THE DEVELOPMENT POTENTIAL OF KWAZULU-NATAL AQUIFERS FOR RURAL WATER SUPPLY

THESIS

Submitted in fulfilment of the requirements for the

Degree of

MASTER OF SCIENCE

of Rhodes University

by

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January 1997

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Abstract

The supply of water to 'disadvantaged' areas of KwaZulu-Natal has in the past received low priority. Local government is now faced with supplying water to large, sometimes dispersed, rural populations. Groundwater has been utilised informally as a water supply for some years, but the impetus provided by the Department of Water Affairs and Forestry's White Paper has compelled those responsible for water supply to seriously consider groundwater as a sustainable option.

The development potential or success of groundwater in its role as a reliable water supply is dependent on acceptance of the resource by the communities, appropriate level of service, yield sustainability and safe quality. Apart from the social aspects, the yield and groundwater quality characteristics of the aquifers under consideration must be used to determine the best hydrogeological features to target during exploration. A total of 993 borehole records, from a recent government drought relief programme, were used to compare the yield, water quality and best geophysical exploration and drilling techniques of the main hydrolithologies in rural KwaZulu-Natal.

The results of comparative analysis shows that the competent rocks of the Natal Group and Natal Metamorphic Province and the karstic Uloa Formation of the Maputaland Group have the best overall potential for water supply. The unconsolidated sediments of the Maputaland Group also have good potential, but have some salinity problems. The Karoo Supergroup sediments and volcanics have moderate potential, with the argillaceous rocks having the worst potential of the Karoo rocks. The contacts between the Ecca Group shales and sandstone have the best potential of the Karoo Supergroup sedimentary hydrolithologies. Fractures clearly enhance the groundwater potential of most hydrolithologies, with fractured Dwyka Group tillites rated as having one of the best development potentials of all the hydrogeological targets in KwaZulu-Natal, despite the hydrolithology's poor water-bearing characteristics.

Dolerite contacts with sedimentary rocks are commonly targeted features in groundwater development. However, the results from this research showed that, apart from the Natal Group's contact with dolerite, these targets have poor development potential. In general, contacts between different hydrolithologies

Health related quality was found to be adversely affected in argillaceous hydrolithologies, such as the majority of Karoo rocks which had high levels of sodium and chloride and Natal Metamorphic Province schists which had elevated sodium, chloride and fluoride. Crystalline and arenaceous hydrolithologies generally exhibited good quality groundwater.

A comparison between the different geophysical methods for each target feature indicates that there are appropriate methods to use to detect anomalies related to water-bearing features. The large number of dry boreholes drilled in locations with recorded geophysical anomalies can be either a function of the water-bearing characteristics of the formation, human error or background noise. The cost of using the different geophysical methods vary considerably. The

order of increasing cost is magnetics, VLF, EM-34, electrical resistivity profiling followed by vertical electrical sounding.

Drilling has a large influence on the development potential of certain aquifers due to the high costs involved. Most of the secondary aquifers will require percussion drilling which is the cheapest method of drilling commonly used. Some very unstable formations within fractured or highly weathered rock may need ODEX drilling to enable drilling to advance. ODEX drilling in these conditions is very costly and can double the cost of drilling compared to air percussion. The unconsolidated sediments of the Maputaland Group can only be drilled by mud rotary or ODEX techniques. The relative costs of these two methods are very similar with ODEX being slightly cheaper. Because of the high expense of drilling in the sands it is recommended that alternative sources, possibly from shallow hand-dug wells, be considered as appropriate methods of accessing groundwater.

The aspects of groundwater yield and quality of aquifers, appropriate geophysical siting and drilling methods, together with social considerations will all contribute to the success of groundwater development in rural KwaZulu-Natal.

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ACKNOWLEDGEMENTS

I would firstly like to thank the Water Research Commission for giving me the opportunity to study for the past two years. I hope that this thesis lives up to the theme of "Water for the People". The Department of Water Affairs and Forestry and in particular, the Directorate: Geohydrology, Mr Braune and Mr Hansmann are to be thanked for allowing me to use the drought relief data and allowing me to study while still working full-time. Other people such as Dr Maud and Dr Botha must also be acknowledged for their expertise which they kindly shared with me.

My supervisors, Mr K. Sami and Prof. R. Jacobs, must be thanked for their guidance, experience, suggestions and encouragement throughout the two years, "thank goodness for e-mail!". I believe the choice of studying at Rhodes was a good one.

I must also thank my family and friends for their belief in me and for the interest they have displayed. Special thanks must go to Régine who has had to put up with me for the past two years. Thanks for the love, encouragement and persistence.

I dedicate this thesis to the memory of my childhood friend, John Restom, whom I wish I could have gone surfing with.

1. INTRODUCTION

1.1. Rural water supply

Water is one of the most vital elements required for human survival. For centuries people in rural and urban areas have tried to ensure that they have enough water to sustain their well being. Traditional sources of water are rivers, ephemeral and perennial springs, hand-dug wells and in more recent times boreholes. The President of South Africa, Nelson Mandela, recalls in his autobiography how "water used for farming, cooking and washing had to be fetched in buckets from streams and springs" when he was growing up in the Transkei (Mandela, 1995).

The aims of rural water supply are to improve access to and reliability of water, improve available water quality and quantity, and increase access to sanitation. These aims should ultimately lead to social, health and economic benefits, and therefore ensure improved quality of life. The supply of safe water is an essential basic human right. Once water has been supplied, people can then aspire to higher levels of service as their income levels increase.

The White Paper on Water Supply and Sanitation Policy (Department of Water Affairs and Forestry, 1994) has clearly set out the objectives of the Department of Water Affairs and Forestry (DWAF) with regards to water supply. Basic water supply is defined in the White Paper as a minimum of 25 litres of water per person per day, at a maximum distance of 200 metres, with a regular, daily flow rate of not less than 0.17 l/s and of a quality in accordance with minimum standards with respect to health related chemical and microbiological contaminants. To achieve water security, the White Paper states that the water supply should not fail more than once in fifty years due to drought and a maximum of one week's interruption in supply per year for the purpose of operation and maintenance is allowed.

It has been recognised that the traditional technical and engineering approach to rural water supply will not succeed (Umgeni Water, 1994). The DWAF's White Paper (1994) has set as one of its policy principles that development should be demand driven and community based. This implies that the community must take part in the planning, implementation and maintenance processes and take on specific responsibilities. In the past, the transfer of resources and commodities to recipients, where the community was passive in its acceptance and gratitude, was considered efficient water supply (Rampine, 1995). The new approach, adopted presently, is that the community is enabled independently to take action, by way of democratic processes involving decision making, planning and implementation of development projects.

Workers active in rural water supply have identified various steps, encompassing a wide range of fields, which are essential in planning a rural water supply scheme (Murray *et al.*, 1995). Firstly, a water committee or similar structure needs to be established. Following on from this, the community requirements, in terms of level of service and usage, must form the basis of the scheme. The scheme would then be designed to meet present and future water demands, based on demographics. Possible sources of water, taking into account existing water sources and regional water supply plans, should be identified. The infrastructural technology required would then be examined to ensure that the appropriate system is designed to result in success of the scheme. Following another White Paper principle that the user pays (DWAF, 1994), the scheme should be assessed in terms of the community's willingness and ability to pay for its operation and maintenance. The proposed scheme should then be put before the community for their final approval before funding is obtained and implementation commences.

The above processes all require a variety of skills, other than engineering science. This demonstrates the multi-faceted approach needed within the scope of rural water supply. Above all, it must be realised that first world standards are not necessarily going to succeed in third world situations. Nkulu (1985, p485) states that:

> "Traditionalism is still very strong. As a result, people in these countries (referring to Africa and less developed countries) still harbour values, norms and attitudes that are not consistent with rational behaviour in a modern economic sense. The question of human values and attitudes which is determined by culture and religion .... is a very serious matter that no analyst can afford to ignore."

The professionals working in rural water supply must understand that the concept of community participation is not a new one in rural communities, as all decisions, which are based on and influenced by beliefs in gods and spirits, laws, rules and customs have always been taken communally with the Chief and his councillors acting as final arbitrators (Rampine, 1995). Thus, it is the knowledge and understanding of these issues which can often be of greater importance than the actual technical aspects of rural water supply.

1.2. Rural areas of KwaZulu-Natal

For the purposes of this thesis it is important to define the term 'rural' of which there are two main views on its definition. The first, and most common, definition is those areas which are outside the juristriction of a local authority. The second definition delineates areas of agricultural activities as 'rural' and is therefore less likely to apply to many areas of KwaZulu-Natal. Various documents have been examined to determine the general viewpoint of the term 'rural', in South Africa.

A discussion document of the Ministry in the Office of the President (1995) acknowledges that there is no legal definition or formally accepted definition of 'rural' in use. A suggested interim definition is given as:

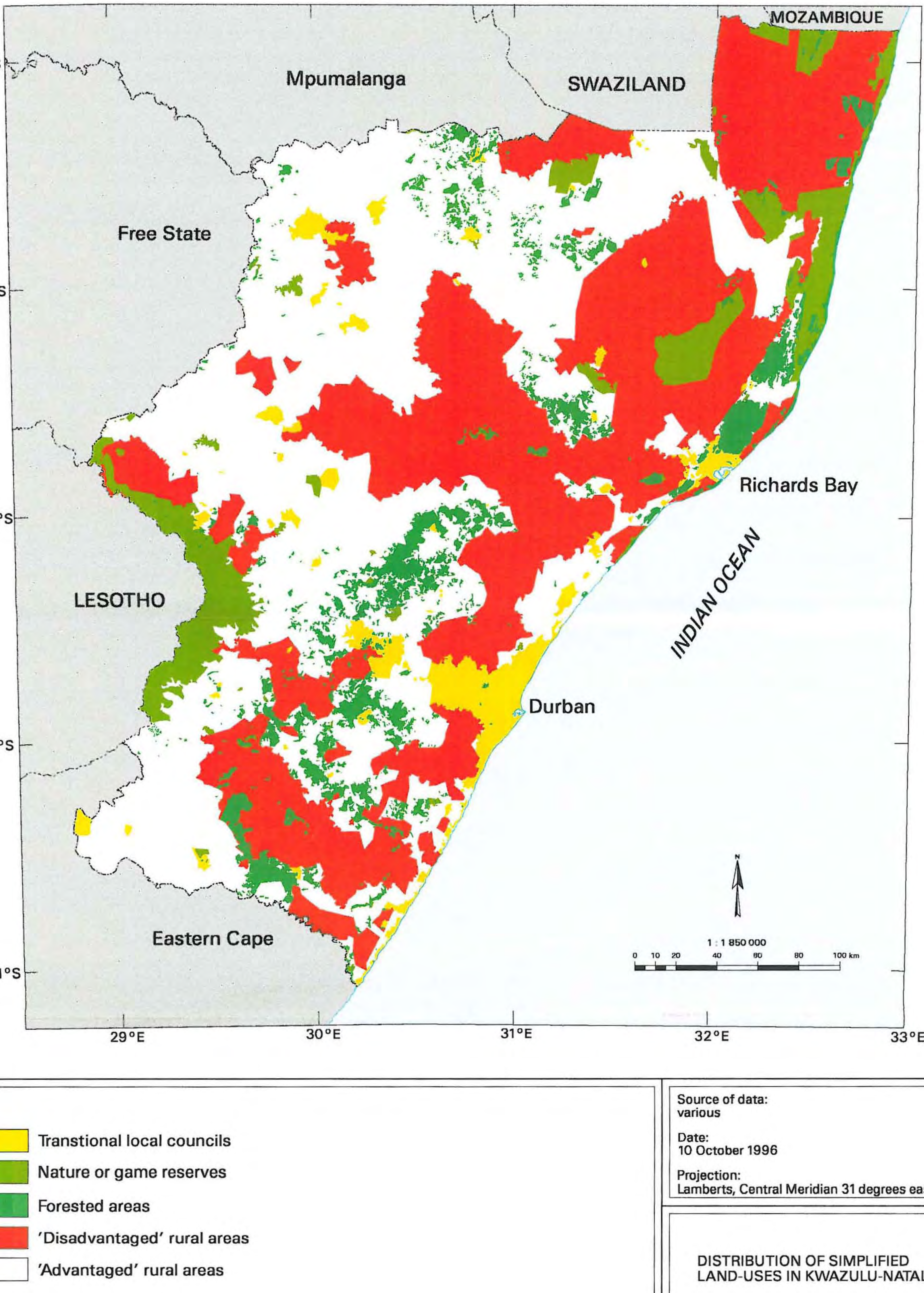
"those areas that have the lowest level of services, and the greatest average distance to the nearest service points. They include large scale farming areas, much - but not all - of the ex-bantustan areas, the small municipalities with little potential to raise taxes sufficient to meet the costs of services. Peri-urban squatter camps, being tied to the economies of contiguous urban areas, do not count as rural, except in the context of sometimes being part of rural municipalities."

A report written for the KwaZulu-Natal Department of Economic Affairs and Tourism and the Development Bank of Southern Africa giving an overview of urbanisation, and rural trends and processes within KwaZulu-Natal, puts forward a different view of 'rural' areas (Seneque, Smit & Maughan-Brown, 1995). Here the emphasis is not on defining 'rural' and treating it as a discrete category but rather treating rural and urban as non-separate and interdependent entities. One of their main arguments for not defining rural and urban is due to the rapidly urbanising population with informal settlements that are functionally linked to formal towns and cities. The traditional use of 'rural', as being areas which are mostly engaged in agricultural activities does also not hold for KwaZulu-Natal, as in most supposedly rural areas, agriculture contributes very little to household income (Seneque, Smit & Maughan-Brown, 1995). Seneque, Smit & Maughan-Brown thus suggest that rural and urban be viewed as the extremes of a continuum.

For the purposes of this thesis, 'rural' will be defined as areas which have undeveloped infrastructure and services, i.e. outside of local authority boundaries. 'Rural' can then be further divided into 'disadvantaged' rural and 'advantaged' rural. 'Disadvantaged' rural are those traditionally 'black' areas which constituted mostly the former KwaZulu districts and Trust land within former Natal. 'Advantaged' rural are the areas owned by white farmers, who in the past have benefited from government subsidies and usually have some type of established infrastructure. This thesis will focus on the 'disadvantaged' rural areas which are in serious need of upliftment in order to bridge the standard of living gap in the province.

As explained before, it has been difficult to arrive at a definition of 'rural' for the purpose of rural water supply. Many sources of information and data have been examined to enable the best spatial description of rural areas in KwaZulu-Natal to be depicted in this thesis. During 1995, Transitional Local Councils had been established within the province prior to Local Community Elections. These areas are not regarded as 'rural' due to the fact that they are serviced and are the responsibility of the Transitional Local Councils. Once these relatively densely populated urban areas, making up 4% of KwaZulu-Natal, have been excluded, the rest of the province can loosely be termed rural. Another type of area which can also be excluded from the topic of this thesis, is that of nature or game reserves. Some 11% of KwaZulu-Natal is made up of these proclaimed reserves, which for the most part comprise Natal Parks Board and KwaZulu reserves. In these reserves, water supply to a majority tourist population, is the responsibility of the owner or curator of the park.

The Survey Services of the KwaZulu-Natal Provincial Administration, have for the past few years been surveying the tribal areas of the province. The maps which they produced have been used for the planning of the 1996 Local Community Elections in KwaZulu-Natal. The tribal areas coincide roughly with the previous KwaZulu districts, with the inclusion of some additional peripheral areas. The coverage generated from these data and the former Transkei enclave, taking up 39% of KwaZulu-Natal, have been used to depict 'disadvantaged' rural areas. The remaining areas can be classed as the 'advantaged' rural areas which fall outside the scope of this study. A summary of the simplified land usage is illustrated in Figure 1.



Source of data:
various

Date:
10 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF SIMPLIFIED LAND-USES IN KWAZULU-NATAL

Figure 1

1.3. Status of rural water supply in KwaZulu-Natal

The supply of domestic water to rural communities in KwaZulu-Natal has in the past received low priority, as development of water sources has concentrated more on supporting the progress of the country's wealthy sector than with upgrading the rural areas. Only in the past six years has there been interest in rural development (pers. comm. The Umvula Trust, 1995).

KwaZulu-Natal comprises the scattered former homelands of KwaZulu and the former province of Natal. Former KwaZulu consisted of 26 KwaZulu districts, whose upkeep and service provision was the responsibility of the KwaZulu government through its various departments. The role of fulfilling water supply was entrusted to both the KwaZulu Department of Works and the Department of Agriculture and Forestry. Up until 1993, over 2550 boreholes had been drilled by these two departments throughout KwaZulu (Groundwater Consulting Services, 1993). Other contributors have been the Joint Services Boards (JSB), Umgeni Water and various non-governmental organisations (NGO's) such as the KwaZulu Water Development Fund, Valley Trust and World Vision Funding (Wiseman and Eberhard, 1988). Donor funding has often been supplied by the Interdependent Development Trust, Umvula Trust, some international funders and loan financing through KwaZulu Finance Corporation and the Development Bank of Southern Africa.

Government drought relief, or crisis intervention, programmes in the province have mainly concentrated on drilling boreholes equipped with handpumps to provide emergency water supplies to rural communities. The DWAF's definition of drought relief, or crisis intervention, is the assistance provided in terms of water provision for domestic consumption to communities where their normal sources have become depleted due to drought (pers. comm. Quilling, 1996). This action also includes the maintenance, upgrading and repair of existing sources. It is acknowledged that the process of crisis intervention, due to its emergency nature, is not a necessarily sustainable action, however, it is deemed necessary in order to prevent loss of human life. Table 1 summarises the activities of borehole drilling in KwaZulu-Natal. Some of the information from the table is not available; this is a reflection of the various organisations' lack of knowledge or control over borehole drilling programmes undertaken.

What Table 1 does show is that there has been some reliance on groundwater in the past and a definite trend towards developing it on a more regular basis.

Table 1. Summary of major borehole drilling activities in rural areas of KwaZulu-Natal.

ORGANISATION	PERIOD	TYPE OF PROJECT	COST R 000's	NUMBER OF PEOPLE SERVED	NUMBER OF BOREHOLES
Port Natal/Ebhodwe JSB	1993 - 1995	schools and communities	1500	555760	not available
Natal Midlands JSB	1991 - 1995	drought relief in KwaZulu districts (includes borehole, springs and infrastructure) schools and communities	249 3064 1500	not available	not available
Zululand JSB			not available	not available	633
Thukela JSB	1994 -1995	drought relief and communities	not available	not available	156
Southern Natal JSB	have drilled in conjunction with KwaZulu Department of Agriculture				
KwaZulu Department of Works	1993 - 1995	schools, clinics and police stations	drilling was undertaken by KwaZulu Department of Agriculture and Forestry		
KwaZulu Department of Agriculture and Forestry	? - 1995	for agricultural purposes and communities	not available	not available	5204
Department of Water Affairs & Forestry	1993 - 1996	drought relief	2500	not available	1422
Umgeni Water	1995	communities	not available	171500	196
Sugar Association of South Africa [1]	1981 - 1984	drought relief	not available	no data	425

1.4. Use of groundwater as a resource

Groundwater is just one of many potential sources of water available to rural communities (Alcock, 1989). However, the use of groundwater is highlighted by its generally available nature, ability to yield even in drought situations and its relatively good quality. Other benefits from using groundwater are that evaporation losses are minimised and that the development of groundwater is not subjected to high capital expenditure as it can be phased in as required (Hodgson, 1995). Groundwater sources are any sources of water that emanate from the subsurface environment and therefore also include springs.

As is well known, surface water suffers from high losses due to evaporation, sedimentation of storage reservoirs and vulnerability to pollution. In many KwaZulu-Natal river catchments, the water quality is generally good in the upper catchments but becomes progressively poorer lower down in the catchment (Umgeni Water, 1994). Pollution of rivers is mostly related to population density, with *E. Coli* often used as an indicator of human pollution.

Groundwater, like other water sources, does have its limitations depending on topography, water quality and availability. As a result of communities mainly living on hill tops in KwaZulu-Natal and aquifers often occurring in valleys, a number of problems are frequently encountered (Plate 1). The first problem is getting access for the drilling rig, and secondly, in transporting water out of the valleys to the point of demand. Another limitation is that some rock types and unconsolidated sediments in KwaZulu-Natal have yielded poor, to undrinkable, quality water. This poor quality is not because of pollution but rather from inherent chemical properties of the host rock or sediments. As is the case in other parts of the world, availability of groundwater will always be a problem in some areas of KwaZulu-Natal where suitable aquifers are not present. Furthermore, groundwater, of the required quantity, cannot always be found at or near the point of demand. This factor is not a major technical drawback, and can be overcome by reticulation from a more suitable aquifer, as is mostly the case in surface water development.

Often groundwater needs to be utilised in conjunction with surface water sources, such as dams, rivers and rainwater harvesting. This option usually optimises the cost and effectiveness of both surface and groundwater. The fact that groundwater comparatively has been found to cost half that of surface water, makes it an attractive option overall (Johnstone, 1994). In general, all the above factors promote the potential use of groundwater by rural communities, where it will be more economical than surface water schemes provided that a suitable aquifer is within reach of the community.

1.5. Past problems

Existing records show that there has been considerable borehole drilling activity over the past few years. However, up until the KwaZulu-Natal Groundwater Mapping Project (Orpen, *et al.*,

1995) there had been very little hydrogeological interpretation carried out in the province. This project initiated by the DWAF had the objectives of populating the National Groundwater Data Base (NGDB) with groundwater data, increasing our understanding of KwaZulu-Natal's hydrogeology and ultimately contributing to the production of two 1 : 500 000 hydrogeological map sheets (Durban and Vryheid), which form part of a national series (DWAF, 1992).

Plate 1. Typical rural landscape in south central KwaZulu-Natal showing scattered homes mostly on hill tops and slopes.

Due to the previous lack of hydrogeological knowledge, there has been no real understanding of the potential use of groundwater in a regional context. Obvious problems and limitations of groundwater use, have historically been related to availability, reliability and quality. These types of problems should be largely resolved by actions such as the production of the hydrogeological maps, awareness regarding the transfer of hydrogeological information to the NGDB and the involvement of hydrogeologists in groundwater development.

Other problems contributing to the sometimes disappointing groundwater yields have been due to a lack of expertise in the form of professional groundwater practitioners in the province. This has often led to inappropriate investigation, interpretation and implementation, each of which can result in failure of the potential groundwater supply scheme. An example of this type of failure can be given as use of the incorrect geophysical method in a particular geological environment. This could be a result of the hydrogeologist lacking experience in the area or because his or her type of geophysical equipment is limited. These types of errors can lead to an unfavourable impression of the potential use of groundwater. Developers of groundwater have previously been disappointed by the low yield and poor quality of boreholes in certain areas. A lack of research and documentation of hydrogeological data on the properties of KwaZulu-Natal aquifers can be given for this poor understanding.

Apart from the technical problems encountered during source development, a large number of boreholes and springs have failed due to lack of maintenance and overuse through population growth or drought. More important, however, is the lack of ownership of the infrastructure which in turn leads to a lack of responsibility and sometimes abuse of the facility. As a worst case scenario, it is reported that approximately 40 boreholes in KwaZulu-Natal are in need of maintenance per week during periods of drought (pers. comm. Quilling, 1996).

A further problem, related to water quality deterioration, has been the lack of education in terms of groundwater use and protection in rural communities. Much pollution of groundwater could be curtailed or prevented if the communities understood some basic groundwater concepts and were able to recognise potentially negative impacts on their water source. Plate 2 and Plate 3 illustrate some of the typical problems associated with lack of groundwater pollution awareness.

1.6. Challenges

All the problems addressed in the previous section are challenges facing practitioners in rural water supply. These challenges can be divided into physical, technical and social. Physical challenges are the identification of geological formations and their target of best groundwater potential, with respect to quality and quantity. These sources would then need to be developed in a manner that satisfies the requirements of the White Paper (DWAF, 1994) and that is both sustainable and environmentally acceptable. Where groundwater is not feasible, alternative sources or effective treatment would need to be examined.

Technical challenges involve appropriate technology being utilised in rural areas for the best chance of success. This could be achieved by guidelines suggesting the best groundwater exploration and drilling methods to use in the various geological environments of KwaZulu-Natal. Monitoring of groundwater quality and water levels would also increase our knowledge of groundwater conditions over time.

The social challenge facing groundwater developers encompasses the empowerment of communities through training and capacity building, the establishment of water communities and reporting structures, to ensure self sufficiency.

Plate 2. Ponding of spilt groundwater around the bore head is a common problem in KwaZulu-Natal, increasing the probability of contaminated groundwater.

Plate 3. Undermining of the concrete block increases the risk of surface water contaminating the groundwater from which the borehole is drawing.

2. AIMS AND OBJECTIVES

The primary objective of this thesis is to evaluate the development potential of KwaZulu-Natal aquifers in 'disadvantaged' rural areas for water supply. The problems identified in the previous chapter, such as the lack of hydrogeological information and knowledge, inappropriate groundwater exploration techniques and the importance of social awareness, are the major points which need to be addressed.

In order to put the rural areas into perspective, an overall description of KwaZulu-Natal is given in Chapter 3. This chapter aims to provide a picture of the physical features of the province that affect the occurrence of and demand for groundwater. The descriptions made of each physical attribute, such as geology, soils or demography, are done so for the entire province and not just for rural areas. The reason for this is that the rural areas form an integral part of the province and therefore cannot be isolated.

A chapter on the principles of hydrogeology is given to provide background hydrogeological understanding into the concepts which follow in other chapters. Theory on the occurrence, movement and chemistry of groundwater are of particular importance in this thesis. Further theory, in the form of groundwater resource evaluation covers aspects such as exploration, groundwater development and evaluation. These are aspects which have great importance, since the success of groundwater schemes depends primarily on their results. Boreholes and wells are the sources examined in this chapter.

Apart from technical and physical aspects, social factors are addressed in order to highlight the importance of community acceptance and participation to achieve success in groundwater development. Unfortunately, this thesis does not devote many pages to the social aspect of rural water supply, but it does point out the need for involving social professionals who can communicate and relate to the communities where the technical professional cannot.

The source of data used in the analysis carried out in this thesis is described and discussed in Chapter 7. A database was created to house all the data captured. Chapter 8 explains the methodology applied in data analysis. The two methods of analysis used are graphical methods for comparative purposes and the geographical information systems used for spatial analysis.

In order to fulfil the objective of this thesis, firstly, the physical nature of the aquifers to be dealt with needs to be addressed. This aspect is covered in the chapter dealing with the hydrogeology of KwaZulu-Natal aquifers. In an effort to gain new insight into their hydrogeology, the aquifers have been separated by means of the different target features occurring within each rock type. For example, in the Natal Group sandstone, analysis is carried out on individual target features, such as fractures and the contact with underlying granites, instead of analysing them as a whole. The distinction between the different target features has been made in order to illustrate their different yield and chemical characteristics. Previous hydrogeological characterisation has not taken such details into account and has been more generalised by lithology (DWAF, 1992). The analysis carried out in this thesis presents a comparison of the different aquifers and makes recommendations on their relative rating or potential as sources of groundwater for KwaZulu-Natal rural water supply.

Also within Chapter 9, comparative analyses into the different types of geophysical methods and their relative successes are made. The aim of this section is to address the past problems of inappropriate geophysical methods being used in certain lithologies. This type of analysis is probably one of the first attempts in comparing the successes of different geophysical methods and the recommendations made should be viewed with some circumspection. A better method of evaluating each method would be to carry out a number of traverses, using different geophysical methods, over the same target feature to identify optimal drilling sites from each method. Boreholes could then be drilled at each site and a comparison of the resultant yields made. Unfortunately, this type of study was not within the scope of this thesis, but instead use was made of similar target features traversed by the various geophysical methods to obtain the comparisons.

To finally be able to rate the development potential of each aquifer, the type of drilling required, which is dependent on the lithology, and thus the relative cost, is made. The relative cost of exploiting each aquifer type is determined primarily by the drilling cost, due to the fact that drilling is the greatest expense in groundwater development. It is the yield and quality of water from aquifers, the use of appropriate and cost effective geophysical siting and drilling methods, together with the recognition for the need of active social inputs, which will contribute to the success of groundwater development in KwaZulu-Natal.

3. STUDY AREA - KWAZULU-NATAL

A description of physical aspects which have an effect on the likely distribution, occurrence and use of groundwater as a water source in KwaZulu-Natal, is given in this chapter in order to place the topic of groundwater development in context for the remainder of this thesis. Rural areas are not specifically described, but they are delineated on the theme maps portraying the various aspects of KwaZulu-Natal. The whole province is covered in this chapter because most of the features form part of the overall character of KwaZulu-Natal and therefore cannot be described in isolation.

3.1. Geology

The rural areas in KwaZulu-Natal contain rocks representing the entire stratigraphic succession of the province. It is for this reason that the stratigraphy of KwaZulu-Natal, as a whole, is described in order from the oldest to the youngest rocks (Figure 2). An emphasis on the lithology and formational environment of each rock type is made as these are, together with geological structures, the most relevant characteristics in terms of hydrogeology.

3.1.1. Barberton Sequence

The oldest rocks in KwaZulu-Natal, forming part of the Kaapvaal craton, are of Swazian age and are represented, only in the north of the province, by the Nondweni Group and Empangeni Metamorphic Suite of the Barberton Sequence and its intrusive granites (Figure 3). The lithology of the Barberton Sequence is described below in Table 2 and Table 3.

The Empangeni Metamorphic Suite and Nondweni Group appear to be of similar age. They have both been intruded by pre-Pongola granitic gneiss, but have differences in lithology and degree of metamorphism (Linström, 1987a). Although the relationship between the Empangeni Metamorphic Suite and Nondweni Group is unclear, it is thought that within the Empangeni Metamorphic Suite, the Ngweni Formation is the retrograde equivalent of the Lubana Formation (Charlesworth, 1981). The lithology of the intrusive granitic gneisses and granite forming part of the basement complex is described in Table 4.

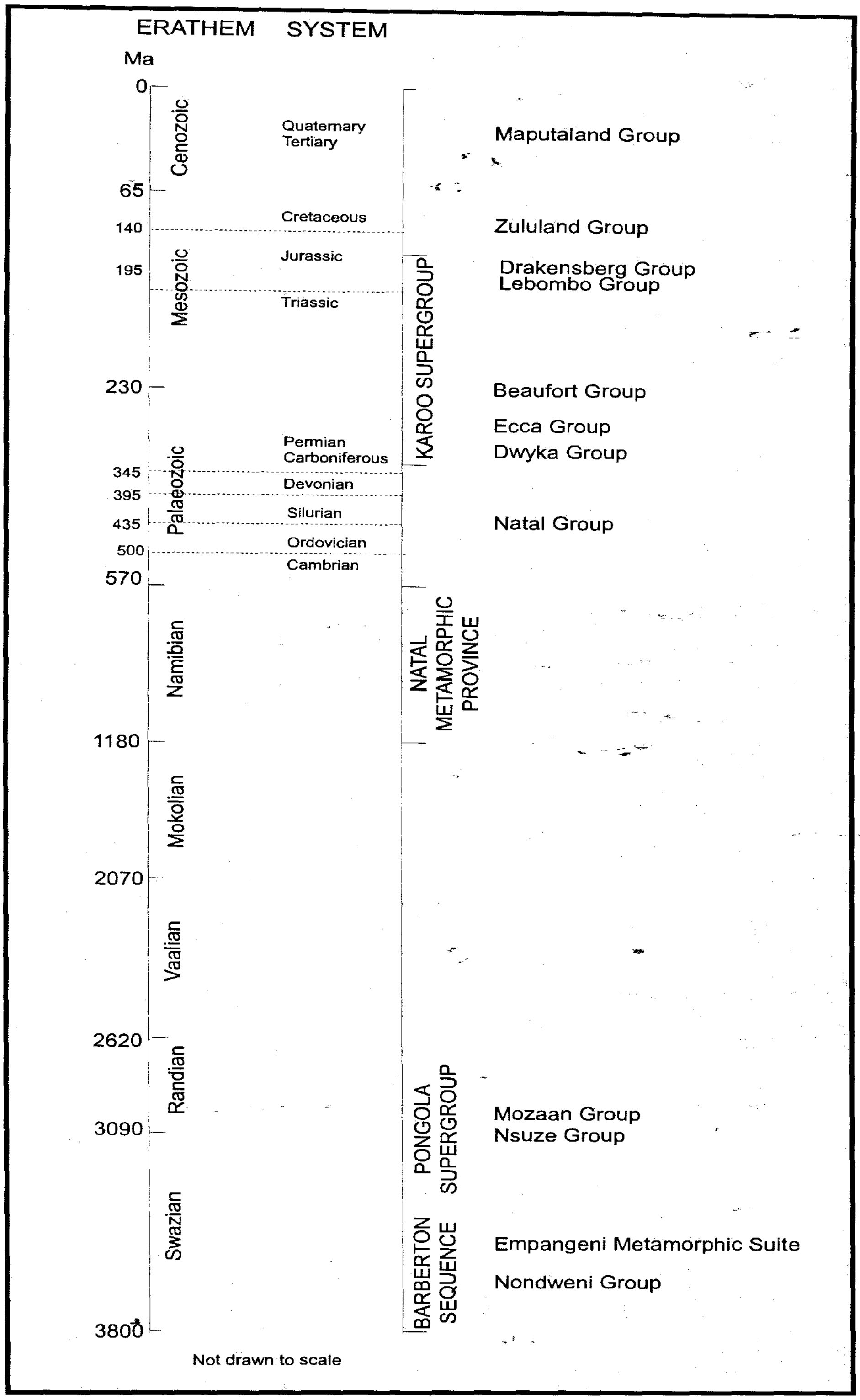


Figure 2. Simplified KwaZulu-Natal stratigraphy.

Table 2. Nondweni Group lithology - in order of increasing age (Linström, 1987a).

FORMATION	LITHOLOGY	PROCESSES
Ultramafic intrusions	serpentinite	intrusive
Mhlatuze	interbedded schistose basic lava and sediments	shearing, recrystallisation and some basic lava has been altered to greenschist due to granitic gneiss intrusions
Nkandla	quartzite, schist, phyllite, banded chert, conglomerate	low-grade regional and dynamic metamorphism

Table 3. Empangeni Metamorphic Suite lithology - in order of increasing age (Linström, 1987a).

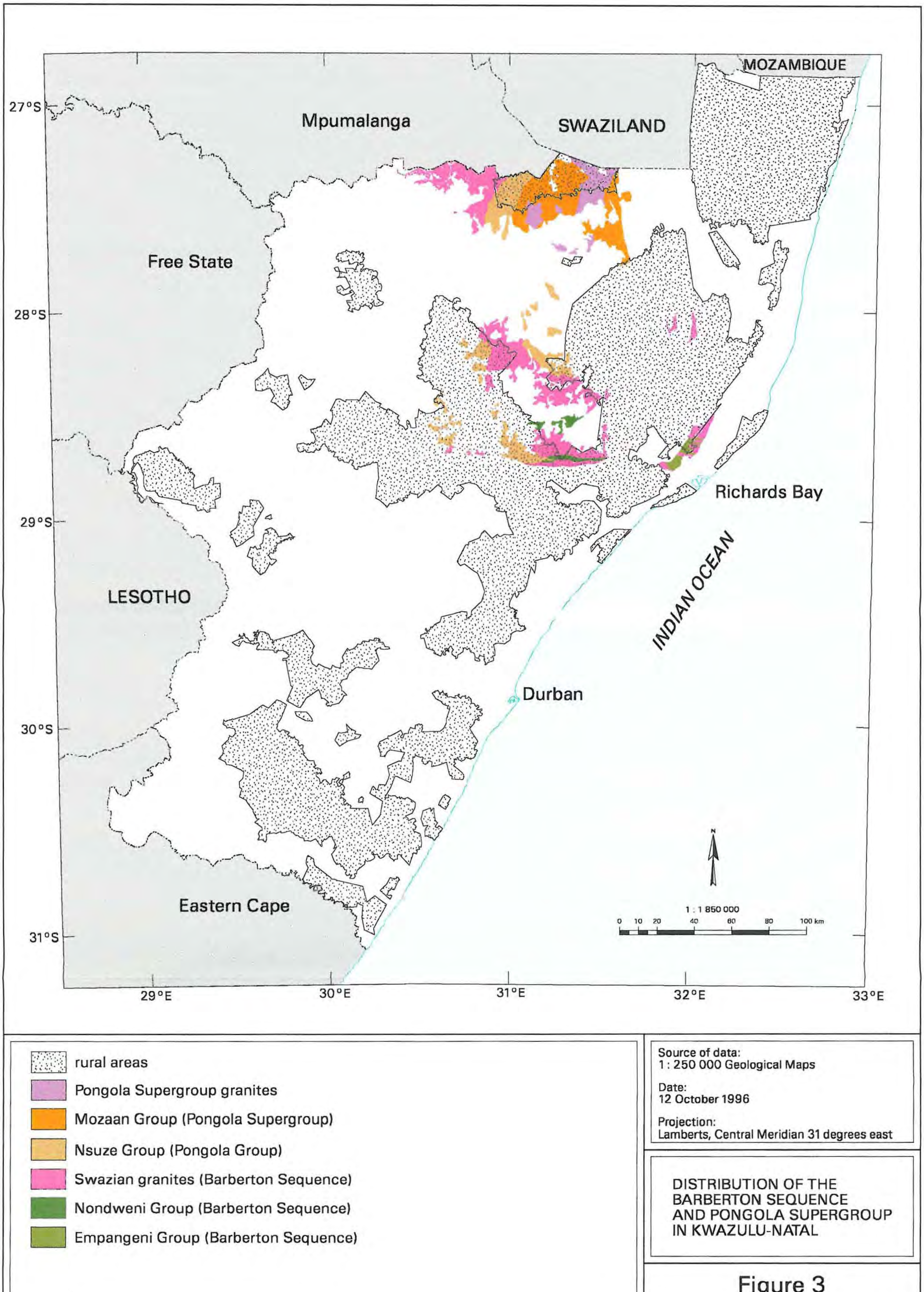
FORMATION	LITHOLOGY	PROCESSES
Ngweni	amphibolitic rocks	retrograde metamorphism, from very high-grade to high-grade
Lubana	melanocratic granoblastite interbanded with gneiss, orthopyroxenite and granolite	two phases of deformation, high grade metamorphism

Table 4. Intrusive granitic gneisses and granite (Linström, 1987a).

FORMATION	LITHOLOGY	PROCESSES
granitic gneiss	well-foliated or banded, fine- to medium-grained leucocratic rock	intrusive
granite	grey, coarse-grained, massive to slightly foliated granite	intrusive, retrograde metamorphism, from very high-grade to high-grade

3.1.2. Pongola Supergroup

The Pongola Supergroup is thought to have developed on a stable continental crust segment. These rocks show evidence of epicratonic volcanism and sedimentation during a period when greenstone-type rock sequences were dominant elsewhere (Gold, 1995).



Source of data:
1 : 250 000 Geological Maps

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF THE BARBERTON SEQUENCE AND PONGOLA SUPERGROUP IN KWAZULU-NATAL

Figure 3

The Pongola Supergroup rocks, found in northern KwaZulu-Natal (Figure 3), can be divided into the lower volcano-sedimentary Nsuze Group, with three sedimentary successions and two volcanic sequences (Table 5) and the upper, mostly clastic Mozaan Group (Table 6). The Pongola Supergroup lies unconformably above the basement granites below it. A period of tilting and erosion, after emplacement of the Nsuze Group and prior to the deposition of the Mozaan Group, has resulted in an unconformity between the two groups (Linström, 1987b).

Table 5. The Nsuze Group lithology - in order of increasing age (Gold, 1995).

FORMATION	LITHOLOGY
Ozwana	transition to Mozaan sedimentation, comprising tuffs, black sandstones, breccias and banded siltstones
Bivane	similar to Nhlebela Formation, includes dacites and rhyolites
Thembeni	quartzites, quartz-wackes, diamictites, shales and dolomites
Nhlebela	basalts, basaltic andesites, andesites
Mantonga	quartz-wackes, conglomerates, diamictites, shales and palaeoregolith

The Mozaan Group is almost entirely sedimentary, but does contain two volcanic sequences near the top of the succession as is shown in Table 6.

Table 6. The Mozaan Group lithology - in order of increasing age (Gold, 1995).

FORMATION	LITHOLOGY
Nkoneni	two arenaceous successions separated by a volcanic unit
Odwaleni	interbedded sandstone, mudstone, ferruginous mudstone, diamictite and basalt
Hlashana	sandstone and siltstone, upward coarsening
Thalu	sandstones, mudstones, ferruginous mudstone and banded iron-formation
Ntombe	ferruginous and non-ferruginous mudstones and siltstones
Sinqeni	two major sandstone units separated by iron-formation

Prior to the tectonic and metamorphic effects on the Nsuze Group, several episodes of intrusion by ultramafic dykes, diabase sills and dykes, porphyritic dykes and syenite occurred. The lithologies of these intrusives are described in Table 7.

Table 7. Post-Pongola intrusions and lithologies (Linström, 1987b).

FORMATION	LITHOLOGY	PROCESSES
Hlagothi Suite	peridotite, gabbro and diorite sills	differentiated, intrusive
syenite	dark green syenite	intrusive
diabase	greenish diabase dykes	low-grade metamorphism

3.1.3. Natal Metamorphic Province

The Namaqua-Natal Metamorphic Province forms part of the global high-grade tectonic Mesoproterozoic Orogeny, which in South Africa stretches from southern Namibia through Namaqualand and eastwards, under Phanerozoic cover to KwaZulu-Natal. Matthews (1972) was the first worker to recognise that the northern Natal Metamorphic Province rocks represented the margin of a continental plate that was deformed in an environment above a subduction zone, as the leading edge of the plate moved into the collision zone with the Kaapvaal craton. Subsequently, he identified four major east-west trending zones: a northern frontal zone, a migmatite and granite-gneiss zone, a granitic zone and a southern granulite zone based on distinct differences in lithology, structure and metamorphism (Hunter, 1981). The latest model for the Natal Metamorphic Province as derived by Thomas *et al.* (1994) submit that the Namaqua-Natal cycle, in KwaZulu-Natal, began with volcanic arcs on juvenile oceanic crust. Subsequent subduction and closure of the Tugela Ocean, north of present day Richard's Bay, led to accretion of the volcanic arcs onto the Kaapvaal Craton and obduction of the Tugela ophiolite.

Thomas *et al.* (1994) further state that the Natal Metamorphic Province can be delineated as comprising three discontinuity-bounded tectonostratigraphic terranes which acquired a structural fabric during the ~1100Ma Kilbaran tectonic event. From north to south, the terranes are known as the Tugela, Mzumbe and Margate Terranes (Table 8).

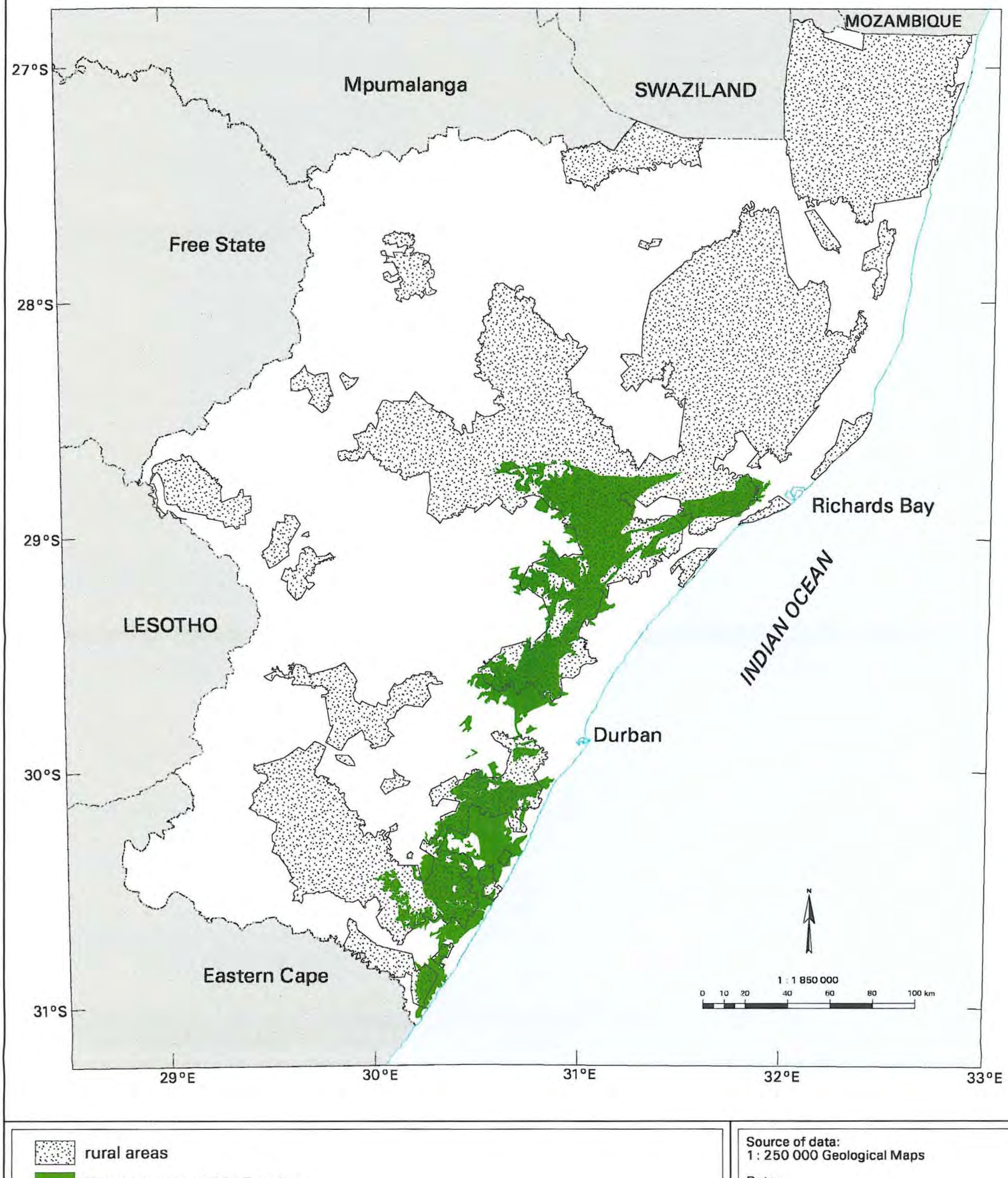
Northeast-directed thrusting and nappe emplacement during the closure of the Tugela Ocean, by the three accreting terranes, resulted in an inverse metamorphic stacking across the belt, with granulite grade rocks occurring in the southern Margate Terrane. The Mzumbe and Margate Terranes were then deformed by numerous SE- to SSE-trending sinistral transcurrent shear zones and mylonite belts (Thomas *et al.*, 1994).

Table 8. Lithology and origin of the Natal Metamorphic Province (Thomas, 1995).

TERRANE	LITHOLOGY	INTERPRETED AS
Tugela	early layered mafic metavolcanic rocks (volcanic arcs) intruded by plagiogranites, mafic-ultramafic complexes, serpentinite and alkaline to peralkaline granitoids	ophiolite complex which was obducted northwards onto the Kaapvaal Craton as four major flat-lying thrust nappes
Mzumbe and Margate	arc-related, felsic to mafic metavolcanic supracrustal gneisses with subordinate metasediments	growth of volcanic arc(s) associated with the subduction of the Tugela Ocean, partial melting of the supracrustal sequences

Figure 4 shows the distribution of the Natal Metamorphic Province. As can be appreciated, the detailed geology of the Natal Metamorphic Province is complex; however it generally comprises granite, granitic gneiss, gneiss, calc-silicate rocks, granulite, charnockite, amphibolite, serpentinite, marble and diorite. The landscape in the granite-gneiss lithology is characterised by domed exposures as depicted in Plate 4.

Plate 4. Typical landscape associated with Natal Metamorphic Province in southern KwaZulu-Natal.



rural areas

Natal Metamorphic Province

Source of data:
1 : 250 000 Geological Maps

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF THE NATAL METAMORPHIC PROVINCE IN KWAZULU-NATAL

Figure 4

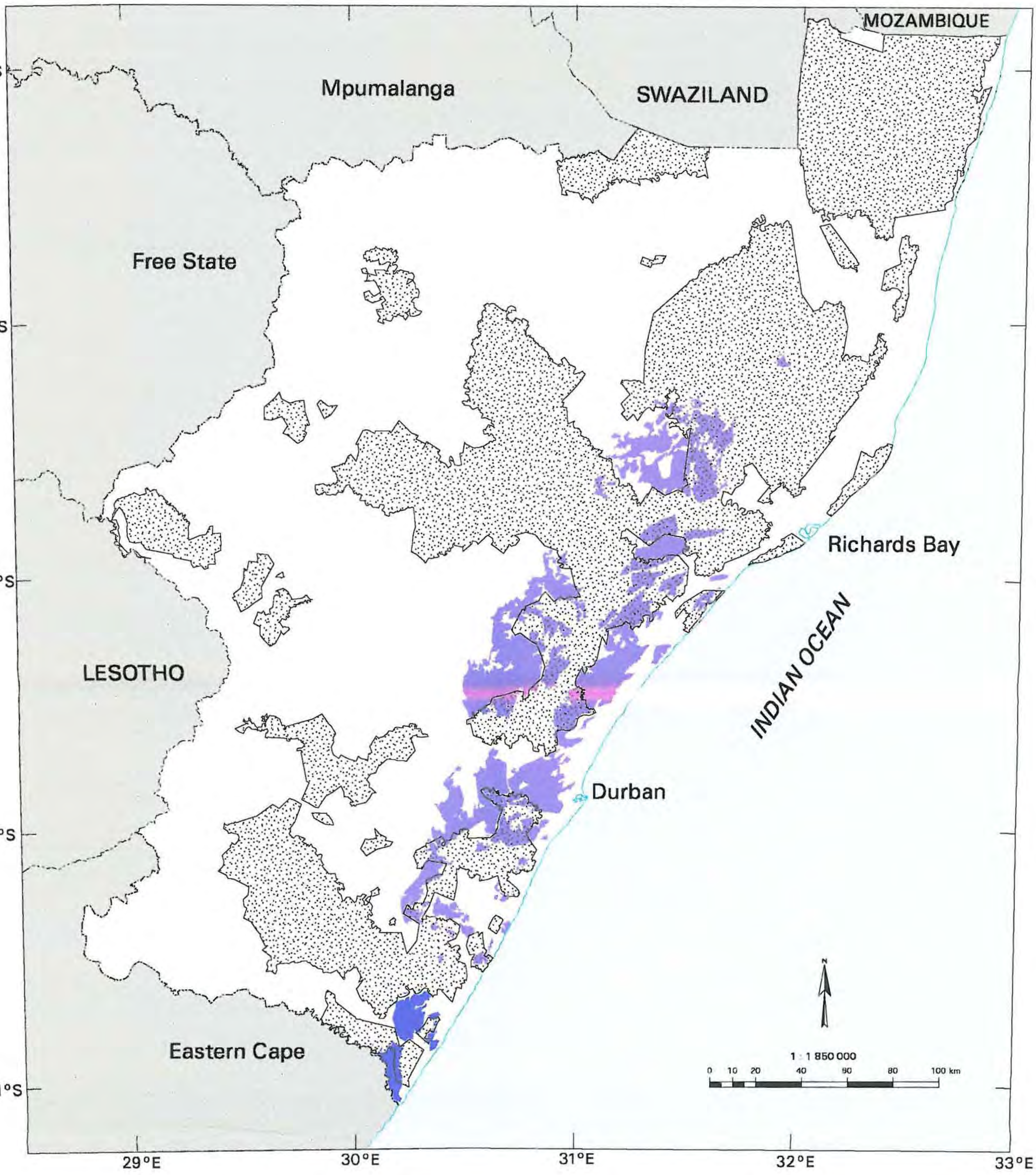
3.1.4. Natal Group and Msikaba Formation

Previously the Natal Group was thought to extend throughout KwaZulu-Natal and was regarded as the lateral equivalent of the Cape Supergroup. Recently, through K-Ar and $^{40}Ar/^{39}Ar$ isotopic data, it has been confirmed that the pale grey marine quartz fossiliferous arenites south of Hibberdene are of Devonian age, while the unfossiliferous fluviatile reddish sandstones covering the rest of the province are Ordovician in age (Thomas *et al.*, 1992). The southern grey rocks have been named the Msikaba Formation (Marshall, 1995) and are likely to be equivalents of the Witteberg Group. The reddish rocks will retain their Natal Group status.

The Natal Group unconformably overlies basement rocks, from which it derived its sediments. Uplift and erosion, followed by the formation of the foreland graben, associated with the Pan African orogenic event in Mozambique led to the deposition of the Natal Group into a foreland graben, the Natal trough, during continued subsidence (Marshall, 1995). The axial gradient of the trough was to the south-southwest. The conglomerates were deposited through fluvial activity and debris flow, whereas the arenaceous and argillaceous sediments were probably deposited by Platte and Bijou Creek type braided rivers (Marshall, 1995).

The Natal Group's distribution through KwaZulu-Natal is from Hlabisa in the north to just south of Hibberdene (Figure 5). This southern boundary coincides with the Dweshhula Basement High reported by Thomas *et al.* (1992) with quartz arenites outcropping to the south and red-beds to the north.

South of the Tugela thrust belt the Natal Group rests non-conformably on rocks of the Natal Metamorphic Province. To the north, the Archaean rocks of the Kaapvaal craton underlie the Natal Group. North of Durban, the Natal Group lies in two sub-parallel belts separated by outcrops of basement rocks. The western belt rocks lie horizontally whereas the eastern belt has a slight eastwards dip, related to the break up of Gondwana (Marshall, 1995).



rural areas
Natal Group
Msikaba Formation

Source of data:
1 : 250 000 Geological Maps

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF THE NATAL GROUP AND MSIKABA FORMATION IN KWAZULU-NATAL

Figure 5

The predominantly reddish-brown, arenaceous component of the Natal Group consists of coarse- to very coarse-grained sandstone with subordinate granule-conglomerate. The coarse-grained rocks are poorly-sorted and immature. The arenaceous rocks are sometimes interbedded with argillaceous and rudaceous units (Plate 5). The detailed stratigraphy of the Natal Group as proposed by Marshall (in prep.) is given in Table 9.

Plate 5. Outcrop of Natal Group sandstone in a road cutting with some darker argillaceous horizons.

Table 9. Stratigraphic subdivision of the Natal Group - in order of increasing age (Marshall, in prep.).

FORMATION	MEMBER	DOMINANT LITHOLOGY
Marianhill	Westville	matrix-supported conglomerate
	Newspaper	arkosic sandstone
	Tulini	small-pebble conglomerate
Durban	Dassenhoek	silicified quartz-arenite
	Situndu	coarse arkosic sandstone
	Kranskloof	silicified quartz-arenite
	Eshowe	arkosic sandstone and shale
	Ulundi	coarse clast-supported conglomerate

3.1.5. Karoo Supergroup

The sediments of the Karoo Supergroup were deposited into an intracratonic basin in the period from 280 to 180 Ma (Smith *et al.*, 1993). The variety of depositional environments was primarily influenced by the northward drift of southwestern Gondwana out of a polar climate and was accentuated by the meteoric drying effect of the surrounding land masses (Smith *et al.*, 1993).

The main Karoo basin was initiated as a result of uplift, compression and erosion of Cape Supergroup rocks. The axial site of the basin was thus determined by the results of the Cape orogeny (Cole, 1992). Before deposition into the gently subsiding foreland basin there was a period of uplift and erosion while southern Gondwana drifted over the south pole, resulting in an ice sheet over the highlands and floating ice on the lowland platform (Tankard *et al.*, 1982). This period was the commencement of Karoo sedimentation. The processes of sedimentation of each group and formation within the Karoo Supergroup are described under their respective sections.

Over 69% of KwaZulu-Natal's surface is covered by Karoo-aged lithologies, including dolerite. This fact stresses the importance of Karoo formations as potential aquifers. Table 10 furnishes a summary of the groups and formations associated with the Karoo Supergroup in KwaZulu-Natal and the distribution of the sedimentary rocks of the Karoo Supergroup is shown in Figure 6.

3.1.5.1. Dwyka Group (formerly Dwyka Formation)

The period of glaciation which followed as a result of the movement of southern Gondwana over the pole, deposited glacial diamictites, sandstones and shales of the Dwyka Group into the Karoo basin. Generally these sediments unconformably overlie Natal Group and basement rocks.

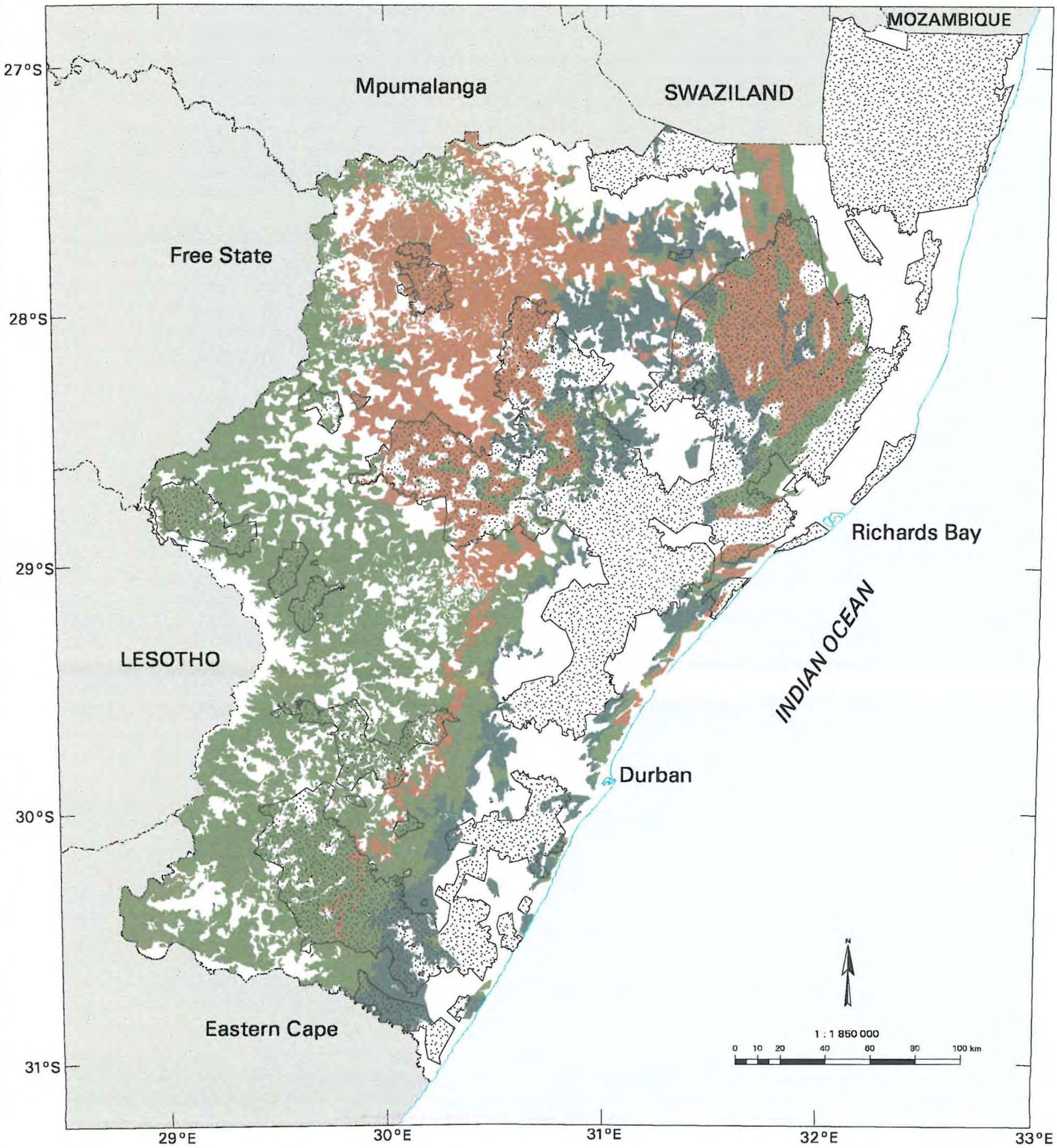
The main rock type of the Dwyka Group is a massive tillite or diamictite. It has a very fine-grained, blue-grey to greenish matrix containing angular to subrounded clasts. The clasts are poorly sorted and range in size from minute grains up to boulders 2 metres in diameter (Plate

6). The clasts comprise sandstone, granite, gneiss, schist, diabase, quartzite, andesitic lava and quartz porphyry. Minor rock types associated with the Dwyka Group include shale, sometimes varved, and sandstone, which occurs near the top of the succession. When weathered, the diamictite becomes a brownish buff colour and has a very high clay content. Fracture surfaces within the Dwyka Group are often iron stained due to oxidation in the presence of water.

Table 10. Karoo Supergroup lithologies in KwaZulu-Natal - in order of increasing age.

GROUP	FORMATION	LITHOLOGY
Drakensberg		basalt
Lebombo	*Jozini*	rhyodacite and rhyolite
	Letaba	basalt
	Clarens	sandstone
	Elliot	sandstone and mudstone
	Nyoka	mudstone interbedded with sandstone
	Ntabene	sandstone with subordinate mudstone
	Molteno	sandstone, mudstone and shale
Beaufort	*Tarkastad*	sandstone with subordinate mudstone
	Adelaide	mudstones alternating with sandstone
	Emakwezini	sandstone alternating with shale and mudstone
	Normandien	sandstone interbedded with shale
Ecca	*Volksrust*	shale and siltstone
	Vryheid	sandstone with subordinate shale
	Pietermaritzburg	shale
Dwyka		diamictite

Plate 6. Lithological nature of Dwyka Group tillite showing clasts of gneiss.



rural areas

Karoo argillaceous rocks

Vryheid Formation sandstone

Dwyka Group tillite

Source of data:
1 : 250 000 Geological Maps

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF KAROO SUPERGROUP SEDIMENTARY ROCKS IN KWAZULU-NATAL

Figure 6

3.1.5.2. Ecca Group

The Dwyka-Ecca transition is generally an abrupt but diachronous contact representing an environmental change from meltwater-influenced alluvial fans issuing into an euxinic lake to more stable lower-energy fluvial systems building out fine-grained deltas into a sea (Smith *et al.*, 1993). The northeastern and eastern Ecca deltas were responsible for the lower Ecca sedimentary rocks now represented in KwaZulu-Natal.

In the northwest, the paraglacial outwash fans, peat bogs and moraine-dammed lakes were succeeded by shallow inundation and the development of small, elongate and lobate deltas (Cadle, 1979). The Vryheid Formation in this area contains five separate bituminous coal seams, which were possibly preserved by rapid basin subsidence and transgression, covering the backswamp peats with fluvial sandstone and the delta plains with carbonaceous siltstone (Smith *et al.*, 1993).

Typically, the lower Ecca coals are low sulphur bituminous coals. Higher up in the Ecca succession the coal is associated commonly with upper delta-plain and strandplain facies in inferred fluvio-deltaic settings, that were locally subjected to marine encroachment which resulted in higher sulphur containing coals (Cadle, 1979).

Rifting of the Natal trough and Nongoma Graben in the east of the province together with sedimentation resulted in up to 15 fluvio-deltaic cycles (Smith *et al.*, 1993). These cycles consist of bioturbated or weakly-laminated shelf mudstone and siltstone overlain by muddy siltstone and sandstone.

The Ecca Group is represented in KwaZulu-Natal by the argillaceous Pietermaritzburg and Volksrust Formations which are separated from each other by the mainly arenaceous Vryheid Formation.

Pietermaritzburg Formation

The Pietermaritzburg Formation shales are well-bedded, dark grey, blue and black shales which rest conformably on the Dwyka Group. The shale becomes characteristically fissile due to fine jointing, often as a result of unloading. Occasionally micaceous beds and thin siltstone beds occur within the shale. Secondary mineralisation by pyrite is also common in the shales. On weathering, the rock turns into a yellowish clay. Dolerites have extensively intruded the Pietermaritzburg Formation, taking advantage of the well-bedded and jointed nature of the shales.

Vryheid Formation

Overlying the Pietermaritzburg Formation conformably is the Vryheid Formation. The boundary is transitional, and is taken at the base of the first sandstone unit above the Pietermaritzburg Formation (Thomas, 1988). The base of the Vryheid Formation comprises interlaminated sandy shale, siltstone and sandstone which passes upwards to laminated or cross-laminated, medium- to fine-grained sandstone. A facies change to coarse-grained, cross-bedded sandstone and grits occurs at the top of the formation (Linström, 1987b).

The Vryheid Formation sandstones can be identified by their pale buff colour, poor sorting and high feldspar content. The feldspars, mainly orthoclase and microcline, weather rapidly and result in some areas having sparse outcrops (de Decker, 1981).

Volksrust Formation

Blue-grey and black, well-laminated, fissile shales of the Volksrust Formation conformably overlie the Vryheid Formation. These shales are very similar to the Pietermaritzburg Formation shales and also weather to a buff colour. Phosphate nodules are apparently characteristic, for example near Weenen (Du Toit, 1918).

3.1.5.3. Beaufort Group

Beaufort Group sediments are thought to have accumulated on vast semi-arid alluvial plains mainly by floodplain aggradation (Smith *et al.*, 1993). The fluvial action resulted in alternating mudstone and sandstone lithosomes with upward-fining textures, red and purple colours, vertebrate fossils, desiccation cracks and palaeopedogenic carbonate horizons (Smith *et al.*, 1993).

In KwaZulu-Natal, the Beaufort Group is represented by the Estcourt and Normandien Formations in the east, the Emakwezini Formation in the northeast and by the Adelaide and Tarkastad Formations in the southwest.

Normandien and Estcourt Formations

The boundary with the underlying Volksrust Formation is conformable but transitional. The transition beds consist of fine- to coarse-grained sandstone, sandy shale and shaly sandstone with interbedded basal black shale (Linström, 1987b). The contact is taken at the base of the first sandstone above the Volksrust Formation.

The Normandien and Estcourt Formations are composed of massive or cross-bedded, fine- to coarse-grained, feldspathic sandstone and dark blue-grey or black, locally carbonaceous shale (Linström, 1987b). The Normandien Formation is represented on the Frankfort 1 : 250 000 geological map but has not yet approved by SACS.

Emakwezini Formation

This formation, as do the Normandien and Estcourt Formations, conformably overlies the Volksrust Formation. It has however, a gradational contact and is found east of the Normandien Formation within the Karoo basin.

The base of the formation is marked by black, locally carbonaceous shale which grades upwards into a more arenaceous succession in which plant remains are found (Linström, 1987b). The rest of the formation consists of fine- to medium-grained and, locally, even coarse-grained greenish grey or buff-coloured sandstone alternating with siltstone and grey or grey-green shale and mudstone. The sandstone is well-bedded and usually feldspathic. Thin beds of maroon mudstone and black carbonaceous, locally micaceous, shale are common. Thin coal seams occur throughout the Emakwezini Formation.

Adelaide Formation

This formation consists of a succession of greenish grey, bluish grey and minor greyish red mudstones alternating with subordinate fine-grained, buff-coloured, litho-feldspathic sandstones, forming upward-fining cycles (de Decker, 1981). The mudstones are usually massive, whereas the sandstones exhibit trough cross-bedding or flat-bedding. The sandstone frequency increases higher up in the succession.

Tarkastad Formation

A greater proportion of sandstone to mudstone, compared to the conformably underlying Adelaide Formation, is characteristic of the Tarkastad Formation. de Decker (1981) describes the sandstones as: yellowish grey to light greenish grey, fine- to medium-grained, flat-bedded and trough and planar cross-bedded litho-feldspathic sandstones and the subordinate mudstones as: bluish grey and red to purple.

3.1.5.4. Post-Beaufort Group sedimentary rocks

Molteno Formation

The Molteno Formation is described by Smith *et al.* (1993) as an intracratonic, bedload-dominated fluvial wedge, derived from a tectonically active upland some distance to the south and southeast. As a whole, the formation is composed of three sedimentary wedges each containing one or more upward-fining sequences which were deposited in a perennial braided stream environment conformably above the Tarkastad Formation sediments.

The sedimentary rocks of the Molteno Formation are sandstones, mudstones and shales. The sandstones comprise mainly coarse-grained quartz and feldspar, with little or no interstitial material. These sandstones have a characteristic glitter which is a result of secondary growth on the quartz grains. The mudstones can be grey, red or purple.

Impersistent thin coal seams, terminating the upward-fining cycles, occur at intervals in the formation. These upwards fining cycles start with massive, poorly sorted coarse sandstone with scattered pebbles, grading firstly into trough and tabular cross-bedded sandstone and then into a mudstone or shale unit (de Decker, 1981).

The Molteno Formation, where it occurs in the west of KwaZulu-Natal, forms a noticeable scarp. The alternating sandstone, mudstone and shale produces a terraced landscape, with sandstone blocks strewn at the base of the scarps (de Decker, 1981).

Ntabene Formation

In northern KwaZulu-Natal, a lateral equivalent of the Molteno Formation is the Ntabene Formation which conformably overlies the Emakwezini Formation. The formation consists of mainly sandstone and subordinate shale. The sandstone is medium-grained and slightly feldspathic, but a coarse-grained, gritty variety, consisting mainly of quartz, is found at a number of localities (Linström, 1987b).

Nyoka Formation

The bright-red or purple Nyoka Formation mudstone follows conformably on the Ntabene Formation. Thin beds of yellow, grey, white or reddish, fine- to coarse-grained feldspathic sandstones are interbedded with the mudstone. The age of this formation, and of the Ntabene Formation, is uncertain, but is tentatively regarded as Triassic (Linström, 1987b).

Elliot Formation

As Gondwana drifted further away from the pole, the climate became increasingly arid. This change in palaeoclimate has been inferred through the evidence of fossils within the sedimentary successions (Smith *et al.*, 1993). Regional facies relationships indicate that the Elliot Formation is the distal equivalent of the coarse braided river deposits of the Molteno Formation (Smith *et al.*, 1993). Interpretation of the formation has led workers to believe that the formation was deposited by meandering, ephemeral streams, transitional flood-fans, playas and the wind (Smith *et al.*, 1993).

The Elliot Formation consists of upward-fining cycles of poorly bedded sandstone, which grades into trough and tabular cross-bedded, fine-grained sandstone and then into a massive-bedded siltstone and mudstone. The sandstone is whitish grey to yellowish grey, occasionally brownish red, medium-grained and feldspathic. Mudstone predominates over the sandstones and is generally red and purple, but occasionally greenish grey.

The Elliot Formation is often referred to as the "red beds". This is due to the striking red colour of the rocks which is probably a result of diagenetic oxidation of iron derived from ferruginous silicate and clay minerals (Eriksson, 1987).

Clarens Formation

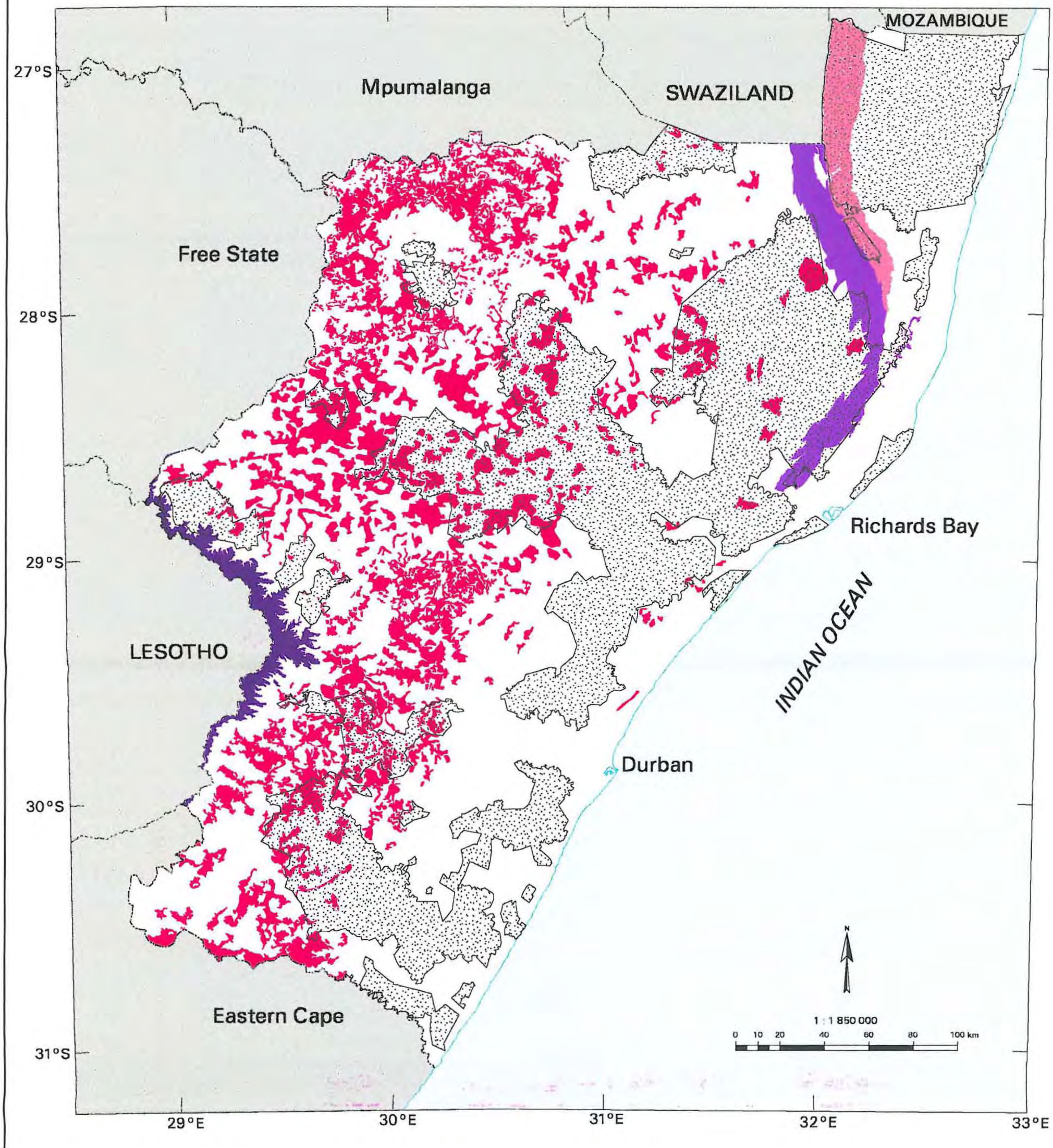
The Clarens Formation conformably overlies the aeolian-influenced upper part of the fluvio-lacustrine Elliot Formation. The Clarens palaeoenvironment is interpreted as an arid distal alluvial fan complex with wadi channels. Within the hot dry continental basins the alluvium was modified by aeolian and marginal playa processes (Smith *et al.*, 1993).

The formation consists of a cream, white or slightly pinkish, well sorted, very fine-grained to fine-grained, poorly bedded calcareous and feldspathic sandstone. Thin intercalated lenses of reddish and blue-grey mudstone occur locally. The sandstone sometimes shows minor baking effects near its upper contact with the overlying basalts (Linström, 1987b).

3.1.5.5. Karoo volcanism

The extrusion of the Karoo flood basalts was linked to the break-up of Gondwana (Smith *et al.*, 1993). Karoo basalts are represented in KwaZulu-Natal within the Lebombo monocline as the Lebombo Group, and within the intracratonic sequences along the Lesotho border as the Drakensberg Group (Figure 7). A regional geochemical variation between the basalts exists which is related to regional tectonic features (Duncan *et al.*, 1984). The Drakensberg Group basalts are a tholeiitic central magma type and the Lebombo Group basalts are olivine-poor (Duncan *et al.*, 1984).

A diachronous relationship with the underlying sediments has been suggested for the basalts (Smith *et al.*, 1993). This arises as a result of some areas showing a transition from sedimentation to volcanism through evidence of sandstone lenses in the basal lavas and the fact that the lavas rest unconformably on the Elliot Formation along the Drakensberg mountains.



- rural areas
- dolerite
- Jozini Formation rhyolite
- Letaba Formation basalt
- Drakensberg Group basalt

Source of data:
1 : 250 000 Geological Maps

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF KAROO SUPERGROUP VOLCANIC ROCKS IN KWAZULU-NATAL

Figure 7

Lock (1978), Dingle *et al.* (1983) and van Rooy (1991) describe the processes by which the basalts were emplaced as an initial phase of explosive magmatic volcanism which laid down pyroclastic breccias and tuffs, followed by a longer period of subdued fissure eruptions which built up thick sequences of basalt flows, associated with numerous vents, diatremes and dolerite dykes and sills. These successive basaltic flows buried large areas of the Clarens landscape effectively bringing Karoo sedimentation to an end.

Lebombo Group

Letaba Formation

The Letaba Formation basalt can be described as a thick succession of amygdaloidal and non-amygdaloidal or massive lava flows with bedded tuffs and sandstone lenses. Amygdales, when they occur, are concentrated in the uppermost third of the lava flows with a thinner amygdaloidal zone at the base (Linström, 1987b). Amygdales are usually filled with calcite, zeolite, chalcedony, opal, chlorite or quartz. The basalts pass upwards into acidic lavas, including rhyolite, dacite, ignimbrite, tuff and subordinate sandstone.

Jozini Formation

The acidic lavas of the Jozini Formation follow conformably over the Letaba Formation. The formation comprises greenish rhyodacite to rhyolitic lavas which weather to a red to purple and dark brown or grey colour. The texture of the lavas ranges from cryptocrystalline to porphyritic, with the feldspars having a speckled appearance (Linström, 1987a). Bristow (1976) has found the lava flows to be extensive flat-lying bodies where each flow is separated by a relatively thin tuff zone.

Drakensberg Group

The Drakensberg Group basalt forms an impressive escarpment along the Drakensberg mountain range. The majority of the group comprises alternating flows of massive, coarsely crystalline basalt and amygdaloidal basalt. These alternations give rise to a stratified appearance. The base of the formation contains intercalations of sandstone similar to the underlying Clarens Formation, pyroclastics and vitreous andesite.

Amygdales are generally present at the top and base of lava flows. The massive (non-amygdaloidal) basalt is grey or greenish black and usually fresher than the easier weathered brownish-red or purple amygdaloidal basalt. The presence of brown palaeosol preserved between lava flows indicates that the extrusion of the basalt occurred over a long period of time (de Decker, 1981).

3.1.5.6. Karoo dolerite

The interpretation of the distribution (Figure 7) and orientation of dolerite dykes and sills is related to geologic history from the Jurassic to the break up of Gondwana (von Vey, 1994). Competent rocks such as granites and tillite allowed magma to fill vertical fractures and joints to form dykes, and the less competent well-bedded sedimentary rocks allowed both dolerite sills and dykes to develop. High pressures which occur at depth also restrict the formation of sills and therefore dykes are prevalent in rocks such as the basement rocks.

The feeder intrusions of the Jurassic flood basalts affected most of the Karoo basin. The Ecca Group, in particular, is extensively intruded by dolerite sills with the major orientation of dykes in these rocks being west-northwest. The Natal Group and basement rocks are less extensively intruded by dolerite. Those dykes which occur in the north of the Kaapvaal craton have a northwest trend. This trend is probably related to pre-existing structural weaknesses in the basement (von Vey, 1994). In the rocks of the Natal Metamorphic Province, dykes are poorly developed.

The early phase break-up of Gondwana is thought to be responsible for the north-south orientation of dykes along the coast and in particular, associated with the Lebombo monocline (von Vey, 1994). Right-lateral strike-slip or reverse movement during late Gondwana break-up is speculated to have influenced the coastal dykes (von Vey, 1994).

Karoo dolerite is generally fine- to medium-grained, exhibiting ophitic and subophitic textures, with unaltered, mildly zoned laths of labradorite, enclosed wholly or partially in larger grains of augite or titan-augite (Thomas, 1988). The grain size of the dolerite varies according to the rates of cooling. Contact-metamorphism associated with dolerite intrusion into Karoo sedimentary rocks is common. Pietermaritzburg Formation shales produce a narrow aureole of hornfels near the contact with the dolerite. Beaufort Group rocks have been intruded by both sills and dykes, of which the metamorphic effect has been the transformation of the mudstones into hard blue-black or grey-white hornfels. Sandstones are metamorphosed to quartzite. The dolerite intrusion itself may also exhibit a chill margin at the contact with the country rock. Jointing of the dolerite as a result of rapid cooling is also common.

Upon weathering, the dolerite disintegrates by the formation of corestones which have a fresh centre and an exfoliating surface. The original minerals are converted to yellow, red or black clays.

3.1.6. Zululand Group

These Cretaceous-aged sediments unconformably overlie the volcanic rocks of the Lebombo Group. Table 11 describes the lithology of the conformably related formations within the Zululand Group and Figure 8 depicts the limited surface distribution of the group because of Quaternary aged cover.

Table 11. Zululand Group lithology - in order of increasing age (du Preez and Wolmarans, 1986).

FORMATION	LITHOLOGY
St Lucia	marine glauconitic siltstone with calcareous concretions
Mzinene	glauconitic, calcareous, marine siltstone or fine clayey sandstone
Makatini	non-marine conglomerate and sandstone interbedded with marine shallow water siltstones

3.1.7. Maputaland Group

The geological history of the Zululand Coastal Plain, which is the location of the Maputaland Group, has been described by Wright (1995) as commencing with short length rivers forming large outwash fans when the sea level was at approximately 130 m above mean sea level (m.s.l). As time progressed these rivers' gradients reduced, forming coastal water bodies including lagoons, associated with the coastal dune barrier. The frequently regressing shallow sea was the recipient of terrigenous and marine sediments. A shallow sea with large tidal flats was formed by a +5 m sea level backflood during the Last Interglacial (125 000BP). The resultant conditions enabled coral growth and the formation of a barrier dune complex to form eastwards of the older Tertiary dune cordons. The older dune stubs formed offshore archipelagos and the palaeo-Pongola River was diverted northwards.

The present dune barrier along the coast comprises reworked sand of sediments older than 18 000BP. The reworking of the sediments was a result of a rapid drop in sea level to 120 m below m.s.l. The transgression caused the coastal rivers to incise and expose the continental shelf sand to the prevailing wind.

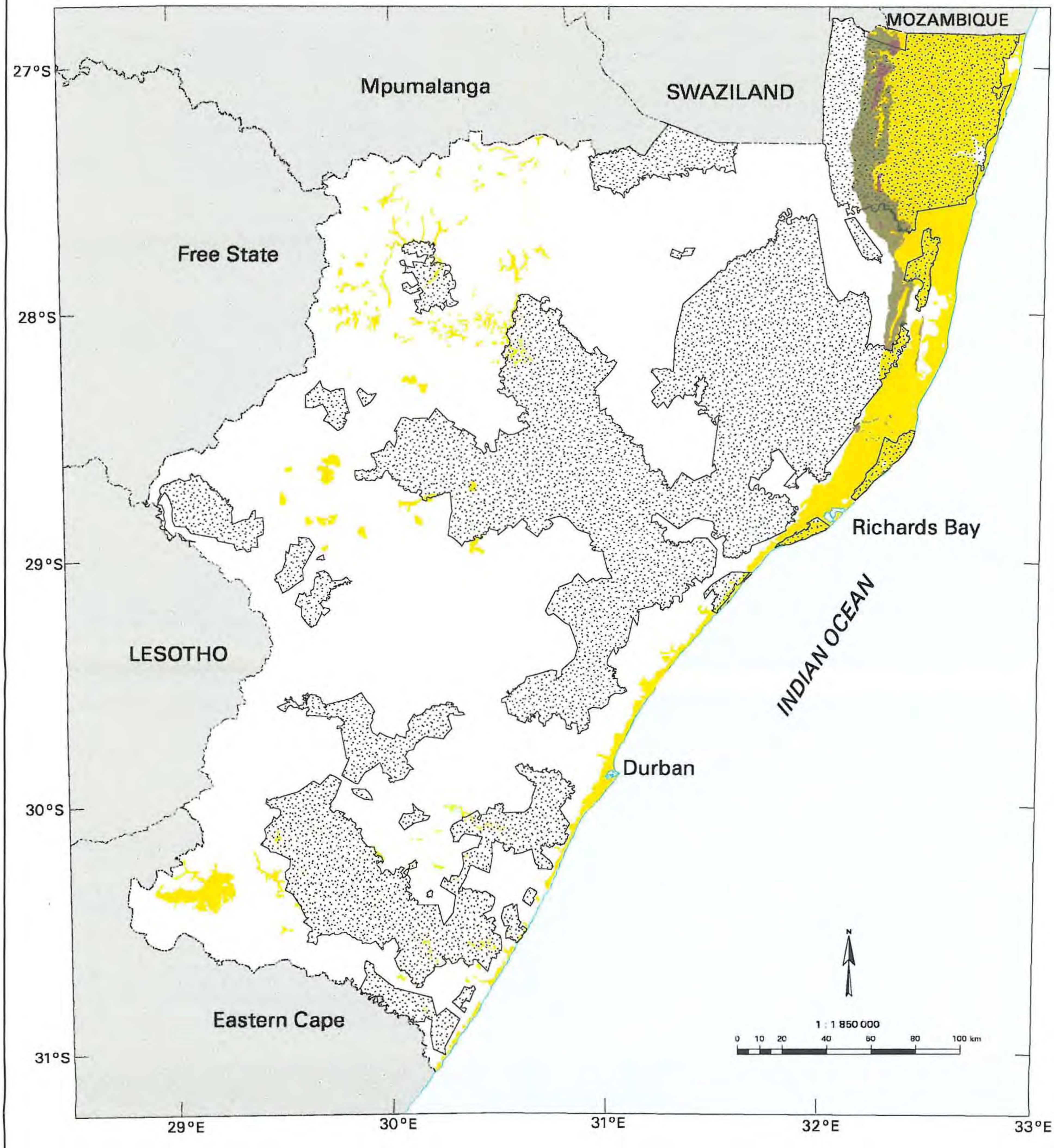
Only the oldest Tertiary cordon along the Pongola River has been lithified and thus the general gradient of the palaeodunes rarely exceeds 10°. Reworking by weathering and dispersal of the oldest dune cordons is common. The reworked dune sand is recognised by its grey to red colour. Gullies are easily formed by rivers cutting down into dune cordons.

The six formations which make up the proposed Maputaland Group (pers comm. Botha, 1995) are summarised in Table 12 as typical profiles. The distribution of the group is shown in Figure 9. It must be noted that the previously known Bluff Formation, Berea Formation and Harbour Beds (King and Maud, 1964)) have been excluded as individual formations but have been included as the weathered component of either the Kosi Bay or Umkwelane Formations.

Table 12. Proposed stratigraphy of the Maputaland Group (pers. comm. Botha, 1995).

SYSTEM	FORMATION	LITHOLOGY
Holocene	*Sibayi* ➔	high coastal dune cordon, calcareous sand
mid- to late Pleistocene	*Kwambonambi* ➔	inland stabilised dunes and redistributed sand (non-calcareous)
	←	weathering profile, "Berea-type" red sand
	Kosi Bay *Port Durnford* ➔	cross-bedded sand, local calcarenite, carbonaceous sand beachrock, coral-bearing coquina and lignite, fossiliferous mudrock
late Miocene to Pliocene	←	weathering profile, "Berea-type" red sand
	Umkwelane *Uloa* ➔	aeolian cross-bedded calcarenite coquina and conglomerate
← Palaeocene, Mesozoic, Palaeozoic and Precambrian bedrock		

Note: all contacts are unconformable
➔ regression
← transgression



rural areas

Sands of the Maputaland Group, Masotcheni Formation and alluvium

Uloa Formation

Zululand Group

Source of data:
1 : 250 000 Geological Maps

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF THE MAPUTALAND GROUP,OTHER QUATERNARY SEDIMENTS AND CRETACEOUS ROCKS IN KWAZULU-NATAL

Figure 8

3.1.8. Other Quaternary sediments

Masotcheni Formation

The colluvial sediments, of the Masotcheni Formation, have been exposed by gullies or dongas common in many inland parts of KwaZulu-Natal (Figure 8). Up to 21 m of the predominantly light-yellow, loosely consolidated clays with poorly developed, fine-grained sandy colluvium, occasional nodular beds and interbedded buried palaeosols have been exposed (Botha *et al.*, 1994). Chronological work carried out by Botha (1992) suggests palaeobadland erosion has been occurring over at least the past 135ka.

Donga formation and subsequent colluvial formation has been found to be associated with areas of irregular topography in the Vryheid Formation and Karoo dolerite geology, with a mean annual rainfall of 600 - 800mm (Botha *et al.*, 1994). Deposition of thinly-bedded or laminated sandy sediment with interbedded lensoid pebble gravel by sheetwash and localised ephemeral gully floor processes has been thought to be responsible for the formation of the colluvium.

Alluvium

Alluvium is found along most of KwaZulu-Natal's major rivers and some of their tributaries, especially in the south. The grain size of the deposits vary and the thicknesses can reach up to 38 metres (Du Toit, 1946). The clayey alluvial sediments of flood plains are often used for crop planting, and the sandier sediments of the river channel and banks are quarried for building sand. Figure 8 illustrates the distribution of the mapped occurrences of alluvium from the published 1 : 250 000 geological map.

3.1.9. Structure and tectonics

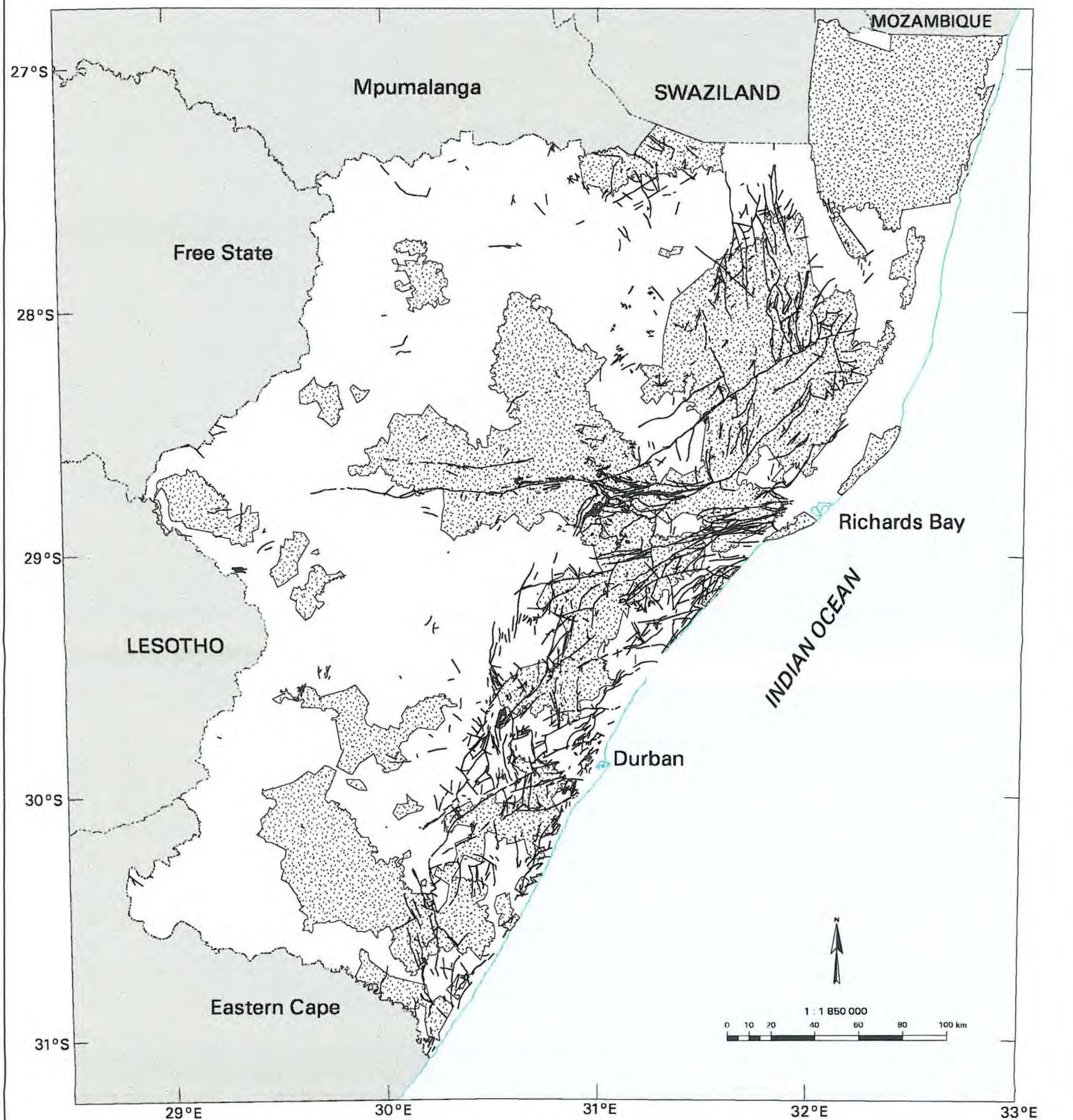
A well defined area running roughly parallel to the coast and extending inland for 70 kilometres and south of Richards Bay is extensively faulted as it forms part of the rifted margin of the continent (Maud, 1961). The resultant physical structures in these Natal Metamorphic Province, Natal Group and Karoo Supergroup rocks are tilted fault blocks, and horst and graben structures. The patterns of the faults are of a conjugate shear nature and trend in a south-north and southwest-northeastly direction (Maud, 1961). The faults affecting this area are younger than Karoo Supergroup age.

The majority of faulting associated with the Natal Metamorphic Province is of Proterozoic age. Faulting is generally more intense in the north towards the Kaapvaal craton margin (von Vey, 1994). The oldest structures are of Archaean age and are found in the Pongola Supergroup and Barberton Sequence rocks in the extreme north of KwaZulu-Natal. The dominant fault directions are east-northeast and north-south.

After capturing structural features from geological maps and landsat imagery, von Vey (1994) states that most of the disconformities' strikes appear to have developed at a high angle to the least principal compressive direction. This implies that the resultant extensional structures, caused by the break-up of Gondwana, could have a potential for high yielding boreholes. Table 13 presents von Vey's determinations for the strike direction of extensional structures. The faults and lineaments captured by von Vey are illustrated in Figure 9 and Figure 10.

Table 13. Favourable strike directions for extensional structures in KwaZulu-Natal (von Vey, 1994).

DOMAIN	FAVOURABLE STRIKE DIRECTION
Kaapvaal craton areas underlain by Archaean rocks	NE, ENE, N-S
Natal Metamorphic Province	NE, ENE,
Natal Group, Msikaba Formation and Karoo Supergroup	ENE, WNW, N-S



rural areas

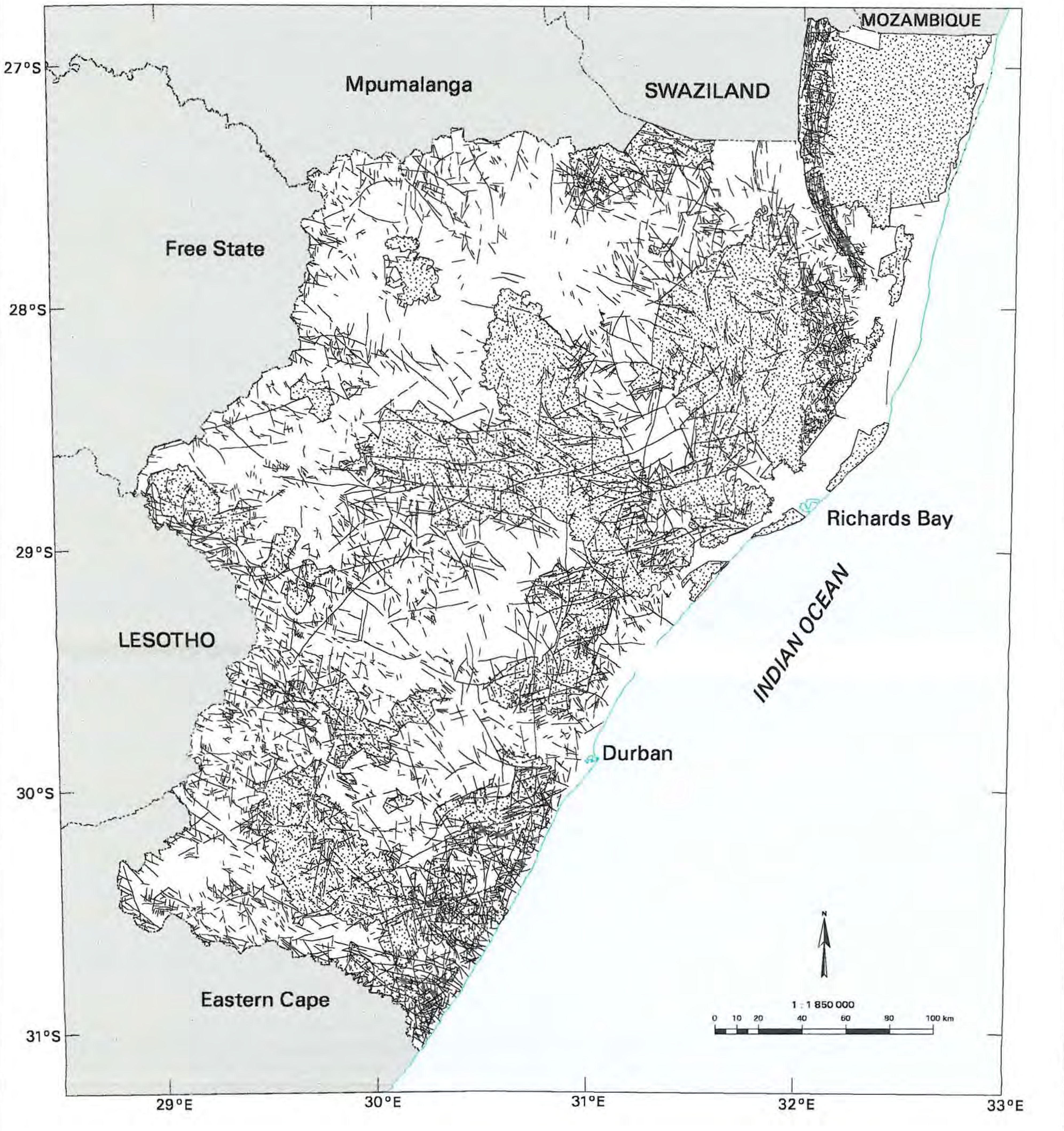
Source of data:
1 : 250 000 geological maps

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF 1:250000
SCALE MAPPED FAULTS
IN KWAZULU-NATAL

Figure 9



rural areas

Source of data:
Council for Geoscience

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF LINEAMENTS TRACED FROM SATELITE IMAGERY

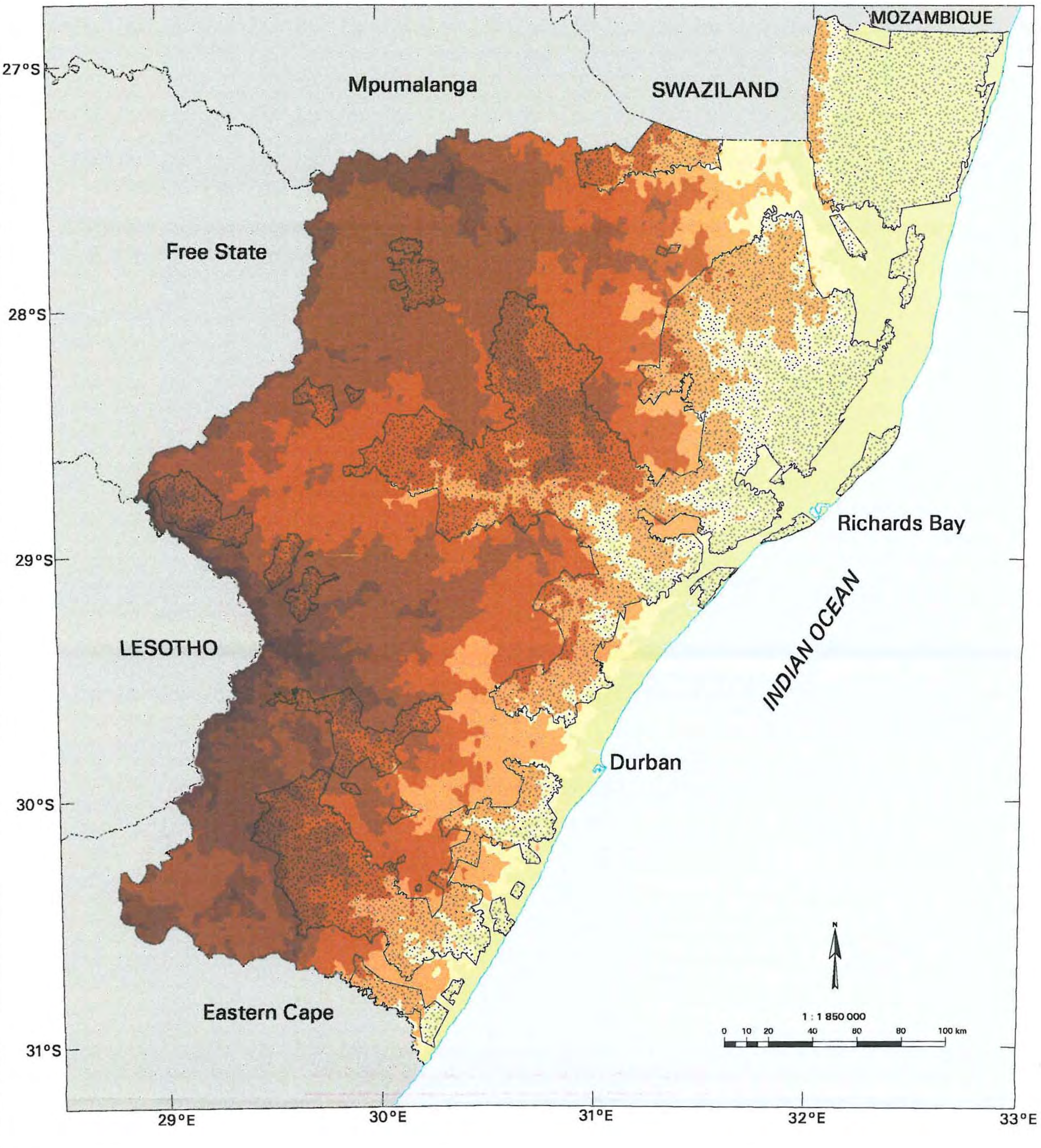
Figure 10

3.2. Terrain morphology and geomorphology

The topography of the province as a whole is described in order to encompass all the different types of terrains found in rural areas. Height above sea level in KwaZulu-Natal ranges from 0 to almost 3000m (Figure 11). Relief in some areas can be extreme. Generally, from west to east, the topography of KwaZulu-Natal can be described as: mountains of the Drakensberg escarpment and eastern plateau slopes descending to the coastal forelands. The topography as we see it today is the result of various geological events, such as the break up of Gondwana, uplift and cycles of erosion (Partridge and Maud, 1987). In turn, the rocks upon which these processes have acted, have reacted in different ways, giving rise to unique landforms for each lithology as will be described further on in this section.

The coastal topography is dominated by extremely flat land and relic dune cordons which originally formed adjacent to palaeo-coastlines (Plate 7). Due to changes in climatic conditions smaller remobilised dune-fields have established themselves mainly over the Zululand coastal plain (Wright, 1995). The sand dunes in the north of the province are reported to be some of the largest in the world (pers. comm. Natal Parks Board, 1995).

Plate 7. Zululand coastal plain topography. Photograph taken from relic dune looking westwards towards the Lebombo mountains in the distance.



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

Source of data:
CCWR minute by minute ascii points

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

TOPOGRAPHY OF KWAZULU-NATAL

Figure 11

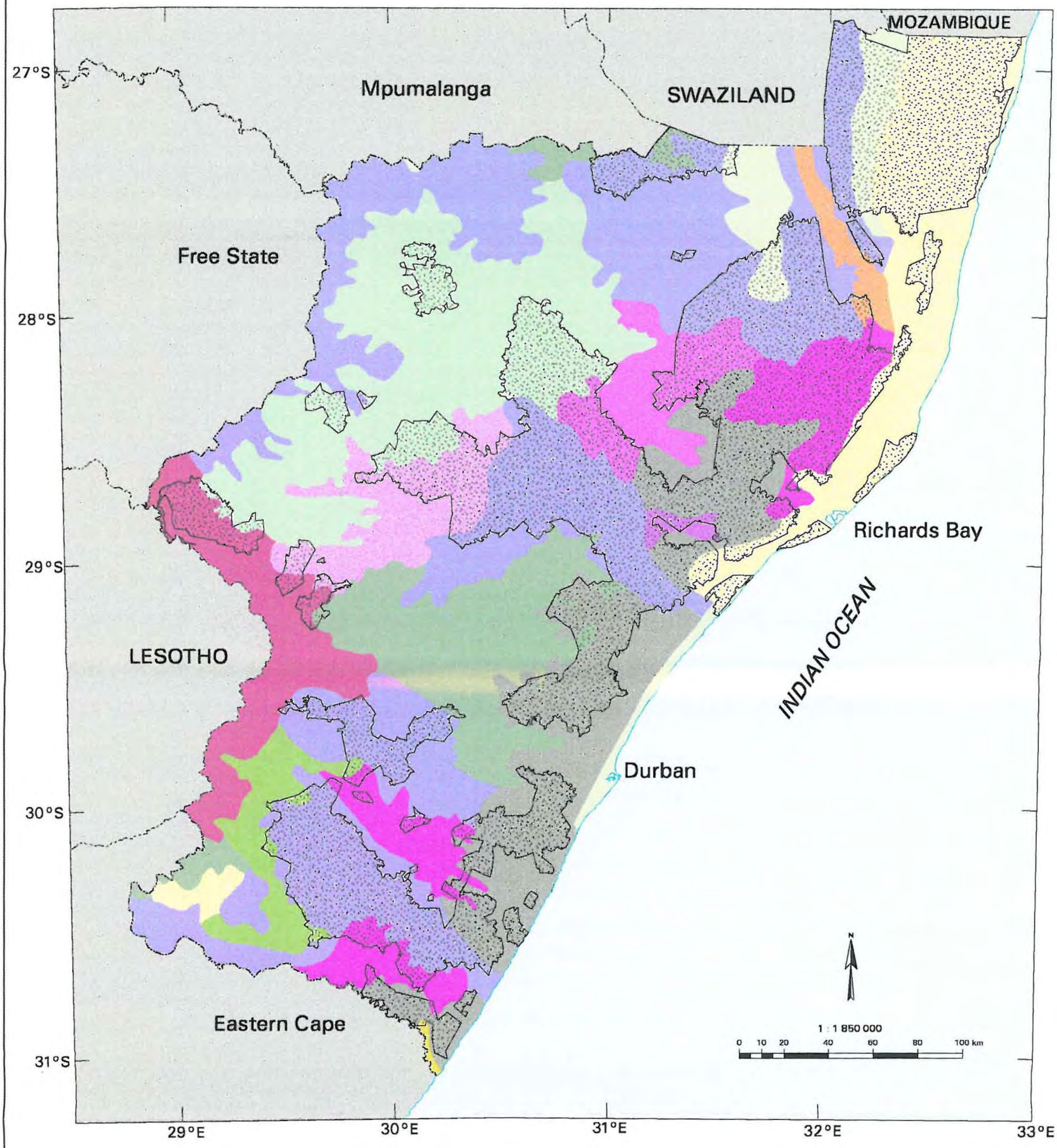
Roughly 20km inland from the low relief of the coastal areas, incised river valleys and rugged topography are encountered, except in the north where the coastal plain extends further inland. These features are typical of the province, and have been largely initiated by uplift of the land mass and dropping sea levels (Partridge and Maud, 1987). The Natal Metamorphic Province bedrock areas of the coastal hinterland are characterised by rounded hills with deeply incised valleys. The resistant Natal Group sandstone in these same areas responded to geomorphic processes by forming impressive cliffs.

