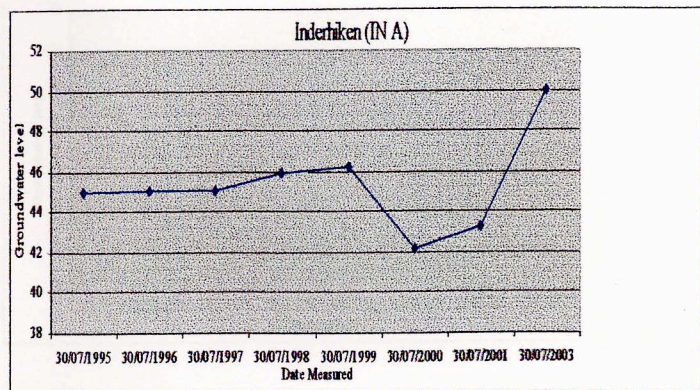
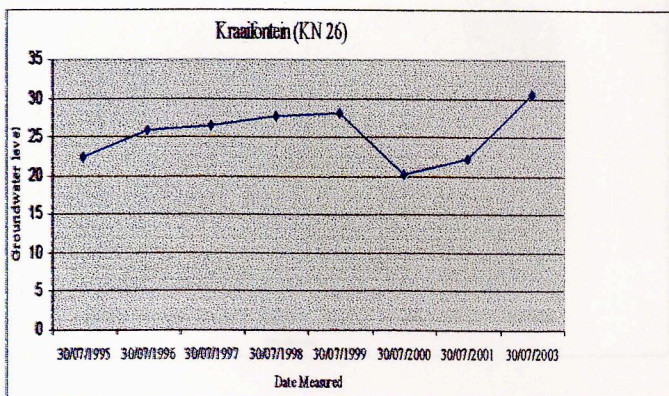
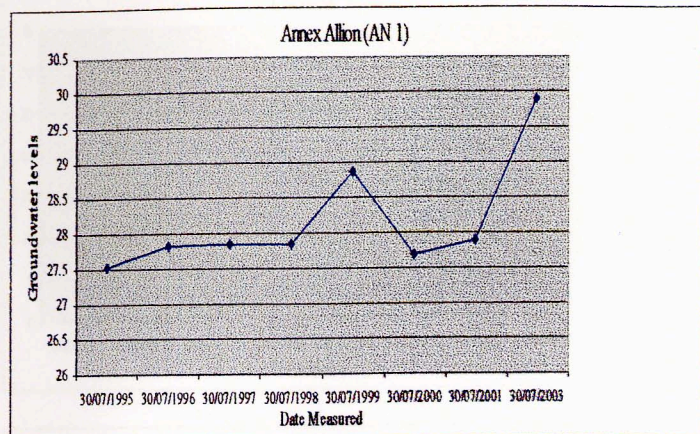
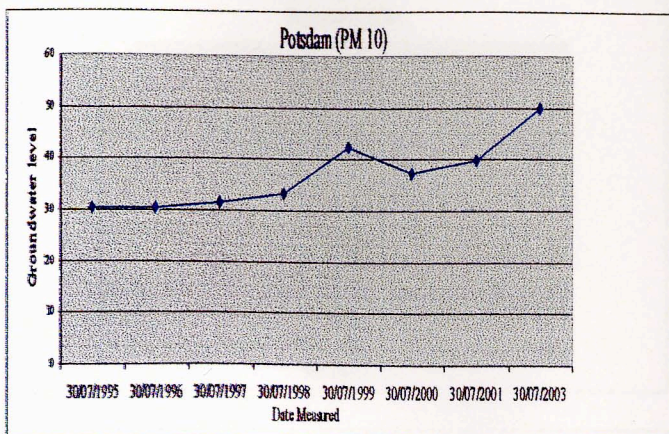