The eastern plateau areas in the west and central parts of the province represent two separate cycles of erosion (Partridge and Maud, 1987). These cycles have resulted in the pre-Karoo and the flat lying Karoo rocks having levelled surfaces with scarps, questas and pointed hills being secondary features of the landscape.

The Drakensberg mountains, comprising predominantly basalt, form the escarpment in the extreme west with high spurs of Karoo Supergroup sediments between the valleys of the major eastwards running rivers. The escarpment separates the elevated interior and inland draining rivers from the coastal margins and eastward flowing rivers. The origin of the escarpment is attributed to a rift-generated feature caused by the break up of Gondwana which has been backworn to it's present position (Partridge and Maud, 1987).

Also of topographic importance is the Lebombo mountain range which separates Swaziland from Mozambique and KwaZulu-Natal. The basalts on the western side of the Lebombo have weathered faster than the more resistant rhyolites to the east. Major rivers, such as the Pongola River, have cut through the range in an effort to reach the sea.

Another method of describing topography is through mapped terrain morphology based on slope form, relief, drainage density and stream frequency (Kruger, 1983). The characterisation of terrain morphological classes from Kruger's work is given in Table 14 and is illustrated in Figure 12. On combining geology with the coverage of terrain morphological classes using a GIS, the predominant geology for each class becomes evident (Table 14), thus highlighting the typical landforms which result from different rock types.



- rural areas
- plains
- undulating plains
- moderately undulating plains
- irregular undulating lowlands with hills
- strongly undulating land
- undulating hills and lowlands
- mountains and lowlands
- undulating mountains and lowlands
- highly dissected hills
- undulating hills
- low mountains
- highly dissected low undulating mountains
- high mountains
- mountains and hill plateaux

Source of data:
Kruger (1983)

Date:
10 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

TERRAIN MORPHOLOGICAL UNITS OF KWAZULU-NATAL

Figure 12

Table 14. Terrain morphological classes (from Kruger, 1983) and percentage distribution over KwaZulu-Natal with predominant geology for each class.

BROAD DIVISION	MAP SYMBOL	DESCRIPTION	COVER %	PREDOMINANT GEOLOGY
Plains with low relief	1	plains	10	Cretaceous and younger sediments
	3	slightly undulating plains	1	Letaba basalt
Plains with moderate relief	9	moderately undulating plains	4	Cretaceous and younger sediments, Karoo S. sediments, Pongola S.
Lowlands, hills and mountains with moderate and high relief	14	irregular undulating lowlands with hills	15	Karoo S. sediments, dolerite, Pongola S.
	15	strongly undulating irregular land	2	Karoo S. sediments and dolerite
Open hills, lowlands and mountains with moderate to high relief	20	undulating hills and lowlands	8	Karoo S. sediments, dolerite, N.M.P
	21	mountains and lowlands	4	Karoo S. sediments and dolerite
	22	undulating mountains and lowlands	2	Karoo S. sediments, dolerite, N.M.P
Closed hills and mountains with moderate and high relief	25	highly dissected hills	0.5	Natal G., N.M.P
	26	undulating hills	6	Letaba basalt, Jozini rhyolite, Karoo S. sediments, dolerite, Natal G., Pongola S. Jozini rhyolite, Karoo S.
	27	low mountains	29	Natal G., N.M.P, Karoo S.
	28	highly dissected low undulating mountains	13	
	29	high mountains	5	Drakensberg G., Karoo S. and dolerite
Table-lands with moderate and high relief	30	mountain and hill plateaux	0.5	Natal G.

NOTE: Karoo S. = Karoo Supergroup
Natal G. = Natal Group
N.M.P = Natal Metamorphic Province
Pongola S. = Pongola Supergroup

Slope analysis carried out using a GIS shows clearly the areas where slope angles are slight and steep. It must be noted that due to the frequent changes in slope and the scale at which the data were collected, the map in Figure 14 appears haphazard. This generated slope map, which identifies the maximum rate of change in height between the cells, compares favourably with the terrain mapping areas delineated by Kruger (1983). Figure 13 summarises the percentage of area covered by different slope ranges. Noticeable areas of low slope are the Zululand coastal plain, northwestern KwaZulu-Natal and a small area in the southwest called the Cedarville Flats. Steeper slopes are generally found along the escarpment and in river valleys, for example, the Tugela and Umkomaas valleys. The highlighted 'disadvantaged' rural areas also have steeper slopes than the surrounding 'advantaged' rural areas.

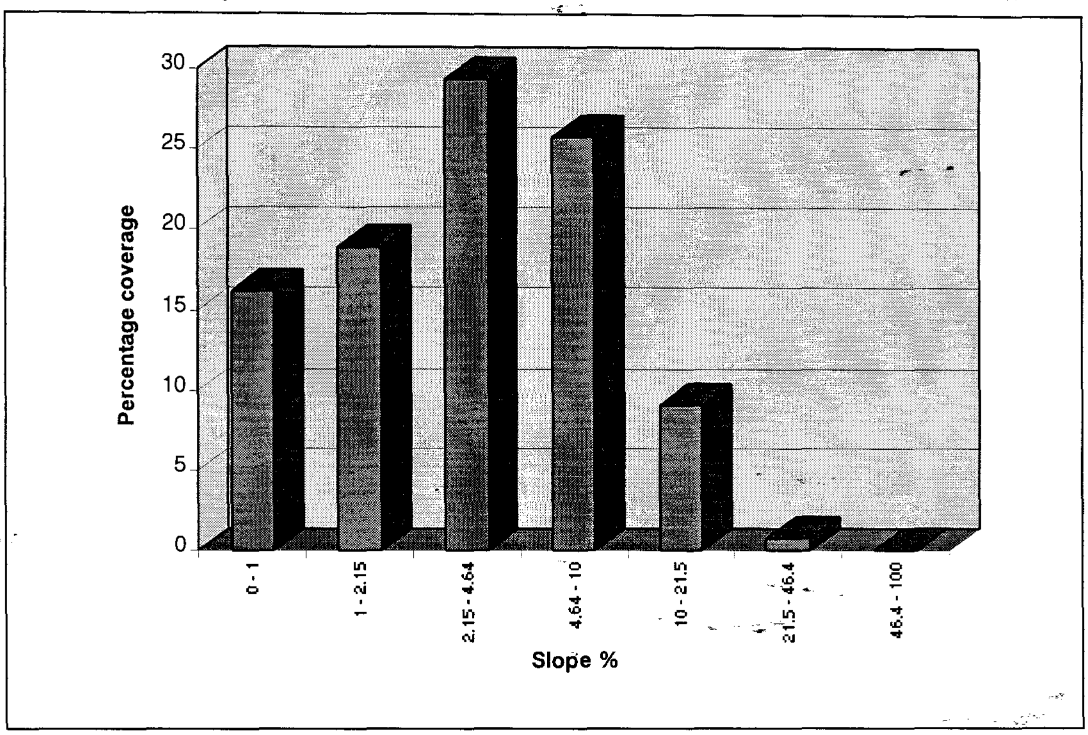
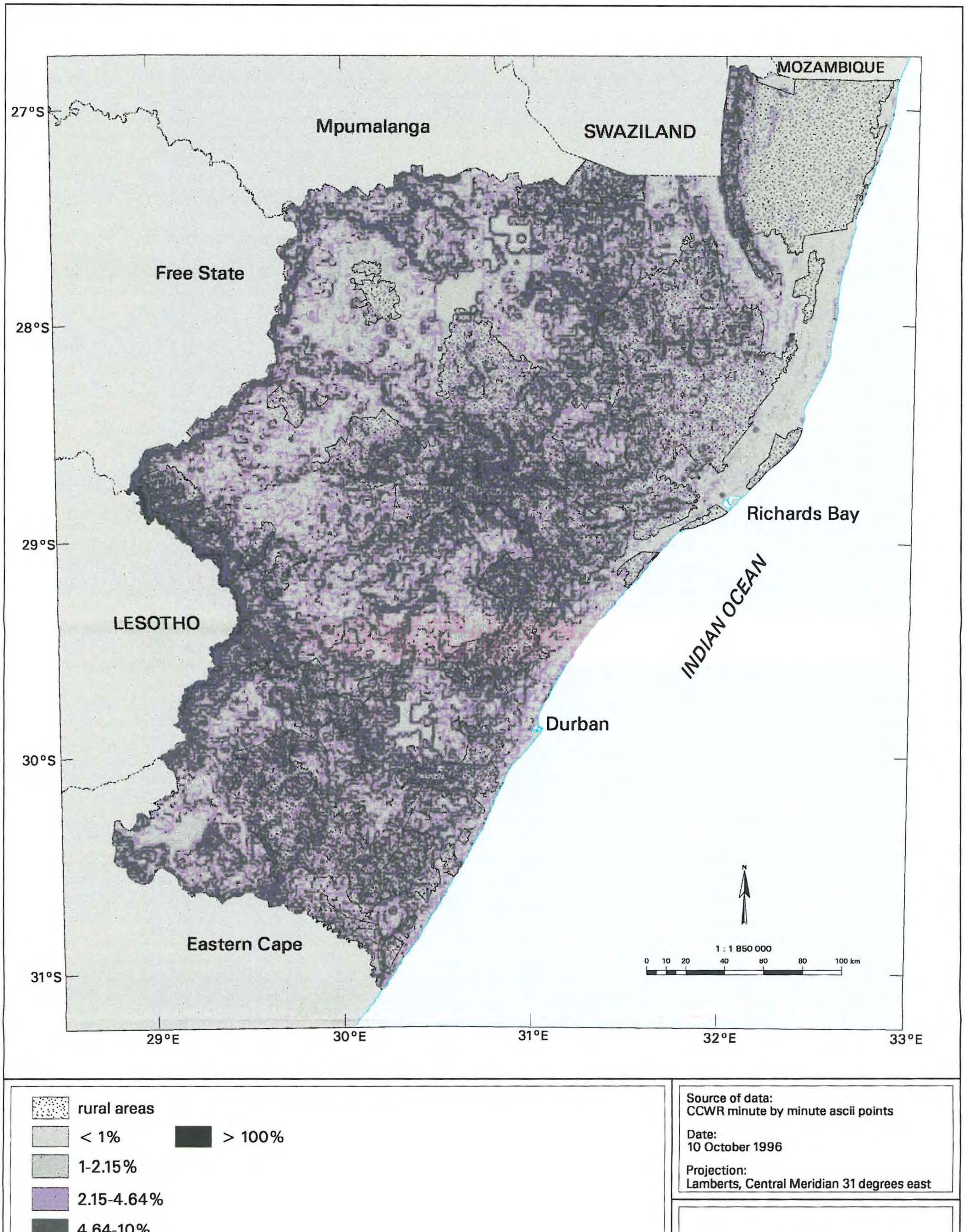


Figure 13. Slope distribution for KwaZulu-Natal.

Another feature relevant to terrain morphology is aspect. Aspect differs from slope in that the down-slope direction of the maximum rate of change in height between cells is calculated. Aspect is expressed in positive degrees from 0 to 360 and is measured clockwise from the north. Generally, as expected, the slope direction is towards the east as shown in Figure 15.



Source of data:
CCWR minute by minute ascii points

Date:
10 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

GIS GENERATED SLOPE DISTRIBUTION OF KWAZULU-NATAL

Figure 14

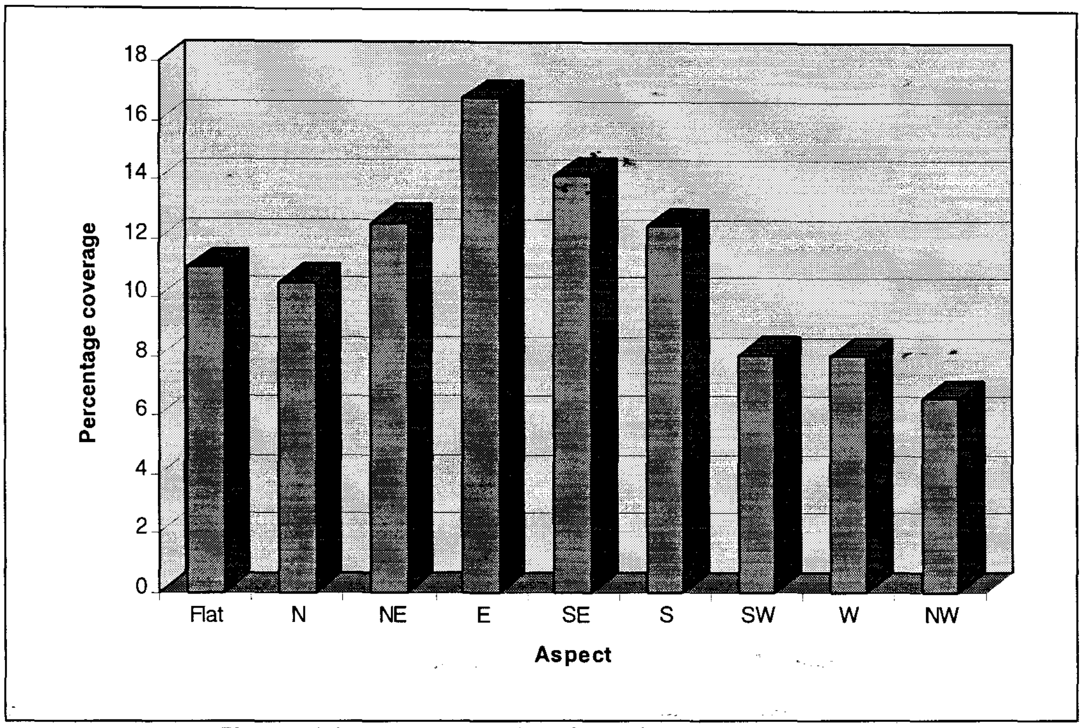


Figure 15. Aspect distribution of KwaZulu-Natal.

All the figures related to topography were derived from one minute by one minute (approximately 1.6km by 1.6km) spaced spot heights above mean sea level. The source of these data was from the Computing Centre for Water Research (CCWR). The points were converted into a raster digital elevation model (DEM) from which further analysis was possible. Due to the size of the cells, cognisance must be made of the relative coarseness of the model.

Surface topography can simplistically be divided into valleys, ridges and side slopes. A grid of these features, for KwaZulu-Natal, was generated by combining slope and aspect features. The resultant map appears rather speckled due to the high relief in many areas and therefore only the percentage coverage is provided in Table 15.

Table 15. Simplified surface feature distribution for KwaZulu-Natal.

FEATURE	PERCENTAGE DISTRIBUTION
side slopes	54
valleys	24
ridges	22

3.3. Climate

The mean annual precipitation (MAP) in KwaZulu-Natal ranges from as low as 538mm to as high as 1558mm p.a. (Midgley *et al.*, 1994b). MAP is high along the Drakensberg escarpment and decreases rapidly with lower altitudes eastwards. Higher precipitation is again encountered along the coast. The highest rainfalls are recorded in the High Drakensberg mountains, the little Berg, the tablelands in the interior and along the coast near Richards Bay. The lowest rainfall occurs on either side of the Lebombo mountains, parts of northern KwaZulu-Natal and parts of the major incised river valleys. Most of the annual rainfall falls in the summer months. Figure 16 reflects the MAP distribution in KwaZulu-Natal.

Evaporation increases from the coast westwards and from south to north. A trough of relatively low evaporation follows the Drakensberg and through to the highlands. Figure 17 depicting evaporation, from Symons pan observations, over KwaZulu-Natal has been sourced from Midgley *et al.* (1994b). This map is soon to be superseded by work being carried out by the Department of Agricultural Engineering of the University of Natal which will result in a map a little different to the present map (Midgley *et al.*, 1994a).

Daily temperatures in KwaZulu-Natal are mostly influenced by latitude and distance, altitude and distance from the sea. Altitude, however, has a greater influence than latitude and distance from the sea. The low lying areas of northeastern KwaZulu-Natal, the coastal areas and the major river valleys are characterised by high temperatures, while the Drakensberg Escarpment, mountain blocks, and high-lying areas protruding from the Drakensberg are characterised by lower temperatures (Schulze, 1982). It has been recorded that a difference in altitude of 1800 metres over a distance of 150 kilometres can cause a 9°C difference in temperature in January (Thorrington-Smith *et al.*, 1978).

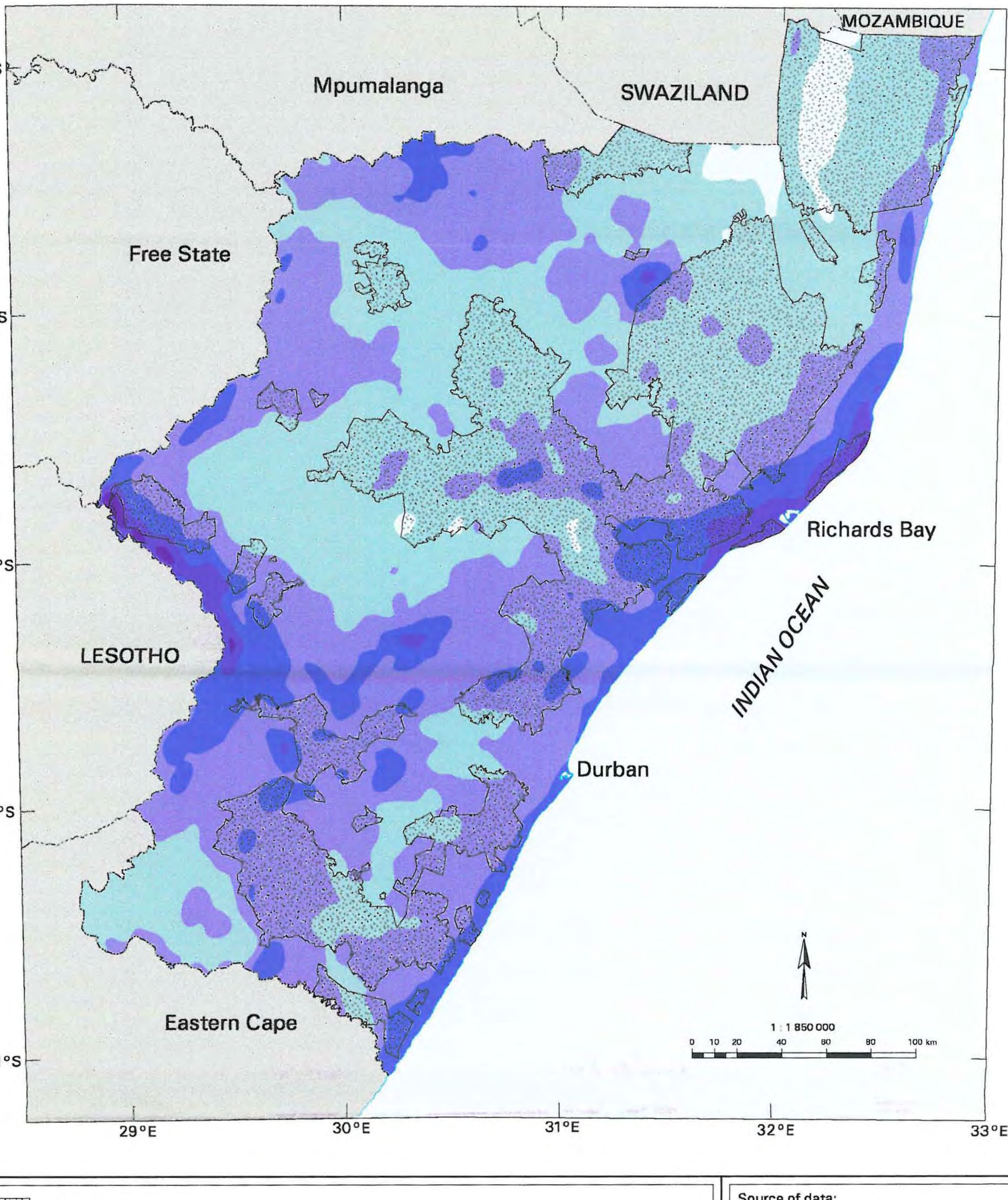
3.4. Hydrology

The rivers of KwaZulu-Natal are steeply graded and drain from west to east, as is reflected by the aspect analysis (Figure 14). Principal catchments are the Umkomaas and Mgeni catchments which fall mostly under the juristriction of the DWAF's agent Umgeni Water, Tugela catchment, which is presently without a government agent, and the Mfolozi, Pongola, Usutu catchments which have partial coverage by the board of Mhlatuze Water. The major rivers have their sources in the Drakensberg mountains, the intermediate sized rivers, such as the Mvoti, Mkuzi and Mgeni, arise in the highlands of the interior, and the coastal hinterland is the source of the smaller rivers.

The major rivers are shown in Figure 18. Water from the Tugela catchment augments water resources of the Olifants and Vaal basins outside of KwaZulu-Natal, through inter-basin water transfers.

Surface run-off for KwaZulu-Natal obtained from run-off data on a quaternary catchment scale is portrayed in Figure 19. The map shows that the highest run-off occurs along a portion of the escarpment, as would be expected considering the steep slope (Figure 14). Generally, run-off decreases towards the coast, but noticeable areas of low run-off generation do occur in the majority of the Tugela, Buffalo and Mfolozi river catchments. The lowest run-off occurs around the central portion of the Mkuze River, west of the Lebombo mountains. The northern parts of the Zululand coastal plain also generates little run-off, on account of the permeability of the sand cover. The areas around Richards Bay and lower south coast have a higher run-off than the rest of the coastline. The quantity of run-off experienced gives an indication of the probable amount of recharge, since run-off is that portion of rainfall that has escaped evaporation and infiltration. This would imply that the greater the run-off, the less recharge is occurring.

Major dams and smaller farm dams permitted by the DWAF are found mostly outside of 'disadvantaged' rural areas. The majority of these dams are found in the Umgeni catchment in order to supply the highest population density of the Durban-Pinetown-Pietermaritzburg area. The distribution of major and permitted farm impoundments are depicted in Figure 18 together with naturally occurring lakes, such as Lake St. Lucia and Lake Mzingazi, which are distributed along the Zululand coastal plain.



rural areas
500 - 600 mm
600 - 800 mm
800 - 1000 mm
1000 - 1200 mm
1200 - 1400 mm
> 1400 mm

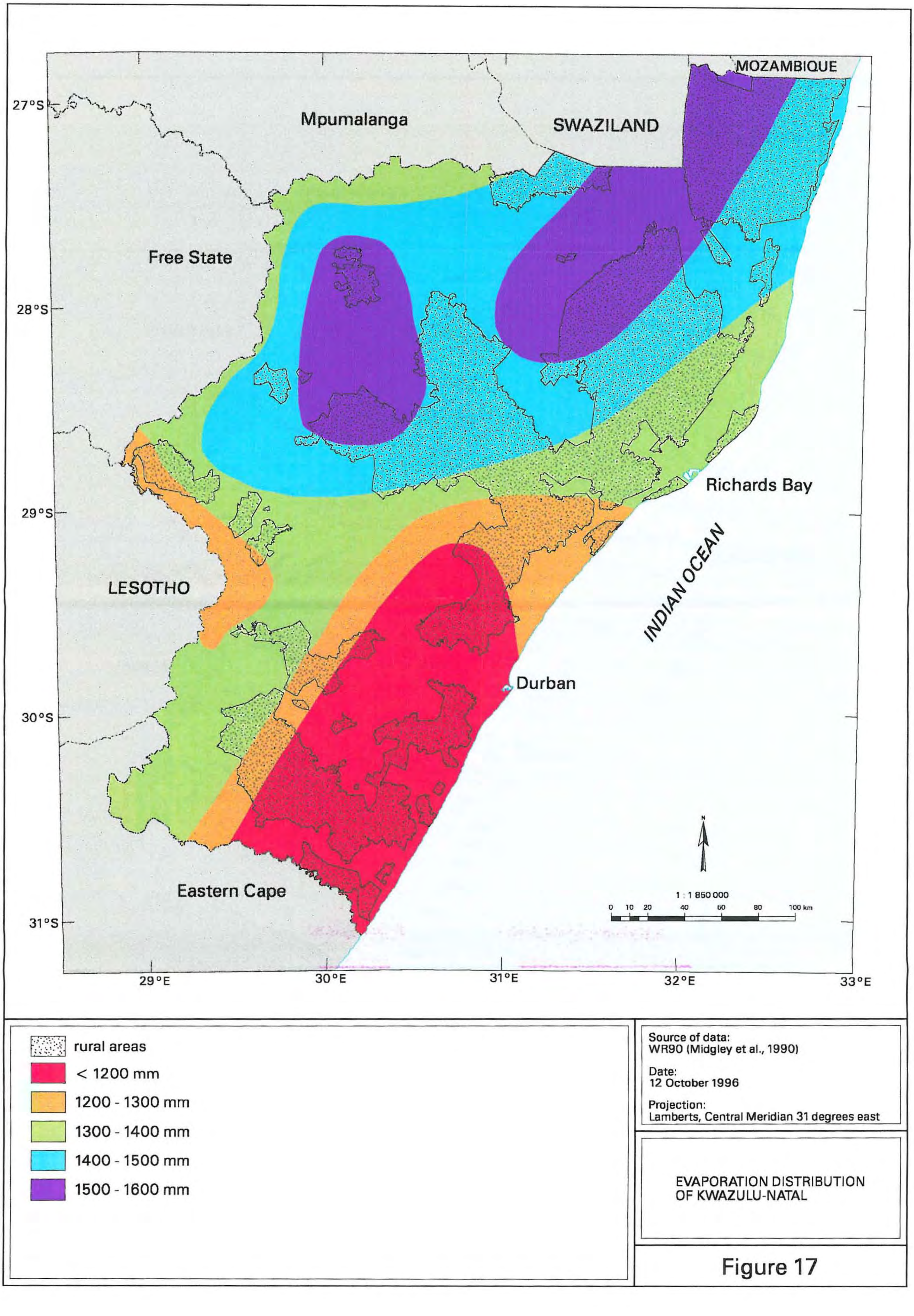
Source of data:
CCWR minute by minute ascii points

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

MEAN ANNUAL PRECIPITATION DISTRIBUTION OF KWAZULU-NATAL

Figure 16



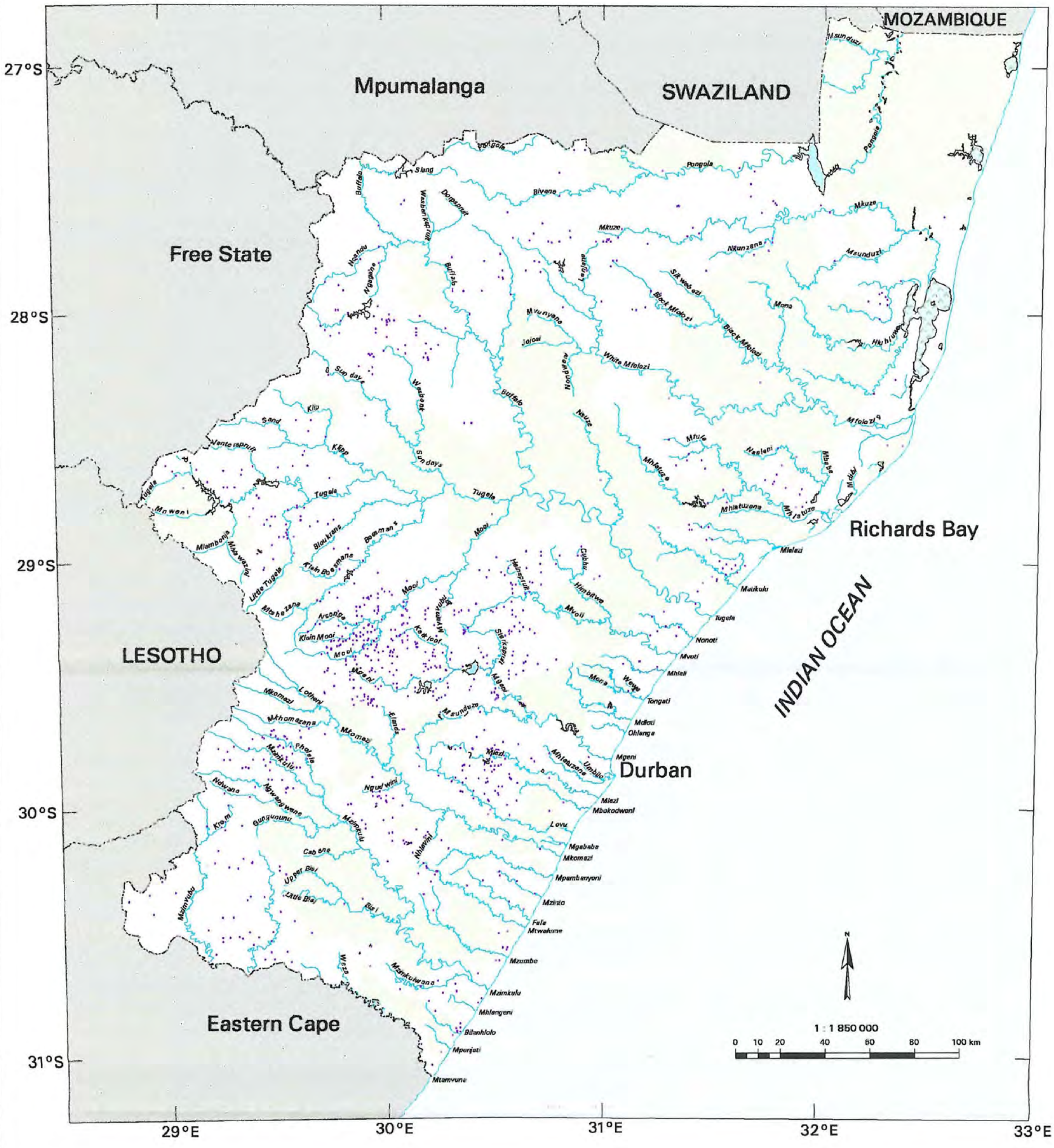
Source of data:
WR90 (Midgley et al., 1990)

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

EVAPORATION DISTRIBUTION
OF KWAZULU-NATAL

Figure 17



- major dams
- natural lakes
- permitted farm dams
- major rivers

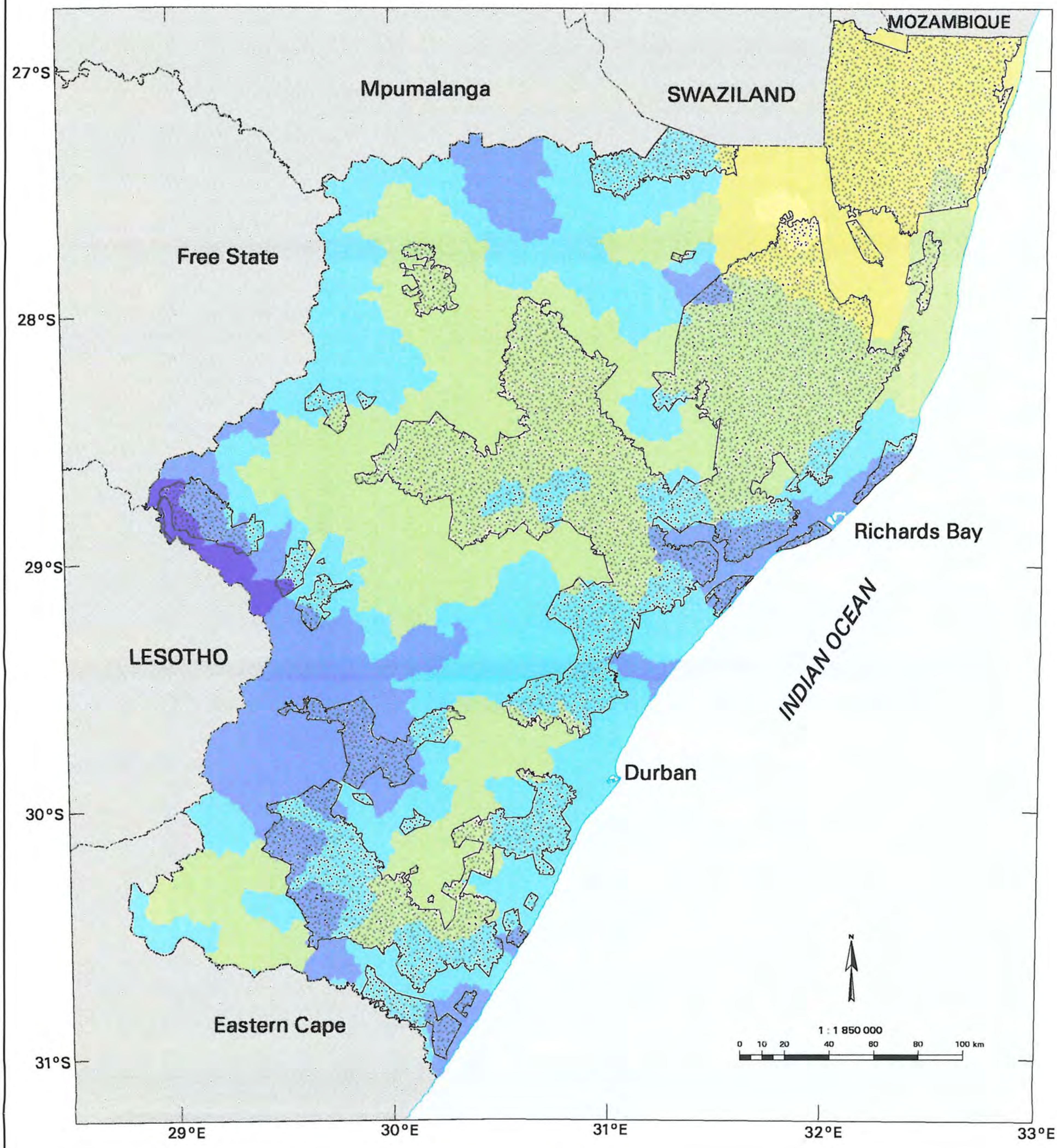
Source of data:
DWAF

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

MAJOR RIVERS, DAMS AND NATURAL LAKE DISTRIBUTION OF KWAZULU-NATAL

Figure 18



rural areas
10 - 20 mm
20 - 50 mm
50 - 100 mm
100 - 200 mm
200 - 500 mm
> 500 mm

Source of data:
WR90 (Midgley et al., 1990)

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF SURFACE RUNOFF PER QUATERNARY CATCHMENT

Figure 19

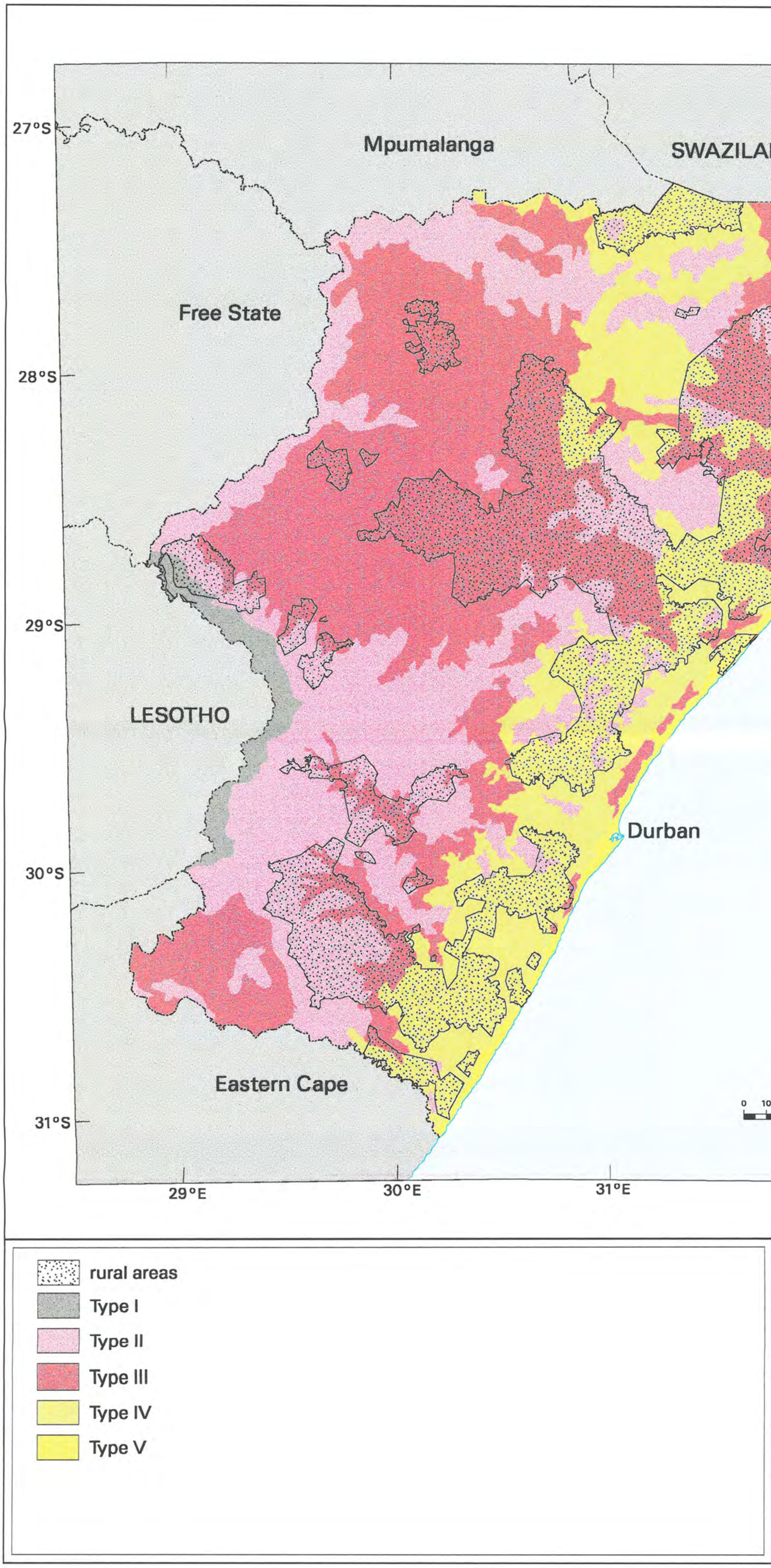
3.5. Soils

Soil characteristics in KwaZulu-Natal are influenced primarily by the parent material of the underlying geology and its formation is affected by factors such as geomorphology, physiography, vegetation and climate. Schulze (1982) points out that it is because of these various interactions that the resultant soils are variable on a local scale. The main classification of soils in South Africa has been described for agricultural purposes by MacVicar *et al.* (1977). This classification is based on a unique vertical sequence of diagnostic horizons of the upper soil level or top soil and the subsoil. All the soils are attributed to a *soil form* and then to a subordinate *series* on the basis of the relevant soil properties which define the classes (MacVicar *et al.*, 1977). For the purpose of this thesis, only the main soil forms in KwaZulu-Natal will be described. The prominent soil patterns given by MacVicar *et al.* (1977), soil groupings by Fitzpatrick (1978) and simple descriptions by Maud (in prep.) are given in Table 16. Figure 20 illustrates the resultant distribution of the simplified soil groupings. As mentioned previously, the geology underlying the different soils has a marked affect on their distribution. This factor is illustrated in Table 17 where the broad soil patterns have been compared with the geology and their percentage distribution given to illustrate each group's importance.

The thickness and clay content of a soil are important factors with respect to recharge processes. A thick soil profile will have a greater capacity to contain water, therefore inhibiting it from infiltrating down to the aquifer. If the soil is clayey or of low permeability, the containment of infiltrating water is increased by the greater adsorption clay has compared to sandy soils. Shrinkage cracks associated with clays will not always provide direct pathways for infiltrating water because they will tend to close up once the clay becomes wet and expands. Recharge to the aquifer can only occur if field capacity is exceeded as discussed in Chapter 4. Work carried out by agriculturists and irrigators has shown that a typical soil of 1m depth has the capacity to contain 100mm of water (Schulze, 1982 and pers. comm. Maud 1996). This implies that recharge through thick and clayey soils is rare, as field capacity can only be exceeded if the rainfall event exceeds 100mm over the short term. Areas of thin soil cover or no soil cover and stream and river channels are thus the most likely places through which recharge is expected to take place.

Table 16. Description of typical forms for the main soil patterns and soil groupings.

BROAD SOIL PATTERNS (from Richards Bay 1 : 250 000 SIRI map)	SOIL GROUPINGS (from Fitzpatrick, 1978)	DESCRIPTION (from Maud, in prep.)	TYPICAL SOIL FORMS (from MacVicar *et al.*, 1978)	SIMPLIFIED GROUPING
not present	1	yellow apedal, freely drained soils occurring at altitude	Champagne Mispah	Type I
A	2, 3	red-yellow apedal, freely drained soils which are usually fairly deep, frequently clayey and occur in areas of high rainfall	Hutton Clovelly Inanda	Type II
B, C, D, E	4, 5, 6, 7, 8, 9,10,11,12, 13	soils with a sandy topsoil abruptly overlying strongly structured clayey subsoil, with or without intervening subsoil ferricrete horizon - usually fairly deep, hydromorphic, lime may be present in the subsoil in low rainfall areas - soil usually occurs on lower slope and valley bottoms and; very dark coloured and red clayey, well structured soils which are moderately deep and have developed on weathered basic rock parent material, lime may be present in low rainfall areas	Avalon Hutton Shortlands Estcourt Sterkspruit Longlands Westleigh Valsrivier Arcadia Bonheim	Type III
F	14, 15, 16, 17, 18	soils with an dark coloured topsoil overlying a weathered rock subsoil - usually shallow to very shallow soils, lime may be present in subsoil in low rainfall areas	Glenrosa Cartref Shortlands Arcadia Avalon Westleigh Mayo Mispah	Type IV
H	19	deep, reddish brown and light coloured apedal sandy soils, usually associated with coastal dunes	Hutton Clovelly Fernwood	Type V



Source of data:
Fitzpatrick (1978)

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF SOILS
IN KWAZULU-NATAL

Figure 20

Table 17. Percentage coverage of the five defined soil groups with the associated predominant lithology.

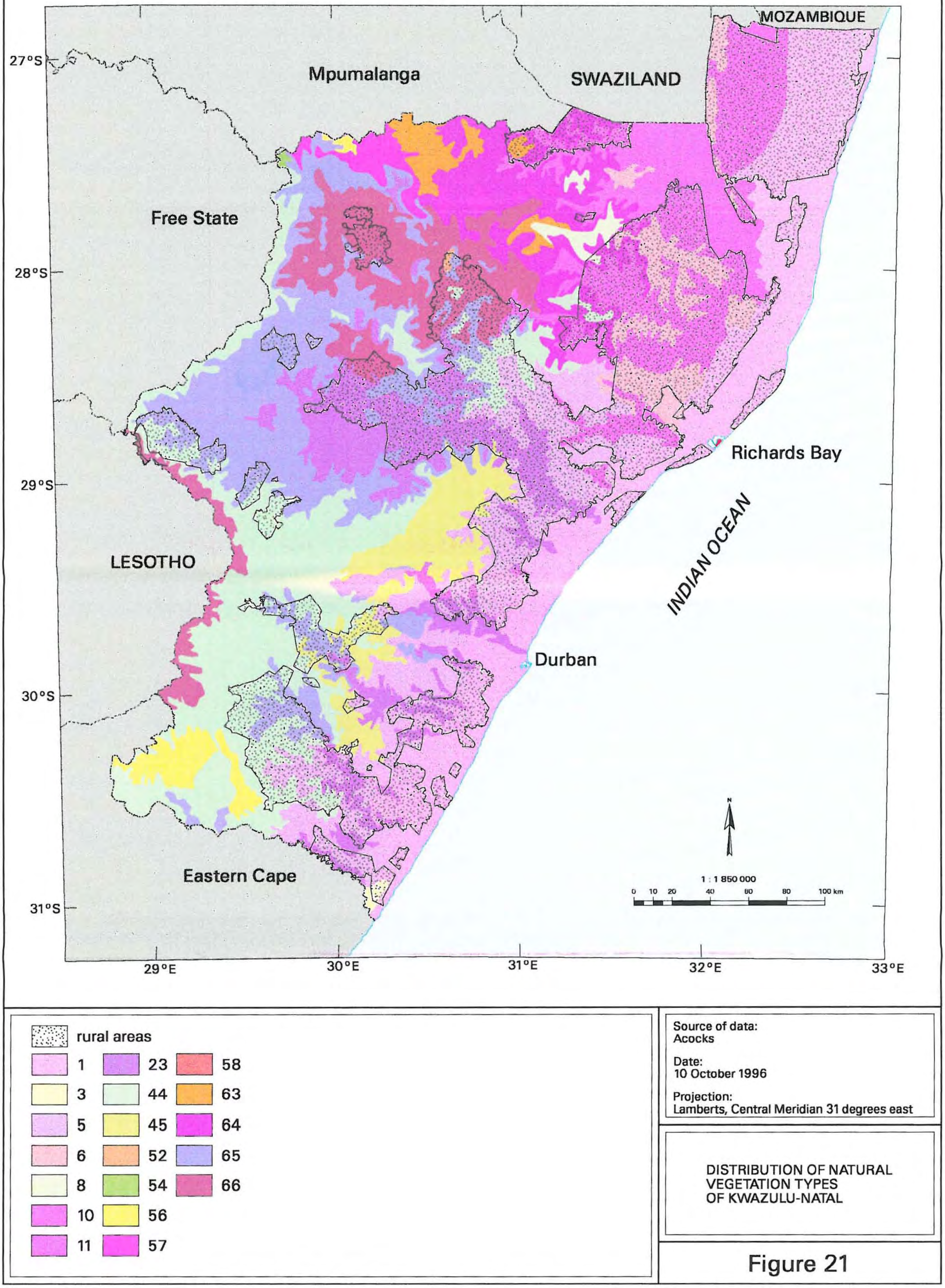
SIMPLIFIED GROUPING	% COVERAGE	PREDOMINANT LITHOLOGY
Type I	2	Drakensberg Group
Type II	25	Karoo Supergroup, Dwyka Group, Natal Group
Type III	43	Karoo Supergroup, dolerite, Lebombo Group, Dwyka Group
Type IV	23	Natal Group, Dwyka Group, Basement rocks
Type V	7	Quaternary sediments

3.6. Vegetation

The distribution of vegetation throughout KwaZulu-Natal is primarily dependent on climate, altitude, aspect, distance from the sea and geology. Table 18 reflects the conditions existing for the various veld types and Figure 21 shows their distribution. These natural veld types have been mapped and described by Acocks (1975) in some detail. It must be noted however, that since Acocks' map was published in 1975 there has been much agricultural development which has altered the distribution of veld types.

Table 18. Physical conditions related to veld type in KwaZulu-Natal (adapted from Acocks, 1975).

ACOCKS VELD TYPE	No.	COVERAGE %	RAINFALL mm/a	ELEVATION m.a.m.s.l.	PROMINENT GEOLOGY
Coastal forest and thornveld	1	15.7	900 - 1500	0 - 450	Zululand and Maputaland Groups, Natal Metamorphic Province (N.M.P)
Pondoland coastal plateau and sourveld	3	0.1	1150 - 1300	400 - 450	Natal Group and N.M.P
The 'Ngongoni veld	5	9.3	750 - 1300	450 - 900	Karoo Supergroup sediments, Natal Group and N.M.P
Zululand thorn veld	6	3.6	750 - 950	150 - 1050	Lebombo Group and Karoo Supergroup sediments
North-eastern mountain sourveld	8	0.6	900 - 1950	-	Karoo Supergroup sediments and dolerite
Lowveld	10	11.6	500 - 750	150 - 600	Zululand, Maputaland and Lebombo Groups, Karoo and Pongola Supergroup sediments
Arid lowveld	11	0.7	needs further study		Lebombo Group and Karoo Supergroup sediments
The valley bushveld	23	9.0	500 - 900	valleys draining to the Indian Ocean	Karoo Supergroup sediments with dolerite, N.M.P
Highland sourveld	44	15.1	750 - 1500	1350 - 2150	Karoo Supergroup sediments with dolerite
Natal mist belt 'Ngongoni veld	45	4.2	900 - 1150	900 - 1350	Natal Group, Karoo Supergroup sediments and dolerite
Themeda veld or turf highveld	52	0.05	650 - 750	1500 - 1750	Vryheid Formation and dolerite
Turf highveld to highland sourveld transition	54	0.05	~750	1700 - 1850	Karoo Supergroup sediments with dolerite
Highland sourveld to cymbopogon-themeda veld transition	56	1.4	650 - 1000	1500 - 2000	Maputaland Group, Karoo Supergroup sediments and dolerite
North-eastern sandy highveld	57	1.2	750 - 950	1600 - 2150	Karoo Supergroup sediments and dolerite
Themeda-Festuca alpine veld	58	1.2	600 - 1900	1850 - 2150	Drakensberg Group, Karoo Supergroup sediments and dolerite
Piet Retief sourveld	63	1.3	750 - 1150	800 - 1700	Karoo Supergroup sediments and dolerite
The northern tall grassveld	64	5.2	-	-	Karoo and Pongola Supergroups
The southern tall grassveld	65	13.4	650 - 900	600 - 1350	Karoo Supergroup sediments and dolerite
Natal sour sandveld	66	6.3	600 - 900	900 - 1350	Karoo Supergroup sediments and dolerite



Source of data:
Acocks

Date:
10 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

DISTRIBUTION OF NATURAL VEGETATION TYPES OF KWAZULU-NATAL

Figure 21

3.7. Demography

KwaZulu-Natal is the third smallest province in South Africa but it contains 22% of the country's population (Figure 22 and Figure 23). This results in the second largest population density in the country, with an average number of 87 people per km^2, in 1991. The demographic data from the 1991 census is displayed in map form as Figure 24.

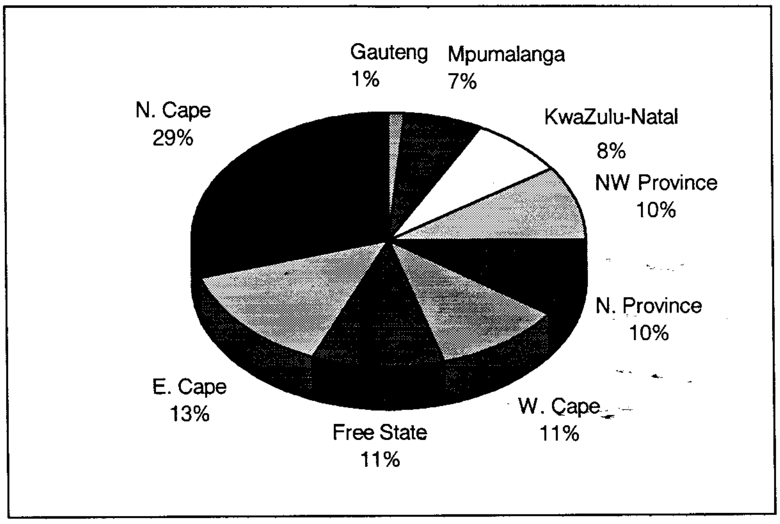


Figure 22. Percentage areas covered by South Africa's provinces.

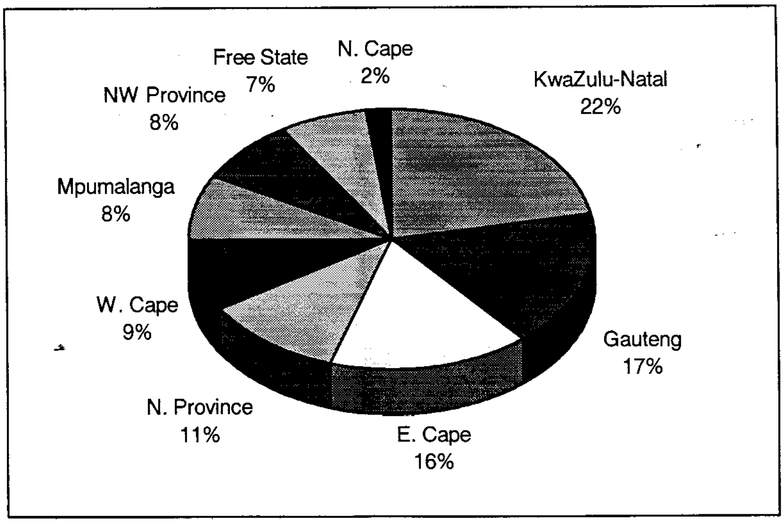
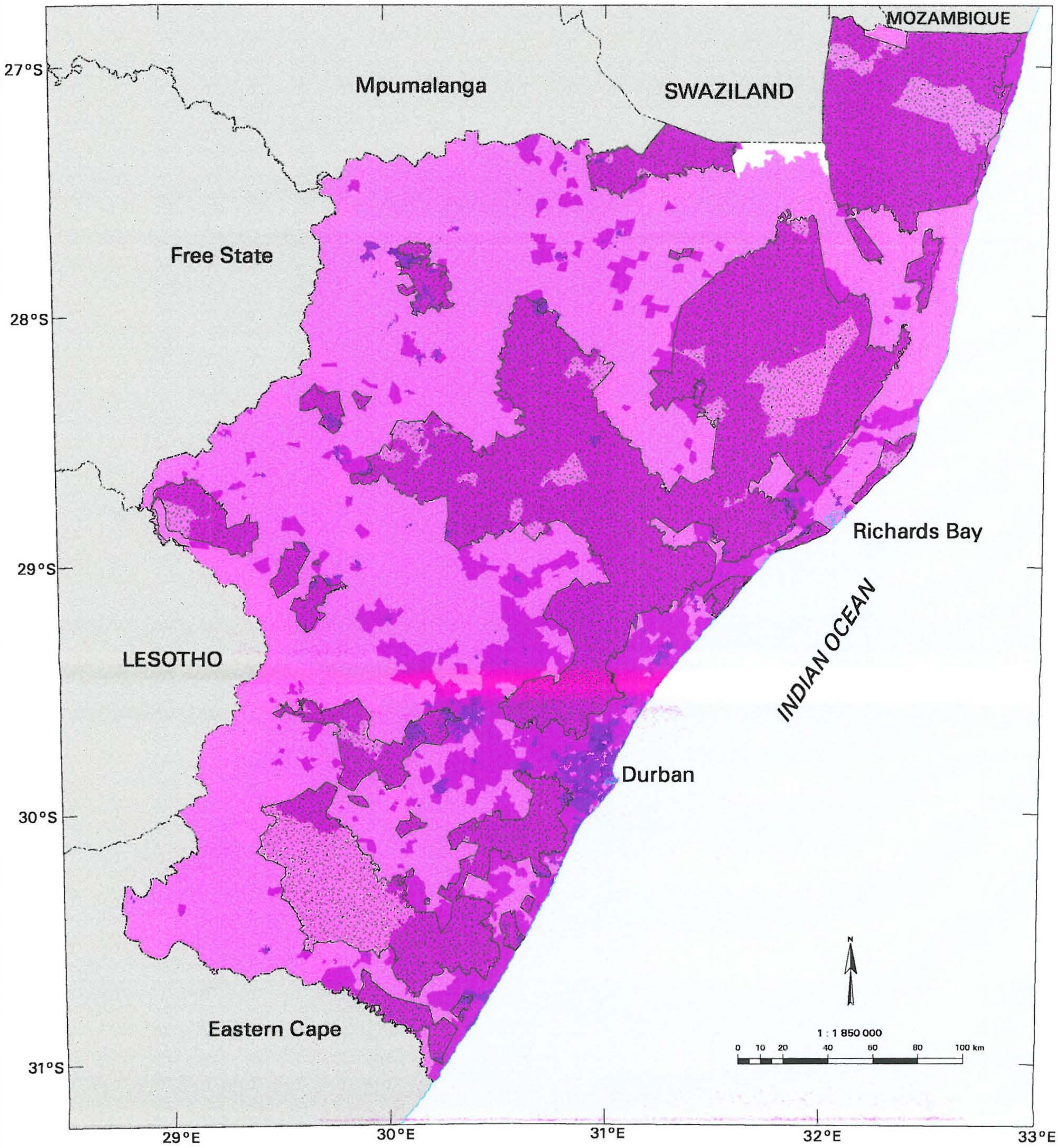


Figure 23. Population distribution by province, 1991 (Meintjes *et al.*,1995).



- rural areas
- < 3
- 3 - 20
- 20 - 500
- 500 - 10000
- > 10000
- no data

Source of data:
1991 Census

Date:
12 October 1996

Projection:
Lamberts, Central Meridian 31 degrees east

POPULATION DENSITY
DISTRIBUTION OF KWAZULU-NATAL

Figure 24

The major process affecting rural areas is a rapid population out-migration of approximately 2.2% p.a. This has had the effective result of a small net migration into peripheral areas, relative rapid growth of the Durban Functional Region (DFR) and a rapid growth in informal settlements throughout KwaZulu-Natal (Seneque, Smit & Maughan-Brown, 1995). All these trends point to the complex migration patterns prevalent in KwaZulu-Natal.

Population decline in rural areas seems to be associated with growth in agriculture, where processes of capital intensification may be leading to a decline in the labour demand and, therefore, a long-term declining population (Seneque, Smit & Maughan-Brown, 1995). Contrary to the expectations of demographers, however, there has been a small net in-migration into some rural areas. Table 19 presents the rural districts experiencing growth. Figure 25 provides a map of the rural or former KwaZulu districts of KwaZulu-Natal. People migrating from Mozambique into Northern Zululand have noticeably played a role in increasing rural populations in the Ingwavuma and Ubombo districts.

Other reasons for migration to rural areas appear to be the displacement of people from the 'advantaged' rural areas and coal fields to the 'disadvantaged' rural areas, especially where land is seen to be available (Seneque, Smit & Maughan-Brown, 1995).

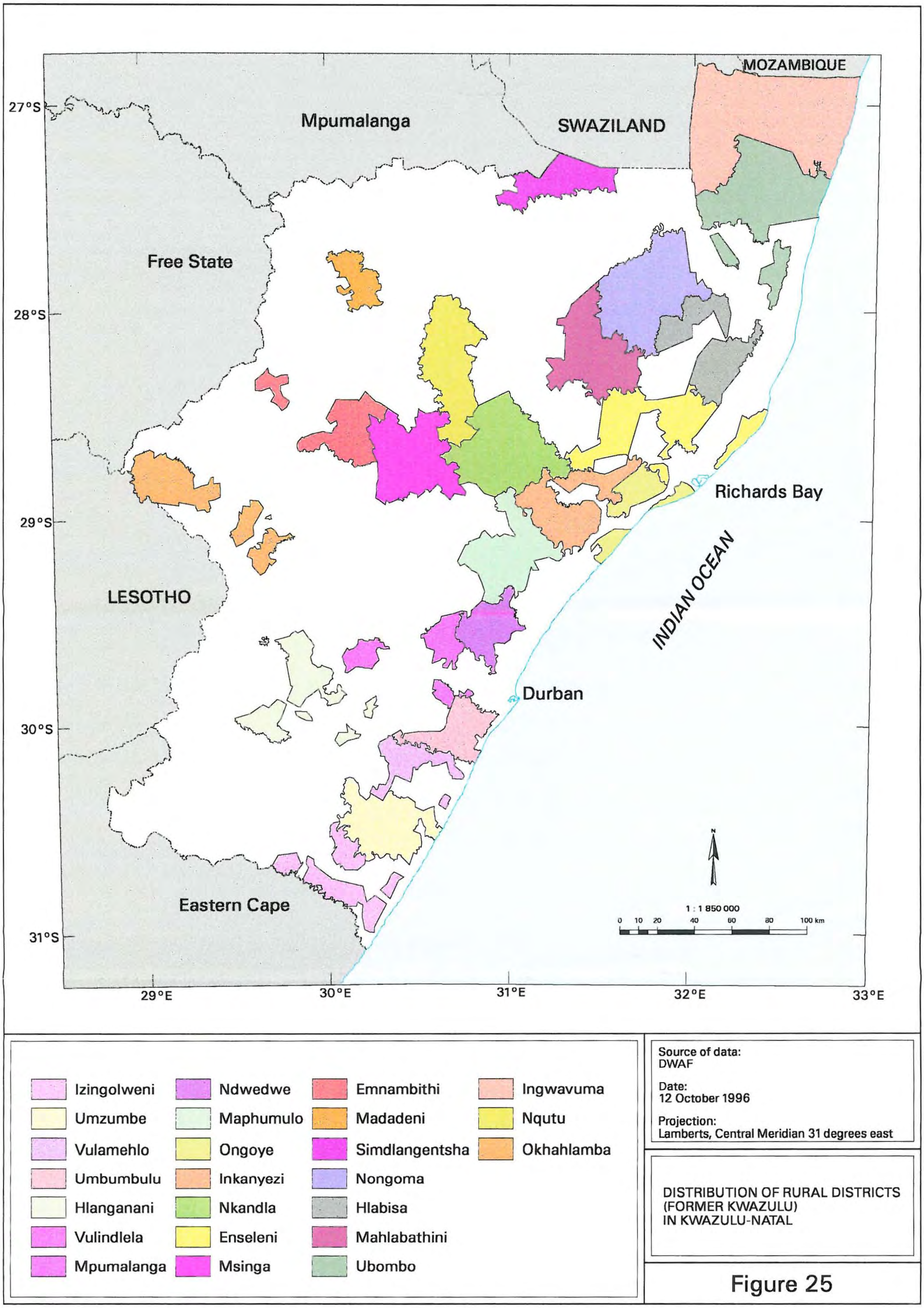
Interestingly, some peripheral rural areas, especially the former Transkei and southern districts are experiencing a net out-migration, possibly as a result of drought and violence. The effect of droughts on out-migration from rural areas is not clear. It is possible that through a combination of crop and stock loss and the difficulty in obtaining water for domestic use, greater numbers of people may have moved out than would otherwise have been expected.

The high growth rates of rural districts, such as Mapumulu and Hlabisa (Table 19) are possibly related to their close proximity to urban centres. Seneque, Smit & Maughan-Brown (1995) suggest that this could be a result of these areas being suitable for people to commute weekly, if not more frequently, to the urban centres for employment. Growth rates may also be attributed to displacement from 'advantaged' rural areas and the natural birth rate. It is extremely difficult to determine what percentage natural growth, due to births, contributes to the overall growth rate in rural areas (pers. comm. Department of National Health and

Population Development, 1996). The reason for this difficulty is due to the large number of unrecorded births in rural areas. However, a figure of one child being born every 26 seconds in South Africa is quoted by the Department of National Health and Population Development as a national overall statistic.

Table 19. Growth in rural KwaZulu districts over the period 1980-1991 (Seneque, Smit & Maughan-Brown, 1995).

AREA	% RURAL GROWTH PER YEAR
Peripheral	
Ingwavuma	2.9
Ubombo	3.1
Nongoma	2.2
Nkandla	2.8
Msinga	2.2
Hlanganani	3.7
Vulamehlo	1.1
Mahlabatani	2.5
Limited Urban Linkage	
Hlabisa	3.4
Simlandgentsha	5.0
Mapumulu	3.0
Adjacent to Major Centres	
Nqutu	4.2
Enseleni	2.6
Inkanyezi	1.8
Ongoye	3.4
Emnambithi	1.4
Ohlahamba	4.4
Ezingolweni	1.0
Emzumbe	1.6



DISTRIBUTION OF RURAL DISTRICTS
(FORMER KWAZULU)
IN KWAZULU-NATAL

Figure 25

Predictions of macro demographic trends from 1985 to 2030 reveal that on average, a population growth rate of 2.4% p.a. can be expected throughout the province (Meintjes *et al.*, 1995). Although the studies have shown that urbanisation is dominant, the absolute size of the rural population will not decline. It is speculated that there may, in fact, be a reverse flow of migration to rural areas as a result of urban unemployment (Seneque, Smit & Maughan-Brown, 1995). Suggested strategies to deal with increasing rural populations are:

i. restructuring the commercial agricultural sector;

ii. promoting non-farm activities; and

iii. delivery of services and infrastructure.

It has also been recognised that HIV/AIDS will have an affect on demography, the demand for certain services and economics of the province, (Whiteside, 1995). A study carried out by the Economic Research Unit of the University of Natal (Whiteside, 1995) revealed that KwaZulu-Natal has the highest levels of HIV and reported AIDS cases in the country. It was also projected that by the year 2000, KwaZulu-Natal will have 9.5 million people infected with HIV. Therefore the estimation of future population sizes for rural water supply must take into account the effects of the HIV epidemic. Due to the backlog of present services, the provision of services to rural communities does not need to be adjusted to take into account potentially decreasing populations. There will, however be a definite increase in demand in the spheres of health care and social services which would need to be planned for.

The delivery of services and infrastructure is one of vital importance to this thesis. Surveys suggest that access to facilities in rural areas of KwaZulu-Natal is lower than that for the rest of South Africa (Seneque, Smit & Maughan-Brown, 1995). One of these particular problems is water supply. It is also pointed out that the level and standard of the proposed infrastructure should be appropriate to rural affordability, and that the design principles should take into account the mobility of rural communities.

If the estimated percentages of population distributions given by Seneque, Smit & Maughan-Brown (1995) of 26% for informal urban, 29% for formal urban and 45% for rural areas are accurate, using calculated population figures of 8 632 300 for 1995, there were 3 884 535 people living in rural areas. This implies that given 25l/day per person, a minimum of 100

Ml/day of water should be supplied to the rural population of KwaZulu-Natal in order to achieve the goals of the White Paper.

Overall, the population in the province is increasing, with the rate of growth in urban areas being about three times that of rural areas. However, the growth of informal settlements, which comprise just over a third of the total urban population, far surpasses that of the formal areas. In planning water supply for the future, it must be expected that two thirds of the population of KwaZulu-Natal will be living in non-formal conditions by 2020, either on the urban fringe in shack settlements, or in rural areas (Seneque, Smit & Maughan-Brown, 1995). This will prove to be a challenging water supply problem which should be planned for in advance.

3.8. Land-use

Many types of land-use activities are carried out over the province of KwaZulu-Natal. Typical land-use types include residential, industrial, conservation and agricultural. Within the category of agricultural land-use, different types of agriculture are practised. The two main divisions of agricultural activity are the farming of livestock and crops. The amount of land used for crop growing is larger than that for livestock rearing. Forestry, sugar cane, maize and sisal farming are the main products of crop farming throughout the province. Livestock farming concentrates on cattle, poultry, goats, sheep and dairy production.

'Disadvantaged' rural areas, in particular, are characterised by their low diversity of land-use types. The majority of rural areas can be described as being used for subsistence cattle and goat rearing, together with dry-land maize subsistence farming. Very few rural areas are afforested even though there have been efforts made by large commercial forestry and sugar cane farming organisations to encourage co-operative farming with the local rural people. Industrial activity within rural areas is also very limited or non-existent. It must be noted however, that even though land-use activities in rural areas, on a regional scale have a relatively low pollution risk, at a more local level one of the most detrimental practices in the majority of rural KwaZulu-Natal is improper sanitation. Also, the effects of neighbouring 'high-risk' land-uses, such as industry, must be recognised as having often negative impacts on rural areas.

4. PRINCIPLES OF HYDROGEOLOGY

4.1. Groundwater in the hydrological cycle

Groundwater forms an integral part of the hydrological cycle. This cycle involves the continuous circulation of water between oceans, the atmosphere and the land (Figure 26). The processes through which surface water becomes groundwater need to be explained in order to understand the occurrence and distribution of groundwater.

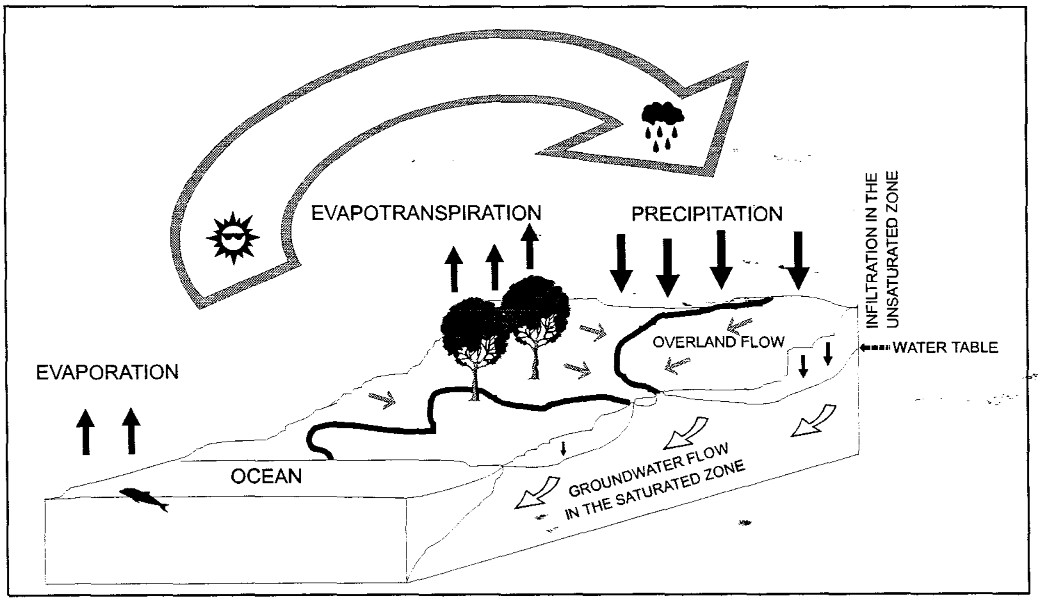


Figure 26. Groundwater in the hydrological cycle.

Condensing water vapour in the atmosphere causes precipitation. Most of the falling precipitation will reach the earth's surface, the rest will evaporate or be intercepted by vegetation or man-made structures from where it will be returned back into the atmosphere through evaporation. Precipitation which does not evaporate will reach the earth's surface. Initially, it may remain on the surface as depression storage and surface moisture to be evaporated back into the atmosphere. Alternatively, if infiltration is limited by either an intense rainfall event, soil infiltration capacity or high gradients, the surface water may flow over the earth's surface as surface run-off. Most surface run-off makes its way towards rivers and streams, and ultimately the ocean. Some run-off may enter the subsurface as transition losses, some by abstraction and some by evaporation. Both stationary and moving surface waters may enter the subsurface by infiltration. Once these infiltrating waters pass the unsaturated zone and reach the saturated zone it can be called groundwater. Groundwater re-emerges at the surface in the form of springs or baseflow where the groundwater table or piezometric surface of a water bearing zone intersects the ground surface or stream channels respectively. All the described processes are illustrated in Figure 27.

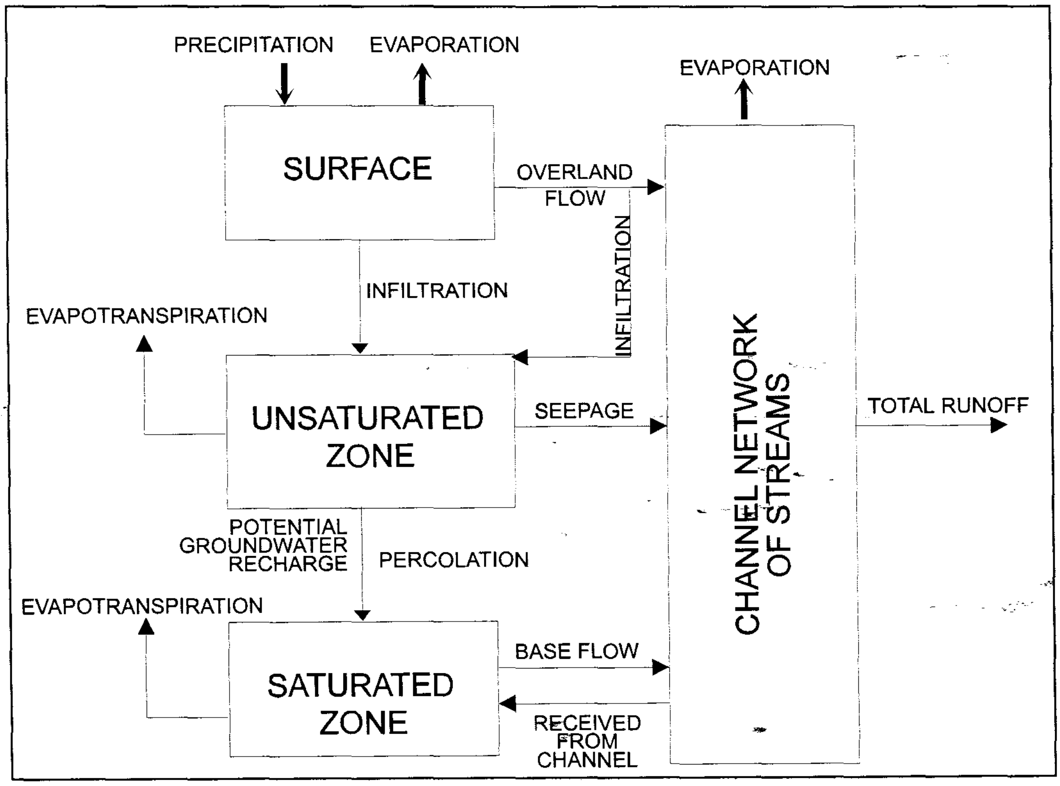


Figure 27. Simplified hydrogeological processes (adapted from Domenico and Schwartz, 1990).

The hydrological cycle is a dynamic and closed system which can be modelled by a simple water balance equation for a specified time period (Rushton and Ward, 1979):

$$\Delta S = P - R - E \qquad \textbf{4.1}$$

where

ΔS = change in stored water or soil water replenishment [L]

R = run-off [L]

P = precipitation [L]

E = evaporation (including evapotranspiration) [L]

The resultant water available, from eq. 4.1, as recharge moves downwards by the force of gravity through a number of subsurface zones towards the potential aquifer. The equation representing recharge is therefore:

$$\text{recharge} = P - R - E \pm \Delta S \qquad \textbf{4.2}$$

There are four possible means of recharge to groundwater. These are i) direct recharge through the soil profile, once the field capacity of the soil has been exceeded; ii) indirect recharge from run-off through surface or near surface fractures; iii) indirect recharge through run-off ponding; and iv) indirect recharge through transmission losses during river run-off and floodout (Lloyd, 1986). Direct recharge is the only recharge process which involves exceeding the field capacity of the soil and therefore results in micropore flow. The indirect processes require macropore flow to recharge groundwater when field capacity is not exceeded.

The uppermost zone of unsaturated material is known as the vadose zone. This zone is partially filled with both air and water. Water found in the uppermost part of the vadose zone is called soil moisture and is the zone from where plants mainly extract water (Figure 28). Soil moisture is affected mostly by transpiration and evaporation which causes both an upwards movement by capillary action and by downward percolation by gravity. In porous materials, the intermediate zone separates the soil moisture zone from the saturated zone. In this zone, the movement is controlled by gravity. Sometimes the intermediate zone may not exist in moist environments where plants can abstract water from the water table or may be more than 300m thick in arid environments (Davis and DeWiest, 1966). The capillary fringe is found at the base of the unsaturated zone. Capillary water is water held above the water table by surface tension. This surface tension is the attractive force exerted at the interface or surface between materials in different physical states, such as soil and water. The capillary fringe is saturated but exists at a pressure less than atmospheric pressure. The contact between the capillary fringe and the saturated zone is the water table and the pressure exerted is equal to atmospheric pressure (Figure 28). Below the water table all the openings in the rock or soil are completely saturated and under pressure greater than atmospheric pressure.

In fractured rock a slightly different situation exists as the zone below the soil moisture zone consists of temporarily, partially saturated jointed and fractured features above a discontinuous water table (Figure 28). The saturated zone, below the unsaturated zone can be spatially variable due to the movement of groundwater being restricted to zones of permeability which are not uniform through out the entire rock formation.

Below the saturated zone in both porous and fractured media, groundwater is found in the unconnected pores or fractures respectively. At even greater depths, groundwater is not found in the interstices but is found in chemical combination with the rock.

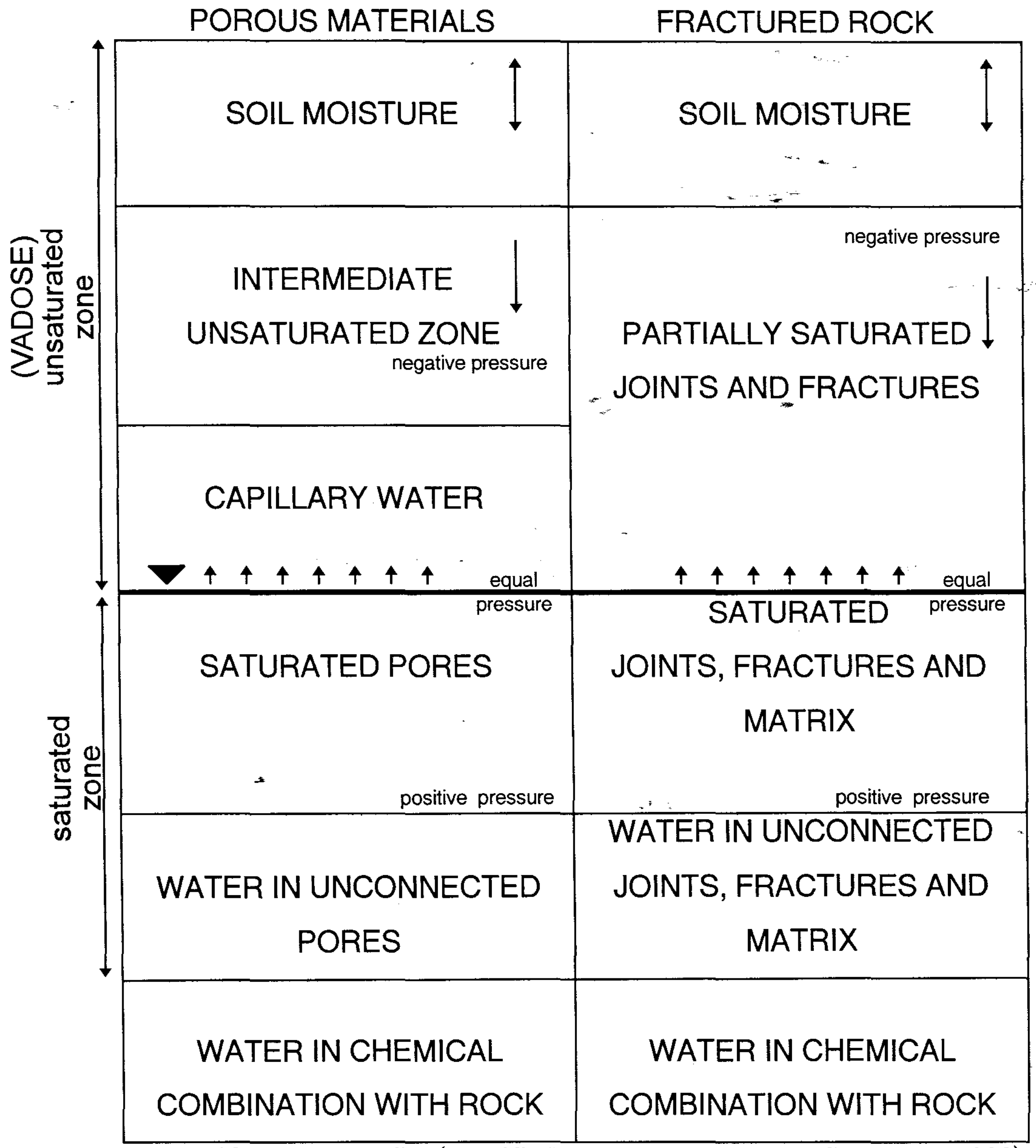


Figure 28. Water profile (modified from Domenico and Schwartz, 1990).

4.2. Aquifers, aquitards and aquicludes

Not all saturated zones will yield usable amounts of groundwater. The occurrence of the saturated zones in many rocks is spatially variable in terms of their hydraulic properties. It is often the porosity and permeability of the rock type that dictates whether the groundwater within a particular rock is economically usable. An aquifer occurs where there is a saturated geological unit which is capable of transmitting and yielding groundwater in sustainable and economic quantities. Rock and soils which store but do not transmit groundwater in sustainable or economic quantities are called aquitards, or aquicludes when they are unable to both store and transmit groundwater.

An aquifer may take the form of unconsolidated sediments, weathered rock or fractured consolidated rock. The ability of these materials to transmit water depends on their internal structure or interstices. Interstices are the void spaces in rock and sediment in which water may be stored and/or transmitted. Primary aquifers are those through which water is transmitted in the original pores or interstices created contemporaneously with formation. These types of aquifers include unconsolidated sediments such as sand and clay, and rocks such as some sedimentary and igneous rocks with significant primary porosity.

Secondary aquifers in which hydraulic characteristics are the result of post-formational processes which have acted upon the rock to induce interstices which previously did not exist. Examples of these processes are tectonic deformation, weathering and unloading stresses. Most aquifers in South Africa fall into this category.

Due to the nature of most aquifers, they cannot be assumed to be of infinite extent. There will be places where aquifers and aquitards laterally change or pinch out, are incised into by surface water channels, or are faulted. These features result in aquifers and aquitards being laterally bounded.

4.3. Physical properties of porous media

The following section describes the inherent physical properties of geological materials which determine their water storage and water-bearing capabilities.

4.3.1. Porosity

The porosity of a material is determined by the ratio of the volume of void space to the total volume of material, which includes voids and solids. It is the property of porosity that determines the ability of an aquifer to store groundwater.

A material with a high porosity may not necessarily have a high permeability. This is the case if the pore spaces are not interconnected, such as some porous basalts, or where the pore spaces are interconnected but are also very small, such as clays. Effective porosity is the portion of porosity that affects the permeability of the material and is defined as the fraction of interconnected pore spaces within the material which transmit groundwater, as opposed to total porosity which does not take into account pore connections.

In primary, mainly unconsolidated, aquifers the major factors affecting porosity are the packing of the grains, their shape, arrangement, sorting, size distribution and the degree of cementation. In igneous and metamorphic rocks, small cavities or inclusions within crystals and small inter-crystal spaces are controlling factors of primary porosity.

Secondary porosity develops in materials which have been subjected to secondary processes, such as shrinkage, mineralisation, unloading, solution, fracturing, weathering, deformation and igneous intrusion. Successional unconformities between different rock types are also the site of potential porosity where voids have been left after weathering and prior to deposition of the following formation. Generally, secondary porosity is developed by the same processes which have resulted in the formation of secondary aquifers. Typical porosity types are shown in Figure 29.

4.3.2. Permeability and hydraulic conductivity

The degree of connectivity of pores in rock and soil affects the permeability (k) of that material, i.e. the ease with which fluid can move through the material. Other factors affecting permeability are particle-size distribution, shape and orientation of particles, pore size and degree of saturation. Permeability is therefore a function of the medium alone.

The unit of measure of permeability is the darcy, with the dimension of [L^2]. One darcy is defined as the permeability required to obtain a specific discharge of 1 cm/s for a fluid with a viscosity of 1cp under a hydraulic gradient that makes the term $\rho g\ \delta h/\delta l$ equal to 1 atm/cm (Freeze and Cherry, 1979). One darcy approximates to $10^{-8}cm^2$.

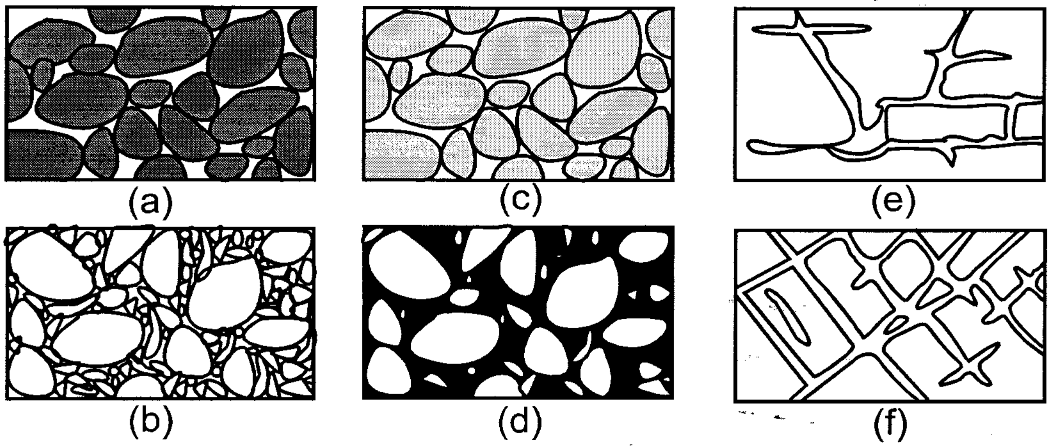


Figure 29. Interstices in rocks and the relation of texture to porosity. (a) well-sorted sedimentary deposit with high porosity; (b) poorly sorted sedimentary deposit with low porosity; (c) well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity; (d) well-sorted sedimentary deposit whose porosity has been decreased by mineralisation in the interstices; (e) rock rendered porous by solution; (f) rock rendered porous by fracturing (after Meinzer, 1942).

Another property which is similar to permeability is hydraulic conductivity (K) with the dimension of [L/T]. Hydraulic conductivity is defined as the permeability of the medium to water or rate of water flow through a cross-section of one square metre under a unit hydraulic gradient at 20°C (Davis and DeWiest, 1966). This reflects the properties of both the medium and the fluid, whereas the permeability reflects the properties of the medium only. The ranges of permeability and hydraulic conductivity for various materials is given in Figure 30.

When hydraulic conductivity is uniform in all directions, the material is termed isotropic. In most cases rocks and soils are anisotropic, that is they have a directional quality of permeability. Structures that may cause anisotropy may be foliation or schistosity in metamorphic rocks, cooling cracks in igneous rocks, bedding planes in sedimentary rocks, clay lenses in sandy materials, fractures and joints. Other factors influencing anisotropy include the orientation of the structures and pressures exerted by overlying materials.

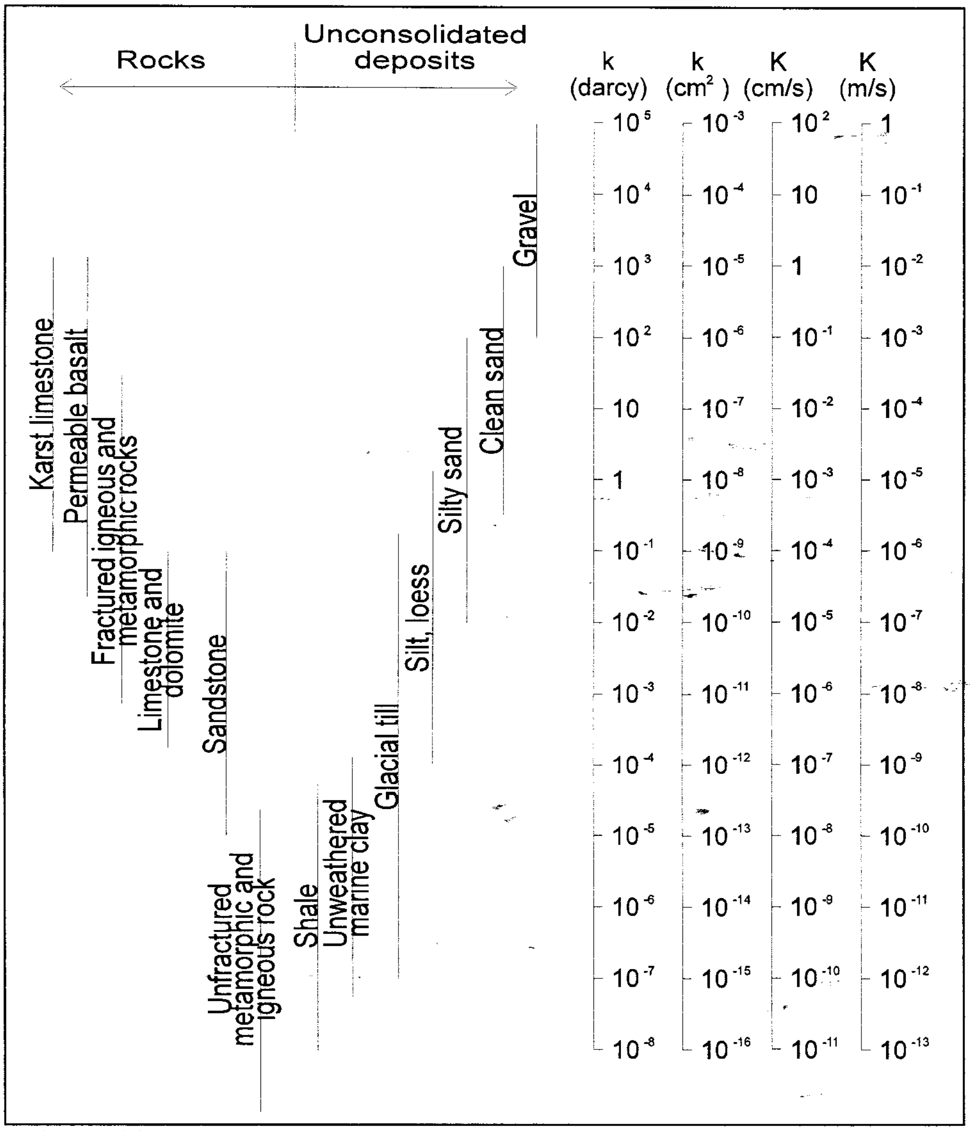


Figure 30. Range of values of permeability and hydraulic conductivity (from Freeze and Cherry, 1979).

An aquifer is considered homogeneous if the permeability is spatially uniform in both the vertical and horizontal directions within the aquifer. Heterogeneous materials, on the other hand, are those which do not conform to homogeneous materials. As truly homogeneous conditions are rare, a number of different heterogeneous conditions have been described by Freeze and Cherry (1979). These include trending heterogeneity which refers to a progressive change in hydraulic conductivity within a particular lithology over distance. This situation develops, for example, in sedimentary rocks where abrupt or transitional facies changes occur.

Where contrasting hydraulically conductive materials are found due to changes in depositional environments, such as interlayered shales and sandstones, layered heterogeneity prevails. Fractured rock offers a discontinuous heterogeneity by its contrasting hydraulic conductivity as the fractures provide preferential flowpaths within the surrounding rock of much lower hydraulic conductivity. Changes in permeability caused by lenses of clay within sands or zones of weathering within crystalline rock also give rise to discontinuous heterogeneity.

Transmissivity is the aquifer characteristic that is commonly used to describe the rate at which a volume of water of the prevailing kinematic viscosity is transmitted through a unit width over the whole thickness of an aquifer under a unit hydraulic gradient [L^2/T]. Simply, the transmissivity of an aquifer is the vertically integrated hydraulic conductivity or permeability of the aquifer over the saturated thickness of the aquifer.

4.3.3. Fracture flow

Fractures are features which form as a function of the rock's tectonic history and competency. The term encompasses both joints and faults. Fracturing generally occurs when the development of cracks causes loss of the original cohesion (Hobbs *et al.*, 1976). A fault is a fracture where displacement has taken place. After fracturing or faulting, the parting may be filled with secondary mineralisation such as calcite, pyrite, quartz or fault breccia. The type of tectonic forces, be they compressional or tensional, will influence the water-bearing properties of fractures. Tensional forces within the earth's crust are the most likely to produce open fractures, while compressional forces will tend to close fractures.

Groundwater flow in fractured rock is primarily through the interconnected fractures in the rock mass with the flow in the unfractured rock mass being much less. It is the fracture properties of orientation, density, aperture opening, smoothness of fracture walls and degree of connectivity which ultimately determine the transmissivity of a fractured aquifer.

Fractured rock is often considered to be a multi-porous medium (Kruseman and de Ridder, 1991). Essentially, there are two components of fractured rock mass, the matrix block and the fractures (Figure 31). The matrix is usually impermeable or of low permeability but has a higher capacity for storage, whereas the fractures usually have a low storage capacity but a high hydraulic conductivity.

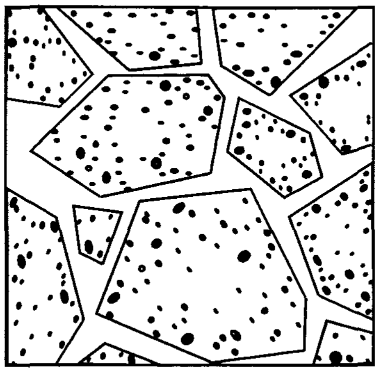


Figure 31. Fractured rock concept of broken rock mass, of irregular size and shape, by fissures (from Boulton and Streltsova, 1977).

4.3.4. Approaches to flow in fractured rock

The conceptualisation of groundwater flow in fractured rock follows either the continuum or discontinuum approach. The continuum approach assumes that the fractured mass is hydraulically equivalent to a porous medium, while the discontinuum approach assumes that the conditions for a continuum approach do not exist and therefore treats flow through individual fractures or fracture sets separately (Domenico and Schwartz, 1990).

By assuming a continuum approach, Darcy's law which was developed at a macroscopic scale in a porous medium can be applied without needing to evolve any new theories. The macroscopic scale is defined as the representative volume of material that contains a statistical average of a hydraulic property which smoothes out microscopic variations resultant from flow variations in individual pores or fractures (Domenico and Schwartz, 1990). To achieve macroscopic conditions in fractured rock, a small volume of the aquifer cannot be sampled as it will be entirely made up of either fractures or else solid rock, a large volume will contain both fractures and solid rock of different proportions. As the volume of rock changes, at a certain point spatial homogeneity may be achieved. Figure 32 illustrates how it possible to obtain a representative volume at several scales. On the other hand, it may not be possible to obtain a representative volume for fractured rock at all. If this is the case, the flow within each fracture needs to be described. This requires characterising all aspects of the fractures and taking into account possible turbulent flow and variations of hydraulic conductivity.

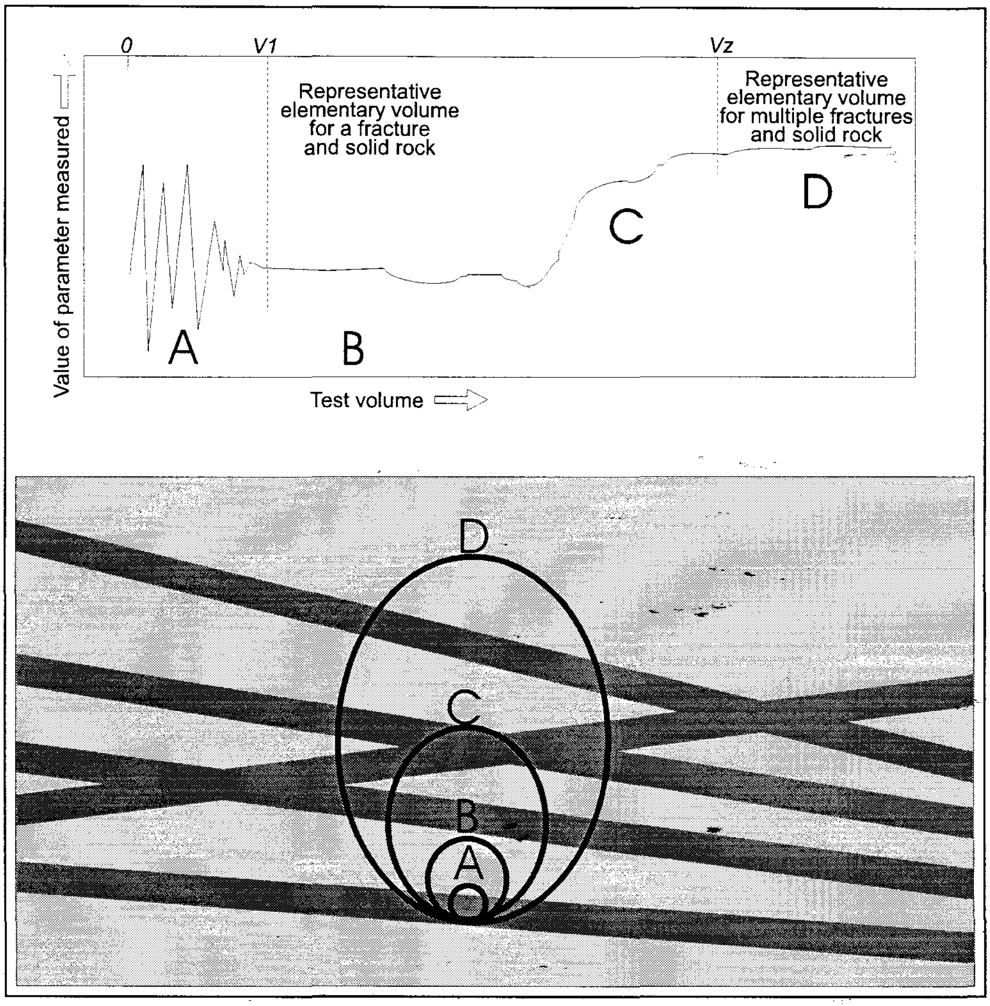


Figure 32. Schematic definition of a representative elementary volume as applied to fractured rock (adapted from Domenico and Schwartz, 1990).

4.4. Hydraulic response of porous media

Once the physical properties and dimensions of porous media have been established it is important to determine the aquifer's hydraulic properties in order to quantify its response to induced stress. Primarily, it is micro-geology and hydraulic conditions which control the properties of aquifers.

4.4.1. Hydraulic head

Differences in elevation and hydraulic pressure cause groundwater to move from levels of higher energy to levels of lower energy. The energy per unit weight of fluid is referred to as hydraulic head. The position of the hydraulic head at any point in the saturated zone is defined by the Bernoulli equation:

$$gz + \frac{P}{\rho_w} + \frac{\upsilon^2}{2} = \text{constant} \qquad \textbf{4.3}$$

where

g = acceleration due to gravity (M/L^3)

z = elevation at the base of the piezometer (L)

P = pressure exerted by the water column (M/L^2)

ϱ_w = fluid density (M/L^3)

v = velocity (L/T)

This equation states that under conditions of steady flow, the total energy [L^2/T^2] of an incompressible fluid is constant at all positions along a flow path in a closed system (Domenico and Schwartz, 1990). If the equation is divided by g, the three terms of the equation are referred to as elevation head, pressure head and velocity head respectively with units of [L]. The elevation head simply represents the elevation at the base of a measuring piezometer above a datum. It therefore represents the work required to increase the elevation of a unit weight of water from the datum to the elevation of the piezometer base. The pressure head represents the work that a fluid is capable of doing because of sustained hydraulic pressure related to the height of the column of water above the measuring point. The sum of the elevation and pressure head is called the total head, hydraulic head or potential energy due to fluid motion. The third term, velocity head, is so small due to slow groundwater velocities that it can be ignored (Domenico and Schwartz, 1990). Hydraulic head is therefore a response to physical conditions. An increase in hydraulic head is usually a result of increased storage or changes in response to increases in pressure head.

The position of the static water level or hydraulic head relative to the upper vertical boundary of the aquifer is another method of classifying aquifers. When the static water level forms the upper boundary of the aquifer, it is termed unconfined. This means that the water is in direct contact, vertically, with the atmosphere through open spaces in the overlying material. The water table or phreatic surface is therefore unimpeded by overlying materials and is free to fluctuate. In other words, this surface can be defined as the surface of atmospheric pressure (Todd, 1980). Where groundwater is confined under pressures significantly greater than atmospheric pressure by a layer of distinctly lower permeability than the material in which the water occurs, the aquifer is called a confined aquifer (Vegter, 1995). Due to the confining pressures, the hydraulic head in the piezometer will be above the upper vertical aquifer boundary. The piezometric surface is defined as an imaginary surface coinciding with the hydraulic head in the aquifer (Todd, 1980). Artesian boreholes result when the piezometric surface of the borehole occurs above the ground surface. This could be due to confining pressure resulting from the borehole being hydraulically connected to its recharge area, which occurs at a greater elevation than the top of the borehole.

A unique type of confined condition contributes to another type of aquifer, called a semi-confined or leaky aquifer. A leaky aquifer will occur vertically adjacent to an aquitard, from which water moves downwards into the aquifer given sufficient hydraulic gradient between the two formations. The piezometric surface will, similarly to confined conditions, occur above the upper vertical aquifer boundary.

Perched water tables are often encountered above clayey or heterogeneous materials and can be confused with the regional water level in shallow boreholes. These perched conditions occur when infiltrating water encounters a relatively impermeable layer which impedes drainage. This layer can be a clay layer or an impervious rock which acts as a discontinuous aquiclude. Percolating water will be trapped above the aquiclude resulting in a local zone of saturation bounded by unsaturated conditions. The perched water is not in hydraulic continuity with other ground or surface waters, although overflow into the aquifer or emergence as a spring below can occur. Conditions that are favourable for the formation of perched water tables are high infiltration rates and large variations in vertical permeabilities. The period of time that the water will remain perched depends on the permeability and thickness of the impermeable layer, the ability of the aquiclude to retain water and recharge conditions. Due to the shallow nature of perched water, it is easily polluted and not sustainable in terms of water supply because of its limited extent.

4.4.2. Storativity

The piezometric behaviour of confined and unconfined aquifers differs due to their different responses to the release of groundwater from storage. In confined aquifers, a reduction in hydraulic head does not necessarily dewater the pore spaces, provided the water level remains above the top of the aquifer. Instead, when groundwater is released from storage the piezometric response is related to the compaction of the entire saturated thickness of the aquifer caused by a decrease in effective stress and the expansion of water caused by decreasing fluid pressure (Freeze and Cherry, 1979). The amount of water released from storage per unit drop in hydraulic head will therefore be related to the coefficient of expansion of water and the coefficient of compressibility of the material. The storativity of confined aquifers is defined as the volume of water that the aquifer releases from storage per unit surface area of aquifer per unit decline in the component of hydraulic head normal to that surface (Freeze and Cherry, 1979). Specific storativity in confined aquifers is defined as the volume of water released from storage per unit volume of the aquifer per unit decline in the piezometric head.

Unconfined aquifers release groundwater from storage through dewatering of the pore spaces in addition to the process described above (Freeze and Cherry, 1979). The storativity of unconfined aquifers, also known as specific yield, is the volume of water released from storage per unit area per unit decline in the water table (Kruseman and de Ridder, 1991). Since porosity controls the storativity of unconfined aquifers, their storativity is higher than that of confined aquifers (Freeze and Cherry, 1979). Table 20 presents values of specific yield for different unconsolidated materials. The storage coefficient or storativity (S) of an aquifer is dimensionless, as it involves a volume of water per volume of aquifer.

Table 20. Typical values of specific yield for unconfined aquifers (adapted from Kruseman and de Ridder, 1991).

MATERIAL	SPECIFIC YIELD%
gravel	23 - 25
sand	23 - 27
silt	8
clay	3
dune sand	38

4.5. Geochemistry of natural groundwater

The quality of groundwater found in aquifers depends on a number of factors which all play a significant role in the development of its geochemistry. Firstly, the geochemistry of the groundwater depends on the recharge water. These recharge waters could be precipitation, surface waters or sea water. Secondly, the subsurface chemical processes which act upon the groundwater as it moves through soils and rock will have a large impact on the groundwater quality. Essentially, this natural movement of groundwater increases the amount of dissolved solids within the unsaturated and saturated zones. Chemical processes in primary aquifers are usually more effective owing to the greater contact times resulting from the large surface contact area and lower flow velocities. In contrast, secondary aquifers only allow contact in the secondary features which decreases the overall effectiveness of chemical processes.

The chemical processes occurring within the unsaturated zone down to the saturated zone will be described in the following section as these cover the majority of process affecting water as it moves from the surface to the aquifer and within the aquifer itself.

4.5.1. Geochemical processes

4.5.1.1. Geochemical processes in the unsaturated zone

The processes occurring in the unsaturated zone are mainly mass transfer processes that influence the concentrations of minor and major ions and organic compounds in groundwater.

The processes of gas dissolution and redistribution of CO_2 in the unsaturated zone are important since they cause a decrease in pH (hydrogen ion concentration), thereby making the water chemically more aggressive. This decrease in pH will subsequently cause an increase the total carbonate content of infiltrating waters. Dissolution occurs by water dissolving CO_2, which occurs in the soil at partial pressures greater than atmospheric pressure.

The dissolved CO_2 in infiltrating water has the effect of causing weak acid reactions on carbonate and silicate minerals and strong base reactions from the dissolution of carbonate, silicate and aluminosilicate minerals. The ultimate result is that alkalinity and cation concentrations increase. The dissolution of another gas, O_2, results in sufficiently large amounts of dissolved oxygen to initially control the redox chemistry (Domenico and Schwartz, 1990).

The solubility of many minerals is dependent on oxidation and reduction reactions. These reactions are unlike most other processes, in that they are mediated by micro-organisms which act as catalysts (Domenico and Schwartz, 1990). The presence or absence of free oxygen in water determines whether oxidising and reducing conditions will occur. Above the water table, generally, oxidising conditions are found. Once oxygen is in contact with minerals it becomes a powerful weathering agent, which is aided by a warm and humid climate. Many oxidised elements become increasingly soluble and thus mobile in the water. The oxidising process generally ceases near the water table (Matthess, 1982), although oxygen bearing groundwater can extend to greater depths. In the presence of oxygen-consuming bacteria, the oxygen content in the water will decrease depending on the oxygen demand of the bacterial species (Matthess, 1982).

Reducing conditions have been found to occur when the oxygen content of the water reaches 0.7 - 0.01 mg O_2/l at 8°C (Matthess, 1982). However, field observations show that the transition from oxidising to reducing conditions is much broader. Schwille and Vorreyer (1969) have found that groundwater from reducing conditions has in addition to an absence or reduced oxygen content, higher H_2S, NO_2^- and NH_4^+, a reduction in sulphate and an absence of nitrate. The oxidation of sulphate minerals such as pyrite in the unsaturated zone is an important redox reaction which produces acid.

Groundwater containing solutes will interact with organic and inorganic adsorbents. Active surfaces for adsorption exist on dissociated and undissociated organic and inorganic dissolved solids. Adsorption can take place through the weaker Van der Waals forces, or through the stronger covalent bonds. If an absorbent is covalently bonded, the minerals can become fixed into the crystal lattice. Materials which act as adsorbents are clays, hydrous iron, and manganese and aluminium oxides and organic substances such as humus. Rock-forming minerals which are adsorbents are mica, feldspar, aluminous augite, hornblende and fine quartz. Most fine-grained rocks, due to their larger surface areas, adsorb more effectively than coarse-grained rocks (Matthess, 1982). Generally, divalent ions displace monovalent ions, although, if monovalent ions are in greater abundance they will displace the divalent ions (Davis and DeWiest, 1966). This process of ion exchange is also reversible. Davis and DeWiest (1966) describe the relative ease of exchangeability of cations or the increasing affinity for adsorption by the series:

$$Li^+ > Na^+ > K^+ > Mg^{2+} > Ca^{2+} > Sr^{2+} > Ba^{2+}$$

It has been found that anion exchange is not as important as cation exchange.

An example of one of the typical exchange reactions is where dissolved Ca^{2+} and Mg^{2+} are exchanged with Na^+ bounded on clayey materials. Minerals which have high exchange capacities are zeolites, vermiculite and montmorillonite clays. High exchange capacities are also possessed by humus and roots of living plants (Davis and DeWiest, 1966).

The unsaturated zone in most profiles always has some organic content which together with the inorganic materials, reacts with the infiltrating water. Of importance is that organic substances have a highly variable solubility which is affected by a number of factors. On the ground surface organic debris can be leached by dissolution, this process is one of the major sources of dissolved organic carbon (DOC) in groundwater. The concentration of DOC will be greatest at the source and decrease with depth through sorption and oxidation. Typical organic substances are humic acids, tannins, lignins, amino acids and phenolic compounds. These substances can also influence the mineral mobility of metals by complexation. Sorption of hydrophobic non-polar organic molecules within the unsaturated zone results in many dissolved organic compounds having low mobility. These molecules tend to partition preferentially into non-polar environments provided by small quantities of solid organic matter (Domenico and Schwartz, 1990). The net result of this process is to reduce the amount of DOC that would normally would have been produced by dissolution. Another common process involving organics is through biodegradation or oxidation by microbiological catalysts in shallow soil environments, where the organic compounds react with oxygen to produce simpler inorganic compounds such as CO_2, and H_20.

4.5.1.2. Geochemical processes in the saturated zone

The chemical reactions occurring within the saturated zone are similar to those occurring in the unsaturated zone. The main reactions are those of weak acid-strong base, dissolution, redox and cation exchange. The major difference between the two environments is the larger amount of water available in which the reactions can take place.

Contact between groundwater and the surrounding rock causes minerals to go into solution or alternatively cause precipitation of minerals from the groundwater into rock cavities or porous spaces. Rock forming minerals may dissolve due to chemical weathering through dissolution, decomposition and hydration. These processes can be enhanced by the presence of inorganic acids and an increase in temperature. Dissolution and precipitation are mainly controlled by pH and Eh (redox potential).

The most important soluble salts in rocks include $CaCO_3$, $CaCO_3.MgCO_3$, $MgCO_3$, NaCl, $CaSO_4$ and $CaSO_4.2H_2O$. Therefore the most important ions in groundwater are Ca^{2+}, Mg^{2+}, Na^+, Cl^-, $SO_4^{2-}$and HCO_3^-. These all show variability in solubility depending on pressure, pH, Eh, temperature of formation and other factors.

Surface recharge water can bring oxygen down into groundwater. Schoeller (1962) revealed that oxygen may also be transported into the groundwater by the charges on the ions Fe^{3+}, Mn^{3+}, SO_4^{2-}, H^+, and $Fe(OH)_3$. Oxygen may then react with various minerals to result in a redox reaction which can produce gases, weak acids and water.

Ion exchange is another important process of geochemical evolution in the saturated zone. The process has, however, been described in the section dealing with the unsaturated zone.

4.5.2. Classification by geochemistry

During the processes of the hydrological cycle, groundwater chemistry evolves along its flow path. The chemical constituents within the groundwater offer a relatively easy method of classifying the water. If the source or path of the groundwater is known, an estimate of the probable geochemistry of the groundwater can also be made.

4.5.2.1. Classification by origin

A genetic classification i.e. classified on the basis of origin, will usually give an indication of the geochemistry of the groundwater.

Cyclic or meteoric water is groundwater which originates from the infiltration of atmospheric water into the unsaturated and saturated zones. The quality of this water is generally controlled by the input water and the host rock as discussed in section 4.5.1.

Connate water is water that has been out of contact with the atmosphere since the formation of the aquifer. This type of groundwater includes water that has been incorporated into sediments during deposition. Another type of ancient water, and less commonly found is water that has been associated with rocks during their metamorphism. Juvenile water includes, magmatic water which is water that has been derived from a magma, volcanic water which is released from magma at shallow depths, and plutonic water which is derived from magma at great depths.

Deep waters are often strongly mineralised due to (i) long residence times; (ii) salts in the subsurface taken into solution; (iii) the resultant brines having a high density and thus lie beneath less dense groundwater.

4.5.2.2. Classification based on dissolved constituents

All waters contain dissolved minerals in varying amounts. Due to the longer contact times groundwater has with rocks, it contains higher concentrations of dissolved components as compared to surface water. The degree of salinity in groundwater depends on the specific surface area of the aquifer matrix, the solubility of its component minerals, geochemical conditions and the duration of the contact. Major geological and other natural sources of the main dissolved constituents are shown in Table 21.

Table 21. Natural occurrence of common solutes in groundwater (Bowen, 1986).

CONSTITUENT	TERRESTRIAL SOURCES
silica	feldspars, ferromagnesian and clay minerals, amorphous silica, chert and opal
iron	igneous rocks: amphiboles, ferromagnesian micas, FeS, FeS_2 and magnetite, Fe_3O_4 sandstone rocks: oxides, carbonates, sulphides or clay minerals
manganese	arises from soils and sediments metamorphic and sedimentary rocks and mica, amphibole hornblende minerals
calcium	amphiboles, feldspars, gypsum, pyroxenes, dolomite, aragonite, calcite, clay minerals
magnesium	amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals
sodium	feldspars (albite), clay minerals, evaporites, NaCl
potassium	feldspars (orthoclase, microcline), some micas, clay minerals
carbonate	limestone, dolomite
bicarbonate	limestone, dolomite
sulphate	oxidation of sulphide ores, gypsum, anhydrite
chloride	sedimentary rocks (evaporites), a little from igneous rocks
fluoride	amphiboles (hornblende), apatite, fluorite, mica
nitrate	atmosphere, legumes, plant debris, animal excrement

A classification based on chemical composition, involving the fraction of dissolved ions described as a percentage of equivalents per million of the anions and cations (meq%) is commonly used to classify the groundwater. A trilinear Piper diagram is best used to depict the characteristic of the groundwater based on it's dominant ions.

Four broad classes of water are used to describe the dominant ions (Figure 33):

i) calcium bicarbonate (Ca, Mg/HCO_3, CO_3) water characterises recently recharged or dolomitic groundwater;

ii) sodium, potassium bicarbonate water characterises alkaline groundwater in arid, sandy or crystalline areas;

iii) calcium, sodium, chloride water occurs less commonly as it characterises brines from extreme evaporitic environments; and

iv) sodium, calcium, magnesium, chloride, sulphate water characterises dissolution environments in mainly arid to semi-arid areas.

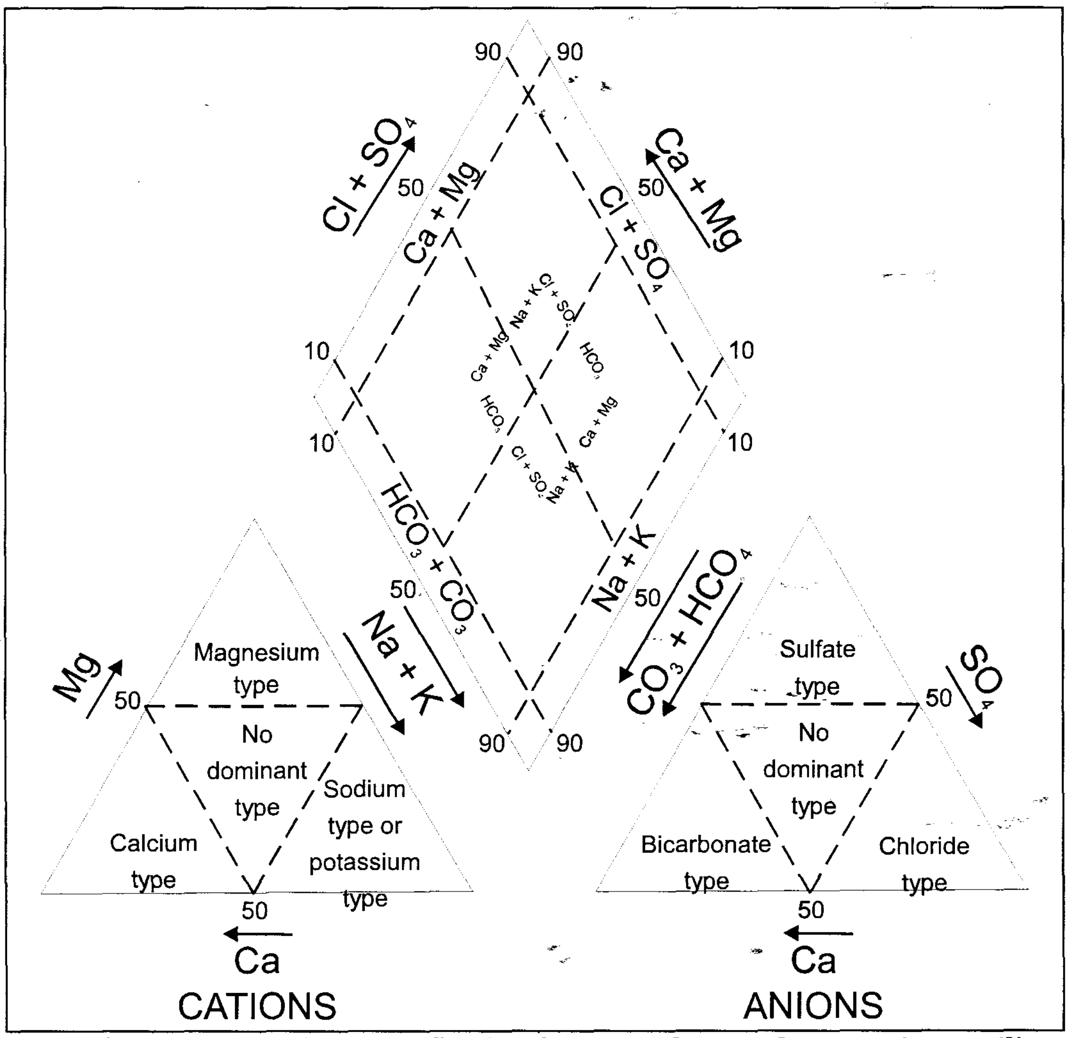


Figure 33. Hydrogeological classification for natural groundwater using a trilinear diagram.

4.5.2.3. Classification on the basis of use

This classification relies on the groundwater's suitability for human, domestic, industrial and agricultural use. Virtually every country has developed ranges of allowable/permissible levels of each physical, chemical and biological constituent in water, depending on the use. In South Africa, the DWAF have published a series of water quality guidelines for each of the recognised users (DWAF, 1993a). In addition to these guidelines the Institute of Water Quality Studies (IWQS) has drawn up a classification system for the assessment of the suitability of borehole water for potability (DWAF, 1996). The IWQS classification (Table 22) is based on the possible effects the various concentrations will have on human health, with the following characteristics generally described as desirable in potable water: clear, transparent, colourless, odourless and constant temperature.

Table 22. Classification for the assessment of the suitability of borehole water for potable use (DWAF, 1996).

CONSTITUENT	CLASS 0	CLASS I	CLASS II	CLASS III
total dissolved solids	0 - 450	450 - 1000	1000 - 2450	> 2450
electrical conductivity (mS/m)	0 - 70	70 - 150	150 - 370	> 370
nitrate plus nitrite as N	0 - 6	6 - 10	10 - 20	> 20
fluoride	0 - 1.0	1.0 - 1.5	1.5 - 3.5	> 3.5
sulphate	0 - 200	200 - 400	400 - 600	> 600
magnesium	0 - 30	30 - 70	70 - 100	> 100
calcium	0 - 32	32	32 - 80	> 80
potassium	0 - 50	50 - 100	100 - 400	> 400
sodium	0 - 100	100 - 200	200 - 400	> 400
chloride	0 - 100	100 - 200	200 - 600	> 600
pH (pH units)	6.0 - 9.0	5.0 - 9.5	4 - 5 or 9.5 - 10	< 4 or > 10
iron	0 - 0.1	0.1 - 0.2	0.2 - 2.0	> 2.0
manganese	0 - 0.05	0.05 - 0.1	0.1 - 1.0	> 1.0
zinc	0 - 3	3 - 5	5 - 10	> 10
arsenic	0 - 0.01	0.01 - 0.05	0.05 - 0.2	> 0.2
cadmium	0 - 0.005	0.005 - 0.01	0.01 - 0.02	> 0.02
faecal coliforms (counts/100ml)	0	0 - 1	1 - 10	> 10

Note: all units of measurement are in mg/l, unless otherwise stated.

Class 0 water is classed as ideal drinking water, suitable for life time use. The values are essentially the same as the target water quality guideline range in the South African Water Quality Guidelines for Domestic Use.

Class I water is still safe for life time use, however some mild health effects may, in very rare cases, occur. There may also be some aesthetic effects.

Class II water is allowable for limited short term or emergency use. Health effects may be felt more commonly, as compared to Class I, especially by those who are long term users of the water. Therefore, it is not recommended that the water be used continuously for life. This is the only class in the guideline which is not specific in terms of the exact duration that the water can be used for. It states that it can be used for short term use, but does not define what length of time 'short term' refers to.

Class III water will cause serious health effects. Particularly in infants and elderly people. Use of this water is not recommended for drinking purposes without adequate treatment.

4.6. Microbiological considerations

In rural areas where sanitation problems are common, the effect of micro-organisms in groundwater can be important. Micro-organisms belonging to other habitats generally do not survive for long in groundwater. This is simply because the conditions do not meet their requirement for survival. Micro-organisms include most pathogenic microbes and indicators of faecal pollution (*Escherichia Coli*). In Europe, an underground travel time of 50 to 70 days is sufficient to eliminate harmful effects of micro-organisms. Lewis and Foster (1980) thought the European travel time to be too conservative and opted for a travel time of ten days under normal hydrogeological conditions. Fractured rock and very coarse, gravely deposits with high transmissivities are particularly susceptible to contamination due to high flow velocities, especially when soil cover is lacking. It has been found that infectious *Hepatitis Epidemia* virus from subsurface percolation had moved up to 200m through an aquifer (Schinzel, 1968). It has been suggested by Xu and Braune (1995) that in South Africa's semi-arid climate, where temperatures are far higher than Europe, a travel time of 30 days be tentatively adopted, and that further investigation be conducted. It must be borne in mind that the distance travelled by any substance is always primarily dependent on the permeability of the material through which it is moving.

Since viruses are smaller than other micro-organisms, such as bacteria, they are transported further in the subsurface and therefore an absence of bacteria will not mean the non-occurrence of viruses. On the other hand, laboratory tests have shown that viruses tend to be easily adsorbed onto clayey and silty particles which limit their distribution (Matthess, 1982).

5. GROUNDWATER RESOURCE EVALUATION

In order to utilise a potential groundwater resource it is necessary to establish the optimal site for abstraction. Together with a knowledge of the probable occurrence of groundwater in the area, exploration is needed to target the most likely site to produce the required groundwater. Development of the source is then necessary to realise its full potential. Incorrect development techniques can have a dramatic effect on the performance of the groundwater resource. Once the resource has been identified and developed sufficiently, it needs to be quantified or evaluated so as to ensure that enough groundwater of acceptable quality exists and that the source will be utilised in a sustainable manner.

5.1. Exploration

5.1.1. Desk study

Before a detailed hydrogeological investigation in the field is planned and conducted, it is beneficial to gather all available geological, hydrological and historical information regarding the area to be investigated. The objective of the desk study is to identify water-bearing formations, potential target features, information which must be collected in the field and identify past problems. The examination of topographical and orthophoto maps, 1 : 250 000 published geological maps, existing hydrogeological reports, 1 : 500 000 hydrogeological maps, aerial photographs, satellite images, rainfall records and existing borehole records will all provide valuable preliminary information regarding the hydrogeology of the area of interest.

Prior to field work it is important to familiarise oneself with the topography, land forms and geomorphology of the area to be investigated. Topographical maps at a scale of 1 : 50 000 or, better still, orthophotographs at a scale of 1 : 10 000 should be studied with a view to identifying the probable groundwater catchments and geological and structural features that could be related to groundwater occurrence. Additional significant information, which will be of use during the investigation, such as access and existing infrastructure can also be gathered.

Initially, geological maps will indicate the stratigraphy, geological structures and lithology to be encountered. This knowledge, together with previous experience, will enable the investigation to be confined to the most promising areas in terms of the occurrence of groundwater. If the DWAF's hydrogeological maps are available (DWAF, 1992), it will be possible to glean some useful information regarding hydrolithology and the probable yield of successful boreholes. It must be noted that these maps are at a 1 : 500 000 scale, which although are not suitable for actual borehole siting, do illustrate a regional perspective of the occurrence of groundwater.

Another useful tool to use in the desk study, is a thorough examination and interpretation of aerial photographs through stereo pairs. Coverage of most of KwaZulu-Natal is available from the Surveyor General. It is also possible, at a cost, to have an area flown in order to capture the latest aerial situation. This last option is not really necessary for hydrogeological purposes due to geological structures only changing over millions of years, as compared to infrastructure, vegetation and human activity which is constantly evolving.

The purpose of aerial photograph interpretation is to identify surface lineaments which could be related to geological features. A geological structure defined by a lineament on an aerial photograph could either be a fracture zone, a fault line, an intrusive dyke or a lithological contact of dipping strata. These features are all regarded as potential targets for the location of groundwater and should be transferred to field maps for confirmation during the field investigation. It must be noted that it is also possible to identify fences, farm boundaries, vegetation lines and roads as linears. Satellite imagery has also found a place in groundwater exploration to aid in tracing large scale regional structures, which could be otherwise missed in aerial photograph interpretation. Images can be obtained from the CSIR in Pretoria.

Data on previously drilled boreholes in the vicinity of the area of interest should be examined in order to get a feel for the type of aquifers likely to be encountered, the probable quality of the groundwater, and an estimate of the depth of water strike, static water level and yield. The best source of existing borehole data is from the Directorate Geohydrology of the DWAF. This Directorate is the custodian of groundwater data for South Africa, which is housed in the National Groundwater Data Base (NGDB). If the particular boreholes that are required have not yet been entered onto the data base, the regional office of Geohydrology usually will be able to assist in providing a contact person who would know more details regarding the boreholes.

At the time of writing this thesis, the Water Law was under review and is expected to result in a new promulgated Water Act by 1998 (pers comm. DWAF, 1996). One of the expected changes of the Water Act is the change in status of groundwater from private water to public water. This will give the Directorate Geohydrology greater control over the drilling of boreholes, the abstraction thereof and the acquisition of borehole data. Until this time, it is not compulsory to forward borehole data to the DWAF, but for obvious reasons it is necessary if the NGDB is to be utilised to its full potential by all users.

5.1.2. Field mapping

After completion of the desk study, it is possible to commence with the field mapping and geophysical work. It is essential that field mapping is carried out in order to obtain a more detailed plan of the area to be surveyed. Due to the relatively small scale of the 1 : 250 000 geological maps, not all geological features relevant to the exploration of groundwater may be depicted. To obtain further information regarding localised features such as lateral lithology changes, fracture zones, joint patterns, minor faults, concealed dykes and depth of weathering, the area must be mapped in detail. The resulting map is best described as a surface representation of the geology and the features associated with groundwater occurrence, in other words a hydrogeological map. If the field mapping and existing borehole data reveal some information related to geology and structure at depth, a three dimensional conceptual model of the site can be formulated. This type of detailed mapping will better enable the hydrogeologist to visualise the hydrogeology and identify the best possible groundwater targets.

5.1.3. Surface geophysics

Following field mapping it is usually necessary to undertake geophysical investigations with the objective of supplementing the field maps, verifying subsurface structures obtained from aerial photograph interpretation and/or geological observations and ultimately to provide the hydrogeologist with a reliable tool for assisting to pin-point the exact location for drilling. Geophysical methods are techniques which measure the physical properties of the earth's materials, such as density, electrical conductivity, magnetic susceptibility and electrical potential. Their purpose in hydrogeology is to locate a physical subsurface anomaly which represents a feature most likely to store and transmit groundwater. If contrasts in geophysical properties are small, the results will be of little value. The principal geophysical methods used in groundwater exploration are described in the following sections.

In using geophysics, the best results are often obtained when more than one geophysical method is used. For example, magnetics is often used in conjunction with either electromagnetics or electrical resistivity as confirmation of anomalies. It is also advisable that once drilling commences, the drilling logs should be compared with the geophysical records to correlate the geophysical data with geology and to enable calibration of the data for future geophysical traverses in similar geological environments.

5.1.3.1.The magnetic method

The magnetic method relies on measurement of the variations of the earth's magnetic field. This is particularly useful where rocks with contrastingly different magnetic fields or intensity are in contact with one another. Natural magnetic anomalies are produced by the mineral magnetite. Other iron-bearing minerals such as hematite, glauconite, hornblende and limonite may also cause anomalies (Davis and DeWiest, 1966).

The magnetic method is limited to where there are magnetically contrasting rocks in the area to be investigated. Also, some magnetic anomalies are not related to hydrogeological targets, in which case this method may be misleading, e.g. pipelines and fences. The method is most commonly used to define the position and orientation of magnetic dykes and sills, commonly dolerite, which are strongly magnetised compared to the host rocks into which they have intruded and whose contact is often a significant water-bearing zone. Similarly, potential water-bearing contacts between rock types of contrasting magnetic intensities can be identified. The presence of some faults can also be revealed provided that either fault breccia or a mineralised zone has been developed and is able to produce a magnetic anomaly.

5.1.3.2.The electromagnetic method

This method, commonly using an EM-34 instrument, induces an electromagnetic current into the ground and then measures the response of the materials in terms of apparent conductivity. The source and the receiver coils both move along the traverse, while the receiver measures the ratio of the quadrature component of the secondary magnetic field to the free space primary magnetic field. There are two main categories of electromagnetic techniques. These are the frequency domain (FDEM) and the time domain (TDEM) methods. FDEM methods pass a sinusoidal current through the source to the subsurface and the receiver measures the resultant secondary field. In TDEM methods, a step function or sawtooth function is used as the source current. During half of the step function cycle, current flow in the source coil ceases. The induction current will then decay back to zero, and it is the decay rate that is measured by the receiver (Botha *et al.*, 1992)

Different coil separations (10m, 20m and 40m) are used to provide different depths of investigation. These separations equate to approximately to 3.8m, 7.6m and 15.2m respectively for vertical coils (Barker *et al.*, 1990) and 10m, 30m and 60m respectively for horizontal coils (McNeil, 1980). Even though horizontal coils have a greater depth of penetration, they are more prone to errors of misalignment. The vertical coils have been found to give less noisy results, and are easier to interpret than vertical coils (Barker *et al.*, 1992). However, their depth of penetration limits their use to shallow groundwater environments. Limitations of this method are revealed in terrains with low conductivity. In these terrains it becomes difficult to magnetically induce sufficient current into the ground to produce a detectable magnetic field at the receiver coil.

Another electromagnetic method gaining in popularity is VLF. This method differs from EM-34 in that there is a fixed source and a moving receiver. The source or transmitter is a cable several hundred metres long that emits a very powerful (300 - 1000 kilowatt) transmission signal (ABEM, 1989). There are a number of these transmitters scattered around the world, with the closest one to KwaZulu-Natal being in Simonstown, Western Cape. The field which is emitted by the transmitter inducts secondary electrical currents into objects with low electrical resistivity. These secondary currents, in turn, create a secondary magnetic field which is picked up by the moving receiver. The advantage of this method over EM-34 is that only one person carrying the receiver is needed to conduct a survey, instead of two people, one carrying a receiver and the other the source. The VLF instrument is as compact as a portable radio and the results obtained compare favourably with the EM-34 method (pers. comm. van Niekerk, 1996). The limitations of the method are fairly restrictive in that the transmitter signal is often weak due to the lack of nearby transmitters. It has been found that the best signal is obtained close to sunset, sunrise and in overcast conditions (pers. comm. van Niekerk, 1996). Another limitation is that in conductive terrains, the skin depth is very limited due to the high frequencies (Botha, *et al.*, 1992).

The electromagnetic method is generally used to locate faults and fracture zones, together with dolerite dykes. The width of the target, the thickness of the overburden and the quality of the groundwater have an effect on the detectability of the target (VSA, 1995).

5.1.3.3.The electrical resistivity method

The variations in the electrical conductivity of underlying geology is measured using an electrical resistivity instrument. In this method, four electrodes arranged in either the Wenner or Schlumberger configuration (Davis and DeWiest, 1966) are inserted into the ground. The outer electrodes induce current into the ground and the inner electrodes measure the difference in the electrical potential. Another method recorded in the literature is the offset Wenner sounding technique which employs a five-electrode array instead of four electrodes (Barker *et al.*, 1992). The two commonly used applications of the resistivity method are described below:

i) *Profiling*

This method of resistivity is used to measure the lateral variations in resistivity by moving a fixed electrode configuration of equal distance (Wenner configuration) along the traverse.

ii) *Vertical electrical sounding (VES)*

The Schlumberger configuration is used to determine the variations in resistivity with depth. To achieve, this the outer electrodes are moved while the inner electrodes remain fixed.

Factors affecting the resistivity of materials are pore or fracture volumes together with the amount and electrical conductivity of groundwater filling them. Limitations of the resistivity method are few, although complex geology is likely to make interpretation impossible without additional information from drilling or other geophysical methods. Like most other geophysical methods, resistivity will be influenced by noise caused by pipes, wires or other man-made structures.

Electrical resistivity methods are well suited to two-layer problems (Davis and DeWiest, 1966). Examples where it is commonly applied are in locating basins of decomposition, fracture zones, contact zones and the water table in primary, unconfined aquifers.

5.1.3.4. Other geophysical methods

Other methods, less commonly used in South Africa, are the gravity and seismic refraction geophysical methods. Gravitational methods measure the variations in the earth's gravity field. This method is more suited to mining exploration and rarely groundwater exploration. Davis and DeWiest (1966) state that seismic refraction methods, which measure the elastic reaction of geological materials to artificially induced vibration, have been used successfully for groundwater exploration. It appears that seismic methods have not been extensively used for groundwater exploration in South Africa due to the higher cost as compared to magnetic, electrical resistivity and electromagnetic methods.

5.1.4. Test drilling

In cases where no geophysical methods are of use, direct drilling needs to be employed to locate a suitable site for development of the groundwater resource. Test drilling is really only used in unconsolidated sediments where the exploitable aquifer occurs as coarser grained sediment lenses within finer grained layers. The drilling required should be relatively cheap and rapid. To achieve this, small diameter rotary core boreholes of NX size (71mm) are drilled using a biodegradable drilling mud or under normal water flush. A standard penetration test is conducted simultaneously with drilling. In doing this, undisturbed Raymond Spoon split samples are collected over 0.45m (Johnstone, 1984). The sediment samples can then be analysed for grain size distribution and permeability. Piezometers may also be installed to provide additional information on permeabilities and water quality (Johnstone, 1984).

If sufficient boreholes are drilled, this method can provide enough information to build a conceptual model of the aquifer system and therefore pinpoint the optimal positions for production boreholes. Another option is that if the exploratory borehole intercepts a suitable aquifer itself, it can be developed into a production borehole.

5.2. Groundwater access, construction and development

The development of a groundwater resource relies on the methods of accessing the groundwater, and the provision of suitable means of abstracting it in an economical and efficient manner. This section only covers the main methods currently used in rural groundwater development in KwaZulu-Natal.

5.2.1. Borehole drilling

The method of borehole drilling must be assessed in order to result in an efficient borehole. Drilling contractors generally use one of two rigs for drilling in South Africa. These are the outdated cable tool rig, and more commonly, the rotary air percussion rig with a down the hole hammer (Plate 8). ODEX drilling is also used in difficult material, such as collapsible sands and extensively fractured rock. Other methods for borehole drilling include rotary drilling with mud or air, reverse circulation and rotary core drilling.

Water supply boreholes commonly have a diameter of between 127mm (5") and 304 mm (12") with most boreholes being drilled at a 165mm (6"). These types of boreholes are usually created by drilling rigs because of the hardness of the rock and/or if the expected depth of the water strike is below 30m. Provided the water-bearing zone is shallow and the rock and soil are soft enough to excavate, a shallow well can constructed.

Augering is another method of developing shallow (< 30m) aquifers. A limitation of this method is that it is difficult to use below groundwater level, as the moisture will cause the hole to collapse, unless a hollow stem auger is used. The diameter of auger holes can range from 100mm to 1,5m.

Wash boring or jetting is used in primary unconsolidated deposits or highly weathered materials. The method involves inserting the casing or a core barrel into the ground by means of washing away the material below the casing or core barrel with a high pressure jet of water. Unfortunately, this very effective method's main drawback is that the sample return is very poor and thus is really limited to inserting well point systems and shallow piezometric monitoring systems.

Plate 8. An air percussion rig in operation.
Note the air compressor to the right of the drilling rig.

5.2.2. Construction

The principles of borehole construction to allow for groundwater abstraction are generally the same for all types of boreholes. Firstly, if the excavation is unstable, the walls need to be supported and secondly, the zone which produces groundwater must be left as open as possible to allow for unhindered flow into a sump.

5.2.2.1. Borehole construction

During drilling, starter casing is often inserted into the top 3 to 10m of boreholes due to the often weathered and unstable nature of the residual rock or soil. Casing may, however, be needed for the full length of the borehole. This decision is generally a function of the geology, groundwater quality, strength requirements of the casing and borehole yield.

Casing is primarily needed to prevent collapse of the borehole and to protect the pumping equipment. If the rock is hard enough and does not contain unstable fractured zones, the borehole may remain uncased for the most part (Figure 34, A). Some boreholes which are not self-supporting may require full length casing, either of fixed diameter or different diameters to counteract various problems (Figure 34, B). Materials used for casing are mostly mild steel or PVC, with the required casing wall thickness a function of borehole depth.

When casing is necessary for the full length of the borehole or to below the aquifer, a screen is inserted opposite the water-bearing zone(s) as illustrated in Figure 34, C and D. The role of the screen is to provide support and to ensure that the groundwater can easily flow into the borehole without bringing with it suspended material, sand and parts of the borehole wall. Screens are available in many different forms but must have the strength to withstand the tension and compression stresses applied during construction and use, a concentrated open area to permit high inflows from relatively thin aquifers, a capacity to selectively filter out and initially, to support the formation, and the ability to be backwashed and jetted without damage during development (Groundwater Division, 1993).

Typically, in hard rock boreholes, slotted casing is used as a screen. The slots can be cut *in situ* or may be machine cut in a controlled environment. The main problem with slotted casing is that the slots cannot be closely spaced due to the primitive method of cutting and the slots are difficult to be cut small enough to retain very fine sand. Perforated or punched screens are the next best available technology to act as screens in boreholes. These comprise punched holes or louvres in sheet metal which is rolled into the required diameter tube.

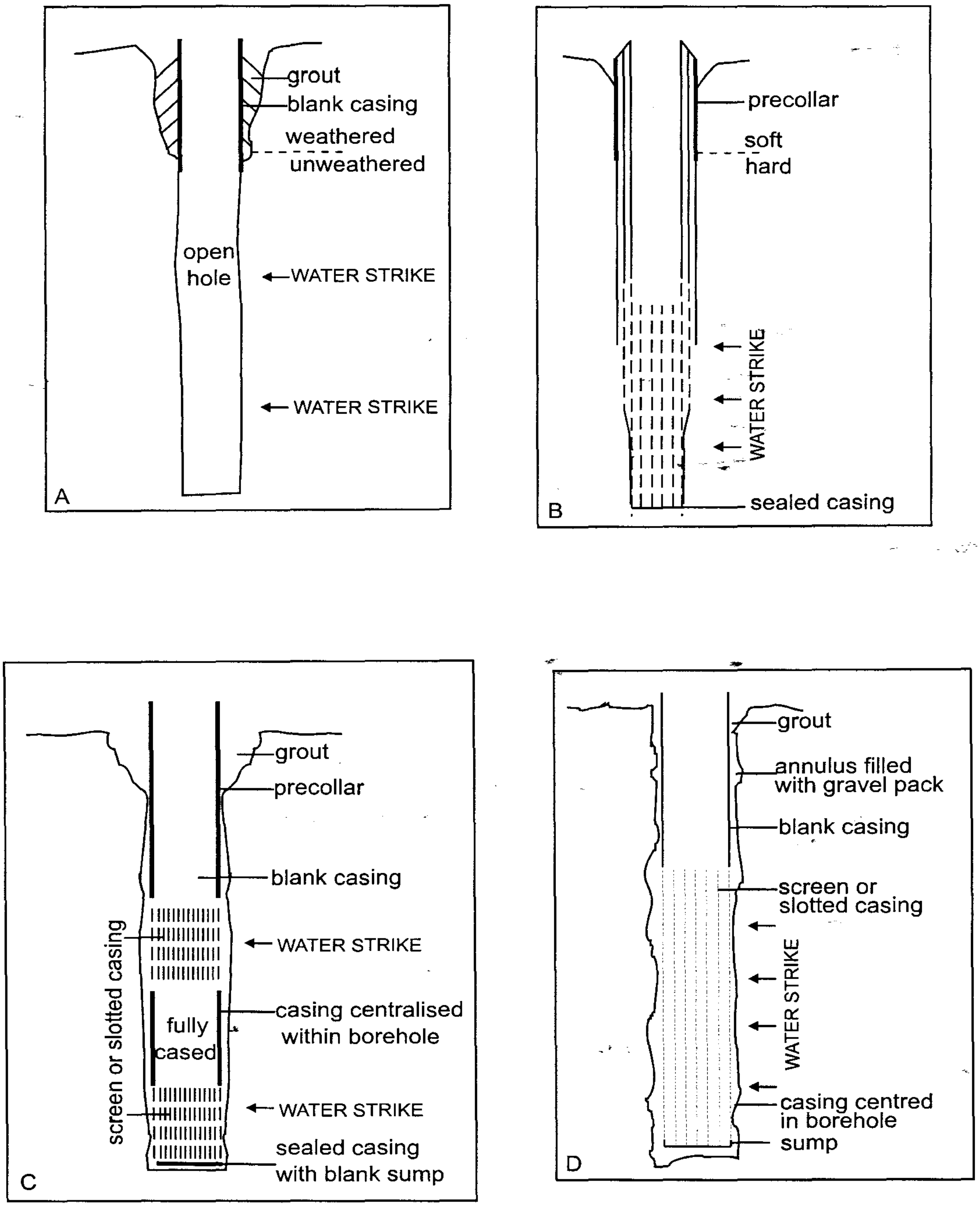


Figure 34. Typical borehole construction methods for various conditions. (A) open hole construction for stable formations. (B) Telescoped casing used in difficult formation. (C) Solid casing and slots used in hard rock with unstable water-bearing zones. (D) Screened borehole used in unconsolidated formations.

For unconsolidated sediments, the above two methods of screening are not always appropriate especially when very fine sand occurs. In order to overcome this, stainless steel well screens have been developed by means of a complex arrangement of wire wrapped to a cylindrical grouping of rods, which are then welded to cylindrical ring couplings at either end (Groundwater Division, 1993). Screens made from PVC are also used extensively as a cheaper option and in areas where groundwater causes corrosion. There are many variations in well screens and it is therefore essential to select the correct type for the prevailing conditions and purpose. For further information on well screens the reader is referred to Driscoll (1986).

There are a number of different materials available for both casing and screens. The selection of the appropriate material is mostly dependent on the groundwater chemistry and the depth it is required. Generally, mild steel is the first option, however, if the groundwater is corrosive, stainless steel is preferred. PVC casing and screens are also being used more frequently in water supply boreholes. In order to enhance the performance of a screen, gravel packing can be inserted into the annulus between the borehole wall and the outside of the screen. The gravel acts as a secondary filter to remove solids from the groundwater entering the borehole and increases aquifer permeability in the vicinity of borehole. The top 5m or more of the annular section between the borehole wall and casing must always be cement grouted with a sanitary seal. This seal ensures that ingress of surface run-off water down the sides of the borehole does not occur, which could otherwise cause contamination of the groundwater resource.

Another means of access to groundwater in KwaZulu-Natal is through the use of shallow screen wells in alluvial channels. A large diameter, commonly 16" or 17", borehole is drilled into the alluvium with the aid of biodegradable drilling mud to support the side walls. Once the required depth for the screen has been determined, a stainless or mild steel sump in which to suspend the pump, approximately 1 metre deep, is placed at the bottom of the hole. If the particle size permits, holes can be punched into the bottom of the sump to promote groundwater circulation to aid in cooling of the pump motor, if a submersible pump is used. A screen, commonly stainless steel, is then positioned above the sump and the rest of the hole is cased to the surface. Gravel packing is placed around the annulus between the screen and casing, and the well sides.

5.2.2.2. Well construction

Wells are different from boreholes in that they usually have a larger diameter, are shallower and are often constructed by hand. The quality of groundwater in wells is also more likely to be adversely affected by human activity around the well. This is due to the static water level usually being closer to the surface which limits the extent that filtration can take place. If a well is not a sealed unit with an external pump spout, the groundwater can become contaminated by dirty lifting utensils and objects falling into the well (Plate 9).

There are two main types of well, namely hand-dug or hand augered wells, and machine excavated or drilled wells. The main difference between them is the diameter, as a hand-dug well needs to be wide enough to enable the labourers to work comfortably as the well progresses. The various methods of well sinking are primarily dependent on the type of material to be excavated (Table 23). The range of practical depths for hand-dug and hand drilled wells usually does not exceed 20m, however, several authors refer to a maximum depth of 30m (Mtunzi, 1984; Chleq and Dupriez, 1990).

After the method of excavation has been decided, the type of lining and the top covering to the well needs to be considered. The lining must comprise a robust and corrosion free material, preferably porous concrete rings, and the covering must be of a suitable standard to protect the well from contamination, while still allowing for easy access to the water (Plate 10 and Figure 35). In self-supporting materials, lining of the well can take place after the excavation has been completed. Where there is problem with stability of the well sides, installation of the lining can occur simultaneously with excavation by allowing it to sink under its own weight as the well is excavated below the bottom of the lining. An excellent source of information regarding well construction, its problems and advantages is given by Mtunzi (1984) in his account of the development of shallow wells for rural water supply in Tanzania.

Table 23. Suitability of well construction techniques for different geological formations (adapted from Mtunzi, 1984).

CHARACTERISTIC	TYPE OF WELL		
	HAND-DUG	HAND DRILLED	MACHINE DRILLED
range of practical depths	0 - 30m	0 - 30m	0 - 300m
diameter	1 - 6m	0.05 - 0.3m	0.1 - 0.5m
geological formation			
clay	yes	yes	yes
silt	yes	yes	yes
sand	yes	yes	yes
gravel	yes	yes	yes
cemented gravel	yes	no	yes
sandstone	yes, if weathered and/or fractured	yes, if weathered and/or fractured	yes
crystalline rock	no	no	no

Plate 9. An unprotected hand-dug well being utilised by a local community on the Zululand coastal plain. Note the lifting device is a plastic container with a roughly made palm leaf rope.

Plate 10. A prototype hand-dug well on the Zululand coastal plain with a suitably constructed concrete apron and channel. Well head protection is still to be placed upon the top rings as shown in Figure 35.

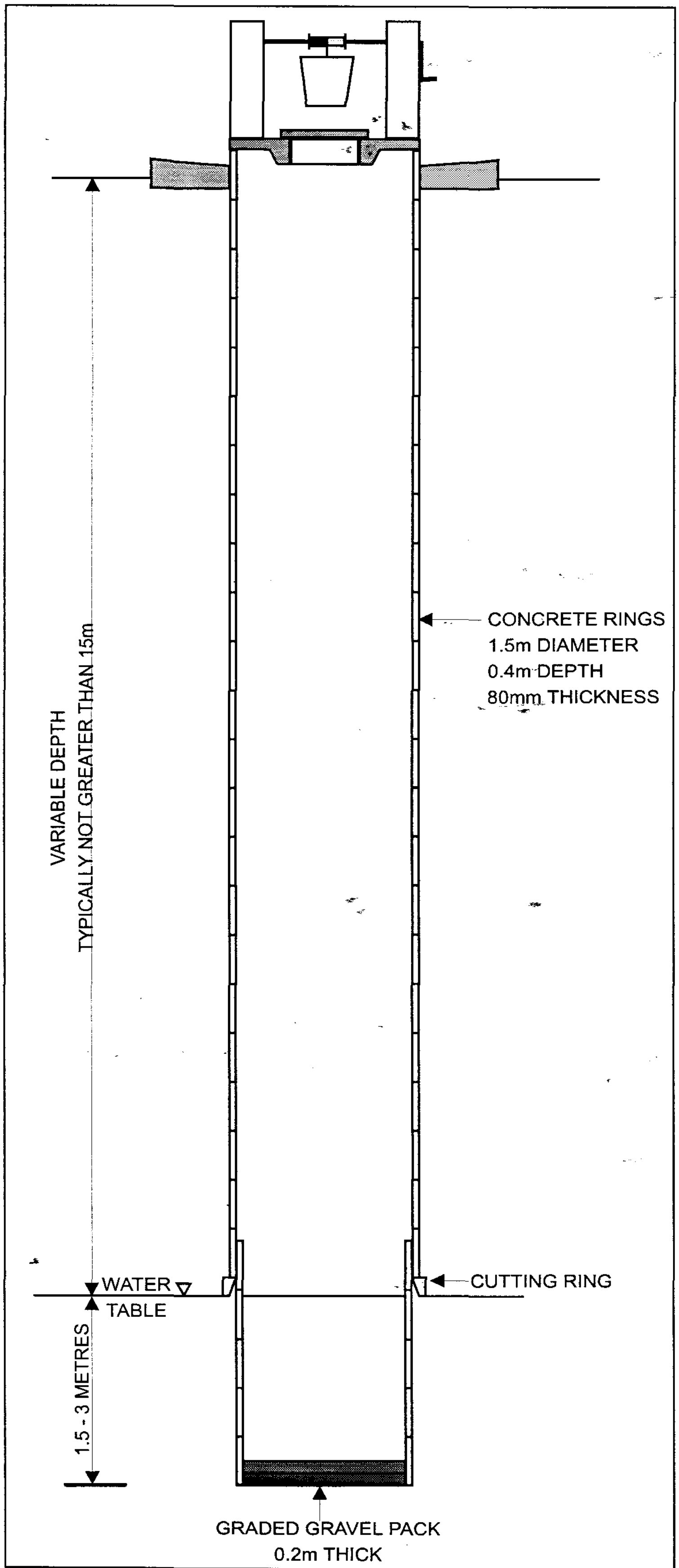


Figure 35. Typical details for shallow well construction.

5.3. Resource evaluation

After a borehole has been drilled, the groundwater resource needs to be evaluated in terms of the quantity it is likely to yield, and the quality of the water. Quantitative evaluation of the groundwater resource will be a deciding factor in determining the pumping rate the resource can sustainably deliver and is therefore one of the most important aspects of groundwater development. The amount of water that may be abstracted from a borehole may be resolved by test pumping the borehole or by empirical methods. Groundwater quality can only be determined by chemical and biological laboratory tests.

Yield tests can range from rough estimates by measuring the air-lift or blown yield, to a thorough pump test. Borehole yield analysis relies on the interpretation of pumping and recovery curves using various analysis procedures. In utilising these methods, one is assuming that the aquifer characteristics, such as transmissivity, storage and hydraulic boundaries, control the potential yield of the borehole. Therefore, in certain cases, by not taking into account the recharge to the aquifer there is a potential of overestimating an aquifer's sustainable yield (Sami and Murray, 1996). Methods which assumes that recharge and storage control the sustainable yield of a borehole are termed aquifer yield methods.

5.3.1. Borehole test pumping

These methods rely on the field determination of aquifer characteristics by hydraulically testing the aquifer. The resultant aquifer characteristics are used in various flow equations to arrive at an expected yield value. Hydraulic or pump tests are based on the principle:

> "....that if we pump water from a well and measure the discharge of the well and the drawdown in the well and in piezometers at known distances from the well, we can substitute these measurements into an appropriate well-flow equation and can calculate the hydraulic characteristics of the aquifer." (Kruseman and de Ridder, 1991).

Disadvantages of pump testing are that controlled conditions in the field are difficult to maintain, mainly due to mechanical problems and human error. It has also been found that borehole yield methods tend to overestimate the yield, particularly in fractured rock where permeabilities are such that groundwater can be abstracted at a faster rate than it can be replenished (Sami and Murray, 1996). The overestimation is also due to permeability being assumed to be the limiting factor, which is not always the case in fractured rock. Other limiting factors may be related to recharge or storativity.

Before a pump test is carried out it is necessary to have an understanding of any surface lithological, stratigraphic and structural features which may influence the flow or recharge of groundwater. Equally important is the borehole information generated during drilling, including information on aquifer depth, thickness and nature of geological layers penetrated and borehole construction details which all define details on aquifer thickness, available drawdown, screen sections etc.

Pumping tests are carried out in order to determine the parameters of transmissivity, storativity, specific capacity, specific yield, borehole efficiency, radius of influence, distance to boundaries and leakage factors. Specific capacity refers to the rate of discharge per unit of drawdown [L^2/T], which is primarily dependent on transmissivity and where the inefficiency is significant, on the pumping rate. Borehole efficiency or borehole performance tests involve determining the groundwater losses through the aquifer and the borehole itself. These losses come about through inefficiencies in the drilling method, borehole and aquifer development, incorrect screen size and turbulence caused by excessive inflow velocities.

The design of a hydraulic test will need to address the following:

- disposal of pumped water away from the borehole
- desired and anticipated drawdown (this will require a prior estimate of transmissivity and storage)
- required design yield
- duration of pumping
- depth of pump placement

Pumping tests must be carried out using a pump which should fulfil certain requirements in order to ensure satisfactory results. It must be able to pump groundwater at a rate sufficient to draw the water level to the desired depth, it must also be capable of variable rate pumping to 20% of its full pumping rate. A non-return mechanism must also be fitted to the pump to prevent water in the rising main from returning to the borehole once the pump has shut down (Groundwater Division, 1993). The pump must be positioned just below the required drawdown depth, or just above the main water-bearing zone, or if the strike is unknown, approximately 1 - 2 metres from the bottom of the borehole. Water level readings must be accurately taken at brief intervals at the start of the test, with the period between readings increasing as the test progresses. This is necessary due to the rapid initial response of the water table to pumping. The discharge rate produced by the pumping must be regularly checked and adjusted if necessary.

5.3.2. Pump test types

There are various types of pump tests which can be carried out, each differs from the other primarily by the variability of the pumping rate. Variable discharge tests are those tests in which the pump rate varies during the test. The two types of tests that qualify as variable discharge tests are step and multi-rate tests.

Step tests comprise a number of increasing steps of discharge, which are carried out to determine the drawdown response for different pumping rates and to ascertain borehole performance. The number of steps should not be less than 3 and the length of each step should last until drawdown stabilises, or not less than 60 minutes duration. From the results of the step test it will be possible to select the optimal pumping rate for a constant discharge test. It will also be possible to evaluate drawdown resulting from aquifer losses (B) and borehole losses (C) from a step test. Aquifer losses represent laminar flow arising from the drawdown response for the gradient required to meet the pumping rate (Kawecki, 1995). Borehole losses represents turbulent flow which occur at the borehole itself and do not relate to aquifer characteristics. Once these parameters are known it is also possible to empirically choose an optimum yield for the borehole based on its drawdown and discharge relationship. The drawdown in a borehole is thus given as:

$$s_w = BQ + CQ^n \qquad \textbf{5.1}$$

where

B = aquifer-loss coefficient
C = borehole-loss coefficient
Q = discharge rate (V/T)
n = turbulence exponent

Well efficiency can also be determined by:

$$E_w = \left\{ \frac{B_1 Q}{(B_1 + B_2)Q + CQ^n} \right\} \times 100\% \qquad 5.2$$

Multi-rate or variable-discharge tests require that the borehole is pumped intermittently at different discharge rates. This test is not commonly carried out in KwaZulu-Natal, however, if there have been problems with the pump and the discharge rate has fluctuated, the data can still be interpreted. The infamous Farmers test is a type of test which could be interpreted as a multi-rate test, however it relies on recommending a yield based on pumping at a high rate until the water level is drawn down to the pump, which is placed near the bottom of the borehole. Thereafter, the rate is decreased until the water level rises to above the pump and then the rate is kept constant for the remainder of the test (Enslin and Bredenkamp, 1963). The recommendation is then made on 60 - 65% of the highest yield the borehole could produce without the water level falling down to the pump. As this test does not determine actual aquifer characteristics it cannot be categorised as a true pump test, unless the drawdown data is interpreted in the correct manner. This fact is reinforced by the overestimation of yield the farmers test has been found to produce (Sami and Murray, 1996).

A constant discharge test is a pump test where the pump rate is kept constant for the entire duration of the test. The purpose of this test is to determine aquifer characteristics that control long term responses to pumping and to identify boundaries which may affect the drawdown response. The test can also be used to determine whether abstraction will reduce the yield of nearby boreholes or springs by lowering groundwater levels.

The slug test is another hydraulic test worth mentioning as it is simple and rapid to undertake. To carry out the test, the water level in a borehole is suddenly lowered or raised (Vivier *et al.*, 1995). Usually, a cylinder is lowered into the borehole in order to displace the water table. The response of the water level is then monitored. A limiting aspect of this test is its ineffectiveness in determining hydraulic parameters further than the immediate vicinity of the borehole.

5.3.3. Recovery tests

After a pump test has been completed and the pump has been shut down, the recovery of the water level in response to the previous pumping regime can be measured. Initially, the water table will recover rapidly and therefore it is advisable that the same time intervals are used at the commencement of the recovery, as at the start of the pumping test. Recovery water levels should be measured until the level has recovered to within 5% of the total drawdown, or for the same length of time as the pump test.

Recovery tests allow the transmissivity of the aquifer to be calculated, which can be used as a check on the transmissivity calculated from the pump test. The recovery method has often been found to be more reliable than pumping test methods of transmissivity determination because recovery occurs at a constant rate, whereas a constant discharge during pumping is often difficult to achieve in the field (Kruseman and de Ridder, 1991). The principle of the recovery test is that it is assumed that after the pump has been shut down, the borehole continues to be pumped at the same discharge rate as before, and that an imaginary recharge equal to the discharge is injected into the borehole (Kruseman and de Ridder, 1991).

5.3.4. Interpretation of pump tests

The process of pump testing is generally not a difficult one, however, the method of interpretation is somewhat more complex. In order to establish the hydraulic characteristics of the aquifer it is essential to determine the probable aquifer type in order to apply the correct analytical model. The characteristic drawdown curves of the two broad aquifer categories, namely unconsolidated aquifers and fractured aquifers are depicted in Figure 36 and Figure 37 respectively, and curves for bounded aquifers in Figure 38. Recognition must be made that there are some aquifer types which display similar hydraulic responses to pumping, for example unconfined, unconsolidated aquifers and fractured or double porosity aquifers, which make the task of aquifer type determination more difficult.

5.3.4.1. Unconsolidated aquifers

Curve interpretation of confined, homogeneous, isotropic aquifers is fairly simple as it should reflect at some point a linear relationship, on a semi-log plot, upon which to calculate the hydraulic characteristics (Kruseman and de Ridder, 1991). This linear part of the curve usually forms the late-time segment of the curve (Figure 36, A and A').

Unconfined, homogeneous, isotropic aquifers usually exhibit a characteristic delayed yield response. The first part of the curve is the early-time segment which reflects instantaneous release of water from storage by the expansion of the water and compaction of the aquifer (Kruseman and de Ridder, 1991). The flat intermediate-time segment reflects the dewatering of the aquifer pores by vertical drainage, which is comparable to leakage. The late-time segment is a steeper section which reflect the drawdown situation where the flow in the aquifer is mostly horizontal again (Figure 36, B and B').

Leaky aquifers behave in a manner similar to confined aquifers for the early-time segment, but with increasing time, draws greater amounts of groundwater from the adjacent aquitard. At some point, discharge will be in equilibrium with leakage from the aquitard thus resulting in steady-state conditions (Figure 36, C and C').

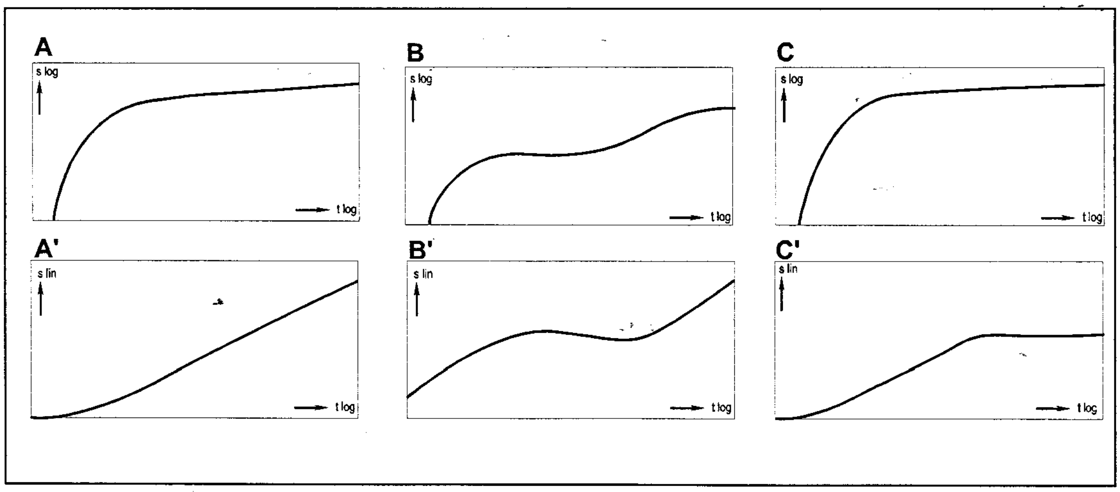


Figure 36. Log-log and semi-log plots of the theoretical time-drawdown relationships of unconsolidated aquifers (after Kruseman and de Ridder, 1991):
Parts A and A': confined aquifers
Parts B and B': unconfined aquifers
Parts C and C': leaky aquifers

5.3.4.2. Consolidated and fractured aquifers

Consolidated, fractured aquifer flow does not conform to homogenous, radial flow but rather flow is dependent on pressure differentials between the rock matrix and fractures. There are different conceptual models for different fracture type situations. Curves A and A' of Figure 37 refer to confined, densely fractured aquifers which display double porosity. Double porosity pertains to a fracture system of high hydraulic conductivity and low storativity surrounded by matrix blocks of low hydraulic conductivity and high relative storativity. Initially during pumping, flow will primarily occur through the fractures in an unsteady-state. Flow from the matrix blocks to the fractures will eventually reach a steady-state with continuous pumping (Kruseman and de Ridder, 1991). The early-time part of the drawdown curve reflects flow contributed only from storage within the fractures. The intermediate-time reflects a transition period during which groundwater is drawn from the matrix blocks into the fractures at an increasing rate due to increasing hydrostatic pressure differentials between the matrix and fractures.. The late-time segment finally reflects the steady state situation of groundwater being drawn from storage in the matrix blocks into the fractures. This type of curve has a similar delayed yield response to the unconfined, unconsolidated system described previously.

When a single, plane vertical fracture of finite extent and high hydraulic conductivity, such as a fault or solution channel, is intersected in a confined, homogeneous, isotropic aquifer of low hydraulic conductivity, the characteristic log-log curve shows a straight line for the early-time segment (Figure 37, B and B'). This part of the curve reflects flow being horizontal, parallel and perpendicular to the fracture due to expansion of the radius of influence. After a period of time, flow to the borehole becomes pseudo-radial as the adjacent formation is dewatered and the curve resembles the late-time part of curve A and A' of Figure 36.

The final curve type to be discussed results from a densely fractured, highly permeable dyke or steeply dipping beds contained within a confined, homogeneous, isotropic, consolidated aquifer of low hydraulic conductivity and high storativity (Figure 37, C and C'). This system has two straight-line segments during early and intermediate-pumping times. At early-time, the flow to the borehole purely through the dyke and at intermediate-time the host rock or aquifer starts contributing to the flow. At late-time flow to the borehole will be pseudo-radial.

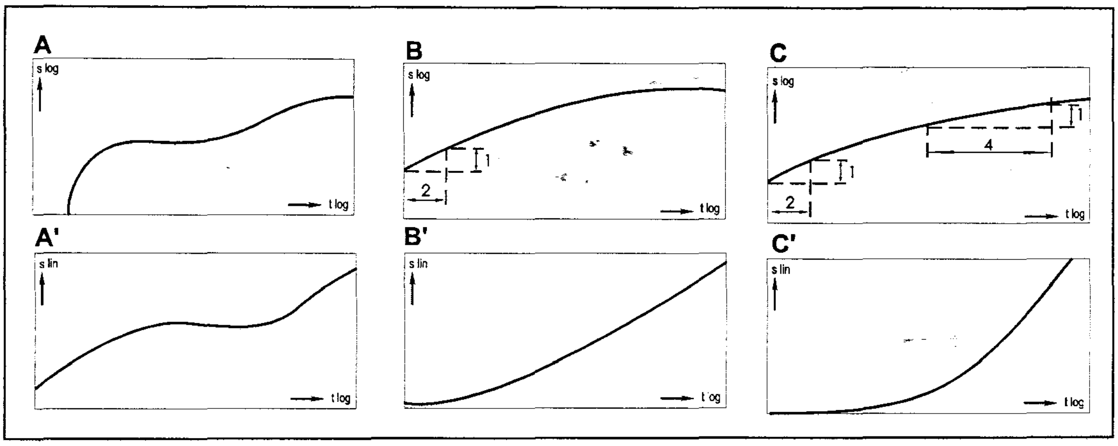


Figure 37. Log-log and semi log plots of the theoretical time-drawdown relationships of consolidated, fractured aquifers (after Kruseman and de Ridder, 1991):
Parts A and A': confined fractured aquifer, double porosity type
Parts B and B': single plane vertical fracture
Parts C and C': permeable dyke in an otherwise poorly permeable aquifer

5.3.4.3. Bounded aquifers

All the drawdown curves discussed above can be affected by recharge or barrier boundaries. Common examples of recharge boundaries are water-bearing faults, stream channels and saturated zones above fractures. Examples of barrier boundaries are dolerite dykes, zones of less permeable fractures and non-water bearing, mineralised faults.

The effect of a recharge boundary on a drawdown curve is to stabilise the drawdown once the cone of depression intercepts a boundary with sufficient recharge (Figure 38, A and A'). The late-time segment of the curve will then begin to deviate from the theoretical curve for the aquifer. Barrier or impermeable boundaries will have the opposite effect on the drawdown. Once the cone of depression reaches the boundary, the rate of drawdown will rapidly increase, as inflow towards the borehole can no longer be intercepted around the circumference of the expanding cone of depression, thus steepening the late-time segment considerably (Figure 38, B and B').

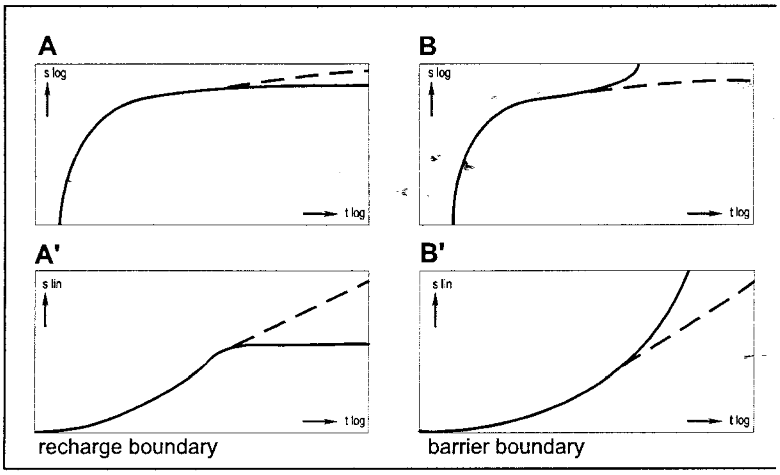


Figure 38. The effect of a recharge boundary (parts A and A') and an impermeable boundary (parts B and B') on the theoretical time-drawdown relationship in a confined, unconsolidated aquifer. The dashed curves are those for unconsolidated , unconfined aquifers (after Kruseman and de Ridder, 1991).

It is important that the correct model is chosen to avoid gross errors in the determination of the hydraulic characteristics by means of the correct analytical method. However, it is acknowledged that aquifer type identification is not always a simple matter as some situations give similar curves. Kruseman and de Ridder (1991) aptly state that:

> " .... analysing a pump test is not merely a matter of opening a particular page of this book and applying the method described there."

5.3.4.4. Assumptions and limitations

Based on the differentiation of aquifers on their occurrence, i.e. confined, leaky, unconfined and bounded, various assumptions are made to enable the characteristics of the aquifer to be calculated. The main assumptions for confined aquifers below apply to all methods, except fractured rock aquifers, with some modifications to account for other conditions given in Table 24.

1. The aquifer has a seemingly infinite areal extent;
2. The aquifer is homogeneous, isotropic, and of uniform thickness over the area influenced by the test;
3. Prior to pumping, the piezometric surface is horizontal (or nearly so) over the area that will be influenced by the test;
4. The aquifer is pumped at a constant discharge rate;
5. The borehole penetrates the entire thickness of the aquifer and thus receives water by horizontal flow;
6. The water removed from storage is discharged instantaneously with decline of head;
7. The diameter of the borehole is small, i.e. the storage in the well can be neglected;
8. Flow is laminar and radial throughout the entire radius of influence.

These assumptions have obviously been derived from work carried out in unconsolidated confined conditions, which are only found on the Zululand coastal plain in KwaZulu-Natal. Most aquifers encountered in KwaZulu-Natal are anisotropic and heterogeneous, due to their secondary nature, which therefore limits the use of all the procedures related to homogeneous and isotropic aquifers. When these types of conditions are encountered, the alternative assumptions given in Table 24 must be used.

5.3.5. Borehole yield analysis methods

After the pump test has been carried out, the drawdown versus time data are plotted on either log-log or semi-log diagrams and an interpretation of hydraulic conditions has been made, various options as to the method of analysis are available. Each method applies to specific hydraulic conditions and has been determined by various authors, from which the method is usually named. Kruseman and de Ridder (1991) cover most of the widely used methods for different aquifer situations. It is important that the assumptions of each method (Kruseman and de Ridder, 1991) are taken into account before any method is used. The majority of methods require the use of observation boreholes (Table 25), however, single borehole tests (Table 26) are more appropriate to rural water development. It is important to note that all these methods only derive values for transmissivity and storativity. It is not these hydraulic characteristics alone that determine the sustainable yield of a borehole.

Other methods used to determine hydraulic conductivity, include calculation from empirical formulae based on grain size distribution, laboratory tests and tracer tests. There have been numerous workers who have examined the relationship between permeability or hydraulic conductivity and porous media. The formulae which have resulted are based on analytical or experimental work. Hazen's formula is one of the most well known methods of determining hydraulic conductivity, in L/T (K) based on a dimensionless coefficient (C) ranging between 0.01 and 0.015 and the maximum grain size of the smallest 10% of the sample (D_{10}):

$$K = CD_{10}^{2} \qquad \textbf{5.3}$$

Table 24. Modifications to the confined aquifer model with general assumptions and limitations (adapted from Kruseman and de Ridder, 1991 and Boulton and Streltsova, 1977).

AQUIFER TYPE	ASSUMPTIONS	LIMITATIONS
leaky	– the flow in the aquitard in vertical – the drawdown in the aquitard is negligible – the water removed from the storage in the aquifer and the water supplied by leakage from the aquitard is discharged instantaneously with decline of head	– often not homogeneous and isotropic – leakage is not uniform
unconfined	– the aquifer is homogeneous and of uniform thickness over the area influenced by the test – the borehole penetrates the entire thickness of the aquifer and thus receives water from the entire saturated thickness of the aquifer	– aquifer is often not homogeneous and isotropic
bounded	– the aquifer is confined or unconfined – within the zone influenced by the pumping test, the aquifer is crossed by one or more straight, fully penetrating recharge or barrier boundaries – recharge boundaries have a constant water level and the hydraulic contacts between the recharge boundaries and the aquifer are as permeable as the aquifer	– it is not always easy to identify boundaries – most boundaries will not be straight
anisotropic	For horizontal anisotropy – the aquifer is homogeneous, aniostropic on the horizontal plane, and of uniform thickness – if the principal directions of anisotropy are known, drawdown data from two piezometers on different rays from the pumped borehole will be sufficient. If the principal directions of anisotropy are not known, drawdown data must be available from at least three rays of piezometers	– rarely uniform thickness – often heterogeneous
uniformly fractured, double-porosity	– the borehole fully penetrates a fracture – the flow to the borehole is in an unsteady state – matrix and fractures are compressible – flow in the matrix is vertical – drawdown in matrix is negligible – there is no contact resistance to seepage flow between the matrix and fracture – the depth of the fracture is small compared with the matrix	– rarely get vertical fractures, most are sub-vertical or near horizontal
single vertical fractures	– the borehole fully penetrates a single vertical fracture – the fracture is plane (i.e. storage in the fracture can be neglected), and its horizontal extent is finite – the borehole is located on the axis of the fracture – with decline in head, water is instantaneously removed from storage in the aquifer – water from the aquifer enters the fracture at the same rate per unit area (i.e. a uniform flux exists along the fracture, or the fracture conductivity is high although not infinite)	– vertical fractures are rare

AQUIFER TYPE	ASSUMPTIONS	LIMITATIONS
single vertical dykes	– the width of the dyke is uniform and does not exceed 10m – the flow through the fracture system is laminar – the uniform fractured part of the dyke can be replaced by a representative continuum to which spatially defined hydraulic characteristics can be assigned – the fractured part of the dyke is bounded above by an impermeable weathered zone and below by solid rock – the borehole fully penetrates the fractured part of the dyke and is represented by a plane sink; flow through the dyke is parallel – the country rock aquifer, which is in hydraulic contact with the fractured part of the dyke is confined, homogeneous, isotropic, and has an apparently infinite areal extent – all water pumped from the borehole comes from storage within the composite system of dyke and aquifer – the ratio of the hydraulic diffusivity of the dyke to that of the aquifer should not be less than 25 – borehole losses and borehole storage are negligible	– dykes are seldom vertical – dykes in KwaZulu-Natal are often not permeable – country rock is rarely homogeneous and isotropic

Table 25. Pump analysis methods for different aquifers using observation boreholes (after Kruseman and de Ridder, 1991).

AQUIFER		METHODS	
		STEADY-STATE	TRANSIENT-STATE
confined		Theim	Theis Cooper-Jacob
leaky		De Glee Hantush-Jacob	Walton Hantush's inflection-point Hantush's curve fitting Neuman-Witherspoon
unconfined		Neuman's curve fitting	Theim-Dupuit
bounded	confined or unconfined	Dietz	Stallman Hantush
	leaky or unconfined		Vandenberg
aniostropic	confined, horizontal anisotropy	Hantush Hantush-Thomas Neuman's extension of the Papadopulos method	
	leaky, horizontal anisotropy	Hantush	
	confined, vertical anisotropy	Week	
	leaky, vertical anisotropy	Week	
	unconfined, vertical anisotropy	Neuman curve fitting Streltsova curve fitting	
multi-layered		Bruggeman (leaky, two-layered aquifer with crossflow through aquitards	Javandel-Witherspoon (confined two-layered aquifer with unrestricted crossflow)
double porosity		Bourdet-Gringarten Kazemi *et al.*	
single vertical fractures		Gringarten-Witherspoon	
single vertical dykes		Boonstra-Boehmer	

Table 26. Pump test analysis methods available for single borehole tests (after Kruseman and de Ridder, 1991).

AQUIFER	VARIABLE RATE	CONSTANT RATE	RECOVERY	SLUG TEST
unconfined			Theis	Bouwer-Rice
confined	Birsoy-Summer Aron-Scott Jacob-Lohman Cooper-Jacob	Papadopulos-Cooper Rushton-Singh Jacob Hurr-Worthington	Theis Birsoy-Summer Eden-Hazel	Cooper
leaky	Hantush	Jacob Hurr-Worthington	Theis	N/A
double porosity	N/A	Warren-Root	N/A	N/A
single vertical fracture	N/A	Gringarten *et al.* Ramey-Gringarten	N/A	N/A
single vertical dykes	N/A	Boonstra-Boehmer	N/A	N/A

Laboratory methods have traditionally been used in engineering geology to determine the hydraulic conductivity of disturbed and undisturbed samples for both consolidated and unconsolidated formations. The method relies on the use of a permeameter, in which flow is maintained through a small sample of material while measurements of discharge and head loss are made. The two types of permeameter tests are the constant head and the falling head tests. Both tests rely on Darcy's law to obtain hydraulic conductivity. Laboratory tests are not reliable since field conditions are almost impossible to duplicate in a laboratory, with undisturbed samples of unconsolidated material being difficult to obtain, while disturbed samples can never be representative of field conditions. Only if an aquifer is completely homogeneous and isotropic could such methods be of value. In addition, since sampling is carried out at certain points, spatial variations of hydraulic conductivity will not easily be defined. The laboratory tests also only measure the vertical component of hydraulic conductivity (K_Z) and not K_X and K_Y.

Tracer tests are another method used to determine field hydraulic conductivity by measuring the time taken for the tracer to travel between two observation boreholes. There are numerous practical limitations of this method which will not be dealt with as the tracer method is not an option for hydraulic characterisation in rural water supply since apart from being costly, an accurate porosity value together with dilution coefficients is required.

5.3.6. Aquifer yield methods

Where recharge may be a limiting factor with regard to long term borehole yield, aquifer yield methods are needed to evaluate an aquifer's potential. These methods have been found to work best for small catchments, highly localised aquifers, or in low recharge areas where multiple boreholes abstract groundwater simultaneously (Sami and Murray, 1996). The methods rely heavily on a number of approximations, including the much debated estimation of recharge.

Aquifer yield methods dependent on recharge estimation methods to estimate exploitation potential are presented by Bredenkamp *et al.* (1995). The potential yield of an aquifer may be estimated by:

$$E_r = A \times P \times C \times D \qquad \textbf{5.4}$$

where E_r = exploitation potential (L^3)
A = catchment area over which recharge to the aquifer can take place (L^2)
P = mean annual precipitation (L)
C = fraction of MAP contributing to recharge
D = abstractable proportion of recharge (commonly taken as a fixed proportion)

Other aquifer yield methods include the storage method, which is based on an estimation of exploitation potential from an estimate of storage in an aquifer and the number of years without recharge (DWAF, 1993b). This method is not recommended due to difficulties in determining storativity, especially in fractured rock. The groundwater throughflow method, based on Darcy's Law, estimates flow through an aquifer using hydraulic conductivity, hydraulic gradient and cross-sectional area for unconfined aquifers or transmissivity and aquifer width for confined aquifer (Sami and Murray, 1996). A method proposed by Sami and Murray (1996) is the exploitation potential method which is similar to the recharge method, with the exception that the parameter D varies depending on a range of aquifer conditions, and is determined from nonograms.

5.3.7. Groundwater quality sampling

The type of groundwater utilisation ultimately depends on the quality of the water. Some groundwater may appear to be aesthetically fit for human consumption, when in fact the quality may be detrimental to human health. In order to determine the suitability or quality of groundwater, samples must be lifted to the surface and analysed. Unfortunately, groundwater sampling is not completely straightforward. A comprehensive manual available on groundwater sampling has been compiled by Weaver (1992). This document covers planning a sampling run, which determinants to select for laboratory analysis and for field analysis, quality assurance, a monitoring programme guide, what containers to use and preservation methods, how to measure water levels, methods of sample collection, how to purge boreholes, filtering devices, the flow-through cell, multiple level sampling, and how to sample springs and seeps. This section will only reflect on the most important aspects of groundwater sampling as it relates to rural water development.

One of the most important principles of groundwater sampling is to obtain a sample that is representative of the aquifer. A grab sample of a standing borehole will not be representative of the aquifer water, but rather a sample of the stagnant water stored by the borehole. This stagnant water can be altered by a number of processes such as leaching or adsorption of certain constituents from or onto the borehole casing or screen, a reduction in heavy metal species precipitated by sulphide produced by sulphate-reducing bacteria commonly found in groundwater, chemical reactions due to changes in the concentration of gases such as oxygen and carbon-dioxide (Weaver, 1992).

It has been found that to obtain a representative sample, the borehole should be purged at least three times the standing water volume (Table 27). Note that for low-yielding boreholes, it may not be possible or necessary to discharge three times the standing water volume, instead one volume of the standing water volume will suffice since it will eliminate the standing water. Another method is to purge until pH, electrical conductivity and Eh are stable. At this point, the sample can be considered representative. Ideally, a flow-through cell should be used to take the field measurements of pH, electrical conductivity and Eh, due to their susceptibility of altering on exposure to the atmosphere. The flow through cell is a closed box or cylinder with an inlet at the base and an outlet at the top. The top of the cell contains water proof glands through which to insert measurement probes.

Table 27. Approximate purging times required based on pumping rate and groundwater volume (adapted from IWQS, 1996).

	LOW YIELDING BOREHOLES x 1 volume of stagnant groundwater				**HIGH YIELDING BOREHOLES x 3 volume of stagnant groundwater**			
Pumping rate	360l/hr (0.1 l/s)		1800l/hr (0.5 l/s)	3600l/hr (1.0 l/s)	7200 l/hr (2.0 l/s)		18000l/h (5.0 l/s)	36000l/h (10.0 l/s)
Length of water column (depth of borehole minus depth to water level in m)	Volume (litres)	Purging time (min)	Purging time (min)	Purging time (min)	Volume (litres)	Purging time (min)	Purging time (min)	Purging time (min)
10	215	35	7	3.5	645	5	2	1
20	428	70	14	7	1283	10	4	2
30	643	107	21	10	1929	16	7	3
40	855	142	28	14	2565	22	9	4
50	1070	178	36	18	3210	27	11	5
60	1283	214	43	21	3848	32	13	6
70	1498	250	50	25	4493	38	15	7.5
80	1710	285	57	28	5130	43	17	8.5
90	1925	320	64	32	5775	48	19	9.6
100	2138	356	71	35	6413	54	21	10.6

The methods used to lift the sample from the borehole are numerous, with collection devices generally consisting of bailers, positive displacement or submersible types, suction lifter and gas contract samplers. Weaver (1992) recommends the use of either the bladder pump or helical motor type positive displacement pumps for best results in groundwater sampling from boreholes and wells.

Typically, unless a dedicated groundwater sampling set-up is used, it will be difficult to sample as per the recommendations by Weaver. In practice, samples can be obtained during borehole development where field measurements of pH and EC must be taken constantly in order to check for any changes in quality. At the end of development, a groundwater sample must be taken for laboratory analysis. This sample should indicate whether the borehole should be equipped or not. A borehole with unsuitable water quality should either be backfilled and stone/concrete plugged, or capped until a time when treatment becomes an option for the source.

The size of the sample collected depends on the requirements of the laboratory that will analyse the water. Therefore, before samples are taken, the size of the sample and type of bottle must be confirmed with the laboratory. In some cases preservation may be necessary. The purpose of preservation is to attempt to retain the sample as close as possible to its original state in the underground environment by retarding biological activity and chemical reactions and to reduce volatility (Weaver, 1992). There are a vast number of preservation techniques to be used for the various parameter determinations. For water supply purposes, the most common method is cooling and preservation by mercuric-chloride.

Bottles, including the cap, must be cleaned thoroughly by rinsing three times with the water to be sampled. The sample must fill the bottle completely and should not contain an air bubble once the bottle is closed as trapped air will provide an environment for changes in water chemistry.

6. SOCIAL ASPECTS OF RURAL WATER SUPPLY

The first policy principle stated in the White Paper (DWAF, 1994) is that "development should be demand driven and community based". This implies that decision making and control will be devolved as far as possible to accountable local structures. Another principle states that there will be integrated development where water and sanitation development are not possible in isolation from development in other sectors. This will require co-ordination between government and other involved parties in an effort to derive the maximum direct and indirect developmental benefits. Examples of these situations can be through education, training and job creation (DWAF, 1994). The process of rural water supply has two distinct aspects which must both be addressed in order to achieve success. These aspects are social and technical. To hydrogeologists, social aspects appear complex and time-consuming. However, most realise that without addressing all the social aspects such as community requirements, political and legal issues, economics, post-implementation management of the scheme, training and education through community participation, the project will not be sustainable.

There have been examples of technical consultants carrying out organisational development without the correct training themselves (pers. comm. DWAF, 1996). This type of action is also detrimental to the success of a project. It is advised that technical consultants accept that the social aspects must be dealt with by professional social scientists, who may require the technical consultants to be involved with various aspects such as maintenance training or capacity building around groundwater issues. An example of this type of involvement can be given for a situation on the Zululand coastal plain. Over the years, government agencies have installed a number of windpumps and shallow wells in the area which has a known high groundwater potential. These sources have often failed the community, primarily because of lack of ownership and responsibility. Compounding the problem, promises were made by politicians during the 1994 elections that piped water will be supplied. This is an unrealistic short term situation due to the extremely dispersed and marginalised nature of the local communities which has resulted in the communities only being willing to accept piped water and a tap. In this situation, both the social scientist and the technical consultant must work together to ensure that the community is provided with information to assist them in making a more informed decision on the type of water supply that can sustain them immediately.

It is apparent that the social and technical aspects of rural water supply must be integrated. The social specialist is not trained to carry out technical work and the technical specialist seldom has the capacity to address all of the social aspects. These two proponents must acknowledge their dependence on each other and work together in a professional manner to ensure success of water supply projects in rural areas.

7. DATA AVAILABILITY

At the time of writing this thesis, there had been much activity in KwaZulu-Natal with respect to water source development, primarily for RDP projects and drought relief purposes. The DWAF, in particular, spent in total approximately R23.5 million in 1995/1996 for drought relief. This cost includes all costs to establish boreholes, to access difficult sites, the cost and installation for handpumps and maintenance costs of broken pumps. The services of groundwater consultants for the siting and drilling supervision of boreholes in communities, within former KwaZulu districts deemed to be in a critical situation, were used due to a lack of Department of Water Affairs and Forestry hydrogeologists. Table 28 summarises the costs for the establishment of boreholes and test pumping only. Drilling contractors were used for borehole drilling.

The information generated by the consultants for the DWAF's drought relief action in 1995/1996, in the form of geophysical data, drilling logs, chemical analyses and pump tests for a total of 993 boreholes has been used in the assessment of aquifers in rural areas for this thesis (Figure 39). The consultants each provided the DWAF with a report containing all the aforementioned data, with little or no overall hydrogeological interpretation. Each record has been examined in terms of the depth of water strike and in which lithology and target feature it was obtained. Once the water-bearing feature had been identified it was coded by lithology and aquifer type (Table 29). Special mention must be made of the secondary porous and featureless classes of aquifers as they are not exactly self-explanatory. Secondary porous aquifers have been differentiated from fractured aquifers because the flow mechanism will be porous flow as opposed to fracture flow which occurs within the fractures of fractured aquifers, with its matrix storing water. Those records classed as featureless, are those in which no recognisable water-bearing feature was identified in the geological log. Mostly the boreholes classed as featureless are dry, but some do give seepage or even quite reasonable yields. The classification of the aquifer as featureless may therefore also be a function of poor logging.

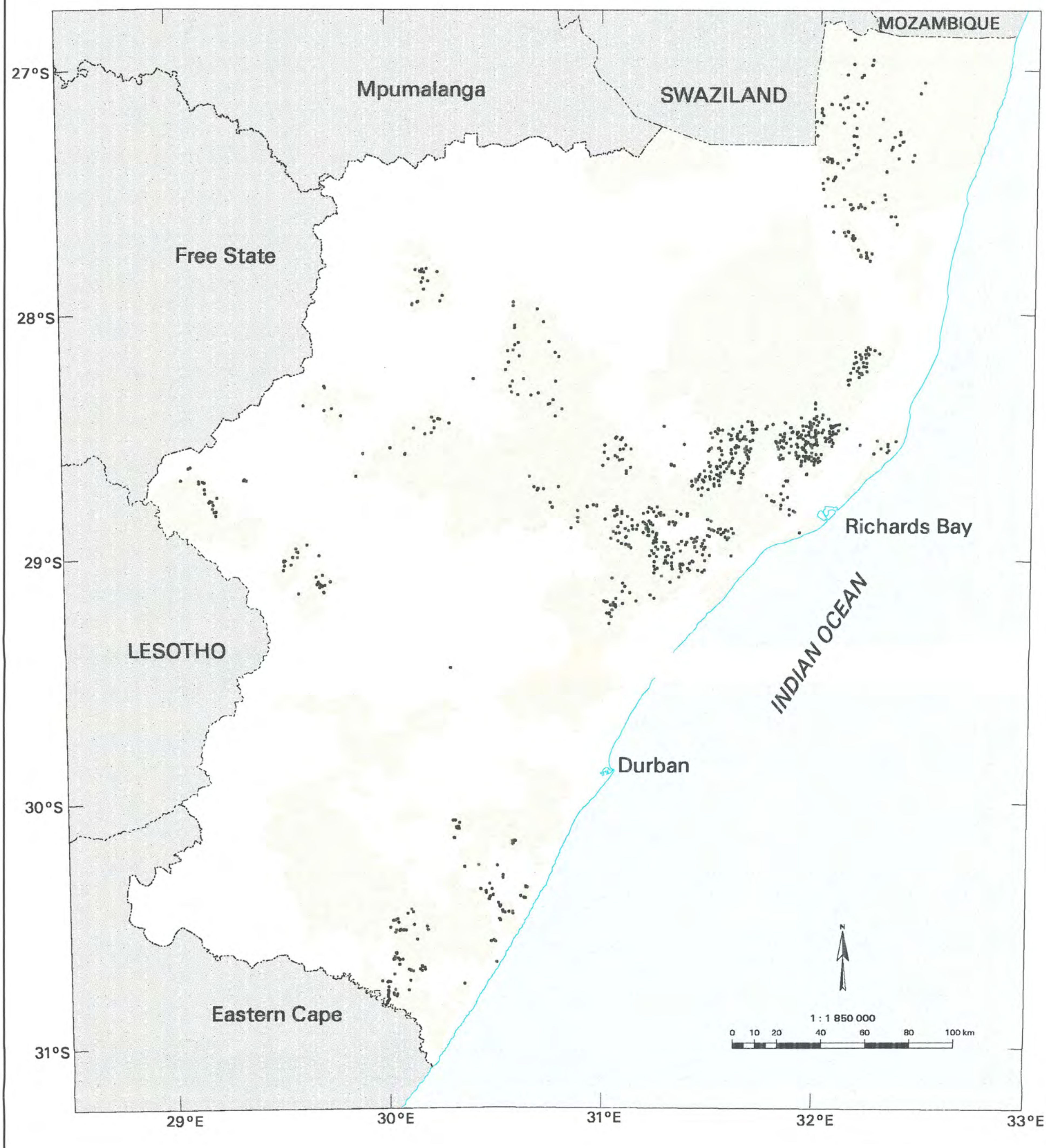
Yields of boreholes were recorded as both blow yields and pump tested yields. The geophysical method used to site the borehole and length of each traverse was also recorded for each borehole. All this information makes up the database which is presented in Appendix A.

Table 28. Summary of costs incurred for the establishment of boreholes for drought relief purposes (values in parenthesis reflect percentage of total cost for the district).

FORMER KWAZULU DISTRICT	CONSULTANTS' SITING AND SUPERVISION COST	DRILLING	% SUCCESS	PUMP TESTING	TOTAL
Enseleni	R733,381 (20%)	R2,671,944 (72%)	78	R321,598 (8%)	R3,726,923
Inkanyezi	R696,508 (36%)	R1,029,100 (52%)	76	R235,826 (12%)	R1,961,434
Nkandla	R201,294 (25%)	R526,767 (65%)	66	R77,070 (10%)	R805,131
Hlabisa	R128,920 (24%)	R339,400 (65%)	75	R57,300 (11%)	R525,620
Ubombo	R234,360 (25%)	R661,059 (70%)	59	R50,736 (5%)	R946,155
Ingwavuma	R172,840 (29%)	R362,732 (62%)	43	R52,528 (9%)	R588,100
Maphumulo	paid by Umgeni Water	R303,966	70	R19,910	R323,876
Madadeni	R95,727 (36%)	R146,166 (55%)	53	R25,614 (9%)	R267,507
Nqutu	R174,561 (37%)	R256,556 (55%)	81	R38,095 (8%)	R469,212
Emnambithi	R105,705 (24%)	R330,075 (74%)	63	R7,936 (2%)	R443,716
Okhahlamba	R255,316 (23%)	R804,430 (71%)	54	R65,130 (6%)	R1,124,876
Vulamehlo Mzumbe Izingolweni (1996)	R239,930 (33%)	R427,623 (58%)	60	R69,498 (9%)	R737,051
Izingolweni (1995)	R153,484 (16%)	R734,741 (79%)	37	R48,561 (5%)	R936,786
TOTAL	R 3,192,026	R 8,594,559		R 1,069,802	R 12,856,387
AVERAGE	25%	67%		8%	

Table 29. Categories for determining aquifer types.

FEATURE OF GROUNDWATER STRIKE	AQUIFER TYPE
unconsolidated sediment	primary porous
weathered rock	secondary porous
fractured rock breccia	fractured
contact between different rock types (including dolerite)	contact
no definable target was obvious from the drilling log or the borehole did not intersect any water-bearing features	featureless (in most cases this type is not an aquifer)



rural areas

• boreholes

Source of data:
DWAF

Date:
26 November 1996

Projection:
Lamberts, Central Merdian 31 degrees east

DISTRIBUTION OF BOREHOLES CAPURED FOR ANALYSIS FROM THE 1995/1996 DROUGHT RELIEF PROGRAMME

Figure 39

7.1. Data limitations

The brief given to the groundwater consultants was not very specific and the requirements from each consultant differed according to the responsible DWAF's official engineer. As a result, the type of pump tests carried out on the successful boreholes varies. Low yielding boreholes (<2l/s) appear to have had a type of Farmer's test carried out on them, which makes it difficult to obtain hydraulic characteristics. Each consultant also used a different method for determining the recommended pump rate or sustainable yield. These methods were not presented in any of the reports. The values derived from the pump testing are, therefore, not consistently determined and will differ from consultant to consultant. However, the pump tested values are used during analysis, wherever possible, because by using the blow test yields, an unrealistic picture will be given of the aquifers' yield potential. This is because the blow test yields are almost always higher than the recommended yield. Figure 40 shows a plot of blow tested versus pump tested yields of the boreholes from the data set which were given a recommended yield by the consultants. A best fit line through the data shows that the pump tested yield is usually a factor of 0.375 of the blow tested yield.

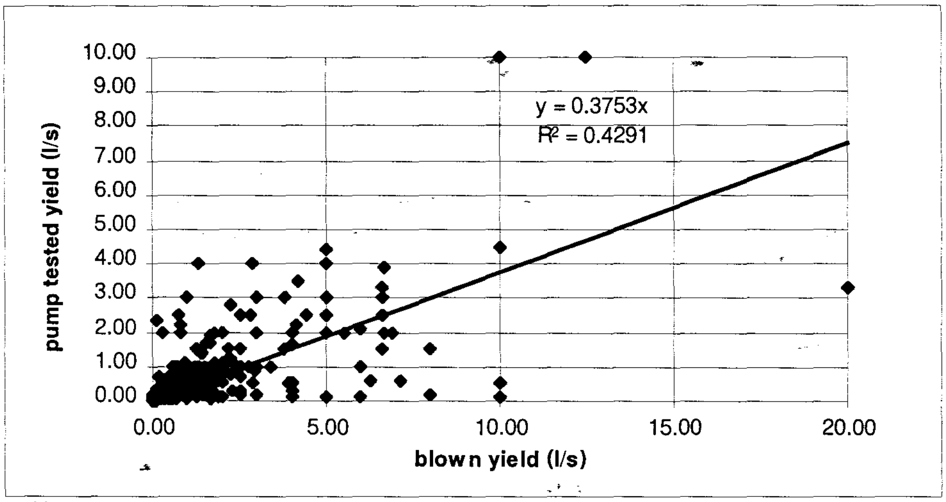


Figure 40. Plot of blown yield versus pump tested yield with a linear regression for boreholes.

Even though 993 borehole records are used for analysis purposes, once each of these boreholes' aquifer type is categorised, the number of records in each category sometimes becomes very small and oftentimes lead to only one record in a category. This situation makes analysis and comparisons not statistically valid because it is not known whether one is dealing with a representative sample. Therefore the results obtained from those categories with less than 10 records can not be regarded with a high level of confidence.

Another limitation of the data is the biased use of different geophysical methods within each hydrolithology. This is a function, firstly, of the consultants' accessibility to certain geophysical instruments, and secondly, of their familiarity and experience with certain instruments. Compounding the problem is the fact that each consultant appears to interpret the geophysical curves differently depending on their experience. The process of borehole siting using geophysics is still not an exact science. This fact is further compounded by the aniostropic nature of most hard rock aquifers, which can support a dry borehole just a few meters away from a high yielding borehole.

These type of problems all contribute to inconsistent data. However, in view of these limitations, each borehole has been examined as a separate entity regardless of which consultant sited the borehole. Despite the above mentioned shortcomings the geophysical data was grouped by hydrolithology so as to be consistent with the other analyses carried out.

8. METHODOLOGY

8.1. Data analysis and presentation

The database generated from the 993 borehole records has been captured on Microsoft Excel. Various filters were applied to group data into different aquifer types and target features within each hydrolithology.

The main purpose of the analysis is to clearly illustrate the characteristics of each target feature in the various hydrolithologies, as they affect rural water supply. The four factors controlling whether groundwater can be developed for rural water supply are: likely yield, the quality of groundwater likely to be encountered, probability of successful borehole siting and the cost of groundwater development. Each of these components is analysed mainly by comparative methods in order to establish those aquifers which are of greater importance in KwaZulu-Natal.

Yield characteristics of each target feature were analysed by means of cumulative distribution plots and median yield values. The use of the median yield is a commonly used method of statistical interpretation in hydrogeological yield analysis. One of the main reasons for using median yield is that it is not influenced by extreme values, whereas the use of a mean would be adversely affected by extreme values (Walpole and Myers, 1978). The percentage of the hydrolithology each target feature forms part of has been given in order to illustrate the relative importance of the feature. Another aspect presented is the number of wet and dry boreholes drilled into each target feature. Where sufficient records are available, this portrayal of wet and dry boreholes provides an indication of the probability of drilling a successful borehole into the various target features.

Another important feature related to the hydrogeology of aquifers is the chemical quality of the groundwater each target feature produces. Quality in terms of its effect on human health and thus potability is illustrated firstly on the frequency of the overall quality class per target feature and secondly, by each constituent analysed. The classification based on the guide for the health related assessment of quality of water supplies has been used for this purpose (DWAF, 1996). An examination of the database (Appendix A) will show that there are numerous water quality variables for which there are results. The groundwater samples were not all analysed at the same laboratory and some of the consultants requested that additional variables be tested for, depending on their own requirements. The analysis of the groundwater quality in this thesis therefore only relates to those constituents which are common to all the records and which are related to health. Those constituents which have been examined are electrical conductivity, pH, fluoride, nitrate, magnesium, sodium, potassium, chloride and sulphate. Constituents such as calcium, iron, phosphate, ammonia and silica have not been included because of their inconsistent presence in the database or because they do not have major effects on human health. Total dissolved solids are not included in the graphical analysis due to its close relationship with electrical conductivity. The mean value for each constituent has been used to reflect the concentration most likely to occur. To give an indication of the variability around the mean, the standard deviation has also been calculated.

The component of the database that takes into account the borehole siting techniques available for each target feature is geophysics. The success of the different geophysical methods used to detect the various target features are presented by means of histograms. The histograms reflect each target feature's yield achieved by different geophysical methods. The yield ranges utilised are those used by the DWAF in their hydrogeological mapping programme. These ranges have been chosen according to levels of exploitation (Table 30). The number of dry boreholes is also a function of the aquifer's characteristics and is included to give an indication of failure.

Table 30. Yield ranges and their capabilities.

YIELD RANGE (l/s)	USE
> 0 - 0.1	handpump for a few families
0.1 - 0.5	handpump for a small community
0.5 - 2.0	motorised pump for a small community
2.0 - 5.0	motorised pump for a large community
> 5	motorised pump for a town

The fourth component of groundwater development affecting the potential of groundwater for rural water supply is the cost of development. The major costs incurred during groundwater development are mostly by borehole drilling and to a lesser extent by the consultants' siting and supervision expenses. Those costs which are fixed regardless of the ultimate result are not regarded in this thesis. Only the costs which do vary according to the geology are integrated into the analysis. Geophysical and drilling methods are the two variable taken into account when finally describing the development potential of KwaZulu-Natal aquifers for rural water supply.

8.2. Spatial representation

An increasingly popular, but more importantly practical and efficient method of capturing, storing, manipulating, analysing and displaying large quantities of spatial data is through geographic information systems (GIS). All of the maps produced in this thesis have been generated using a GIS. Some of the data displayed on the maps is primary data, such as rivers and forestry. Other features given on the maps are secondary and have been derived from a number of different sources or by manipulation processes, for example slope. In order to appreciate the GIS methodology utilised in this thesis, some principles of GIS are explained.

Many definitions of GIS have evolved over the past two decades as the system has developed (Fraser, 1991). However, a simplified definition given by ESRI (1992) adequately defines GIS as:

> A computer system capable of holding and using data describing places on the earth's surface.

It should be stressed that a GIS is not a system for map making, but rather an analytical tool. The basic concept of a GIS is that it links spatial features with geographic and descriptive information about those features. This information is stored as attributes of the graphically represented feature. All information pertaining to the features make up a database. The three basic pieces of information that a user needs to know about every feature stored in the system are: what is it, where is it and how does it relate to other features? The use of a GIS can easily answer these questions through its ability to associate data with features on a map and to create new relationships to aid in analysis.

8.2.1. Data structure

Geographic information is represented as features with associated attributes. Features are distinctly different from one another and can be either points, tics, nodes, lines or polygons. A point is a spatial object with no area. An example of this would be a borehole representing a known position on the earth's surface with its associated information, such as longitude, latitude, water strikes, geology, static water level, yield, etc. A line is a spatial object made up of a connected sequence of points. Common line features include roads and rivers. Each line would have information about the feature, such as the length of a road or the average flow along a particular section of river. Nodes are special kinds of points, usually indicating the junction between lines or the ends of line segments. A polygon is an area bounded by a closed loop of straight line segments. Each polygon will have it's own information, for example, geology could be represented by different polygons with information about the area, stratigraphy, lithology and average weathering depth. Tics are registration or geographic control points on a map which allow all features to be registered to the same co-ordinate system.

All the above features are thus represented in a vector model, where the position of each feature is defined by its placement on the earth's surface. Each different type of spatial feature or theme in a GIS is referred to as a data layer, data plane or coverage. Another method of representing data is through a raster model. This model revolves around a grid of regularly subdivided cells. The location of geographic features or conditions is defined by the row and column position of the cells they occupy. The value within each cell indicates the type of feature or condition that is found at that location. Therefore, the cells of the raster model do not exactly correspond to the spatial entities they represent in the real world.

A third model which is based on vector-based topological data is the Triangular Irregular Network (TIN). This model is best used to represent terrain data. A TIN represents the terrain surface as a set of interconnected triangular facets. For each of the three vertices, the geographic location (XY co-ordinate) and the elevation (Z co-ordinate) values are encoded. Table 31 reflects the spatial data types of coverages used in this thesis.

Table 31. Spatial data types of coverages used in this thesis.

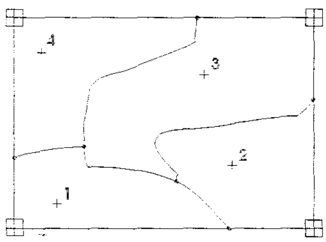
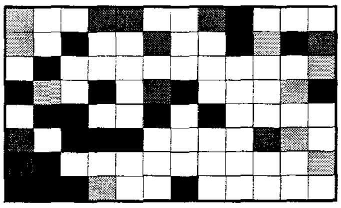
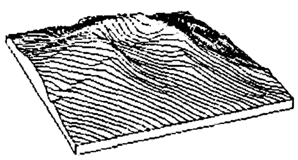
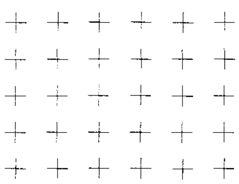
PRIMARY DATA	point	line	polygon	grid (raster)
land use			✓	
geology			✓	
lineaments		✓		
faults		✓		
terrain morphology units			✓	
evaporation			✓	
rivers		✓		
dams and natural lakes			✓	
soils			✓	
natural vegetation			✓	
population density			✓	
boreholes	✓			
SECONDARY DATA				
topography (derived from minute by minute point data)				✓
slope (derived from topography)				✓
mean annual precipitation (derived from minute by minute point data)				✓

8.2.2. GIS software

The GIS packages used in this thesis were Arc/Info and ArcView2, both products of the Environmental Systems Research Institute. A number of large KwaZulu-Natal organisations, such as the DWAF, Durban Metro Council, CSIR, the Natal Parks Board, University of Natal, Pietermaritzburg and Umgeni Water are users of this software, which although costly, is more powerful than most other systems. Digital data conversion of most of the commonly used data was relatively uncomplicated, however some complex DXF files proved to be somewhat difficult to convert.

Arc/Info consists of a number of modules which if used in an integrated manner can strongly enhance the use of a GIS. Some of the functions within the modules which were used for geographic data modelling as shown in Table 32.

Table 32. Summary of the geographic data models used in this thesis (after ESRI, 1992).

GEOGRAPHIC DATA SET	STRUCTURE	SPATIAL OBJECTS	USES
Data layer 	vector arc-node topological georelational	arcs nodes polygons annotation	• cartographic database • automation and update of spatial data • linear feature modelling • base maps for cartography • spatial database management
Grids 	raster georelational	cells	• spatial analysis and modelling • spatial process modelling
TIN 	surface triangulated - irregular network	xyz nodes edges triangles	• surface representation • surface modelling and display (e.g., contouring, 3-D displays, profiles)
Lattices 	surface digital elevation model grid raster	xyz points	• surface representation • surface modelling and display (e.g., shades relief, 3-D display, slope/aspect)

9. HYDROGEOLOGY OF RURAL KWAZULU-NATAL AQUIFERS

There are a number of different aquifer systems within the province of KwaZulu-Natal. Secondary aquifers are the most abundant, with primary aquifers covering only 13% of the province. The nature of the rock types or lithology and their tectonic history are the main controlling features of the aquifers' characteristics. For the sake of simplification, the different formations occurring within the province have been grouped into lithologies of similar hydrogeological character which are called hydrolithologies.

All the unconsolidated materials of Quaternary age have been grouped into one hydrolithology which includes most of the Maputaland Group, alluvium and the Masotcheni Formation. The Uloa Formation of the Maputaland Group has been grouped separately due to its characteristic karstic nature. The Zululand Group forms a hydrolithology on its own. The volcanics of the Drakensberg Group, Jozini and Letaba Formations together with intrusive dolerite each form separate groups. The large number of formations constituting the sedimentary rocks of the Karoo Supergroup have been grouped together because of their predominant argillaceous nature, with the exception of the Vryheid Formation which is mainly arenaceous. The tillites of the Dwyka Group are also grouped separately. The Natal Group sandstone is given its own status and is not linked to any other hydrolithology. The basement rocks are separated into the rocks of the Natal Metamorphic Province, the Pongola Supergroup and the Barberton Sequence. The Pongola Supergroup and Barberton Sequence have further subdivisions within their main groups and intrusive acid rocks. Table 33 summarises the groupings and subdivisions as described. Note that the symbols given to each hydrolitholgical group are not always the standard symbol given on the Geological Survey geological maps. Where a number of formations have been grouped, a new symbol has been given.

In order to get an indication of the relative extent of the different potential aquifers, the percentage coverage of each hydrolithology has been calculated for rural areas and compared to the coverage for the entire province (Figure 41). This graph shows that the important aquifers, based on their surface occurrence, are: argillaceous Karoo rocks (P), Vryheid Formation (Pv), Karoo dolerite (Jd), Quaternary deposits (Q), Natal Metamorphic Province (NMP), Natal Group sandstone (O-Sn) and Dwyka Formation tillite (C-Pd).

Table 33. Description of grouped hydrolithologies for KwaZulu-Natal used in this thesis.

DESCRIPTION	GROUPING	SYMBOL
Quaternary sediments	Maputaland Group Masotcheni Formation river alluvium	Q
Uloa Formation	Uloa Formation	Tu
Zululand Group siltstones and sandstones	Zululand Group	Km
dolerite	Karoo Supergroup dolerite	Jd
Jozini rhyolite	Jozini Formation	Jj
Letaba basalt	Letaba Formation	Jl
Drakensberg basalt	Drakensberg Group	Jdb
Karoo argillaceous rocks	all Karoo Supergroup sedimentary rocks except Vryheid Formation and Dwyka Group	P
Ecca sandstone	Vryheid Formation	Pv
Dwyka tillite	Dwyka Group	C-Pd
Natal Group sandstone	Natal Group	O-Sn
Natal Metamorphic Province basement	Natal Metamorphic Province	NMP
Pongola basement	Pongola Supergroup • intrusive granite • Mozaan Group • Nsuze Group	 Rg Rm Zn
Barberton basement	Barberton Sequence • intrusive rocks • Empangeni Metamorphic Suite • Nondweni Group	 Zg Zi Zd

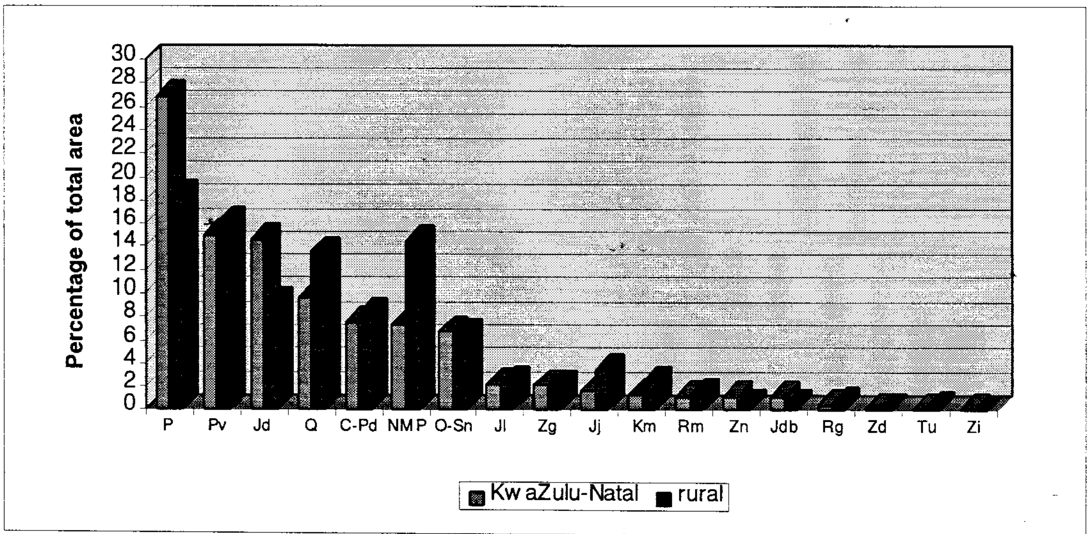


Figure 41. Graph showing percentage coverage of hydrolithologies in KwaZulu-Natal and rural areas with KwaZulu-Natal.

In addition to a determination of the most commonly occurring hydrolithologies in rural areas, an assessment of the distribution of population densities based on each hydrolithology has been made (Figure 42). This graph shows that together with the hydrolithologies mentioned previously, that the Jozini and Letaba Formations are also aquifers which form part of a significant groundwater demand by the rural population based on their surface distribution. This thesis will therefore focus on those aquifers occurring in KwaZulu-Natal which are expected to have greater groundwater demands. The groundwater demand on these hydrolithologies is supported by the number of boreholes drilled into each type during the drought relief programme (Figure 43).

This chapter describes the hydrogeology of each hydrolithology, presents hydrogeological relevant statistics based on the data collected during the drought relief programme, and makes conclusions on the results obtained. Some of the targets features within each hydrolithology do not have much data due to the limited number of boreholes, thereby reducing the validity of interpretation and yield characterisation.

9.1. Target feature yield

The quantity of groundwater an aquifer is capable of yielding is one of the important aspects to assess when deciding whether an aquifer is suitable for use in water supply. Experience has shown that some aquifers in KwaZulu-Natal have significantly higher yields than others. However, previous work carried out on the characterisation of groundwater was undertaken at a scale of 1 : 250 000 so that spatial variability between and within hydrolithologies was masked. The data available in this thesis allowed the different target features within each hydrolithology to be characterised in terms of the recommended groundwater yield.