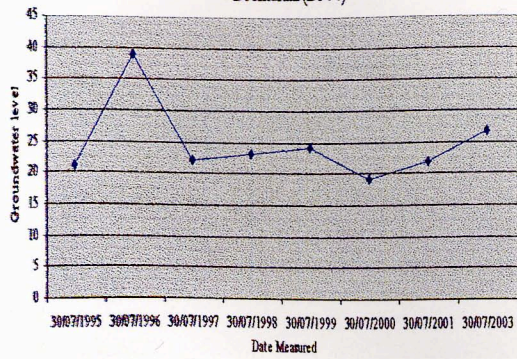
APPENDIX G

TIME SERIES PLOTS OF BOREHOLE WATER LEVELS

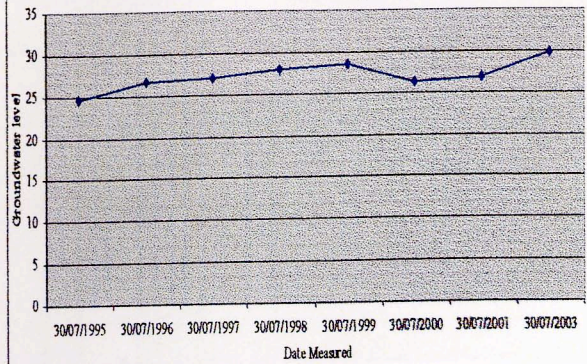




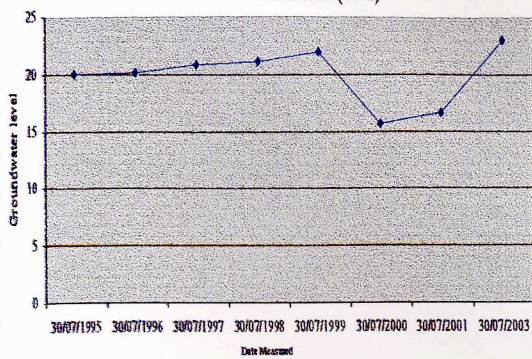
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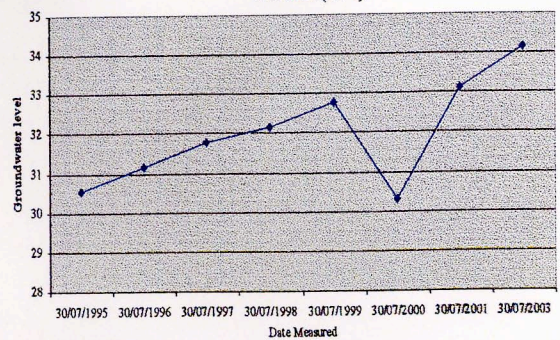
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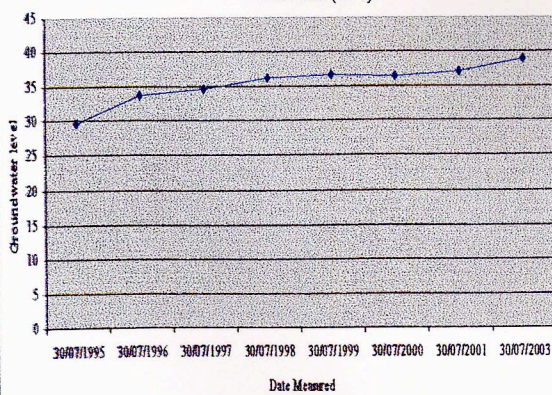
Gelukfontein (GN 2)