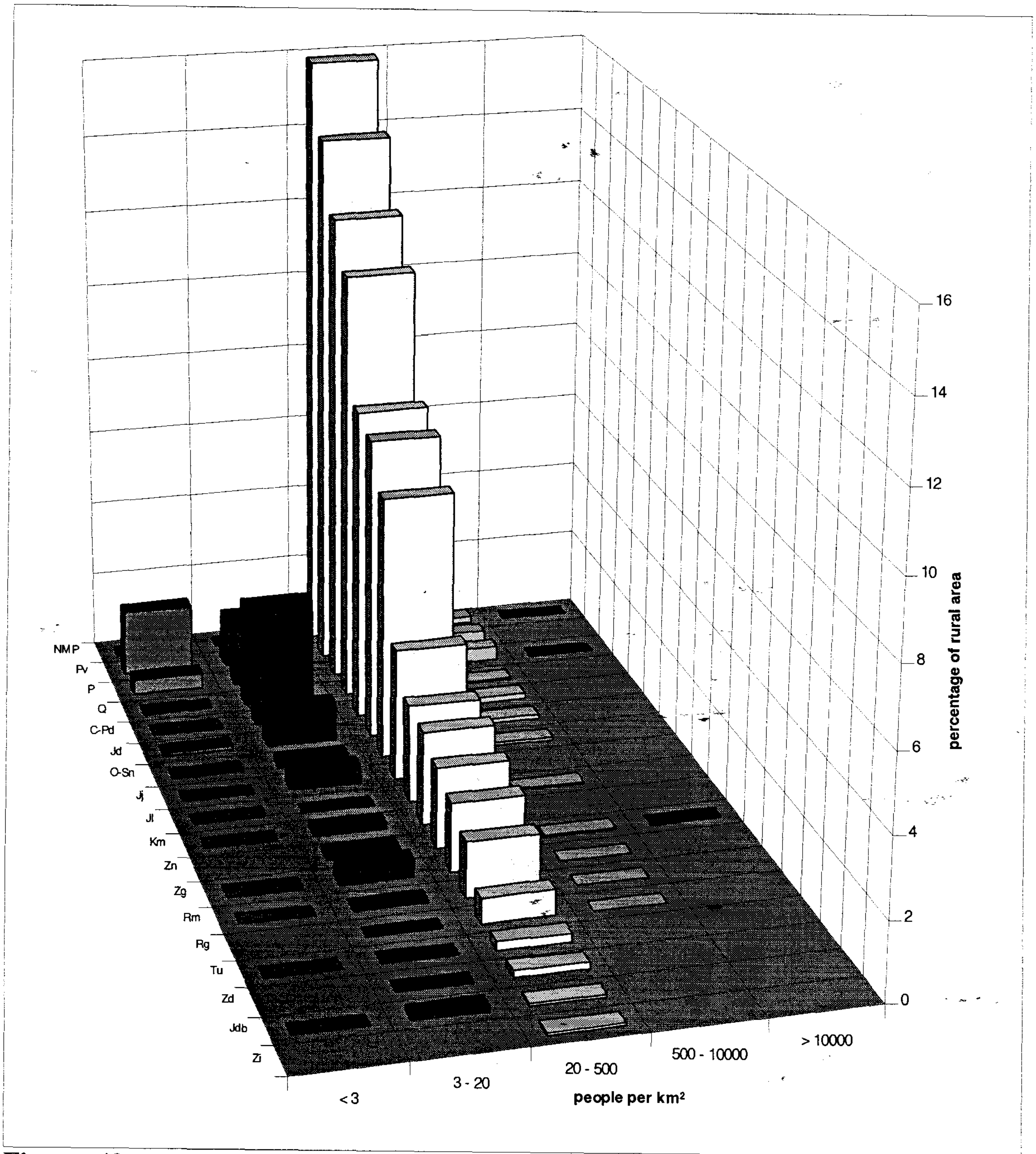


Figure 42. Percentage of rural areas covered by the various hydrolithologies over population density.

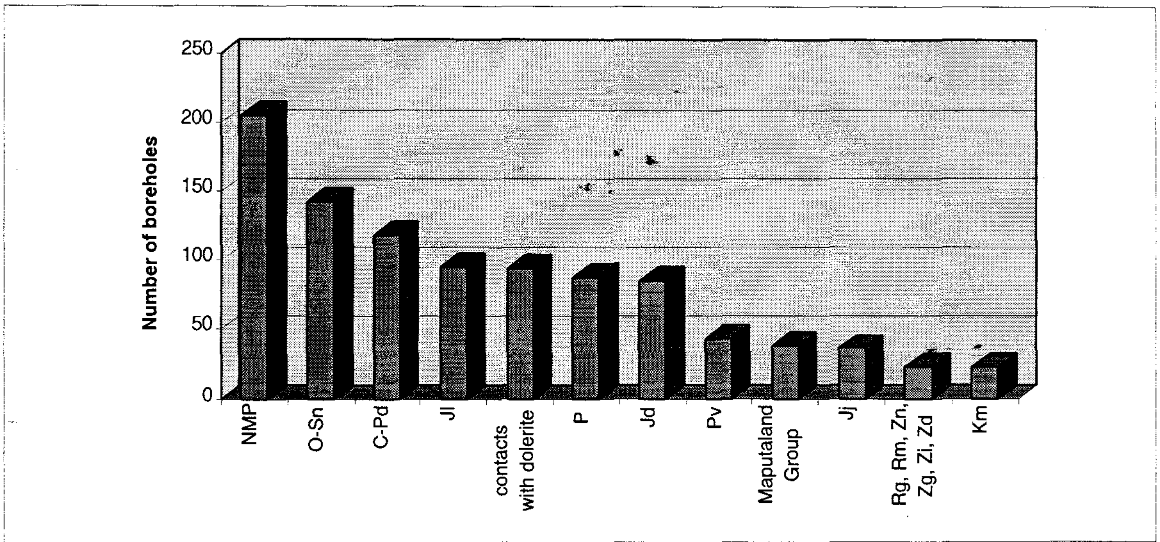


Figure 43. Number of boreholes drilled into each hydrolithology during the drought relief programme.

9.1.1. Karoo argillaceous rocks

The predominantly argillaceous nature of most of the Karoo sediments results in low primary hydraulic conductivities which have been enhanced by fracturing. Porosity studies carried out by van Wyk (1963) on these sedimentary rocks in northern KwaZulu-Natal suggest a porosity average range of 2.4 - 26.9%. The severe compaction and diagenesis these sediments have undergone cause low porosity of these rocks (van Wyk, 1963). The Beaufort mudstones are the only rocks which have considerable porosity, however, their low groundwater yield implies that the pores are not well connected and/or that the pore suction is high. Weathering of these rocks is limited with the products of weathering having a high clay content which further limits permeability. Table 34 presents the water-bearing features intersected during drilling, with the median yield of each feature given together with the number of wet and dry boreholes (Figure 45). The secondary permeability imparted by fracturing in these rocks produces yields which vary from 0 - 2 l/s (Figure 44). The median yield of 0.2 l/s is typical of yields expected from very fine-grained rocks.

The second type of water-bearing feature in Karoo argillaceous rocks are contact aquifers. Arenaceous Karoo sedimentary rocks are the most common rock type, other than dolerite, in contact with argillaceous Karoo sedimentary rocks. The often well defined bedding plane, which separates the two rock types, provides a preferential flow path through which groundwater may flow. Where lithologies have gradational changes from argillaceous to arenaceous and no defined contact plane exists, no opportunity for preferential groundwater flow will be found. A total of 27 boreholes intersected the argillaceous and arenaceous Karoo contact (Table 34 and Table 35). Over 50% of the strikes were dry, but the successful boreholes generally had a higher yield than the fractured rock targets (Figure 46).

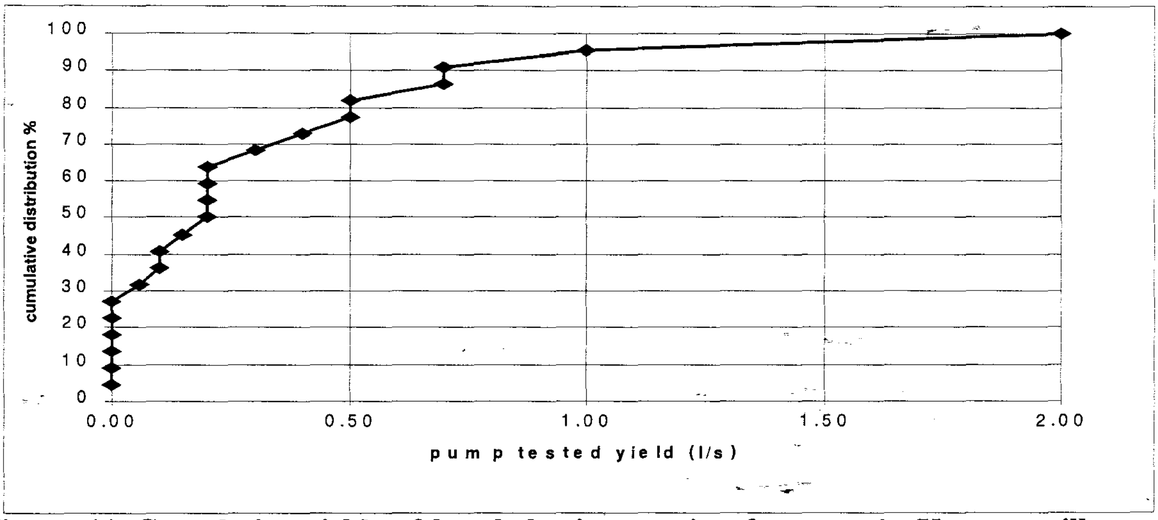


Figure 44. Cumulative yields of boreholes intersecting fractures in Karoo argillaceous rocks.

Table 34. Hydrogeological targets within Karoo argillaceous rocks.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
fractured	22	91.67	0.20	6	25.00
secondary porous	1	4.17	0.00	1	100.00
contact with Karoo arenaceous rocks	1	4.17	0.50	0	0.00
TOTAL	24			7	

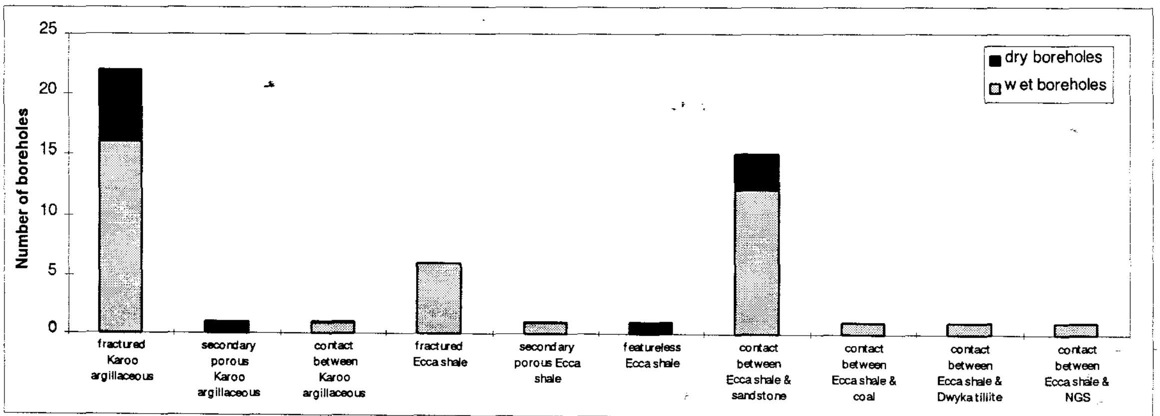


Figure 45. Summary of wet and dry boreholes drilled into Karoo argillaceous rocks and Ecca shales.

The arenaceous rocks interbedded within the Karoo argillaceous hydrolithology have been separated during analysis because of their distinct character. van Wyk (1963) gives the porosity of Karoo arenaceous rocks a value of between 5.4 - 6.8%. The cumulative distribution of yields for the three target features within the Karoo arenaceous rock is given in Figure 46 and the summary statistics in Table 35 and Figure 47. The fractured rock targets exhibit a low percentage of dry boreholes and the majority of the boreholes yield in the region of 0.1 l/s. A yield of over 7.0 l/s was obtained by one borehole which intersected a major fault. Weathered or secondary porous Karoo arenaceous rock appears to have some potential, however, as weathering is limited, only two boreholes struck water in such a target. The yield results of the contact between the arenaceous and argillaceous Karoo rocks has been discussed previously.

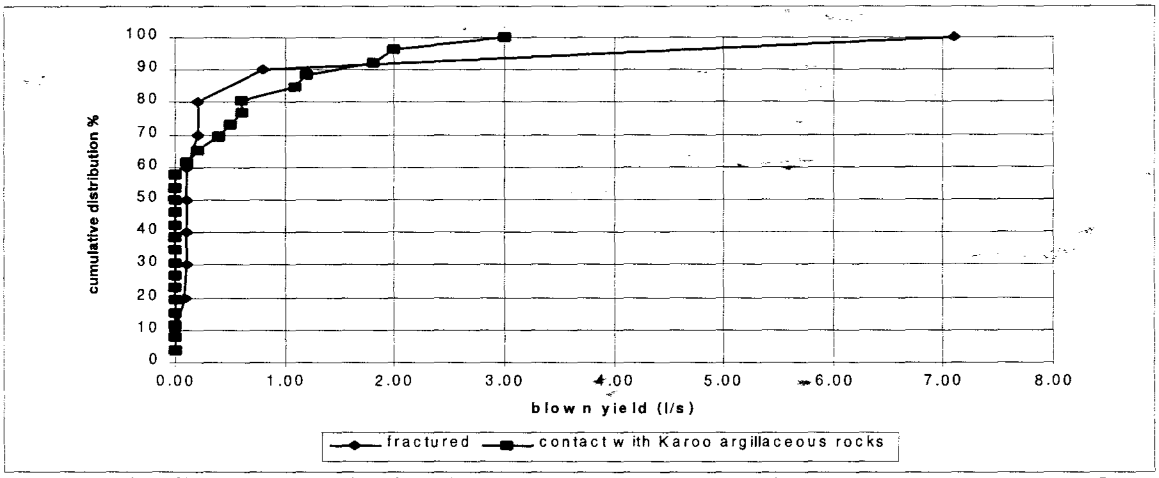


Figure 46. Cumulative distribution of blow tested yields in Karoo arenaceous rocks.

Table 35. Hydrogeological targets within Karoo arenaceous rocks.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
fractured	10	26.32	0.10	1	2.63
secondary porous	2	5.26	0.33	1	50.00
contact with Karoo argillaceous rocks	26	68.42	0.00	15	57.69
TOTAL	38			17	

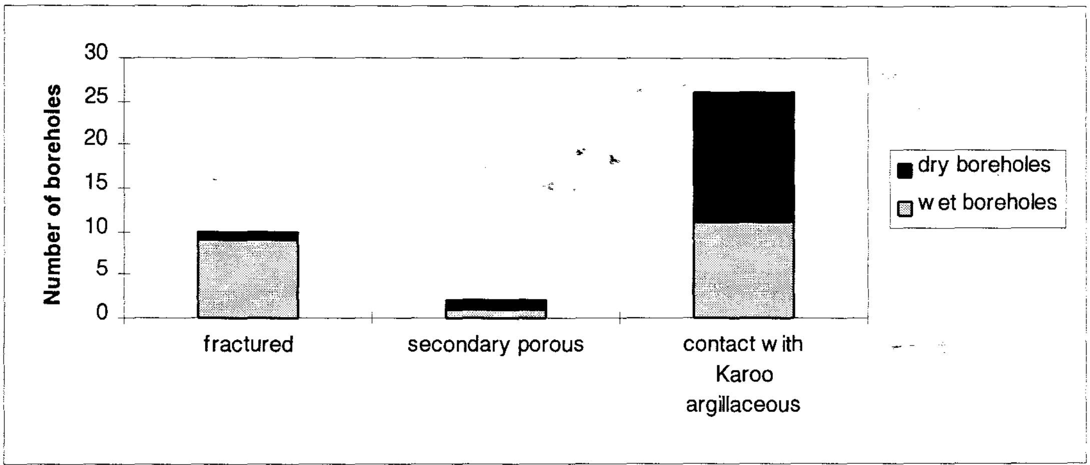


Figure 47. Summary of wet and dry boreholes in Karoo arenaceous rocks.

The Ecca shales differ from the Karoo argillaceous rocks due to their relationship with the underlying formations, resulting in different target features (Table 36), even though they have very similar lithological characteristics to the Karoo argillaceous rocks. The porosity as determined by van Wyk (1963) is 2.5 - 2.7% for the Volksrust Formation and 1.5 - 3.1% for the Pietermaritzburg Formation. The similarities between the Karoo argillaceous rock and the Ecca shales is also evident in their similar cumulative distribution of yields for fractured aquifers (Figure 44 and Figure 48). The contact between the Ecca shales (Volksrust Formation) and the top of the Vryheid Formation seems to yield more groundwater than the fractured Ecca shale. The contacts with coal, Natal Group and Dwyka Group rocks were only intersected once each, thereby limiting comparisons. Figure 45 includes the wet and dry borehole statistics for the Ecca shales.

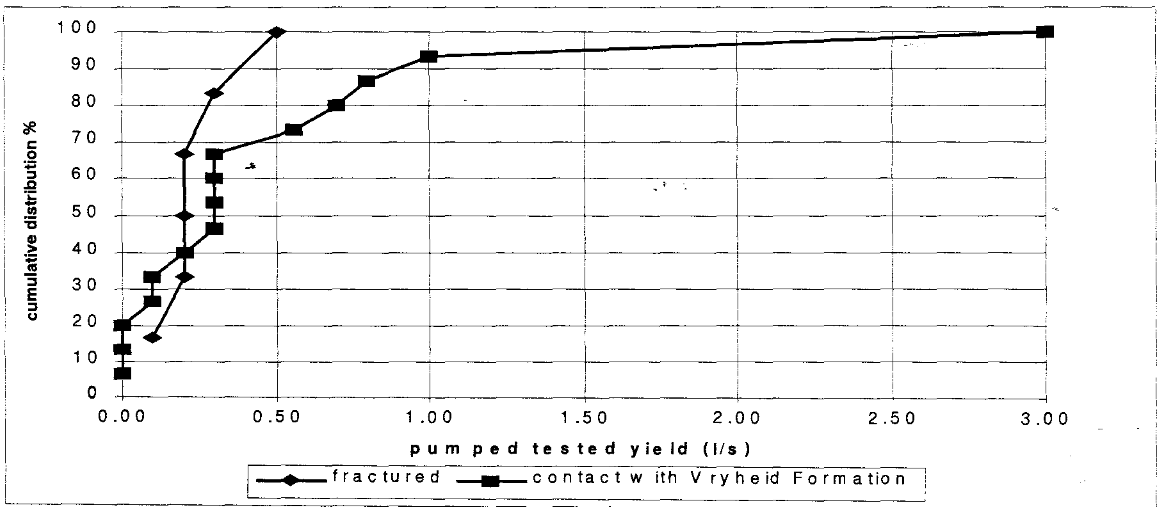


Figure 48. Cumulative distribution of yields in Ecca shales.

Table 36. Hydrogeological targets within Ecca shales.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
fractured	6	23.08	0.20	0	0.00
secondary porous	1	3.85	0.30	0	0.00
featureless	1	3.85	0.00	1	100.00
Volksrust Formation contact with Vryheid Formation	15	57.69	0.30	3	20.00
contact with coal	1	3.85	0.30	0	0.00
contact with Dwyka Group	1	3.85	0.30	0	0.00
contact with NGS	1	3.85	0.15	0	0.00
TOTAL	26			4	

9.1.2. Vryheid Formation

The Vryheid Formation consists mostly of arenaceous rocks with a lesser amount of argillaceous sedimentary rock and coal. The generally coarse-grained nature of the sandstones does not provide primary porosity due to the effective cementation of the grains. van Wyk (1963) gives average porosity ranges of 4.0 - 12.9% for the arenaceous rocks of the Vryheid Formation and 1.8 - 2.5% for the argillaceous rocks. Weathering of these rocks is limited due to the resistant nature of the quartz grains. Figure 49 depicts the cumulative distribution of the yields. The number of target features is limited to fractures and contacts with the Pietermaritzburg Formation shale (Table 37 and Figure 50). The fractures in the arenaceous Vryheid Formation are by far the best target features within the hydrolithology. The median yield of 0.4 l/s is high for KwaZulu-Natal aquifers and only just over 16% of drilled boreholes were dry. The Pietermaritzburg Formation shale of the Ecca Group has a lower median yield at its contact with the Vryheid Formation, than does the Volksrust Formation. There were also a large proportion of dry boreholes drilled on this contact. One borehole was drilled into a rare weathered zone which produced 6.0 l/s. Whether this high blown yield is sustainable for a period of time is questionable.

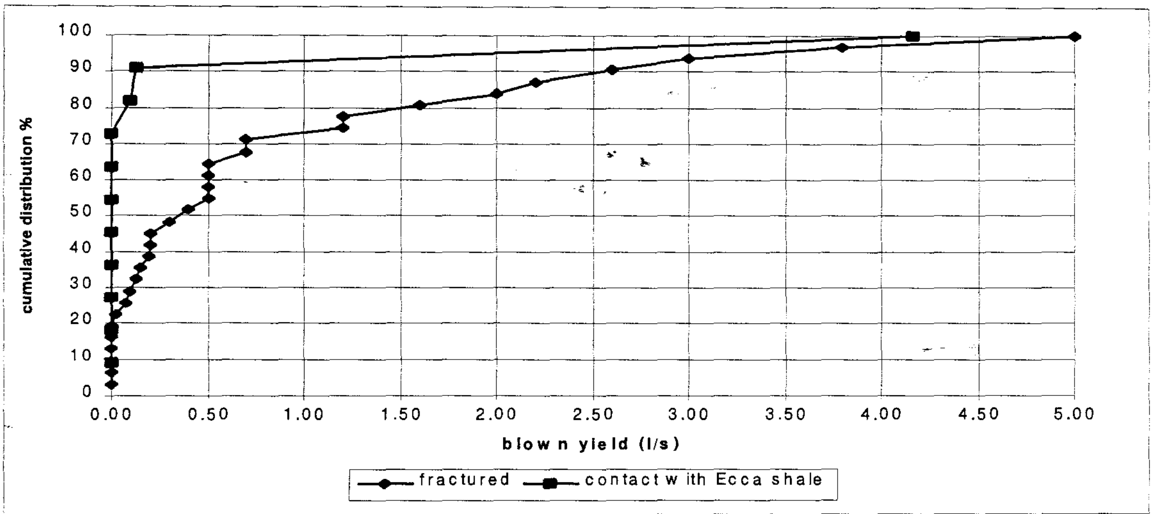


Figure 49. Cumulative distribution of blow tested yields in Vryheid Formation sandstone.

Table 37. Hydrogeological targets in Vryheid Formation sandstones of the Ecca Group.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
fractured	31	72.09	0.40	7	16.28
secondary porous	1	2.33	6.00	0	0.00
contact with Ecca shale	11	25.58	0.00	8	72.73
TOTAL	43			15	

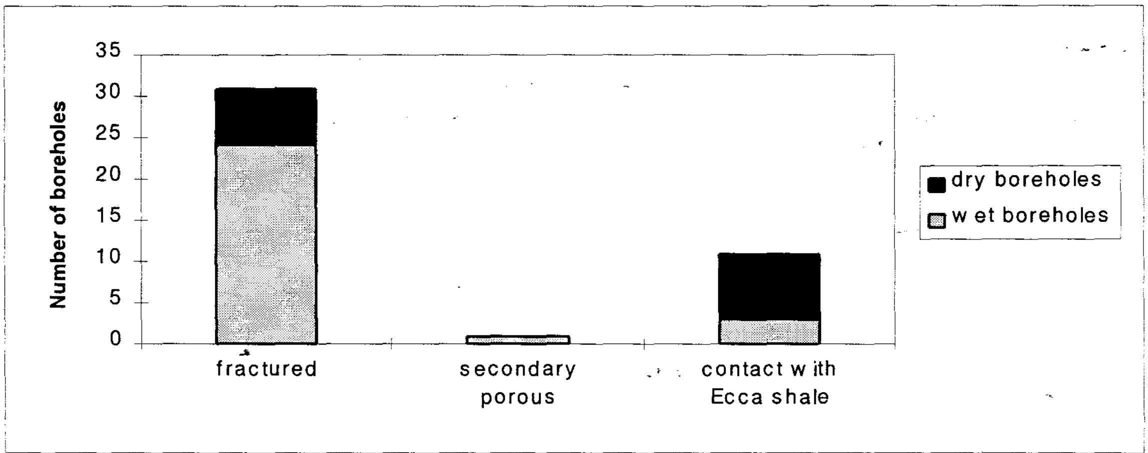


Figure 50. Summary of wet and dry boreholes drilled into Vryheid Formation sandstone aquifers.

9.1.3. Natal Metamorphic Province

The Natal Metamorphic Province essentially comprises metamorphosed crystalline rock with lesser amounts of argillaceous metamorphosed rock. The rocks display varying degrees of metamorphism such that very weakly metamorphosed granite remains called a granite. For the most part, the rocks of the Natal Metamorphic Province behave hydraulically as typical basement rocks, where the process of weathering plays an important role in the development of water-bearing zones.

Where the greatest depth of weathering occurs it can generally be assumed that it has been influenced by a fracture zone (Barker *et al.*, 1992). It therefore makes sense to site a borehole where the weathering depth is at a maximum. The thickness and lithology of the regolith or weathered zone depends upon bedrock type, the extent of fracturing, subsequent erosion and climate. Thicker regoliths are linked to older rocks and higher rainfall. Fissure systems in the granite enhance weathering and may leave rounded blocks in the regolith known as corestones. The transition between weathered and solid bedrock is usually a gradual one, but can in some instances be a sharp contact. In granite and gneiss lithologies the regolith is mostly comprised of quartz grains, mica and clay minerals.

Weathering in crystalline rocks usually results in a material which has a high porosity but low permeability due to the clay content in the weathered rock. Generally, the regolith system is in hydraulic connectivity with the underlying fractured or solid bedrock. Hence, a borehole drilled below the regolith will draw from the storage above. The Natal Metamorphic Province is more faulted than the other hydrolithologies. This fact is illustrated in Figure 51. The susceptibility of these basement rocks to faulting is probably due to their brittle nature compared to the more ductile behaviour of the argillaceous sedimentary rocks and to its greater age, which has exposed it to more tectonic activity.

The extent of weathering and its effect on permeability is evident from the low number of secondary porous targets encountered during drilling in the Natal Metamorphic Province (Table 38). Those boreholes which struck weathered zones only produced a median yield of between 0.14 and 0.34 l/s and none of them were dry. Fractures below regoliths, particularly in the granites and granite gneisses, also yielded in the region of 0.1 l/s but approximately 27% of the boreholes were dry. The general shape of the cumulative distribution yields for all the fractured Natal Metamorphic Province rocks is fairly uniform (Figure 52). Figure 53 summarises the occurrence of wet and dry boreholes graphically.

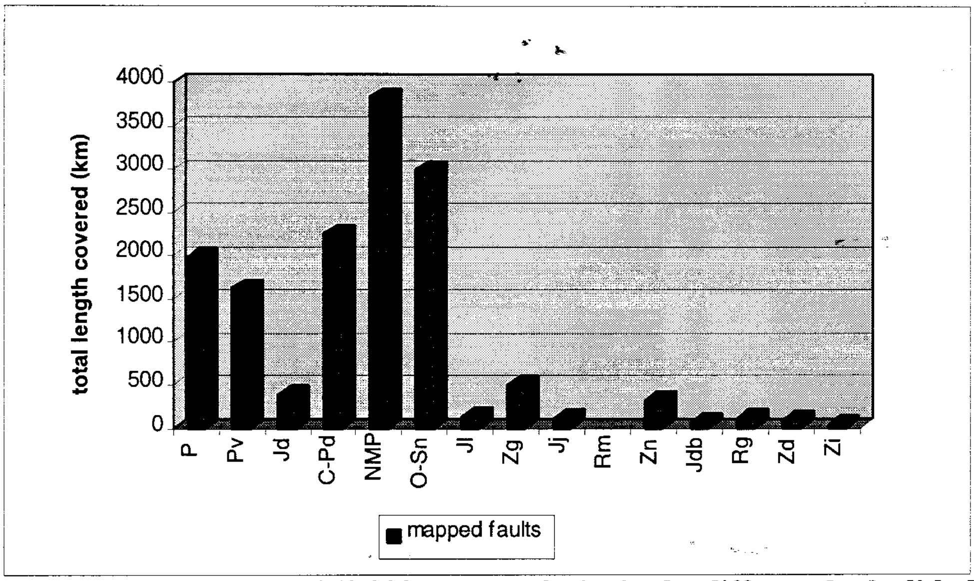


Figure 51. Total length of 1 : 250 000 mapped faults in the different hydrolithologies.

Table 38. Hydrogeological targets and lithologies within the Natal Metamorphic Province.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
fractured amphibolite	41	19.90	0.07	14	34.15
fractured diorite	9	4.37	0.07	4	44.44
fractured quartzite	1	0.49	0.00	1	100.00
fractured migmatite	3	1.46	0.08	1	33.33
fractured schist	13	6.31	0.14	3	23.08
fractured gneiss	59	28.64	0.19	16	27.12
secondary porous gneiss	3	1.46	0.14	0	0.00
featureless gneiss	3	1.46	0.00	2	66.67
gneiss/schist contact	1	0.49	5.00	0	0.00
fractured granite	55	26.70	0.10	15	27.27
secondary porous granite	7	3.40	0.36	0	0.00
featureless granite	11	5.34	0.00	11	100.00
TOTAL	206	100.00		67	

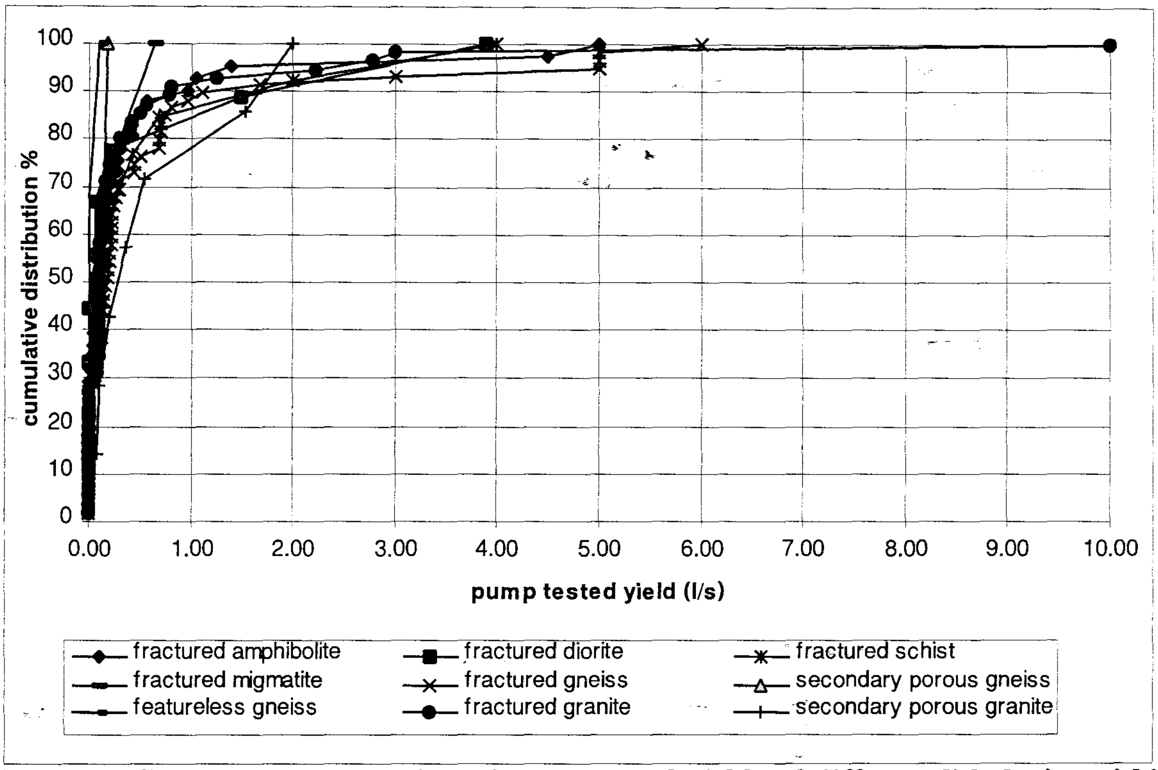


Figure 52. Cumulative distribution of pump tested yields of different lithologies within the Natal Metamorphic Province.

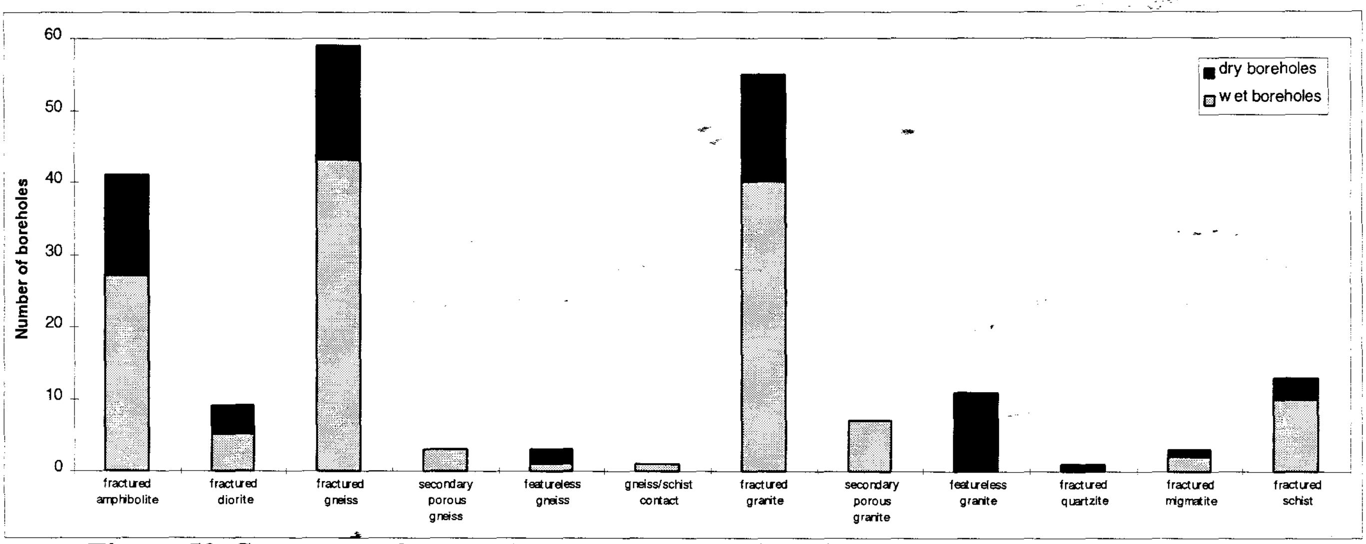


Figure 53. Summary of wet and dry boreholes drilled into Natal Metamorphic Province rocks.

9.1.4. Quaternary sediments

The extent of the Quaternary sediments in KwaZulu-Natal and its coverage of almost 9% of rural areas makes these primary aquifers some of the most important in the province. The majority of the sediments form part of the proposed Maputaland Group and its associated formations. It is in this group, and not in river alluvium or the Masotcheni Formation, that the boreholes were drilled during the drought relief programme. This section will therefore only focus on the formations of the Maputaland Group and the hydrogeology of each formation will be described in order of increasing depth or age.

The Berea-type red sands, often found on dune ridges, are the weathered component of dune sands and are rich in fine-grained material. The groundwater potential in these sands is low due to the elevated position at which they are generally found. However, in places where the dune sand overlies bedrock at shallow depths, groundwater can be encountered at the contact. In this case, the sands are not the aquifer but they do provide storage to the more permeable contact zone. The Sibayi Formation is similar in its hydrogeology to the Berea-type sand, except that the colour of the sand is more yellow brown and is not as fine-grained.

The Kwambonambi Formation for the most part comprises redistributed sands varying from fine- to coarse-grained in places. It is mainly within this formation that shallow hand-dug wells are common. The two underlying formations have been derived from the well known upper and lower Port Durnford Formations. These have now been named the Kosi Bay and Port Durnford Formation respectively (pers. comm. Botha, 1995). The collective thickness of these two formations has been reported to be up to 75 m. The grain sizes of the formations are generally fine, though coarser sand lenses and palaeochannels are present. The fine grain size of the materials results in low permeability but does provide for vast storage to feed the underlying Uloa and Umkwelane Formations. Areas where coarser-grained deposits are encountered within the Port Durnford and Kosi Bay Formations, do in themselves, constitute good aquifers. The only aquifer characteristics given in the literature for the sand of the Maputaland Group are provided in Table 39.

Table 39. Hydraulic conductivity of Maputaland Group sands (Meyer and Godfrey, 1995).

AQUIFER	HYDRAULIC CONDUCTIVITY (m/day)
cover sands	15.6
older aeolian sands	0.87
Port Durnford Formation	4.3

The Sibayi, Kwambonambi, Kosi and Port Durnford Formations are those which collectively contain the groundwater target of fine sand (Table 40). These formations have not been separated due to the borehole logs not differentiating between the formations.

Table 40. Hydrogeological targets in the Maputaland Group.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
palaeochannels	7	18.42	1.53	1	14.29
fine sands	18	47.37	0.05	5	27.78
Uloa Formation	1	2.63	2.50	0	0.00
contact with Zululand Group	12	31.58	0.00	7	58.33
TOTAL	38			13	

Also of importance are the Uloa and Umkwelane Formations, which form part of the Maputaland Group, but are Tertiary in age. These lowermost formations essentially comprise coquina, conglomerates and calcarenites. They have been found to have the highest potential as aquifers within the coastal plain. Unfortunately, the extent of the Uloa and Umkwelane Formations is not continuous and collectively they range in thickness from 25 m to very thin. Meyer and Godfrey (1995) state that, depending on the thickness and degree of weathering or karstification, yields of up to 25 l/s can be attained. Due to the great thickness of the overlying sediments it is difficult to identify the location of the Uloa Formation using geophysical techniques.

The graph showing cumulative yield distributions for the Maputaland Group sediments is presented in Figure 54. This graph confirms that the coarser deposits in palaeochannels yield more groundwater than the extensive fine sands. The one borehole drilled into the Uloa Formation fulfilled its high yield potential and gave a yield of 2.5 l/s. The low yield of the sands is probably more a function of incorrect siting methods than its actual potential as will be described in a following section. The contact at the base of the sands with the Zululand Group is not a reliable target, as almost 60% of the boreholes were dry. Figure 55 summarises the number of wet and dry boreholes drilled into the Maputaland Group.

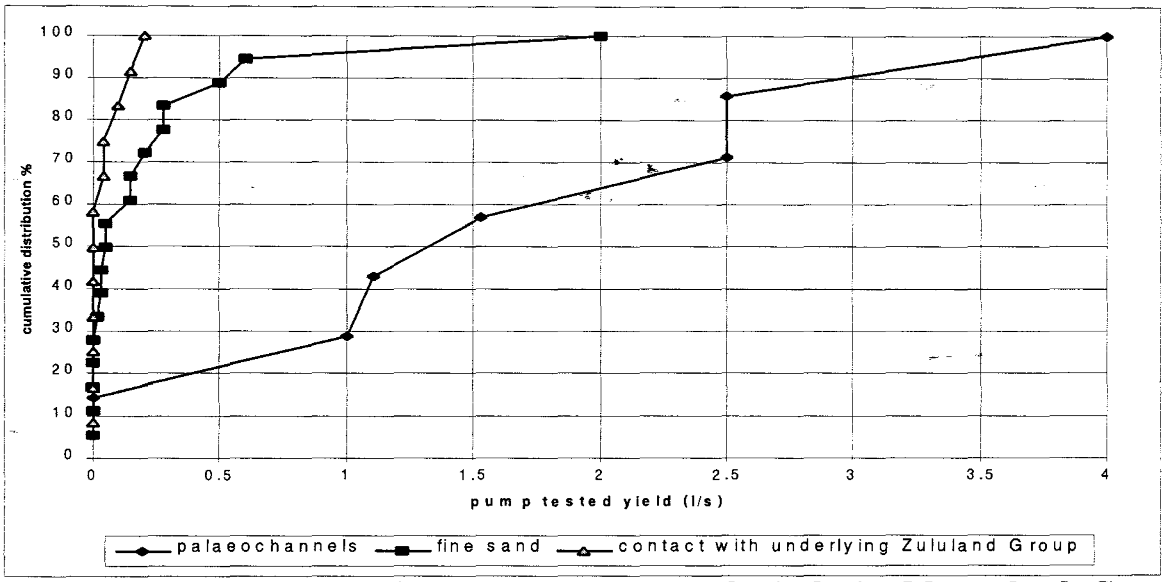


Figure 54. Cumulative distribution of pump tested yields in Maputaland Group sediments.

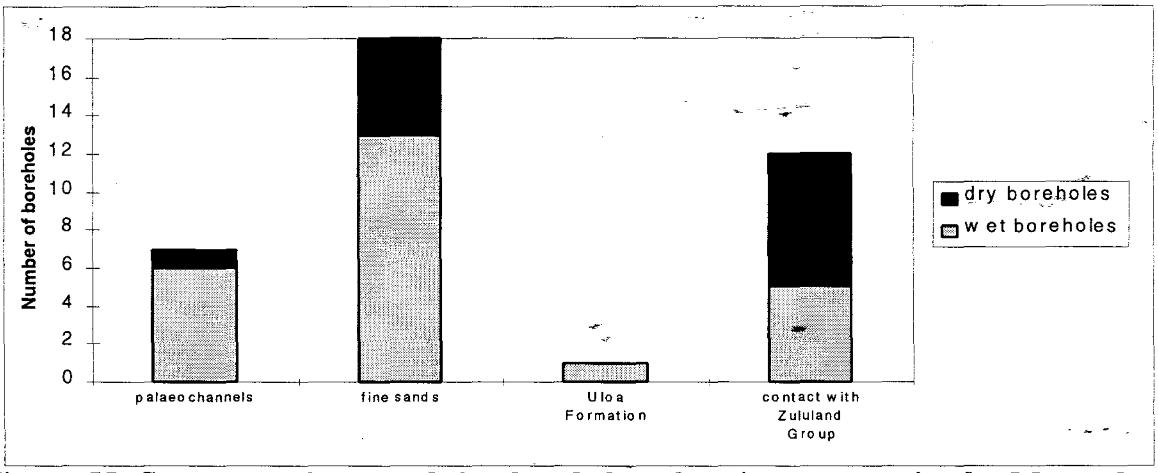


Figure 55. Summary of wet and dry boreholes of various targets in the Maputaland Group.

The Cretaceous-aged Zululand Group resting unconformably above the Karoo Supergroup volcanic rocks also need mentioning. These argillaceous rocks, viz. St Lucia and Mzinene Formations have a low permeability and are renowned for yielding saline groundwater. The high salt content of these siltstones is a result of their marine origin. Groundwater from this formation is not recommended for potable water supply unless it is treated. The basal conglomerate horizon of the Makatini Formation is potentially the best aquifer in the group even though no known boreholes have been drilled into the formation. Table 41 shows that of the 22 boreholes drilled, 20 of them were dry, thus confirming the low water-bearing potential of the Zululand Group.

Table 41. Hydrogeological targets with the Zululand Group.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
reworked material	1	4.55	0.13	0	0.00
sandstone/siltstone contact	14	63.64	0.00	13	92.86
siltstone	7	31.82	0.00	7	100.00
TOTAL	22			20	

9.1.5. Dwyka Group

The Dwyka Group is generally not an aquifer and is only mentioned as being of importance because of the large rural area that it underlies. The lithified till consists of a fine-grained matrix with inclusions of foreign rock. The porosity derived by van Wyk (1963) from seven samples ranges between 0.5 and 1.3%. There is no primary permeability and groundwater flow is restricted to fractures. It is evident from the large number of dry boreholes drilled into the rock that it has low water-bearing potential (Table 42). The fractured tillite produces a median yield of 0.1 l/s, however, larger faults intersected do produce greater amounts of water. For example, a borehole in Inanda is reported to have intersected a major fault and associated breccia in Dwyka tillite and to have yielded in excess of 8 l/s (pers. comm. van Niekerk, 1996). Three of the boreholes drilled into fractured tillite during the drought relief programme are thought to have intersected large faults and have yields of greater than 2.0 l/s (Figure 56). Smaller faults have been shown to yield generally less than the major faults. This could be attributed to the fact that the larger faults have created a greater spread of sympathetic faulting which increases connectivity and hence more groundwater collection occurs.

The only other accessible targets of the Dwyka Group are its contacts with underlying lithologies. The Dwyka Group's contact with Natal Group sandstone was expected to have a higher yield than proved to be the case and it's contact with basement rocks was only intersected three times. A large number of dry holes were drilled during the programme, probably due to the massive and often structureless nature of the tillite. The fact that some boreholes were drilled into unfractured tillite is cause for concern considering geophysics was used to site the boreholes. This aspect will be dealt with in a following section.

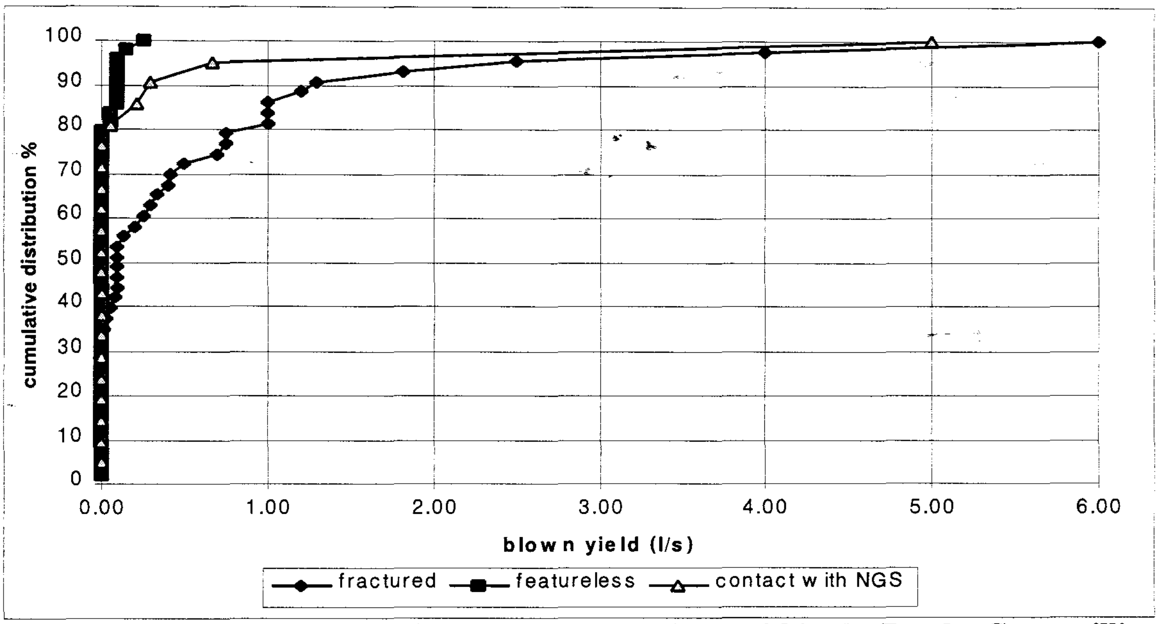


Figure 56. Cumulative distribution of blow tested yields within the Dwyka Group tillites.

Table 42. Hydrogeological targets in Dwyka Group tillite.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
fractured	43	36.13	0.10	14	32.56
secondary porous	1	0.84	0.00	1	100.00
featureless	49	41.18	0.00	39	79.59
contact with NGS	21	17.65	0.00	16	76.19
contact with NMP	2	1.68	0.05	1	50.00
contact with Dwyka shale	2	1.68	0.97	0	0.00
contact with Swazian granite	1	0.84	1.53	0	0.00
TOTAL	119			71	

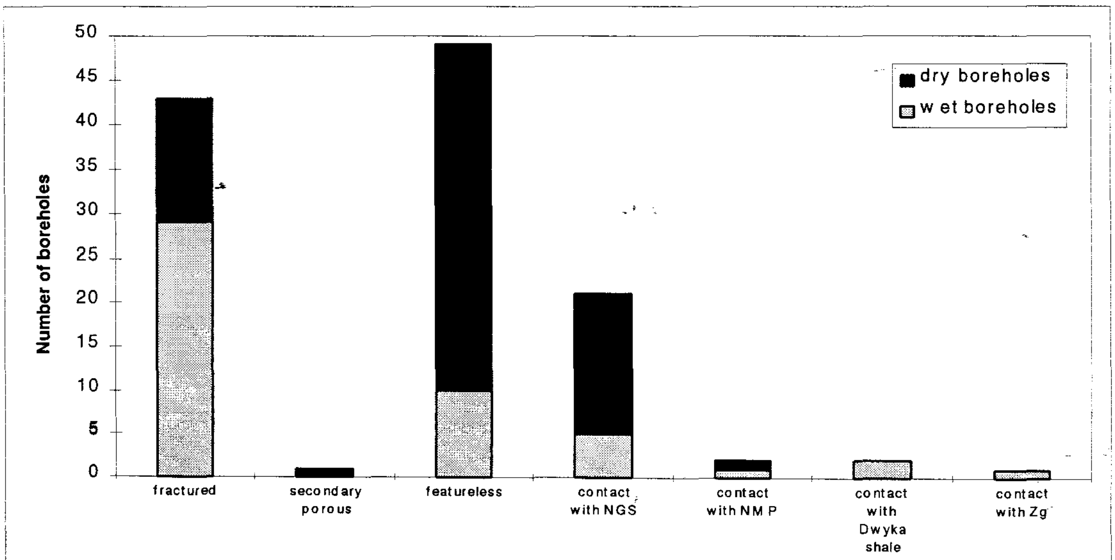


Figure 57. Summary of wet and dry boreholes drilled into Dwyka Group tillite.

9.1.6. Dolerite

Dolerite in the form of sills or sheets underlie almost 9% of rural areas in KwaZulu-Natal. Below the surface of sedimentary Karoo rocks, an additional vast amount of intrusive dolerite sills and dykes also occurs. Feeder dykes through the Natal Group sandstone and basement rocks of the Natal Metamorphic Province, Pongola Supergroup and the Barberton Sequence also occur. van Wyk (1963) states that the yield of more than 80% of the successful boreholes drilled into sedimentary rocks are directly or indirectly the results of the effects produced by dolerite intrusions on the normally non-water bearing rocks. The host rock into which dolerite has intruded often displays some alteration as a result. These changes are due to the "baking" effects of the intrusion (van Wyk, 1963). The process of "baking" involves the hardening of the host rock at the contact with dolerite and the formation of a chill margin in the dolerite itself. Another process that also occurs near the contact zone is a very slight disturbance of the host rock (van Wyk, 1963). During the intrusion of dolerite, Du Toit (1918) found that the sedimentary rocks above it are displaced. This displacement causes fracturing which is commonly observed in borehole records. Older dolerite intrusions can themselves be intruded by younger intrusions which in turn will cause fracturing. Where the climate is humid and damp, weathering of the dolerite along these contacts and fractures further enhances the water-bearing capabilities of these zones by increasing the storativity of the dolerite.

Dolerite sills within argillaceous Karoo sedimentary rocks are more common than dolerite dykes due to the well-bedded nature of the rocks into which they have intruded. Dolerite sills within the argillaceous Karoo rocks represents 21% of the total Karoo rock surface area, and 15.5% of the total length of 1 : 250 0000 mapped dolerite dykes in KwaZulu-Natal intrude the surface of Karoo rocks (Figure 58).

An assessment of the cumulative distribution of yields for the different lithologies in contact with intrusive dolerite shows that over half of the contacts give a median of zero (Figure 59 and Table 43). In particular, it is surprising to see that the dolerite contact with Vryheid Formation and Ecca shales exhibit poor yields. The fractures within these two hydrolithologies were previously shown to yield a greater amount of groundwater than the contacts. This could point to the fact that the hydraulic conductivity of the dolerite contact plane is not as high as what would be expected, and that the fractures have a much higher hydraulic conductivity. The same explanation for the 80% dry boreholes intersecting the contact between dolerite and the Dwyka Group can be given as for the Ecca Group shales. The Jozini Formation also has a high percentage of dry boreholes at its contact with the dolerite intrusions. However, there are some very high yielding strikes, which give the impression that this contact can give yields that deviate substantially from the standard.

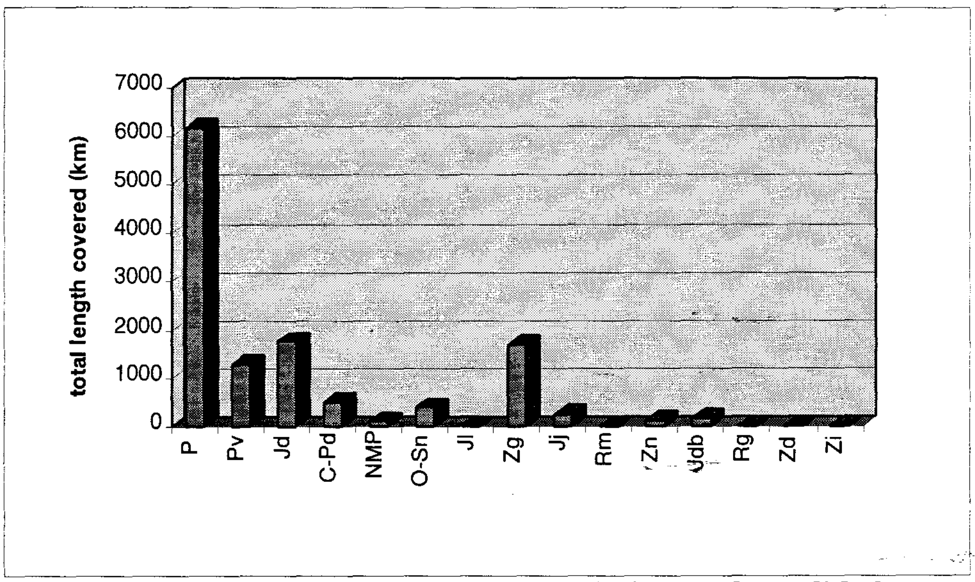


Figure 58. Total length of mapped dolerite dykes within each hydrolithology covering KwaZulu-Natal.

The Karoo argillaceous and arenaceous rocks, with a total of 24 records between them, each produced one third dry boreholes. The median yield of the Karoo arenaceous rocks' contact with dolerite was slightly lower than that of the argillaceous rock's, but this could be attributed to the low number of boreholes drilled into it. The Natal Group sandstone's contact with dolerite proves to be the best contact to exploit upon reflection of its median yield compared to the other contacts (Table 43). As was the case in the Karoo rocks, there was a failure rate of a third of the total number of boreholes drilled into the contact. The success rate of 66% is, however, the maximum obtained from all the contacts.

The basement rocks are not commonly intruded by dolerite sills but rather by dykes. This is illustrated by the large percentage of dykes contained within the Swazian aged intrusive granites (Zg) in Figure 58. Unfortunately, not many boreholes intersected the dolerite contact within the Natal Metamorphic Province and Swazian granites (Table 43). The two boreholes drilled into the Natal Metamorphic Province were both dry, however, this does not mean that all contacts will be non-water bearing. Due to the scarcity of data for this contact feature, not much can be concluded, suffice to say that the author does know of instances where the average yields of this contact have been found to be approximately 0.1 l/s in successful boreholes. The median yield of the contact of dolerite dykes with the older Swazian granites is 0.23 l/s which is enhanced by the lack of dry boreholes.

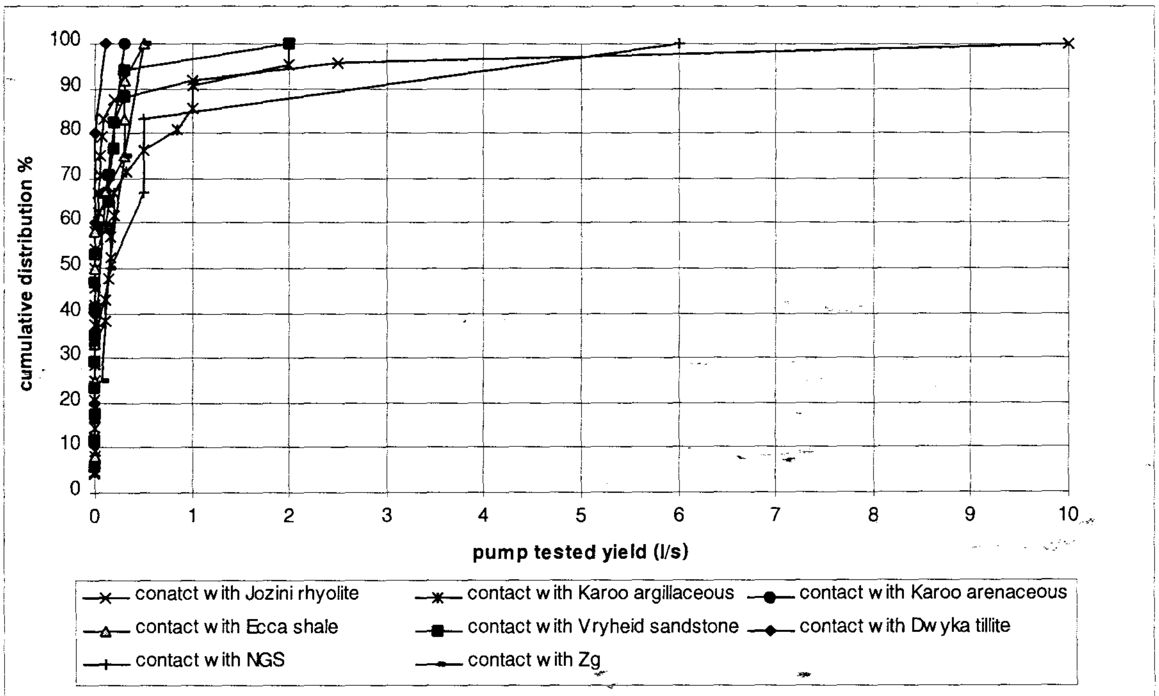


Figure 59. Cumulative distribution of pump tested yields for contacts of host rocks with dolerite intrusions.

Table 43. Hydrogeological contacts with dolerite.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
contact with Jozini rhyolite	24	25.53	0.00	14	58.33
contact with Karoo arenaceous rocks	3	3.19	0.10	1	33.33
contact with Karoo argillaceous rocks	21	22.34	0.16	7	33.33
contact with Vryheid Formation	17	18.09	0.00	9	52.94
contact with Ecca shale	12	12.77	0.00	7	58.33
contact with Dwyka tillite	5	5.32	0.00	4	80.00
contact with NGS	6	6.38	0.33	2	33.33
contact with NMP	2	2.13	0.00	2	100.00
contact with Swazian granite	4	4.26	0.23	0	0.00
TOTAL	94			46	

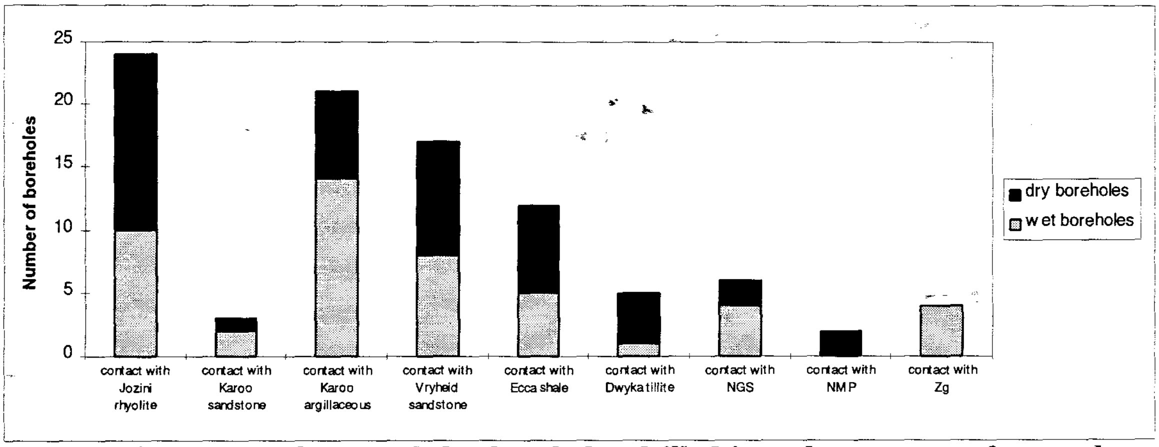


Figure 60. Summary of wet and dry boreholes drilled into the contacts of a number of lithologies with dolerite.

Apart from the actual contact plane acting as a water-bearing feature, the dolerite itself contains fractures and weathered zones capable of yielding groundwater. In some areas, thick dolerite sills are the only geological materials from which target features must be sought. More commonly, however, fractured or weathered dolerite sills may yield groundwater without direct influence from the contact plane. Fractures within the dolerite may be an indirect result of the process of intrusion, but due to this fact being difficult to determine from the geological logs, fractured and secondary porous type aquifers in dolerite have been isolated from the contact type aquifers. Fracturing in dolerite is more abundant than in argillaceous host rocks because of its higher competence.

Fractured dolerite produces a high groundwater yield, as demonstrated in the cumulative distribution plots (Figure 61) where the majority of the boreholes striking fractures are above 0.1 l/s and only less than 17% are dry (Table 44 and Figure 62). Weathering processes act upon dolerite in the same manner as upon the crystalline basement rocks. Contact zones or fractures are susceptible to weathering since they often contain the groundwater to act as an enhanced weathering agent. It is often in these zones that reddish clayey secondary porous material can be found. The weathered dolerite, because of its high clay content resulting from the weathering of feldspars, has a low permeability and a high storativity. It therefore acts as a storage matrix "sponge" which contributes groundwater to underlying fractures or contact planes. Significant groundwater strikes from weathered zones are few (Table 44), with the greater percentage of the strikes occurring in fractures. Boreholes intersecting water-bearing secondary porous material did produce a median yield similar to that of fractured dolerite, however, yields greater than 1.0 l/s are not to be expected (Figure 61). A summary of the total number of wet and dry boreholes is provided in Figure 62.

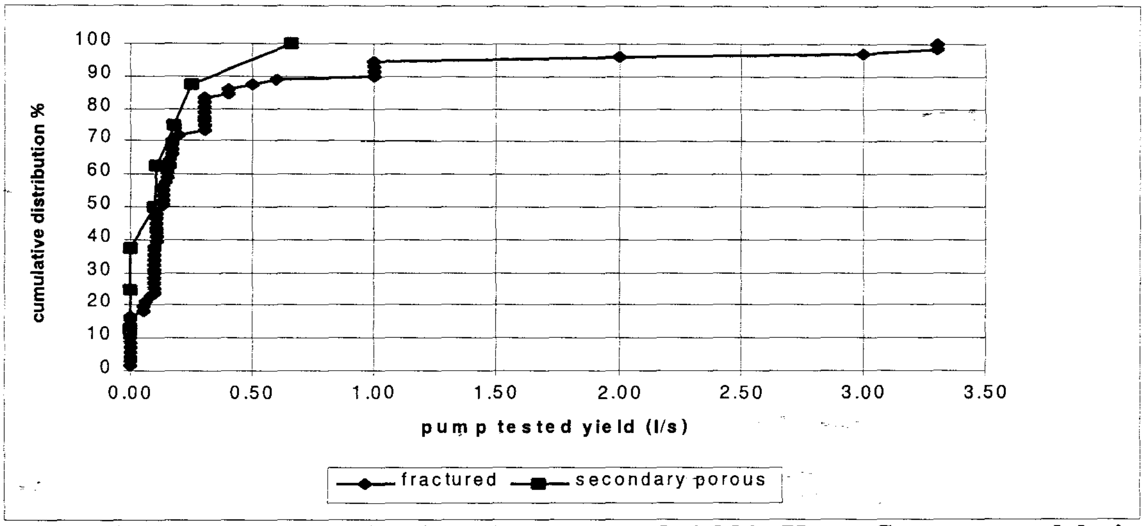


Figure 61. Cumulative distribution of pump tested yield in Karoo Supergroup dolerite.

Table 44. Hydrogeological targets in dolerite.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD	DRY	% DRY WITHIN THE TARGET
fractured	71	83.53	0.13	12	16.90
secondary porous	8	9.41	0.11	3	37.50
featureless	5	5.88	0.00	5	100.00
secondary porous/featureless contact	1	1.18	0.10	0	0.00
TOTAL	85			20	

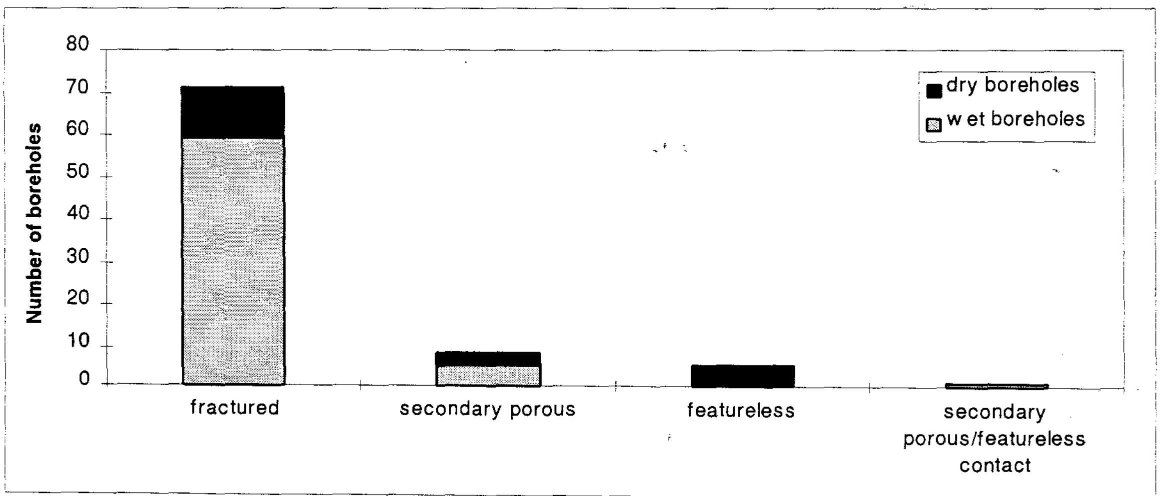


Figure 62. Summary of wet and dry boreholes drilled into various targets within dolerite.

9.1.7. Natal Group

The Natal Group sandstones are one of the best hydrolithological prospects for groundwater in KwaZulu-Natal. van Wyk (1963) determined that the average porosity for the Natal Group sandstones ranges between 9.0 and 16.9%, however, cementation of the pore spaces restricts primary porosity. Boreholes drilled into the Natal Group were the second highest in number of the total 993 boreholes drilled in the programme, with fractures being the most common feature intersected (Table 45). Given the low percentage of dry boreholes, the large number of boreholes yielding in excess of 1.0 l/s, together with the high median yield of 0.14 l/s, the fractured aquifers of the Natal Group sandstones are shown to be relatively productive. Secondary porosity aquifers induced by weathering have a median yield of 0.32 l/s, but have a slightly larger failure rate than purely fractured aquifers. This could be attributed to the fact that there is a fair amount of feldspar in the sandstones which produces a slightly to moderately clayey product, thereby decreasing fracture permeability.

The contacts of Natal Group sandstone with the various underlying formations were only intersected seven times. This is not really enough data to give suitable comment on each of their likelihood's of producing groundwater, although, the contact with the Natal Metamorphic Province appears to give a promising median yield of 0.6 l/s.

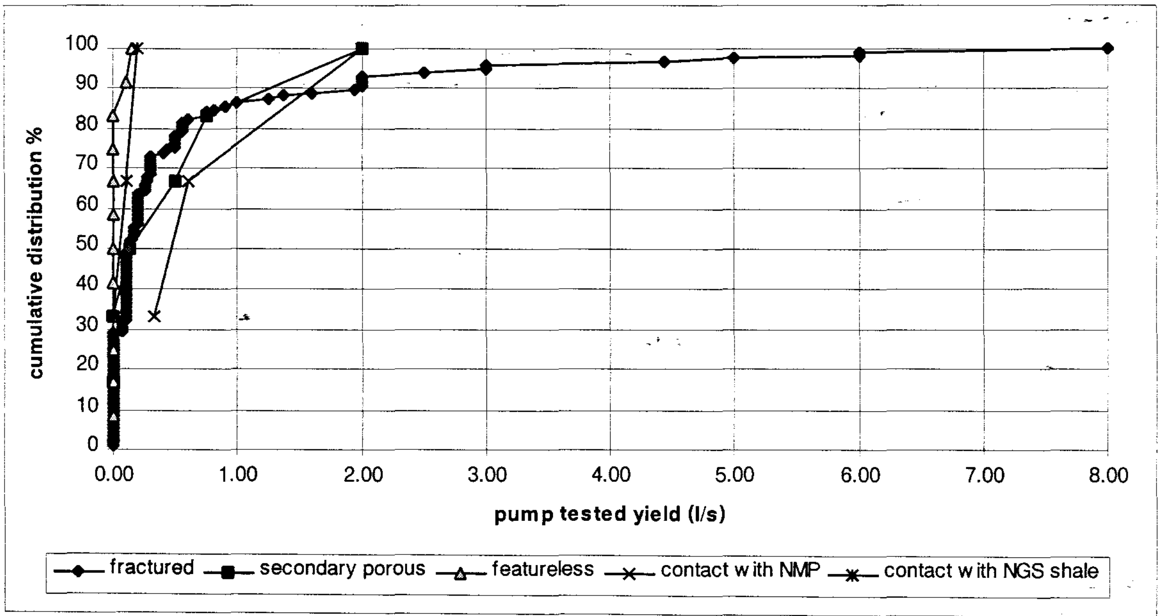


Figure 63. Cumulative distribution of pump tested yield for targets in Natal Group sandstone.

Table 45. Hydrogeological targets in Natal Group sandstone.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
fractured	118	82.52	0.14	34	28.81
secondary porous	6	4.20	0.32	2	33.33
featureless	12	8.39	0.00	10	83.33
contact with NMP	3	2.10	0.60	0	0.00
contact with NGS shale	3	2.10	0.10	1	33.33
contact with Swazian granite	1	0.70	0.00	1	100.00
TOTAL	143	100.00		48	

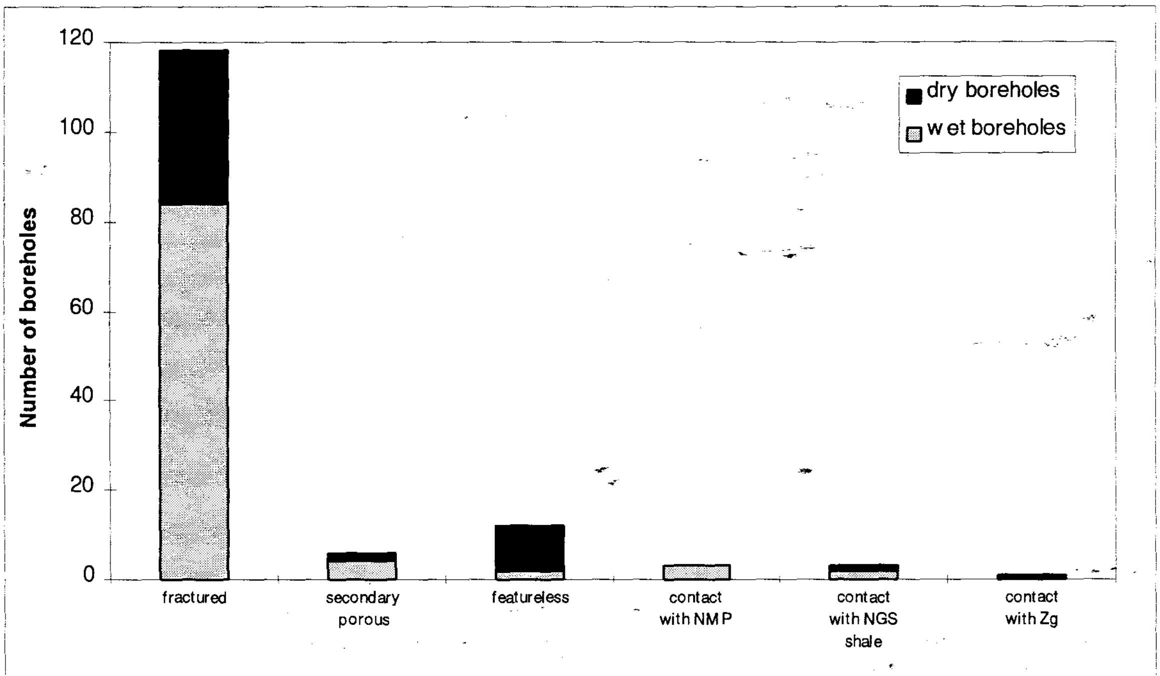


Figure 64. Summary of wet and dry boreholes drilled into different targets in Natal Group sandstone.

9.1.8. Lebombo Group

Both the rhyolites and basalts of the Jozini and Letaba Formations of the Lebombo Group are examined in this section. Initially, on the basis of surface occurrence of the various hydrolithologies, only the Jozini Formation was to be studied, however, due to the large number of boreholes drilled into the Letaba Formation basalts during the drought relief programme, they have also been included in the analysis.

9.1.8.1. Jozini Formation

The rhyolite has a distinct character, in that it contains large numbers of internal rhyolite flows which present themselves as dyke-like bodies. These structures are thought to be the feeders through which the lava reached the ground surface (van Wyk, 1963). Fracturing commonly occurs along the contacts of these lava flows, and it was into these fractured features that most of the boreholes were drilled (Table 46). The median yield of the fractured rhyolite is 0.13 l/s, which was lower than that obtained of the three records from the secondary porous aquifers. The fractured aquifers, however, produced a higher success rate than the secondary porous features. The majority of the boreholes from both features gave a similar cumulative distribution yield plot, except for extreme values (Figure 65). The fractured features have a high yielding capability, while the secondary porous features could only produce a maximum of under 3.0 l/s. A large proportion of the boreholes which were drilled into rhyolite contained no discernible potential water-bearing features and were therefore classed as featureless (Figure 66). On only one occasion was pyroclastic tuff material interbedded with the rhyolite, as reported by van Wyk (1963), intersected. The yield generated from this one feature can only be classified as seepage.

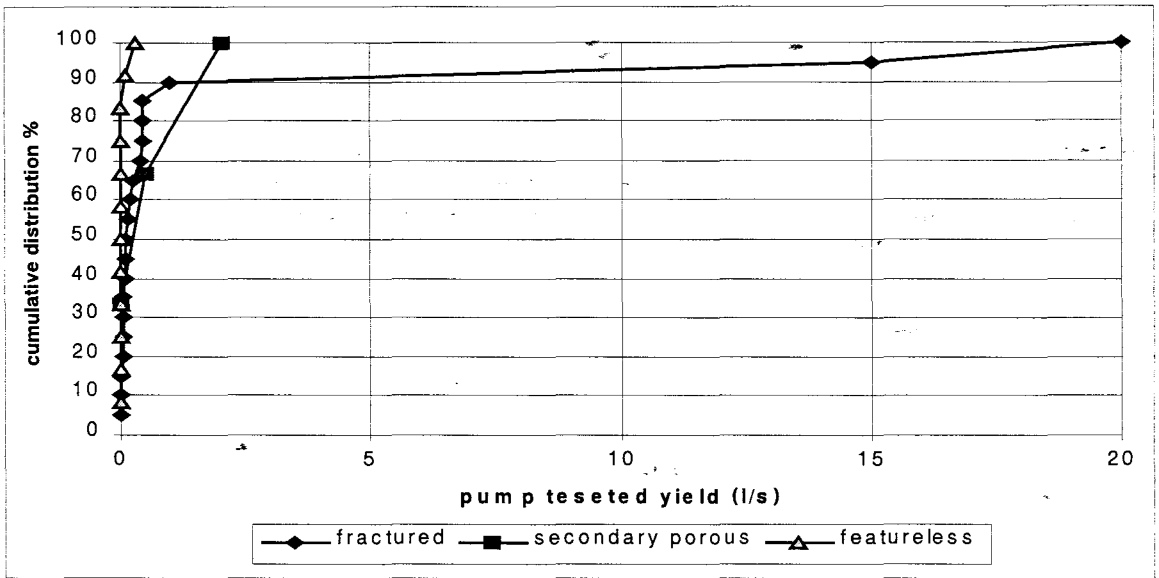


Figure 65. Cumulative distribution of pump tested yields in Jozini Formation rhyolite.

Table 46. Hydrogeological targets in Jozini Formation rhyolite.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
fractures	20	55.56	0.13	3	15.00
secondary porous	3	8.33	0.48	1	33.33
featureless	12	33.33	0.00	9	75.00
tuff/rhyolite contact	1	2.78	0.09	0	0.00
TOTAL	36			13	

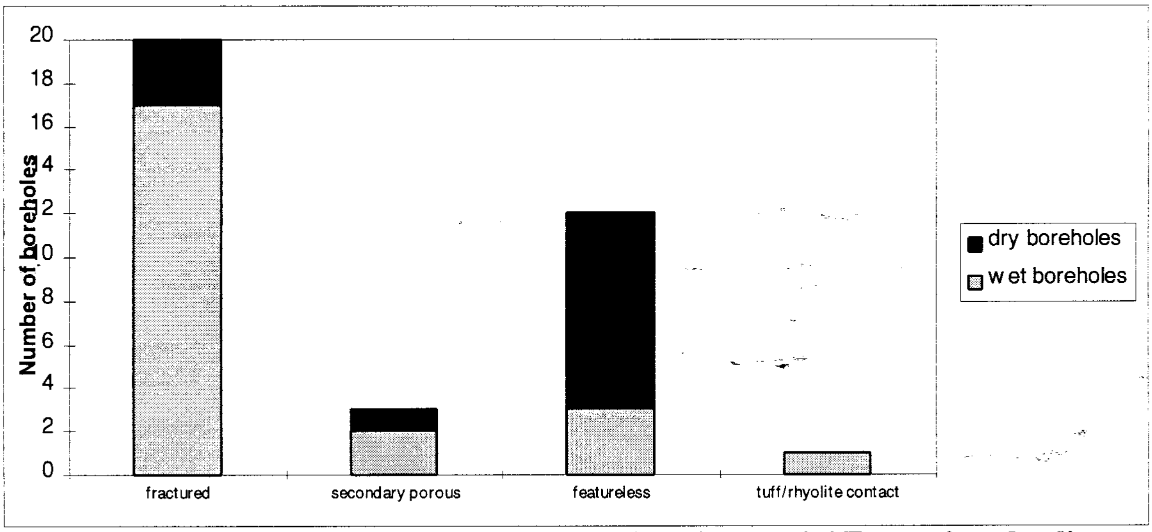


Figure 66. Summary of wet and dry boreholes drilled into Jozini Formation rhyolite.

9.1.8.2. Letaba Formation

van Wyk (1963) states that where two or more joint sets intersect in the Letaba Formation basalts, weathering basins of up to 26 m deep could form. The locations of these basins of decompostion are not characteristic of either hills or valleys, but are random. The weathered material has a low transmissivity and therefore does not itself yield water. Groundwater should generally be encountered at the transition between weathered and fresh rock. The thickness of the transition can be anything from 0.5 to 12m (van Wyk, 1963). As can be seen in Table 47, most of the successful boreholes were in fractures and not many were in secondary porous material. This target feature has one of the highest success rates of all the hydrolithologies analysed. The median yield, however, is average at 0.15 l/s. Figure 67 shows that five of the highest yielding boreholes yielded between 1.0 and 4.0 l/s.

As was expected, the actual weathered zone encountered above and below the fractures did not often produce water. Those four boreholes, which specifically intersected secondary porous basalt aquifers produced by weathering, gave the same median yield as that for the fractured aquifers. The single borehole tapping the basalt contact with the underlying Karoo argillaceous rocks did produce a small amount of groundwater. A borehole intersecting a pegmatite vein gave a good yield of 0.5 l/s. The occurrence of granitic pegmatite in the basalt is probably a result of large scale fracturing due to a nearby granitic intrusion.

Table 47. Hydrogeological targets in the Letaba Formation basalts.

TARGET	NUMBER OF BOREHOLES	TARGET % WITHIN GROUP	MEDIAN YIELD (l/s)	DRY	% DRY WITHIN THE TARGET
fractured	89	92.71	0.15	1	1.12
secondary porous	4	4.17	0.15	1	25.00
featureless	1	1.04	0.00	1	100.00
contact with Karoo argillaceous rock	1	1.04	0.10	0	0.00
contact with pegmatite	1	1.04	0.50	0	0.00
TOTAL	96			3	

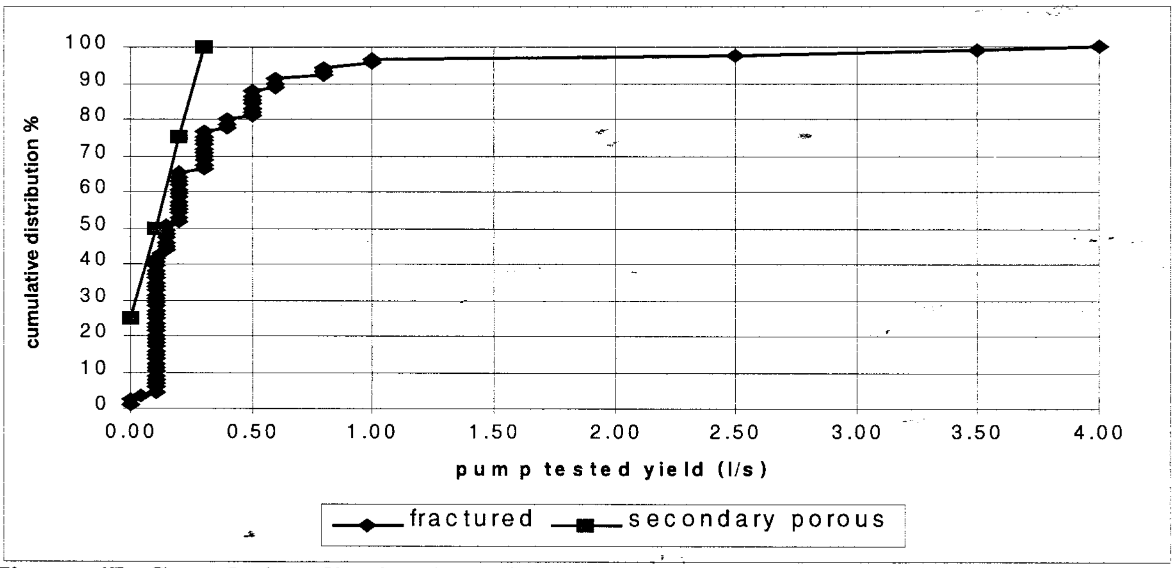


Figure 67. Cumulative distribution of pump tested yield in the various targets of the Letaba Formation basalts.

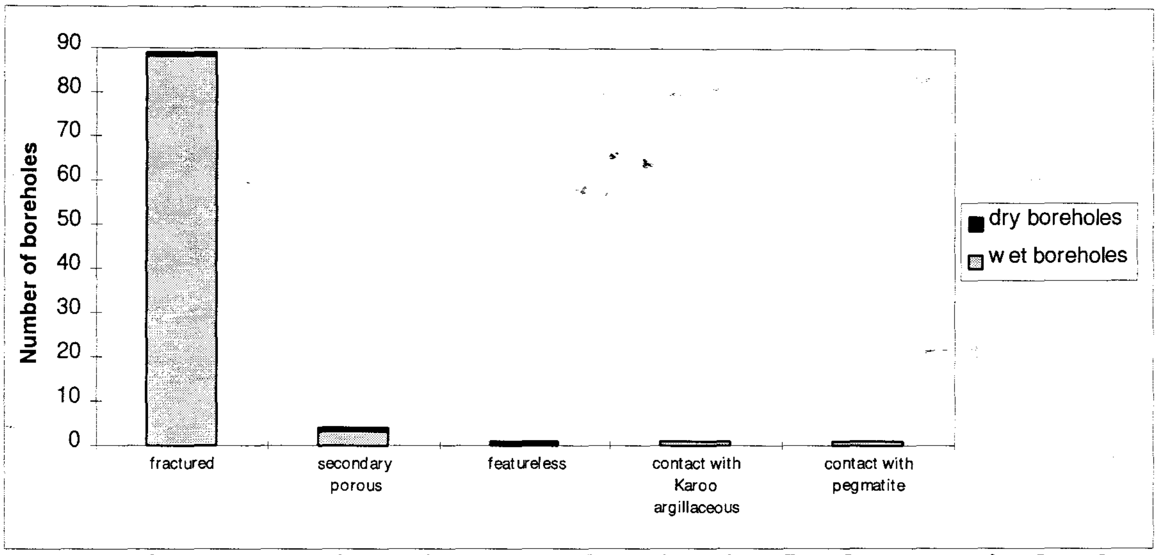


Figure 68. Summary of wet of dry boreholes drilled into Letaba Formation basalt.

9.2. Health related quality

One of the current methods of water quality classification used in rural water supply is based on the assessment of certain key constituents which have an effect on human health (DWAF, 1996). Almost 99% of the successful boreholes drilled in the drought relief programme were sampled for most of these health related constituents. The main health related problems associated with natural groundwater are high electrical conductivity, fluoride and nitrate values. The results of the chemical analysis are used to compare each target feature's chemistry with others in the same hydrolithology, and between hydrolithologies.

9.2.1. Karoo argillaceous rock

The drought relief drilling programme did not successfully drill into water-bearing Karoo argillaceous rock to the extent expected, considering the large area these rocks cover in rural areas. The groundwater chemistry results in this hydrolithology are therefore not as representative as they should be, but some comments can be made on the relatively large number of Class III waters encountered in the fractured targets (Figure 69).

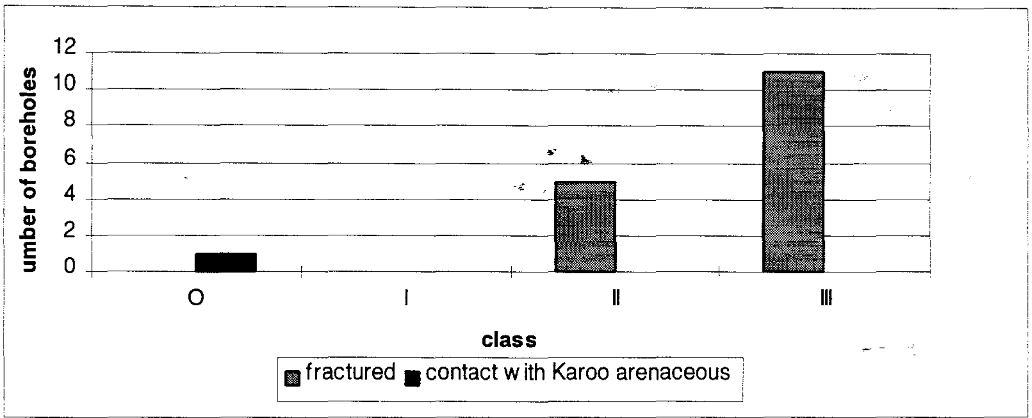
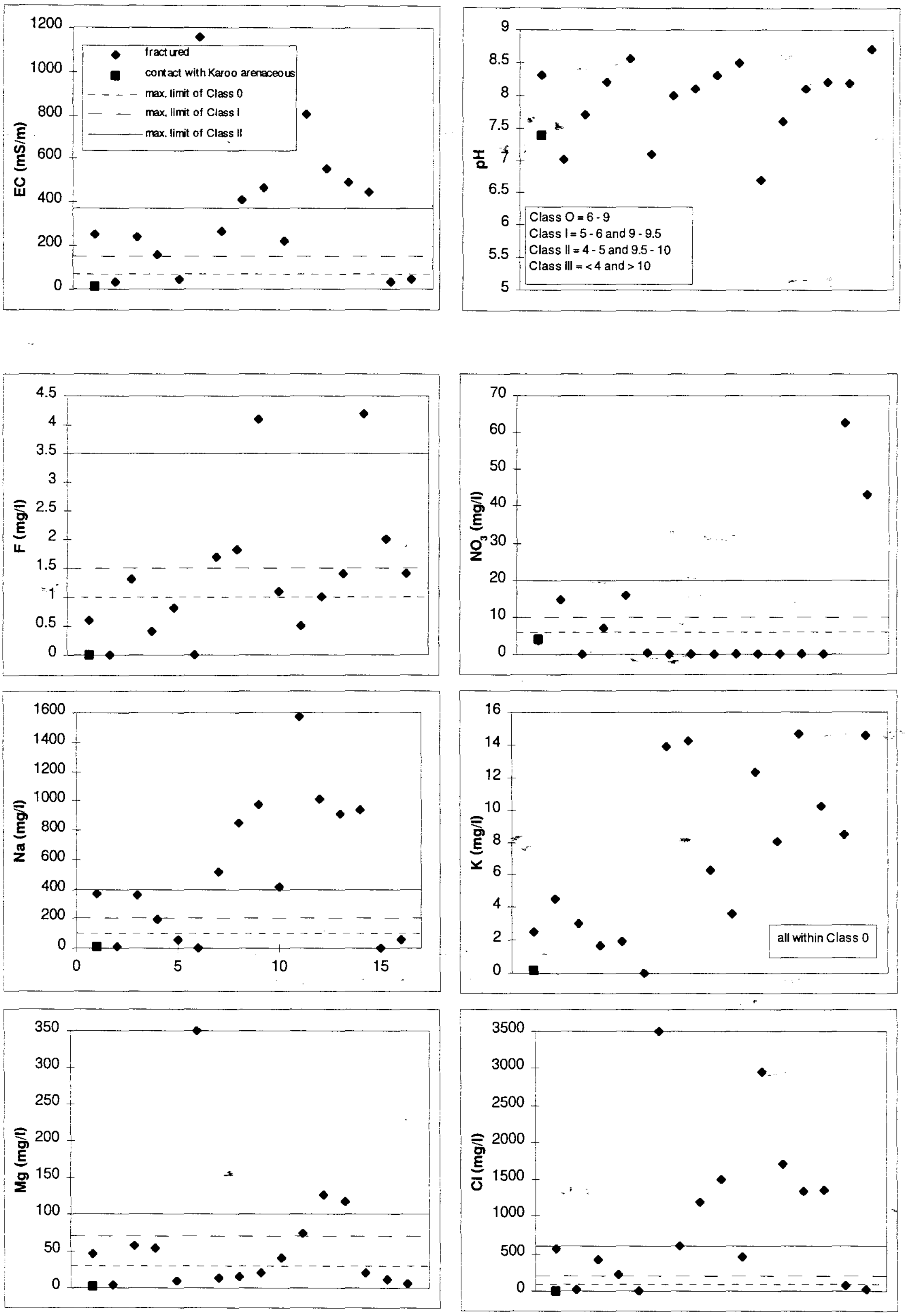


Figure 69. Summary of overall groundwater quality classes in Karoo argillaceous rocks.

The fractured aquifers in Karoo argillaceous rock failed chemically, i.e. Class II or III, on high salts (Figure 70). The electrical conductivity values mostly fell into Class II and III, with the associated sodium and chloride concentrations also falling within the same categories. Magnesium displayed similar concentrations, but fell predominantly into Class II. The high salinity of groundwater in argillaceous rocks is probably derived by cation exchange with the feldspars and clays of the host rock. The high fluoride values in some of the samples are also probably a result of the contributions from feldspar, mica and clay.

The one sample from the contact between Karoo argillaceous and arenaceous rock did not display the same characteristics as the fractured rock. All the measured health related constituents fell into Class 0. Table 48 provides a summary of the statistics obtained from the chemical data in Karoo argillaceous targets. This table shows that, in general, fractured argillaceous Karoo aquifers have poor quality groundwater, particularly with respect to salinity. The single sample taken at the contact with Karoo arenaceous rock is not enough to be able to make a statement on the quality of the target feature, suffice to say that the quality should be somewhat better than the fractured target.


fractured
contact with Karoo arenaceous
max. limit of Class 0
max. limit of Class I
max. limit of Class II
EC (mS/m)
pH
Class O = 6 - 9
Class I = 5 - 6 and 9 - 9.5
Class II = 4 - 5 and 9.5 - 10
Class III = < 4 and > 10
F (mg/l)
NO_3 (mg/l)
Na (mg/l)
K (mg/l)
all within Class 0
Mg (mg/l)
Cl (mg/l)

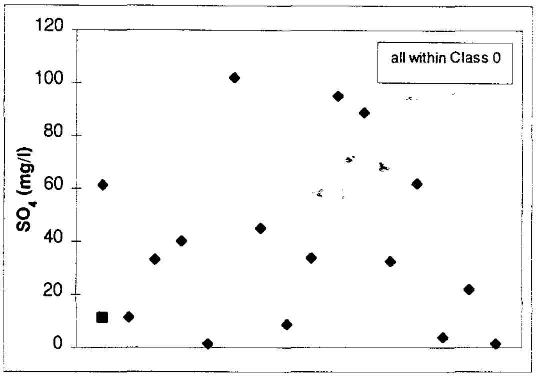


Figure 70. Scatter plots displaying class limits of health related constituents for groundwater quality in Karoo argillaceous targets.

Table 48. Statistics of health related chemistry in Karoo argillaceous groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED KAROO ARGILLACEOUS (16)			KAROO ARGILLACEOUS CONTACT WITH KAROO ARENACEOUS (1)	
	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS
pH	8.0	0	0.6	7.4	0
EC (mS/m)	350.5	II	307.6	14.0	0
TDS (mg/l)	2238.3	II	1949.3	72.0	0
Mg (mg/l)	60.3	I	86.0	2.0	0
Na (mg/l)	547.9	III	469.9	11.0	0
K (mg/l)	8.0	0	5.0	0.2	0
Cl (mg/l)	993.8	III	1048.2	8.0	0
SO_4 (mg/l)	40.1	0	33.5	11.0	0
NO_3 (mg/l)	9.2	I	18.2	4.2	0
F (mg/l)	1.5	0	1.2	0.0	0
OVERALL		III			0

The number of samples abstracted from boreholes in Karoo arenaceous rock is similar to those taken from the argillaceous rock, with similar chemical results confirming their close interbedded nature (Table 48 and Table 49). Once again, the fractured rock targets yielded groundwater only in Class III, while the contact with argillaceous rock produced groundwater in both Class 0 and III (Figure 71). The single secondary porous sample also fell into Class III. Overall, groundwater from targets within this hydrolithology were found to be unpotable without appropriate treatment.

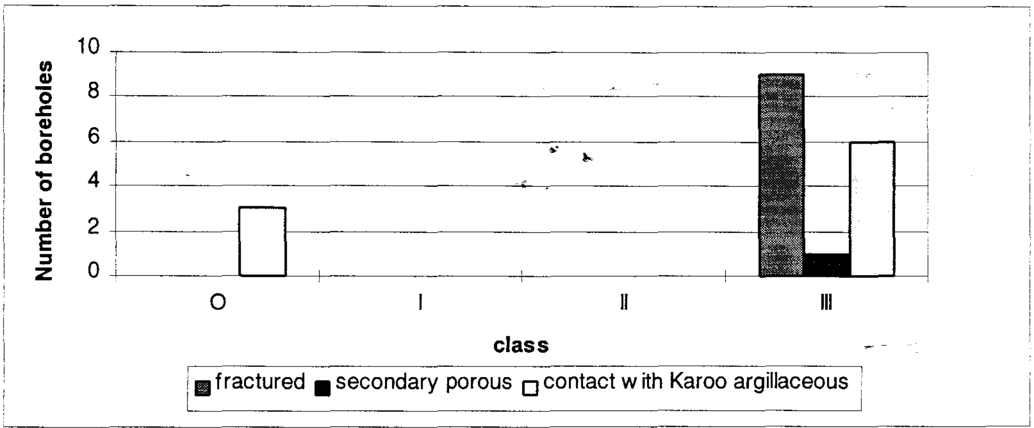
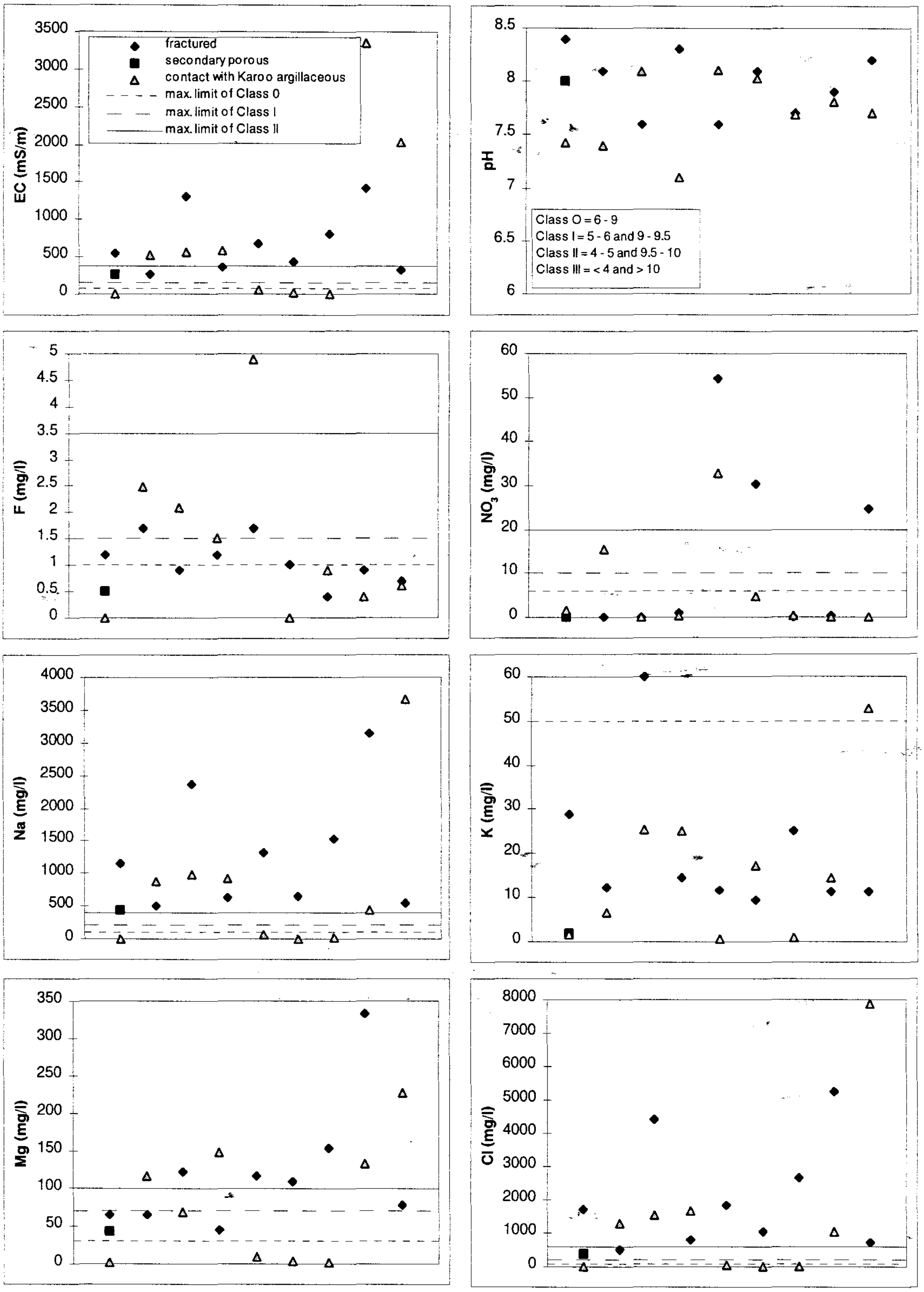


Figure 71. Summary of overall groundwater quality classes in Karoo arenaceous rocks.

High electrical conductivity, sodium and chloride values in the fractured aquifers, as in the case of the argillaceous rock, are the main reason for most of the samples falling into Class III. Magnesium concentrations are found to be spread between Class I, II and III. The sulphate concentrations are generally higher than those in the fractured argillaceous rock. A reason for high sulphate values in the Karoo rocks could be due to oxidation of pyrite which is commonly mineralised into fractures. Fluoride values in fractured arenaceous rock only exceeded Class I on one occasion, which suggests from the limited samples that this constituent is probably not a problem in the arenaceous rocks due to limited cation exchange with clays. Potassium values rarely exceed Class 0. Nitrate was mostly within Class 0, but two samples fell into the Class III range giving a large standard deviation of 19.7 mg/l. Any nitrate in groundwater is probably not natural and is a result of human or animal activity.

The secondary porous sample displayed similar characteristics to those of the fractured rock but of a slightly lesser concentration. Those rocks in contact with Karoo argillaceous rocks yielded groundwater which either fell into Class 0 or III. This highly variable nature (Table 49) makes it impossible to determine which class the contact aquifer is overall likely to result in. Figure 72 displays all the graphs of the health related constituent concentrations.


EC (mS/m)
fractured
secondary porous
contact with Karoo argillaceous
max. limit of Class 0
max. limit of Class I
max. limit of Class II
pH
Class O = 6 - 9
Class I = 5 - 6 and 9 - 9.5
Class II = 4 - 5 and 9.5 - 10
Class III = < 4 and > 10
F (mg/l)
NO_3 (mg/l)
Na (mg/l)
K (mg/l)
Mg (mg/l)
Cl (mg/l)

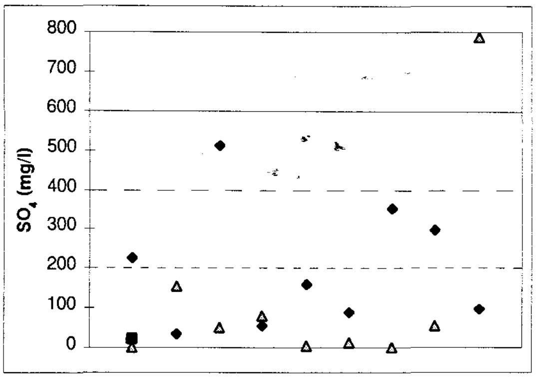


Figure 72. Scatter plots displaying class limits of health related constituents for groundwater quality in Karoo arenaceous targets.

Table 49. Statistics of health related chemistry in Karoo arenaceous groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED KAROO ARENACEOUS (9)			SECONDARY POROUS KAROO ARENACEOUS (1)		KAROO ARENACEOUS CONTACT WITH KAROO ARGILLACEOUS (9)		
	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS	MEAN	CLASS	STANDARD DEVIATION
pH	8.0	0	0.3	8.0	0	7.7	0	0.3
EC (mS/m)	677.9	III	426.7	254.0	II	791.1	III	1153.1
TDS (mg/l)	4501.8	III	2872.9	1644.0	II	2980.2	III	4328.4
Mg (mg/l)	120.7	III	87.2	42.0	I	78.7	II	82.1
Na (mg/l)	1316.2	III	917.3	447.0	III	773.8	III	1161.6
K (mg/l)	20.5	0	16.3	2.0	0	16.1	0	17.0
Cl (mg/l)	2102.8	III	1695.9	393.0	II	1498.7	III	2497.6
SO_4 (mg/l)	202.4	I	159.6	22.0	0	127.0	0	252.4
NO_3 (mg/l)	12.3	II	19.7	0.0	0	6.2	I	11.3
F (mg/l)	1.1	I	0.4	0.5	0	1.4	I	1.6
OVERALL		III			III		III	

The Ecca shales have an overall better groundwater quality compared to Karoo argillaceous and arenaceous rocks. Figure 73 shows the number of boreholes within each class per target in the Ecca shales. The electrical conductivity in fractured targets is generally below Class I, although one sample of Class III did occur (Figure 74). The mean electrical conductivity given in Table 50 is positively skewed due to one very high extreme value. The predominate ions responsible for electrical conductivity are sodium, magnesium and chloride. Fluoride and nitrate concentrations fall within Class 0, except for one sample which had elevated nitrate levels of Class III. Sulphate concentrations for all targets were within Class 0.

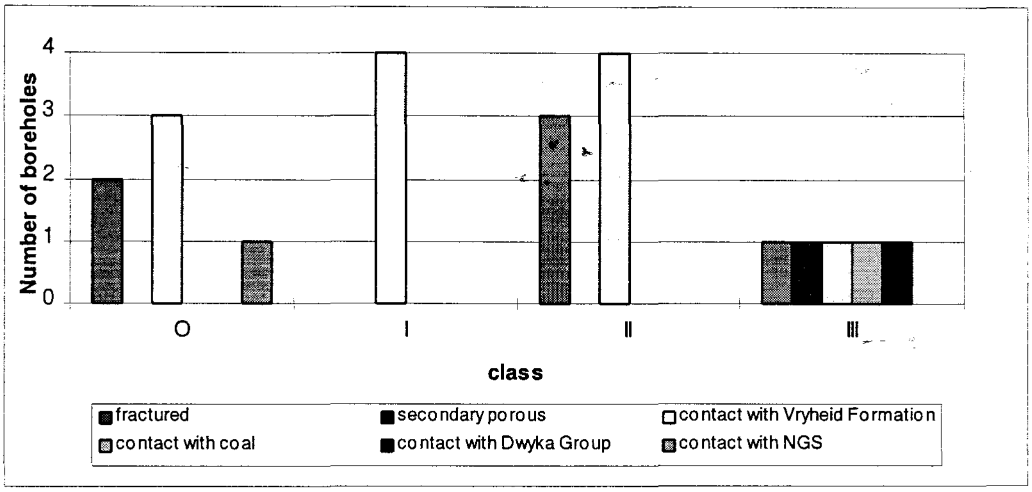
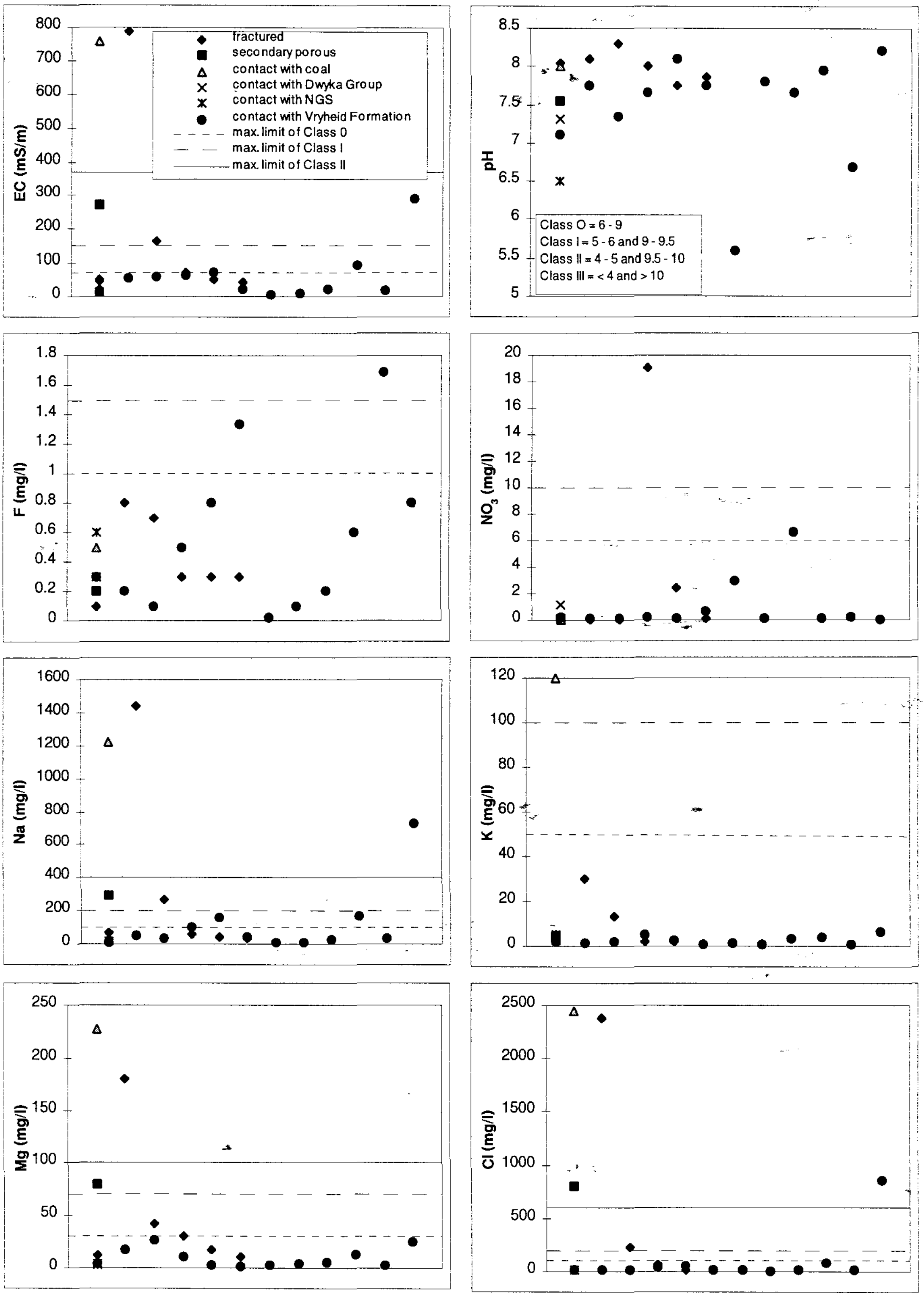


Figure 73. Summary of overall groundwater quality classes in Ecca shales.

The single sample representing the secondary porous target had higher electrical conductivity, magnesium, sodium and chloride values than the fractured samples, resulting in Class II and III categorisation. Groundwater sampled from the one contact between coal and shale reflected a very poor quality water with only fluoride, nitrate and sulphate contributing to Class 0. The rest of the constituents all fell into Class III, including potassium. These high values lead one to the belief that the groundwater has been contaminated chemically by interaction with the coal.

Other contacts between Ecca shale and different rock types appear to produce good quality groundwater. It's contacts with the Dwyka Group and Natal Group, in particular, yield Class 0 groundwater, while the shales in contact with Vryheid Formation sandstones tend to yield mainly Class 0 and I groundwater. One of the extreme samples from the Vryheid Formation contact displayed higher concentrations of fluoride, sodium and chloride which resulted in an overall class of III. This sample can be ignored as not being representative, probably due to interactions with another lithology

Table 50 reflects that the quality of fractured Ecca shale is generally of Class II. This class of groundwater may only be used for a short period of time, or must be treated for long term use. The other target features are only represented by one sample which is statistically unsatisfactory. The only comment that can be made about these single samples is that the secondary porous Ecca shale appears to have a similar chemical character to the fractured shale, and that the coal contact produces very poor quality groundwater. The contacts with the Natal and Dwyka Groups appear to produce good quality groundwater.


EC (mS/m)
fractured
secondary porous
contact with coal
contact with Dwyka Group
contact with NGS
contact with Vryheid Formation
max. limit of Class 0
max. limit of Class I
max. limit of Class II
pH
Class O = 6 - 9
Class I = 5 - 6 and 9 - 9.5
Class II = 4 - 5 and 9.5 - 10
Class III = < 4 and > 10
F (mg/l)
NO3 (mg/l)
Na (mg/l)
K (mg/l)
Mg (mg/l)
Cl (mg/l)

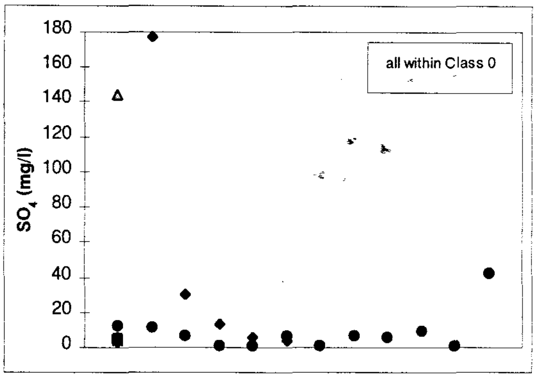


Figure 74. Scatter plots displaying class limits of health related constituents for groundwater quality in Ecca shales.

Table 50. Statistics of health related chemistry in Ecca shale groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED ECCA SHALE (6)			SECONDARY POROUS ECCA SHALE (1)	
	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS
pH	8.0	0	0.2	7.6	0
EC (mS/m)	194.4	II	294.2	274.0	II
TDS (mg/l)	1331.5	II	1859.5	2260.0	II
Mg (mg/l)	48.6	I	65.5	80.0	II
Na (mg/l)	319.8	II	555.8	296.0	II
K (mg/l)	8.8	0	11.2	4.3	0
Cl (mg/l)	453.8	II	949.1	800.0	III
SO_4 (mg/l)	39.3	0	68.1	5.0	0
NO_3 (mg/l)	3.6	0	7.6	0.1	0
F (mg/l)	0.4	0	0.3	0.2	0
OVERALL		II			III

Table 51. Statistics of health related chemistry in Ecca shale groundwater continued. Numbers in parenthesis indicate number of samples.

	CONTACT WITH VRYHEID FORMATION (12)			CONTACT WITH COAL (1)		CONTACT WITH DWYKA GROUP (1)		CONTACT WITH NATAL GROUP (1)	
	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS	VALUE	CLASS	VALUE	CLASS
pH	7.5	0	0.7	8.0	0	7.3	0	6.5	0
EC (mS/m)	59.2	0	77.4	760.0	III	34.7	0	12.8	0
TDS (mg/l)	472.1	I	614.6	4762.0	III	248.0	0	85.0	0
Mg (mg/l)	9.3	0	9.1	228.0	III	3.6	0	2.0	0
Na (mg/l)	113.9	I	201.6	1222.0	III	47.0	0	17.0	0
K (mg/l)	2.4	0	1.7	119.8	II	4.7	0	2.2	0
Cl (mg/l)	92.6	0	240.6	2444.0	III	15.3	0	15.0	0
SO_4 (mg/l)	8.8	0	11.2	144.0	0	3.0	0	4.0	0
NO_3 (mg/l)	0.9	0	2.0	0.1	0	1.2	0	0.1	0
F (mg/l)	0.6	0	0.5	0.5	0	0.3	0	0.6	0
OVERALL		I			III		0		0

9.2.2. Vryheid Formation

The majority of the boreholes drilled into the Vryheid Formation gave groundwater in the Class 0 and I range. Those boreholes intersecting the contact with Ecca shales, however, gave groundwater which was of a poorer quality. Figure 75 shows a graph of the distribution of quality classes amongst the target groups.

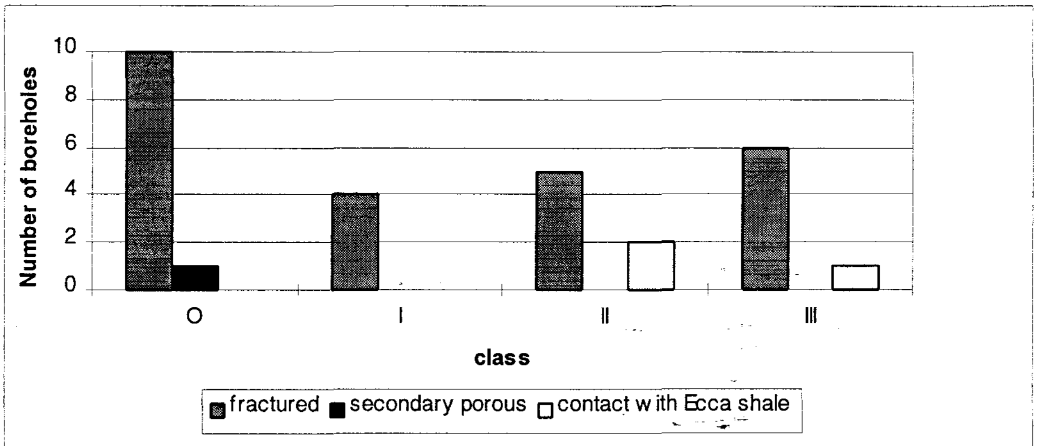
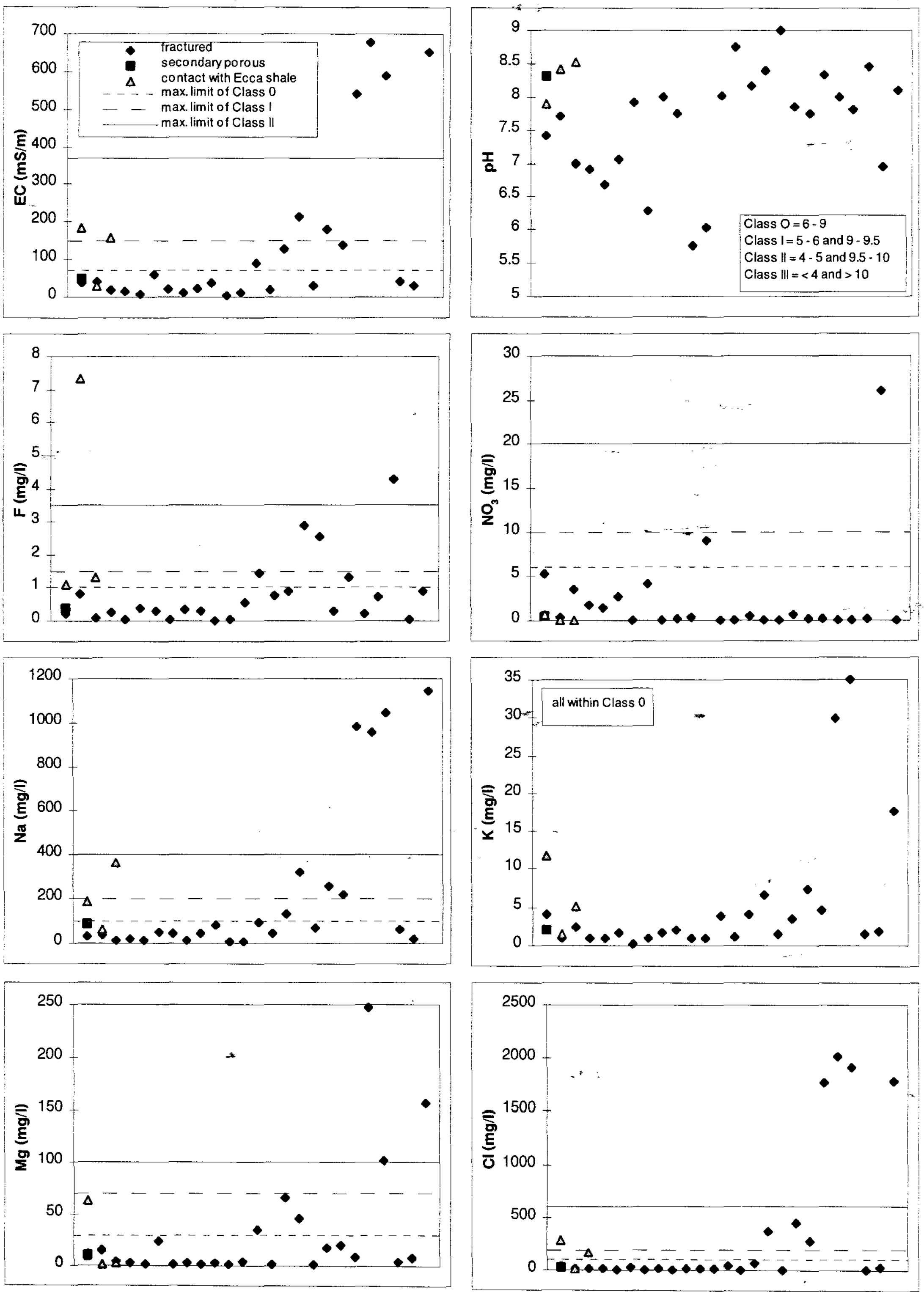


Figure 75. Summary of overall groundwater quality classes for the Vryheid Formation.

Groundwaters emanating from the fractures within the Vryheid Formation mostly have an electrical conductivity in the Class 0 range, however, some samples where scattered throughout the other three classes (Figure 76). Table 52 shows the mean electrical conductivity of fractured Vryheid Formation sandstone to be within Class I, despite being skewed by a few high values. Sodium and chloride naturally follow the same trend as electrical conductivity but the values are slightly higher giving a mean value in Class II. Sulphate concentrations were all well within Class 0, but showed a slightly higher concentration than the other targets. This is probably a result of pyrite having been mineralised within the fractures. Fluoride, due to the low clay content, and nitrate in fractured Vryheid sandstone are generally within Class 0 but a few samples did stray into the higher classes.

Weathering of the Vryheid Formation which induces secondary porosity results in a hydrogeological target which yields excellent quality groundwater in Class 0 from the only successful borehole. This type of water noticeable contrasts with the groundwater emanating from the contact between the Vryheid Formation sandstones and the Ecca Group shales (Figure 75). The reason for the poorer quality groundwater at the contact was due to high sodium, chloride and fluoride as shown in Figure 76 which is probably related to interactions with clays in the shale.



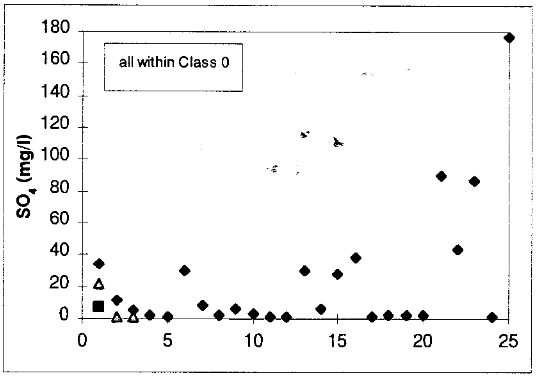


Figure 76. Scatter plots displaying class limits of health related constituents for groundwater quality in Vryheid Formation targets.

Table 52. Statistics of health related chemistry in Vryheid Formation groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED VRYHEID FORMATION (25)			SECONDARY POROUS VRYHEID FORMATION (1)		CONTACT WITH ECCA SHALE (3)		
	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS	MEAN	CLASS	STANDARD DEVIATION
pH	7.6	0	0.8	8.3	0	8.3	0	0.3
EC (mS/m)	144.4	I	217.4	49.8	0	123.0	I	81.5
TDS (mg/l)	943.0	I	1337.1	336.0	0	908.7	I	572.0
Mg (mg/l)	31.5	I	58.0	10.4	0	22.3	0	35.2
Na (mg/l)	227.1	II	368.1	89.0	0	204.3	II	149.9
K (mg/l)	5.4	0	8.9	<2.0	0	6.1	0	5.2
Cl (mg/l)	353.5	II	685.8	21.0	0	155.0	I	138.5
SO_4 (mg/l)	24.4	0	40.5	7.0	0	8.0	0	12.1
NO_3 (mg/l)	2.3	0	5.4	0.1	0	0.3	0	0.4
F (mg/l)	0.8	0	1.0	0.4	0	3.3	II	3.5
OVERALL		II			0		II	

9.2.3. Natal Metamorphic Province

The large number of targets within the Natal Metamorphic Province may seem to make Figure 77 appear somewhat complex. To avoid further complications, the scatter plots of each constituent have been separated according to lithology (Figure 78, Figure 79 and Figure 80).

The overall groundwater quality of the Natal Metamorphic Province is good, however the schists are noticeably of a poorer quality. This is possibly due to the greater surface area of the fine-grained weathered product, thereby increasing contact area and thus cation exchange. Another possibility is that the original sediment, before diagenesis and metamorphism, may have been deposited into a marine environment which resulted in brackish connate water.

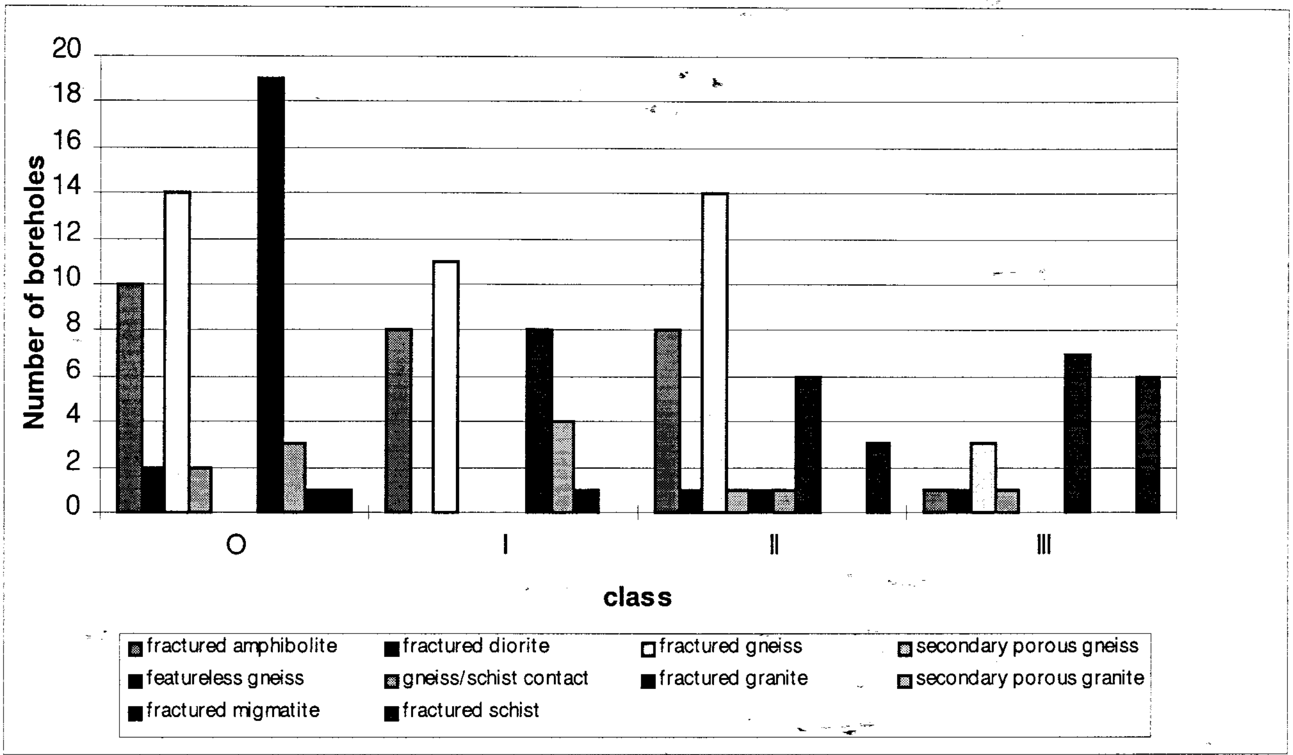
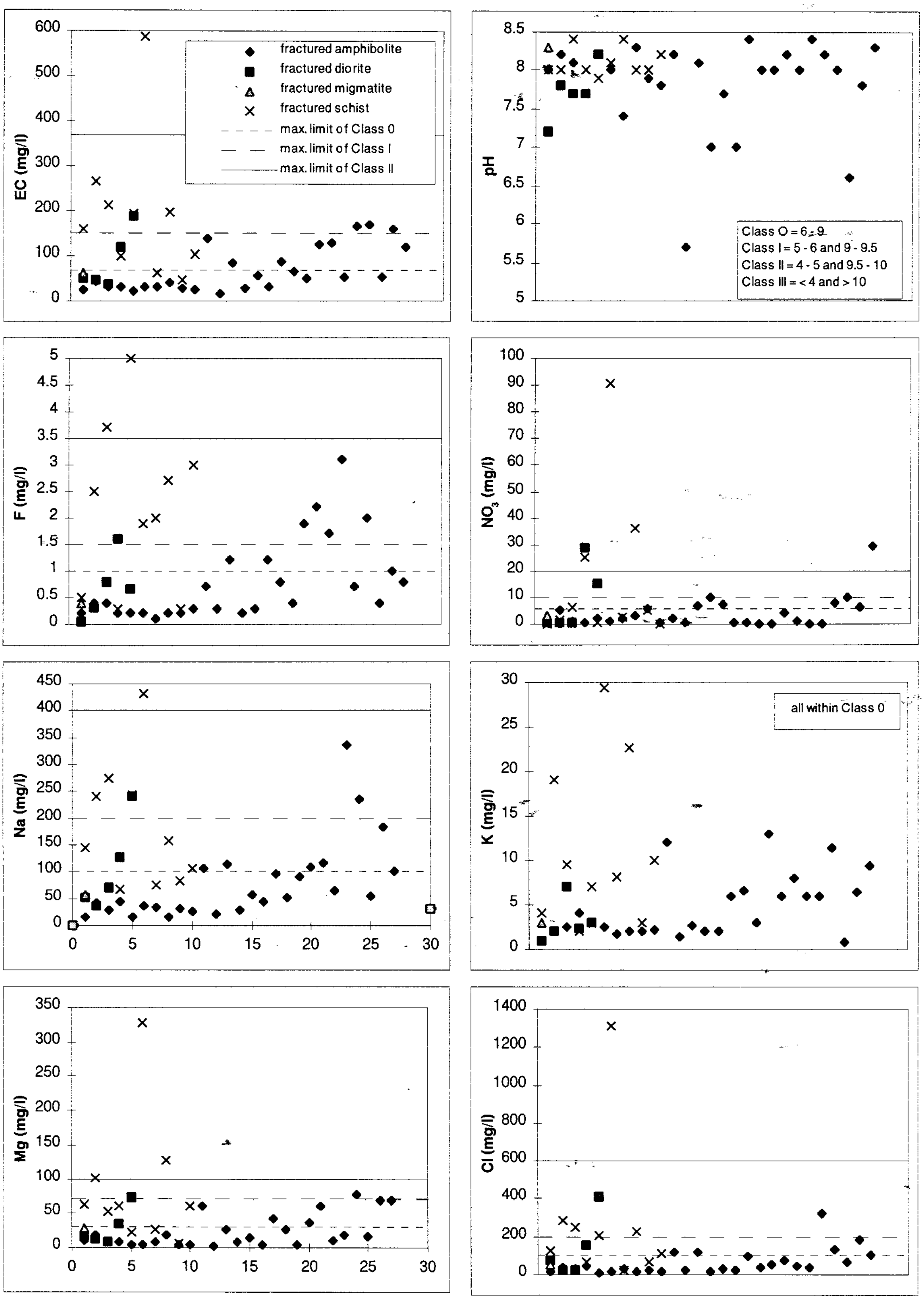


Figure 77. Summary of overall groundwater quality classes in Natal Metamorphic Province rocks.

The majority of fractured amphibolite groundwater fell into Class 0 with the remainder into Class I and II. None of the samples were in Class III. Those constituents which consistently contributed to the Class I and II groundwaters were electrical conductivity, fluoride, sodium, chloride and sulphate (Figure 78). However, taking into consideration all 27 samples, a mean in Class I for total dissolved solids and Class 0 for the rest of the constituents resulted. Fractured diorite follows similar trends in chemical concentrations to fractured amphibolite (Class I), with the exception of sodium, chloride and nitrate which vary considerably, while the fractured migmatite produced excellent quality groundwater.

As mentioned previously, the schists produced the worst quality groundwater of the rocks encountered in the Natal Metamorphic Province. In particular, the constituent which gave the poorest result was fluoride. The high fluoride values found in schists and other argillaceous rocks may be related to the substitution of fluoride for $(OH)^-$ in mica minerals. Nitrate and sodium fell mainly within Class 0 but tended to give some higher concentrations. Some of the constituents, such as magnesium and chloride were found to be highly variable.


EC (mg/l)
fractured amphibolite
fractured diorite
fractured migmatite
fractured schist
max. limit of Class 0
max. limit of Class I
max. limit of Class II
pH
Class O = 6 - 9
Class I = 5 - 6 and 9 - 9.5
Class II = 4 - 5 and 9.5 - 10
Class III = < 4 and > 10
F (mg/l)
NO_3 (mg/l)
Na (mg/l)
K (mg/l)
all within Class 0
Mg (mg/l)
Cl (mg/l)

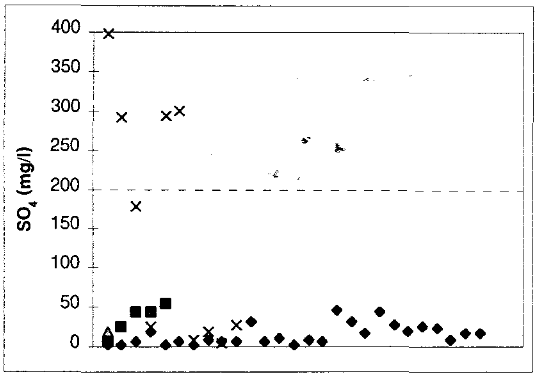


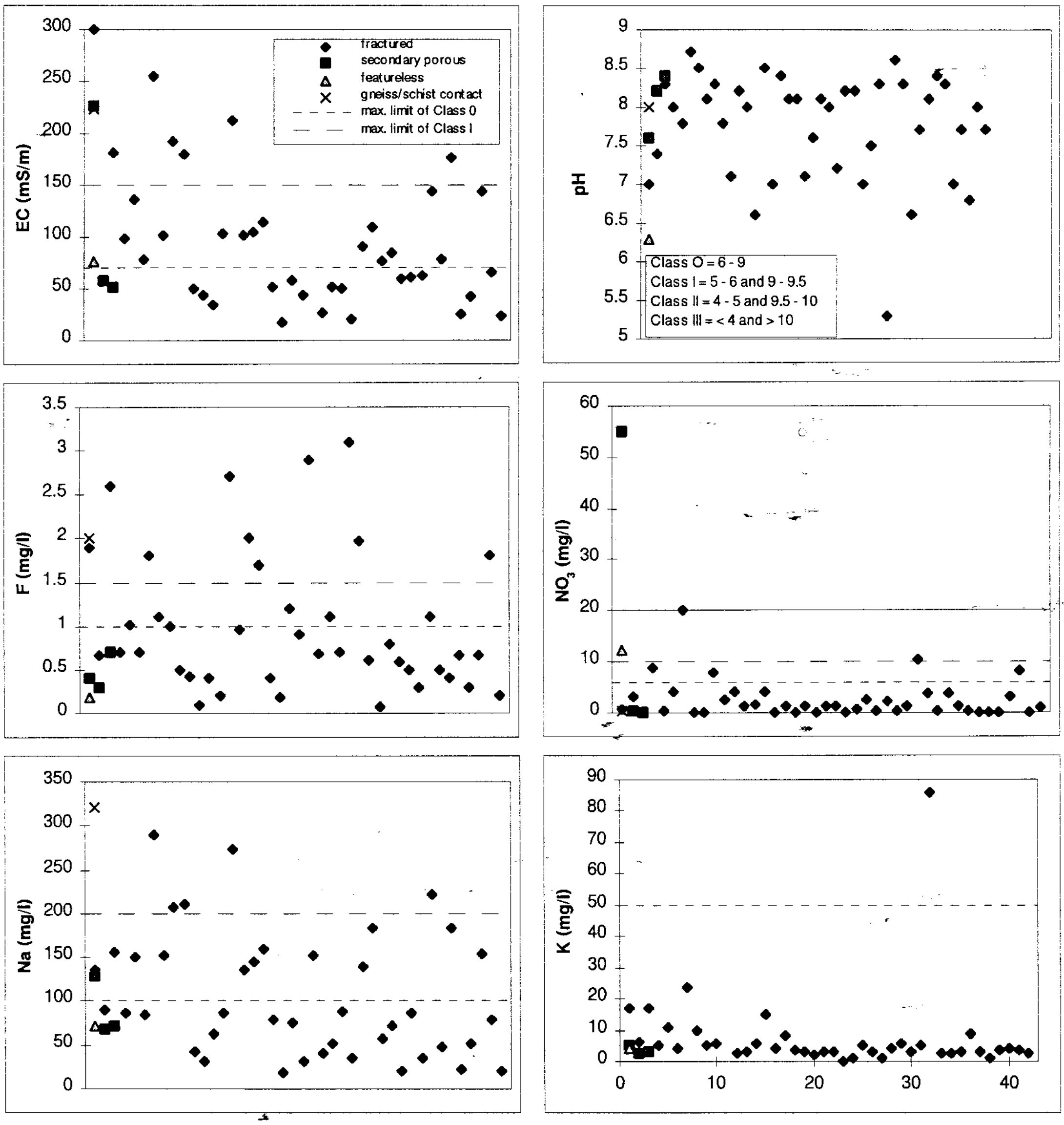
Figure 78. Scatter plots displaying class limits of health related constituents for groundwater quality in fractured Natal Metamorphic Province targets.

Table 53. Statistics of health related chemistry in fractured Natal Metamorphic Province rock groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED AMPHIBOLITE (27)			FRACTURED DIORITE (5)			FRACTURED MIGMATITE (1)		FRACTURED SCHIST (10)		
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS	MEAN	CLASS	STANDARD DEVIATION
pH	7.8	0	0.6	7.7	0	0.4	8.3	0	8.1	0	0.2
EC (mS/m)	68.3	0	49.4	88.0	I	63.7	63.0	0	192.3	II	155.1
TDS (mg/l)	525.5	I	409.0	573.8	I	407.5	488.0	I	1301.1	II	930.7
Mg (mg/l)	23.6	0	23.5	28.7	0	26.3	29.0	0	84.9	II	92.4
Na (mg/l)	77.8	0	74.1	105.2	I	83.0	58.0	0	182.4	I	115.3
K (mg/l)	4.6	0	3.5	3.1	0	2.3	3.0	0	11.5	0	9.1
Cl (mg/l)	62.3	0	67.9	135.8	I	161.4	48.0	0	267.0	II	378.5
SO_4 (mg/l)	15.1	0	12.5	34.4	0	19.0	19.0	0	154.6	0	154.1
NO_3 (mg/l)	4.0	0	5.9	9.0	I	12.9	2.9	0	16.8	II	28.6
F (mg/l)	0.8	0	0.8	0.7	0	0.6	0.4	0	2.2	II	1.5
OVERALL		I			I			I		II	

The four targets within the gneisses of the Natal Metamorphic Province each gave similar types of groundwater. The fractures produced a groundwater which tended to be somewhat variable especially with respect to electrical conductivity, magnesium, chloride and sulphate. Of these constituents sulphate was the only one to give a Class III result, the rest were distributed between Class 0 and II. Fluoride, nitrate and sodium fell mainly into Class 0 or I but did have some results in Class II. Even though Table 54 shows the mean values for fractured gneiss to result in Class I groundwater, the individual values generally present fractured gneiss as being of moderate quality due to the large number of Class II values, thereby making it less desirable for drinking purposes without treatment.

The three samples obtained from the secondary porous gneiss targets were highly variable with two of the samples' constituents mostly falling into Class 0 and one into Class III. This may be because of different residence times or because the poorer quality groundwater may have been in contact with schist. Sulphate concentrations were low and resulted in Class 0. One sample taken from a featureless target gave Class II groundwater due to high nitrates. The groundwater emanating from the contact between gneiss and schist yielded a water which was similar in composition to groundwater from fractured schist.



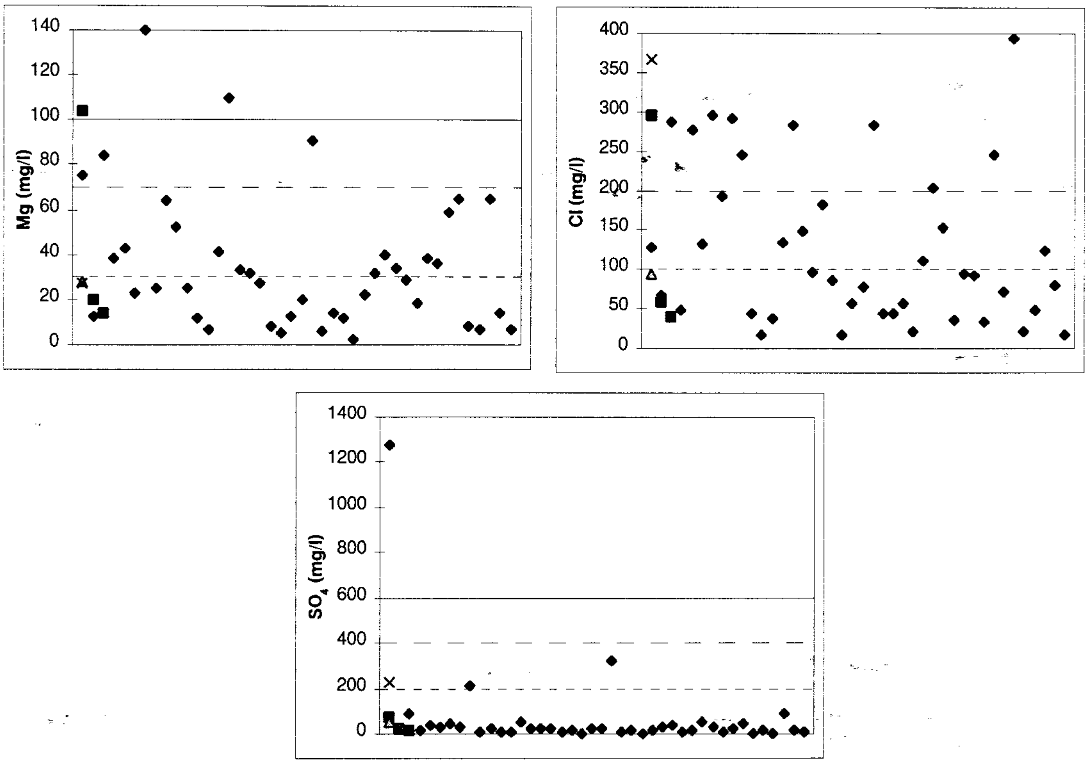
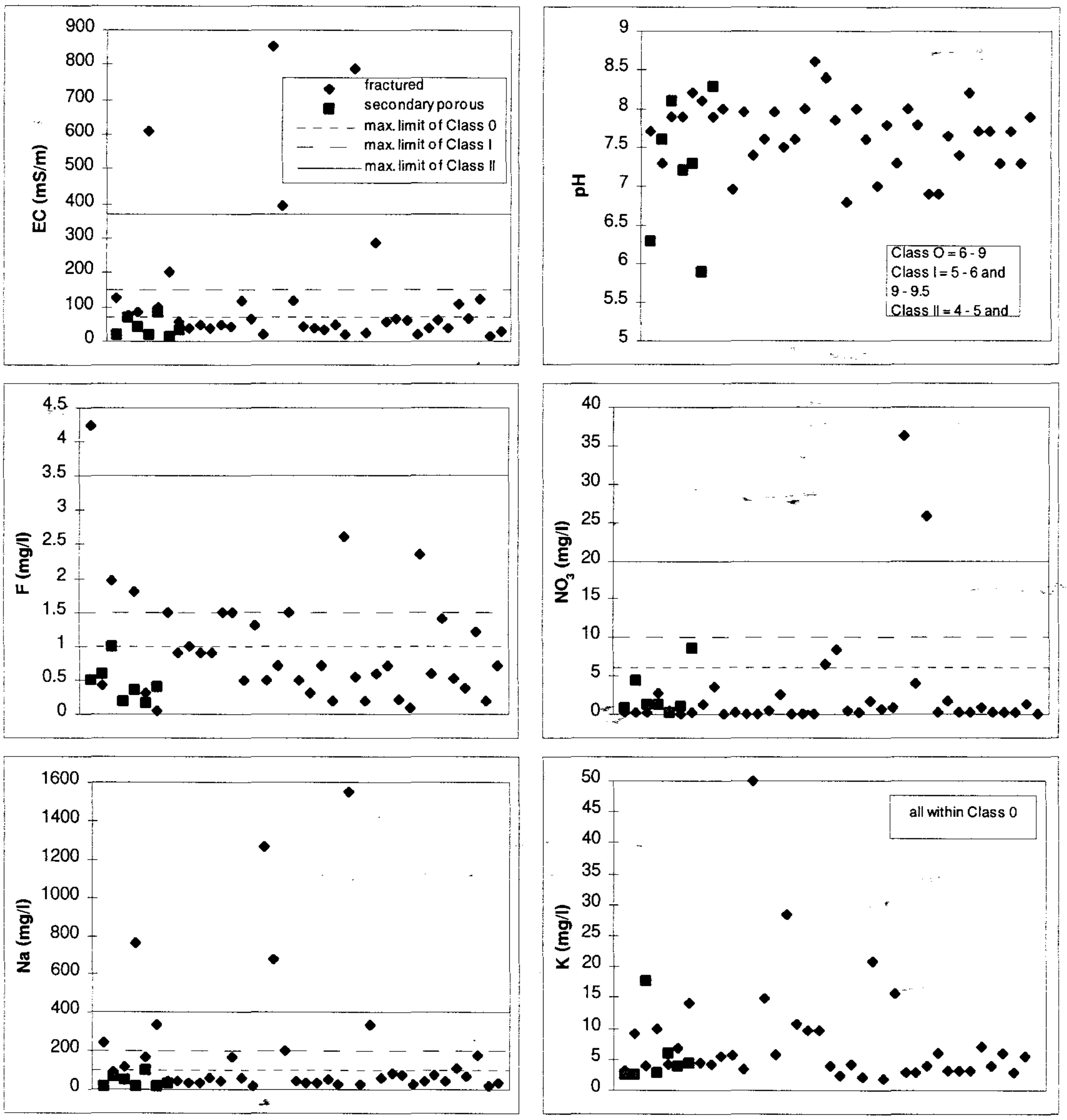


Figure 79. Scatter plots displaying class limits of health related constituents for groundwater quality in Natal Metamorphic Province gneiss.

Table 54. Statistics of health related chemistry in Natal Metamorphic Province gneiss groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED GNEISS (42)			SECONDARY POROUS GNEISS (3)			FEATURELESS GNEISS (1)		CONTACT WITH SCHIST (1)	
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS	VALUE	CLASS
pH	7.8	0	0.7	8.1	0	0.4	6.3	0	8.0	0
EC (mS/m)	98.0	I	67.5	111.8	I	99.8	76.0	I	223.0	II
TDS (mg/l)	662.1	I	471.6	757.0	I	598.6	504.0	I	1268.0	II
Mg (mg/l)	35.4	I	30.5	46.0	I	50.3	28.0	0	27.0	0
Na (mg/l)	105.7	I	70.6	88.7	0	34.1	71.0	0	321.0	II
K (mg/l)	7.5	0	13.5	3.5	0	1.2	not taken	N/A	4.1	0
Cl (mg/l)	126.4	I	99.8	131.0	I	142.3	95.0	0	366.0	II
SO_4 (mg/l)	64.4	0	200.0	36.0	0	34.1	51.0	0	226.0	I
NO_3 (mg/l)	2.4	0	3.8	18.5	II	31.7	12.4	II	0.3	0
F (mg/l)	1.0	I	0.8	0.5	0	0.2	0.2	0	2.0	II
OVERALL		I			II			II		II

Aquifers in Natal Metamorphic Province granite were limited to fractured and secondary porous zones. The fractured granite generally yielded groundwater in the Class 0 to I range. Most of the constituents, however, occasionally contribute to Class II and III results. Nitrate, in particular, exhibits three results in Class III. This could point to the ease through which contamination may move through the fractures from the surface. The secondary porous samples gave a better groundwater quality than the fractures with all of the constituents falling into Class 0 or I (Figure 80). The statistics generated from all the samples of each target explicitly show that the secondary porous target has a better quality compared to the fractures (Table 55). The reason for this is unknown, however, if the number of secondary porous samples was greater there may have been a greater standard deviation within the samples.



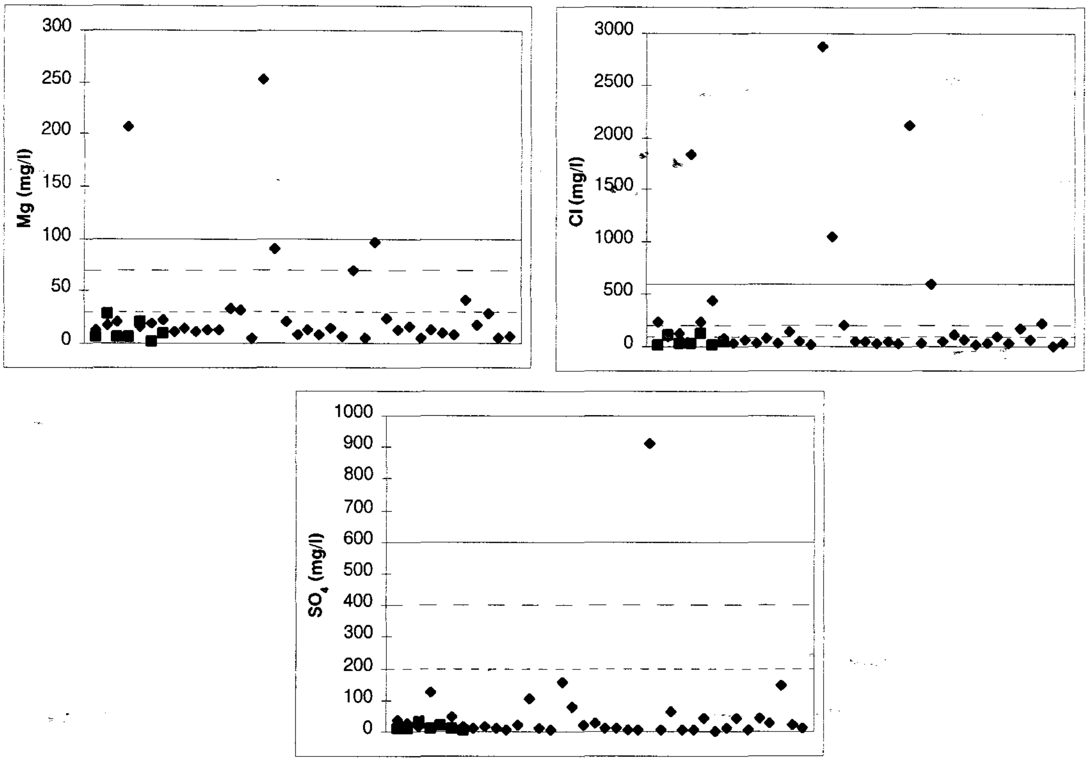


Figure 80. Scatter plots displaying class limits of health related constituents for groundwater quality in Natal Metamorphic Province granite.

Table 55. Statistics of health related chemistry in Natal Metamorphic Province granite groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED NMP GRANITE (38)			SECONDARY POROUS NMP GRANITE (7)		
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION
pH	7.7	0	0.4	7.2	0	0.9
EC (mS/m)	130.7	I	200.3	39.8	0	27.6
TDS (mg/l)	811.3	I	1209.0	271.7	0	177.5
Mg (mg/l)	31.9	I	52.1	11.4	0	9.7
Na (mg/l)	190.9	I	336.0	42.3	0	30.4
K (mg/l)	8.0	0	9.0	5.8	0	5.4
Cl (mg/l)	300.7	II	630.3	52.7	0	45.6
SO_4 (mg/l)	55.5	0	147.9	13.5	0	9.1
NO_3 (mg/l)	2.7	0	7.1	2.5	0	3.0
F (mg/l)	0.9	0	0.8	0.5	0	0.3
OVERALL		II			0	

9.2.4. Quaternary sediments

The best target in terms of groundwater quality in the Maputaland Group is the fine sand which covers most of the Zululand coastal plain (Figure 81). The coarser-grained palaeochannels appear to yield groundwater of a poorer quality, especially with respect to electrical conductivity. The reason for this is that the groundwater could be travelling a greater distance due to the higher permeability, thereby causing the groundwater to come into contact with more salts within the sands. Another reason is due to the concentration of flow in the high permeability palaeochannels relative to the sands.

The Uloa Formation, as expected, does contain excellent quality groundwater. The two samples that intersected the contact between the Maputaland and Zululand Groups, have a distinctly different character. The scatter plots of the health related constituent concentrations are shown in Figure 82.

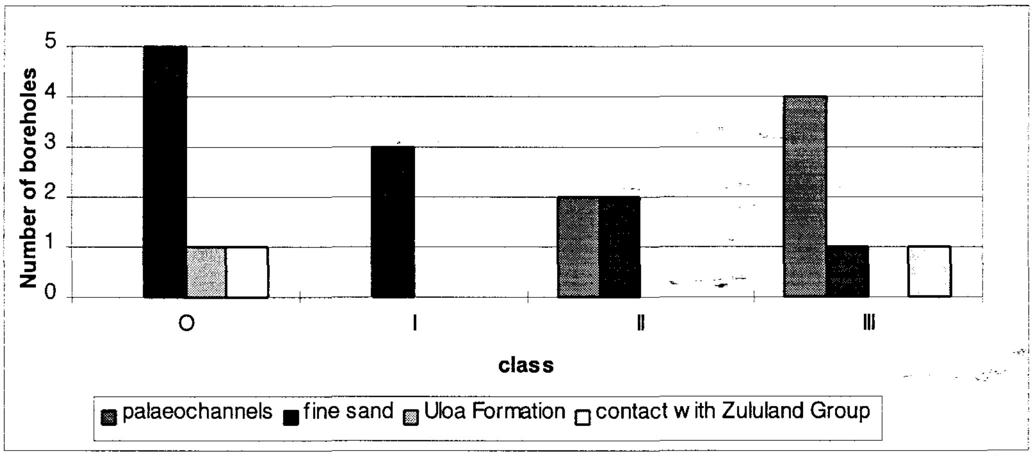
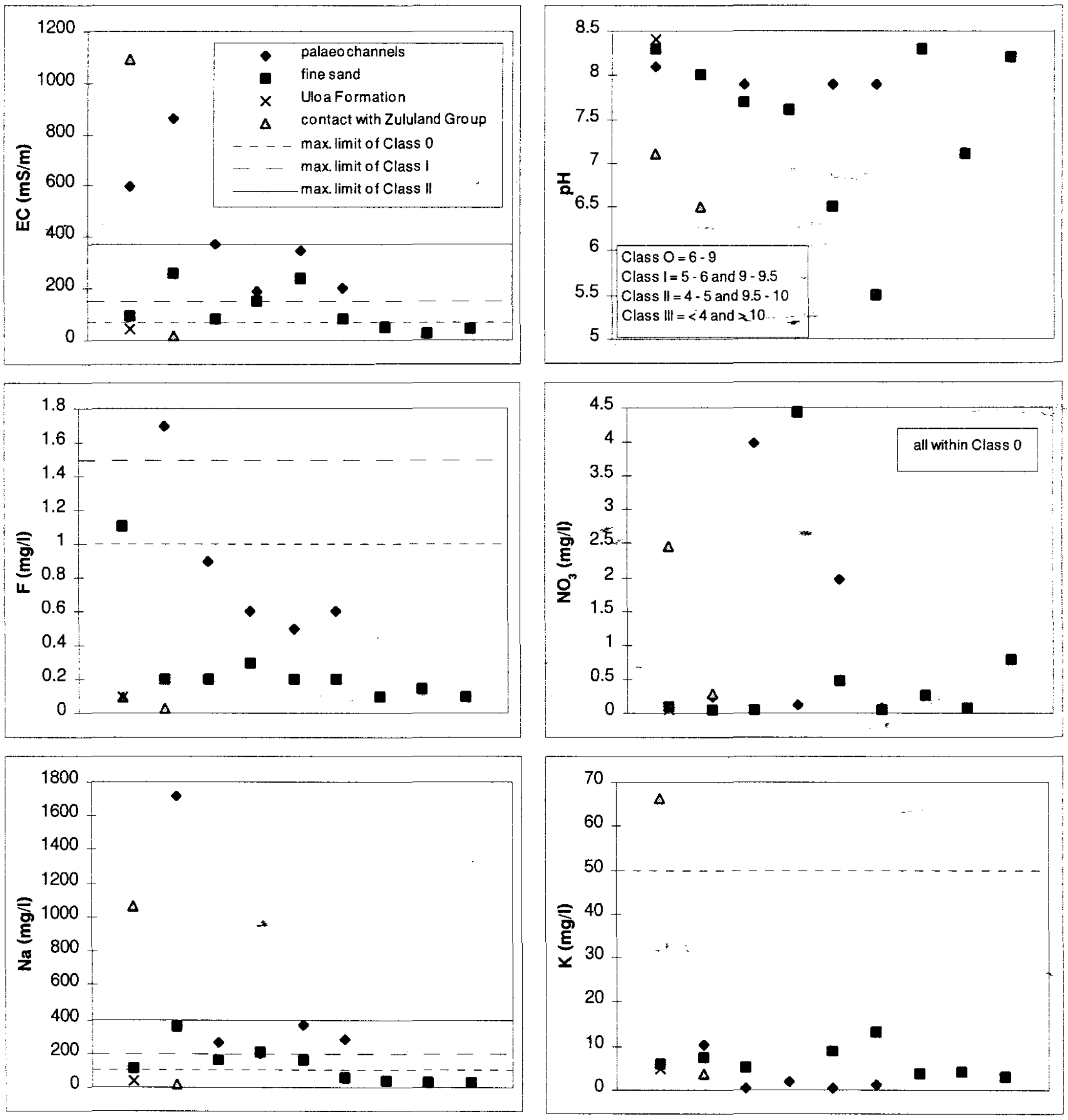


Figure 81. Summary of overall groundwater quality classes in Maputaland sediments.

Palaeochannels in the Maputaland Group display electrical conductivities in Class II and III. The associated cations of high concentration are sodium and magnesium. Chloride also falls into either Class II or III. Fluorides are almost always in Class 0, but one sample fell into Class II. No problems with respect to nitrates were encountered and sulphates were mainly within Class 0 or I.

The fine sands of the Maputaland Group show lower electrical conductivities which do not transcend the Class II limit. Most of the constituents remain within either Class 0 or I. Sodium and chloride, however, fall into Class II and III. Groundwater emanating from the Uloa Formation was of excellent quality.

In contrast to the Uloa Formation, the underlying contact of the Maputaland Group and the Zululand Group siltstones had two extremely contrasting results. One of the sample's constituents all fell within Class 0 and the other constituents, except one, in Class III. The reason for this uncertain because the drilling of both boreholes ceased less than one metre after the contact was encountered. The only possible explanation is that the siltstone of the poor quality borehole could have been saturated and thus contributed to the groundwater inflow, while the good quality borehole intersected dry siltstone. Even though few boreholes were drilled into the Maputaland Group hydrolithology, direct comparison shows that the aquifer quality in order of preference is, Uloa Formation, fine sands, palaeochannels and the Maputaland Group contact with Zululand Group.



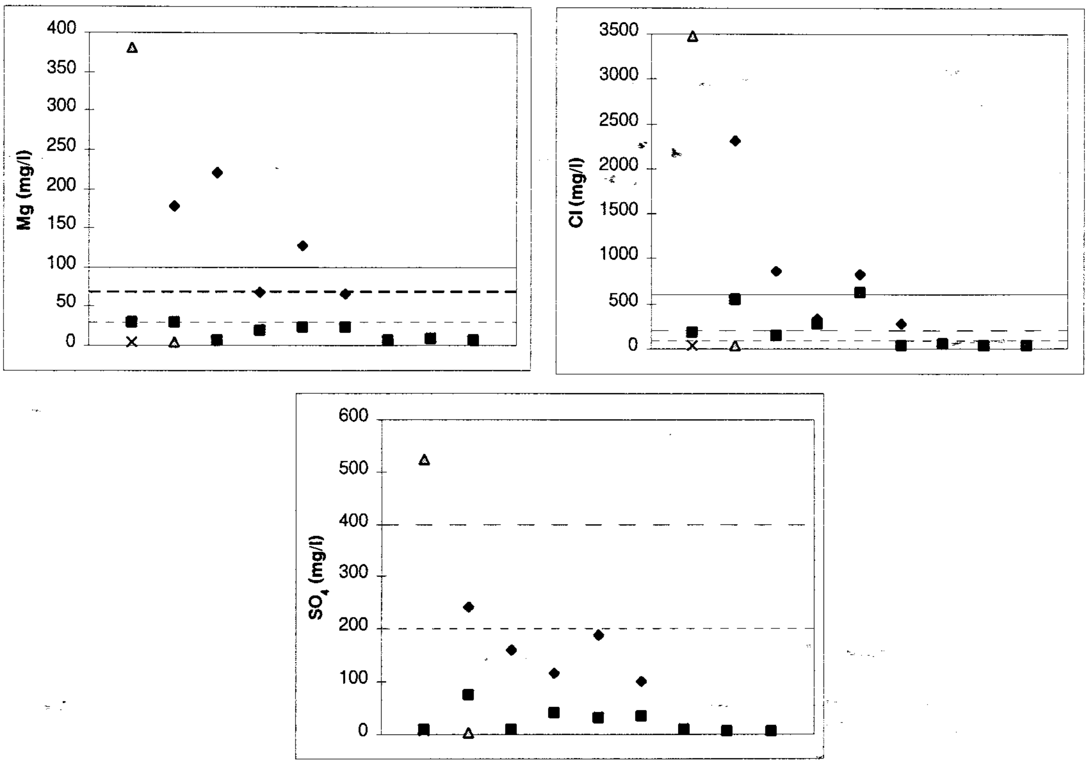


Figure 82. Scatter plots displaying class limits of health related constituents for groundwater quality in Maputaland Group targets.

Table 56. Statistics of health related chemistry in Maputaland Group groundwater. Numbers in parenthesis indicate number of samples.

	MAPUTALAND GROUP PALAEOCHANNELS (6)			MAPUTALAND GROUP FINE SAND (9)			ULOA FORMATION (1)		MAPUTALAND GROUP CONTACT WITH ZULULAND GROUP (2)		
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS	MEAN	CLASS	STANDARD DEVIATION
pH	7.9	0	0.2	7.5	0	1.0	8.4	0	6.8	0	0.4
EC (mS/m)	427.5	III	237.6	113.5	I	84.7	41.1	0	557.5	III	761.6
TDS (mg/l)	2607.2	III	1775.1	715.8	I	466.6	307.0	0	3462.5	III	4725.6
Mg (mg/l)	131.6	III	60.8	17.1	0	10.1	5.0	0	192.8	III	267.6
Na (mg/l)	564.0	III	577.2	127.4	I	109.3	33.0	0	545.3	III	740.6
K (mg/l)	2.7	0	3.8	6.4	0	3.3	4.8	0	35.0	0	44.4
Cl (mg/l)	922.2	III	736.9	217.2	II	226.3	38.0	0	1758.0	III	2429.6
SO_4 (mg/l)	162.0	0	50.8	24.2	0	23.8	7.0	0	264.5	I	368.4
NO_3 (mg/l)	1.3	0	1.5	0.7	0	1.4	0.0	0	1.4	0	1.5
F (mg/l)	0.9	0	0.4	0.3	0	0.3	0.1	0	0.1	0	0.0
OVERALL		III			II			0		III	

9.2.5. Dwyka Group

The majority of boreholes intersecting Dwyka Group tillite yield Class 0 and Class I groundwater. This result is quite unexpected, as it contradicts popular belief that the Dwyka Group yields poor quality groundwater. Some of the boreholes intersecting contacts with Dwyka Group tillite and other rocks did, however, yield poorer quality waters.

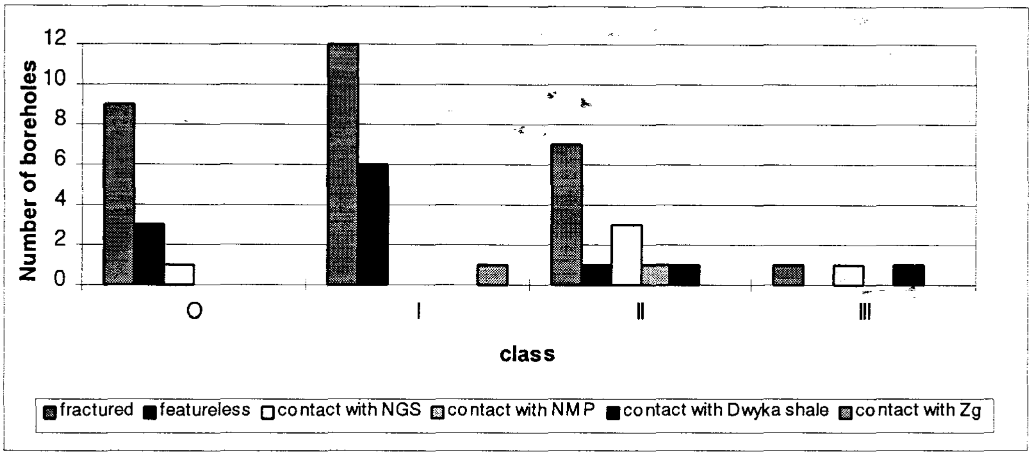


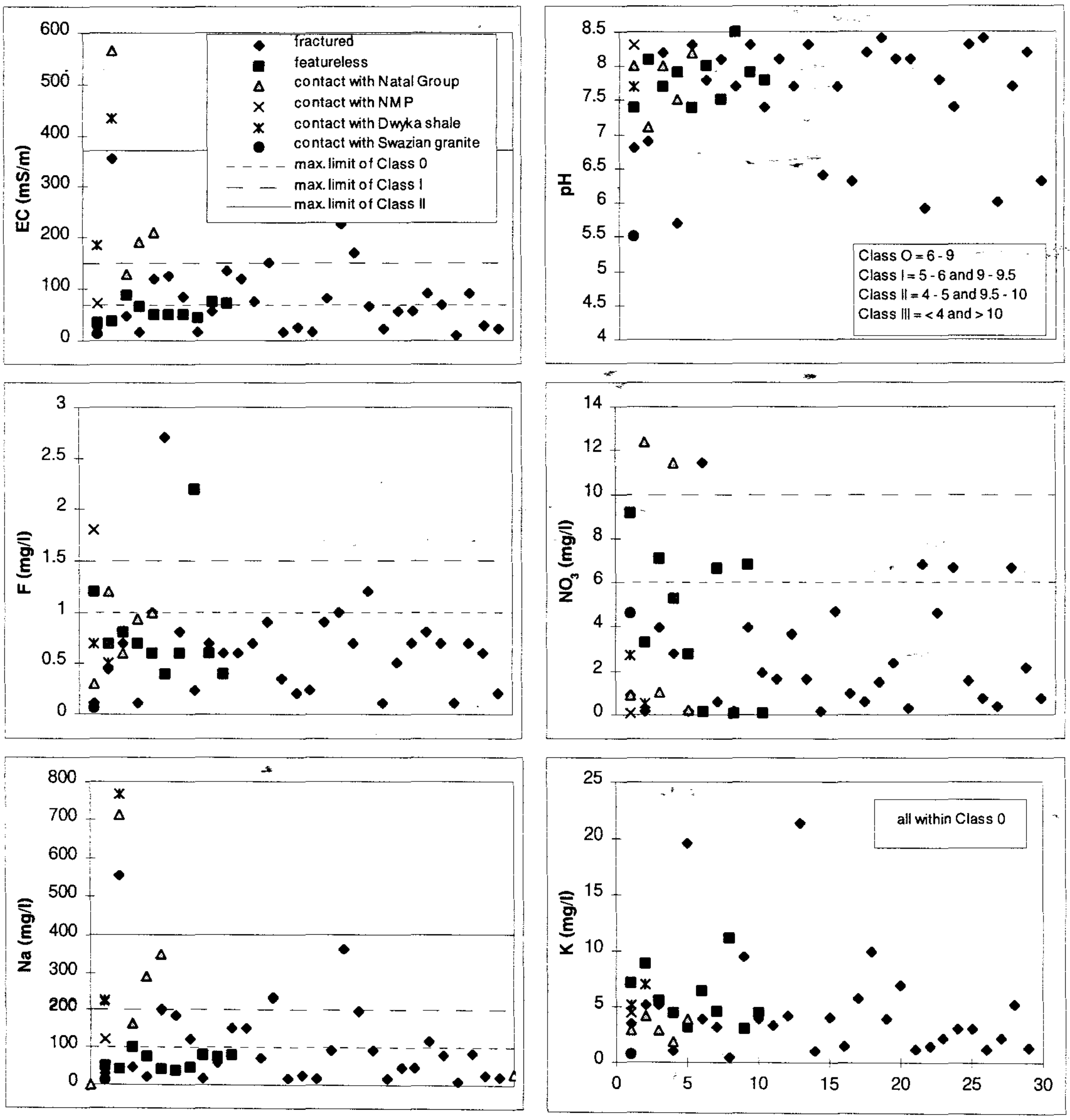
Figure 83. Summary of overall groundwater quality classes in the Dwyka Group.

For the most part, the health related constituents of fractured Dwyka Group tillite groundwater resulted in Class 0 and I water (Figure 84). This is true for electrical conductivity, fluoride, nitrate, sodium and chloride, however, there are also some Class II results. Chloride was the only constituent to rise into Class III in some samples. One sample in fractured Dwyka tillite has an electrical conductivity of 570 mS/m which deviates substantially from the majority of the samples and is therefore not regarded as representative. The classification of the mean constituent values is Class I (Table 57) with the greatest deviation coming from those constituents which fall in the Class I range.

The groundwater samples taken from boreholes not intersecting recognisable water-bearing structures, but still producing some groundwater were overall of better quality than the fractured rock. The majority of the constituents are in Class 0 and the remainder in Class I. As the featureless target is not a hydrogeological target of significance, the results of groundwater quality are not really relevant, other than to note that the quality is somewhat better than that from higher yielding fractures. The reason for this quality difference is not known. The contact aquifers at the Dwyka tillite and Dwyka shale interface have values of electrical conductivity, sodium, magnesium and chloride levels mostly in Class II and III. Sodium and chloride values in particular are high, as shown in Table 57.

Groundwater quality at the contacts of Dwyka Group tillite and other rock types is worse than in the fractures (Table 58). This point is typically illustrated by the Natal Group sandstone contact with the tillite. At this contact the electrical conductivity is distributed between Class II and III. The ions of sodium, magnesium and chloride are spread through Class 0 to III. Fluoride appears to be the only constituent which remains below Class I. The mean of all the values for the Dwyka Group's contact with Natal Group gives a class of II.

The single sample taken from the contact with the underlying Natal Metamorphic Province rocks shows the groundwater to be of good quality, except with respect to fluoride which fell into Class II. High fluorides are generally expected within granites but as proven in the Natal Metamorphic Province granites and gneisses, this is not always the case (Table 54 and Table 55). The contact with the Swazian granite aquifers produced excellent groundwater with only the pH level reaching Class I.



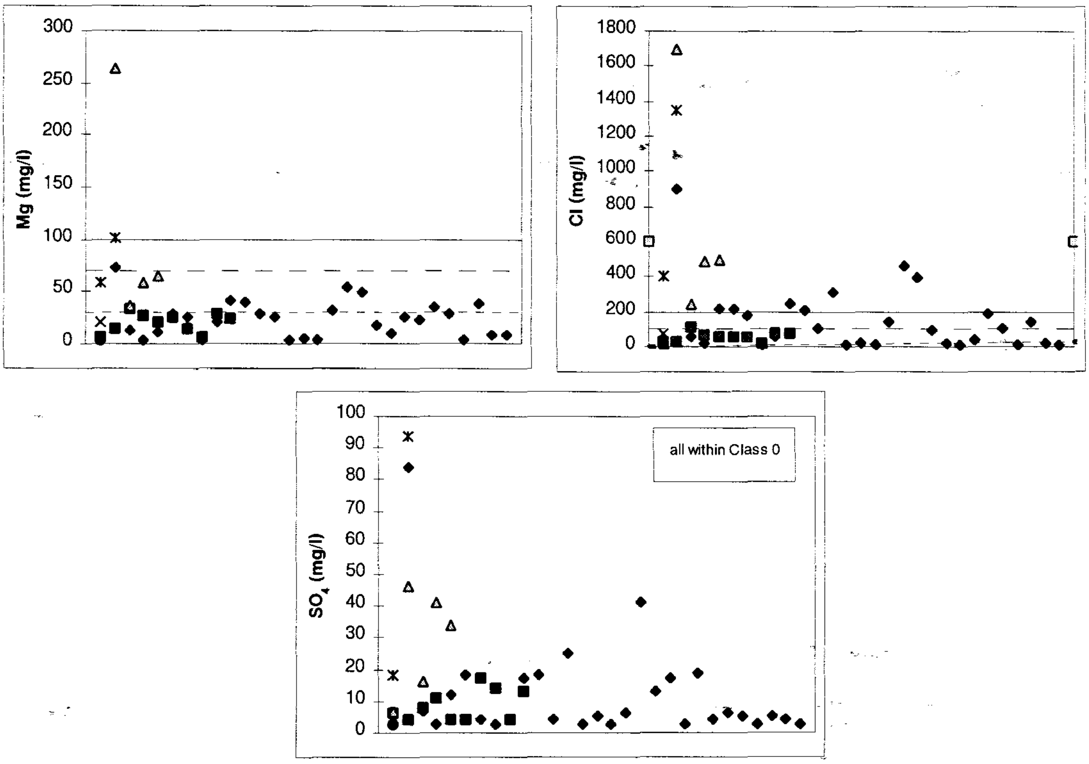


Figure 84. Scatter plots displaying class limits of health related constituents for groundwater quality in Dwyka Group targets.

Table 57. Statistics of health related chemistry in Dwyka Group groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED DWYKA GROUP (29)			FEATURELESS DWYKA GROUP (10)			DWYKA GROUP CONTACT WITH DWYKA SHALE (2)		
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION
pH	7.5	0	0.9	7.8	0	0.3	7.9	0	0.3
EC (mS/m)	81.7	I	75.1	56.9	0	17.6	309.5	II	174.7
TDS (mg/l)	560.6	I	482.2	439.3	0	124.0	1937.0	II	1029.5
Mg (mg/l)	22.8	0	17.5	19.7	0	9.3	80.0	II	29.7
Na (mg/l)	105.8	I	119.4	62.8	0	22.7	495.5	III	381.1
K (mg/l)	4.7	0	4.9	5.9	0	2.6	6.1	0	1.3
Cl (mg/l)	145.1	I	188.8	57.3	0	27.0	878.5	III	669.6
SO_4 (mg/l)	11.8	0	16.4	8.5	0	4.9	56.0	0	53.7
NO_3 (mg/l)	2.5	0	2.7	4.1	0	3.4	1.6	0	1.6
F (mg/l)	0.6	0	0.5	0.8	0	0.5	0.6	0	0.1
OVERALL		I			0			III	

Table 58. Statistics of health related chemistry in Dwyka Group groundwater continued. Numbers in parenthesis indicate number of samples.

	CONTACT WITH NMP (1)		CONTACT WITH NATAL GROUP (5)			CONTACT WITH SWAZIAN GRANITE (1)	
	VALUE	CLASS	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS
pH	8.3	0	7.8	0	0.5	5.5	I
EC (mS/m)	71.3	I	223.5	II	204.5	13.5	0
TDS (mg/l)	575.0	I	1274.6	II	1439.6	112.0	0
Mg (mg/l)	20.0	0	86.0	II	102.1	3.3	0
Na (mg/l)	122.0	I	307.0	II	259.2	11.3	0
K (mg/l)	4.4	0	3.2	0	0.9	0.7	0
Cl (mg/l)	78.0	0	587.4	II	652.5	16.6	0
SO_4 (mg/l)	18.0	0	28.9	0	16.8	2.8	0
NO_3 (mg/l)	0.1	0	5.2	0	6.2	4.6	0
F (mg/l)	1.8	II	0.8	0	0.4	0.1	0
OVERALL		II		II			I

9.2.6. Dolerite

Groundwater from fractured dolerite has a mean quality of Class II which is not as good as would be hoped for from such an important groundwater target (Figure 85 and Table 59). The few secondary porous targets also exhibit a poor overall groundwater quality.

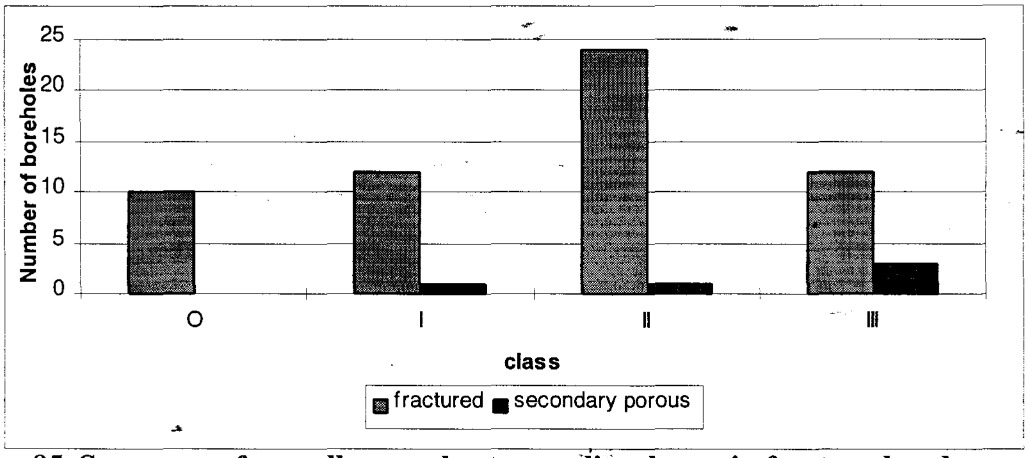
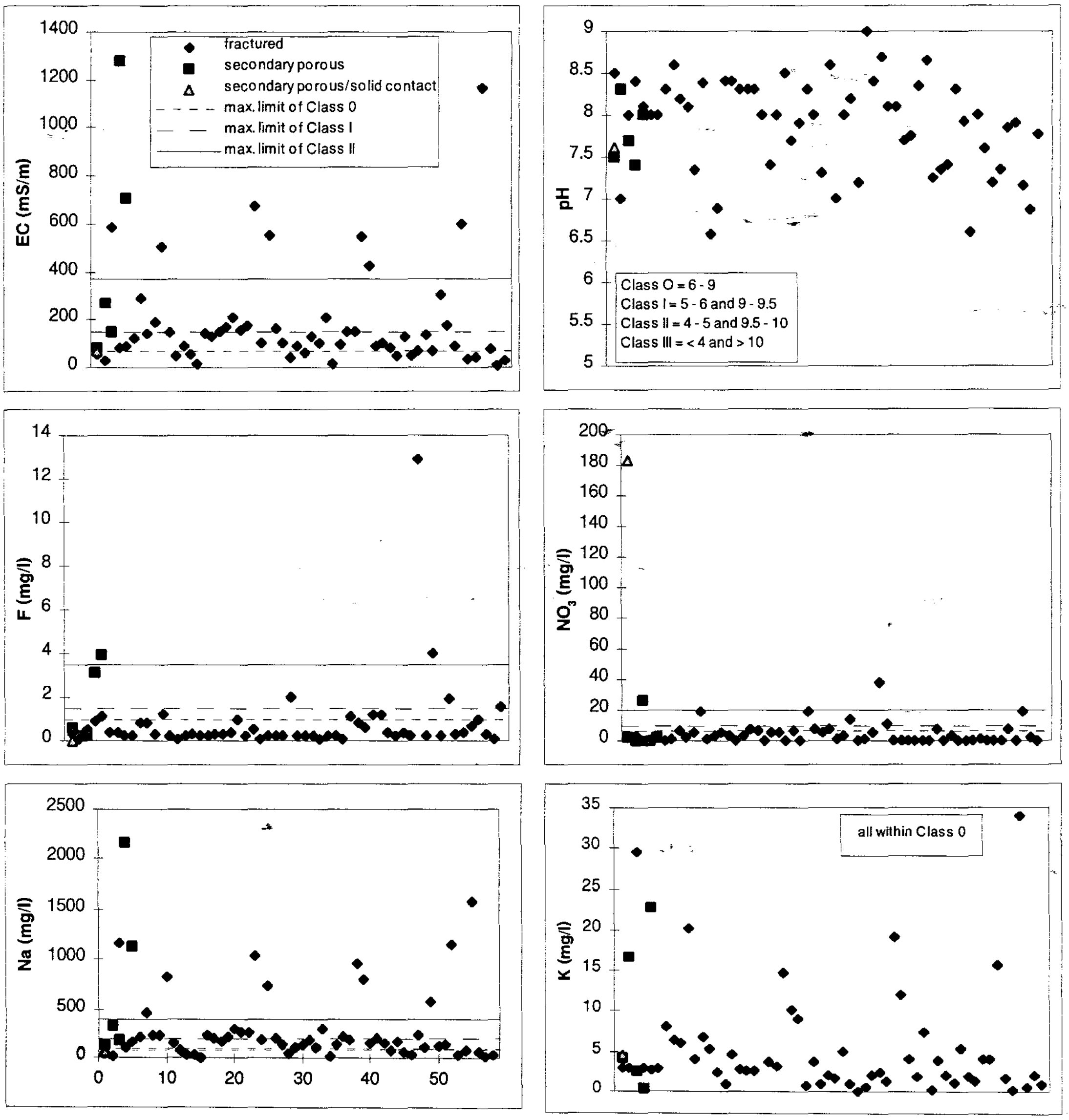


Figure 85. Summary of overall groundwater quality classes in fractured and secondary porous dolerite.

The majority of all the health related constituents in fractured dolerite fell within the Class I limit, with few occurrences in Class II and III. Figure 86 may be misleading, however, as it shows the majority of samples falling within Class 0 or I, while Figure 85 shows that overall most constituents fell into Class II. This can be explained by the realisation that it takes only one constituent to fall within Class II for the overall classification to be Class II. In addition, all of the constituents had some results in Class II. Generally, it is sodium and chloride that are responsible for the poor quality in groundwater emanating from dolerite (Table 59).

Figure 86 clearly shows that the groundwater samples taken from secondary porous dolerite aquifers are of a poorer quality than fractured aquifers. Fluoride and nitrate were the only constituents to have Class 0 results, while the rest mostly fell into Class II or III. The single sample taken at the contact between secondary porous and featureless dolerite displayed a similar character to the average fractured dolerite groundwater but had a very high level of nitrate which may be a result of human or animal contamination.



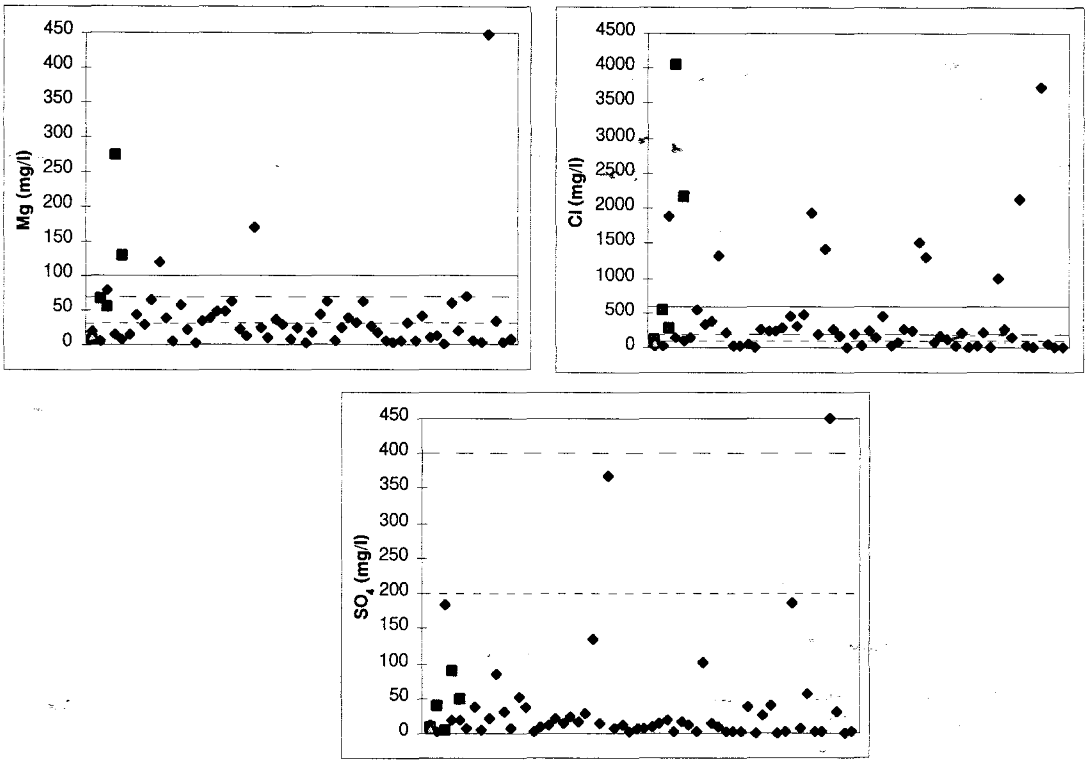


Figure 86. Scatter plots displaying class limits of health related constituents for groundwater quality in dolerite targets.

Table 59. Statistics of health related chemistry in dolerite groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED DOLERITE (58)			SECONDARY POROUS DOLERITE (5)		
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION
pH	7.9	0	0.6	7.8	0	0.4
EC (mS/m)	179.5	II	207.9	496.5	III	500.9
TDS (mg/l)	1140.0	II	1213.7	2965.8	III	2893.8
Mg (mg/l)	37.3	I	62.6	105.9	III	103.1
Na (mg/l)	277.5	II	335.4	795.2	III	861.0
K (mg/l)	5.3	0	6.8	9.3	0	9.8
Cl (mg/l)	413.7	II	682.0	1432.0	III	1680.7
SO_4 (mg/l)	38.9	0	80.9	38.6	0	34.6
NO_3 (mg/l)	4.1	0	6.6	6.1	I	11.1
F (mg/l)	0.8	0	1.7	1.6	II	1.8
OVERALL		II			III	

The quality of the groundwater of Karoo dolerite in contact with Karoo rocks is generally poor, particularly with respect to the contacts with Karoo argillaceous and arenaceous rock and the Jozini Formation. This fact leads one to believe that the quality of the groundwater emanating from the contact with dolerite and its host rock tends to take on a quality more like the host rock than the dolerite itself. This is probably due to recharge waters moving through the host rock before encountering the dolerite contact.

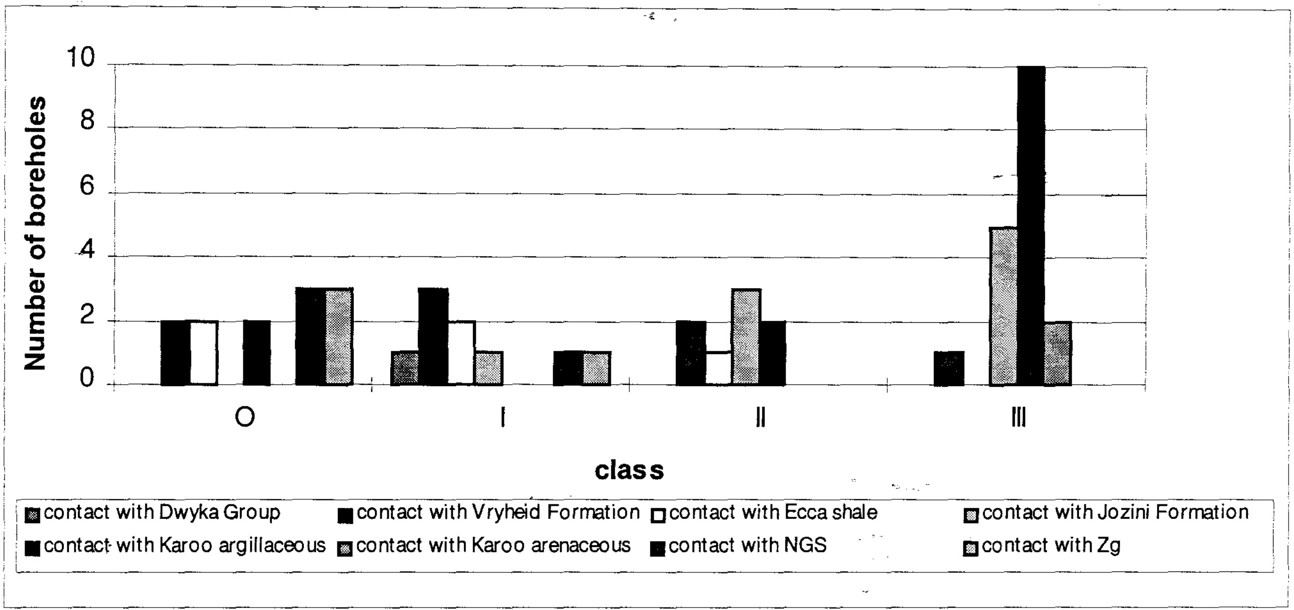
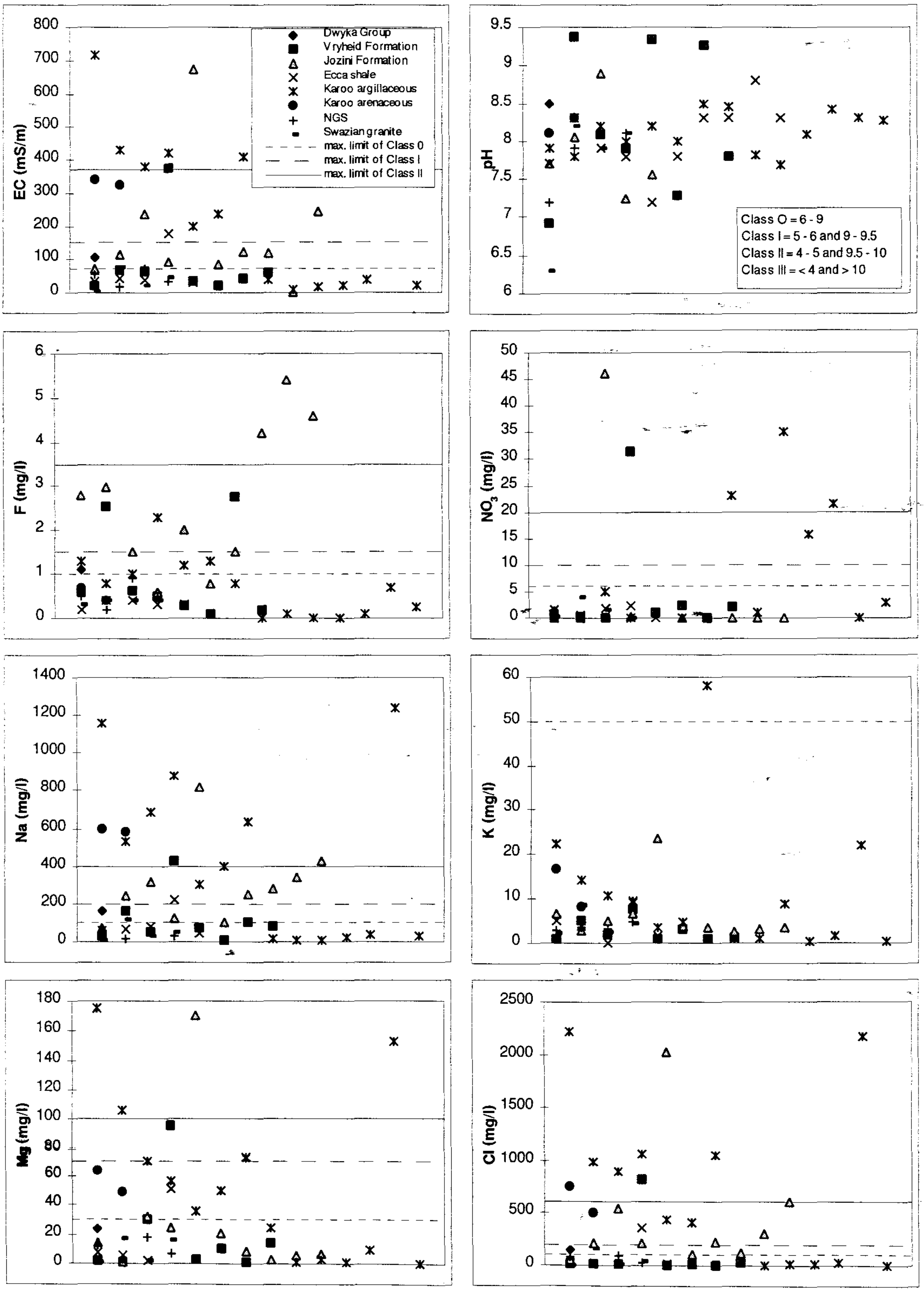


Figure 87. Summary of overall groundwater quality classes at dolerite contacts.

From the graphs in Figure 88, the contacts which are the worst in terms of groundwater quality are those against Karoo argillaceous and arenaceous rocks, the Jozini Formation and some Vryheid Formation. The high overall electrical conductivity at the Karoo argillaceous contact falls within Class II and III. Together with the high nitrate, sodium and chloride levels, this contact consistently yields Class II or III groundwater. The Karoo arenaceous contact is similar to the argillaceous rock contact but most the health related constituents fall within Class II. Table 60 reflects that sodium and chloride contribute to a Class III classification for both argillaceous and arenaceous Karoo rock contacts.

The contact with Ecca shales produces predominantly Class 0 and I groundwater and occasionally Class II and III groundwater where high electrical conductivity, sodium and chloride are concerned. The groundwaters of the Vryheid Formation and dolerite contact are similar in composition to that of the Ecca shale contact (Table 61).

The Dwyka Group tillite contact with dolerite produced groundwater of excellent to good quality with all the constituents in the single sample falling within Class 0 or I (Table 61). The same cannot be said for the dolerite contact with the Jozini Formation rhyolites which although contained a number of Class 0 and I results, had variable concentrations of electrical conductivity, fluoride, nitrate, sodium and chloride (Table 60). The pre-Karoo rocks of the Natal Group and Swazian granites produces good quality water at their contacts with dolerite dykes (Table 62).



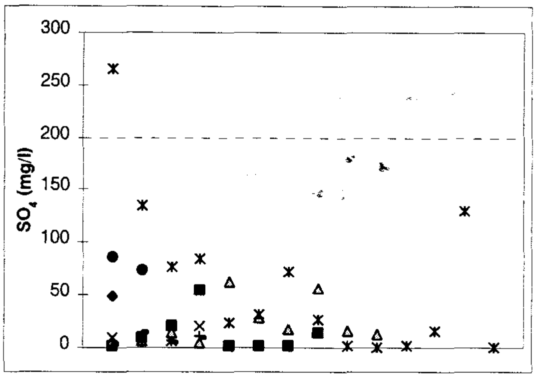


Figure 88. Scatter plots displaying class limits of health related constituents for groundwater quality in dolerite contacts.

Table 60. Statistics of health related chemistry in dolerite contact groundwater. Numbers in parenthesis indicate number of samples.

	CONTACT WITH JOZINI FORMATION (10)			CONTACT WITH KAROO ARGILLACEOUS (14)			CONTACT WITH KAROO ARENACEOUS (2)		
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION
pH	8.0	0	0.4	8.1	0	0.3	8.2	0	0.1
EC (mS/m)	195.7	II	190.3	262.1	II	258.8	333.5	II	13.4
TDS (mg/l)	1205.5	II	991.8	1715.1	II	1709.5	2197.0	II	83.4
Mg (mg/l)	28.7	0	51.0	54.1	I	56.9	56.5	I	10.6
Na (mg/l)	297.1	II	214.7	425.0	III	440.1	587.0	III	9.9
K (mg/l)	6.1	0	6.3	11.3	0	15.4	12.5	0	5.9
Cl (mg/l)	437.2	II	586.4	663.5	III	776.2	621.5	III	177.5
SO_4 (mg/l)	22.5	0	20.8	61.8	0	75.2	80.0	0	8.5
NO_3 (mg/l)	4.8	0	14.5	8.1	I	11.7	0.2	0	0.1
F (mg/l)	2.6	II	1.7	0.7	0	0.7	0.6	0	0.2
OVERALL		II			III			III	

Table 61. Statistics of health related chemistry in dolerite contact groundwater continued. Numbers in parenthesis indicate number of samples.

	CONTACT WITH ECCA SHALE (5)			CONTACT WITH DWYKA GROUP (1)		CONTACT WITH VRYHEID FORMATION (8)		
	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS	MEAN	CLASS	STANDARD DEVIATION
pH	7.9	0	0.6	8.5	0	8.2	0	1.0
EC (mS/m)	64.7	0	63.5	106.0	I	84.9	I	118.6
TDS (mg/l)	564.8	I	564.4	711.0	I	615.9	I	732.7
Mg (mg/l)	13.6	0	21.0	23.0	0	19.7	0	32.4
Na (mg/l)	94.6	0	72.1	164.0	I	116.9	I	132.8
K (mg/l)	3.9	0	3.5	6.0	0	2.7	0	2.4
Cl (mg/l)	86.0	0	151.1	144.0	I	112.1	I	281.7
SO_4 (mg/l)	8.4	0	7.0	49.0	0	13.1	0	18.5
NO_3 (mg/l)	1.3	0	1.0	1.4	0	4.8	0	10.8
F (mg/l)	0.3	0	0.1	1.1	I	1.0	0	1.1
OVERALL		I			I		I	

Table 62. Statistics of health related chemistry in dolerite contacts continued. Numbers in parenthesis indicate number of samples.

	CONTACT WITH NATAL GROUP (4)			CONTACT WITH SWAZIAN GRANITE (4)		
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION
pH	7.8	0	0.4	7.6	0	0.9
EC (mS/m)	43.7	0	23.3	36.9	0	31.2
TDS (mg/l)	310.3	0	156.7	266.8	0	207.8
Mg (mg/l)	10.0	0	6.5	8.9	0	8.8
Na (mg/l)	39.3	0	22.9	51.9	0	46.9
K (mg/l)	3.5	0	0.8	4.4	0	2.9
Cl (mg/l)	49.8	0	41.9	54.0	0	68.4
SO_4 (mg/l)	7.5	0	2.5	7.7	0	4.9
NO_3 (mg/l)	0.3	0	0.1	1.4	0	1.7
F (mg/l)	0.5	0	0.3	0.4	0	0.1
OVERALL		0			0	

9.2.7. Natal Group

The groundwater quality of the Natal Group sandstones is good, with a small percentage of samples falling into Class III (Figure 89). The numerous groundwater samples taken from the fractured Natal Group sandstone make generalisations on the health related quality relatively accurate. Electrical conductivity, as an indicator of poor water, does not appear to be a problem in these groundwaters, although elevated sodium, magnesium and chloride do sometimes result in Class III groundwater (Figure 90). Fluoride, potassium and sulphate are always within Class 0. Nitrate was found to fall into Class I and II on occasion. The mean of all the constituents in fractured Natal Group, except chloride, result in Class 0. The standard deviation of electrical conductivity, total dissolved solids, sodium and chloride are quite high due to the variability of these constituents, while the others have small deviations (Table 63). The groundwaters from featureless targets followed a similar trend to fractured targets but resulted in worse quality. The samples taken from secondary porous aquifers were of Class 0 quality.

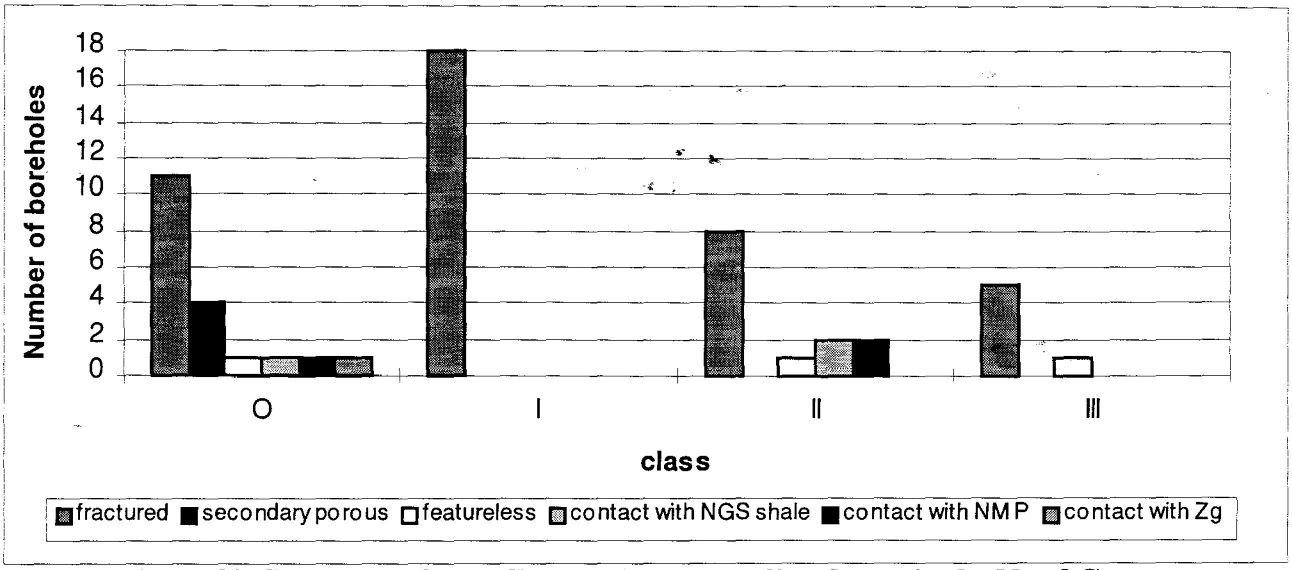
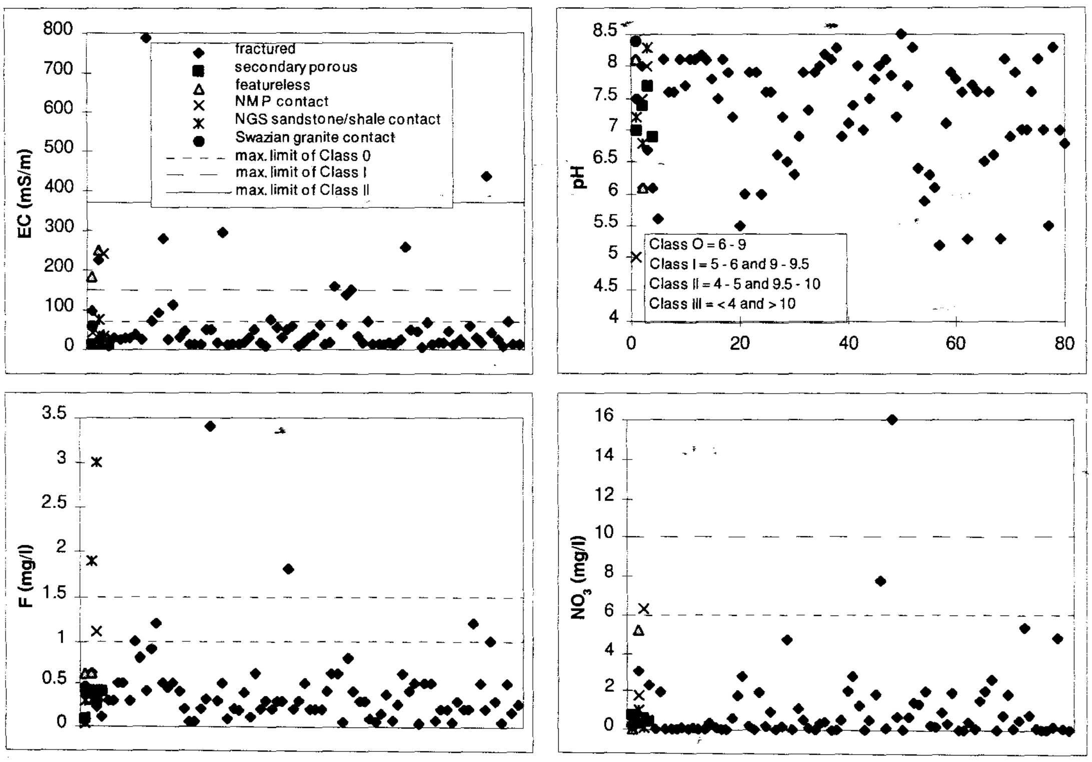


Figure 89. Summary of overall groundwater quality classes in the Natal Group.

The Natal Group sandstone's contact with underlying rocks appears to take on the general chemical composition of that of the fractured Natal Group rock, with the exception of fluoride which may be slightly elevated due to contributions from the acid rocks of the Natal Metamorphic Province and the shales of the Natal Group (Table 64). The quality of the single groundwater sample in contact with the Archaean Swazian granites was excellent.



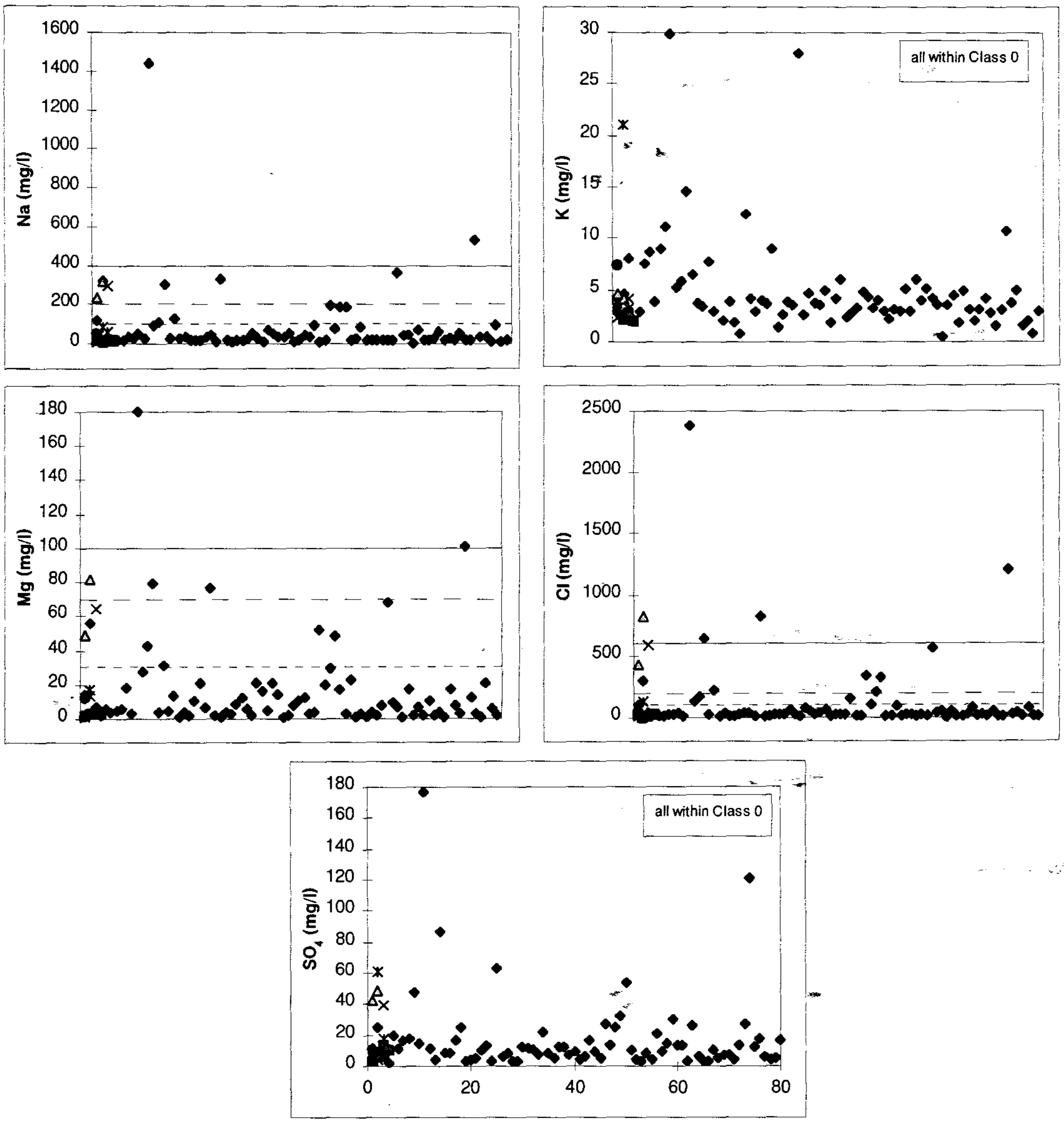


Figure 90. Scatter plots displaying class limits of health related constituents for groundwater quality in Natal Group sandstone targets.

Table 63. Statistics of health related chemistry in Natal Group groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED NATAL GROUP (80)			SECONDARY POROUS NATAL GROUP (4)			FEATURELESS NATAL GROUP (2)		
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION
pH	7.3	0	0.8	7.3	0	0.4	7.1	0	1.4
EC (mS/m)	63.0	0	110.2	15.2	0	6.7	217.0	II	46.7
TDS (mg/l)	422.4	0	695.6	103.8	0	49.3	1243.5	II	256.7
Mg (mg/l)	16.1	0	26.9	3.3	0	1.3	65.5	I	23.3
Na (mg/l)	78.6	0	179.3	15.0	0	4.7	277.5	II	57.3
K (mg/l)	4.9	0	4.7	2.8	0	0.9	4.4	0	0.4
Cl (mg/l)	118.7	I	317.6	15.0	0	8.1	628.0	III	272.9
SO_4 (mg/l)	17.1	0	25.8	8.0	0	4.4	45.5	0	4.9
NO_3 (mg/l)	1.1	0	2.2	0.5	0	0.2	2.6	0	3.6
F (mg/l)	0.4	0	0.5	0.3	0	0.1	0.6	0	0.0
OVERALL		I			0			III	

Table 64. Statistics of health related chemistry in Natal Group groundwater continued. Numbers in parenthesis indicate number of samples.

	NATAL GROUP CONTACT WITH NATAL GROUP SHALE (3)			NATAL GROUP CONTACT WITH NMP (3)			NATAL GROUP CONTACT WITH SWAZIAN GRANITE (1)	
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS
pH	7.4	0	0.8	6.8	0	1.6	8.4	0
EC (mS/m)	40.7	0	32.6	106.0	I	116.0	56.3	0
TDS (mg/l)	281.0	0	209.5	793.7	I	511.1	406.0	0
Mg (mg/l)	7.7	0	8.1	26.0	0	33.5	12.0	0
Na (mg/l)	53.7	0	37.5	113.2	I	160.4	52.0	0
K (mg/l)	9.3	0	10.1	3.1	0	1.0	7.5	0
Cl (mg/l)	50.3	0	69.0	210.7	II	325.3	55.0	0
SO_4 (mg/l)	28.3	0	28.9	15.9	0	20.0	10.0	0
NO_3 (mg/l)	0.6	0	0.5	3.0	0	2.9	0.2	0
F (mg/l)	1.7	II	1.4	0.5	0	0.6	0.4	0
OVERALL		II			II			0

9.2.8. Lebombo Group

9.2.8.1. Jozini Formation

Most of the groundwater samples from the Jozini Formation fall within Class II or Class III. Six of the fractured aquifers' water gave an overall Class 0 or I quality (Figure 91). The main reason for the poor quality is due to high salinity and fluoride levels.