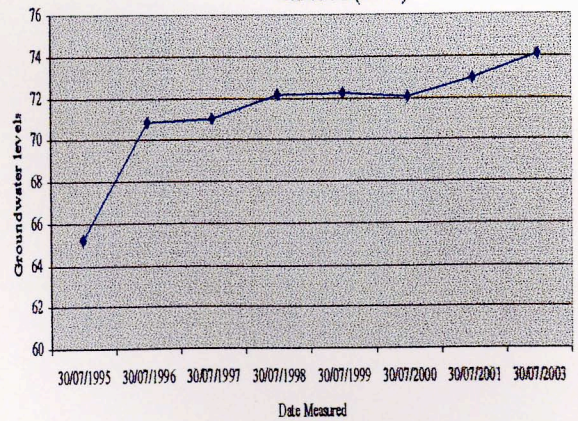
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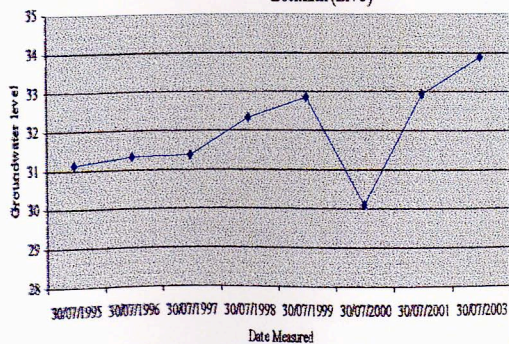
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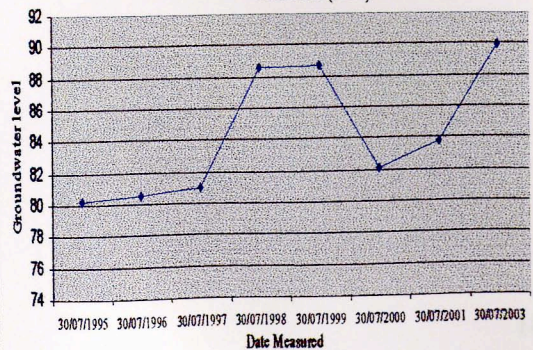
Meanderthal (ML 43)



Boemzien (BN 3)

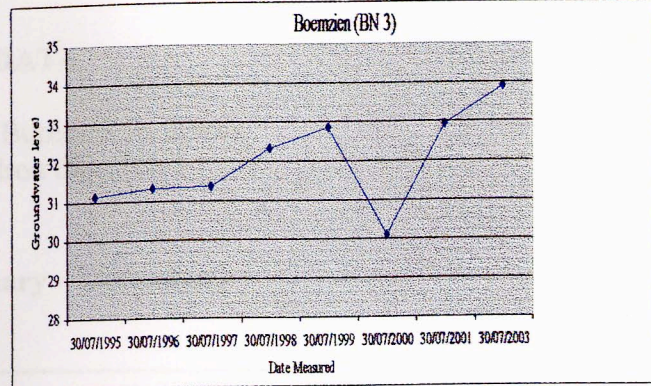
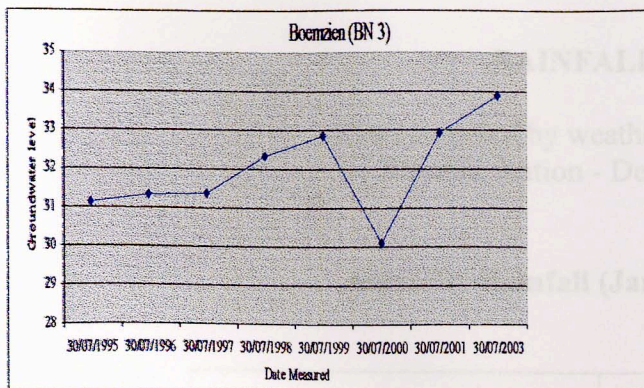


Klein Collie (KE A)



APPENDIX B

DENDRUS RAINFALL DATA FOR THE 1995-2001 PERIOD



Year	Rainfall (mm)
1995	312.5
1996	364.8
1997	377.8
1998	364.3
1999	322.8
2000	643.8
2001	281.6
	297
	244.5

APPENDIX H

DENDRON RAINFALL DATA FOR THE 1995- 2004 PERIOD

RAINFALL DATA

(Data supplied by weather Bureau S.A, 2004)
Rainfall Station - Dendron 0721562 1

Annually Rainfall (January – December)

Year	Rainfall (mm)
1995	312.5
1996	564.8
1997	377.8
1998	364.3
1999	323.8
2000	643.8
2001	281.6
2002	297
2003	244.5