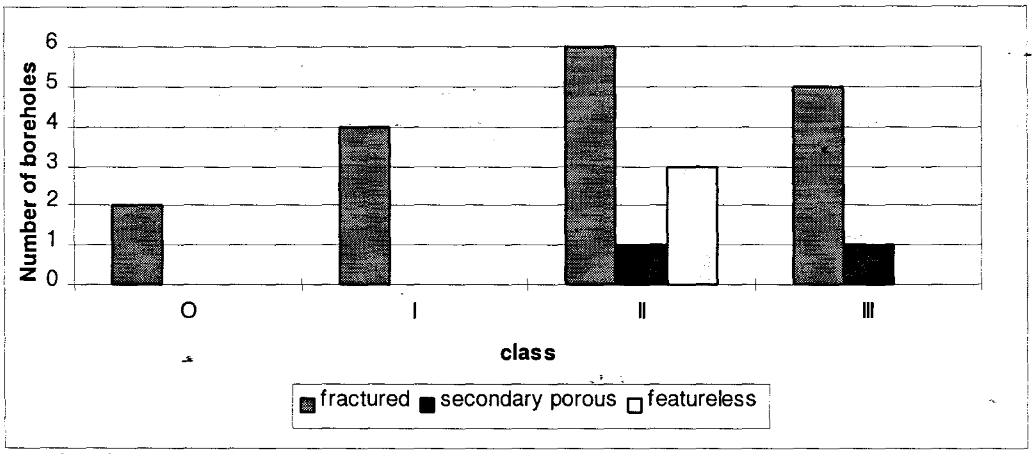
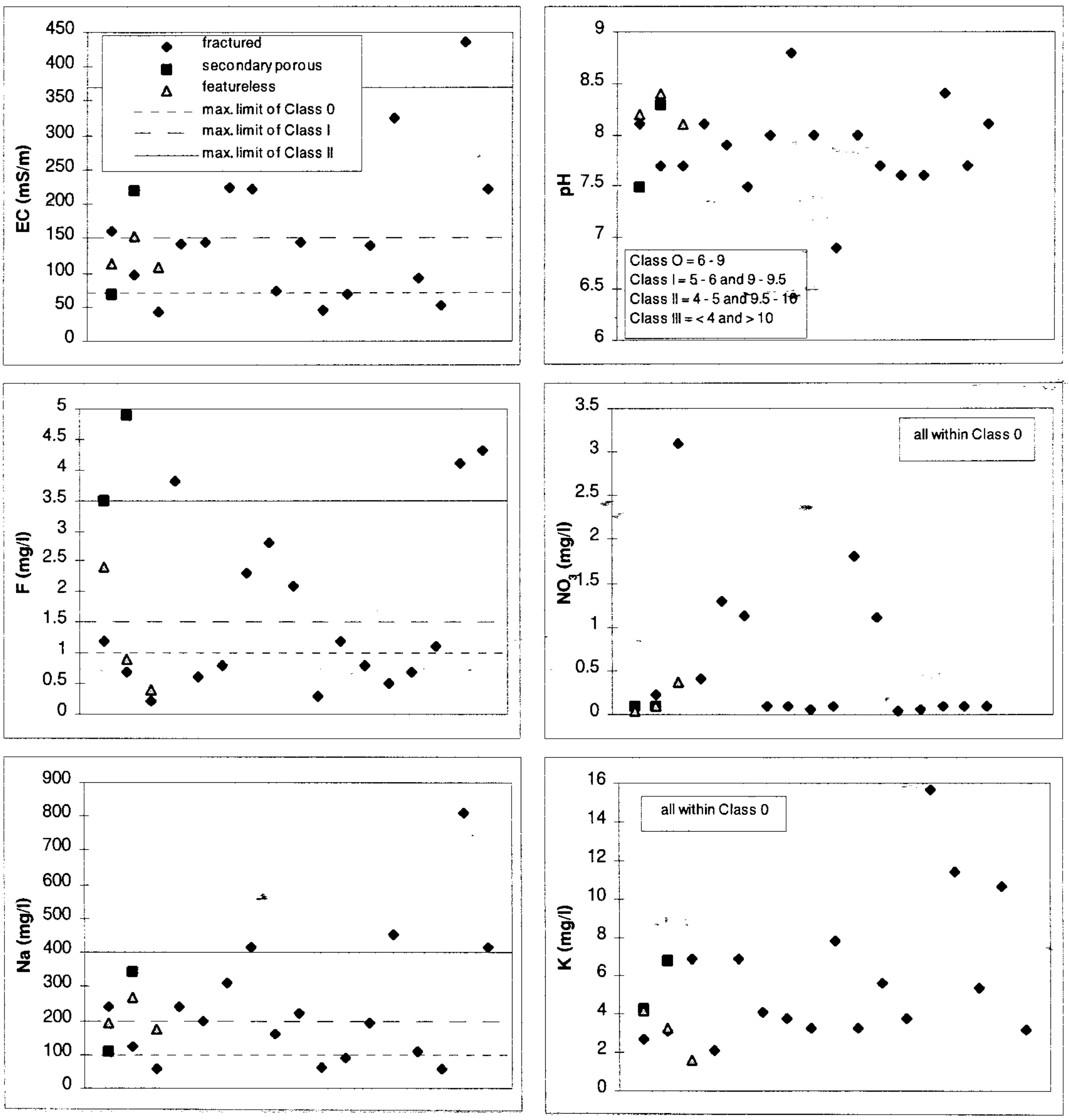


Figure 91. Summary of overall groundwater quality classes in the Jozini Formation.

The fractured and secondary porous targets in the Jozini Formation rhyolites produced similar overall groundwater qualities despite the quality fluctuations which appear to occur in the fractured aquifers. The electrical conductivity of the fractured aquifer was mainly found to fall into Class I or II with a spread of classes resulting from fluoride, sodium, and chloride.

Magnesium was the only constituent not to rise above Class I. The two samples from the secondary porous aquifer were similar to the fractured aquifer samples apart from the fact that the fluoride levels were higher and resulted in Class II and III classification. This is shown in Table 65 where a mean Class III for fluoride puts the secondary porous target into Class III overall, compared to Class II overall for fractured targets. The groundwater produced by featureless or unknown sources within the Jozini Formation was poor due to fluoride, sodium and chloride. These three constituents appear to be the main problem with the groundwater quality of the Jozini Formation (Figure 92 and Table 65).



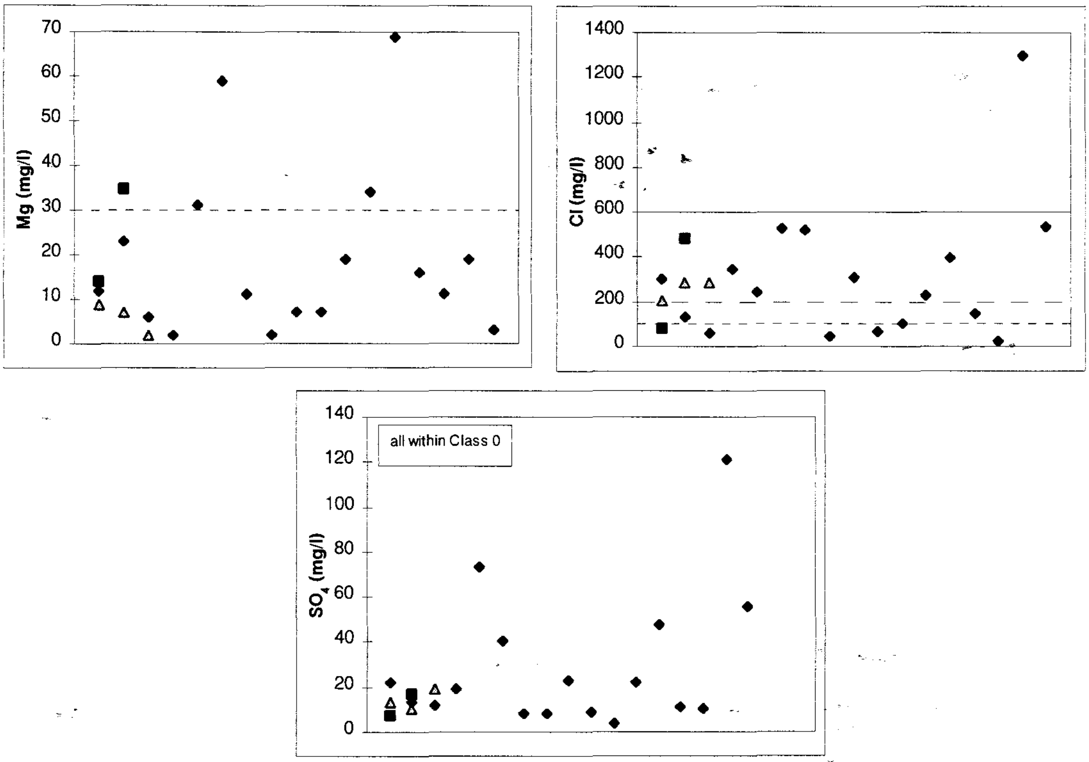


Figure 92. Scatter plots displaying class limits of health related constituents for groundwater quality in Jozini Formation rhyolite.

Table 65. Statistics of health related chemistry in Jozini Formation groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED JOZINI FORMATION (17)			SECONDARY POROUS JOZINI FORMATION (2)			FEATURELESS JOZINI FORMATION (3)		
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION
pH	7.9	0	0.4	7.9	0	0.6	8.2	0	0.2
EC (mS/m)	154.5	II	106.2	143.6	I	105.3	124.8	I	23.7
TDS (mg/l)	935.2	I	567.0	936.5	I	488.6	773.7	I	156.9
Mg (mg/l)	19.5	0	19.3	24.5	0	14.8	6.0	0	3.6
Na (mg/l)	243.9	II	194.0	226.5	II	167.6	212.7	II	50.3
K (mg/l)	5.9	0	3.7	5.6	0	1.8	3.0	0	1.3
Cl (mg/l)	309.6	II	308.5	279.5	II	285.0	258.0	II	44.2
SO_4 (mg/l)	29.4	0	30.6	12.0	0	7.1	14.0	0	4.6
NO_3 (mg/l)	0.6	0	0.9	0.1	0	0.0	0.2	0	0.2
F (mg/l)	1.6	II	1.4	4.2	III	1.0	1.2	I	1.0
OVERALL		II			III			II	

9.2.8.2. Letaba Formation

The majority of the groundwater found within the fractures of the Letaba Formation basalt resulted in an overall Class II quality (Figure 93). This is mainly due to high nitrate, sodium, magnesium and chloride levels. Nitrate, sodium and chloride, and thus electrical conductivity also contributed to occasional Class III results (Figure 94). On the other hand, the groundwater quality in the secondary porous aquifers was better but occasional Class III water did result from higher level of nitrate. Table 66 shows that the fractured target yields Class II water due to elevated salinity and the secondary porous target mostly Class 0, except nitrate which is Class I.

Basalt contacts with underlying Karoo argillaceous rock yielded groundwater of a similar quality to that of fractured basalt. Once again the poorer quality arose from elevated sodium and chloride. The single borehole penetrating a granitic pegmatite vein yielded excellent quality groundwater.

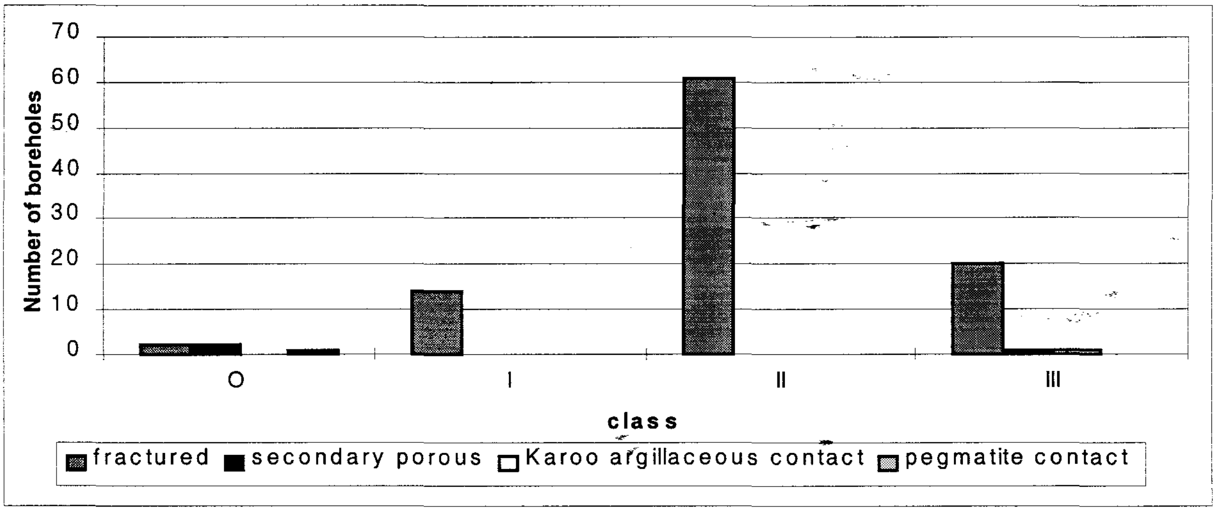
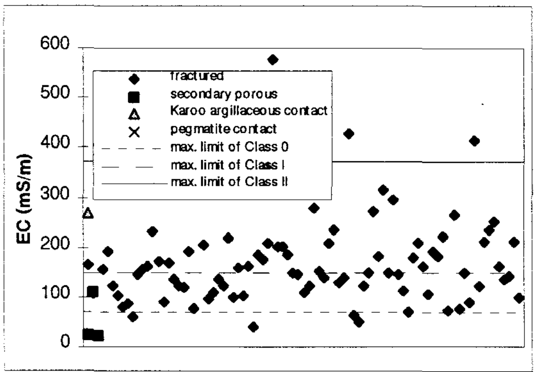
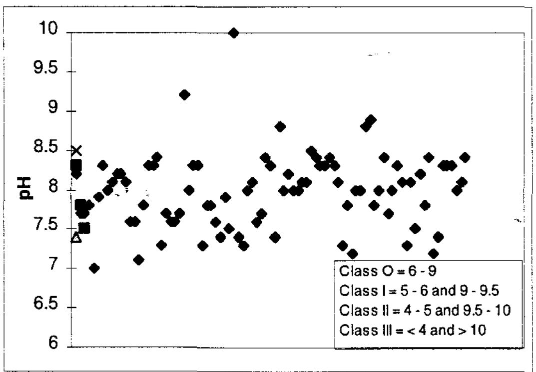


Figure 93. Summary of overall classes in the Letaba Formation.





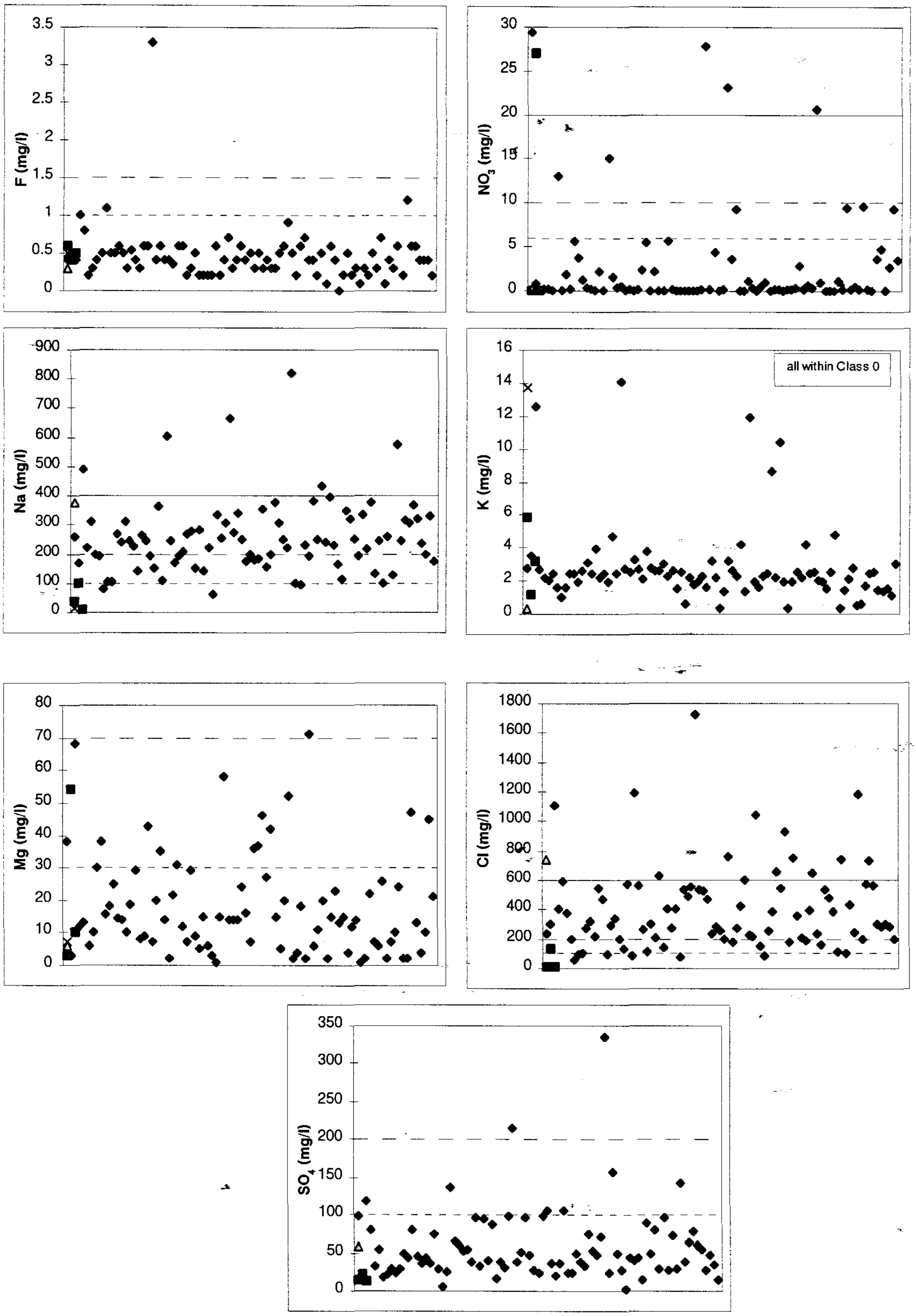


Figure 94. Scatter plots displaying class limits of health related constituents for groundwater quality in Letaba Formation basalt.

Table 66. Statistics of health related chemistry in Letaba Formation groundwater. Numbers in parenthesis indicate number of samples.

	FRACTURED LETABA FORMATION (87)			SECONDARY POROUS LETABA FORMATION (3)			CONTACT WITH KAROO ARGILLACEOUS (1)		CONTACT WITH PEGMATITE (1)	
	MEAN	CLASS	STANDARD DEVIATION	MEAN	CLASS	STANDARD DEVIATION	VALUE	CLASS	VALUE	CLASS
pH	8.0	0	0.5	7.9	0	0.4	7.4	0	8.5	0
EC (mS/m)	170.9	II	89.2	51.1	0	51.9	267.0	II	21.9	0
TDS (mg/l)	1024.1	II	484.8	406.7	0	410.0	1355.0	II	175.0	0
Mg (mg/l)	18.0	0	15.4	22.3	0	27.6	6.0	0	7.0	0
Na (mg/l)	256.6	II	126.1	47.0	0	45.5	377.0	II	16.0	0
K (mg/l)	2.8	0	2.4	3.4	0	2.4	0.3	0	13.7	0
Cl (mg/l)	399.7	II	290.2	51.0	0	69.3	743.0	III	9.0	0
SO_4 (mg/l)	57.8	0	47.1	16.3	0	4.2	58.0	0	13.0	0
NO_3 (mg/l)	2.8	0	5.9	9.0	I	15.6	0.1	0	0.0	0
F (mg/l)	0.5	0	0.4	0.5	0	0.1	0.3	0	0.5	0
OVERALL		II			I			III		0

9.3. Geophysical methods for borehole siting in KwaZulu-Natal

This section evaluates the different types of geophysical methods used for borehole siting in each hydrolithology. As mention previously, the type of geophysics used is primarily a function of what equipment the consultant has available and the results obtained are a function of the aquifer characteristics and of the consultants' expertise in interpreting the geophysical readings.

The different geophysical methods used and the frequency of use is shown in Figure 95. As can be seen in the graph, the electromagnetic method out weighs the other methods with respect to its frequency of use. The reason for this is that it is a very popular method amongst many hydrogeologists and geophysicists, in particular two consultants of the six who use this method extensively were awarded the largest contracts. Magnetics is mostly used as a supporting method for electromagnetics, however not all the consultants used a supporting method to confirm their primary geophysical method. Those records which did not have any account of how the borehole was sited have been classed as having no geophysics (none). Some of the boreholes were sited purely by geological observation and have therefore been classed as such.

This analysis hopes to identify the best geophysical methods to use for the various hydrogeological targets within each hydrolithology. The graphs which follow have been used to reflect the relative performance of each method against the others in order to gain some idea of the success of each method. Graphs have only been included where there is more than one borehole drilled into a target feature. In some cases, too few boreholes were sited using a particular technique to allow any meaningful comment on the method's applicability. Only the primary geophysical method has been included in the analysis for the sake of consistency.

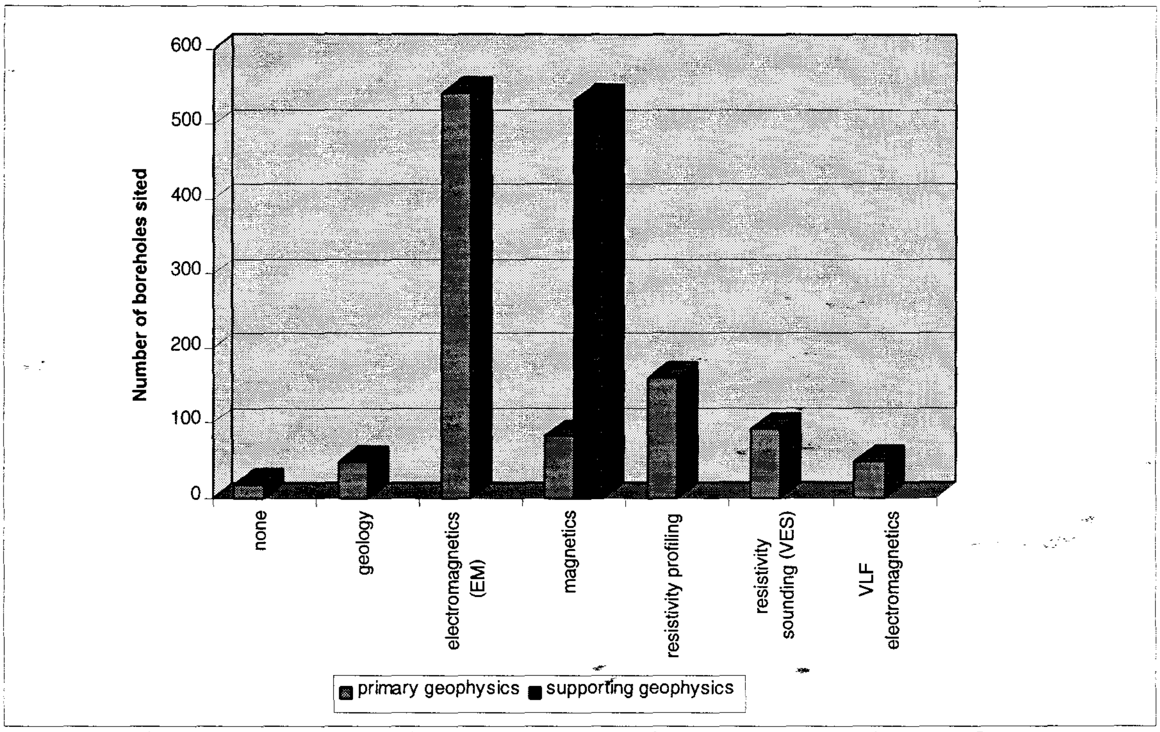


Figure 95. Number of boreholes sited with each geophysical method.

9.3.1. Karoo argillaceous rock

The majority of boreholes sited in Karoo argillaceous rock relied on the electromagnetic method or more specifically, EM-34 (Figure 96). Too few boreholes were sited by other techniques, and therefore a comparison of the methods is not possible. It suffices to say that just under half of the boreholes drilled were dry, which suggests that the electromagnetic (EM) method might not be the ideal method to use. Unfortunately, electrical resistivity methods were not used on the argillaceous Karoo rocks, thereby eliminating the opportunity to compare results with the EM method.

Since EM was the only geophysical technique, apart from one borehole sited by magnetics, used in fractured Karoo arenaceous rock, no comment can be made on whether it is a suitable siting technique (Figure 97).

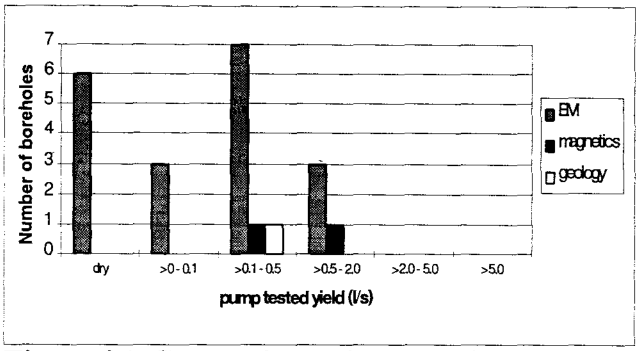


Figure 96. Comparison of geophysical methods per yield range for fractured Karoo argillaceous rock.

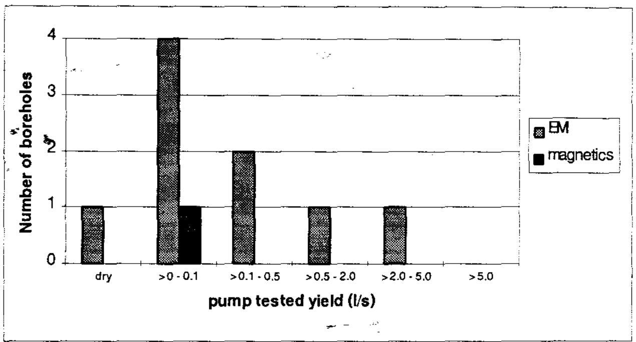


Figure 97. Comparison of geophysical methods per yield range for fractured Karoo arenaceous rock.

No conclusive results can be obtained from the two boreholes sited in the secondary porous arenaceous Karoo rocks (Figure 98). However, it is probable that the EM method would be able to successfully locate the rarely occurring weathered zones in the rocks.

From the results of the two geophysical methods used to site boreholes at the contact between Karoo argillaceous and arenaceous rock, EM appears to have the most success, excluding the dry boreholes which are a function of the aquifer characteristics (Figure 99). The majority of the successful boreholes fall within the 0.5 - 2.0 l/s range compared to the magnetic method which mostly resulted in dry boreholes.

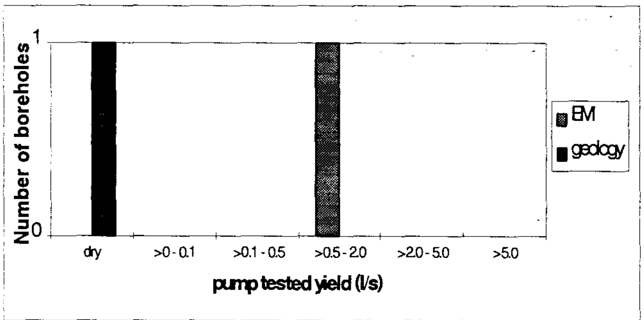


Figure 98. Comparison of geophysical methods per yield range for secondary porous Karoo arenaceous rock.

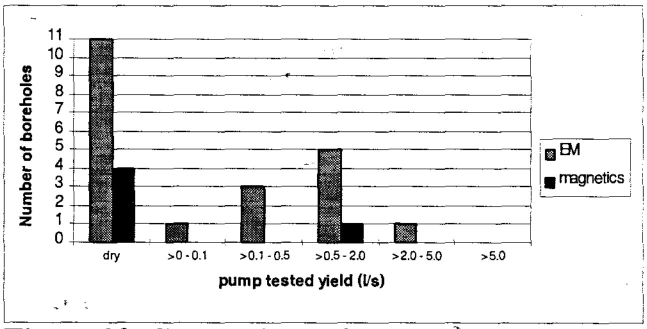


Figure 99. Comparison of geophysical methods per yield range for the Karoo arenaceous contact with Karoo argillaceous rock.

The few boreholes intersecting fractured Ecca shale were mostly sited with the vertical electrical sounding resistivity method (Figure 100). EM, magnetic and VLF methods also were successful. However, it is proposed that due to the nature of the water-bearing zones in the shales that vertical electrical sounding (VES) and EM would give the better results over a larger number of samples.

As was the case for the fractured Ecca shale targets, VES was used more than the other methods for the contact between the Ecca shale (Volksrust Formation) and the Vryheid Formation. The contact was also located by EM, magnetics and resistivity profiling (Figure 101). However, due to these other methods only having one record per yield range, no comparisons can be made with VES. It could therefore be said that any of the geophysical methods capable of locating the contact by identifying the difference between argillaceous and arenaceous rock may be used. In this respect, the electrical resistivity methods would probably give the best results.

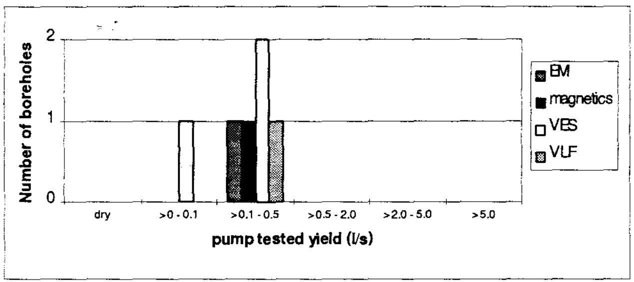


Figure 100. Comparison of geophysical methods per yield range for fractured Ecca shale.

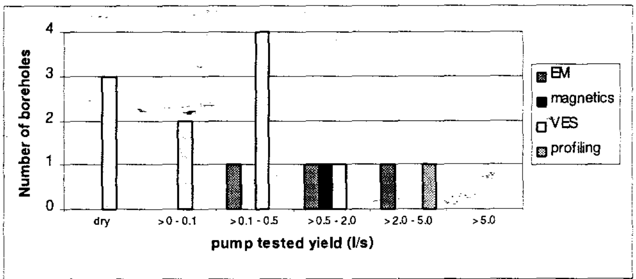


Figure 101. Comparison of geophysical methods per yield range for the Ecca shale contact with the Vryheid Formation.

9.3.2. Vryheid Formation

Once again, EM dominates the geophysical methods used to locate fractures. Figure 102 shows that the majority of the boreholes yielded between 0.1 - 2.0 l/s, however VES resulted in higher rates of high yielding boreholes. The magnetic method was also used with some success where bigger faults with associated breccia and displacement occur. Three high yielding boreholes were also sited by geological observation.

The boreholes intersecting secondary porous aquifers within the Vryheid Formation were mostly located by EM (Figure 103). As this target is not a good aquifer in terms of yield, the results of geophysics will not be discussed further. Only two methods were used to site the poor water-bearing contact between the Vryheid Formation and Ecca shale, namely EM and

VES. Of the two methods, VES did not produce any successful boreholes. This graph is very similar to that of the secondary porous target (Figure 104).

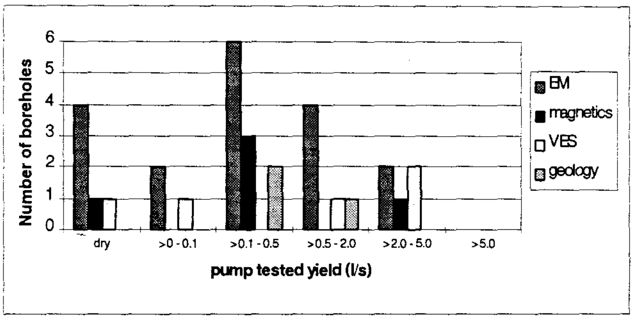


Figure 102. Comparison of geophysical methods per yield range for fractured Vryheid Formation.

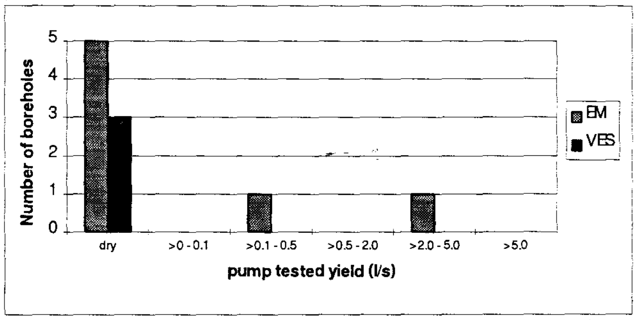


Figure 103. Comparison of geophysical methods per yield range for secondary porous Vryheid Formation.

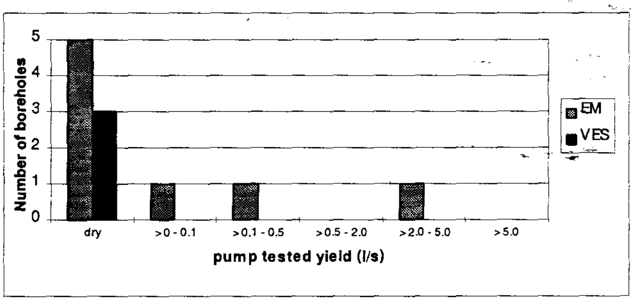


Figure 104. Comparison of geophysical methods per yield range for Vryheid Formation contact with Ecca shale.

9.3.3. Natal Metamorphic Province

All the different lithologies encountered in the Natal Metamorphic Province are considered separately for the geophysical analysis, as was the case for the water quality analysis. The boreholes drilled into fractured amphibolite were mostly sited by the resistivity profiling method, with the majority of the successful boreholes falling within the 0.1 - 0.5 l/s yield range (Figure 105). This is somewhat better than yields achieved by the VLF method, which yielded most of its successful boreholes in the > 0 - 0.1 l/ range. EM was only used on one occasion.

Fracturing in diorite was located mainly by VES which had its highest rate of success in the lowest yield range (Figure 106). The single EM record is not sufficient for comparison purposes.

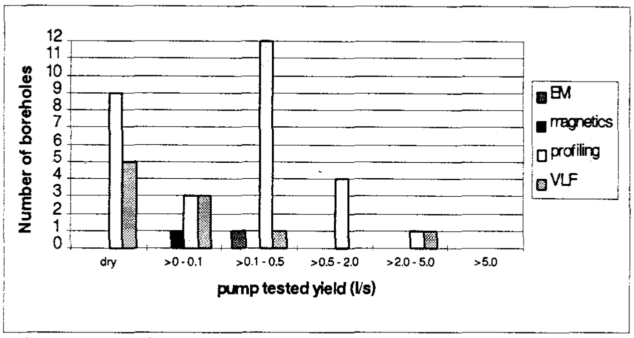


Figure 105. Comparison of geophysical methods per yield range for fractured amphibolite.

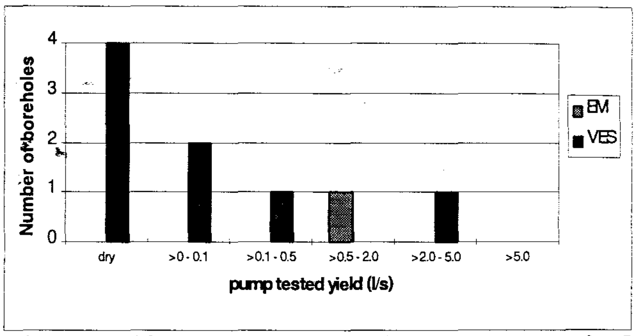


Figure 106. Comparison of geophysical methods per yield range for fractured diorite.

Fractured migmatite was located by profiling and VLF. Of the two methods, Figure 107 shows that the VLF method was not successful on its only attempt. In fractured schist, the resistivity profiling method was used most frequently, with most of the borehole yields ranging between 0.1 - 0.5 l/s (Figure 108). Magnetics and VLF cannot be discounted because they also produced successful boreholes.

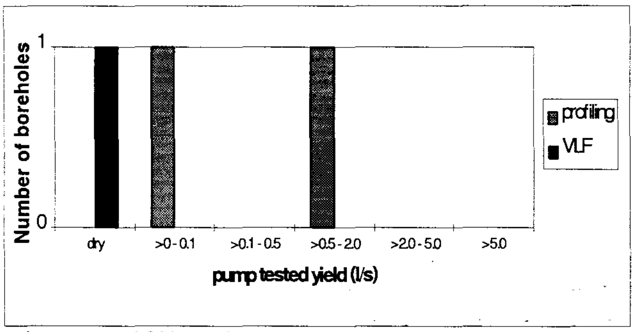


Figure 107. Comparison of geophysical methods per yield range for fractured migmatite.

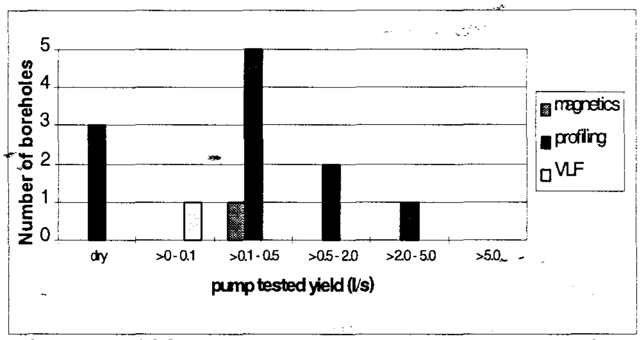


Figure 108. Comparison of geophysical methods per yield range for fractured schist.

The resistivity profiling method used in fractured gneiss had a good success rate in the 0.5 - 2 l/s yield range as shown in Figure 109. This method appears to be superior to magnetics, VLF and VES because of it's ability in locating laterally contrasting resistivities at fracture zones. Locating secondary porous gneiss aquifers also appears to be successful with both the profiling and VES resistivity methods (Figure 110), however, too few records were available to be more conclusive.

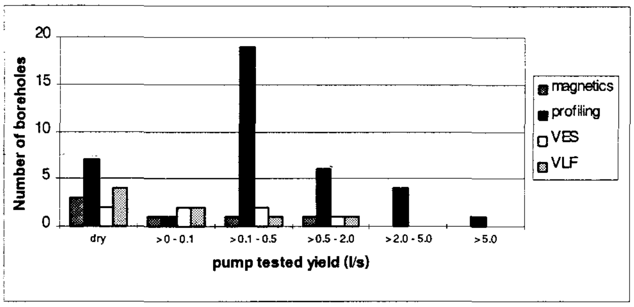


Figure 109. Comparison of geophysical methods per yield range for fractured gneiss.

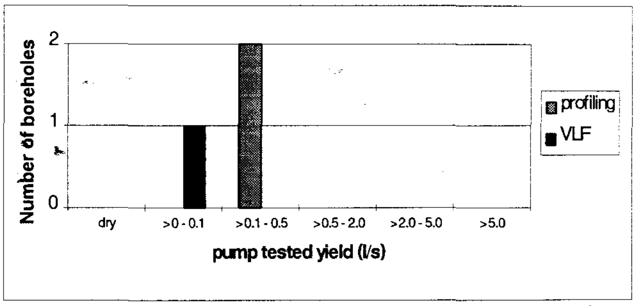


Figure 110. Comparison of geophysical methods per yield range for secondary porous gneiss.

EM and VES were used for the majority of boreholes sited in fractured granite (Figure 111). The EM method resulted in most of its boreholes falling within the > 0 - 0.1 l/s yield range, while the VES method had an even spread between > 0 - 5.0 l/s. As in fractured gneiss, the resistivity profiling method sited most its successful boreholes within the yield range of 0.5 - 2.0 l/s. It is the resistivity profiling and EM methods which therefore appear the best in the fractures of the Natal Metamorphic Province granites.

The few boreholes drilled into secondary porous granite were sited by three methods (Figure 112). If a straight comparison of the geophysical methods is made, VES would appear to be the best method because both boreholes sited by this method were successful in the 0.5 - 2.0 l/s yield range, whereas the other methods' boreholes are spread between > 0 - 2.0 l/s. VES should be considered the better method because it can successfully determine vertical depths, and especially depths of weathering.

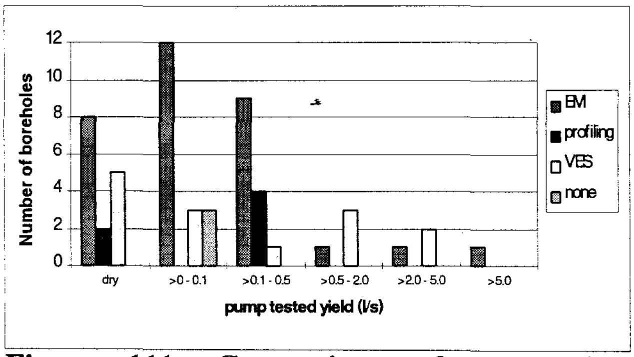


Figure 111. Comparison of geophysical methods per yield range for fractured granite.

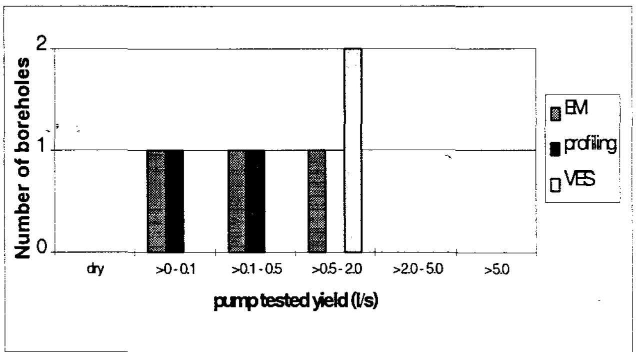


Figure 112. Comparison of geophysical methods per yield range for secondary porous granite.

The graph showing the use of EM in siting eleven boreholes in granite which had no discernible hydrogeological features in the drilling log is important because it shows that the EM method located anomalies which are not associated with any water-bearing features or else the anomalies were spurious (Figure 113).

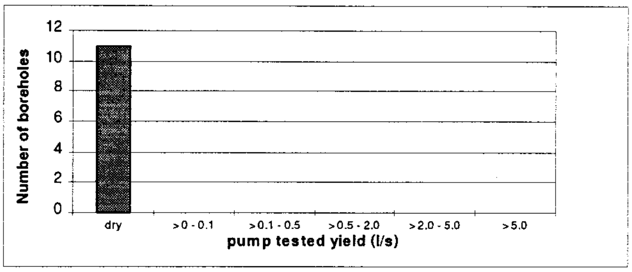


Figure 113. Distribution of yield ranges for the EM-34 method in featureless granite.

In general, the fractured lithologies of the Natal Metamorphic Province are best sited by means of profiling, or by the EM method as a second choice. The secondary porous aquifers within the crystalline rocks appear to best located by either VES or profiling.

9.3.4. Quaternary sediments

The thick cover of unconsolidated sands, comprising the Quaternary sediments of the Maputaland Group, makes the use of geophysics for borehole siting highly problematic in this hydrolithology. EM was used for the siting of three of the boreholes drilled into the Maputaland Group, with the probable aim of detecting saturated, coarser-grained deposits within the fine-grained mass. The reasoning for the use of magnetics for the siting of one borehole is unknown.

The location of near surface palaeochannels (Figure 114) by geological observation was undertaken by tracing subtle surface depressions from an existing river channel (pers. comm. Retief, 1996). This method therefore does away with the need for exploration boreholes to locate coarse-grained deposits, but will not always be as successful.

In the fine sands which comprise the majority of the Maputaland Group, siting by geological and topographic observations was relatively successful (Figure 115). Random siting will probably yield similar results with slightly lower yields than those sited geologically due to the fact that the fine sands have abundant water, but limited permeability. This will mean that the sands will produce wet boreholes but that the yield may be low. Those boreholes sited with some technical observations should therefore have the added advantage of increasing the likelihood of intercepting groundwater based on observations, such as vegetation lines and surface topography.

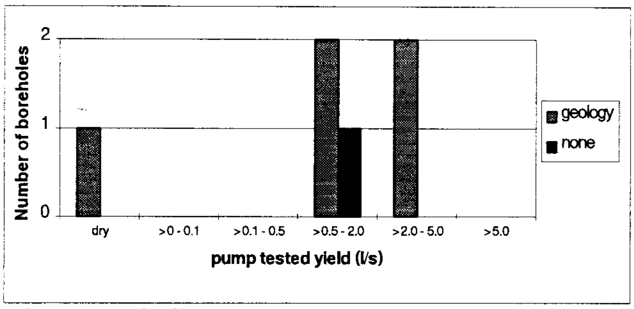


Figure 114. Comparisons of siting methods per yield range for palaeochannels.

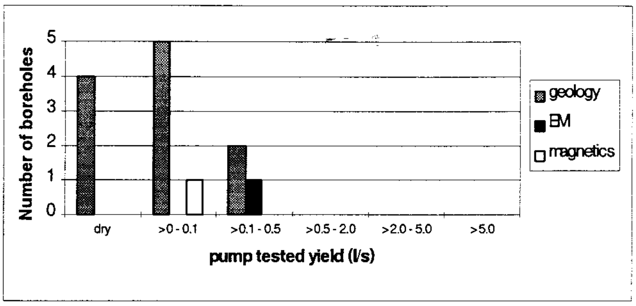


Figure 115. Comparisons of siting methods per yield range for palaeochannels.

It is possible that a shallow depth of unconsolidated sands above the siltstones of the Zululand Group may be penetrated by EM, as reflected in Figure 116. If this is the case, the EM method could be used to detect the contact, however the Zululand Group should not be penetrated more than 1 m during drilling due to it's poor groundwater quality. VES could also be utilised to detect the contact by measuring the resistivity difference between the sands and the siltstone. Geological maps can be used to estimate the depth to the contact in other instances.

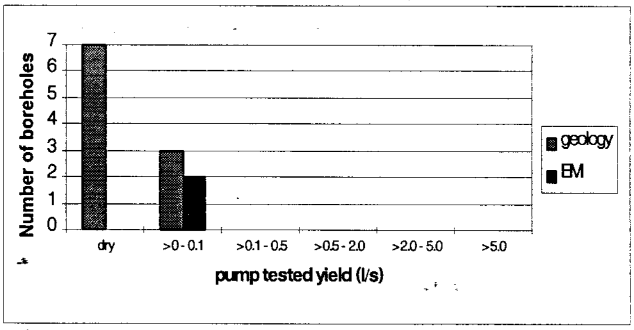


Figure 116. Comparisons of siting methods per yield range for Maputaland Group sand contact with Zululand Group.

9.3.5. Dwyka Group

The low success rate of boreholes in the Dwyka Group during the drought relief programme caused some consternation amongst the consultants. It is hoped that the results of these analyses will highlight the reason for the high failure rate encountered during development of these aquifers. The graph in Figure 117 shows that fractures were mainly located by means of EM. Upon examination of the graph, the method of VLF, even though used less, appears to have been the more successful method. The majority of the VLF sited boreholes yielded more than 0.1 l/s, whilst the EM method resulted in borehole yields on the lower end of the yield ranges. The large number of unsuccessful boreholes, identified by EM which were drilled into featureless rock further illustrates the poor performance of EM in Dwyka Group tillite (Figure 118). The VES method in fractures also did not perform well. It must be acknowledged that the Dwyka Group is a difficult rock in which to find groundwater, even though a potential water-bearing feature may be located.

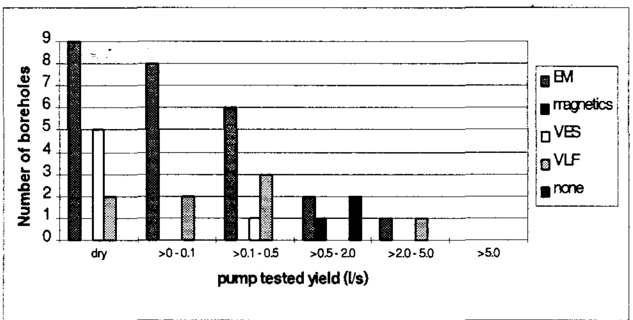


Figure 117. Comparison of geophysical methods per yield range for fractured Dwyka tillite.

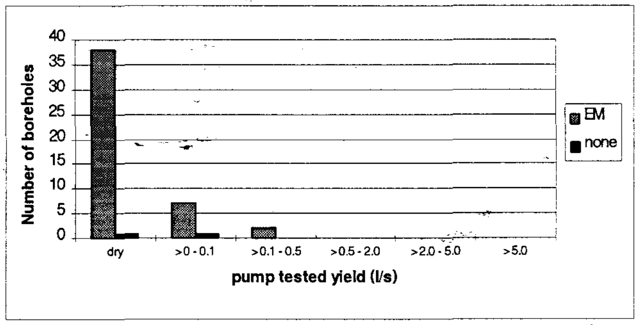


Figure 118. Comparison of geophysical methods per yield range for featureless Dwyka tillite.

The contacts of the Dwyka Group with underlying rocks have poor geophysical data since the successful boreholes intersecting the Natal Group contact total four and only two boreholes reached the contact with the Natal Metamorphic Province (Figure 119 and Figure 120). These contacts have proved to yield little groundwater and therefore should be avoided unless the overlying Dwyka Group tillite is sufficiently fractured to allow water to percolate down to the contact. The lithological change to shale within the Dwyka Group appears to have been located by both the EM and profiling resistivity methods with some success (Figure 121).

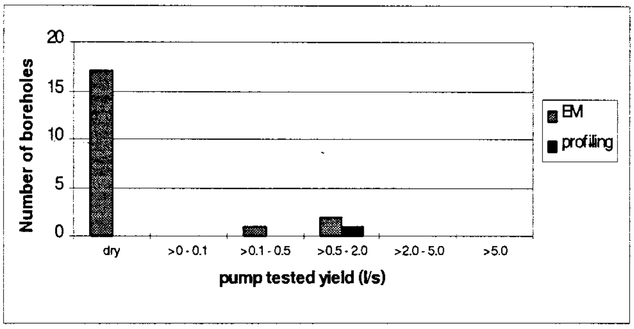


Figure 119. Comparison of geophysical methods per yield range for the Dwyka tillite contact with Natal Group sandstone.

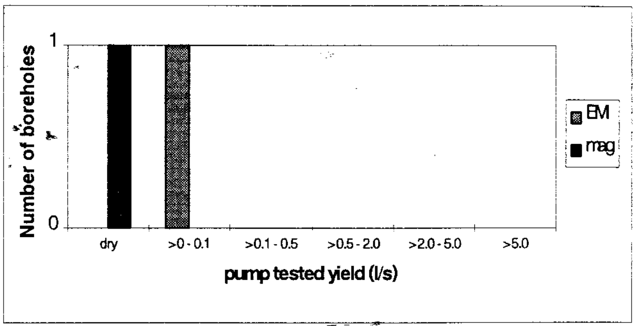


Figure 120. Comparison of geophysical methods per yield range for the Dwyka tillite contact with Natal Metamorphic Province.

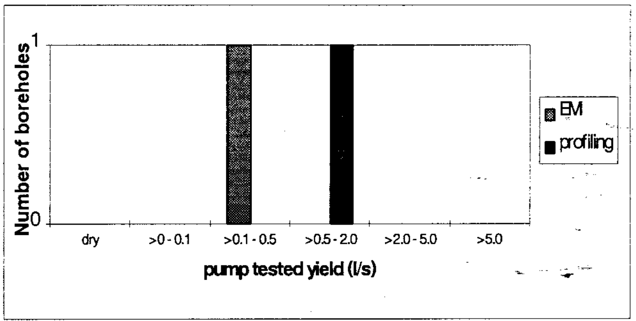


Figure 121. Comparison of geophysical methods per yield range for the Dwyka tillite contact with Dwyka shale.

9.3.6. Dolerite

Fractured dolerite was most successfully located by EM, with the VES resistivity method also yielding reliable results (Figure 122). Both EM and VES produced the majority of their successful borehole yields in the 0.1 - 0.5 l/s range. The magnetic and VLF methods were only used a few times, but they also seem to have produced some good results. Resistivity profiling appears to have fared worst of all the geophysical methods. The reason for the low success rate of resistivity profiling is probably due to a lack of resistivity contrast in the dolerite either side of the fractures.

VES, EM and magnetics were used with some success in locating boreholes within the secondary porous material of dolerite (Figure 123). However, the small number of records does not allow for comparisons to be made.

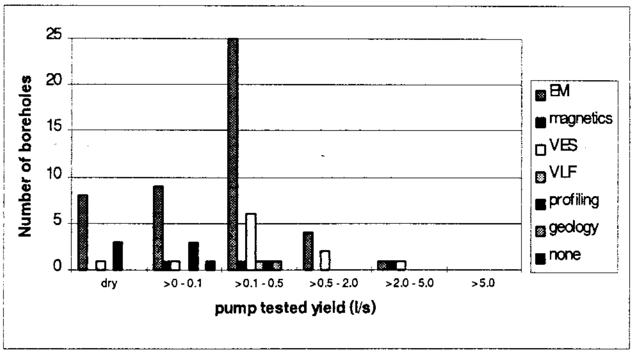


Figure 122. Comparison of geophysical methods per yield range for fractured dolerite.

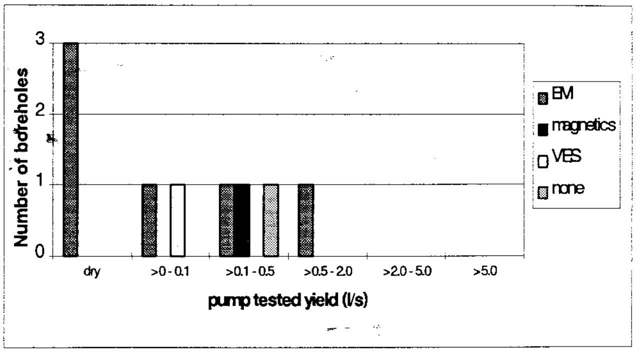


Figure 123. Comparison of geophysical methods per yield range for secondary porous dolerite.

Once again, EM produced some anomalies in featureless dolerite (Figure 124). On one occasion each, magnetics and VES did likewise. The reason for the geophysics registering an anomaly is uncertain. The poor water-bearing contact dolerite has with the Dwyka Group was only detected by EM during the drought relief programme (Figure 125). As no other method was used, it is not possible to evaluate a better method.

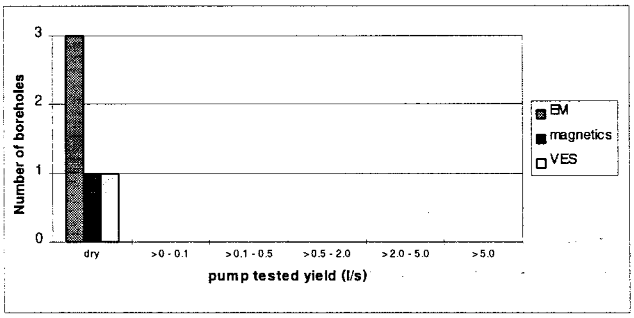


Figure 124. Comparison of geophysical methods per yield range for featureless dolerite.

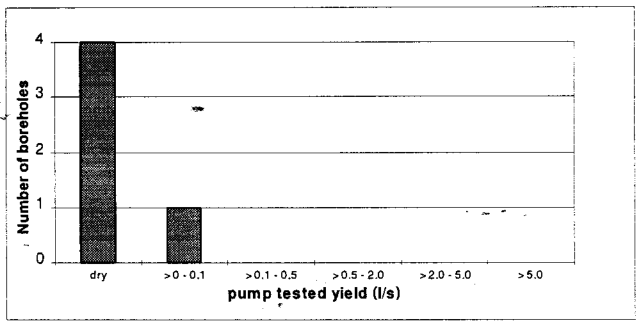


Figure 125. Distribution of yield ranges for the EM-34 method at dolerite's contact with Dwyka tillite.

Figure 126 shows that the eight successful boreholes drilled through the dolerite contact with the Vryheid Formation produced yields in the range 0.1 - 0.5 l/s by the siting methods of EM and geological observation. The highest yield was obtained from a borehole sited by the VES resistivity method.

Only two geophysical methods were used to site boreholes at the dolerite and Ecca shale contact (Figure 127). Of the two methods, VLF did not have any success and VES produced four boreholes within the 0.1 - 0.5 l/s range.

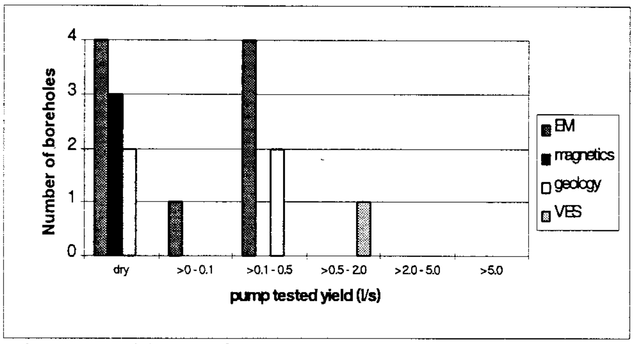


Figure 126. Comparison of geophysical methods per yield range for dolerite's contact with Vryheid Formation.

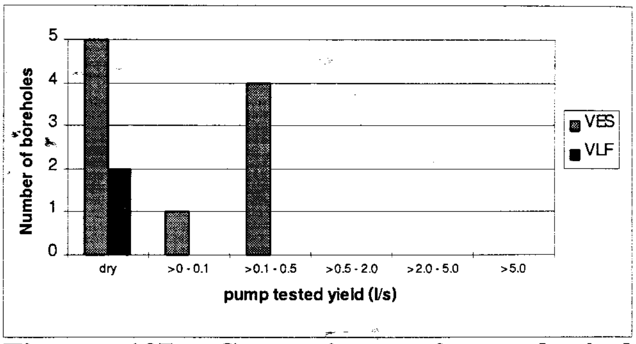


Figure 127. Comparison of geophysical methods per yield range for dolerite's contact with Ecca shale.

The magnetic method was used more frequently than the other geophysical methods in locating the contact between dolerite dykes and Jozini Formation rhyolite. Figure 128 shows, however, that the majority of the boreholes sited by this method fall within the lowest yield range. It must be kept in mind that even though the contact was located successfully, the poor water-bearing character of this contact resulted in a large number of dry boreholes. The other methods of EM and VLF had erratic results which were too few for comparison with the magnetic method.

The contact aquifer between dolerite and Karoo argillaceous rock was located only by means of EM (Figure 129) and therefore no comment on its relative performance as a siting technique can be made.

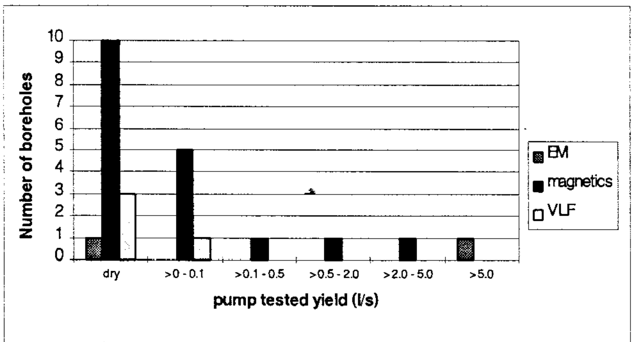


Figure 128. Comparison of geophysical methods per yield range for dolerite's contact with Jozini rhyolite.

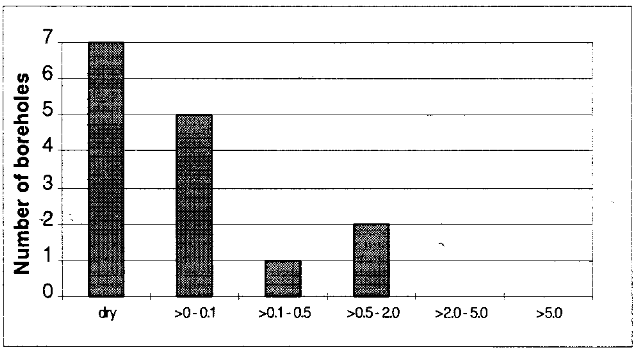


Figure 129. Distribution of yield ranges for the EM-34 method at dolerite's contact with Karoo argillaceous rocks.

The two methods of EM and magnetics utilised in siting the contact between dolerite and Karoo arenaceous rock were both similarly successful as shown in Figure 130. Even without any records from other methods, it can be stated that either of these two methods would be effective for siting dolerite contacts within Karoo arenaceous rock. As profiling was the only method of borehole siting on the contact of dolerite with Natal Group sandstone no comparison can be made with other methods Figure 131.

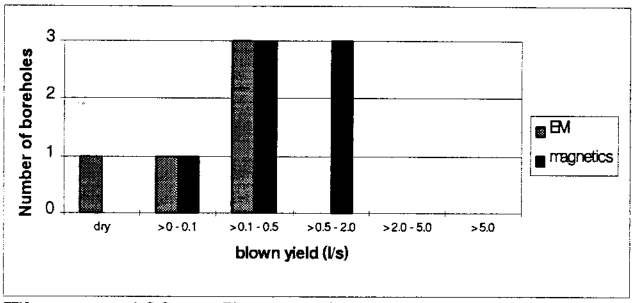


Figure 130. Comparison of geophysical methods per yield range for dolerite's contact with Karoo arenaceous rocks.

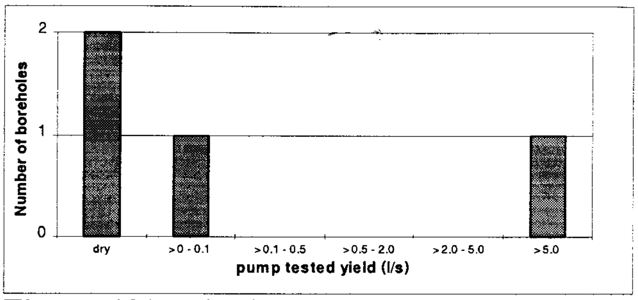


Figure 131. Distribution of yield ranges for resistivity profiling at dolerite's contact with Natal Group sandstone.

The four boreholes drilled into the contact between dolerite dykes and the Swazian granites were mainly sited by the EM method, with only one sited by VLF (Figure 132). Comparisons between the two methods are not worthwhile because of the small number of boreholes involved.

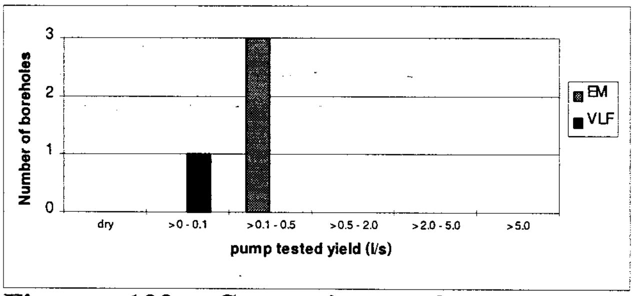


Figure 132. Comparison of geophysical methods per yield range for dolerite's contact with Swazian granite.

9.3.7. Natal Group

A good range of geophysical methods were used to detect fractures in Natal Group sandstone, allowing useful comparisons to be made between the methods (Figure 133). Approximately, an equal number of boreholes were sited by the EM and resistivity profiling methods. Of the two methods, resistivity profiling produced a greater percentage of the higher yielding boreholes than EM. VES also had reasonable success, with the majority of its boreholes yielding between 0.5 - 2 l/s (Figure 133).

The EM method was once again the primary method of geophysical siting in secondary porous Natal Group sandstone (Figure 134). The small number of records limits the amount of comparisons to be made.

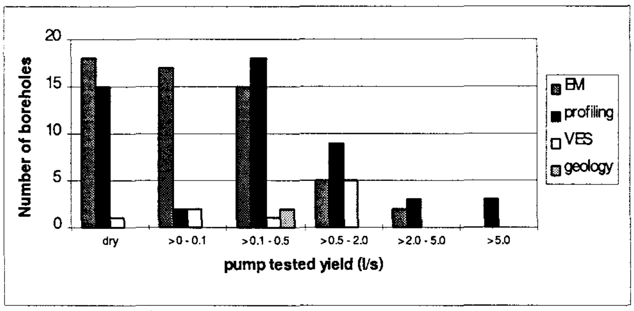


Figure 133. Comparison of geophysical methods per yield range for fractured Natal Group sandstone.

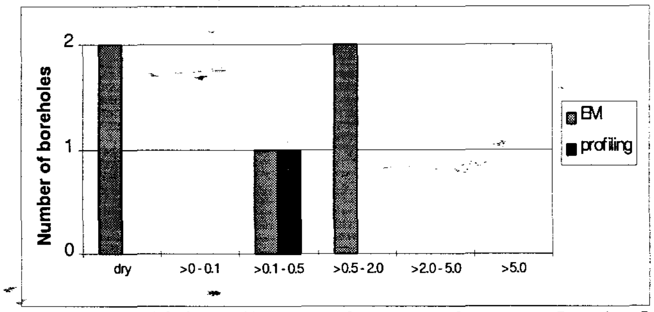


Figure 134. Comparison of geophysical methods per yield range for secondary porous Natal Group sandstone.

EM produced eight dry boreholes as a result of false anomalies being recorded compared to the two produced by the resistivity profiling method (Figure 135). Those wet boreholes in the Natal Group sandstone classed as featureless are probably a result of seepage or incomplete geological logging of the borehole.

The Natal Group's unconformable contact with the underlying Natal Metamorphic Province was only intersected three times and each intersection was located by a different geophysical method (Figure 136). This does not provide enough data from which to compare the techniques. EM was the sole geophysical method used to site the three boreholes at the lithological change in the Natal Group from sandstone to a shaley material (Figure 137).

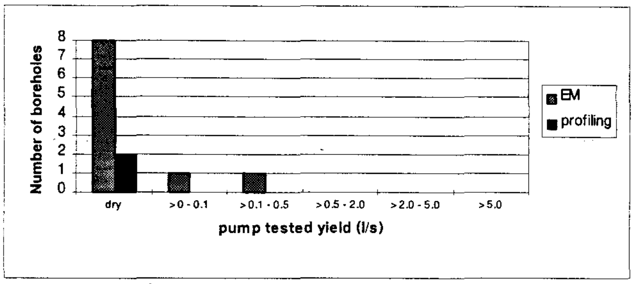


Figure 135. Comparison of geophysical methods per yield range for featureless Natal Group sandstone.

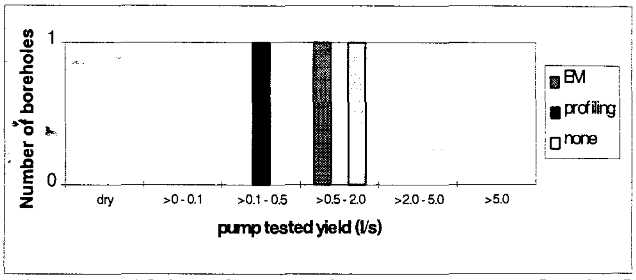


Figure 136. Comparison of geophysical methods per yield range for Natal Group sandstone contact with Natal Metamorphic Province.

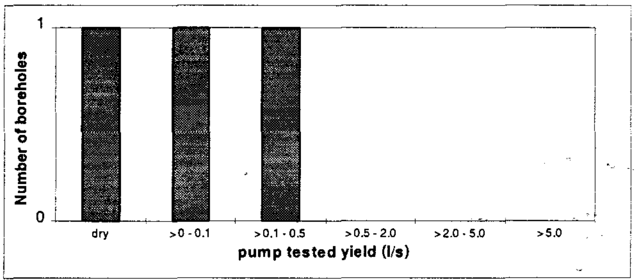


Figure 137. Distribution of yield ranges for the EM-34 method at Natal Group sandstone's contact with Natal Group shale.

9.3.8. Lebombo Group

9.3.8.1. Jozini Formation

Both the magnetic and EM methods were used successfully to site boreholes in fractured Jozini Formation rhyolite. Figure 138 shows that magnetics was used more frequently than EM and that geological observations resulted in all three boreholes being successful.

The three boreholes representing secondary porous aquifers in Jozini Formation rhyolite were sited by EM and magnetic methods (Figure 139). Too few records are therefore available for comparative purposes.

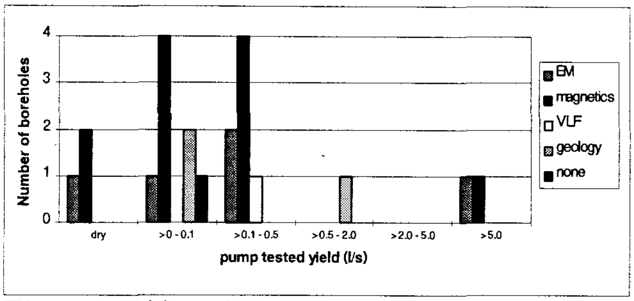


Figure 138. Comparison of geophysical methods per yield range for fractured Jozini rhyolite.

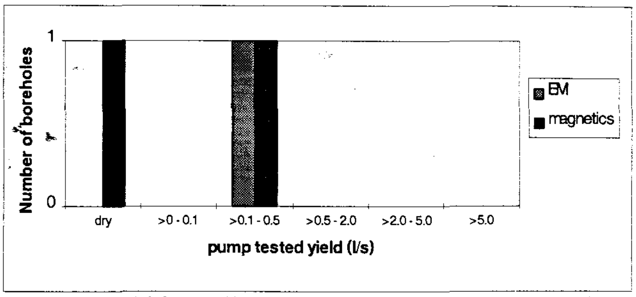


Figure 139. Comparison of geophysical methods per yield range for secondary porous Jozini rhyolite.

The EM method once again resulted in the greatest number of dry boreholes in featureless rhyolite (Figure 140). Magnetics resulted in a minor number of dry boreholes within featureless rhyolite and three which did yield some groundwater.

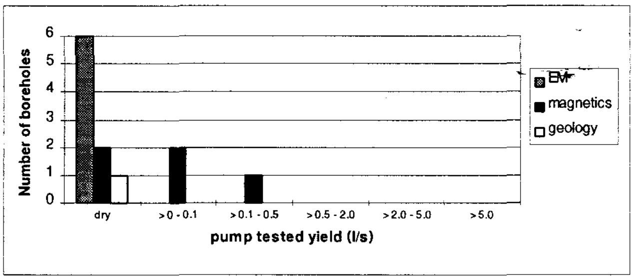


Figure 140. Comparison of geophysical methods per yield range for featureless Jozini rhyolite.

9.3.8.2. Letaba Formation

The principal geophysical method utilised in locating fractured basalt of the Letaba Formation was EM (Figure 141). The majority of the successful boreholes yielded between > 0 - 0.5 l/s, with a minimal number of dry boreholes. The few magnetically sited boreholes followed the same trend but were much few in number.

A number of other targets in the basalt were located with EM. A comparison of the yields obtained from each target is made in Figure 142 where EM was the only geophysical method used. The graph shows that EM was fairly successful in secondary porous basalt, at the contact with underlying Karoo argillaceous rock and in locating a pegmatite vein.

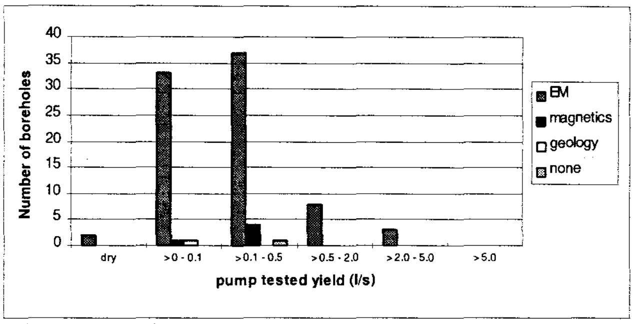


Figure 141. Comparison of geophysical methods per yield range for fractured Letaba Formation basalt.

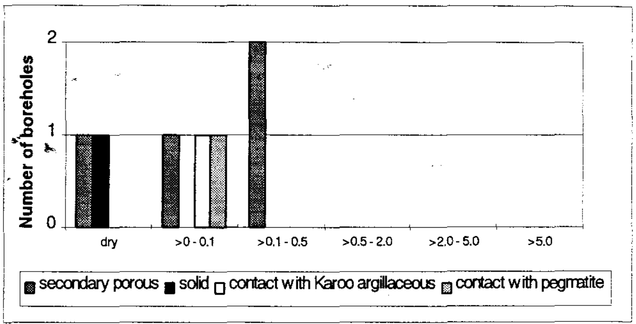


Figure 142. Comparisons of the use of EM-34 per yield range for various targets within the Letaba Formation basalt.

9.4. Drilling

One of the highest costs involved in groundwater development is the drilling of boreholes. Other costs, such as consultants fees, pump testing and groundwater quality testing also have an overall effect on the total cost of developing groundwater. These costs are generally fixed costs and are not regarded further. The comparative cost of the principal drilling techniques used in KwaZulu-Natal is examined for the purpose of using the results as a component to be considered when planning to develop groundwater.

The main drilling technique utilised in KwaZulu-Natal is percussion with a down the hole hammer (DTH), mud rotary and ODEX are usually only being used where the formations are highly unstable, e.g. unconsolidated sediments and highly weathered rock. Other techniques such as jetting and augering can be used in the unconsolidated formations, but not in the rock aquifers. Table 67 reflects the different drilling techniques available and gives an indication of the rate of penetration for each hydrolithology.

The cost of each drilling technique is primarily influenced by the depth of drilling. The deeper a borehole is drilled the greater the cost becomes per metre of advancement. The basic cost of an average percussion drilled borehole of 100m depth in either Karoo argillaceous, Karoo arenaceous, Ecca shale, Vryheid Formation, Natal Metamorphic Province, Dwyka Group, Karoo dolerite, Natal Group, Jozini Formation or Letaba Formation is represented by Table 68. Hydrolithologies with highly weathered and fractured brittle rock, such as Natal Group Province rocks, Natal Group and dolerite may require ODEX drilling at some point in its development. This type of situation is demonstrated in Table 68 which has been calculated based on 20 m of ODEX drilling and 80 m of normal percussion drilling. The unconsolidated sediment aquifers of the Maputaland Group are mostly accessed by means of either mud rotary or ODEX drilling. Mud rotary drilling is usually practised where the unstable sand is not very coarse. This method, therefore, allows for the annular space between the screen and side walls to be filled with gravel pack. ODEX drilling is used where a gravel pack is not necessary owing to the coarse nature of the sedimentary deposits. The palaeochannels of the Maputaland Group, in particular, have been successfully drilled by the ODEX method. Table 69 summarises the variable costs of both the mud rotary and ODEX drilling methods based on the drilling of a 30m borehole with a 3m screened area.

Table 67. Relative performance of the main methods of borehole drilling in rural KwaZulu-Natal hydrolithologies.

HYDROLITHOLOGY	DTH	DIRECT ROTARY (WITH FLUIDS)	REVERSE ROTARY (WITH FLUIDS)	ODEX	JETTING	AUGER
Karoo argillaceous rock	5***	5	5	N/A	N/A	N/A
Karoo arenaceous rock	5***	5	4	N/A	N/A	N/A
Ecca shale	5***	5	5	N/A	N/A	N/A
Vryheid Formation sandstone	5***	5	3	N/A	N/A	N/A
Natal Metamorphic Province	5***	3	3	4	N/A	N/A
Quaternary sediments	2	N/A	5***	4**	5*	2
Dwyka Group tillite	5***	5	3	N/A	N/A	N/A
Karoo dolerite	5***	3	3	N/A	N/A	N/A
Natal Group sandstone	5***	5	3	N/A	N/A	N/A
Jozini Formation rhyolite	5***	4	3	N/A	N/A	N/A
Letaba Formation basalt	5***	4	3	N/A	N/A	N/A

Rate of penetration:		Recommendation:
1 impossible	4 medium	*** best option
2 difficult	5 rapid	** 2nd best option
3 slow	6 very rapid	* 3rd best option

Table 68. Comparative cost between percussion and ODEX drilling for a typical depth of 100 m in consolidated rock.

ITEM	PERCUSSION (100 m)	PERCUSSION (80 m) ODEX (20 m)
set up at site	R 300.00	R 300.00
drilling (216mm)	R 1,275.00	R 1,275.00
casing (165mm)	R 900.00	R 900.00
drilling (165mm)	R 5,100.00	R 3,900.00
driving shoe	N/A	R 500.00
ODEX drilling (165mm)	N/A	R 7,000.00
TOTAL	R 7,575.00	R 13,875.00

Table 69. Comparative cost between mud rotary and ODEX drilling for a typical depth of 30 m in unconsolidated material.

ITEM	MUD ROTARY (30 m)	ODEX (30 m)
set up at site	R 1,500.00	R 300.00
drilling (254mm)	R 4,500.00	R 10,500.00
casing (165mm)	R 1,620.00	N/A
screen (165mm)	R 2,850.00	N/A
driving shoe	N/A	R 500.00
gravel pack	R 50.00	N/A
backfilling	R 540.00	N/A
water haulage (50km)	R 375.00	N/A
TOTAL	R 11,435.00	R 11,300.00

The tables above clearly show that for single method drilling, percussion drilling is the cheapest method followed by mud rotary and ODEX. The latter two methods will ultimately cost very much the same, and it should be the nature of the geological material to be drilled through that will dictate which method would be the most suitable. The cost of percussion together with ODEX in highly fractured or weathered rock almost doubles the cost of using percussion on its own. This implies that it would probably be more profitable to drill at another location not requiring ODEX rather than spend double the cost of percussion. If the depth of drilling needing ODEX is less than 20 m, it could still be appropriate to utilise ODEX, especially if the site is the only option.

10. DISCUSSION

The focus of this thesis has been upon the development potential of the different aquifers in rural KwaZulu-Natal. Factors influencing this potential are yield, groundwater quality and the existence of suitable siting and drilling methods. Yield and groundwater quality are the main controlling factors when deciding whether or not groundwater can be used in rural water supply. When developing a groundwater resource, a borehole will be drilled and if it strikes water, a blow test will give an indication of the yield of the borehole. Once the quality of the groundwater is known, it will prescribe whether the groundwater requires treatment or not. A pump test will provide further information for determining the sustainable yield, which will be used to design the scheme to satisfy its likely demand. The ideal situation would require groundwater of Class 0 or I quality, while groundwater of Class II or III quality would require treatment thus affecting the cost of the scheme. Other options in the case of poor quality groundwater would be to mix the groundwater with a better quality water source or alternatively, to look for another source of water if use of groundwater is not possible at all. It must be realised that all groundwater will not be of excellent quality and that treatment may be necessary, as is mostly the case when surface water is used. However, for treatment to be economically viable in rural water supply, the sustainable yield must be high enough to justify the expense.

In many cases in KwaZulu-Natal, groundwater is the only option available for rural water supply due to the contamination of rivers or insufficient low flows. Where groundwater is to be considered, it is important to have an idea of the probable yield and quality of the targets to be encountered, the appropriate geophysical exploration method to use and whether or not drilling costs will be excessive. In order to combat the problems related to the poor perception of groundwater due to low success rates, there must be a move away from drilling purely to strike water without prior knowledge of the likely hydrogeological targets, quantity and quality of the groundwater in the area. If these factors are regarded, a higher success rate in groundwater development is achievable. Use of the results of this research together with a thorough desk study, followed by adequate field reconnaissance of the area should be able to answer the questions of what the probable yield and quality of the targets to be encountered should be and the appropriate geophysical exploration method to use in locating the targets.

Those responsible for the siting of boreholes must take principles of groundwater movement and occurrence into account when deciding on target features to be explored by geophysical methods. Another factor which would increase the success rate of groundwater development is the use of appropriate geophysical methods to locate the identified targets. The objective of geophysics is defeated if, for example, EM-34 is used in all hydrolithologies because it is the only instrument available. The appropriate geophysical equipment must be taken into the field to increase the probability of siting successful boreholes. The data generated during the drought relief programme provided an opportunity for some interesting comparisons to be made on the success of different geophysical methods in each hydrolithology.

The fact that the type of drilling technique influences the overall cost of developing groundwater, is good reason to incorporate the type of drilling as a component in determining the potential of the various hydrolithologies. In general, only percussion, mud rotary and ODEX drilling techniques are used in KwaZulu-Natal, with percussion being the cheapest method and mud rotary being the most expensive.

A total of 65 target features were identified throughout all the hydrolithologies. An overall assessment of the relative performance of these targets has been based on a rating system which takes into account the median yield and mean health related quality of each target (Table 70 and Table 71).

Table 70. Ratings given for each target feature dependent on median yield and mean quality.

MEDIAN YIELD (l/s)	MEAN CLASS 0	MEAN CLASS I	MEAN CLASS II	MEAN CLASS III
0 or dry	26	26	26	26
> 0 - 0.1	17	18	19	20
0.1 - 0.5	7	8	15	16
0.5 - 2.0	5	6	13	14
2.0 - 5.0	3	4	11	12
> 5.0	1	2	9	10

Table 71. Overall target feature rating dependent on median yield and mean health related quality for all hydrolithologies. Parenthesis indicates the number of groundwater samples/total number of boreholes drilled into the target.

TARGET	MEDIAN YIELD (l/s)	MEAN QUALITY	RATING
secondary porous Vryheid Formation (1/1)	6	0	1
Uloa Formation (1/1)	2.5	0	3
Dwyka tillite contact with Swazian granite (1/1)	1.53	I	6
Karoo argillaceous contact with Karoo arenaceous rock (1/1)	0.5	0	7
Letaba basalt contact with pegmatite (1/1)	0.5	0	7
secondary porous NMP granite (7/7)	0.36	0	7
dolerite contact with NGS (4/6)	0.33	0	7
secondary porous Natal Group (4/6)	0.32	0	7
Ecca shale contact with Dwyka Group (1/1)	0.3	0	7
dolerite contact with Swazian granite (4/4)	0.23	0	7
Ecca shale contact with NGS (1/1)	0.15	0	7
fractured NMP gneiss (42/59)	0.19	I	7
fractured Natal Group (80/118)	0.14	I	7
Ecca shale contact with Vryheid Formation (12/15)	0.3	I	8
secondary porous Letaba basalt (3/4)	0.15	I	8
fractured Dwyka tillite (29/43)	0.1	I	8
NMP gneiss/schist contact (1/1)	5	II	11
NGS contact with NMP (3/3)	0.6	II	13
Maputaland Group palaeochannels (6/7)	1.53	III	14
Dwyka tillite contact with Dwyka shale (2/2)	0.97	III	14
fractured Vryheid Formation (25/31)	0.4	II	15
fractured Ecca shale (6/6)	0.2	II	15
fractured Letaba basalt (87/89)	0.15	II	15
fractured NMP schist (10/13)	0.14	II	15
secondary porous NMP gneiss (3/3)	0.14	II	15
fractured dolerite (58/71)	0.13	II	15
fractured Jozini rhyolite (17/20)	0.13	II	15
fractured NMP granite (38/55)	0.1	II	15
NGS contact with NGS shale (3/3)	0.1	II	15
secondary porous Jozini rhyolite (2/3)	0.48	III	16
secondary porous Karoo arenaceous rock (1/2)	0.33	III	16
secondary porous Ecca shale (1/1)	0.3	III	16
Ecca shale contact with coal (1/1)	0.3	III	16
fractured Karoo argillaceous rock (16/24)	0.2	III	16
dolerite contact with Karoo argillaceous rock (14/21)	0.16	III	16
secondary porous dolerite (5/8)	0.11	III	16
fractured Karoo arenaceous rock (9/10))	0.1	III	16
dolerite contact with Karoo arenaceous rocks (2/3)	0.1	III	16
Letaba basalt contact with Karoo argillaceous rock (1/1)	0.1	III	16
fractured NMP migmatite (1/3)	0.08	I	18
fractured NMP diorite (5/9)	0.07	I	18
fractured NMP amphibolite (27/41)	0.07	I	18
Maputaland Group fine sands (9/18)	0.05	II	18

TARGET	MEDIAN YIELD (l/s)	MEAN QUALITY	RATING
Dwyka tillite contact with NMP (1/2)	0.05	II	19
featureless Dwyka tillite (10/49)	0	0	26
NGS contact with Swazian granite (1/1)	0	0	26
secondary porous Karoo argillaceous rock (dry/1)	0	dry	26
featureless Ecca shale (dry/1)	0	dry	26
Vryheid Formation contact with Ecca shale (3/11)	0	dry	26
fractured NMP quartzite (dry/1)	0	dry	26
featureless NMP granite (dry/11)	0	dry	26
secondary porous Dwyka tillite (dry/1)	0	dry	26
dolerite contact with NMP (dry/2)	0	dry	26
featureless dolerite (dry/5)	0	dry	26
featureless Letaba basalt (dry/1)	0	dry	26
dolerite contact with Dwyka tillite (1/5)	0	I	26
dolerite contact with Ecca shale (5/12)	0	I	26
dolerite contact with Vryheid Formation (8/17)	0	I	26
featureless NMP gneiss (1/3)	0	II	26
Dwyka tillite contact with NGS (5/21)	0	II	26
dolerite contact with Jozini Formation (10/24)	0	II	26
featureless Jozini rhyolite (3/12)	0	II	26
Karoo arenaceous contact with Karoo argillaceous rocks (9/26)	0	III	26
Maputaland Group contact with Zululand Group (2/12)	0	III	26
featureless Natal Group (2/12)	0	III	26

If the above table is broken down into four parts, some trends are uncovered. Those features which only had one record or have been classified as featureless are not considered in this discussion.

i. The highest rated 25% of the target features contain fractured Natal Group sandstone and Natal Metamorphic Province gneiss, together with contacts between dolerite and Swazian granites. All of these hydrolithologies are brittle rocks due to their quartz and feldspar contents. Fractured Dwyka Group tillite also features in the top 25% of the table which indicates that compared to other target features, the Dwyka Group can have good yielding boreholes. The contact between the Ecca Group's Volksrust and Vryheid Formations also proved itself to be a good target feature. Weathered Natal Metamorphic Province granite rates as one of the highest potential aquifers. All of these formations produce groundwater that does not require treatment, since their quality is either Class 0 or I.

ii. The next 35% of the target features include the high yielding palaeochannels of the Maputaland Group, fractured Natal Metamorphic Province schist and granite and secondary Natal Metamorphic Province porous gneiss. The majority of the target features falling within this percentile are the fractured Karoo Supergroup sedimentary and igneous rocks together with their contacts with dolerite. The quality of all these groundwaters are such that they would require treatment.

iii. Fractured Karoo argillaceous and arenaceous rock and their contacts with dolerite together with secondary porous dolerite, the fine sands of the Maputaland Group and fractured Natal Metamorphic Province rocks, excluding granite and gneiss, fall into the following 10% of the target features. These targets either have a yield less than 0.1 l/s or are very low yielding Class III groundwater.

iv. A rating of 26 has been given to the targets which are either dry or have a median yield of 0 l/s. These are the targets which fall into the last 30% of all 65 target features. The majority of these are dolerite contacts and secondary porous sedimentary rocks. A cumulative distribution plot of the ratings assigned to each target is given in Figure 143.

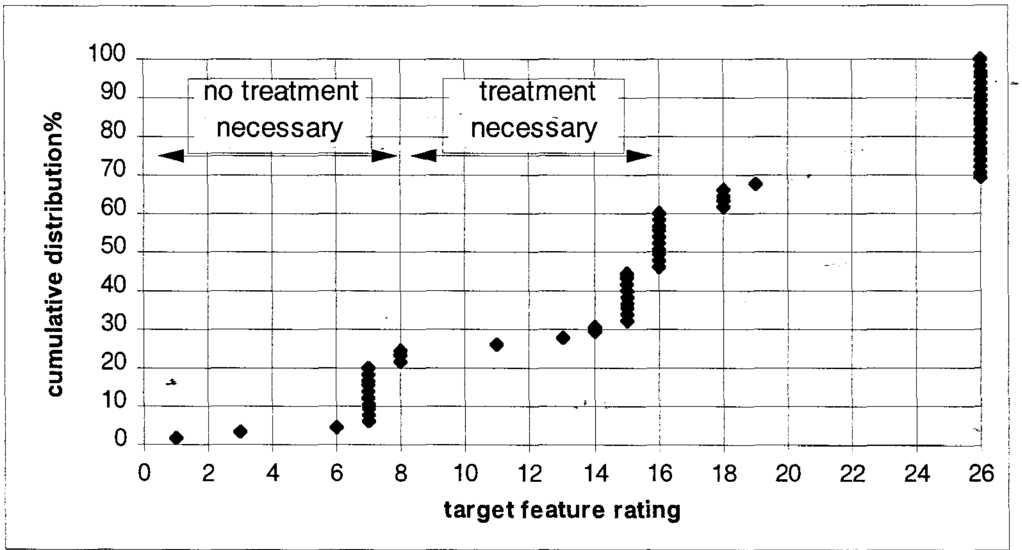


Figure 143. Cumulative distribution plot depicting frequency occurrence of target feature hydrogeological ratings.

Contacts between different hydrolithologies have poor data and are features that should be studied in greater detail in order to determine their potential as suitable aquifers. For example, boreholes drilled around Ulundi into the contact between the Dwyka and Natal Groups produced very high yields, while the same contact penetrated during the drought relief programme gave very low yields.

A summary of the recommended geophysical method per hydrolithology is provided in Table 72. This table has a noticeable lack of data in the contact target category. A comparison based on the cost per day of each geophysical method and its effectiveness, which is dependent on typical progress and personnel required, is supplied in Table 73. Weights have been assigned to the cost per day (x 0.5) and personnel required (x 2) in an effort to highlight that the number of people involved in each method has a greater impact than the cost per day on the total cost of geophysical siting. A relative rating of the five methods shows that the order of increasing cost effectiveness is VES, resistivity profiling, EM, VLF and magnetics.

Once the components influencing the groundwater development potential are put together, an overall comparison between the target features within each hydrolithology can be made. Table 74 presents the final ratings of each target feature. The final rating was arrived at by assessing the ratings of yield and quality, geophysics and drilling method relative to one another. Where records of less than five exist, the final rating was reduced due to lower confidence levels in the preliminary ratings.

Table 72. Recommended exploration geophysical techniques for hydrogeological target features.

HYDROLITHOLOGY	PRIMARY	CONTACT	FRACTURED	SECONDARY POROUS
Karoo argillaceous rock	N/A	not enough data	EM	no aquifer
Karoo arenaceous rock	N/A	Karoo argillaceous EM	EM	not enough data
Ecca shale	N/A	Vryheid Formation VES, EM	VES, EM	no aquifer
Vryheid Formation sandstone	N/A	not enough data	EM, VES, magnetics	no aquifer
Natal Metamorphic Province	N/A	not enough data	profiling, EM	VES, profiling
Quaternary sediments	difficult	possibly EM and VES	N/A	N/A
Dwyka Group tillite	N/A	not enough data	VLF	no aquifer
Karoo dolerite	N/A	Karoo argillaceous EM Karoo arenaceous EM, magnetics Dwyka Group not enough data Vryheid Formation EM Ecca shale not enough data Natal Group not enough data Jozini Formation magnetics Swazian granite not enough data	EM, VES	not enough data
Natal Group sandstone	N/A	not enough data	profiling, VES	not enough data
Jozini Formation rhyolite	N/A	not enough data	EM, magnetics	EM, magnetics
Letaba Formation basalt	N/A	not enough data	EM, magnetics	not enough data

Table 73. Geophysical method rating dependent on rate per day and effectiveness based on typical progress and personnel required.

METHOD	EQUIPMENT COST (R/per day)	R	x 0.5	APPROXIMATE NUMBER OF KILOMETRES TRAVERSED OR SOUNDINGS PER DAY	R	PERSONNEL REQUIRED	R	x 2	TOTAL	R
electromagnetics										
EM-34	300,00	4	2	2 km	3	1 operator + 1 labourer	2	4	9 (0.69)	3
VLF	150,00	3	1.5	3 km (if a good signal is received)	2	1 operator	1	2	5.5 (0.42)	2
magnetics	80,00	2	1	3 - 4 km	1	1 operator	1	2	3 (0.23)	1
electrical resistivity										
profiling	60,00	1	0.5	1.5 km	4	1 operator + 4 labourers	3	6	10.5 (0.81)	4
VES	60,00	1	0.5	8 soundings/day	5	1 operator + 4 labourers	3	6	11.5 (0.88)	5

R = relative rating
where lower numbers indicate better rating

Table 74. Relative rating within each hydrolithology based on yield, quality, geophysical method and drilling. Parenthesis indicates number of groundwater samples/total number of boreholes drilled into the target. Targets in italics have also been included in the dolerite hydrolithology. Underlined geophysical methods denote suggested method in the light of a lack of data. R = rating.

HYDROLITHOLOGY	MEDIAN YIELD (l/s)	MEAN QUALITY	REASON FOR FAILURE	R	GEOPHYSICS	R	DRILLING	R	FINAL RELATIVE RATING
KAROO ARGILLACEOUS									
Karoo argillaceous contact with Karoo arenaceous rock (1/1)	0.5	0		7	EM	3	DTH	1	3
fractured Karoo argillaceous rock (16/24)	0.2	III	EC, Na, Cl	16	EM	3	DTH	1	1
dolerite contact with Karoo argillaceous rock (14/21)	*0.16*	*III*	*EC, Na, Cl*	*16*	*EM, magnetics*	*3*	*DTH*	*1*	2
secondary porous Karoo argillaceous rock (dry/1)	0	dry		26	no aquifer				
KAROO ARENACEOUS									
secondary porous Karoo arenaceous rock (1/2)	0.33	III	EC, Na, Cl	16	not enough data		DTH	1	3
fractured Karoo arenaceous rock (9/10))	0.1	III	EC, Mg, Na, Cl, NO3	16	EM	3	DTH	1	1
dolerite contact with Karoo arenaceous rocks (2/3)	*0.1*	*III*	*EC, Na, Cl*	*16*	*EM, magnetics*	*3,1*	*DTH*	*1*	*2*
Karoo arenaceous contact with Karoo argillaceous rocks (9/26)	0	III	EC, Mg, Na, Cl	26	EM	3	DTH	1	4
ECCA SHALE									
Ecca shale contact with Dwyka Group (1/1)	0.3	0		7	not enough data		DTH	1	3
Ecca shale contact with NGS (1/1)	0.15	0		7	not enough data		DTH	1	4
Ecca shale contact with Vryheid Formation (12/15)	0.3	I	TDS, EC	15	VES, EM	5,3	DTH	1	1
fractured Ecca shale (6/6)	0.2	II	EC, Na, Cl	15	VES,EM	5,3	DTH	1	2
secondary porous Ecca shale (1/1)	0.3	III	EC, Mg, Na, Cl	16	not enough data		DTH	1	7
Ecca shale contact with coal (1/1)	0.3	III	EC, Mg, Na, K, Cl	16	not enough data		DTH	1	6
featureless Ecca shale (dry/1)	0	dry		26	no aquifer				
dolerite contact with Ecca shale (5/12)	*0*	*I*	*TDS*	*26*	*EM, magnetics*	*3,1*	*DTH*	*1*	*5*
VRYHEID FORMATION									
secondary porous Vryheid Formation (1/1)	6	0		1	not enough data		DTH	1	4
fractured Vryheid Formation (25/31)	0.4	II	Na, Cl	15	EM, VES, magnetics	3,5, 1	DTH	1	1

HYDROLITHOLOGY	MEDIAN YIELD (l/s)	MEAN QUALITY	REASON FOR FAILURE	R	GEOPHYSICS	R	DRILLING	R	FINAL RELATIVE RATING
dolerite contact with Vryheid Formation (8/17)	*0*	*I*	*EC, Na, Cl*	*26*	*EM*	*3*	*DTH*	*1*	*2*
Vryheid Formation contact with Ecca shale (3/11)	0	II		26	not enough data		DTH	1	3
NATAL METAMORPHIC PROVINCE									
secondary porous NMP granite (7/7)	0.36	0		7	profiling, EM	4,3	DTH	1	1
fractured NMP gneiss (42/59)	0.19	I	EC, Mg, Na, Cl	7	profiling, EM	4,3	DTH ODEX	1 2	2
NMP gneiss/schist contact (1/1)	5	II	EC, Na, Cl, F	11	profiling, EM	4,3	DTH	1	7
secondary porous NMP gneiss (3/3)	0.14	II	NO3	15	profiling, EM	4,3	DTH	1	3
fractured NMP schist (10/13)	0.14	II	EC, Mg, Cl, NO3, F	15	profiling, EM	4,3	DTH	1	5
fractured NMP granite (38/55)	0.1	II	Cl	15	profiling, EM	4,3	DTH	1	4
fractured NMP migmatite (1/3)	0.08	I	TDS	18	profiling, EM	4,3	DTH ODEX	1 2	6
fractured NMP diorite (5/9)	0.07	I	EC, Na, Cl, NO3	18	profiling, EM	4,3	DTH	1	8
fractured NMP amphibolite (27/41)	0.07	I	TDS	18	profiling, EM	4,3	DTH ODEX	1 2	9
fractured NMP quartzite (dry/1)	0	dry		26	profiling, EM	4,3	DTH	1	11
featureless NMP gneiss (1/3)	0	II	NO3	26	no aquifer				
featureless NMP granite (dry/11)	0	dry		26	no aquifer				
dolerite contact with NMP (dry/2)	*0*	*dry*		*26*	*magnetics, EM*	*1,3*	*DTH*	*1*	*10*
MAPUTALAND GROUP									
Uloa Formation (1/1)	2.5	0		3	none		mud rotary	3	1
Maputaland Group palaeochannels (6/7)	1.53	III	EC, Mg, Na, Cl	14	none		ODE26	2	2
Maputaland Group fine sands (9/18)	0.05	II	Cl	18	none		mud rotary	3	3
Maputaland Group contact with Zululand Group (2/12)	0	III	EC, Mg, Na, Cl	26	EM	3	mud rotary ODE26	3 2	4
DWYKA GROUP									
Dwyka tillite contact with Swazian granite (1/1)	1.53	I	pH	6	not enough data		DTH	1	2
fractured Dwyka tillite (29/43)	0.1	I	EC, Na, Cl	8	VLF	2	DTH	1	1

HYDROLITHOLOGY	MEDIAN YIELD (l/s)	MEAN QUALITY	REASON FOR FAILURE	R	GEOPHYSICS	R	DRILLING	R	FINAL RELATIVE RATING
Dwyka tillite contact with Dwyka shale (2/2)	0.97	III	EC, Na, Cl	14	not enough data		DTH	1	6
Dwyka tillite contact with NMP (1/2)	0.05	II	F	19	not enough data		DTH	1	3
secondary porous Dwyka tillite (dry/1)	0	dry		26	no aquifer				
featureless Dwyka tillite (10/49)	0	0		26	no aquifer				
dolerite contact with Dwyka tillite (1/5)	*0*	*I*	*EC, Na, Cl, F*	*26*	*not enough data*		*DTH*	*1*	*4*
Dwyka tillite contact with NGS (5/21)	0	II	EC, Mg, Na, Cl	26	not enough data		DTH	1	5
DOLERITE									
dolerite contact with NGS (4/6)	0.33	0		7	magnetics, EM	1,3	DTH	1	1
dolerite contact with Swazian granite (4/4)	0.23	0		7	magnetics, EM	1,3	DTH	1	2
fractured dolerite (58/71)	0.13	II	EC, Na, Cl	15	EM, VES	3,5	DTH	1	3
dolerite contact with Karoo argillaceous rock (14/21)	0.16	III	EC, Na, Cl	16	EM, magnetics	3	DTH	1	4
secondary porous dolerite (5/8)	0.11	III	EC, Mg, Na, Cl, F	16	EM	3	DTH	1	6
dolerite contact with Karoo arenaceous rocks (2/3)	0.1	III	EC, Na, Cl	16	EM, magnetics	3,1	DTH	1	5
dolerite contact with NMP (dry/2)	0	dry		26	magnetics, EM	3,1	DTH	1	11
featureless dolerite (dry/5)	0	dry		26	no aquifer				
dolerite contact with Dwyka tillite (1/5)	0	I	EC, Na, Cl, F	26	magnetics, EM	1,3	DTH	1	7
dolerite contact with Ecca shale (5/12)	0	I	TDS	26	magnetics, EM	1,3	DTH	1	8
dolerite contact with Vryheid Formation (8/17)	0	I	EC, Na, Cl	26	EM, magnetics	3,1	DTH	1	9
dolerite contact with Jozini Formation (10/24)	0	II	EC, Na, Cl, F	26	magnetics	1	DTH	1	10
NATAL GROUP									
dolerite contact with NGS (4/6)	*0.33*	*0*		*7*	*magnetics, EM*	*1,3*	*DTH*	*1*	*1*
secondary porous Natal Group (4/6)	0.32	0		7	not enough data		DTH	1	3
fractured Natal Group (80/118)	0.14	I	Cl	7	profiling, VES	4,5	DTH	1	2
NGS contact with NMP (3/3)	0.6	II	Cl	13	not enough data		DTH	1	4
NGS contact with NGS shale (3/3)	0.1	II	F	15	not enough data		DTH	1	5
NGS contact with Swazian granite (1/1)	0	0		26	not enough data		DTH	1	6
featureless Natal Group (2/12)	0	III	EC, Na, Cl	26	no aquifer				

HYDROLITHOLOGY	MEDIAN YIELD (l/s)	MEAN QUALITY	REASON FOR FAILURE	R	GEOPHYSICS	R	DRILLING	R	FINAL RELATIVE RATING
JOZINI FORMATION									
fractured Jozini rhyolite (17/20)	0.13	II	EC, Na, Cl, F	15	EM, magnetics	3,1	DTH	1	1
secondary porous Jozini rhyolite (2/3)	0.48	III	Na, Cl, F	16	EM, magnetics	3,1	DTH	1	2
featureless Jozini rhyolite (3/12)	0	II	Na, Cl	26	no aquifer				
dolerite contact with Jozini Formation (10/24)	*0*	*II*	*EC, Na, Cl, F*	*26*	*magnetics*	*1*	*DTH*	*1*	*3*
LETABA FORMATION									
Letaba basalt contact with pegmatite (1/1)	0.5	0		7	EM, magnetics	3,1	DTH	1	2
secondary porous Letaba basalt (3/4)	0.15	I	NO3	8	not enough data	3,1	DTH	1	3
fractured Letaba basalt (87/89)	0.15	II	EC, Na, Cl	15	EM, magnetics	3,1	DTH	1	1
Letaba basalt contact with Karoo argillaceous rock (1/1)	0.1	III	EC, Na, Cl	16	EM, magnetics	3,1	DTH	1	4
featureless Letaba basalt (dry/1)	0	dry		26	no aquifer				

The Karoo argillaceous hydrolithology, covering the greatest surface area in KwaZulu-Natal, has three target features for groundwater exploration. Fractured argillaceous rock is the most promising feature, although its quality is poor. The contact between argillaceous and arenaceous rock has excellent quality groundwater, but in considering the Karoo arenaceous contact with argillaceous rock in the preceding hydrolithology (Table 74), the overall quality of this contact must be regarded as poor. The Karoo argillaceous contact with dolerite also produces poor quality groundwater. The success rate in fractured Karoo argillaceous rocks and dolerite intruded into Karoo argillaceous rocks is expected to be very similar. Groundwater quality problems to be expected will be related to high salinity. The preferred method of geophysical exploration in the Karoo argillaceous hydrolithology should be through electromagnetics. Percussion drilling is generally the only drilling technique required. Figure 144 illustrates the nature of the typical target features and their ratings relative to one another.

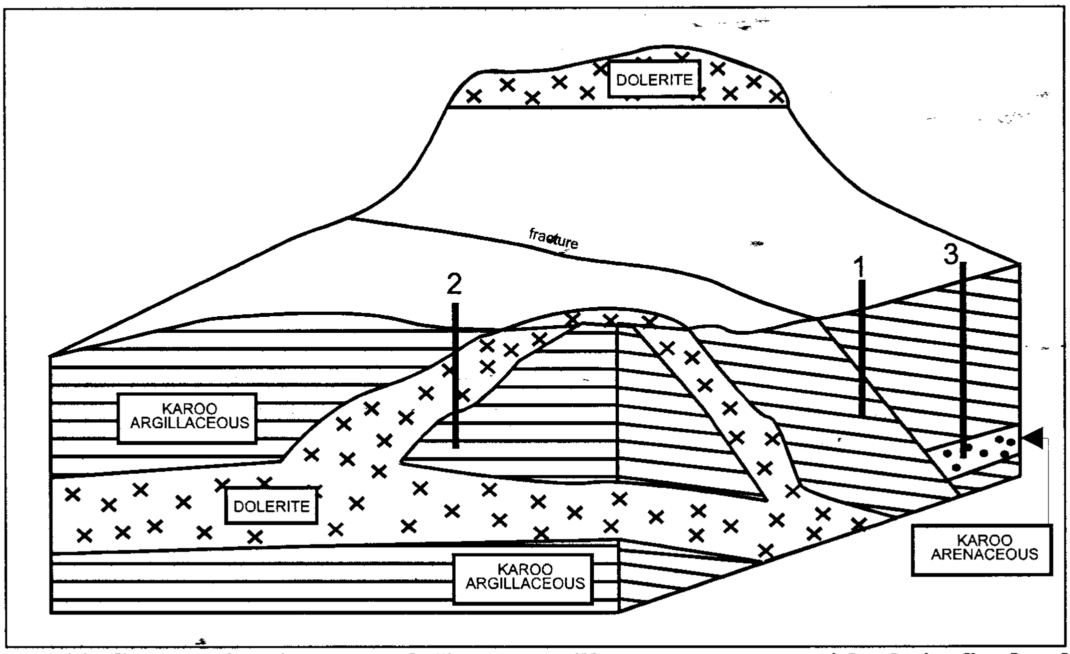


Figure 144. Schematic diagram of Karoo argillaceous targets with their final relative ratings.

The final rating of Karoo arenaceous targets is similar to that in Karoo argillaceous rock, except the secondary porous target may compare more favourably than the contact with Karoo argillaceous rock (Figure 145). The quality in all targets is poor with almost all the groundwater containing a Class III constituent. Constituents which will be problematic will be sodium, magnesium and chloride. Again, electromagnetics can generally be relied upon to site boreholes and percussion for drilling.

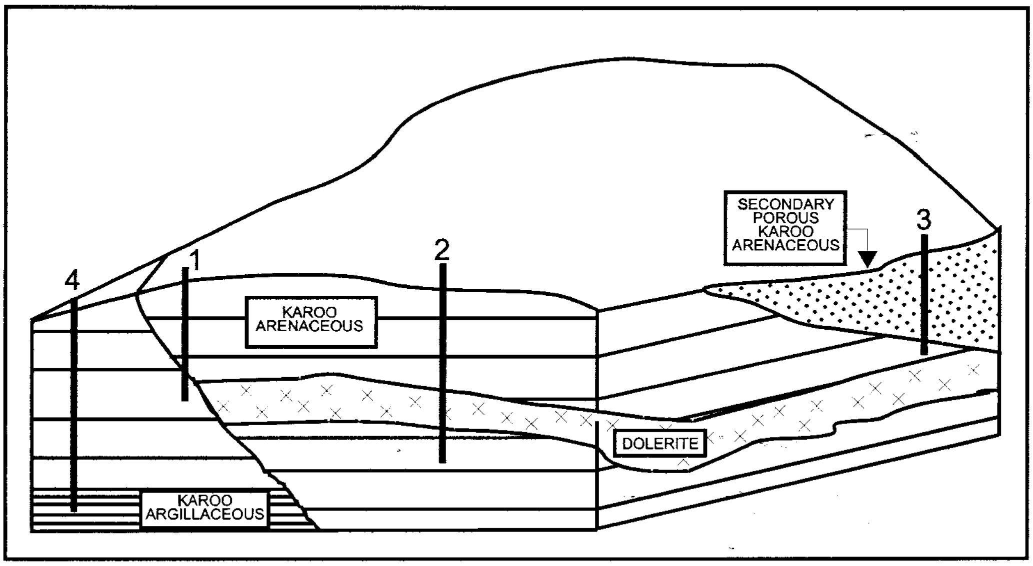


Figure 145. Schematic diagram of Karoo arenaceous targets with their final relative ratings.

The targets within the Ecca shales have lower salinity groundwater than the rest of the Karoo argillaceous rocks, except for secondary porous shales or those in contact with coal. The contact between the shales and the underlying Vryheid Formation appears to be the best aquifer, followed by fractured shale which has a mean quality of Class II. Contacts with the Dwyka Group, Natal Group, dolerite and coal have successively worse ratings, mostly as a consequence of low yields. Secondary porous shale, due its high clay content, has the worst rating. Vertical electrical sounding and electromagnetics are the recommended geophysical methods of borehole siting. The target features of the Ecca shale hydrolithology are similar to those shown in Figure 144, although the ratings are slightly different.

The fractured targets of the Vryheid Formation have the highest rating compared to its contacts with both dolerite and Ecca shale. Secondary porous Vryheid Formation has been given the worst rating owing to uncertainty being cast by the single record, regardless of its very high yield and excellent quality. As in the Ecca shales, vertical electrical sounding and electromagnetics should be used during exploration, particularly in locating fractures. Magnetics can also be used but only where dolerite or large faults are expected. The drilling technique will mostly be by percussion. A diagram showing the typical target features and their relative rating is presented in Figure 146.

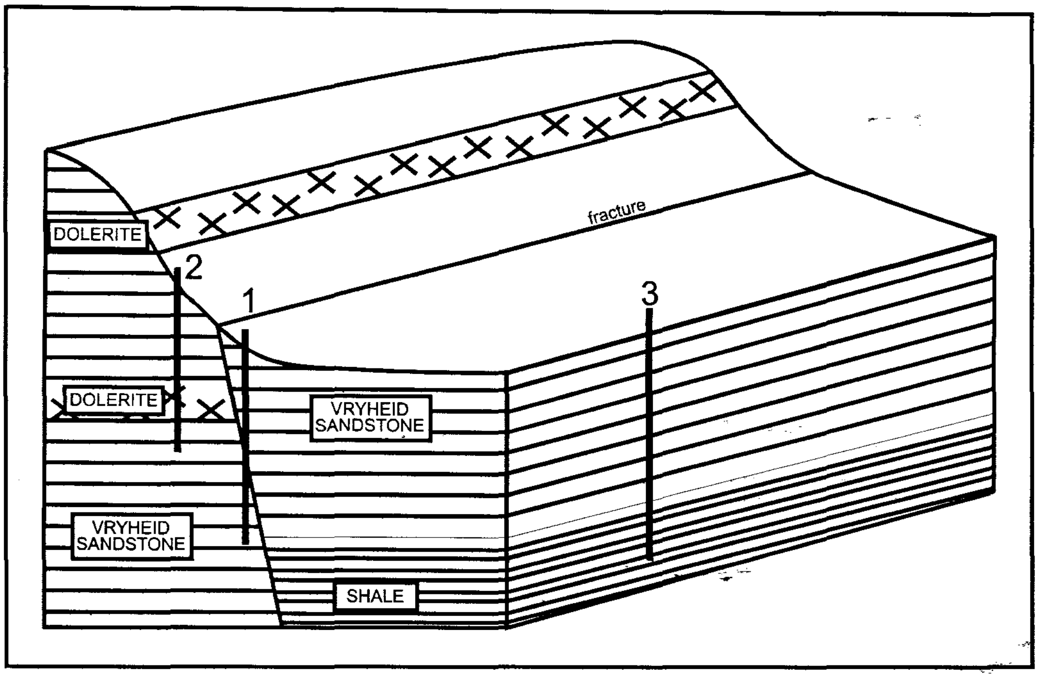


Figure 146. Schematic diagram of Vryheid Formation targets with their final relative ratings.

The various lithologies comprising the Natal Metamorphic Province are difficult to rate against one another. Some subjective licence has been used to arrive at the final ratings because some of the targets have too few records. What does become clear is that the abundant granites and gneiss have the best potential, whether the groundwater be in fractures or weathered zones. The groundwater quality is generally not worse than Class II. If the groundwater in Natal Metamorphic Province aquifers is classed as Class II it is mainly due to salinity levels. Fractures within schists appear promising, however the groundwater quality is affected by high fluoride concentrations. The rest of the lithologies, namely migmatite, diorite and quartzite have poor potential. Generally, percussion drilling should be used, but in highly fractured and weathered zones, ODEX drilling may occasionally be required. The dolerite contact with the Natal Metamorphic Province was intersected only twice, which resulted in a poor rating because both boreholes were dry. Further study should be conducted at this particular target, especially in Natal Metamorphic Province lithologies. Figure 147 illustrates the relative ratings of the different target features occurring in the Natal Metamorphic Province. The most appropriate geophysical methods to be used in crystalline rocks should be electrical resistivity profiling or electromagnetics.

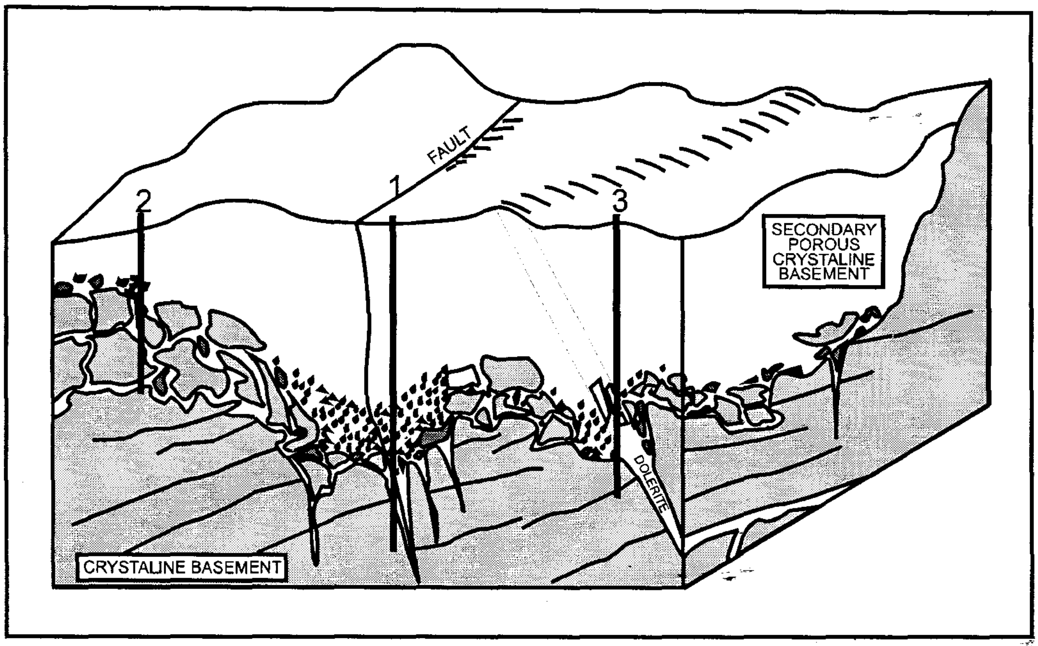


Figure 147. Schematic diagram of Natal Metamorphic Province targets with their final relative ratings.

Groundwater development on the Zululand coastal plain should target the discontinuous Uloa Formation as a first option (Figure 148). This is due to its excellent quality and high yields. The palaeochannels and fine sands of the Maputaland Group are more abundant than the Uloa Formation and should be utilised more extensively than they have been in the past. Unfortunately, the groundwater quality in these targets is subjected to salinity problems. The Zululand Group siltstones must be avoided due to the highly saline groundwaters that they contain. It is proposed that the coarse deposits of the Maputaland Group be developed by ODEX, with exploration by means of pilot holes and geological observation, and that the fine sands be developed by shallow hand-dug wells. The location of proposed shallow wells should be confirmed by exploration augering.

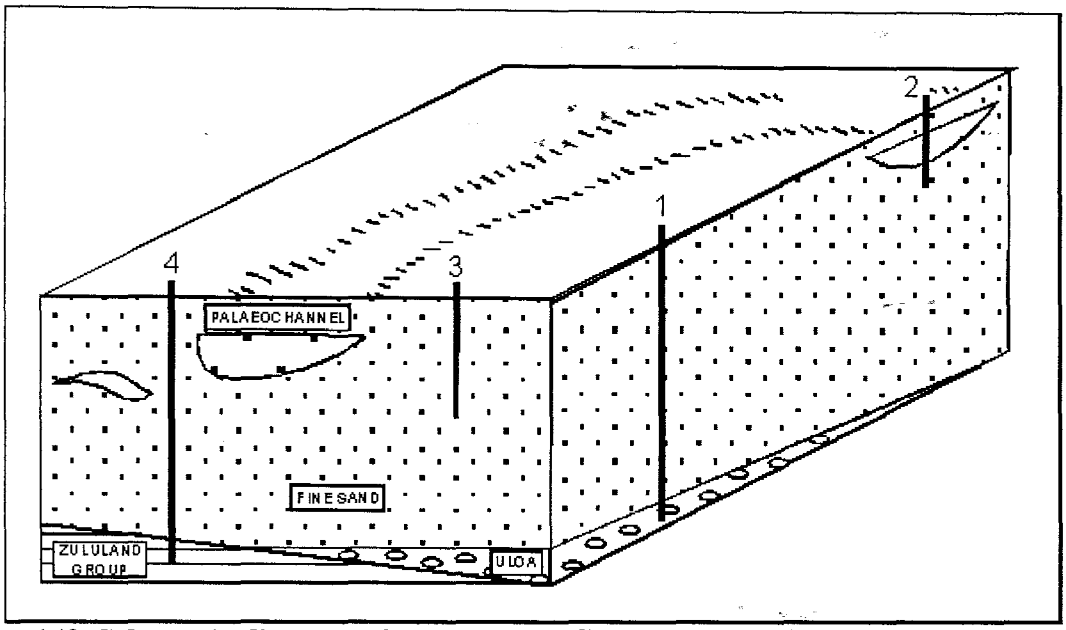


Figure 148. Schematic diagram of Maputaland Group targets with their final relative ratings.

The perception that the Dwyka Group is one of the poorest aquifers can be altered by the knowledge that the quality of the groundwater produced can be better than previously thought. Fractures should be the first source of groundwater to be considered, with contacts at basement rock level producing the next best target (Figure 149). More frequently, the contact between tillite and Natal Group sandstone or dolerite will be encountered, however, these targets have been shown to be frequently dry. The proposed method of geophysical exploration is by VLF, partly due to the poor results electromagnetics have had in the past. Percussion drilling will always be used to access the groundwater due to the consolidated nature of the rock.

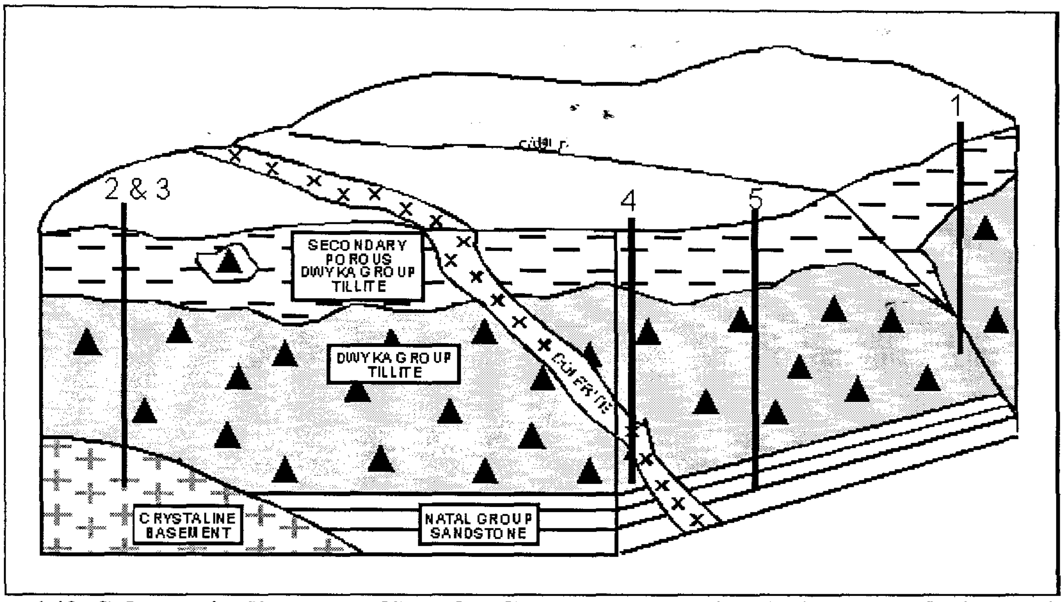


Figure 149. Schematic diagram of Dwyka Group targets with their final relative ratings.

The development potential of contacts between dolerite and its host rocks are addressed in the discussion on individual hydrolithologies. Fractured dolerite, although suffering from some salinity problems, is a relatively good target which can be detected by electromagnetics or vertical electrical sounding. Weathered dolerite will generally have a poorer quality than the fractured target, probably as a result of increased rock-water interactions. In highly fractured dolerite, ODEX drilling in conjunction with percussion may be required to advance through the unstable sections.

The Natal Group sandstone has the highest potential of all the hydrolithologies in KwaZulu-Natal, with respect to development for rural water supply. The sandstone's contact with dolerite has the highest rating, primarily owing to its high median yield. The high yield is probably a result of extensive and interconnected fracturing due to the competent nature of both the sandstone and dolerite. Fractured targets are promoted above the secondary porous targets because the weathered sandstone often is clayey and not very deeply developed. Contacts with underlying basement rocks are the fourth best option, however, fluoride levels may be a problem. Resistivity methods are best employed when siting boreholes in this hydrolithology and magnetics should be used when targeting the dolerite contacts. The suggested target ratings are shown in Figure 150.

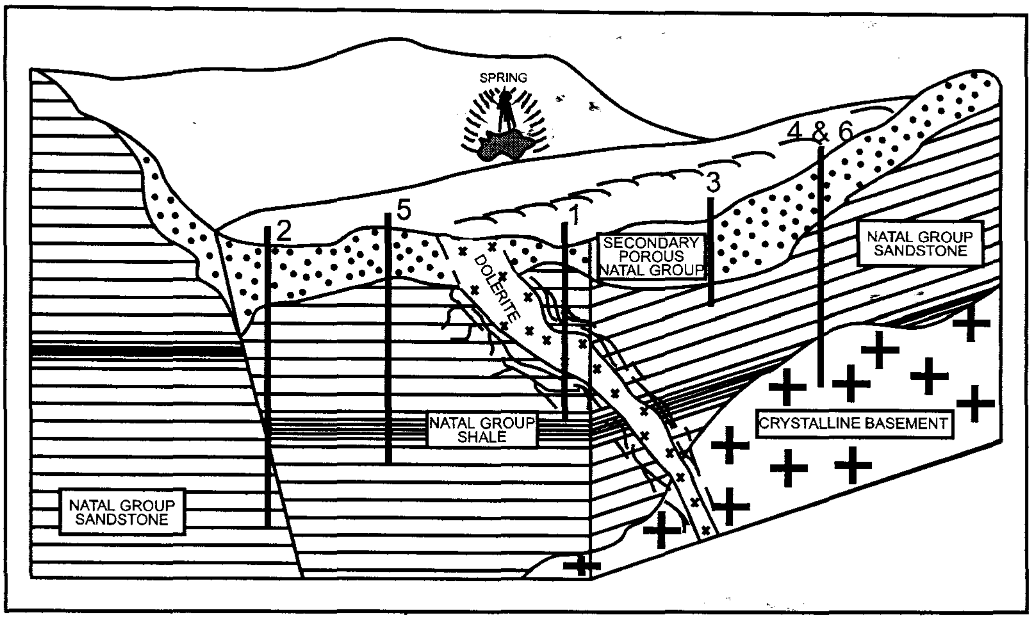


Figure 150. Schematic diagram of Natal Group targets with their final relative ratings.

The extrusive volcanic rocks of the Lebombo Group generally have groundwater quality of Class II, which precludes its prolonged use without treatment. The moderate to poor quality of the groundwater is a result of salinity levels in both the Jozini Formation rhyolite and Letaba Formation basalt, with the rhyolite groundwater also suffering from high fluoride levels. The fractured targets from both formations are the best prospects amongst the rest of their respective hydrolithologies. Secondary porous targets are the second best option in the Jozini Formation, followed by the contact with intrusive dolerite (Figure 151). Electromagnetic or magnetic methods are the best geophysical techniques for siting in the rhyolites and percussion is the most appropriate for drilling.

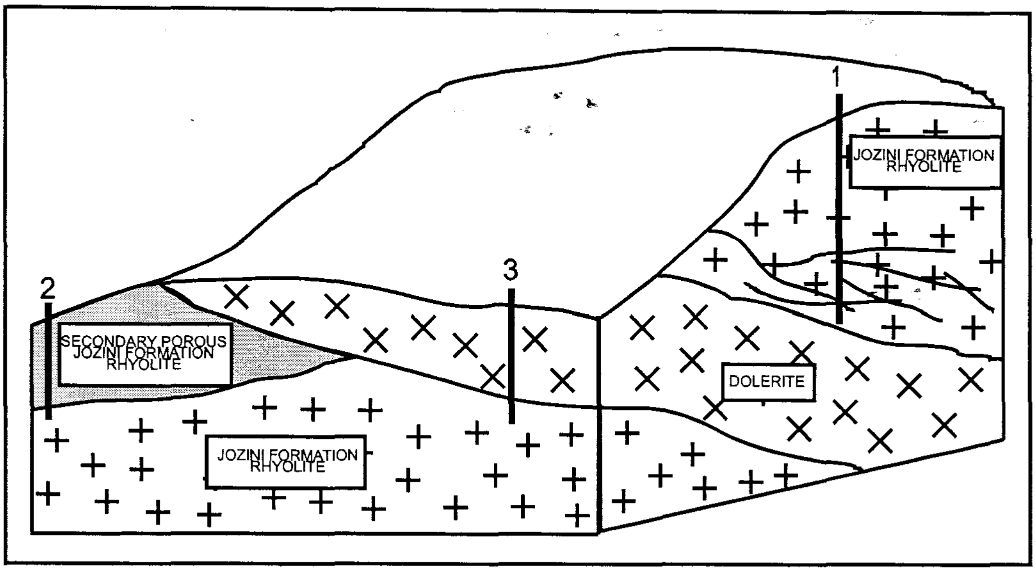


Figure 151. Schematic diagram of Jozini Formation targets with their final relative ratings.

Targets features within the Letaba Formation all produce reasonable groundwater yields. The intrusive contact with pegmatite veins is a primary target, which should be followed by secondary porous targets and the underlying contact with Karoo argillaceous rock. Dolerite does intrude into the Letaba Formation, but was not recorded in any of the drilling logs. This raises some doubt as to whether those responsible for logging were able to recognise the dolerite within the basalt. If this is the case, the fractured targets would include some of the dolerite contact targets. The dolerite contact target depicted in Figure 152 is therefore rated with a question mark. Similarly to the rhyolites, siting should be carried out by means of electromagnetic or magnetic geophysics and drilling by percussion.

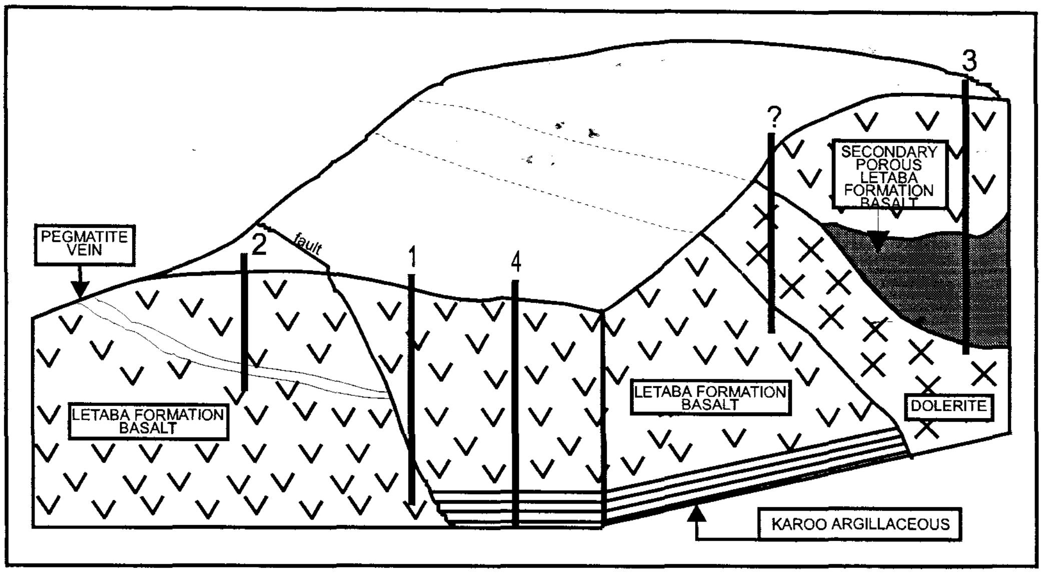


Figure 152. Schematic diagram of Letaba Formation targets with their final relative ratings.

10.1. Recommendations

The data analysed in this thesis confirm some known facts and reveal many new facts regarding hydrogeological targets in the different hydrolithologies occurring in KwaZulu-Natal. These facts must be used firstly to determine whether groundwater is a viable option in the area under consideration, and secondly, to be confident that the best target features are located. The more abundantly occurring secondary aquifers of the province are relied upon for a large proportion of rural water supply. Of these 'hard rock' type aquifers, the Natal Group sandstone clearly has the highest potential taking into account all possible target features. The other hydrolithologies, in decreasing order of development potential, are: Natal Metamorphic Province granites and gneiss, the Ecca Group shales and Vryheid Formation, the Dwyka Group, dolerite, Karoo argillaceous and arenaceous rocks, the Letaba Formation and Jozini Formation. In almost all the hydrolithologies, fractures were shown to be the highest rated target feature, followed by contacts with other rock types and secondary porous targets. The analyses also depicted dolerite contacts as generally not being the best targets, compared to other available targets features, but this may be a function of too few records.

The low rating of the Karoo argillaceous and arenaceous rocks is unfortunate, since they cover the greatest surface area in rural KwaZulu-Natal. If, however, a larger number of records from these hydrolithologies were available, a different result may have been arrived at. Further work should be carried out on specific contacts between hydrolithologies, such as: the Natal Group's contact with the Natal Metamorphic Province and the Dwyka Group's contact with the Natal Metamorphic Province.

The Zululand coastal plain, being the only extensive primary aquifer in the province, has a large rural population which does not have access to much water, due to a lack of rivers. The groundwater resources must be developed to their full potential if the demand is to be met in a cost effective manner. There is abundant groundwater available, although its quality is variable. The Uloa Formation must be delineated and protected as it has the best potential of all the targets within the Maputaland Group. The sands of the Maputaland Group can be utilised inexpensively by shallow wells, with the cost of drilling in these formations being the highest of all the hydrolithologies in KwaZulu-Natal. A forthcoming report by Meyer *et al.* (in prep.) should hopefully provide some useful hydrogeological information to aid in the development of the coastal plain sands.

This research has also shown that appropriate geophysical methods should be considered when siting boreholes in each hydrolithology and even for each individual target features. The use of only one geophysical method for groundwater exploration must be questioned. The choice of method should be the best method for the particular hydrolithology and the siting must be supported by a secondary method.

Drilling in the secondary aquifers is almost always by means of percussion, with ODEX sometimes being required where unstable conditions, due to highly weathered or fractured zones, occur. The use of ODEX drilling can increase the cost of drilling substantially and it should, therefore, only be used if potential borehole sites are limited. The cost of borehole drilling on the Zululand coastal plain is expensive, owing to the requirement of mud rotary or ODEX drilling techniques. Where possible, alternative methods, such as hand-dug wells, should be used to access the groundwater.

11. SUMMARY AND CONCLUSION

The implementation of rural water supply schemes using groundwater is dependent on a number of factors. Past failures have resulted from not considering all these factors. One of the first factors to be considered is whether the community requiring the water supply is satisfied with groundwater as a source. After the community's requirements, in terms of level of service, and water quantity have been determined, the scheme must be designed to meet both present and future population demands. Alternative sources must also be examined and the physical and technical aspects of groundwater for the particular situation studied. For dealings with communities, the services of a social expert to communicate with the community in order to identify all their concerns and needs is required.

The hydrolithology underlying the area of concern will dictate whether a groundwater option is feasible. The two aspects determining the hydrogeological potential of an aquifer are yield and groundwater quality. To be able to consider the potential of the hydrolithology, the possible targets to be encountered together with their expected yield and quality limitations must be determined. This thesis contributes to comparisons between target features, with regard to median yield and mean quality, from data collected from a recent drought relief programme carried out by the DWAF.

The most favourable hydrolithologies in terms of development potential, on the basis of yield and quality, are the Natal Group sandstones, the Natal Metamorphic Province gneiss and the Uloa Formation. The brittle nature of the latter two hydrolithologies may explain why yields are higher, than the majority of the Karoo sedimentary rocks. In the brittle rocks, fractures remain open while in comparison, ductile argillaceous rocks will deform in a more plastic manner and therefore have less well developed fractures, except where major faults occur. The Uloa Formation is the only known occurrence of a karst type aquifer in KwaZulu-Natal. Fractures are the only feature worth targeting in Dwyka Group tillite. The surprisingly high median yield of these normally non-water bearing rocks is probably due to the fractures acting as the only real conduit of groundwater and therefore all groundwater within the rock makes its way towards these features. The contact between the Volksrust and Vryheid Formations of the

Ecca Group is also rated highly, with the groundwater generally being of a better quality than the rest of the Karoo sedimentary rocks.

The groundwater emanating from palaeochannels of the Maputaland Group, fractured Natal Metamorphic Province schist and granite and secondary Natal Metamorphic Province porous gneiss have the next best potential but often require treatment. Also categorised as having a similar potential are the Ecca Group, Vryheid Formation, dolerite, Jozini Formation and Letaba Formation.

Those targets with low yields or very poor quality are the Karoo argillaceous and arenaceous rocks, their contacts with dolerite together with secondary porous dolerite, the fine sands of the Maputaland Group and fractured Natal Metamorphic Province rocks, excluding granite and gneiss. The lowest rated targets were shown to be most of the dolerite contacts and secondary porous Karoo sedimentary rocks, especially argillaceous types.

Once the best available targets have been recognised, an appropriate geophysical method must be identified in order to be confident that the target features will be detected. It is not satisfactory to use one method only because it happens to be the only method the hydrogeologist or geophysicist has in their possession. A comparison of the relative success of several methods shows that in most cases there is a clear indication that one or two methods surpass the others. Apart from being able to carry out geophysics and interpret the data, the responsible person must consider the probable movement and occurrence of groundwater in the area as it affects the feature targeted.

The cost of drilling must also be taken into account before a final decision can be made on the potential of the aquifer for development. This is because the cost of drilling is one of the greatest costs involved in groundwater development. In general, percussion drilling will be used to access the secondary 'hard rock' aquifers of the province, but specialised ODEX drilling may be required in difficult cases, such as in unstable, very weathered and fractured formations within the Natal Group and Natal Metamorphic Province. Mud rotary and ODEX are the only drilling techniques that will be successful in the unconsolidated sands of the Maputaland Group and other primary deposits, such as alluvium. The cost of the latter two drilling methods is roughly double that of percussion drilling and if possible the use of shallow wells must be considered as an alternative means of accessing groundwater.

After selecting the most suitable hydrogeological targets, drilling will commence. The construction of the borehole through the correct use of casing and screens will allow the borehole to perform near its maximum capability. Following the completion of the borehole by means of development, pump testing must be carried out to determine the sustainable yield of the groundwater resource. Recognised pump testing procedures must be followed and the interpretation of the pump test data must be according to appropriate methods. The shape of the drawdown curve should, firstly, allow an identification or confirmation of the aquifer type to be made, e.g. consolidated and confined or bounded, and secondly, together with recovery curves, the aquifer characteristics responsible for the yield of groundwater may be derived. Both borehole and aquifer methods may be used to determine its sustainable yield. The main difference between these two methods is that the borehole method relies on the response of the borehole to pumping and is primarily controlled by transmissivity, storativity and hydraulic boundaries, while aquifer methods rely on estimations of recharge and storage. The correct application of all aspects of groundwater development will ultimately promote the use of groundwater as a reliable resource.

Boreholes may not always be the best option for groundwater development. Springs and wells must therefore also be considered as viable options. These sources of groundwater should be viewed as appropriate methods of groundwater development and not as second rate options.

It is knowledge the groundwater yield and quality of aquifers, appropriate geophysical siting and drilling methods, together with the recognition for the need of active social inputs throughout the process, which will contribute to the success of groundwater development in rural KwaZulu-Natal.

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APPENDIX A

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
1	B101304	Ingwavuma	32.0794	-27.3878	70	14.40	62			12.50	10.00	Jozini rhyolite	Jozini rhyolite/dolerite	3	contact
2	B101305	Ingwavuma	32.1297	-27.3744	66	17.70	40			2.00	2.00	Jozini rhyolite	dolerite	3	fractured
3	B101306 A	Ingwavuma	32.1664	-27.3497	60		-999			0.00		Zululand Group	Zululand siltstone		featureless
4	B101306 B	Ingwavuma	32.1647	-27.3497	79		-999			0.00		Zululand Group	Zululand siltstone		featureless
5	B101306 C	Ingwavuma	32.1652	-27.3511	60		-999			0.00		Zululand Group	Zululand siltstone		featureless
6	B101307 A	Ingwavuma	32.1547	-27.3128	100		-999			0.00		Zululand Group	Zululand sandstone/siltstone		contact
7	B101307B	Ingwavuma	32.1556	-27.3122	60		-999			0.00		Zululand Group	Zululand sandstone/siltstone		contact
8	B101308	Ingwavuma	32.1056	-27.4058	102	18.90	42	84		0.40	-1.00	Jozini rhyolite	dolerite	3	fractured
9	B101309 A	Ingwavuma	32.1656	-27.2763	91		-999			0.00		Zululand Group	Zululand sandstone/siltstone		contact
10	B101309 B	Ingwavuma	32.1522	-27.2756	70		-999			0.00		Zululand Group	Zululand sandstone/siltstone		contact
11	B101309 C	Ingwavuma	32.1528	-27.2747	96		-999			0.00		Zululand Group	Zululand sandstone/siltstone		contact
12	B101310	Ingwavuma	32.0558	-27.3791	110	57.00	54	60		0.20	0.16	Jozini rhyolite	Jozini rhyolite	2	fractured
13	B101311 A	Ingwavuma	32.0422	-27.3697	150		-999			0.00		Jozini rhyolite	Jozini rhyolite		featureless
14	B101311 C	Ingwavuma	32.0347	-27.3647	110		-999			0.00		Jozini rhyolite	Jozini rhyolite		featureless
15	B101312	Ingwavuma	31.9864	-27.2758	100	3.60	27	41		0.20	0.24	Jozini rhyolite	Jozini rhyolite	0	fractured
16	B101313 A	Ingwavuma	32.0886	-27.1483	120		-999			0.00		Jozini rhyolite	Jozini rhyolite		featureless
17	B101313 B	Ingwavuma	32.0514	-27.1475	130		-999			0.00		Jozini rhyolite	Jozini rhyolite		fractured
18	B101313 C	Ingwavuma	32.0494	-27.1469	149		-999			0.00		Jozini rhyolite	Jozini rhyolite		featureless
19	B101314	Ingwavuma	32.1656	-27.2431	82		-999			0.00		Zululand Group	Zululand sandstone/siltstone		contact
20	B101315 A	Ingwavuma	32.1550	-27.1922	60	7.80	49			0.20	-1	Zululand Group	Zululand sandstone/siltstone		contact
21	B101315 B	Ingwavuma	32.1556	-27.1931	48		-999			0.00		Zululand Group	Zululand sandstone/siltstone		contact
22	B101316	Ingwavuma	32.1247	-27.1592	80	6.70	32			0.20	0.09	Jozini rhyolite	Jozini tuff/rhyolite		contact
23	B101317 A	Ingwavuma	32.1931	-27.1633	36		-999			0.00		Maputaland sand	Zululand sandstone/siltstone		contact
24	B101317 B	Ingwavuma	32.1019	-27.1642	41		-999			0.00		Jozini rhyolite	Zululand sandstone/siltstone		contact
25	B101318 A	Ingwavuma	32. 2102	-27.1372	36		-999			0.00		Maputaland sand	Zululand sandstone/siltstone		contact
26	B101318 B	Ingwavuma	32.2106	-27.1389	36		-999			0.00		Maputaland sand	Zululand sandstone/siltstone		contact
27	B101319	Ingwavuma	32.0533	-27.3852	115	16.70	101			2.50	1.00	Jozini rhyolite	dolerite/Jozini rhyolite	3	contact
28	B10131A B	Ingwavuma	32.0411	-27.3708	120		-999			0.00		Jozini rhyolite	Jozini rhyolite		featureless
29	B101320	Ingwavuma	32.1077	-27.2222	55	6.30	36			0.71	1.00	Jozini rhyolite	dolerite	2	fractured
30	B101321	Ingwavuma	32.1097	-27.1194	60	7.60	21			0.66	0.66	Jozini rhyolite	dolerite	3	secondary porous
31	B101322 A	Ingwavuma	32.0056	-27.1811	45		-999			0.00		Jozini rhyolite	dolerite/Jozini rhyolite		contact
32	B101322 B	Ingwavuma	32.0061	-27.1653	150		-999			0.00		Jozini rhyolite	dolerite/Jozini rhyolite		contact
33	B101323	Ingwavuma	32.1233	-27.0253	60	8.65	30			6.67	2.00	Jozini rhyolite	Jozini rhyolite	3	secondary porous
34	B101324	Ingwavuma	32.1522	-26.8817	60	10.60	25			1.00	0.48	Jozini rhyolite	Jozini rhyolite	2	secondary porous
35	B101324 A	Ingwavuma	32.1531	-26.8817	140		-999			0.00		Jozini rhyolite	Jozini rhyolite		featureless
36	B101327	Ingwavuma	32.1714	-27.3225	25	9.40	24			0.27	0.13	Zululand Group	Zululand clay/gravel	3	primary
37	B101327 A	Ingwavuma	32.0064	-27.1672	30		24			1.11	-1.00	Maputaland sand	Maputaland palaeochannel	3	primary
38	B101328 B	Ingwavuma	32.1708	-27.1450	30		-999			0.00		Zululand Group	Zululand siltstone		secondary porous/featureless
39	B101328 B	Ingwavuma	32.1692	-27.1453	51		-999			0.00		Zululand Group	Zululand siltstone		secondary porous/featureless
40	B101329 A	Ingwavuma	32.2361	-26.9839	20		-999			0.00		Maputaland sand	Zululand sandstone/siltstone		contact
41	B101329 B	Ingwavuma	32.2347	-26.9850	36		-999			0.00		Maputaland sand	Zululand sandstone/siltstone		contact
42	B101330 A	Ingwavuma	32.1958	-27.0258	23		-999			0.00		Zululand Group	Zululand siltstone		featureless
43	B101330 B	Ingwavuma	32.1866	-27.0350	80		-999			0.00		Zululand Group	Zululand siltstone		featureless
44	B101331	Ingwavuma	32.2397	-26.9636	20	3.25	15			0.60	0.50	Maputaland sand	Maputaland sand	1	primary
45	B101332	Ingwavuma	32.1528	-26.9814	120	18.40	115			15.00	-1.00	Jozini rhyolite	Jozini rhyolite	3	fractured
46	B101333	Ingwavuma	32.1206	-27.1150	88	12.20	79			20.00	-1.00	Jozini rhyolite	Jozini rhyolite	3	fractured
47	B101334	Ingwavuma	32.0536	-27.3706	140	33.20	85			0.80	0.40	Jozini rhyolite	Jozini rhyolite	1	fractured
48	B101335	Ingwavuma	32.0314	-27.3811	150	4.60	136			0.08	0.10	Jozini rhyolite	Jozini rhyolite	2	featureless
49	B101336	Ingwavuma	32.0336	-27.3814	107	8.00	42	94		0.25	0.10	Jozini rhyolite	Jozini rhyolite	3	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
1	EM	250	MAG	250	8.3	246	1330	82	196	33	7	424	3.6	606	13	0.06	0.1	4.6		0.02	13.5
2	EM	310	MAG	310	7.9	1163	6821	602	291	241	448	1579	33.9	3714	450	0.19	0.1	1		0.01	9.5
3	EM	115																			
4	EM	115	MAG	115																	
5	EM	115																			
6	EM	135	MAG	135																	
7	EM	135	MAG	135																	
8	EM	370	MAG	370	8.3	135	863	52	256	21	10	241	5.3	219	41	0.91	0.1	12.9		0.04	6.4
9	EM	160	MAG	160																	
10	EM	160																			
11	none																				
12	EM	400	MAG	400	8.8	72.8	590	12	303	5	2	158	3.3	41	8	0.04	0.1	2.8		0.03	11.7
13	EM	200																			
14	EM	200	MAG	200																	
15	EM	260	MAG	260	6.9	44.1	268	25	92	10	7	61	3.3	65	9	0.04	0.1	0.3		0.03	14.1
16	EM	130	MAG	130																	
17	EM	130	MAG	130																	
18	EM	130																			
19	EM	350																			
20	EM	170																			
21	EM	170																			
22	EM	280																			
23	EM	160																			
24	EM	160																			
25	EM	180																			
26	EM	180																			
27	MAG	115			8.3	120	971	25	406	10	3	281	2.4	118	56	0.15	0.1	4.2		0.02	10.9
28	EM	200	MAG	200																	
29	EM	300	MAG	300	7.6	88.8	713	105	288	42	19	142	4	145	8	0.05	0.1	1.9		0.02	28.6
30	EM	170	MAG	170	8	708	4148	529	346	212	129	1128	22.7	2172	50	0.07	2.1	3.9		0.02	27.4
31	MAG	300																			
32	EM	340	MAG	340																	
33	EM	280	MAG	280	8.3	218	1282	142	275	57	35	345	6.8	481	17	0.05	0.1	4.9		0.02	18.5
34	EM	110	MAG	110	7.5	69.1	591	100	274	40	14	108	4.3	78	7	0.04	0.1	3.5		0.03	19.1
35	EM	110	MAG	110																	
36	none				7.9	916	5145	999	274	400	308	1032	67	2694	300	0.07	1.5	2		0.02	8.5
37	none				8.1	600															
38	geology																				
39	geology																				
40	EM	210	MAG	210																	
41	EM	160	MAG	160																	
42	EM	285	MAG	285																	
43	EM	285	MAG	285																	
44	MAG	180			8.3	92.4	673	110	222	44	29	110	6	192	8	8.66	0.1	1.1		0.02	16.3
45	EM	260	MAG	260	7.7	437	2466	207	96	83	19	810	10.6	1300	121	0.14	0.1	4.1		0.01	6.4
46	MAG	70			8.1	221	1292	75	200	30	3	415	3.2	536	56	0.04	0.1	4.3		0.01	20.4
47	MAG	130			8	67.5	535	80	224	32	19	88	5.6	104	4	0.04	1.8	1.2		0.02	22.7
48	MAG	75			8.4	152	937	42	283	17	7	270	3.3	283	10	0.04	0.1	0.9		0.03	22.7
49	geology				8	222	1312	70	264	28	11	416	3.8	519	8	0.05	0.1	2.3		0.01	19

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
50	B101337	Ingwavuma	31.9839	-27.2178	152	61.20	133			0.13	0.10	Jozini rhyolite	dolerite	1	fractured
51	B101338	Ingwavuma	32.0056	-27.2228	152	61.20	85			0.09	0.07	Jozini rhyolite	Jozini rhyolite	0	fractured
52	B101338 A	Ingwavuma	32.0047	-27.2217	152		-999			0.00		Jozini rhyolite	Jozini rhyolite		featureless
53	B101339	Ubombo	32.4767	-27.0542	25.23	7.13	13			-1.00	0.28	Maputaland sand	Maputaland sand	2	primary
54	B101340	Ubombo	32.4581	-27.0989	25.23	5.91	12			-1.00	0.28	Maputaland sand	Maputaland sand	1	primary
55	B101341	Ingwavuma	32.0133	-27.1925	132	46.80	88			1.30	1.00	Jozini rhyolite	Jozini rhyolite	1	fractured
56	B101341 A	Ingwavuma	32.0164	-27.3728	152		-999			0.00		Jozini rhyolite	Jozini rhyolite		featureless
57	B102273	Ubombo	32.1142	-27.6703	132	64.80	105			0.30	0.30	Jozini rhyolite	Jozini rhyolite	2	featureless
58	B102274	Ubombo	32.1208	-27.6842	91	31.70	42	70		0.33	0.13	Letaba basalt	Letaba basalt	2	fractured
59	B102275 A	Ubombo	32.2342	-27.7861	138		-999			0.00		Maputaland sand	Jozini rhyolite/dolerite		contact
60	B102275 B	Ubombo	32.2339	-27.7850	145		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
61	B102276	Ubombo	32.2206	-27.7742	102	54.20	67			0.67	0.08	Jozini rhyolite	Jozini rhyolite	2	fractured
62	B102276 A	Ubombo	32.2175	-27.7742	131		-999			0.00		Jozini rhyolite	Jozini rhyolite		fractured
63	B102277	Ubombo	32.2206	-27.7719	102	20.60	59			0.57	0.10	Jozini rhyolite	Jozini rhyolite/dolerite	1	fractured
64	B102278 A	Ubombo	32.1928	-27.7678	138		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
65	B102278 B	Ubombo	32.1894	-27.7667	144		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		featureless
66	B102278 C	Ubombo	32.1908	-27.7622	144		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
67	B102279	Ubombo	32.2164	-27.7514	101	25.30	38			0.08	0.06	Jozini rhyolite	Jozini rhyolite	1	fractured
68	B102280	Ubombo	32.2178	-27.7636	120	78.50	96			0.67	0.42	Jozini rhyolite	Jozini rhyolite	2	fractured
69	B102281	Ubombo	32.2431	-27.7558	65	7.00	11			0.28	0.10	Jozini rhyolite	Jozini rhyolite	2	fractured
70	B102281 A	Ubombo	32.2414	-27.7550	130		-999			0.00		Jozini rhyolite	Jozini rhyolite		fractured
71	B102282 A	Ubombo	32.1786	-27.7409	145		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
72	B102283	Ubombo	32.1564	-27.7017	106	36.90	68			1.43	0.19	Jozini rhyolite	Jozini rhyolite/dolerite	2	contact
73	B102284	Ubombo	32.1628	-27.6942	102	20.10	43			0.14	0.06	Jozini rhyolite	Jozini rhyolite/dolerite	2	contact
74	B102285 A	Ubombo	32.1508	-27.6939	140		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
75	B102285 B	Ubombo	32.1508	-27.6936	130		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
76	B102286	Ubombo	32.1542	-27.6822	120	27.10	78			0.50	0.42	Jozini rhyolite	Jozini rhyolite	3	fractured
77	B102287 A	Ubombo	32.1317	-27.6664	141		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
78	B102287 B	Ubombo	32.1336	-27.6686	129		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
79	B102288	Ubombo	32.0594	-27.5661	121	68.70	44	98		0.14	0.05	Jozini rhyolite	Jozini rhyolite/dolerite	3	contact
80	B102288 A	Ubombo	32.0647	-27.6686	151		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
81	B102289	Ubombo	32.0253	-27.5636	101	10.00	64			0.08	0.01	Jozini rhyolite	Jozini rhyolite	2	featureless
82	B102290	Ubombo	32.0164	-27.4947	104	32.40	49			0.17	0.03	Jozini rhyolite	Jozini rhyolite	2	fractured
83	B102291	Ubombo	32.0131	-27.4703	126	10.60	94			0.97	0.07	Jozini rhyolite	Jozini rhyolite	3	fractured
84	B102292	Ubombo	32.0603	-27.4581	110	8.53	55			0.56	0.04	Jozini rhyolite	Jozini rhyolite/dolerite	2	contact
85	B102293	Ubombo	32.0661	-27.4494	101	31.04	94			0.22	0.08	Jozini rhyolite	Jozini rhyolite/dolerite	3	contact
86	B102294	Ubombo	32.0703	-27.4428	98	47.03	87			1.05	0.42	Jozini rhyolite	Jozini rhyolite	1	fractured
87	B102295	Ubombo	32.1119	-27.5358	120	72.47	109			2.50	2.50	Jozini rhyolite	Jozini rhyolite/dolerite	3	contact
88	B102296	Ubombo	32.1403	-27.5567	120	30.21	40			0.08	0.04	Jozini rhyolite	Jozini rhyolite/dolerite	2	contact
89	B102296 A	Ubombo	32.1419	-27.5569	132		-999			0.00		Jozini rhyolite	Jozini rhyolite		secondary porous
90	B102297 A	Ubombo	32.1456	-27.5772	125		-999			0.00		Jozini rhyolite	Jozini rhyolite		featureless
91	B102297 B	Ubombo	32.1447	-27.5769	150		-999			0.00		Jozini rhyolite	Jozini rhyolite/dolerite		contact
92	B102298	Ubombo	32.1522	-27.5714	93	4.24	11			0.33	0.25	Jozini rhyolite	dolerite	3	secondary porous
93	B102299	Ubombo	32.1867	-27.5569	30	18.91	24			2.50	1.53	Maputaland sand	Maputaland palaeochannel	3	primary
94	B102300	Ubombo	32.1772	-27.5681	21	10.18	15			2.83	2.50	Maputaland sand	Maputaland palaeochannel	3	primary
95	B102301	Ubombo	32.1914	-27.5642	26	13.52	22			5.00	4.00	Maputaland sand	Maputaland palaeochannel	2	primary
96	B102302	Ubombo	32.2064	-27.5708	19	8.50	12			2.78	1.00	Maputaland sand	Maputaland palaeochannel	3	primary
97	B102303	Ubombo	32.0361	-27.4511	151	85.10	145			0.14	0.22	Jozini rhyolite	Jozini rhyolite	2	fractured
98	B102304	Ubombo	32.2431	-27.5472	20	6.40	16			4.44	2.50	Maputaland sand	Maputaland palaeochannel	2	primary

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
50	MAG	80			8.1	85.9	674	32	292	13	6	176	2.7	88	20	0.04	2.4	1.1		0.01	24.9
51	geology				7.7	41.7	255	20	77	8	6	56	6.9	58	12	0.29	3.1	0.2		0.03	12.8
52	geology																				
53	geology				8	259	1589		357	125	30	359	7.2	557	75	0.04	0.04	0.2		0.01	
54	geology				7.7	81.5	608		215	16	7	159	5.3	148	10	0.04	0.04	0.2		0.016	
55	geology				8.4	52.6	420	100	226	40	11	55	5.4	21	10	0.04	0.1	1.1		0.05	18.6
56	MAG	210																			
57	MAG	220			8.1	108.6	624		75	48	2	176	1.6	284	19	0.04	0.36	0.4		0.009	
58	MAG	400			10	175	878		30	70	1	253	1.5	486	31	0.04	0.04	0.6		0.014	
59	MAG	150																			
60	MAG	150																			
61	MAG	270			7.9	143	934		269	45	31	200	6.9	243	73	0.04	1.29	0.6		0.021	
62	MAG	400																			
63	MAG	210			7.8	84	637		260	54	21	104	3.9	108	29	0.04	0.05	0.8		0.016	
64	VLF	115	MAG	115																	
65	VLF	115	MAG	115																	
66	VLF	300	MAG	300																	
67	MAG	490			7.7	96.8	742		316	61	23	124	3.1	131	13	0.04	0.22	0.7		0.012	
68	MAG	200			7.7	139	983		362	54	34	192	3.8	230	22	0.04	1.1	0.8		0.027	
69	MAG	260			7.5	224	1429		327	530	59	313	4.1	530	40	0.04	1.12	0.8		0.013	
70	MAG	260																			
71	MAG	150																			
72	MAG	250			8.3	123.4	875		299	15	8	247	3.3	218	18	0.04	0.06	1.5		0.013	
73	VLF	280	MAG	280	7.8	91.4	640		187	42	24	125	6.6	209	4	0.04	0.17	0.6		0.037	
74	MAG	75																			
75	MAG	75																			
76	VLF	250	MAG	250	7.6	326	1718		142	64	69	453	15.7	393	48	0.04	0.04	0.5		0.07	
77	MAG	165																			
78	MAG	165																			
79	MAG	150			7.9	237	1343		112	93	32	316	5	539	14	0.87	46.02	1.5		0.009	
80	MAG	150																			
81	MAG	300			8.2	113.8	760		253	25	9	192	4.2	207	13	0.04	0.04	2.4		0.011	
82	MAG	250			8.1	161	864		201	45	12	238	2.7	297	22	0.04	0.05	1.2		0.021	
83	none				8.1	142	729		83	15	2	240	2.1	344	19	0.04	0.41	3.8		0.018	
84	MAG	300			7.7	69.8	533		272	48	14	73	6.7	50	6	0.04	0.04	2.8		0.012	
85	MAG	260			7.2	674	3914		424	288	171	820	23.6	2025	63	0.08	0.93	2		0.019	
86	MAG	250			7.6	91.9	632		239	146	16	108	11.4	146	11	0.04	0.05	0.7		0.01	
87	MAG	300			8.8	180	1054		310	11	6	341	3.1	296	15	0.04	0.04	5.4		0.036	
88	MAG	300			8.3	115.5	758		243	6	1	240	2.7	203	7	0.04	0.04	3		0.022	
89	MAG	200																			
90	MAG	175																			
91	MAG	175																			
92	MAG	250			7.4	1279	7518		553	258	273	2163	0.3	4057	90	0.1	0.26	3.1		0.019	
93	geology				8	863	6037		1232	76	178	1713	10.3	2312	243	0.08	0.24	1.7		0.012	
94	geology				7.9	369	2427		583	185	220	265	0.3	869	159	0.08	3.99	0.9		0.014	
95	geology				7.6	186	1161		304	85	67	194	1.8	325	117	0.06	0.11	0.6		0.011	
96	geology				7.9	345	2053		310	154	127	368	0.3	827	189	0.1	1.96	0.5		0.027	
97	MAG	140			8	144	730		113	27	7	220	7.8	305	23	0.04	0.06	2.1		0.029	
98	geology				7.9	202	1358		474	53	66	280	1	278	102	0.05	0.06	0.6		0.018	

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
99	B102305 A	Ubombo	32.3558	-27.6358	35		-999			0.00		Maputaland sand	Maputaland sand/Zululand siltstone		contact
100	B102305 B	Ubombo	32.3275	-27.6044	28		-999			0.00		Maputaland sand	Maputaland sand/Zululand siltstone		contact
101	B102305 C	Ubombo	32.3472	-27.6042	35		-999			0.00		Maputaland sand	Maputaland sand/Zululand siltstone		contact
102	B102306	Ubombo	32.3264	-27.3306	49	43.44	-999			0.00		Maputaland sand	Maputaland sand		primary
103	B102307	Ubombo	32.3325	-27.3197	47	43.62	-1			-1.00	0.03	Maputaland sand	Maputaland sand		primary
104	B102308	Ubombo	32.3636	-27.3111	38	36.34	-999			0.00		Maputaland sand	Maputaland sand		primary
105	B102309	Ubombo	32.3819	-27.2969	46	36.51	-1			-1.00	0.04	Maputaland sand	Maputaland sand/Zululand siltstone		contact
106	B102309 A	Ubombo	32.3769	-27.2981	44		-999			0.00		Maputaland sand	Maputaland sand		primary
107	B102310	Ubombo	32.3669	-27.2681	49	35.00	-1			-1.00	0.04	Maputaland sand	Maputaland sand/Zululand siltstone		contact
108	B102311	Ubombo	32.3658	-27.2564	45	32.92	-1			-1.00	0.05	Maputaland sand	Maputaland sand	2	primary
109	B102312 A	Ubombo	32.3408	-27.2783	37		-999			0.00		Maputaland sand	Maputaland sand/Zululand siltstone		contact
110	B102313	Ubombo	32.2725	-27.2925	23	12.90	-1			-1.00	0.10	Maputaland sand	Maputaland sand/Zululand siltstone	3	contact
111	B102314	Ubombo	32.2856	-27.2050	27	25.92	-1			-1.00	0.01	Maputaland sand	Maputaland sand		primary
112	B102317	Ubombo	32.4322	-27.3514	42	18.47	-1			-1.00	0.03	Maputaland sand	Maputaland sand	3	primary
113	B102318	Ubombo	32.4247	-27.3775	42	15.01	-1			-1.00	0.05	Maputaland sand	Maputaland sand	1	primary
114	B102319 A	Ubombo	32.4247	-27.3769	42		-999			0.00		Maputaland sand	Maputaland sand		primary
115	B102320 A	Ubombo	32.3019	-27.5339	49		-999			0.00		Maputaland sand	Maputaland palaeochannel		primary
116	B102320 B	Ubombo	32.2975	-27.5158	47		-999			0.00		Maputaland sand	Maputaland sand/Zululand siltstone		contact
117	B102321 A	Ubombo	32.3606	-27.3667	42		-999			0.00		Maputaland sand	Maputaland sand/Zululand siltstone		contact
118	B102322 A	Ubombo	32.3056	-27.4203	37		-999			0.00		Maputaland sand	Maputaland sand/Zululand siltstone		contact
119	B103105	Hlabisa	32.1481	-28.2714	152	4.95	56			0.10	0.11	Karoo argillaceous	Karoo argillaceous/dolerite	3	fractured
120	B103105 A	Hlabisa	32.1486	-28.2711	80		-999			0.00		Karoo argillaceous	dolerite		fractured
121	B103106	Hlabisa	32.1419	-28.2917	52	2.95	12			0.66	0.18	Karoo sandstone	secondary porous	3	primary
122	B103107	Hlabisa	32.1386	-28.2733	52	3.80	39			5.00	0.13	Letaba basalt	dolerite	3	fractured
123	B103108	Hlabisa	32.1628	-28.2242	62	6.70	21			0.70	0.17	Letaba basalt	dolerite	1	fractured
124	B103109	Hlabisa	32.1894	-28.2611	82	17.00	67			0.60	0.11	Letaba basalt	dolerite	2	fractured
125	B103110	Hlabisa	32.1658	-28.2053	152	10.00	134			0.40	0.10	Karoo sandstone	dolerite	2	fractured
126	B103111	Hlabisa	32.1497	-28.2442	122	11.72	22	102		0.70	0.10	Karoo argillaceous	dolerite	3	fractured
127	B103112	Hlabisa	32.2003	-28.2442	62	8.00	35			0.60	0.13	Letaba basalt	dolerite	1	fractured
128	B103112 A	Hlabisa	32.1997	-28.2489	102		-999			0.00		Letaba basalt	dolerite		fractured
129	B103112 B	Hlabisa	32.2019	-28.2497	102		-999			0.00		Letaba basalt	dolerite		fractured
130	B103113	Hlabisa	32.1919	-28.2439	62	7.50	21			1.90	0.13	Letaba basalt	dolerite	3	fractured
131	B103114	Hlabisa	32.2097	-28.2172	98	19.00	27			0.30	0.16	Letaba basalt	dolerite	2	fractured
132	B103114 A	Hlabisa	32.1981	-28.5389	104		-999			0.00		dolerite	dolerite		featureless
133	B103114 B	Hlabisa	32.1875	-28.2222	104		-999			0.00		Karoo sandstone	dolerite		featureless
134	B103115	Hlabisa	32.2222	-28.2181	50	7.30	15	41		10.00	0.13	Letaba basalt	dolerite	2	fractured
135	B103116	Hlabisa	32.2244	-28.2031	50	3.28	13	21		1.00	0.17	Letaba basalt	dolerite	3	fractured
136	B103117	Hlabisa	32.2078	-28.2003	56	2.00	9	21		0.50	0.17	Letaba basalt	dolerite	2	fractured
137	B103118	Hlabisa	32.1997	-28.1844	62	6.70	18			1.50	0.17	Karoo argillaceous	Karoo argillaceous/dolerite	2	secondary porous/featureless
138	B103118 A	Hlabisa	32.1983	-28.1872	104		-999			0.00		Letaba basalt	dolerite		fractured
139	B103118 B	Hlabisa	32.1975	-28.1856	104	18.00	39			0.08	0.00	Letaba basalt	dolerite		fractured
140	B103119	Hlabisa	32.1806	-28.2353	62	8.12	49			1.00	0.11	Karoo sandstone	dolerite	2	fractured
141	B103120	Hlabisa	32.2214	-28.1814	98	29.60	46	86		0.60	0.10	Letaba basalt	dolerite	2	fractured
142	B103121	Hlabisa	32.2219	-28.1503	62	13.72	15	55		0.60	0.11	Letaba basalt	dolerite	2	fractured
143	B103121 A	Hlabisa	32.2222	-28.1517	80		-999			0.00		Letaba basalt	dolerite		fractured
144	B103122	Hlabisa	32.2178	-28.1675	62	7.90	9	50		6.00	0.11	Letaba basalt	dolerite	2	fractured
145	B103123	Hlabisa	32.1925	-28.1686	62	5.05	47			0.60	0.11	Karoo sandstone	dolerite	2	fractured
146	B103124	Hlabisa	32.1997	-28.1778	62	6.90	65			0.70	0.13	Letaba basalt	dolerite	1	fractured
147	B103125	Hlabisa	32.2294	-28.1644	50	4.34	12			1.00	0.18	Letaba basalt	dolerite	3	secondary porous

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
99	geology																				
100	geology																				
101	geology																				
102	geology																				
103	geology																				
104	geology																				
105	geology																				
106	geology																				
107	geology																				
108	geology				7.6	151	886		212	51	20	210		277	42	0.04	4.44	0.3		0.014	
109	geology																				
110	geology				7.1	1096	6804		391	798	382	1069	66.4	3476	525	0.05	2.47	0.1		0.016	
111	geology																				
112	geology				6.5	238	1281		159	246	24	159	8.8	618	30	0.04	0.48	0.2		0.009	
113	geology				5.5	82.2	575		301	53	23	54	13.1	30	35	0.19	0.04	0.2		0.036	
114	geology																				
115	geology																				
116	geology																				
117	geology																				
118	geology																				
119	EM	85	MAG	85	7.8	428	2740	527	627	211	106	533	14.1	976	135	0.38	0.04	0.8		0.012	16.4
120	EM	85	MAG	85																	
121	EM	310	MAG	310	8	254	1644	75	580	30	42	447	2	393	22	0.04	0.01	0.5		0.016	17.6
122	EM	180	MAG	180	8	676	4105	410	538	164	169	1042	14.7	1923	134	0.36	0.08	1		0.011	12.1
123	EM	490	MAG	480	9	96	692	72	310	29	23	142	2	81	16	0.04	5	0.2		0.02	26.5
124	EM	210	MAG	210	8.4	138	948	57	321	23	34	235	4.5	251	9	0.05	0.05	0.2		0.025	21.9
125	EM	380	MAG	380	8	120	834	42	344	17	14	220	3	149	8	0.05	0	0.4		0.033	38.2
126	EM	260	MAG	260	8	287	1759	127	504	51	44	466	8	533	37	0.16	0.8	0.4		0.022	7
127	EM	260	MAG	260	8.5	103.6	821	57	284	23	23	188	10	185	15	0.17	6.77	0.2		0.031	15.3
128	EM	160	MAG	140																	
129	EM	260	MAG	260																	
130	EM	260	MAG	260	7.7	550	2885	804	23	322	9	739	9	1410	367	0.78	0.08	0.5		0.016	7.6
131	EM	133	MAG	133	7	126	742	55	197	22	17	199	5	236	9	0.15	3	0.2		0.105	16.1
132	EM	133	MAG	133																	
133	EM	133	MAG	133																	
134	EM	360	MAG	360	7.9	163	964	115	261	46	35	210	0.8	264	7	0.04	18.96	0.1		0.019	27.5
135	EM	240	MAG	240	8.4	150	1077	107	257	43	39	230	2.4	270	11	0.05	37.73	0.2		0.026	26.6
136	EM	450	MAG	440	8.7	151	895	112	266	45	32	199	1.3	243	3	0.05	11.03	0.1		0.022	27
137	EM	220	MAG	200	8.2	198	1122	77	242	31	36	301	3.5	426	24	0.04	0.97	1.2		0.006	10.2
138	EM	110	MAG	100																	
139	EM	110	MAG	100																	
140	EM	250	MAG	250	8.4	124.7	959	97	338	39	37	203	2.8	240	12	0.15	2.66	0.3		0.024	14.7
141	EM	170	MAG	170	8.3	144	969	100	251	40	29	232	6.4	323	5	0.06	6.18	0.2		0.058	14.8
142	EM	200	MAG	195	8.3	148	987	132	345	53	48	182	2.6	227	21	0.07	7.37	0.2		0.042	20.2
143	EM	200	MAG	195																	
144	EM	250	MAG	250	8.3	166	1059	130	332	52	48	218	2.5	289	15	0.05	6.38	0.2		0.023	26.6
145	EM	400	MAG	390	8.3	206	1074	165	410	66	63	299		445	23	0.04	0.01	0.3		0.013	26.4
146	EM	300	MAG	120	8.3	103.6	722	92	242	37	29	148	3.7	164	11	0.04	7.63	0.2		0.011	26.3
147	EM	210	MAG	210	7.7	147	1067	125	302	50	54	199	2.5	273	5	0.05	25.96	0.2		0.006	18.4

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
148	B103125 A	Hlabisa	32.2339	-28.1689	104		-999			0.00		Letaba basalt	dolerite		fractured
149	B103126	Hlabisa	32.2400	-28.1458	152	14.14	100			0.21	0.10	Letaba basalt	dolerite	2	fractured
150	B103127	Hlabisa	32.2300	-28.1386	104	8.50	60			0.14	0.11	Letaba basalt	dolerite	2	fractured
151	B103128	Hlabisa	32.2614	-28.1511	62	8.22	49			0.40	0.11	Letaba basalt	dolerite	2	fractured
152	B103129	Hlabisa	32.1731	-28.1783	62	25.15	33			0.90	0.15	Karoo argillaceous	dolerite	1	fractured
153	B103130	Hlabisa	32.1717	-28.1589	62	21.54	37			8.00	0.16	dolerite	dolerite	2	fractured
154	B103131	Hlabisa	32.2250	-28.2372	50	4.11	15	34		2.50	0.16	Letaba basalt	dolerite	2	fractured
155	B103132	Hlabisa	32.1772	-28.1992	62	8.95	27	56		4.00	0.11	Karoo sandstone	dolerite	2	secondary porous
156	B103133	Hlabisa	32.2250	-28.2372	74	14.03	51			1.25	0.11	Letaba basalt	dolerite		fractured
157	B103133 A	Hlabisa	32.2250	-28.2372	110		-999			0.00		Letaba basalt	dolerite		fractured
158	B103134	Hlabisa	32.2836	-28.1647	62	9.10	20	38		6.25	0.60	Maputaland sand	dolerite	2	fractured
159	B202191	Enseleni	31.4933	-28.7242	126	37.57	45			0.10	0.10	Zng	Letaba basalt	0	secondary porous
160	B202192	Enseleni	31.4661	-28.7181	120	41.86	81			0.15	0.15	Zd	Zd	0	secondary porous
161	B202193	Enseleni	31.4619	-28.7478	108	47.70	70			0.30	0.20	NMP	NMP granite	0	secondary porous
162	B202194	Enseleni	31.4475	-28.7233	111	36.36	82			1.00	0.50	Zng	Letaba basalt/pegmatite	0	contact
163	B202195	Enseleni	31.4178	-28.7111	117	55.60	79	92		0.70	0.30	dolerite	Letaba basalt	0	secondary porous
164	B202196	Enseleni	31.4208	-28.7083	130	64.50	112			1.00	0.20	Zng	Zng	0	secondary porous
165	B202197	Enseleni	31.4169	-28.6917	64	29.92	36			3.00	2.00	Zng	NGS	0	secondary porous
166	B202198 A	Enseleni	31.4736	-28.6933	158		-999			0.00		Zng	NGS		featureless
167	B202198 B	Enseleni	31.4697	-28.6889	158		-999			0.00		NGS	NGS		secondary porous
168	B202198 C	Enseleni	31.4708	-28.6894	158		-999			0.00		NGS	NGS		secondary porous
169	B202199	Enseleni	31.4664	-28.6864	92	36.30	36	72		1.30	0.30	NGS	NGS	0	fractured
170	B202200	Enseleni	31.4361	-28.6936	120	23.64	53			0.30	0.20	Zng	Zng	0	secondary porous
171	B202201	Enseleni	31.4439	-28.6861	86	56.42	38	63		0.40	0.50	Zng	Zng	0	secondary porous
172	B202202	Enseleni	31.4353	-28.6831	121	37.54	89			0.30	0.50	Zng	NGS	0	fractured
173	B202203	Enseleni	31.4508	-28.6736	104	32.80	79			0.50	0.50	Zng	Zng	0	secondary porous
174	B202204	Enseleni	31.4556	-28.6639	104	49.60	74			0.50	0.30	Zng	Zng/dolerite	0	contact
175	B202205	Enseleni	31.5631	-28.6183	143	36.50	43			0.30	0.20	NGS	Zng	1	secondary porous
176	B202206	Enseleni	31.5325	-28.6317	144	127.00	120			0.10	0.00	NGS	NGS/shale	0	contact
177	B202206 A	Enseleni	31.5322	-28.6311	144		-999			0.00		NGS	Karoo argillaceous/dolerite	0	contact
178	B202207	Enseleni	31.5353	-28.6400	120	56.60	90			3.00	0.20	NGS	NGS	0	fractured
179	B202208	Enseleni	31.5011	-28.6311	112	58.50	62			0.50	0.10	NGS	NGS	1	fractured
180	B202209	Enseleni	31.5036	-28.6275	120	62.00	80			0.10	0.10	NGS	NGS	0	fractured
181	B202210	Enseleni	31.4950	-28.6150	135	60.58	51	106		0.15	0.10	NGS	NGS	0	fractured
182	B202211	Enseleni	31.5481	-28.6294	121	47.30	96			0.10	0.10	NGS	NGS	3	fractured
183	B202211 A	Enseleni	31.5514	-28.6322	150		-999			0.00		NGS	NGS	0	featureless
184	B202212	Enseleni	31.5481	-28.6297	49	26.06	34	36	48	1.50	0.50	Zng	Zng	0	fractured
185	B202213	Enseleni	31.5033	-28.6833	104	66.00	84	93		0.20	0.15	NGS	Zng	0	fractured
186	B202214	Enseleni	31.5214	-28.7103	61	18.90	31			8.00	1.50	Zng	Zng	1	secondary porous
187	B202215	Enseleni	31.4758	-28.6489	137	91.10	109			0.75	2.50	NGS	NGS	0	fractured
188	B202216	Enseleni	31.5203	-28.7022	37	17.20	28			2.00	0.50	Zng	Zng/dolerite	0	contact
189	B202217	Enseleni	31.3833	-28.5414	122	50.56	82			0.80	0.75	NGS	NGS	0	secondary porous
190	B202218	Enseleni	31.4806	-28.6736	104	81.20	61	92		2.50	0.30	NGS	NGS	0	fractured
191	B202219	Enseleni	31.5333	-28.6644	71	30.60	36	42		0.50	0.50	NGS	NGS/dolerite	0	contact
192	B202220	Enseleni	31.5508	-28.6742	121	68.80	87			0.10	0.10	NGS	NGS	0	fractured
193	B202221	Enseleni	31.5431	-28.6892	70	15.20	44	50		0.40	0.25	NGS	NGS	0	fractured
194	B202221 A	Enseleni	31.5406	-28.6889	150		-999			0.00		NGS	NGS		fractured
195	B202222	Enseleni	31.5211	-28.6811	121	25.30	69			0.10	0.10	NGS	NGS	0	fractured
196	B202223	Enseleni	31.5072	-28.6528	151	71.00	78	125		0.15	0.10	NGS	NGS	0	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
148	EM	150	MAG	150																	
149	EM	270	MAG	270	8.6	188	1346	190	442	76	65	244	6	383	21	0.11	2.59	0.2		0.017	15
150	EM	280	MAG	280	8	155	965	65	250	26	21	265	3.7	304	17	0.04	5.14	0.3		0.005	9.3
151	EM	480	MAG	480	7.4	176	935	130	62	52	12	266	3.1	474	28	0.04	5.35	0.4		0.007	4
152	EM	270	MAG	270	7.3	89.2	590	67	152	27	25	118	2.1	192	7	0.04	7.6	0.2		0.005	18.9
153	EM	480	MAG	470	8	99	737	105	261	42	42	112	1	143	15	0.04	14.2	0.2		0.017	30.7
154	EM	170	MAG	170	8.2	208	1370	170	405	68	62	298	0	446	20	0.04	0	0.2		0.019	26.4
155	none				8.3	266	1504	142	370	57	67	338	16.7	534	39	0.85	0.06	0.2		0.02	12.3
156	EM	200	MAG	200																	
157	EM	200	MAG	200																	
158	EM	490	MAG	490	8	175	979	235	196	94	59	131	4	259	185	0.04	1.4	0.2		0.012	22.8
159	EM	800	MAG	400	8.3	21.8	176		81	3	3	36	5.9	12	15		0.06	0.6		0.037	4.3
160	EM	100	MAG	100	8.2	23.1	176		80	4	3	36	6	12	18		0.04	0.6		0.052	4.4
161	EM	600	MAG	300	8.1	43	300		118	16	6	49	17.6	29	31		1.19	1		0.047	2.9
162	EM	500	MAG	500	8.5	21.9	175		87	10	7	16	13.7	9	13		0.04	0.5		0.044	18.2
163	EM	280	MAG	140	7.5	20.5	164		86	15	10	8	3.2	10	13		0.04	0.5		0.049	6.3
164	EM	400	MAG	200	7.8	11.7	101		50	4	4	12	3.5	6	9		0.07	0.2		0.051	19.5
165	EM	80	MAG	40	6.9	14.1	94		30	3	3	17	2	20	10		0.38	0.4		0.047	15.6
166	EM	200	MAG	200																	
167	EM	860	MAG	430																	
168	EM	400	MAG	200																	
169	EM	1000	MAG	500	7.5	11.4	83		32	6	3	11	2.3	8	9		0.5	0.2		0.022	9.6
170	MAG	100			7.4	18.2	151		77	10	6	12	10.3	11	7		0.07	0.4		0.014	4.8
171	EM	200	MAG	200	8.1	20.2	153		78	9	9	13	7.3	11	7		0.04	0.2		0.019	8.4
172	Geology				7.7	17.1	124		53	5	3	24	3	11	10		0.65	0.3		0.121	18.1
173	EM	610	MAG	300	8.1	11.6	138		60	8	5	21	3.2	15	11		0.05	0.3		0.07	20.8
174	EM	200	MAG	100	7.9	19.5	140		59	4	2	33	2.5	14	5		1.57	0.4		0.036	23.1
175	EM	560	MAG	280	7.8	79.1	558		244	46	20	83	4	88	20		0.04	0.4		0.014	19.9
176	EM	300	MAG	150	7.2	12.2	69		23	4	2	13	3.7	10	6		0.78	0.3		0.026	9
177	EM	300	MAG	150																	
178	EM	450	MAG	340	7.9	17.4	120		42	4	6	24	2.7	21	10		0.51	0.6		0.204	11.7
179	EM	1200	MAG	600	5.6	28.7	213	102	97	31	6	20	3	15	20		0.04	0.3		0.028	11.5
180	EM	660	MAG	330	8.1	25.2	190		82	22	4	19	7.6	16	11		1.93	0.3		0.06	5.3
181	EM	900	MAG	500	7.6	28.7	201		81	16	5	31	8.7	21	17		0.04	0.5		0.03	5.2
182	EM	500	MAG	300																	
183	EM	500	MAG	300																	
184	EM	1000	MAG	500	8	20.4	140		60	8	6	23	2.9	17	7		0.86	0.3		0.052	14.4
185	EM	940	MAG	470	7.8	13	89	13.2	27	2	2	21	4.1	15	12		0.1	0.3		0.02	5.3
186	EM	400	MAG	200	8.2	67.2	463	201	202	31	30	59	2.7	76	12		0.87	0.5		0.014	11.7
187	EM	400	MAG	200	7	16.2	132		44	7	3	19	3.1	15	27		0.75	0.5		0.17	18.6
188	EM	640	MAG	320	8.1	46.2	312	108	143	17	16	48	4.4	42	9		0.1	0.4		0.014	20.2
189	EM	400	MAG	200	7.7	25	176		79	22	5	20	2.8	14	13		0.61	0.3		0.021	14.7
190	EM	360	MAG	180	7.8	17.8	115		44	11	4	15	2.8	15	5		1.85	0.4		0.066	10.4
191	EM	800	MAG	400	7.9	16.5	110		52	12	3	12	3.4	9	5		0.3	0.2		0.02	11.4
192	EM	400	MAG	200	7.6	29.5	190		75	21	6	25	3.9	24	18		0.04	0.5		0.054	9.1
193	EM	460	MAG	250	6.9	9.9	59		19	2	1	11	3.5	8	7		0.51	0.2		0.04	11.7
194	EM	460	MAG	240																	
195	EM	320	MAG	160	8.1	36.9	371		145	28	18	48	8.9	43	48		0.04	0.3		0.015	7.4
196	EM	840	MAG	460	7.7	24.8	178		79	11	3	29	11.1	13	14		0.07	1		0.041	3.8

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
197	B202224	Enseleni	31.5500	-28.6739	121	33.70	51	91		0.30	0.20	NGS	NGS	0	fractured
198	B202225	Enseleni	31.8775	-28.5456	98	15.40	43	87		0.30	-1.00	Ecca shale	Ecca shale	3	fractured
199	B202226	Enseleni	31.5006	-28.6722	121	47.10	61	101		0.35	0.10	NGS	NGS	3	fractured
200	B202227	Enseleni	31.3364	-28.6289	132	22.06	72			0.80	1.00	NGS	NGS	0	fractured
201	B202228	Enseleni	31.3225	-28.6261	72	25.62	43			1.20	0.50	NGS	NGS	0	secondary porous
202	B202229	Enseleni	31.3228	-28.6225	132	29.69	60			0.30	0.30	NGS	NGS		fractured
203	B202229 A	Enseleni	31.3242	-28.6236	158		-999			0.00		NGS	Dwyka tillite		secondary porous
204	B202230	Enseleni	31.8250	-28.6006	145	5.33	29			0.15	0.15	Karoo sandstone	Ecca sandstone	3	fractured
205	B202231	Enseleni	31.8206	-28.5922	110	13.32	62	94		0.40	0.20	Karoo argillaceous	Karoo argillaceous/dolerite	3	contact
206	B202232	Enseleni	31.8414	-28.5967	158	14.05	88	97		0.10	0.10	Karoo sandstone	Karoo sandstone	3	fractured
207	B202232 A	Enseleni	31.8392	-28.5967	54		-999			0.00		Karoo sandstone	dolerite		featureless
208	B202233	Enseleni	31.8297	-28.5819	55	3.35	24	41		0.50	0.40	Karoo argillaceous	Karoo argillaceous	2	fractured
209	B202234 A	Enseleni	31.8514	-28.4508	152		-999			0.00		Ecca sandstone	Ecca sandstone		fractured
210	B202234 B	Enseleni	31.8489	-28.4492	145		-999			0.00		Ecca sandstone	Ecca sandstone		fractured
211	B202235 A	Enseleni	31.8692	-28.5733	120		-999			0.00		Karoo sandstone	Karoo sandstone		secondary porous
212	B202236	Enseleni	31.8425	-28.5247	61	9.37	22			0.40	0.50	Karoo argillaceous	Karoo argillaceous	3	fractured
213	B202236 A	Enseleni	31.8431	-28.5217	32		-999			0.00		Karoo argillaceous	Karoo argillaceous/dolerite		contact
214	B202237	Enseleni	31.7928	-28.4572	80	38.40	45	75		0.08	-1.00	Ecca sandstone	Ecca sandstone	3	fractured
215	B202238	Enseleni	31.8458	-28.5083	100	14.43	49			0.30	0.20	Karoo argillaceous	Karoo argillaceous	3	fractured
216	B202239	Enseleni	31.8108	-28.5333	120	12.10	81			0.40	0.15	Karoo argillaceous	Karoo argillaceous	3	fractured
217	B202240	Enseleni	31.8233	-28.5314	72	3.90	29			0.50	0.30	Karoo argillaceous	Karoo sandstone/shale	3	contact
218	B202241	Enseleni	31.8108	-28.5289	107	5.40	60	77		0.50	0.30	Karoo argillaceous	Karoo argillaceous	3	fractured
219	B202242	Enseleni	31.8281	-28.5231	96	10.40	45	63		0.40	0.20	Karoo argillaceous	Karoo sandstone/shale	3	contact
220	B202243 A	Enseleni	31.8061	-28.5269	158		-999			0.00		Ecca sandstone	Ecca sandstone		fractured
221	B202244	Enseleni	31.8153	-28.5483	82	11.00	40			0.50	-1.00	Karoo argillaceous	Karoo argillaceous	3	fractured
222	B202245	Enseleni	31.8556	-28.5335	81	23.15	40			0.50	0.30	Karoo argillaceous	dolerite	3	fractured
223	B202246	Enseleni	31.8431	-28.5533	149	6.45	22	117		0.30	0.15	Karoo argillaceous	Karoo argillaceous/dolerite	3	contact
224	B202246 A	Enseleni	31.8431	-28.5528	54		-999			0.00		Karoo argillaceous	Karoo argillaceous		fractured
225	B202247	Enseleni	31.8203	-28.5583	81	17.30	31	41		2.00	-1.00	Karoo argillaceous	Karoo argillaceous/dolerite	3	contact
226	B202248	Enseleni	31.8272	-28.4986	60	17.80	27			0.30	0.20	Ecca shale	Ecca shale	2	fractured
227	B202249	Enseleni	31.8392	-28.5069	108	22.66	48			0.30	0.10	Ecca shale	dolerite	3	fractured
228	B202250	Enseleni	31.8333	-28.5486	140	22.96	40			0.30	-1.00	Ecca shale	coal/Ecca shale	3	contact
229	B202251	Enseleni	31.5453	-28.7078	80	65.80	71			0.30	0.20	NGS	NGS	1	fractured
230	B202252 A	Enseleni	31.6411	-28.4889	122		-999			0.00		NGS	NGS		featureless
231	B202252 B	Enseleni	31.6403	-28.4875	144		-999			0.00		NGS	NGS		fractured
232	B202253 A	Enseleni	31.6292	-28.4978	140		-999			0.00		Dwyka tillite	dolerite/Dwyka tillite		contact
233	B202253 B	Enseleni	31.6267	-28.5067	153		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
234	B202254 A	Enseleni	31.6267	-28.5067	188		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
235	B202255 A	Enseleni	31.6283	-28.5158	150		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
236	B202256	Enseleni	31.6333	-28.5500	110	83.20	89			0.20	0.10	Dwyka tillite	NGS	1	fractured
237	B202257 A	Enseleni	31.6411	-28.5211	153		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
238	B202257 B	Enseleni	31.6389	-28.5236	153		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
239	B202258	Enseleni	31.6239	-28.5447	160	11.10	130	150		0.50	0.20	Dwyka tillite	NGS	0	fractured
240	B202259 A	Enseleni	31.6553	-28.5167	150		-999			0.00		NGS	NGS		fractured
241	B202259 B	Enseleni	31.6572	-28.5161	123		-999			0.00		NGS	NGS		featureless
242	B202260 A	Enseleni	31.6628	-28.5072	130		-999			0.00		Dwyka tillite	NGS		fractured
243	B202260 B	Enseleni	31.6603	-28.5081	131		-999			0.00		NGS	NGS		fractured
244	B202261	Enseleni	31.6642	-28.5186	153	112.90	132			0.30	2.00	Dwyka tillite	Dwyka tillite/NGS	2	contact
245	B202261 A	Enseleni	31.6681	-28.5194	150		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
197	EM	600	MAG	300	7.3	9.9	61		17	2	2	12	3.8	12	7		0.07	0.2		0.041	7.6
198	MAG	140			8.1	788	5069	900	650	64	180	1440	29.8	2384	177		0.04	0.8		0.021	3.9
199	EM	360	MAG	180	8.1	788	5069	900	650	64	180	1440	29.8	2384	177		0.04	0.8		0.021	3.9
200	EM	800	MAG	400	7.6	13.8	86	15.7	28	3	2	15	4.5	12	6		1.5	0.5		0.024	5.4
201	EM	200	MAG	250	7.4	10.8	75		37	3	3	9	2.2	4	6		0.36	0.4		0.038	15.7
202	EM	400	MAG	200																	
203	EM	170	MAG	200																	
204	MAG	200			7.8	587	3735	662	409	97	102	1044	35	1916	43		0.04	0.7		0.054	3.7
205	MAG	400			8	237	1733	340	650	54	50	400	4.8	400	31		<0.04	1.3		0.013	15.9
206	MAG	135			8.1	264	1921	371	628	43	64	498	12.2	511	35		<0.04	1.7		0.023	12.8
207	MAG	135																			
208	MAG	300			7.7	237	1685		604	74	58	357	3	421	33		0.04	1.3		0.01	13.5
209	EM	400	MAG	200																	
210	EM	400	MAG	200																	
211	Geology																				
212	EM	300	MAG	150	8.1	493	3416	654	750	71	116	906	14.7	1330	62		0.04	1.4		0.03	11.2
213	EM	300	MAG	150																	
214	EM	680	MAG	340	8	678	4066		535	70	247	958	29.8	2014	90		0.06	0.2		0.005	8.5
215	EM	200	MAG	100	8.3	464	2831	167	217	34	20	971	6.3	1496	34		0.04	4.1		0.018	9.2
216	EM	600	MAG	300	8.1	410	2508		319	35	15	847	14.2	1196	9		0.07	1.8		0.019	5.2
217	EM	600	MAG	300	7.1	582	3684	893	587	114	148	927	25	1673	80		0.18	1.5		0.044	7.5
218	EM	800	MAG	400	7.6	554	3547		433	46	126	1012	8.06	1700	32.5		0.16	1		0.05	4.3
219	EM	600	MAG	300	8.1	563	3331	432	500	61	68	982	25.3	1531	50		0.06	2.1		0.016	6.8
220	EM	400	MAG	200																	
221	EM	500	MAG	250	8.2	449	2805	205	345	49	20	939	10.2	1358	4		0.07	4.2		0.024	5.1
222	EM	600	MAG	300	8.1	427	2507	257	251	60	26	802	11.9	1286	13		0.04	0.8		0.024	3.8
223	EM	160	MAG	80	8.2	381	2770		766	87	70	683	10.7	885	77		4.92	1		0.01	7.3
224	EM	160	MAG	80																	
225	EM	600	MAG	300	8.3	743	4611	954	623	130	153	1239	22.1	2176	131		0.06	0.7		0.013	8.6
226	EM	600	MAG	300	8.3	162	1201	238	485	26	42	270	13.14	227	30		0.04	0.7		0.04	5.5
227	EM	240	MAG	120	8.2	504	3224	643	640	63	118	824	20.2	1310	85		5.08	0.8		0.02	4.2
228	EM	640	MAG	320	8	760	4762	1242	393	122	228	1222	119.8	2444	144		0.05	0.5		0.02	3.5
229	Geology				7.9	73.1	504	198.65	222	45	21	70	3.6	72	22		0.04	0.3		0.018	4.8
230	EM	300	MAG	150																	
231	EM	300	MAG	150																	
232	EM	500	MAG	250																	
233	EM	500	MAG	250																	
234	EM	1100	MAG	550																	
235	EM	400	MAG	200																	
236	EM	1000	MAG	500	8.1	71.6	513		185	20	27	96	5.3	126	11		0.11	0.4		0.012	3.6
237	EM	580	MAG	290																	
238	EM	580	MAG	290																	
239	EM	700	MAG	350	8	55.4	354		155	22	16	53	28	49	7.9		0.3	0.2		0.05	6.4
240	EM	400	MAG	200																	
241	EM	400	MAG	200																	
242	EM	1000	MAG	500																	
243	EM	400	MAG	200																	
244	EM	400	MAG	200	8	129	919		312	78	37	161	2.9	240	16		1	0.6		0.006	
245	EM	600	MAG	300																	

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
246	B202262	Enseleni	31.7667	-28.4658	44	10.72	20	22	27	2.60	-1.00	Ecca sandstone	Ecca sandstone	3	fractured
247	B202263	Enseleni	31.6875	-28.5272	101	18.00	50	51		0.40	0.15	Dwyka tillite	Dwyka tillite/shale	2	contact
248	B202264 A	Enseleni	31.6986	-28.5231	151		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
249	B202264 B	Enseleni	31.6992	-28.5231	120		-999			0.00		Ecca shale	Dwyka tillite		featureless
250	B202265	Enseleni	31.7003	-28.4925	140	21.60	108			5.00	2.00	Dwyka tillite	Dwyka tillite/NGS	2	contact
251	B202266	Enseleni	31.7178	-28.4778	81	7.75	21			0.70	0.50	Dwyka tillite	Dwyka tillite	2	fractured
252	B202267	Enseleni	31.7042	-28.4792	81	42.40	66			0.22	0.15	Dwyka tillite	Dwyka tillite/NGS	3	contact
253	B202268 A	Enseleni	31.6972	-28.4600	150		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
254	B202268 B	Enseleni	31.6958	-28.4597	150		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
255	B202269	Enseleni	31.6939	-28.4478	151	91.40	139			0.50	0.60	NGS	NGS	2	fractured
256	B202269 A	Enseleni	31.6944	-28.4486	151		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
257	B202270 A	Enseleni	31.6764	-28.4458	150		-999			0.00		NGS	NGS		featureless
258	B202271 A	Enseleni	31.6483	-28.4667	150		-999			0.00		NGS	NGS		fractured
259	B202272	Enseleni	31.6958	-28.4778	150	60.30	127			0.30	0.10	Dwyka tillite	Dwyka tillite	2	fractured
260	B202273 A	Enseleni	31.6697	-28.5492	151		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
261	B202274	Enseleni	31.6622	-28.5578	68	30.84	50			0.20	0.10	Dwyka tillite	Dwyka tillite	2	fractured
262	B202275	Enseleni	31.6739	-28.5619	90	42.59	68			0.14	0.10	Dwyka tillite	Dwyka tillite	2	fractured
263	B202275 A	Enseleni	31.6744	-28.5619	120		-999			0.00		Dwyka tillite	Dwyka tillite/dolerite		contact
264	B202276	Enseleni	31.6903	-28.5572	60	22.20	40	50		2.30	0.30	Dwyka tillite	NGS	2	fractured
265	B202277	Enseleni	31.6847	-28.5694	130	23.00	92			0.10	0.10	Dwyka tillite	Dwyka tillite	2	fractured
266	B202278	Enseleni	31.6642	-28.5703	179	77.45	54			0.10	0.00	Dwyka tillite	Dwyka tillite	2	fractured
267	B202279	Enseleni	31.6711	-28.5800	134	36.19	53	74		0.12	0.10	Dwyka tillite	Dwyka tillite/dolerite	1	contact
268	B202279 A	Enseleni	31.6717	-28.5806	128		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
269	B202279 B	Enseleni	31.6706	-28.5814	62		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
270	B202280 A	Enseleni	31.6783	-28.5931	132		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
271	B202280 B	Enseleni	31.6792	-28.5908	130		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
272	B202281	Enseleni	31.6803	-28.5994	62	40.00	50			0.75	0.50	Dwyka tillite	Dwyka tillite	2	fractured
273	B202282	Enseleni	31.6744	-28.6156	92	62.40	81			0.75	0.15	Dwyka tillite	Dwyka tillite	1	fractured
274	B202283	Enseleni	31.6611	-28.6278	126	94.60	110			1.30	4.00	Dwyka tillite	Dwyka tillite	1	fractured
275	B202283 A	Enseleni	31.6606	-28.6283	121		-999			0.00		Dwyka tillite	dolerite		featureless
276	B202284	Enseleni	31.6386	-28.6169	150	84.56	110			0.02	0.10	Dwyka tillite	Dwyka tillite	0	fractured
277	B202285	Enseleni	31.6442	-28.6481	151	96.95	139			0.10	0.10	Dwyka tillite	NGS	1	fractured
278	B202286	Enseleni	31.6439	-28.6589	86	58.00	52	67		0.10	0.10	Dwyka tillite	Dwyka tillite	1	fractured
279	B202287	Enseleni	31.6539	-28.6375	101	43.70	74	76		1.20	0.70	Dwyka tillite	Dwyka tillite	1	fractured
280	B202288	Enseleni	31.6478	-28.6764	130	81.20	90			1.81	2.00	Karoo argillaceous	Karoo sandstone/shale	3	contact
281	B202289	Enseleni	31.6553	-28.6628	120	36.40	74			0.06	-1.00	Karoo argillaceous	Karoo argillaceous	3	fractured
282	B202290	Enseleni	31.6431	-28.6972	145	69.00	57	79		0.10	-1.00	Karoo argillaceous	Karoo argillaceous/dolerite	3	contact
283	B202291	Enseleni	31.6353	-28.6964	50	22.60	25			0.22	0.20	Karoo argillaceous	Karoo argillaceous/dolerite	3	contact
284	B202292	Enseleni	31.6153	-28.6592	138	60.00	99			0.30	0.20	dolerite	dolerite/Ecca sandstone	3	contact
285	B202293	Enseleni	31.6042	-28.6558	145	130.30	118	126		0.10	-1.00	NGS	dolerite	2	fractured
286	B202294	Enseleni	31.6044	-28.6492	145	59.90	125			0.10	0.10	NGS	NGS	3	fractured
287	B202295	Enseleni	31.5422	-28.6678	160	36.50	150			0.26	0.20	NGS	NGS/shale	2	contact
288	B202296	Enseleni	31.5500	-28.6578	101	38.85	40			0.10	0.10	NGS	NGS	0	fractured
289	B202297	Enseleni	31.5675	-28.6528	62	35.90	38			0.30	0.20	NGS	NGS	0	fractured
290	B202298	Enseleni	31.5792	-28.6400	153	125.00	84			0.10	0.00	NGS	NGS	1	fractured
291	B202299 A	Enseleni	31.5889	-28.6297	145		-999			0.00		NGS	NGS		fractured
292	B202299 B	Enseleni	31.5864	-28.6300	145		-999			0.00		NGS	NGS		fractured
293	B202300 A	Enseleni	31.5919	-28.6172	145		-999			0.00		NGS	NGS		fractured
294	B202301	Enseleni	31.6000	-28.6100	74	27.45	66			6.60	3.00	NGS	NGS	3	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
246	EM	400	MAG	200	8.1	653	4262		735	89	156	1145	17.6	1780	177		0.04	0.9		0.026	12.5
247	EM	1300	MAG	650	7.7	186	1209		341	68	59	226	5.1	405	18		2.71	0.7		0.026	
248	EM	200	MAG	100																	
249	EM	200	MAG	100																	
250	EM	1200	MAG	600	8.2	211	1577		468	59	65	348	3.9	494	34		0.19	1		0.012	11.2
251	EM	1200	MAG	600	8.4	226	1558		484	39	54	362	9.8	455	41		1.47	1		0.092	10.3
252	EM	240	MAG	120	7.1	564	3612		483	120	264	713	4.16	1700	46.4		12.4	1.2		0.05	12.8
253	EM	400	MAG	200																	
254	EM	500	MAG	250																	
255	EM	300	MAG	150	7.9	258	1806		539	113	68	360	5.1	563	30		1.91	0.6		0.015	13.9
256	EM	300	MAG	150																	
257	EM	400	MAG	200																	
258	EM	800	MAG	400																	
259	EM	600	MAG	300	8.3	152	975		269	29	26	232	21.3	306	25		1.63	0.9		0.017	2
260	EM	500	MAG	250																	
261	EM	800	MAG	400	8.1	119	845		301	53	39	151	3.3	208	18		1.6	0.6		0.017	6.1
262	EM	200	MAG	100	7.4	134	860		308	72	40.8	148	3.92	246	17.2		1.9	0.6		0.05	9.6
263	EM	200	MAG	100																	
264	EM	800	MAG	400	8	159	1154		327	99	52	197	3.3	343	27		7.75	0.6		0.018	8.2
265	EM	1000	MAG	500	8.3	120	780		246	20	11	198	19.6	216	12		0.12	1		0.043	1.9
266	EM	1000	MAG	500	7.8	127	815		285	52	28.8	183	3.9	215	18.1		11.4	2.7		0.05	7.1
267	EM	700	MAG	350	8.5	106	711		243	21	23	164	6	144	49		1.43	1.1		0.023	1.2
268	EM	340	MAG	170																	
269	EM	340	MAG	170																	
270	EM	500	MAG	250																	
271	EM	500	MAG	250																	
272	EM	800	MAG	400	8.1	169	1091		286	77	49	195	3.9	392	13		2.37	0.7		0.039	9.2
273	EM	460	MAG	230	8.1	65.5	472		180	21	18	91	6.9	97	17		0.3	1.2		0.034	1.6
274	EM	300	MAG	150	8.4	68.7	509		208	32	28	80	3	105	5		0.73	0.7		0.021	10.7
275	EM	300	MAG	150																	
276	EM	800	MAG	400	6.8	26.1	167		40	6	6	28.6	3.42	42	5.1		0.85	0.11		0.05	15
277	EM	800	MAG	400	8.2	90.7	641	245	215	29	42	108	5.8	169	4		0.04	0.9		0.013	3.1
278	EM	400	MAG	200	8.1	83.8	572		176	29	25	120	3.1	175	4		0.56	0.8		0.007	3.2
279	EM	640	MAG	320	8.3	90.7	657		218	40	35	115	3	185	6		1.52	0.8		0.029	9.4
280	EM	800	MAG	400	7.8	3350	2301		389	127	134	441	14.6	1051	54		0.08	0.4		0.01	10.5
281	EM	480	MAG	240	7.1	1155	7394	2500	320	416	350			3499	102		0.2			<0.05	7.6
282	MAG	200			7.9	714	4854		614	257	175	1154	22.3	2229	266		0.15	1.3		0.02	14.1
283	MAG	200			8.5	408	2454		400	87	73	634	58	1042	72		0.1	0.8		0.041	5.9
284	EM	520	MAG	260	7.9	375	2388		554	182	96	425	7.5	809	55		31.29	0.5		0.035	18.3
285	EM	340	MAG	170	8.1	151	1135		404	112	39	159	4	215	31		18.49	0.8		0.011	14.7
286	EM	420	MAG	260	8.1	281	1535		253	103	79	300	14.6	640	87		0.04	1.2		0.029	9.3
287	EM	800	MAG	400	8.3	33.6	286		144	10	4	61	3.3	11	18		0.05	3		0.011	2.2
288	EM	1200	MAG	600	7.8	23.8	157		66	12	4	22	6.5	22	8		0.3	0.5		0.047	10.2
289	EM	480	MAG	240	8.2	30	204		90	16	5	33	2.7	30	5		0.4	0.3		0.017	15.6
290	EM	800	MAG	400	7.5	94.9	607		298	58	14.4	122	2.96	106	11.1		0.73	0.46		0.05	17.2
291	EM	500	MAG	250																	
292	EM	500	MAG	250																	
293	EM	1200	MAG	600																	
294	EM	600	MAG	300	7.6	438	2449		243	186	101	534	10.6	1199	121		0.06	0.2		0.007	17.9

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
295	B202301 A	Enseleni	31.6000	-28.6097	150		-999			0.00		NGS	NGS		fractured
296	B202302	Enseleni	31.5750	-28.6139	133	59.30	112			0.30	0.15	NGS	NGS	3	fractured
297	B202303	Enseleni	31.6069	-28.5969	150	65.80	97			0.10	0.10	Ecca sandstone	Ecca sandstone/shale	2	contact
298	B202304	Enseleni	31.6197	-28.5756	103	28.70	34	79		0.03	-1.00	Dwyka tillite	Dwyka tillite	3	fractured
299	B202304 A	Enseleni	31.6206	-28.5747	150		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
300	B202305	Enseleni	31.9731	-28.5725	111	55.40	67	87	101	4.00	1.60	Dwyka tillite	NGS	0	fractured
301	B202306 A	Enseleni	31.6175	-28.5517	116		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
302	B202306 C	Enseleni	31.6192	-28.5533	144		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
303	B202306B	Enseleni	31.6211	-28.5542	144		-999			0.00		Dwyka tillite	NGS		featureless
304	B202307	Enseleni	31.6000	-28.5614	89	72.00	41			0.10	0.10	NGS	NGS	2	fractured
305	B202308 A	Enseleni	31.5986	-28.5756	145		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
306	B202308 B	Enseleni	31.6019	-28.5792	150		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
307	B202309	Enseleni	31.6000	-28.5033	100	52.50	89	91		0.50	0.50	Dwyka tillite	Dwyka tillite	1	fractured
308	B202310 A	Enseleni	31.5953	-28.5214	113		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
309	B202311 A	Enseleni	31.6039	-28.5181	150		-999			0.00		Dwyka tillite	Dwyka tillite/NGS		contact
310	B202311 B	Enseleni	31.5986	-28.5181	144		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
311	B202312	Enseleni	31.6072	-28.4767	168	146.10	145			0.05	0.00	Dwyka tillite	Dwyka tillite/NGS	0	contact
312	B202313	Enseleni	31.5881	-28.4972	80	35.00	40	50		0.06	0.10	Dwyka tillite	Dwyka tillite	0	fractured
313	B202314	Enseleni	31.5467	-28.6042	149	112.60	61			0.10	0.00	NGS	NGS/Zgn	0	contact
314	B202315	Enseleni	31.5567	-28.5833	100	37.60	76			0.08	0.10	NGS	NGS	0	fractured
315	B202316	Enseleni	31.5542	-28.5661	123	87.00	31	80		0.08	0.10	NGS	NGS	0	fractured
316	B202317	Enseleni	31.5456	-28.5547	125	57.20	66			0.60	0.10	NGS	NGS	0	fractured
317	B202317 A	Enseleni	31.5414	-28.5561	130		-999			0.00		NGS	NGS		fractured
318	B202318	Enseleni	31.7606	-28.4753	68	10.80	19	25	60	0.20	0.15	Ecca sandstone	Ecca sandstone	2	fractured
319	B202319	Enseleni	31.5092	-28.5550	130	41.80	102			0.25	0.20	NGS	Zng	0	fractured
320	B202320	Enseleni	32.0506	-28.4328	43	19.50	27	36		3.90	0.50	Letaba basalt	Letaba basalt	2	fractured
321	B202321 A	Enseleni	31.5011	-28.5603	150		-999			0.00		NGS	NGS		fractured
322	B202322 A	Enseleni	31.4947	-28.5686	151		-999			0.00		NGS	NGS		fractured
323	B202322 B	Enseleni	31.4942	-28.5681	151		-999			0.00		NGS	NGS		fractured
324	B202323	Enseleni	32.2778	-28.5203	35	20.60	15			1.10	0.60	Maputaland sand	Maputaland sand	0	primary
325	B202324	Enseleni	31.5525	-28.5264	118	47.80	94			0.80	2.00	NGS	NGS	0	fractured
326	B202325	Enseleni	31.5597	-28.4814	80	43.40	64	65		2.90	0.50	Dwyka tillite	NGS	1	fractured
327	B202326 A	Enseleni	31.5431	-28.4819	150		-999			0.00		NGS	NGS		fractured
328	B202327	Enseleni	31.5361	-28.4961	185	51.12	129	137	158	0.30	0.30	Dwyka tillite	NGS	1	fractured
329	B202328 A	Enseleni	31.5383	-28.4767	151		-999			0.00		NGS	NGS		fractured
330	B202328 B	Enseleni	31.5397	-28.4750	144		-999			0.00		NGS	NGS		fractured
331	B202329	Enseleni	31.5258	-28.4878	159	86.40	137			1.80	0.50	Dwyka tillite	NGS/dolerite	1	contact
332	B202330	Enseleni	31.5050	-28.4944	151	82.00	64	129	139	0.40	0.20	Dwyka tillite	NGS	0	fractured
333	B202331	Enseleni	31.5119	-28.5131	160	127.00	140			0.70	0.75	NGS	NGS	0	fractured
334	B202332	Enseleni	31.9511	-28.6597	39	26.20	30			0.20	0.15	Maputaland sand	Maputaland sand/Zululand siltstone	0	contact
335	B202333	Enseleni	31.9494	-28.6619	120	13.35	46	110		0.44	0.10	Zi	Zi	1	fractured
336	B202334	Enseleni	31.9411	-28.5883	120	19.95	46			0.10	0.10	Letaba basalt	Letaba basalt	2	fractured
337	B202335	Enseleni	31.9450	-28.5950	60	4.70	11	35		0.30	0.20	Letaba basalt	Letaba basalt	2	fractured
338	B202336	Enseleni	31.9422	-28.6058	70	15.40	38	54		0.80	0.30	Letaba basalt	Letaba basalt	2	fractured
339	B202337	Enseleni	32.2950	-28.5528	48	2.80	15			0.30	0.20	Maputaland sand	Maputaland sand	0	primary
340	B202338	Enseleni	32.0056	-28.4458	61	7.30	20	45		0.30	0.15	Letaba basalt	Letaba basalt	2	fractured
341	B202339	Enseleni	31.9928	-28.4364	130	19.50	112			2.00	-1.00	Karoo sandstone	Karoo sandstone/shale	3	contact
342	B202340	Enseleni	31.9919	-28.4967	108	43.60	93			0.20	0.15	Letaba basalt	Letaba basalt	3	fractured
343	B202341	Enseleni	31.9894	-28.4875	54	31.60	40	46		0.60	0.30	Letaba basalt	Letaba basalt	3	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
295	EM	600	MAG	300																	
296	EM	540	MAG	270	7.6	294	1806		279	161	76	330	12.4	822	63		0.18	0.3		0.04	13.9
297	EM	400	MAG	200	7.9	182	1267		506	81	63	185	11.8	283	22		0.71	1.1		0.018	12.6
298	EM	250	MAG	125	6.9	354	2267		430	108	72	554	5.16	900	84		0.16	0.45		0.05	17.1
299	EM	250	MAG	125																	
300	EM	600	MAG	300	6.6	47.6	288		88	21	10	56	3.1	80	10		0.04	0.2		0.035	15.6
301	EM	530	MAG	260																	
302	EM	530	MAG	260																	
303	EM	530	MAG	260																	
304	EM	680	MAG	340	7.5	113	723		220	52	31.2	130	3.7	225	8.3		0.08	0.44		0.05	13.2
305	EM	860	MAG	430																	
306	EM	400	MAG	200																	
307	EM	800	MAG	400	8.2	82.2	548		198	27	31	91	5.7	141	6		0.55	0.9		0.036	5
308	EM	400	MAG	200																	
309	EM	400	MAG	200																	
310	EM	500	MAG	250																	
311	EM	1200	MAG	600	8	20.4	140		60	8	6	23	2.9	17	7		0.86	0.3		0.052	14.4
312	EM	400	MAG	200	8.2	46	298		112	18	13	47	5.1	53	7		3.99	0.7		0.012	2.1
313	EM	800	MAG	400	8.4	56.3	406	154	185	42	12	52	7.5	55	10		0.2	0.4		0.017	7.9
314	EM	1000	MAG	500																	
315	EM	400	MAG	200	8.1	29.1	218		101	28	5	25	3.4	17	17		0.04	0.5		0.044	12.3
316	EM	600	MAG	300	7.9	43.9	328		146	33	13	34	7.7	35	25		0.04	0.4		0.034	3.9
317	EM	480	MAG	240																	
318	EM	600	MAG	300	8.4	213	1379	299	452	44	46	317	6.6	373	38		0.07	0.9		0.016	5.1
319	EM	600	MAG	300	7.9	33.9	256		115	17	9	35	6.1	29	14		1.42	0.4		0.028	17.4
320	none				7.7	193	1033		22	46	1	333	1.9	532	90		0.07	0.1		0.005	12.3
321	EM	240	MAG	120																	
322	EM	240	MAG	120																	
323	EM	240	MAG	120																	
324	EM	400	MAG	200	8.3	47.2	354		161	49	7	40	3.7	48	8		0.27	0.1		0.04	12.4
325	EM	500	MAG	250	8.1	26.5	196		86	25	4	23	3.1	20	7		1.86	0.3		0.011	11.3
326	EM	280	MAG	140	8.3	72.4	493		199	31	23	86	2.2	97	4		1.44	0.3		0.014	14.4
327	EM	500	MAG	250																	
328	EM	400	MAG	200	8.1	63.3	449		163	25	20	80	4.8	105	13		0.09	0.6		0.12	8.2
329	EM	200	MAG	100																	
330	EM	200	MAG	100																	
331	EM	840	MAG	420	8.1	70.4	477		195	58	18	55	3.2	96	7		0.33	0.9		0.015	10.1
332	EM	600	MAG	300	8.1	49.4	345		162	33	21	34	4.6	44	12		0.04	0.3		0.02	5.4
333	EM	760	MAG	380	7.8	51.9	388		192	52	9	38	4.1	38	13		0.04	0.4		0.023	5.9
334	EM	400	MAG	200		48															
335	Geology				8.1	97.2	690		215	16	6	197	4.5	179	23		0.27	0.6		0.013	5.9
336	EM	600	MAG	300	7.7	105	592		46	46	3	168	3.5	298	14		0.83	0.5		0.018	5.3
337	EM	600	MAG	300	8.3	108	694		138	45	7	177	3.2	250	23		4.32	0.5		0.024	13.7
338	MAG	300			8.4	148	741		25	77	2	195	2.4	382	52		0.04	0.7		0.02	7.7
339	EM	400	MAG	200	7.1	26.1	167		60	13	7.8	25.8	4	40	4.9		0.08	0.14		<0.05	7.8
340	EM	400	MAG	200	7.4	209	1314		173	124	15	307	2.5	554	99		0.06	0.2		0.015	8.9
341	EM	800	MAG	400	7.7	2030	13741		54	1061	227	3659	52.9	7887	787		0.04	0.6		0.01	2.1
342	EM	400	MAG	200	7.3	578	3160		55	429	58	665	0.6	1725	215		0.04	0.4		0.01	3.6
343	EM	400	MAG	200	8.3	273	1604		305	66	71	382	8.6	656	48		0.09	0.4		0.017	14.1

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
344	B202342	Enseleni	31.9903	-28.4789	85	63.00	64			0.10	-1.00	Letaba basalt	Letaba basalt	3	fractured
345	B202343	Enseleni	31.9733	-28.4642	42	20.00	30			0.30	0.20	Letaba basalt	Letaba basalt	3	secondary porous
346	B202344	Enseleni	31.9861	-28.6108	120	4.95	77			0.10	0.10	Letaba basalt	Zng	2	fractured
347	B202345	Enseleni	31.9847	-28.5964	120	39.90	60	79		0.60	0.30	Letaba basalt	Letaba basalt	2	fractured
348	B202346	Enseleni	31.9842	-28.6222	61	16.97	45			0.42	0.20	Zd	Zd	2	fractured
349	B202347	Enseleni	32.0028	-28.6111	120	3.60	66			0.36	0.50	Zng	Zi/Zng	3	contact
350	B202348	Enseleni	31.9733	-28.6053	121	18.40	87	107		0.55	0.30	Letaba basalt	Letaba basalt	3	fractured
351	B202349	Enseleni	31.9472	-28.5703	98	68.80	76			0.02	0.10	Letaba basalt	Letaba basalt	2	fractured
352	B202350	Enseleni	31.9422	-28.5636	54	4.15	14			4.20	3.50	Letaba basalt	Letaba basalt	2	fractured
353	B202351	Enseleni	32.2619	-28.5736	43	21.84	37	40		6.60	2.50	Maputaland sand	Uloa coquina	0	primary
354	B202352	Enseleni	31.9350	-28.5528	55	3.93	36			1.60	0.70	Karoo argillaceous	Karoo argillaceous	2	fractured
355	B202353 A	Enseleni	31.9317	-28.5583	111		-999			0.00		Letaba basalt	Karoo argillaceous		secondary porous
356	B202353 B	Enseleni	31.9314	-28.5581	102		-999			0.00		Karoo argillaceous	Karoo argillaceous		contact
357	B202354	Enseleni	31.9600	-28.5978	76	10.30	16	58		0.33	0.20	Letaba basalt	Letaba basalt	2	fractured
358	B202355	Enseleni	31.9483	-28.5861	78	17.10	21			0.11	0.10	Letaba basalt	Letaba basalt	2	fractured
359	B202356	Enseleni	31.9517	-28.5919	71	10.95	41	51		1.33	0.50	Letaba basalt	Letaba basalt	2	fractured
360	B202357	Enseleni	31.9731	-28.5881	78	27.00	48			0.10	0.10	Letaba basalt	Letaba basalt	2	fractured
361	B202359	Enseleni	32.3269	-28.5339	20	5.00	18			0.30	0.20	Maputaland sand	Maputaland sand/Zululand siltstone	0	contact
362	B202360	Enseleni	31.9264	-28.6111	72	10.00	22	30		5.00	2.50	Letaba basalt	Letaba basalt	2	fractured
363	B202361	Enseleni	31.8994	-28.5714	73	7.70	24	45		0.08	0.10	Letaba basalt	Letaba basalt	2	fractured
364	B202362	Enseleni	31.9069	-28.5956	60	21.50	19	28		0.36	0.10	Letaba basalt	Letaba basalt	1	fractured
365	B202363	Enseleni	31.9153	-28.5867	60	40.00	26	38		0.11	0.10	Letaba basalt	Letaba basalt	1	fractured
366	B202364 A	Enseleni	31.9014	-28.5833	152		-999			0.00		Karoo argillaceous	Karoo argillaceous		fractured
367	B202365	Enseleni	31.9250	-28.6242	80	42.00	25	69		1.30	0.60	Letaba basalt	Letaba basalt	2	fractured
368	B202366	Enseleni	32.3267	-28.5436	18	4.70	7	13		4.00	2.00	Maputaland sand	Maputaland sand	0	primary
369	B202367	Enseleni	32.3319	-28.5597	30	6.45	25			0.30	0.15	Maputaland sand	Maputaland sand	0	primary
370	B202368	Enseleni	31.9517	-28.5331	80	55.00	66			0.20	0.15	Letaba basalt	Letaba basalt	2	fractured
371	B202369	Enseleni	31.9678	-28.5375	63	16.00	41			0.60	0.40	Letaba basalt	Letaba basalt	3	fractured
372	B202370	Enseleni	31.9953	-28.5289	81	22.80	40	53		0.25	0.20	Letaba basalt	Letaba basalt	3	fractured
373	B202371	Enseleni	31.9792	-28.5400	90	34.90	15			0.34	0.20	Letaba basalt	Letaba basalt	3	fractured
374	B202372	Enseleni	31.9878	-28.5375	81	29.40	61			0.10	0.10	Letaba basalt	Letaba basalt/Karoo argillaceous	3	contact
375	B202373	Enseleni	31.9694	-28.5428	108	10.05	10	60	90	1.60	0.60	Letaba basalt	Letaba basalt	3	fractured
376	B202374	Enseleni	31.9744	-28.5508	61	18.10	27	49		0.50	0.30	Letaba basalt	Letaba basalt	2	fractured
377	B202375	Enseleni	31.9931	-28.6017	60	4.95	12	14		0.90	1.00	Letaba basalt	Letaba basalt	2	fractured
378	B202376	Enseleni	31.9283	-28.5514	50	6.00	16			0.30	0.20	Letaba basalt	Letaba basalt	2	fractured
379	B202377	Enseleni	31.9639	-28.5875	71	8.45	17	52		0.45	0.20	Letaba basalt	Letaba basalt	2	fractured
380	B202378	Enseleni	31.9328	-28.5158	35	2.40	9	20		0.14	0.10	Letaba basalt	Letaba basalt	1	fractured
381	B202379	Enseleni	32.0242	-28.4161	101	36.00	37	48	81	0.57	0.20	Letaba basalt	Karoo argillaceous	3	fractured
382	B202380	Enseleni	32.0211	-28.4292	70	29.50	52	65		4.00	0.50	Letaba basalt	Letaba basalt	2	fractured
383	B202381	Enseleni	31.9983	-28.4592	92	60.00	82			0.40	0.20	Letaba basalt	Letaba basalt	3	fractured
384	B202382	Enseleni	32.0267	-28.4781	54	45.00	16			0.15	0.10	Letaba basalt	Letaba basalt	2	fractured
385	B202383	Enseleni	31.9417	-28.5408	60	17.00	21	30		0.11	0.10	Letaba basalt	Letaba basalt	2	fractured
386	B202384	Enseleni	31.9461	-28.5367	44	6.65	16			0.35	0.15	Letaba basalt	Letaba basalt	2	fractured
387	B202385	Enseleni	31.9025	-28.5372	32	3.00	13			0.80	-1.00	Karoo sandstone	Karoo sandstone	3	fractured
388	B202386	Enseleni	31.9039	-28.5381	122	20.30	92			0.10	-1.00	Karoo sandstone	Karoo sandstone	3	fractured
389	B202387	Enseleni	31.9081	-28.5492	44	4.82	27	39		7.10	0.60	Karoo sandstone	Karoo sandstone	3	fractured
390	B202388	Enseleni	32.0714	-28.4850	140	34.30	54			0.06	0.10	Letaba basalt	Letaba basalt	2	fractured
391	B202389	Enseleni	32.0722	-28.4667	121	40.60	101			0.10	0.10	Letaba basalt	Letaba basalt	2	fractured
392	B202390	Enseleni	32.0875	-28.4569	81	11.55	65			0.44	-1.00	Letaba basalt	Letaba basalt	3	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
344	EM	400	MAG	200	7.7	403	2091		84	194	68	489	12.6	1104	119		0.04	0.4		0.011	2.9
345	EM	400	MAG	200	7.8	111	880		313	74	54	97	1.2	131	21		27.01	0.4		0.036	15.5
346	EM	360	MAG	180	8.1	124	720		82	26	6	222	7.6	335	22		0.04	1		0.042	1.4
347	EM	480	MAG	240	8.1	181	1015		32	108	6	248	2.2	541	71		0.15	0.4		0.008	3
348	Geology				8.3	205	1181		210	37	19	335	4.3	480	50		0.09	0.3		0.005	18.7
349	EM	360	MAG	180	8.2	266	1659	451	319	72	66	403	9.1	675	45		0.04	0.2		0.008	21
350	EM	360	MAG	180	7.3	314	2015		50	231	11	435	10.4	929	336		0.04	0.2		0.012	4.7
351	EM	400	MAG	200	7.8	157	829		50	46	12	222	2.7	405	80		0.12	1		0.005	8.4
352	EM	500	MAG	250	8.1	211	1517		599	51	45	331	1.1	284	35		9.26	0.4		0.024	20.5
353	EM	400	MAG	200	8.4	41.1	307		143	45	5	33	4.8	38	7		0.04	0.1		0.018	15.9
354	EM	600	MAG	300	8.2	157	1194		493	57	54	196	1.7	212	40		6.82	0.4		0.025	18.4
355	EM	300	MAG	150																	
356	EM	300	MAG	150																	
357	MAG	200			7.4	122	1056		377	76	36	184	2.2	199	99		0.06	0.3		0.058	16.8
358	MAG	100			7	191	1052		34	60	13	312	2.2	589	33		0.08	0.8		0.022	7.5
359	MAG	160			8	181	876		26	97	2	215	1.5	479	50		0.05	0.3		0.013	9.1
360	EM	640	MAG	320	7.9	122	732		35	54	6	199	2	374	54		0.04	0.2		0.018	6.1
361	EM	800	MAG	400	6.5	19	121		20	7	3.6	21.6	3.64	40	4		0.28	0.03		<0.05	9.6
362	EM	600	MAG	300	8	143	781		123	62	10	197	1.5	299	48		2.69	0.4		0.03	17
363	EM	400	MAG	200	8.3	102	693		162	19	10	192	2.4	196	18		12.97	0.3		0.044	12.8
364	EM	1000	MAG	500	8	78.3	627		317	50	30	81	1.6	57	21		0.04	0.4		0.019	13.8
365	EM	400	MAG	200	8.1	87.3	741		343	50	38	103	1	92	29		1.96	0.5		0.016	9.6
366	EM	500	MAG	280																	
367	EM	280	MAG	140	8.2	90.6	526		49	50	7	127	2.8	247	30		0.43	0.4		0.017	12.8
368	EM	400	MAG	200	8.2	44.1	309		137	50	6	30	2.9	45	5		0.77	0.1		0.025	8.8
369	EM	440	MAG	220																	
370	EM	360	MAG	180	8	202	981		47	65	14	273	2.2	531	38		0.04	0.7		0.027	3
371	EM	900	MAG	450	7.8	210	1162		28	108	4	320	2.4	651	40		0.33	0.5		0.03	6.2
372	EM	600	MAG	340	8.8	279	1510		102	128	37	352	0.3	761	105		0.17	0.5		0.01	18.5
373	EM	300	MAG	150	8	152	1062		372	86	46	155	1.3	179	36		23.14	0.3		0.019	21.9
374	EM	400	MAG	200	7.4	267	1355		34	129	6	377	0.3	743	58		0.08	0.3		0.018	3.6
375	EM	400	MAG	200	7.8	413	2198		41	241	10	574	0.5	1180	142		0.08	0.3		0.011	11.1
376	EM	360	MAG	180	7.8	150	1084		472	41	20	239	1.9	178	23		0.12	0.5		0.038	18.6
377	EM	600	MAG	300	8.3	162	1208		372	47	13	319	1.4	298	55		4.65	0.6		0.017	15.5
378	EM	600	MAG	300	8.2	140	876		247	39	27	199	3.2	270	20		3.62	0.4		0.039	10.1
379	EM	400	MAG	200	8	208	1515		442	51	42	376	2.6	426	36		9.29	0.3		0.013	22.4
380	EM	400	MAG	200	8.2	60.9	390	80	140	6	15.6	102	1.58	100	22.9		0.08	1.1		0.05	2
381	EM	600	MAG	300	8.5	219	1487	243.48	364	30	41	418	3.6	455	95		0.08	1.1		0.028	4.2
382	EM	400	MAG	200	8.3	221	1419		415	44	22	377	2.5	386	80		0.04	0.2		0.005	34.9
383	EM	400	MAG	200	8	236	1188		44	104	15	304	2.3	603	106		0.04	0.3		0.04	2.2
384	Geology				8.2	146	1000		285	35	18	270	2.4	270	30		5.68	0.5		0.027	14
385	EM	340	MAG	170	8.1	157	1020		248	64	25	241	2.4	318	49		3.78	0.5		0.015	21.2
386	EM	800	MAG	400	8.1	201	1200		162	68	14	341	1.8	524	51		0.05	0.3		0.044	22.1
387	EM	600	MAG	300	7.9	1420	10095		746	148	334	3150	11.4	5242	298		0.2	0.9		0.019	12.8
388	EM	200	MAG	100	7.6	1310	8191		168	518	122	2372	59.9	4398	512		0.04	0.9		0.033	2.3
389	EM	300	MAG	150	8.2	317	2337		575	84	78	547	11.3	712	95		24.49	0.7		0.013	10.5
390	EM	400	MAG	200	7.6	164	1052		500	54	14.4	310	1.9	217	43.2		1.2	0.59		<0.05	19.7
391	EM	400	MAG	200	7.6	233	1041		31	116	14	245	2.6	543	81		0.25	0.5		0.03	5.2
392	EM	400	MAG	200	8	164	968	149	243	39	12	252	2.5	230	43		20.59	0.2		0.009	24.9

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
393	B202391	Enseleni	32.0794	-28.4611	84	56.00	65			1.00	0.30	Letaba basalt	Letaba basalt	3	fractured
394	B202392	Enseleni	32.0708	-28.4631	150	41.22	49	140		0.25	0.15	Letaba basalt	Letaba basalt	2	fractured
395	B202393	Enseleni	32.0594	-28.4606	114	67.60	82			1.33	1.00	Letaba basalt	Letaba basalt	2	fractured
396	B202394	Enseleni	32.0639	-28.4694	121	82.50	95			0.10	0.10	Letaba basalt	Letaba basalt	2	fractured
397	B202395	Enseleni	32.0542	-28.4833	66	10.60	37			0.10	0.10	Letaba basalt	Letaba basalt	1	fractured
398	B202396	Enseleni	32.0558	-28.4922	54	1.50	10			0.88	0.30	Letaba basalt	Letaba basalt	2	fractured
399	B202397	Enseleni	32.1014	-28.4556	102	58.10	61			0.77	0.80	Letaba basalt	Letaba basalt	2	fractured
400	B202398	Enseleni	32.0967	-28.4803	60	7.00	21			0.16	0.10	Letaba basalt	Letaba basalt	2	fractured
401	B202399	Enseleni	32.1347	-28.4725	60	30.50	24			0.06	0.10	Letaba basalt	Letaba basalt	2	fractured
402	B202400	Enseleni	31.9553	-28.5289	66	17.50	43	53		0.40	0.20	Letaba basalt	Letaba basalt	2	fractured
403	B202401	Enseleni	31.9458	-28.5247	66	23.10	30	54		0.60	0.20	Letaba basalt	Letaba basalt	2	fractured
404	B202402	Enseleni	32.3233	-28.5681	33	2.20	33			0.40	0.15	Maputaland sand	Maputaland sand	0	primary
405	B202403	Enseleni	31.9086	-28.5111	92	11.80	70			0.50	0.30	Karoo sandstone	dolerite/Karoo sandstone	3	contact
406	B202404 A	Enseleni	31.9447	-28.5022	120		-999			0.00		Letaba basalt	Letaba basalt		fractured
407	B202405	Enseleni	31.9225	-28.5094	68	11.90	29			0.04	0.10	Letaba basalt	Letaba basalt	2	fractured
408	B202406	Enseleni	31.9169	-28.5056	68	7.20	39	56		0.80	0.20	Letaba basalt	Letaba basalt	3	fractured
409	B202407	Enseleni	31.9347	-28.4806	53	21.30	30			0.20	0.10	Letaba basalt	Letaba basalt	1	fractured
410	B202408	Enseleni	31.9469	-28.4639	62	15.80	30	44	56	0.14	0.10	Karoo sandstone	Letaba basalt	2	fractured
411	B202409	Enseleni	31.9583	-28.4994	71	2.37	27	47		10.00	0.50	Letaba basalt	Letaba basalt	1	fractured
412	B202410 A	Enseleni	31.9594	-28.4869	150		-999			0.00		Letaba basalt	Letaba basalt		secondary porous
413	B202411	Enseleni	31.9614	-28.4675	85	32.00	28	78		0.30	0.15	Letaba basalt	Letaba basalt	3	fractured
414	B202412	Enseleni	31.9703	-28.4764	70	42.00	47			0.60	0.20	Letaba basalt	Letaba basalt	1	fractured
415	B202413	Enseleni	31.9697	-28.5081	113	41.20	107			2.00	0.80	Letaba basalt	Letaba basalt	3	fractured
416	B202414	Enseleni	31.9939	-28.5175	56	10.10	14	44		0.20	0.10	Letaba basalt	Letaba basalt	1	fractured
417	B202415	Enseleni	31.9986	-28.5403	102	27.00	74			0.25	0.15	Letaba basalt	Letaba basalt	2	fractured
418	B202416	Enseleni	31.9833	-28.5078	75	29.90	60			0.10	-1.00	Letaba basalt	Letaba basalt	3	fractured
419	B202417	Enseleni	31.9250	-28.4983	80	29.90	70			0.20	-1.00	Karoo sandstone	Karoo sandstone	3	fractured
420	B202418	Enseleni	31.8736	-28.5153	96	18.30	80			0.08	-1.00	dolerite	Karoo sandstone	3	fractured
421	B202420	Enseleni	31.9106	-28.4875	52	0.00	14	23		0.20	0.20	Karoo sandstone	Karoo sandstone/shale	3	contact
422	B202420 A	Enseleni	31.9067	-28.4881	120		-999			0.00		Letaba basalt	Letaba basalt		fractured
423	B202421	Enseleni	31.9044	-28.4961	52	18.10	33			0.10	-1.00	Karoo sandstone	Karoo sandstone	3	fractured
424	B202422 A	Enseleni	32.3639	-28.5222	60		-999			0.00		Maputaland sand	Maputaland sand		primary
425	B202423	Enseleni	31.9908	-28.5033	65	44.40	50	60		1.30	0.50	Letaba basalt	Letaba basalt	3	fractured
426	B202424 A	Enseleni	32.0036	-28.4886	120		-999			0.00		Letaba basalt	Letaba basalt		featureless
427	B202425	Enseleni	32.0208	-28.4892	96	2.40	69			0.10	0.10	Letaba basalt	Letaba basalt	2	fractured
428	B202426	Enseleni	31.9667	-28.4556	110	63.90	77			0.20	0.10	Letaba basalt	Letaba basalt	2	fractured
429	B202427	Enseleni	31.9642	-28.4458	133	16.30	63			0.20	-1.00	Karoo sandstone	Karoo sandstone	3	fractured
430	B202428	Enseleni	31.9806	-28.4514	54	13.80	32	37		0.20	0.10	Letaba basalt	Letaba basalt	1	fractured
431	B202430	Enseleni	31.8858	-28.4861	86	39.40	47	70		0.20	-1.00	Karoo sandstone	dolerite	3	fractured
432	B202432	Enseleni	31.8817	-28.4894	50	26.00	27	34		0.14	-1.00	Karoo sandstone	dolerite/Karoo sandstone	3	contact
433	B202432 A	Enseleni	31.8825	-28.4894	44		-999			0.00		Karoo sandstone	dolerite/Karoo sandstone		contact
434	B202434 A	Enseleni	31.8467	-28.4939	122		-999			0.00		Karoo argillaceous	Karoo argillaceous		fractured
435	B202434 B	Enseleni	31.8464	-28.4950	152		-999			0.00		Karoo argillaceous	Karoo argillaceous		fractured
436	B202439	Enseleni	31.8775	-28.4692	56	18.80	33	48		0.22	0.15	Karoo argillaceous	NMP amphibolite	2	fractured
437	B202439 A	Enseleni	31.8739	-28.4694	152		-999			0.00		Karoo argillaceous	Karoo argillaceous		fractured
438	B202442	Enseleni	31.9306	-28.4625	100	31.20	67			0.10	-1.00	Karoo sandstone	Karoo sandstone	3	fractured
439	B202442 A	Enseleni	31.9314	-28.4619	120		-999			0.00		Karoo sandstone	Karoo sandstone		fractured
440	B202445	Enseleni	31.9239	-28.4289	145	36.40	100			0.06	-1.00	Karoo sandstone	dolerite	3	fractured
441	B202446	Enseleni	32.0428	-28.5144	84	14.30	56	72		0.31	0.20	Letaba basalt	Letaba basalt	0	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
393	EM	400	MAG	200	7.2	296	1449	340	10	133	2	396	0.3	748	157		0.13	0.1		0.009	11.1
394	EM	400	MAG	200	7.6	186	962		33	87	14	250	1.9	470	97		0.17	0.4		0.013	2.4
395	EM	400	MAG	200	8.3	136	800		178	3	4	236	1.3	278	27		0	0.4		0.019	32
396	EM	400	MAG	200	7.1	174	867		36	72	10	224	3.1	466	46		0.23	0.3		0.012	6.8
397	EM	360	MAG	180	7.8	89.3	572		290	30	18.7	141	2.42	95	37		0.06	0.53		<0.05	6.1
398	EM	300	MAG	150	8	145	839		113	49	15	231	1.9	354	49		0.3	0.6		0.038	4.3
399	EM	400	MAG	200	7.2	212	1067		28	74	2	316	1.7	574	64		0.22	0.2		0.011	9.6
400	EM	400	MAG	200	8.3	170	1044		301	39	29	265	3.9	289	43		2.19	0.4		0.022	9.8
401	EM	400	MAG	200	8.3	137	799		109	32	8	246	2.2	341	36		0.04	0.3		0.018	17
402	EM	600	MAG	300	8.1	129	893		295	24	5	249	4.2	225	24		0.04	0.5		0.022	9
403	EM	400	MAG	200	8.1	140	934		347	27	20	223	1.3	212	23		1.06	0.6		0.02	15.4
404	EM	200	MAG	100																	
405	EM	660	MAG	320	8.3	324	2138	299	730	39	49	580	8.3	496	74		0.3	0.4		0.011	23.3
406	EM	400	MAG	200																	
407	EM	400	MAG	200	8.4	124	779		158	47	9	193	2.4	194	74		15.12	0.6		0.023	8.9
408	EM	300	MAG	150	8.5	429	2734		599	30	52	821	11.9	1036	50		0.34	0.9		0.015	14.8
409	EM	400	MAG	200	7.3	119	759		420	63.2	42.8	151	1.96	130	29.9		1.5	0.6		<0.05	26.9
410	EM	400	MAG	200	7.7	191	1079		76	28	7	362	4.7	575	5		0.26	3.3		0.018	1.1
411	EM	400	MAG	200	8.1	73.1	533		182	22	7	132	4.8	109	30		1.09	0.5		0.074	7.1
412	EM	600	MAG	300																	
413	EM	400	MAG	200	7.7	148	943		213	79	24	176	2.3	230	48		27.79	0.6		0.032	12.9
414	EM	460	MAG	240	8.4	64.3	365		47	22	2	97	1.9	146	38		0.05	0.5		0.038	5.4
415	EM	640	MAG	320	7.4	235	1342		31	181	2	308	2.4	730	79		0.06	1.2		0.015	3.7
416	EM	700	MAG	350	7.6	76.4	577		244	32	20	108	2.4	89	25		0.53	0.4		0.005	19.5
417	EM	400	MAG	200	8.4	145	850		224	52	16	197	1.6	282	27		0.09	0.4		0.039	28.6
418	EM	400	MAG	200	7.6	372	2238		64	178	35	602	14.1	1194	136		0.04	0.6		0.034	6.2
419	EM	240	MAG	120	8.1	425	2660		429	87	110	647	9.5	1059	89		30.16	1		0.019	10.7
420	EM	540	MAG	170	8.4	549	3640		335	53	64	1157	29	1698	226		0.12	1.2		0.019	2.2
421	EM	100	MAG	50	7.4	517	3309		740	138	116	879	6.5	1290	153		15.6	2.5		<0.05	9.6
422	EM	100	MAG	50																	
423	EM	400	MAG	200	8.3	347	2226		544	40	44	628	14.5	774	56		0.91	1.2		0.044	3.2
424	EM	400	MAG	200																	
425	EM	500	MAG	250	7.3	264	1374		44	236	6	243	0.3	737	97		0.09	0.3		0.073	7.6
426	EM	520	MAG	260																	
427	EM	400	MAG	200	7.7	207	1045		27	117	14	244	2.7	567	66		0.22	0.4		0.011	5.1
428	EM	400	MAG	200	9.2	96.9	561		28	31	2	168	2.5	263	61		0.04	0.4		0.053	5.8
429	EM	400	MAG	200	7.7	799	5156		208	159	154	1532	25	2681	352		0.08	0.4		0.052	1.3
430	EM	600	MAG	300	8	110	703		360	22	21.6	195	3.28	115	52		0.17	0.36		<0.05	5.5
431	EM	170	MAG	170	8.1	546	3275		439	91	63	952	19.1	1512	101		0.07	1.1		0.023	5.9
432	EM	100	MAG	100	8.1	343	2256		586	34	64	594	16.6	747	86		0.09	0.7		0.006	12.4
433	EM	100	MAG	100																	
434	EM	340	MAG	170																	
435	EM	400	MAG	200																	
436	EM	200	MAG	100	8.2	166	1283		449	29	18	337	6	320	25		0.16	0.7		0.01	24
437	EM	200	MAG	100																	
438	EM	200	MAG	100	7.6	670	4290		660	90	116	1315	11.48	1850	159		54.3	1.7		<0.05	4.9
439	EM	200	MAG	100																	
440	EM	400	MAG	200	8	583	3781		285	75	79	1170	29.5	1894	184		0.09	0.5		0.039	4.5
441	EM	400	MAG	200	8.3	50.6	324		100	21.2	3.6	94.6	1.58	88	32.5		0.53	0.2		<0.05	6.3

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
442	B202447	Enseleni	32.0339	-28.5097	61	12.50	36			0.10	0.10	Letaba basalt	Letaba basalt	2	fractured
443	B202448	Enseleni	32.0492	-28.5117	61	8.35	31			0.29	0.20	Letaba basalt	Letaba basalt	2	fractured
444	B202449	Enseleni	32.0564	-28.5075	96	8.60	14	55		0.14	0.10	Letaba basalt	Letaba basalt	2	fractured
445	B202452	Enseleni	31.9892	-28.3708	133	32.60	129			0.20	0.10	Karoo argillaceous	Karoo argillaceous	3	fractured
446	B202453	Enseleni	31.9897	-28.3667	82	18.40	69			0.16	-1.00	Karoo argillaceous	dolerite/Karoo argillaceous	3	contact
447	B202455	Enseleni	31.9833	-28.4317	130	13.90	46			1.33	-1.00	dolerite	dolerite	3	fractured
448	B202456	Enseleni	31.9956	-28.4222	133	45.70	128			0.20	-1.00	Letaba basalt	Karoo argillaceous	3	fractured
449	B202461	Enseleni	31.9889	-28.3917	96	0.00	92			0.10	0.10	Karoo argillaceous	Karoo argillaceous	2	fractured
450	B202462	Enseleni	32.0381	-28.5250	60	1.32	12	35	42	1.25	0.80	Letaba basalt	Letaba basalt	2	fractured
451	B202463	Enseleni	32.0653	-28.5192	54	3.05	12	14	36	1.00	0.60	Letaba basalt	Letaba basalt	2	fractured
452	B202466	Enseleni	32.0742	-28.4942	60	9.50	15			0.04	-1.00	Letaba basalt	Letaba basalt	3	fractured
453	B202468	Enseleni	32.0861	-28.4928	80	62.00	30	44		0.10	-1.00	Letaba basalt	Letaba basalt	3	fractured
454	B202469	Enseleni	32.0661	-28.4986	60	13.90	18			0.20	0.10	Letaba basalt	Letaba basalt	1	fractured
455	B202470	Enseleni	32.0178	-28.5786	78	14.30	24			0.24	0.15	Zng	dolerite/Zng	1	contact
456	B202471	Enseleni	31.0125	-28.5742	131	20.30	77	115	130	0.10	0.10	dolerite	Zng	3	fractured
457	B202474	Enseleni	32.0042	-28.5936	134	19.00	119			0.24	0.15	Zng	Zng	2	fractured
458	B202477	Enseleni	32.0108	-28.6061	78	4.75	43	65		0.36	0.30	Letaba basalt	Letaba basalt	2	fractured
459	B202479	Enseleni	32.0722	-28.5314	61	13.35	31	45		1.33	0.30	Letaba basalt	Letaba basalt	1	fractured
460	B202480	Enseleni	32.0667	-28.5450	60	9.45	34			2.85	4.00	Letaba basalt	Letaba basalt	1	fractured
461	B202481	Enseleni	32.0547	-28.5264	61	18.00	31	46		0.46	0.30	Letaba basalt	Letaba basalt	2	fractured
462	B202482	Enseleni	31.9933	-28.5789	66	30.90	36	62		0.10	0.10	Letaba basalt	Letaba basalt	2	fractured
463	B202484	Enseleni	31.9233	-28.6264	128	48.40	120			1.00	0.50	Letaba basalt	Letaba basalt	1	fractured
464	B202485 A	Enseleni	31.8633	-28.7539	120		-999			0.00		Zng	Zng		featureless
465	B202486	Enseleni	31.8714	-28.8258	108	12.60	71			0.45	0.20	NMP	NMP granite	0	fractured
466	B202488	Enseleni	31.7656	-28.7478	61	16.60	35			0.20	0.15	Ecca shale	NMP granite	3	fractured
467	B202490	Enseleni	31.8322	-28.7397	124	6.66	108			0.64	0.40	Zng	Zng	2	fractured
468	B202492	Enseleni	31.8433	-28.7633	86	71.70	60	71		0.10	-1.00	NMP	NMP granite	3	fractured
469	B202492 A	Enseleni	31.8433	-28.7639	61		-999			0.00		NMP	NMP granite/dolerite		contact
470	B202493	Enseleni	31.8303	-28.8017	119	8.80	102			0.20	-1.00	NMP	NMP granite	3	fractured
471	B202495	Enseleni	31.8322	-28.7867	124	1.90	48	100		0.10	0.10	NMP	NMP granite	2	fractured
472	B202496	Enseleni	31.8714	-28.8039	144	3.60	79	139		0.45	0.15	NMP	NMP granite	2	fractured
473	B202499	Enseleni	31.8003	-28.7714	81	21.00	36			0.35	-1.00	NMP	NMP granite	3	fractured
474	B202501	Enseleni	31.7889	-28.7689	116	49.90	96			0.12	0.10	NMP	NMP granite	2	fractured
475	B202502	Enseleni	31.8628	-28.6886	140	63.20	113			0.10	0.10	Letaba basalt	Letaba basalt	3	fractured
476	B202503	Enseleni	31.8542	-28.6886	108	28.00	27	69		0.10	0.10	Letaba basalt	Letaba basalt	2	fractured
477	B202504	Enseleni	31.8442	-28.7083	78	1.85	18	42	63	0.69	0.40	Letaba basalt	Letaba basalt	1	fractured
478	B202505	Enseleni	31.9261	-28.6058	84	41.40	52			1.30	0.50	Letaba basalt	Letaba basalt	2	fractured
479	B202506	Enseleni	31.9347	-28.5867	72	55.20	8	40		0.10	0.10	Letaba basalt	Letaba basalt	0	fractured
480	B202507	Enseleni	32.0961	-28.4806	120	33.90	94			0.10	0.10	Letaba basalt	Letaba basalt	3	fractured
481	B203315	Inkanyezi	31.3357	-28.9848	86	60.63	27	31	78	0.50	0.25	NGS	NGS	0	fractured
482	B203316	Inkanyezi	31.2565	-28.9043	61	3.41	25	33	53	0.16	0.16	NMP	NMP granite	0	fractured
483	B203317	Inkanyezi	31.3088	-28.9937	96	31.94	40	91		0.30	0.16	NGS	NGS	0	fractured
484	B203318	Inkanyezi	31.3133	-28.9703	76	15.42	27	46	66	0.90	0.20	NGS	NGS	2	fractured
485	B203319 A	Inkanyezi	31.2890	-28.4668	101		-999			0.00		NGS	NGS		fractured
486	B203320 A	Inkanyezi	31.2825	-28.9595	128		-999			0.00		NGS	NGS		fractured
487	B203320 B	Inkanyezi	31.2822	-28.9602	104		-999			0.00		NGS	NGS		fractured
488	B203320 C	Inkanyezi	31.2803	-28.9572	122		-999			0.00		NGS	NGS		fractured
489	B203321 C	Inkanyezi	31.2970	-28.9427	122		-999			0.00		NGS	NGS		fractured
490	B203322	Inkanyezi	31.2378	-28.8983	66	27.90	49			0.48	0.25	NMP	NGS	0	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
442	EM	400	MAG	200	8.3	137	875		180	47	31	209	2.7	302	54		2.31	0.6		0.021	10.7
443	EM	440	MAG	220	8.3	122	872		206	35	18	232	2.3	254	75		0.89	0.6		0.034	6.5
444	EM	600	MAG	300	8.3	121	951		311	18	12	268	2.1	209	38		5.44	0.6		0.054	16.5
445	EM	360	MAG	180	8	266	1667		374	21	13	514	13.9	601	45		0.04	1.7		0.012	2.2
446	EM	400	MAG	200	8	420	2961		686	30	56	879	9.5	1061	85		0.04	2.3		0.105	3.5
447	EM	400	MAG	200	7.2	602	3612	492	94	85	68	1142	15.5	2128	56		0.33	0.3		0.017	2.8
448	Geology				6.7	805	4943		34	196	75	1569	12.3	2959	89		0.11	0.5		0.008	1.3
449	EM	400	MAG	200	8.3	251	1475	395	276	81	47	367	2.5	563	61		3.57	0.6		0.041	24.6
450	EM	400	MAG	200	8.3	251	1475		276	81	47	367	2.5	563	61		3.57	0.6		0.041	24.6
451	EM	400	MAG	200	8.4	124	994		345	30	24	243	0.6	193	39		9.64	0.6		0.022	21
452	EM	440	MAG	220	8.2	166	1219		321	63	38	257	2.8	238	98		29.37	0.4		0.034	13.4
453	EM	520	MAG	260	7.3	218	1228		40	163	7	278	3.8	632	96		0.04	0.2		0.025	2.3
454	EM	400	MAG	200	7.8	98.2	775		309	36	29	151	2.8	136	33		2.13	0.3		0.008	16.4
455	EM	600	MAG	320	8.2	76.3	540		157	21	17	118	8.4	154	14		3.83	0.4		0.03	17.2
456	EM	400	MAG	200	8	243	1625		538	39	42	421	8.8	396	61		0.07	0.7		0.042	8.5
457	EM	380	MAG	190	8.3	172	1089		330	23	24	297	5.2	309	25		0.4	0.5		0.018	10.3
458	EM	400	MAG	200	8	114	696		192	29	23	164	2.5	205	27		2.78	0.4		0.023	13.4
459	EM	400	MAG	200	8.8	70.4	450		70	8	13.2	112	2.18	190	1.9		0.11	0		<0.05	1.6
460	EM	400	MAG	200	8.4	100	713	139	223	21	21	172	3	193	15		3.53	0.2		0.024	21.7
461	EM	400	MAG	200	8.9	179	1162	142	260	32	15	348	4.2	398	44		0.62	0.2		0.019	24.7
462	EM	480	MAG	240	7.8	160	868		39	27	9	283	2.6	402	95		0.04	0.5		0.044	8.1
463	EM	600	MAG	300	8.1	77.9	625		229	41	26	101	1.4	105	28		9.37	0.7		0.02	15.7
464	none																				
465	none				7	19.8	127	35	30	4	6	28	2	35	5.5		1.7	0.2		0.4	3.5
466	EM	400	MAG	200	8.6	395	2492		421	70	90	681	10.8	1047	79		0.04	0.5		0.02	6.6
467	none				8.2	242	1587		484	39	51	391	3	443	67		0.33	1		0.005	11.6
468	none				7.9	610	3513		309	172	207	764	9.8	1844	127		2.66	0.2		0.011	8
469	none																				
470	EM	260	MAG	130	7.8	786	4916		109	109	69	1552	20.8	2114	911		0.53	2.6		0.011	2.8
471	EM	400	MAG	200	8.2	100	619		125	21	16	169	4.2	230	23		0.35	1.8		0.012	5.1
472	EM	480	MAG	240	8.4	117	817		289	17	21	197	9.6	201	20		0.06	0.7		0.022	7.4
473	EM	600	MAG	300	8	287	1819		376	99	97	334	15.7	592	63		36.15	0.2		0.024	16.5
474	EM	400	MAG	200	8.1	201	1128		204	32	19	335	6.7	438	48		0.04	0.3		0.091	15.9
475	EM	560	MAG	280	7.6	102	555	178	24	63	5	143	2.6	273	40		<0.04	0.2		0.019	5.9
476	EM	900	MAG	450	7.4	163	880	276	32	86	15	220	3	404	88		5.72	0.2		0.009	8.6
477	EM	480	MAG	240	8.4	107	778		293	28	14	192	2	164	15		0.91	0.3		0.014	26.1
478	EM	600	MAG	300	7.5	148	854	168	20	64	2	259	2.1	428	73		0.15	0.1		0.012	6.8
479	EM	500	MAG	250	7.9	39.2	250		65	9	6	62	2.3	75	16		0.13	0.2		0.019	3
480	EM	260	MAG	130	7.5	184	1005	150	33	55	3	334	2.6	531	39		<0.04	0.2		0.012	10
481	PROFILING	140			7.1	15.4	88		17	2	2	19	5	20	9	0.04	2.05	0.3		0.107	13
482	PROFILING	80			8	31.9	214		92	14	8	35	2.3	31	10	0.04	0.44	0.3		0.028	13.6
483	PROFILING	150			7.6	13.3	83		27	3	2	17	4.2	13	6	0.04	0.95	0.5		0.03	13.2
484	PROFILING	120			8.3	57.1	420		185	47	14	54	3.7	62	12	0.05	0.04	1.8		0.025	11.8
485	PROFILING	140																			
486	PROFILING	160																			
487	PROFILING	120																			
488	PROFILING	120																			
489	PROFILING	150																			
490	PROFILING	180			7.4	30.7	233		101	13	8	38	1.9	32	4	0.04	2.82	0.5		0.059	19.1

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
491	B203323 A	Inkanyezi	31.3075	-28.9580	121		-999			0.00		NGS	NGS		fractured
492	B203323 B	Inkanyezi	31.3072	-28.9578	121		-999			0.00		NGS	NGS		fractured
493	B203324	Inkanyezi	31.2547	-28.9108	61	7.61	28	46		0.32	0.30	NMP	NMP granite	0	fractured
494	B203325	Inkanyezi	31.2543	-28.9397	95	8.02	23	49	83	0.16	0.16	NGS	NMP granite	0	fractured
495	B203326	Inkanyezi	31.2517	-28.9600	128	80.42	87	107		0.75	0.75	NGS	NGS	0	fractured
496	B203327 A	Inkanyezi	31.2543	-28.8343	122		-999			0.00		NMP	NMP gneiss		fractured
497	B203327 B	Inkanyezi	31.1410	-28.8480	122		-999			0.00		NMP	NMP gneiss		fractured
498	B203328 A	Inkanyezi	31.2622	-28.9697	122		-999			0.00		NGS	NGS		fractured
499	B203329 A	Inkanyezi	31.0893	-28.8608	122		-999			0.00		NMP	NMP schist		fractured
500	B203329 B	Inkanyezi	31.0892	-28.8592	122		-999			0.00		NMP	NMP schist		fractured
501	B203330	Inkanyezi	31.2545	-28.9273	122	1.40	44	66	96	0.02	0.08	NMP	dolerite	1	fractured
502	B203330 A	Inkanyezi	31.2547	-28.9275	122		-999			0.00		NMP	dolerite		fractured
503	B203331	Inkanyezi	31.0760	-28.8772	61	31.72	46	50		0.40	0.42	NMP	NMP schist	2	fractured
504	B203332	Inkanyezi	31.2433	-28.9347	110	2.90	17	104		0.14	0.14	Alluvium	NMP amphibolite	1	fractured
505	B203333	Inkanyezi	31.0537	-28.8975	71	14.52	16	31	57	0.44	0.69	NMP	NMP schist	3	fractured
506	B203334	Inkanyezi	31.2145	-28.9125	41	5.60	25			6.60		Alluvium	NGS	1	fractured
507	B203335	Inkanyezi	31.0827	-28.9023	128	57.20	81	111	119	0.08	0.08	NMP	NMP migmatite	0	fractured
508	B203336	Inkanyezi	31.2877	-28.9413	98	64.34	87			0.40	0.16	Letaba basalt	dolerite/NGS	0	contact
509	B203337	Inkanyezi	31.1252	-28.8928	122	57.00	48	51	70	0.08	0.04	NMP	NMP amphibolite	3	fractured
510	B203338	Inkanyezi	31.1208	-28.8350	120	34.84	108			0.35	0.20	NMP	NMP gneiss	3	fractured
511	B203339	Inkanyezi	31.1453	-28.8870	116	62.60	87	104		1.80	1.11	NMP	NMP gneiss	1	fractured
512	B203340	Inkanyezi	31.1933	-28.9013	61	5.00	23			5.00	-1.00	NMP	NMP gneiss	0	fractured
513	B203341 A	Inkanyezi	31.1093	-28.8847	122		-999			0.00		NMP	NMP gneiss		fractured
514	B203343 A	Inkanyezi	31.1417	-28.8733	140		-999			0.00		NMP	NMP amphibolite		fractured
515	B203344	Inkanyezi	31.1622	-28.8877	110	56.00	95	98	107	1.67	1.67	NMP	NMP gneiss	2	fractured
516	B203345	Inkanyezi	31.0673	-28.9042	122	31.00	72			0.40	0.50	NMP	NMP amphibolite	2	fractured
517	B203346 A	Inkanyezi	31.1672	-28.8710	140		-999			0.00		NMP	NMP amphibolite		fractured
518	B203347	Inkanyezi	31.1145	-28.9177	66	4.57	8	20		0.95	1.05	NMP	NMP amphibolite	1	fractured
519	B203348	Inkanyezi	31.1110	-28.9207	73	56.00	67			8.30	-1.00	NMP	NMP amphibolite	2	fractured
520	B203349	Inkanyezi	31.0763	-28.9352	128	44.30	68	105	119	0.09	0.11	NMP	NMP gneiss	3	fractured
521	B203350	Inkanyezi	31.2203	-28.9137	71	15.20	33	47		0.40	0.21	NMP	NMP gneiss	1	fractured
522	B203351	Inkanyezi	31.2175	-28.8972	71	31.47	51	58		0.14	0.14	NMP	NMP amphibolite	0	fractured
523	B203353	Inkanyezi	31.3022	-28.9713	61	0.00	15	21	37	3.30	-1.00	NGS	NGS	0	fractured
524	B203354	Inkanyezi	31.2403	-28.9442	59	5.90	27	44		0.33	0.56	NMP	NMP amphibolite	2	fractured
525	B203355	Inkanyezi	31.0437	-28.9245	98	37.56	85	90		4.17	-1.00	NMP	NMP schist	2	fractured
526	B203356	Inkanyezi	31.1112	-28.9495	86	45.00	47	54	77	0.41	0.31	NMP	NMP schist	3	fractured
527	B203357	Inkanyezi	31.0920	-28.9458	76	16.00	38	67	73	0.14	0.13	NMP	NMP schist	3	fractured
528	B203358	Inkanyezi	31.1147	-28.9488	122		56			0.00	-1.00	NMP	NMP schist		fractured
529	B203359	Inkanyezi	31.1258	-28.9567	104	15.20	22	53	82	0.30	0.18	NMP	NMP schist	3	fractured
530	B203360	Inkanyezi	31.1272	-28.9510	122	20.80	31	47	84	0.08	0.14	NMP	NMP schist	3	fractured
531	B203361	Inkanyezi	31.1360	-28.9633	104	38.30	55	93		5.00	-1.00	NMP	NMP gneiss	1	fractured
532	B203362	Inkanyezi	31.2328	-28.9750	61	20.00	35			0.35	0.50	NGS	NGS	0	fractured
533	B203363	Inkanyezi	31.2433	-28.9865	21	5.00	18			8.30	-1.00	NMP	NMP gneiss	0	fractured
534	B203364	Inkanyezi	31.2555	-28.9990	106	41.00	68	74	92	2.00	-1.00	NGS	NGS	0	fractured
535	B203365	Inkanyezi	31.2500	-28.9211	118	4.90	80			0.45	0.06	NGS	dolerite	0	fractured
536	B203366	Inkanyezi	31.3310	-28.8567	96	51.80	20	86		0.08	0.17	NGS	dolerite	0	fractured
537	B203367	Inkanyezi	31.3687	-28.8255	88	39.00	54	59	70	2.60	-1.00	NGS	NGS	1	fractured
538	B203368	Inkanyezi	31.3148	-28.8580	120	58.62	74	87		0.07	0.06	NGS	dolerite	0	fractured
539	B203369	Inkanyezi	31.3497	-28.8147	118		-999			0.00		NGS	dolerite/NGS		contact

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
491	PROFILING	90																			
492	PROFILING	90																			
493	PROFILING	180			7.8	55.2	424		200	32	23	57	2.9	41	6	0.1	3.91	0.6		0.014	13.9
494	PROFILING	180			7.6	47.5	367		176	30	15	53	4.2	41	4	0.04	0.15	0.7		0.128	20.1
495	PROFILING	200			7.6	47.3	341		145	46	7	43	3.5	51	13	0.04	0.04	0.5		0.314	28.8
496	PROFILING	80																			
497	PROFILING	170																			
498	PROFILING	200																			
499	PROFILING	150																			
500	PROFILING	120																			
501	PROFILING	120			8.4	79.1	498		145	24	14	114	3	146	19	0.04	0.04	0.9		0.013	11.3
502	PROFILING	120																			
503	PROFILING	110			8.4	61.2	576		319	32	27	76	8.1	21	9	0.04	2.78	2		0.017	20.6
504	PROFILING	210			8.1	83.3	656		258	41	26	115	2.7	116	10	0.05	6.59	1.2		0.033	15.5
505	PROFILING	120			8	196	1662		694	95	128	159	22.6	229	18	0.05	36.37	2.7		0.035	27.3
506	PROFILING	180			8.3	71	536		232	35	21	91	2	74	4	0.04	4.8	0.5		0.018	13.9
507	PROFILING	120																			
508	PROFILING	90			7.2	53.2	378		151	36	12	61	2.8	74	7	0.04	0.39	0.5		0.13	16.4
509	PROFILING	120			8.3	117.2	998		414	68	69	100	9.4	100	17	0.05	29.12	0.8		0.017	14.1
510	PROFILING	120			8.5	212	1509		627	20	110	273	15	283	23	0.07	4	2.7		0.011	7
511	PROFILING	120			8.4	77.8	614		284	33	59	48	8.6	72	45	0.06	0.05	0.5		0.027	14.9
512	PROFILING	120			7.7	42	266		103	13	7	52	3.4	48	3	0.05	3.18	0.3		0.042	24.4
513	PROFILING	120																			
514	PROFILING	80																			
515	PROFILING	210			8.3	176	1083		163	71	65	183	3	394	3	0.04	0	0.4		0.006	8.4
516	PROFILING	120			8	170	1535		783	63	77	236	11.4	132	24	0.05	7.62	2		0.032	17
517	PROFILING	120																			
518	PROFILING	120			8.4	89	733		326	49	43	95	6.5	95	46	0.04	0.34	0.8		0.013	14.9
519	PROFILING	140			7.8	160	1292		594	79	69	184	6.4	183	17	0.04	6.4	1		0.017	17.6
520	PROFILING	120			8.5	254	1916		800	57	140	289	23.5	296	44	0.07	20.17	1.8		0.015	17.3
521	PROFILING	80			7	102	664		338	44	33	136	4.2	149	19.1	0.01	0.09	0.96		0.07	7.1
522	PROFILING	150			8.1	32.2	230		105	24	8	28	2.5	28	7	0.04	1.08	0.4		0.068	16.6
523	PROFILING	120			8.1	42.4	334		169	33	12	35	3.7	30	12	0.04	0.04	1		0.019	18.2
524	PROFILING	140			6.6	54	324		108	25.6	16.4	54	0.84	63	8.3	0.13	10.1	0.39		0.01	9.4
525	PROFILING	150			8.2	103.1	700		454	39.6	60	107	10	107	27	0.01	0.03	3		0.01	8.7
526	PROFILING	180			8.1	586	3630		494	225	327	431	29.3	1314	299	0.09	90.48	1.9		0.025	23.6
527	PROFILING	120			8	266	1653		499	95	102	240	19	288	292	0.07	1.52	2.5		0.019	23.9
528	PROFILING	120																			
529	PROFILING	160			7.9	194	995		130	56	22	242	7.1	208	293	0.05	0.56	5		0.017	11.9
530	PROFILING	150			8.4	211	1368		415	69	52	275	9.5	247	179	0.05	6.24	3.7		0.019	14.3
531	PROFILING	120			6.8	144	968		530	81	65	154	4.3	124	88	0.01	8.3	0.66		1.8	15.5
532	PROFILING	160			6.4	11.4	66		19	1	1	15	3.1	13	3	0.04	1.32	0.1		0.041	16.5
533	PROFILING	120			7.7	23.8	151		71	9	7	21	2.8	17	4	0.04	0.96	0.2		0.018	15.2
534	PROFILING	160			6.9	12.1	65		19	1	1	15	4.1	12	7	0.04	0.09	0.2		0.095	17.5
535	PROFILING	120			8.5	54	418		209	37	20	50	3	34	11	4	1.7	0.3		0.008	17.6
536	PROFILING	140			7.2	13.5	98		36	7.3	4.2	11.7	0.6	18.5	3.5	0.01	0.58	0.11		0.01	5
537	PROFILING	140			7.9	57.5	468		242	48	17	51	2.8	48	4	0.04	0.52	0.2		0.056	21.6
538	PROFILING	120			7	25	132		38	8	5	22	3	31	3	0.04	2.8	0.1		0.015	13.8
539	PROFILING	120																			

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
540	B203370	Inkanyezi	31.1942	-28.8582	89	1.90	28	61	73	0.58	0.64	NMP	NMP migmatite	1	fractured
541	B203371	Inkanyezi	31.2205	-28.8542	131	38.60	50	81		0.40	0.42	NMP	NMP amphibolite	0	fractured
542	B203372	Inkanyezi	31.2285	-28.8605	131	42.28	95			0.14	0.28	NMP	NMP amphibolite	0	fractured
543	B203373	Inkanyezi	31.2273	-28.8650	131	12.60	32	82		1.44	1.39	NMP	NMP amphibolite	0	fractured
544	B203374	Inkanyezi	31.1938	-28.8222	96	64.60	76	87		2.50	-1.00	NMP	NMP schist	0	fractured
545	B203375	Inkanyezi	31.3958	-28.9407	51	4.00	11			0.94	1.11	NGS	NGS	1	fractured
546	B203376	Inkanyezi	31.3958	-28.9392	130	47.40	90	110		0.08	0.14	NGS	NGS	0	fractured
547	B203377	Inkanyezi	31.2377	-28.8703	79	4.35	25	69		0.11	0.14	NMP	NMP amphibolite	0	fractured
548	B203378	Inkanyezi	31.2137	-28.8175	131	54.00	87	109		0.08	0.06	NMP	NMP amphibolite	0	fractured
549	B203379	Inkanyezi	31.2422	-28.8157	124	14.30	98	106		0.17	0.22	NMP	NMP gneiss	2	fractured
550	B203380 A	Inkanyezi	31.2667	-28.82[illegible]5	130		-999			0.00		NMP	NMP amphibolite		fractured
551	B203381	Inkanyezi	31.2892	-28.8297	141	109.00	122	128		0.08	0.11	NMP	NMP amphibolite	2	fractured
552	B203382	Inkanyezi	31.2753	-28.8192	131	120.00	126			0.00		NMP	NMP amphibolite		fractured
553	B203383 A	Inkanyezi	31.2753	-28.8307	120		-999			0.00		NMP	dolerite		fractured
554	B203384 A	Inkanyezi	31.2583	-28.7962	131		-999			0.00		NMP	NMP gneiss		featureless
555	B203385	Inkanyezi	31.2215	-28.7982	78	22.40	65			0.50	0.22	NMP	NMP amphibolite	0	fractured
556	B203386	Inkanyezi	31.2323	-28.8033	94	41.80	75			0.28	0.28	NMP	NMP gneiss	1	fractured
557	B203387	Inkanyezi	31.2085	-28.8677	88	22.70	36	85		1.00	0.97	NMP	NMP amphibolite	0	fractured
558	B203388 A	Inkanyezi	31.2022	-28.8645	140		-999			0.00		NMP	NMP amphibolite		fractured
559	B203389	Inkanyezi	31.2073	-28.8868	124	45.00	60			0.30	0.31	NMP	NMP amphibolite	1	fractured
560	B203390	Inkanyezi	31.2118	-28.8780	78	24.00	36	69		0.22	0.14	NMP	NMP amphibolite	1	fractured
561	B203391 A	Inkanyezi	31.1927	-28.8582	120		-999			0.00		NMP	NMP quartzite		fractured
562	B203392	Inkanyezi	31.2172	-28.8870	118	18.00	52	95	114	0.28	0.28	NMP	NMP amphibolite	1	fractured
563	B203393	Inkanyezi	31.2053	-28.8825	101	21.00	55	81		0.14	0.15	NMP	NMP gneiss	0	fractured
564	B203394	Inkanyezi	31.3973	-28.8335	86	61.60	67	78		0.19	0.28	NGS	NGS	0	fractured
565	B203395	Inkanyezi	31.3975	-28.8228	113	3.80	57	90		0.10	0.19	NGS	NGS	0	fractured
566	B203396	Inkanyezi	31.4327	-28.9277	60	0.00	39	43		6.00	-1.00	NGS	NGS/dolerite	0	contact
567	B203397 A	Inkanyezi	31.3717	-28.9368	126		-999			0.00		NGS	NGS		fractured
568	B203398	Inkanyezi	31.4172	-28.9245	121	2.20	65	92		0.07	0.11	NGS	NGS	0	fractured
569	B203399	Inkanyezi	31.3908	-28.9508	142	87.56	109			0.08	0.08	NGS	NGS	2	fractured
570	B203400	Inkanyezi	31.4802	-28.9607	51	5.00	30			10.00	-1.00	NMP	NMP gneiss	2	fractured
571	B203401 A	Inkanyezi	31.3578	-28.9482	140		-999			0.00		NGS	NGS		fractured
572	B203402	Inkanyezi	31.9195	-28.8990	61	19.00	49	52		0.33	0.22	Maputaland sand	NMP gneiss	2	fractured
573	B203403	Inkanyezi	31.6020	-28.9953	71	22.48	47	56		0.19	0.14	Dwyka tillite	NMP gneiss	2	fractured
574	B203404	Inkanyezi	31.5893	-28.9202	130	45.00	109			0.00	0.11	NMP	NMP gneiss	2	featureless
575	B203405	Inkanyezi	31.5835	-28.9280	100	10.55	46	62	82	10.00	-1.00	Karoo sandstone	NMP gneiss/schist	2	contact
576	B203406	Inkanyezi	31.5735	-28.9185	136	28.00	36	122		1.30	0.69	NMP	NMP gneiss	2	fractured
577	B203407	Inkanyezi	31.5393	-28.8993	70	10.00	32	52	62	0.22	0.19	NMP	NMP gneiss	0	fractured
578	B203408	Inkanyezi	31.5522	-28.8858	120	2.61	4			0.07	0.11	NMP	NMP gneiss	1	fractured
579	B203409	Inkanyezi	31.6115	-28.9028	100	2.50	7			0.07	0.14	NMP	NMP gneiss	0	secondary porous
580	B203410	Inkanyezi	31.5428	-28.8865	41	3.80	12			0.50	0.75	NMP	NMP gneiss	0	fractured
581	B203411	Inkanyezi	31.4920	-28.8470	110		-999			0.00		NGS	NGS		fractured
582	B203412	Inkanyezi	31.5008	-28.9163	121	6.50	36	97		0.13	0.08	NMP	NMP gneiss	1	fractured
583	B203413	Inkanyezi	31.5082	-28.8532	71	29.50	57			5.00	4.44	NGS	NGS	0	fractured
584	B203414	Inkanyezi	31.4918	-28.9122	118	16.00	28			0.07	0.14	NMP	NMP gneiss	0	fractured
585	B203415	Inkanyezi	31.5098	-28.8893	105	64.60	87	93		0.14	0.14	NGS	NGS	0	secondary porous
586	B203416	Inkanyezi	31.3133	-28.8657	141	26.00	47	61		0.17	0.17	NGS	NGS	0	fractured
587	B203417	Inkanyezi	31.4978	-28.8840	11	19.30	85	108		8.33	-1.00	NGS	NGS	0	fractured
588	B203418	Inkanyezi	31.3442	-28.8612	101	18.36	41	85		6.94	-1.00	NGS	NGS	0	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
540	PROFILING	120			8.3	63	488		234	30	29	58	3	48	19	0.04	2.9	0.4		0.02	12.9
541	PROFILING	160			7.4	31.3	203		87	12	8	33	1.7	31	3	0.04	2.17	0.1		0.29	21
542	PROFILING	90			8	31.1	208		103	16	4	35	2.5	14	6	0.04	0.89	0.2		0.055	22.1
543	PROFILING	120			7.8	24.5	180		88	11	5	27	2.2	17	7	0.04	0.53	0.3		0.023	22.1
544	PROFILING	120			8	47	342		115	12	7	83	3	68	5	0.04	5.2	0.3		0.108	21.8
545	PROFILING	120			7.7	68	567		283	62	17	67	3.6	47	26	0.06	0.05	0.5		0.04	17.2
546	PROFILING	120			7.9	48.3	334		162	41	10	33	3.9	38	10	0.04	0.21	0.2		0.193	17.9
547	PROFILING	90			8.2	45	320		142	26	18	41	2	34	3	0.32	5.4	0.4		0.016	14
548	PROFILING	120			8	26	207		114	19	11	16	1	11	3	0.04	1.7	0.2		0.014	29.5
549	PROFILING	180			8.4	105.2	824		392	34	32	144	8.4	96	24	0.06	1.18	2		0.009	9.7
550	PROFILING	140																			
551	PROFILING	120			8.4	54	370		169	27	10	64	6	35	18	0.04	0.2	3.1		0.007	16.6
552	PROFILING	120																			
553	PROFILING	120																			
554	PROFILING	150																			
555	PROFILING	120			8.2	22	171		85	23	5	16	3	9	3	0.04	1.9	0.2		0.032	17.5
556	PROFILING	120			8.2	51	365		160	27	14	51	5	45	16	0.04	2.5	1.1		0.014	15.1
557	PROFILING	120			7.9	28	202		71	18	5	32	2	24	7	0.04	6	0.2		0.064	22.1
558	PROFILING	120																			
559	PROFILING	80			7	32	244		124	11	5	45	6	19	6	0.04	0.4	1.2		0.017	8.6
560	PROFILING	120			7	29	222		88	14	9	28	2	15	3	0.04	9.9	0.2		0.016	17.4
561	PROFILING	100																			
562	PROFILING	170			7.7	55	360		170	27	14	58	2	29	8	0.04	7.5	0.3		0.005	16.4
563	PROFILING	100			8.2	43	287		141	29	12	32	2.8	16	6	0.04	3.95	0.1		0.058	16.4
564	PROFILING	120			8	38.8	282		130	31	10	36	4.1	31	6	0.04	1.28	0.2		0.08	17.7
565	PROFILING	120			6.9	49	301		134	28.9	12.5	50	1.43	64	11.3	0.03	1.1	0.11		0.54	11.1
566	PROFILING	120			8.1	34.5	276		136	37	7	29	4.7	20	11	0.04	0.07	0.5		0.05	19.2
567	PROFILING	150																			
568	PROFILING	150			7.2	11	62		14	3	1	17	3	18	3	0.04	0.6	0.2		0.099	11.3
569	PROFILING	120			8	226	1763		780	99	56	317	4.6	297	25	0.04	3.03	0.6		0.006	15.6
570	PROFILING	120			8	65.2	413		153	33	14	79	3.5	79	17	0.04	0.04	1.8		0.019	20.5
571	PROFILING	120																			
572	PROFILING	120			8.1	114.3	213		240	39	27	159	3.5	182	7	0.04	0.1	1.7		0.034	16.6
573	PROFILING	80			7.8	180	982		228	49	52	211	5.6	244	9	0.06	7.72	0.5		0.021	14.4
574	PROFILING	140			6.3	76	504		122	44	28	71		95	51	0.01	12.4	0.19		0.05	14
575	PROFILING	120			8	223	1268		199	77	27	321	4.1	366	226	0.04	0.32	2		0.016	11.3
576	PROFILING	120			8.3	110.1	818		251	41	32	184	5.7	203	40	0.04	1.28	0.6		0.016	9.3
577	PROFILING	80			8	34	260		104	7	7	63	3	37	9	0.04	1.2	0.4		0.098	23.8
578	PROFILING	80			8.1	102	708		220	25	25	153	10	192	32	0.04	0.1	1.1		0.032	13.4
579	PROFILING	120			8.2	57.5	425		182	34	20	67	2.7	58	21	0.04	0.16	0.3		0.019	17.1
580	PROFILING	120			6.6	60.9	373		134	13.4	18.1	86	2.8	92	28	0.01	3.8	0.49		0.03	8.7
581	PROFILING	120																			
582	PROFILING	80			8.7	78	536		160	45	23	85	4	131	32	0.2	4.2	0.7		0.041	13.3
583	PROFILING	120			7	23	142		26	3	3	35	5	44	18	0.04	0	0.3		0.473	21.2
584	PROFILING	80			7.1	50	290		160	43	25	42		43	20	0.02	2.5	0.43		0.16	14
585	PROFILING	140			7	11	70		14	3	2	14	4	22	3	0.04	0.8	0.1		0.089	8.2
586	PROFILING	120			6.6	11.1	69		28	4	1	11	3	8	8	0.04	0.04	0.1		0.01	6.8
587	PROFILING	120			6.8	12.4	127		18	3.3	1.7	16.1	2.9	16.8	16.7	0.02	0.02	0.25		0.5	5
588	PROFILING	120			7	14.4	123		48	8.5	6.1	11.6	0.7	11.9	5.2	0.01	0.11	0.17		0.03	6.8

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
589	B203419	Inkanyezi	31.5663	-28.8997	121	5.00	42	89	112	0.20	0.19	NMP	NMP amphibolite	0	fractured
590	B203420 A	Inkanyezi	31.5120	-28.8882	121		-999			0.00		NGS	NGS		featureless
591	B203421	Inkanyezi	31.5210	-28.8928	86	30.80	51			0.18	0.25	NGS	NMP gneiss	0	fractured
592	B203422 A	Inkanyezi	31.5868	-28.8940	141		-999			0.00		NMP	NMP gneiss		fractured
593	B203423 A	Inkanyezi	31.5548	-28.9078	121		-999			0.00		NMP	NMP amphibolite		fractured
594	B203424 A	Inkanyezi	31.6037	-28.8835	131		-999			0.00		NMP	NMP amphibolite		fractured
595	B203425 A	Inkanyezi	31.5750	-28.8897	121		-999			0.00		NMP	NMP amphibolite		fractured
596	B203426	Inkanyezi	31.4283	-28.9405	76	28.30	63			0.44	0.44	NMP	NMP gneiss	0	fractured
597	B203427	Inkanyezi	31.4392	-28.9363	81	4.00	37	60	72	0.33	0.19	NMP	NMP gneiss	0	secondary porous
598	B203428	Inkanyezi	31.4327	-28.9277	51	0.00	17			1.38	1.38	NGS	NGS	0	fractured
599	B203429 A	Inkanyezi	31.4325	-28.9570	121		-999			0.00		NMP	NMP gneiss		fractured
600	B203430 A	Inkanyezi	31.4328	-28.9608	121		-999			0.00		NMP	NMP gneiss		fractured
601	B203431	Inkanyezi	31.4747	-28.9687	81	6.55	12	17		0.10	0.22	NMP	NMP gneiss	0	fractured
602	B203432	Inkanyezi	31.4692	-28.9912	67	30.00	3	51		0.25	0.28	dolerite	NGS	1	fractured
603	B203433	Inkanyezi	31.4425	-28.9788	96	43.80	74	82		0.13	0.11	NMP	NMP gneiss	2	fractured
604	B203434	Inkanyezi	31.2240	-28.9962	96	37.70	73	77		0.22	0.22	NMP	NMP gneiss	0	fractured
605	B203435	Inkanyezi	31.2908	-29.0262	126	73.00	115			0.58	0.44	NGS	NGS	0	fractured
606	B203436	Inkanyezi	31.4795	-29.0158	61	10.50	28			1.54	1.67	dolerite	Dwyka tillite/shale	3	contact
607	B203437	Inkanyezi	31.5020	-28.9935	101	0.70	48	66	84	1.11	0.56	Ecca shale	Ecca shale/sandstone	3	contact
608	B203438 A	Inkanyezi	31.4635	-28.9560	131		-999			0.00		NMP	NMP amphibolite		fractured
609	B203439	Inkanyezi	31.3067	-29.0257	131	25.00	50			0.07	0.11	NGS	NGS	1	fractured
610	B203440 A	Inkanyezi	31.2972	-29.0167	121		-999			0.00		NGS	NGS		fractured
611	B203441	Inkanyezi	31.2982	-29.0007	121	21.80	50			0.33	0.08	NGS	NGS	0	fractured
612	B203442	Inkanyezi	31.4687	-28.9447	121	36.80	47	77	100	1.50	0.97	NMP	NMP gneiss	2	fractured
613	B203443	Inkanyezi	31.4760	-28.9322	105	19.60	74	92		0.22	0.19	NMP	NMP gneiss	1	fractured
614	B203444 A	Inkanyezi	31.3388	-28.8705	119		-999			0.00		dolerite	dolerite		fractured
615	B203445	Inkanyezi	31.4437	-28.9197	90	4.10	49	78		0.09	0.17	NGS	NGS	0	fractured
616	B203446	Inkanyezi	31.3267	-29.0002	61	18.10	42			2.00	-1.00	NGS	NGS	1	fractured
617	B203447	Inkanyezi	31.3262	-29.0247	76	39.70	57	60		0.50	0.50	NGS	NGS	1	fractured
618	B203448	Inkanyezi	31.3657	-29.0294	116	51.50	62	73	103	3.88	-1.00	NMP	NMP gneiss	0	fractured
619	B203449	Inkanyezi	31.3668	-28.9762	51	14.30	21			0.67	0.69	NMP	NMP gneiss	2	fractured
620	B203450	Inkanyezi	31.3605	-29.0827	78	32.40	54	69		0.24	0.28	NMP	NMP gneiss	0	fractured
621	B203451	Inkanyezi	31.3710	-29.0605	61	10.45	41	46		0.26	0.22	NMP	NMP granite	0	fractured
622	B203452	Inkanyezi	31.3640	-29.0357	121		23	59		0.00		NMP	NMP granite		fractured
623	B203453	Inkanyezi	31.3663	-29.0470	76	17.10	49	62		0.42	0.44	NMP	NMP gneiss	2	fractured
624	B203454	Inkanyezi	31.2455	-29.0197	121	52.00	37	57		0.00		NMP	NMP gneiss		fractured
625	B203455 A	Inkanyezi	31.2482	-29.0520	121		-999			0.00		NGS	NGS		featureless
626	B203456	Inkanyezi	31.2440	-29.0657	41	12.30	20	23		1.67	1.94	NGS	NGS	1	fractured
627	B203457 A	Inkanyezi	31.2440	-29.0387	121		-999			0.00		NMP	NGS		fractured
628	B203458	Inkanyezi	31.3290	-29.0497	86	36.70	62	66		0.72	0.56	NGS	NGS	0	fractured
629	B203459	Inkanyezi	31.3267	-29.0378	121	44.00	69	106		0.22	0.19	NGS	NGS	0	fractured
630	B203460	Inkanyezi	31.3787	-29.0328	56	18.40	30			1.67	0.08	NMP	NMP granite	0	secondary porous
631	B203461	Inkanyezi	31.3193	-29.1033	51	25.20	33			0.20	0.19	NGS	NGS	0	fractured
632	B203462	Inkanyezi	31.4782	-29.0542	51	21.05	29	39		0.67	0.69	Dwyka tillite	Dwyka tillite/NGS	2	contact
633	B203463	Inkanyezi	31.3765	-29.0297	61	29.60	36			0.27	0.36	NMP	NMP granite	0	secondary porous/featureless
634	B203465	Inkanyezi	31.4003	-29.0473	61	5.80	44	52		0.33	0.33	dolerite	NGS/NMP granite	2	contact
635	B203466	Inkanyezi	31.4092	-29.0547	131	20.55	120			0.08	0.07	NMP	NMP amphibolite	1	fractured
636	B203468 A	Inkanyezi	31.4090	-29.0263	121		-999			0.00		NMP	NMP granite		fractured
637	B203469	Inkanyezi	31.4205	-29.0175	51	15.20	28	36		0.33	0.55	dolerite	NGS	0	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
589	PROFILING	120			7.7	31	238		84	11	8	44	4	47	18	0.04	0.4	0.2		0.022	12.9
590	PROFILING	120																			
591	PROFILING	90			8.1	44	328		110	33	20	32	3	78	20	0.04	1.4	0.9		0.136	17.1
592	PROFILING	120																			
593	PROFILING	120																			
594	PROFILING	120																			
595	PROFILING	120																			
596	PROFILING	160			8.2	50	425		195	22	12	88	3	56	3	0.06	0.4	0.7		0.06	18.1
597	PROFILING	120			8.4	51	398		194	19	14	71	3	40	12	0.04	0.1	0.7		0.024	17.2
598	PROFILING	120			7.6	17	99		22	5	2	22	5	26	3	0.04	2.6	0.2		0.195	10.9
599	PROFILING	120																			
600	PROFILING	160																			
601	PROFILING	120			8.1	51	362		118	20	8	78	3	86	17	0.04	1.1	0.4		0.146	24
602	PROFILING	120			7	64	375		62	14	12	95	6	153	17	0.09	0	0.2		0.024	23
603	PROFILING	80			8.3	192	1300		326	120	64	207	5	291	213	0.04	0	1		0.013	16.4
604	PROFILING	120			7.1	16.6	145		62	8.8	4.9	17.5	1.9	17.6	2.9	0.17	0.06	0.19		0.16	6.4
605	PROFILING	120			8.5	35	321		144	35	17	21	4	15	54	0.04	0	0.4		0.025	7.9
606	PROFILING	170			8.1	433	2665		238	51	101	765	7	1352	94	0.04	0.5	0.5		0.091	15.9
607	PROFILING	100			8.2	288	2318		512	34	25	729	6	853	42	2.05	0	0.8		0.257	7.8
608	PROFILING	150																			
609	PROFILING	150			5.5	13.7	82		20	7.5	3.9	20		19	3.9	0.02	1.8	0.06		0.07	8.9
610	PROFILING	150																			
611	PROFILING	120			6.1	10	82		8	1.2	1.5	14.3	2.2	23	1.8	0.12	2.3	0.11		0.07	1.1
612	PROFILING	140			8.1	143	979		343	36	36	221	3	244	20	0.04	0.2	1.1		0.016	10.6
613	PROFILING	80			6.6	103	754		102	39.5	41	87	5.85	134	50	0.03	1.6	0.21		0.28	9.8
614	PROFILING	150																			
615	PROFILING	220			7.2	14	103		32	5	4	21	4	26	3	0.04	0.2	0.2		0.053	9.7
616	PROFILING	120			7	31	196		100	24.3	7.4	20	1.61	18.5	13.4	0.02	5.3	1.2		0.12	10.1
617	PROFILING	170			5.9	13.6	99		18	3.92	3.27	18.3	2.96	26	8.2	0.01	2.06	0.05		0.03	3.7
618	PROFILING	120			7	24.4	154		94	26.5	8.2	21.1	1.11	20	13.7	0.01	0.05	0.66		0.05	3.7
619	PROFILING	120			5.3	76	647		6	14.1	40	57	2.87	152	5.4	0.02	10.3	0.08		0.02	8.2
620	PROFILING	120			7.2	26.8	218		56	5.5	5.6	41.1	0.8	45	8	0.02	0.5	0.68		0.05	6.9
621	PROFILING	80			7.3	21.3	199		44	8.8	4.7	23.6	1.7	34	6.4	0.01	0.75	0.54		0.19	2.1
622	PROFILING	120																			
623	PROFILING	120			7	20	198		50	4.3	2.2	35.5	0.9	20	11.7	0.01	2.1	3.1		0.3	6.2
624	PROFILING	120																			
625	PROFILING	180																			
626	PROFILING	120			5.3	10.9	64		6	1.7	1.5	12.7	2	15	4.8	0.01	0.79	0.06		0.17	3.5
627	PROFILING	120																			
628	PROFILING	120			6.1	15.7	134		38	7.12	3.4	18.7	2.87	16.5	21.2	0.01	0.21	0.36		1.07	5
629	PROFILING	120			6.5	14.7	139		14	3.4	2.9	17.2	3.7	29	3.5	0.1	4.7	0.19		0.15	4.2
630	PROFILING	120			6.3	17.5	123		48	8.33	6.65	18.9	2.56	18.8	12.5	0.01	0.78	0.49		0.07	8
631	PROFILING	120			6.3	30	124		86	16.7	8.7	24	8.9	30	11.9	0.01	0.01	0.39		0.02	8.9
632	PROFILING	120			7.5	193	125		288	42.9	58	290	1.9	486	41	0.02	11.4	0.93		0.01	6.6
633	PROFILING	120			7.2	19.7	166		50	5.9	5.7	18.9	2.9	25	9.1	0.02	1.3	0.2		0.04	4.5
634	PROFILING	120			5	40	805		2	0.6	1	10.6	2.3	10	4.8	0.01	0.78	0.03		0.03	5
635	PROFILING	120			5.7	16.1	132		28	7.7	1.4	21	1.4	25	6.7	0.01	0.47	0.28		0.1	4
636	PROFILING	120																			
637	PROFILING	120			6.3	12.5	110		12	2.2	1.3	16.2	5.1	31	4.1	0.01	0.25	0.14		0.07	4

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
638	B203470 A	Inkanyezi	31.4252	-29.0197	121		-999			0.00		dolerite	NGS		fractured
639	B203471	Inkanyezi	31.2590	-29.0468	66	22.30	50			6.66	-1.00	NGS	NGS	1	fractured
640	B203472 A	Inkanyezi	31.2793	-29.0788	121		-999			0.00		NGS	NGS		fractured
641	B203473	Inkanyezi	31.4468	-29.0553	76	14.74	30			0.12	0.14	dolerite	NGS	0	fractured
642	B203475 A	Inkanyezi	31.4675	-29.0617	121		-999			0.00		Dwyka tillite	NGS/dolerite		fractured
643	B204170	Nkandla	31.8972	-28.8142	121	38.20	39			0.33	0.08	Maputaland sand	NMP gneiss	3	secondary porous/featureless
644	B204170 A	Nkandla	31.8897	-28.8100	138		-999			0.00		Maputaland sand	NMP migmatite		fractured
645	B204170 B	Nkandla	30.8894	-28.8106	146		-999			0.00		NMP	NMP amphibolite		fractured
646	B204171	Nkandla	30.8897	-28.8397	146	59.33	103			0.18	0.06	NMP	NMP amphibolite	1	fractured
647	B204172 A	Nkandla	30.8897	-28.8567	146		-999			0.00		NMP	NMP gneiss		featureless
648	B204173	Nkandla	30.8578	-28.8819	103	30.58	56			1.54	0.42	NMP	NMP amphibolite	0	fractured
649	B204174	Nkandla	30.6861	-28.7142	102	21.71	90			0.28	0.07	NMP	NMP schist	2	fractured
650	B204175	Nkandla	30.7011	-28.7272	103	10.00	60	83		10.00	4.50	Dwyka tillite	NMP amphibolite	1	fractured
651	B204176 A	Nkandla	30.7047	-28.7203	150		-999			0.00		NMP	NMP gneiss		fractured
652	B204176 B	Nkandla	30.7050	-28.7206	150		-999			0.00		NMP	NMP gneiss		fractured
653	B204177	Nkandla	30.7986	-28.7139	121	35.00	96			0.50	0.14	NMP	NMP schist	3	fractured
654	B204178	Nkandla	30.7303	-28.7222	131	14.60	112			0.15	0.05	Ecca shale	NMP amphibolite	2	fractured
655	B204179	Nkandla	30.9336	-28.7961	141	31.40	2			0.13	0.06	NMP	NMP amphibolite	2	fractured
656	B204179 A	Nkandla	30.9328	-28.7936	141		-999			0.00		NMP	NMP amphibolite		fractured
657	B204180	Nkandla	30.9617	-28.7878	120	19.00	68			0.10	0.07	NMP	NMP amphibolite	2	fractured
658	B204180 A	Nkandla	30.9625	-28.7878	150		-999			0.00		NMP	NMP amphibolite		fractured
659	B204180 B	Nkandla	30.9628	-28.7883	150		-999			0.00		NMP	NMP amphibolite		featureless
660	B204181	Nkandla	30.9767	-28.7922	120	42.10	92			0.16	0.70	NMP	NMP gneiss	1	fractured
661	B204181 A	Nkandla	30.9772	-28.7892	150		-999			0.00		NMP	NMP gneiss		fractured
662	B204182	Nkandla	31.0161	-28.8461	125	19.90	65	113		4.00	0.27	NMP	NMP gneiss	2	fractured
663	B204183	Nkandla	31.0614	-28.8333	102	41.00	60			0.50	0.07	NMP	NMP gneiss	2	fractured
664	B204183 A	Nkandla	31.0600	-28.8333	150		-999			0.00		NMP	NMP amphibolite		fractured
665	B204184	Nkandla	31.0714	-28.8272	150	49.50	137			2.00	0.14	NMP	NMP gneiss	0	fractured
666	B204184 A	Nkandla	31.0700	-28.7942	150		-999			0.00		NMP	NMP gneiss		fractured
667	B204185	Nkandla	31.0550	-28.8100	102	23.00	42			0.76	0.80	NMP	NMP gneiss	1	fractured
668	B204186	Nkandla	31.0622	-28.8094	150	34.30	90			0.07	0.07	NMP	NMP gneiss	1	fractured
669	B204186 A	Nkandla	31.0625	-28.8103	150		-999			0.00		NMP	NMP gneiss		fractured
670	B204187	Nkandla	31.0731	-28.8067	140	55.90	57			0.17	0.05	NMP	NMP gneiss	3	fractured
671	B204188 A	Nkandla	31.0942	-28.8139	140		-999			0.00		NMP	NMP gneiss		fractured
672	B204188 B	Nkandla	31.0944	-28.8236	140		-999			0.00		NMP	NMP gneiss		fractured
673	B204189	Nkandla	30.7611	-28.7778	130	83.40	110			0.41	0.20	dolerite	Ecca shale	2	fractured
674	B204189 A	Nkandla	30.7608	-28.7775	150		-999			0.00		dolerite	Ecca shale/dolerite		contact
675	B204190	Nkandla	30.7717	-28.7983	125	18.20	36			0.10	0.14	dolerite	dolerite	0	fractured
676	B204190 A	Nkandla	30.7694	-28.7958	150		-999			0.00		dolerite	Ecca shale/dolerite		contact
677	B204191	Nkandla	31.1142	-28.6611	90	16.30	65			0.06	0.07	NGS	Zng/dolerite	0	contact
678	B204192	Nkandla	31.1142	-28.6497	66	20.50	36			1.53	0.42	NGS	Dwyka tillite/Zng	1	contact
679	B204193	Nkandla	31.1331	-28.6358	102	9.20	18			0.74	0.33	dolerite	Zng	1	secondary porous
680	B204194	Nkandla	31.0964	-28.6031	96	12.80	31			1.82	0.80	Dwyka tillite	Dwyka tillite	1	fractured
681	B204195	Nkandla	31.0822	-28.6058	114	8.70	24	66		2.92	0.90	Dwyka tillite	Zng	1	fractured
682	B204196	Nkandla	31.1358	-28.5606	90	24.40	47			1.17	0.55	Dwyka tillite	Zd	0	fractured
683	B204197	Nkandla	31.0858	-28.5628	150	9.50	40			0.10	0.08	Dwyka tillite	Dwyka tillite	0	fractured
684	B204198	Nkandla	31.1003	-28.5608	96	14.00	32			0.42	0.50	Dwyka tillite	Dwyka tillite	0	fractured
685	B204199	Nkandla	31.1106	-28.5442	144	39.60	96			0.04	0.08	Dwyka tillite	Zd	0	fractured
686	B204218	Nkandla	31.0886	-28.5225	102	67.45	96			2.20	1.25	Dwyka tillite	NGS	0	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
638	PROFILING	120																			
639	PROFILING	170			5.5	8.2	65		12	2.8	1.1	10.1	1.5	11.9	6.1	0.01	0.18	0.06		0.06	2
640	PROFILING	140																			
641	PROFILING	80			7.9	49.4	401		204	33.4	20.5	42	1.8	42	13.8	0.01	0.02	0.31		0.05	9.9
642	PROFILING	120																			
643	VLF	360			7.6	227	1448		367	150	104	128	4.9	295	75	0.07	55.1	0.4		0.018	
644	VLF	180																			
645	VLF	180																			
646	VLF	350			8.2	136	913		430	52	60	106	12	117	32	0.04	2	0.7		0.013	
647	MAG	350																			
648	VLF	330			8.3	42	287		153	29	18	16	2	12	9	0.04	3	0.2		0.013	
649	VLF	490			8	158	1241		309	127	63	145	4	125	398	0.04	0.1	0.5		0.013	
650	VLF	450			8	65	548		280	57	27	52	3	36	31	0.08	0	0.4		0.006	
651	MAG	150																			
652	MAG	150																			
653	MAG	250			8	101	844		358	78	61	66	2	63	26	0.04	25.2	0.3		0.009	
654	MAG	130			8	50	414		178	18	5	91	13	49	17	0.04	0.1	1.9		0.045	
655	VLF	110			8.2	126	921		441	84	37	109	6	75	45	0.04	4.4	2.2		0.013	
656	VLF	110																			
657	VLF	90			8	127.6	998		556	54	61	117	7.9	46	28	0.05	0.85	1.7		0.028	
658	VLF	90																			
659	VLF	90																			
660	MAG	175			8.6	85	670		360	54	34	71	5	36	13	0.05	3.7	0.8		0.026	
661	MAG	175																			
662	MAG	160			8	213	1287		258	116	91	152	0.027	282	319	0.06	0	2.9		0.027	
663	VLF	100			8.3	182	1118		348	56	84	156	17	286	91	0.04	0	2.6		0.015	
664	VLF	100																			
665	VLF	80																			
666	VLF	80																			
667	VLF		MAG	170	7.7	62.9	467		257	32	38	34	2.4	34	7	0.04	1.25	0.3		0.016	
668	VLF	90			8	98	725		364	52	38	87	5	49	12	0.04	8.7	0.7		0.013	
669	VLF	90																			
670	MAG	260			7	300	2236		138	430	75	135	17	128	1277	0.04	0.5	1.9		0.01	
671	VLF	100																			
672	VLF	100																			
673	VLF	110			8	73	571		218	51	31	61	2	63	13	0.04	19.1	0.3		0.009	
674	VLF	110																			
675	VLF	200			8	43	318		164	26	8	48	1	11	3	0.04	5	0.2		0.022	
676	VLF	200																			
677	VLF	200			6.3	5.76	75		16	1.3	0.6	8.7	2.2	6.1	2.8	0.02	0.21	0.3		0.01	
678	VLF	200			5.5	13.5	112		20	7.1	3.3	11.3	0.7	16.6	2.8	0.01	4.6	0.06		0.01	
679	VLF	170			5.9	10.8	107		38	7.4	3.4	8.2	0.3	7.6	2.8	0.02	0.76	0.05		0.02	
680	MAG	200			6	9.9	93		31	3.4	3.5	9.9	1.2	6.6	2.8	0.01	0.4	0.11		0.01	
681	VLF	120			5.9	11.5	157		32	6.1	3.9	8.9	0.9	7.8	2.8	0.02	0.78	0.07		0.06	
682	VLF	210			6.5	18.4	133		64	13.2	5.8	12.3	1.1	9.2	2.8	0.01	1.4	0.09		0.01	
683	VLF	150	MAG	140	7.7	16.4	102		67	10	3.9	16.5	0.5	5.9	2.8	0.01	0.18	0.23		0.02	
684	VLF	150	MAG	150	6.3	15.9	136		49	6	3.7	18.6	1.5	12.9	2.8	0.01	0.97	0.23		0.14	
685	VLF	200			6.5	31.3	228		76	8.4	21.5	19.8	1	39.7	2.8	0.03	0.79	0.09		0.28	
686	VLF	350	MAG	350	6.5	16.3	132		60	9.37	6.91	14.1	1.86	12.9	2.8	0.04	2	0.08		0.14	

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
687	B204219	Nkandla	31.0956	-28.5147	120	23.10	42			0.08	0.18	Dwyka tillite	Dwyka tillite	1	fractured
688	B204220	Nkandla	31.0694	-28.5108	102	13.35	42	63		0.32	0.14	Dwyka tillite	NGS	2	fractured
689	B204221	Nkandla	31.0647	-28.5161	72	15.80	31	64		6.00	2.08	Dwyka tillite	Dwyka tillite	0	fractured
690	B204222	Nkandla	31.0617	-28.5878	102	32.14	42			1.00	0.19	Dwyka tillite	Dwyka tillite	1	fractured
691	B204223	Nkandla	31.0725	-28.5936	126	46.60	98			0.33	0.06	Dwyka tillite	Dwyka tillite	0	fractured
692	B204224	Nkandla	31.0294	-28.6003	102	29.35	38			0.57	0.22	Zn	Zn	1	fractured
693	B204225	Nkandla	31.0053	-28.6278	102	14.90	72			1.33	0.81	Dwyka tillite	NGS	1	fractured
694	B204226 A	Nkandla	31.0147	-28.5447	150		-999			0.00		dolerite	Dwyka tillite		fractured
695	B204226 B	Nkandla	31.0147	-28.5450	150		-999			0.00		dolerite	Dwyka tillite		fractured
696	B205200	Mapumulo	31.2264	-29.1550	101	77.30	62			0.10	0.10	NGS	NGS/shale	2	contact
697	B205201	Mapumulo	31.2447	-29.1681	95	59.20	76	83		0.48	0.30	NGS	NGS	2	fractured
698	B205202	Mapumulo	31.0489	-29.0869	140	56.70	69			0.17	0.10	NMP	NMP granite	0	fractured
699	B205203	Mapumulo	31.1608	-29.1794	81	32.00	51	54		6.90	2.00	NGS	NMP granite	1	secondary porous/featureless
700	B205204	Mapumulo	31.0375	-29.2275	121	40.84	96			0.24	0.15	NMP	NMP granite	1	fractured
701	B205205 A	Mapumulo	31.0358	-29.2317	150		-999			0.00		NMP	NMP granite		fractured
702	B205205 B	Mapumulo	31.0972	-29.1406	150		-999			0.00		NMP	NMP granite		fractured
703	B205206	Mapumulo	31.0533	-29.1956	80	43.70	57	69		0.05	0.10	NMP	NMP granite	0	fractured
704	B205206 A	Mapumulo	31.0578	-29.1933	150		-999			0.00		NMP	NMP granite		featureless
705	B205207 A	Mapumulo	31.0419	-29.1956	150		-999			0.00		NMP	NMP granite		featureless
706	B205207 B	Mapumulo	31.0431	-29.1958	150		-999			0.00		NMP	NMP granite		featureless
707	B205208	Mapumulo	31.0353	-29.2717	120	64.90	96	104		6.60	1.50	NMP	NMP diorite	3	fractured
708	B205209	Mapumulo	31.0453	-29.2433	120	59.02	88			0.10	0.10	NMP	NMP granite	1	fractured
709	B205210	Mapumulo	31.0647	-29.1936	150	32.30	35			0.10	0.10	NMP	NMP granite	0	fractured
710	B205211	Mapumulo	31.0667	-29.2028	105	25.05	27	82		0.10	0.10	NMP	NMP granite	0	fractured
711	B205215 A	Mapumulo	31.0486	-29.2150	150		-999			0.00		NMP	NMP granite		fractured
712	B205216	Mapumulo	31.0247	-29.2283	90	5.80	30	82		0.19	0.15	NMP	NMP granite	0	fractured
713	B205222	Mapumulo	31.0175	-29.1825	81	47.30	59			1.00	3.00	NMP	NMP granite	0	fractured
714	B205225	Mapumulo	31.0108	-29.1792	121	74.87	30	115		0.10	0.10	NMP	NMP granite	0	fractured
715	B205228	Mapumulo	31.0972	-29.1406	150	37.90	46			0.10	0.10	NMP	NMP granite	0	fractured
716	B205229	Mapumulo	31.1314	-29.1458	150	67.30	136			0.06	0.10	NMP	NMP granite	1	fractured
717	B205230	Mapumulo	31.0986	-29.1081	90	53.20	59			0.10	0.10	NMP	NMP granite	1	fractured
718	B205230 A	Mapumulo	31.1086	-29.1208	150		-999			0.00		NMP	NMP granite		featureless
719	B205231	Mapumulo	31.0261	-29.1825	121	53.50	51	72	108	0.68	0.50	NMP	NMP granite	0	fractured
720	B205232 A	Mapumulo	31.0547	-29.1850	110		-999			0.00		NMP	NMP granite		fractured
721	B205234	Mapumulo	31.0675	-29.1697	84	43.15	48			0.11	0.10	NMP	NMP granite	0	fractured
722	B205236	Mapumulo	31.0986	-29.1892	71	19.50	29			0.10	0.10	NGS	NGS	-1	fractured
723	B301293 A	Madadeni	30.1681	-27.8753	120		-999			0.00		Ecca sandstone	Ecca sandstone		fractured
724	B301294	Madadeni	30.1983	-27.8708	90	4.19	25	37		1.70	0.30	Ecca sandstone	dolerite	2	fractured
725	B301295	Madadeni	30.1789	-27.9042	120	7.24	43	87		0.80	0.30	Ecca sandstone	Ecca shale/sandstone	1	contact
726	B301296	Madadeni	30.1750	-27.8586	90	9.34	57			3.00	2.00	Ecca sandstone	Ecca sandstone	2	fractured
727	B301297	Madadeni	30.1264	-27.9633	102	4.73	17	45		5.00	2.00	Ecca sandstone	dolerite/Ecca sandstone	1	contact
728	B301298	Madadeni	30.2536	-27.9533	120		-999			0.00		Ecca sandstone	Ecca sandstone/shale		contact
729	B301298 A	Madadeni	30.2536	-27.9533	120		-999			0.00		Ecca sandstone	Ecca sandstone/shale		featureless
730	B301299	Madadeni	30.2414	-27.8333	120	6.51	65	78		0.20	0.10	Ecca sandstone	Ecca shale	2	fractured
731	B301300 A	Madadeni	30.1486	-27.9569	132		-999			0.00		dolerite	dolerite/Ecca shale		contact
732	B301300 B	Madadeni	30.1514	-27.9550	120		-999			0.00		dolerite	Ecca shale/sandstone		contact
733	B301301	Madadeni	30.1250	-27.9681	102	2.10	32	43		0.90	0.30	Ecca sandstone	Ecca shale/sandstone	0	contact
734	B301302	Madadeni	30.1711	-27.8222	120	17.07	30	108		0.50	0.30	Ecca sandstone	Ecca shale/sandstone/dolerite	2	contact
735	B301302 A	Madadeni	30.1606	-27.8300	120		-999			0.00		Ecca sandstone	Ecca shale/sandstone		contact

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
687	VLF	250			5.7	14.8	130		38	5.01	3.85	20	0.95	14.5	2.8	0.02	2.8	0.11		0.04	
688	VLF	210			6	16.7	127		56	11.4	6.96	12.6	0.75	7.7	2.8	0.01	1.9	3.4		0.8	
689	VLF	200			6.3	22.3	169		86	13.3	8.32	21.3	1.34	11.8	2.8	0.01	0.72	0.21		0.1	
690	VLF	200			5.9	22.6	175		54	11.1	9.2	15.2	1.2	18	2.8	0.02	6.8	0.11		0.05	
691	VLF	350			6.4	15	115		70	7.7	2.9	17.7	1	6.6	2.8	0.02	0.11	0.34		0.05	
692	VLF	200			5.3	6.65	60		11	0.9	3.3	5.9	0.1	4	2.8	0.01	2.7	0.03		0.01	
693	VLF	180			5.3	2.84	34		5	0.2	0.6	3.8	0.5	2.5	2.8	0.01	0.38	0.03		0.01	
694	VLF	200																			
695	VLF	200																			
696	EM	450			6.8	76.3	488	109.84	65	16	17	87	21	130	61		1	1.9		0.05	2.4
697	EM	570	MAG	100	7.85	138	886	268.98	350	60	29	182	4.4	210	25		16	0.05		0.05	19
698	EM	200			7.9	54	343	160	150	28	22	45	14	82	17		0.2	0.05		0.05	3.5
699	EM	470	MAG	220	8.3	32.4	207	79.4	50	16	9.6	34	4.5	45	4.8		8.6	0.4		0.05	17
700	EM	410	MAG	220	7.85	42.5	278	109.4	95	30	8.4	43	9.6	52	27		6.5	1.5		0.05	8.4
701	EM	300	MAG	300																	
702	EM	600	MAG	300																	
703	EM	590	MAG	300																	
704	EM	370	MAG	300																	
705	EM	580	MAG	300																	
706	EM	580	MAG	300																	
707	EM	420	MAG	240	7.7	119	759	325	245	72	35	128	2.4	155	44		29	1.6		0.05	15
708	EM	770	MAG	395	8	37.3	239	97.2	135	20	11.5	40.6	4.4	27	8		1.2	1.5		0.05	7
709	EM	560	MAG	260	6.95	47	301	144.09	115	35.2	13.7	36	4.2	61	15		3.6	0.9		0.05	12
710	EM	210	MAG	200	7.95	35.6	228	99.31	135	22	10.8	34	5.5	27	10		0.05	1		0.05	5.4
711	EM	580	MAG	300																	
712	EM	580	MAG	300																	
713	EM	210	MAG	200	7.3	11.9	76	23	32	2	4.3	13	2.9	7	20		1.2	0.2		0.05	15
714	EM	250	MAG	250	7.4	47	301	99.26	120	20	12	56	5.8	76	7		0.2	0.9		0.05	0.6
715	EM	490			7.6	40	253	105	130	20	13.2	40	3.5	31	19		0.02	0.9		0.05	2.1
716	EM	690			7.95	119	759	218.09	343	34	32.4	165	50	142	103		0.1	1.5		0.05	6.9
717	EM	290	MAG	300	7.5	66.3	424	217.32	290	36	31	58.2	14.9	42	10		0.4	1.5		0.05	4.9
718	EM	780																			
719	EM	300	MAG	300	7.65	20	128	50	70	11.2	5.3	24	6	16	2.5		1.6	0.1		0.05	16.5
720	EM	490	MAG	260																	
721	EM	400	MAG	400	7.6	20	127	49.68	55	12	4.8	17	5.7	17	4		2.6	0.5		0.05	9
722	EM	480	MAG	250																	
723	VES	7X																			
724	VES	8X			7.7	86.8	672	152	380	34	16.3	161	4.1	72	10		0.1	0.6	0.41		
725	VES	14X			8.1	71	524	29	300	8.3	2	161	2.3	54	1		0.1	0.8	0.01		
726	VES	7X			7.75	138	840	169	230	33	21	216	7.3	277	2		0.1	0.3	0.01		
727	VES	3X			7.8	58.8	480	140	270	32	14.5	80	1.4	20	14		2.2	0.2	0.01		
728	VES	4X																			
729	VES	7X																			
730	VES	6X			8.05	50.6	508	114	260	27	11.3	71	5.2	16.1	6		0.1	0.1	0.27		
731	VES	5X																			
732	VES	5X																			
733	VES	3X			7.75	53.1	448	182	280	44	17.4	54	1.5	14.1	11		0.1	0.2	0.01		
734	VES	3X			7.95	92.6	680	129	390	30	13.1	165	3.7	82	9		0.1	0.6	0.29		
735	VES	4X																			

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
736	B301303 A	Madadeni	30.1800	-27.8342	120		-999			0.00		Ecca sandstone	Ecca sandstone/shale		contact
737	B301303 B	Madadeni	30.1667	-27.8333	120		-999			0.00		Ecca sandstone	Ecca shale/dolerite		contact
738	B301304	Madadeni	30.2642	-27.9306	90	5.54	16	59		0.50	0.30	Ecca sandstone	Ecca shale/sandstone	1	contact
739	B301305 A	Madadeni	30.1403	-27.8250	120		-999			0.00		Ecca sandstone	Ecca shale/sandstone		contact
740	B301306	Madadeni	30.1911	-27.8194	102	0.70	84			0.20	0.10	Ecca sandstone	Ecca shale/sandstone	2	contact
741	B302421 A	Nqutu	30.5556	-28.2342	120		-999			0.00		Ecca sandstone	dolerite/Ecca shale		contact
742	B302422	Nqutu	30.4061	-28.2706	120	3.60	52			0.10	0.10	Ecca sandstone	dolerite	1	fractured
743	B302423	Nqutu	30.5653	-28.1578	90	5.50	56			2.00	1.00	Ecca sandstone	dolerite	0	fractured
744	B302424	Nqutu	30.5906	-28.1547	90	17.30	54			1.20	0.30	Ecca sandstone	dolerite	2	fractured
745	B302425	Nqutu	30.5978	-28.1333	95	4.40	16			0.10	0.10	Ecca sandstone	Ecca sandstone	0	fractured
746	B302426	Nqutu	30.6142	-28.1244	78	9.00	25			0.10	0.10	Ecca sandstone	dolerite	1	secondary porous
747	B302427	Nqutu	30.5917	-27.9583	100	2.50	52			0.10	0.10	Ecca shale	Ecca shale/dolerite	0	contact
748	B302427 A	Nqutu	30.5908	-27.9739	117		-999			0.00		Ecca sandstone	Ecca shale/dolerite		contact
749	B302428	Nqutu	30.5978	-28.0536	95	47.73	50			2.00	0.50	Ecca sandstone	Ecca shale	0	fractured
750	B302428 A	Nqutu	30.5964	-28.0631	90		-999			0.00		Ecca sandstone	Ecca shale/dolerite		contact
751	B302429	Nqutu	30.7311	-28.0400	90	16.11	44	70		6.00	1.00	Ecca sandstone	Ecca sandstone	0	secondary porous
752	B302430	Nqutu	30.7022	-27.9872	105	16.72	23	40	60	3.80	1.50	Ecca sandstone	Ecca sandstone	0	fractured
753	B302431	Nqutu	30.7561	-28.1214	90	12.55	46			1.20	0.30	Ecca shale	Ecca sandstone	0	fractured
754	B302432	Nqutu	30.6183	-28.1789	120	31.00	84			0.50	0.30	Ecca sandstone	dolerite	1	fractured
755	B302433	Nqutu	30.7847	-28.1653	120	8.26	105			1.00	0.30	Ecca shale	Ecca shale/dolerite	1	contact
756	B302434 A	Nqutu	30.6386	-28.2719	120		-999			0.00		Ecca shale	Ecca shale		featureless
757	B302435	Nqutu	30.5764	-28.3025	90	8.26	30			1.20	1.00	Ecca sandstone	Ecca shale/sandstone	0	contact
758	B302436	Nqutu	30.6639	-28.6722	110	28.00	36			0.10	0.10	dolerite	Ecca shale/Dwyka tillite	3	contact
759	B302437	Nqutu	30.7867	-28.2825	110	34.90	82			4.00	0.30	Ecca shale	Ecca shale	0	fractured
760	B302438	Nqutu	30.8014	-28.1819	120	1.72	99			2.50	0.30	dolerite	dolerite	0	fractured
761	B302439	Nqutu	30.7061	-28.3306	132	9.37	18			0.20	0.10	Ecca sandstone	Ecca shale/sandstone	2	contact
762	B302440	Nqutu	30.6722	-28.3389	90	8.45	37	65		0.80	0.30	Ecca shale	Ecca shale/dolerite	1	contact
763	B302441	Nqutu	30.7589	-28.3736	90	15.94	73			1.25	0.30	dolerite	dolerite	2	fractured
764	B302441 A	Nqutu	30.7517	-28.3767	120		-999			0.00		Ecca shale	dolerite		featureless
765	B302442	Nqutu	30.7850	-28.4247	90	8.01	27			1.00	0.30	Ecca shale	Ecca shale	3	secondary porous/fractu
766	B302443	Nqutu	30.8153	-28.3956	90	7.85	22	65		0.50	0.30	Ecca shale	Ecca shale/dolerite	2	contact
767	B302444	Nqutu	30.6117	-28.3367	90	5.12	65			1.00	0.50	Ecca sandstone	Ecca shale/dolerite	0	contact
768	B302445 A	Nqutu	30.7747	-28.3583	120		-999			0.00		dolerite	dolerite		fractured
769	B302446	Nqutu	30.5875	-28.2808	120	10.65	60	77		0.50	0.30	Ecca sandstone	dolerite	0	fractured
770	B302447	Nqutu	30.5689	-28.2042	100	0.00	30	64		3.00	3.00	Ecca sandstone	dolerite	2	fractured
771	B302448	Nqutu	30.5833	-28.3258	120	62.37	78			3.00	1.00	dolerite	dolerite	1	fractured
772	B303327	Ladysmith	29.7153	-28.2986	120	4.02	46	80		0.21	0.15	Ecca sandstone	Ecca sandstone/dolerite	2	contact
773	B303328	Ladysmith	29.7156	-28.3981	81	2.80	64			0.56	0.30	Ecca sandstone	Ecca sandstone/dolerite	0	contact
774	B303329 A	Ladysmith	30.1289	-28.4722	121		-999			0.00		Ecca sandstone	Ecca sandstone		fractured
775	B303329 B	Ladysmith	30.1283	-28.4717	149		-999			0.00		Ecca sandstone	Ecca sandstone/dolerite		contact
776	B303330	Ladysmith	30.1811	-28.4967	97	1.40	21	80		0.22	0.10	Ecca sandstone	dolerite	1	fractured
777	B303331	Ladysmith	30.0189	-28.5533	150	14.40	110			0.13	0.10	Ecca sandstone	Ecca sandstone	2	fractured
778	B303331 A	Ladysmith	30.0189	-28.5536	120		-999			0.00		Ecca sandstone	Ecca sandstone/dolerite		contact
779	B303331 B	Ladysmith	30.0197	-28.5528	150		-999			0.00		Ecca sandstone	Ecca sandstone/dolerite		contact
780	B303334 A	Ladysmith	30.2928	-28.4528	126		-999			0.00		Ecca sandstone	Ecca sandstone/shale		contact
781	B303334 B	Ladysmith	30.2939	-29.4522	120	6.60	80	96		4.16	2.20	Ecca sandstone	Ecca sandstone/shale	2	contact
782	B303335	Ladysmith	30.2497	-28.4364	150	3.30	54	118		0.50	0.40	Ecca sandstone	Ecca sandstone	2	fractured
783	B303336	Ladysmith	30.2411	-28.4344	150	4.60	147			0.85	0.50	Ecca sandstone	dolerite	3	fractured
784	B303338 A	Ladysmith	30.2239	-28.4442	150		-999			0.00		Ecca sandstone	Ecca sandstone/dolerite		contact

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
736	VES	3X																			
737	VES	2X																			
738	VES	3X			7.65	60.8	500	108	290	26	10.5	100	5.1	34	1		0.2	0.5	0.01		
739	VES	2X																			
740	VES	4X			7.8	6.88	180	34	36	8.1	3.4	7.4	0.7	4.5	7		0.1	0.1	0.37		
741	VES	5X																			
742	VES	5X			7.35	47	400	67	210	18.3	5.2	80	6.8	17.2	7		1.1	0.3	0.18		
743	VES	11X	MAG	350	7.35	34	228	105	160	34	5	36	1.6	14.3	3		0.1	0.4	0.01		
744	VES	10X	MAG	420	7.75	99.6	668	84	270	24	5.9	205	1.9	169	3		0.2	1.2	0.01		
745	VES	8X			7.4	36.9	360	119	110	28	12	30	4.1	33	34		5.2	0.2	0.01		
746	VES	9X	MAG	400	7.5	82.5	592	88	220	24	6.7	148	4.2	124	9		2.2	0.6	0.01		
747	VES	3X			7.7	33.5	380	62	150	12.9	7.2	57	4.9	29	9		1.6	0.2	0.01		
748	VES	4X																			
749	VES	4X			7.85	43.6	312	150	200	43	10.4	33	0.8	17.8	4		0.1	0.3	0.01		
750	VES	4X																			
751	VES	6X			8.3	49.8	336	61	230	7.4	10.4	89	2	21	7		0.1	0.4	0.01		
752	VES	6X			7.75	36.6	268	24	180	5.6	2.5	81	2.1	8.6	3		0.2	0.3	0.01		
753	VES	8X	MAG	550	7.05	61	420	228	280	50	25	50	1.7	25	30		2.7	0.4	0.01		
754	VES	6X			8.35	80.2	612	31	240	8.9	2.2	160	7.3	110	3		0.4	1.2	0.01		
755	VES	8X			8.05	44.1	408	69	202	18.9	5.3	70	3.7	19	6		0.4	0.4	0.14		
756	VES	13X	MAG	750																	
757	VES	6X			7.35	58.9	368	242	300	54	26	36	1.8	18.8	7		0.1	0.1	0.01		
758	VES	8X			7.3	34.7	248	48	130	13.4	3.6	47	4.7	15.3	3		1.2	0.3	2.6		
759	VES	8X	MAG	600	7.75	49	328	169	250	40	16.9	44	2.1	14.6	6		2.4	0.3	0.01		
760	VES	8X			8.65	44.7	296	69	200	18.7	5.5	81	0.1	25	3		0.1	0.4	0.01		
761	VES	9X	MAG	400	7.65	21.4	192	74	100	21	5.3	22	3.2	10.5	6		6.6	0.2	0.31		
762	VES	8X			8.9	37.6	256	36	180	11.5	1.9	82	0.1	15.7	6		1.9	0.4	0.18		
763	VES	3X			7.25	124.6	792	306	360	70	32	168	3.8	201	38		7.1	0.2	0.01		
764	VES	4X																			
765	VES	5X	MAG	500	7.55	274	2260	761	350	173	80	296	4.3	800	5		0.1	0.2	0.01		
766	VES	5X			7.25	177.8	1564	420	400	84	51	221	9.1	356	19.8		2.4	0.3	0.01		
767	VES	7X	MAG	350	7.55	30.3	216	76	150	26	2.7	43	1.5	10.5	1		0.1	0.3	0.01		
768	VES	9X																			
769	VES	10X			7.35	44.2	288	87	230	25	5.9	65	2	8	1		0.4	0.4	0.01		
770	VES	10X	MAG	400	7.15	75.7	484	278	310	57	33	62	0.6	43	31		19.3	0.3	0.01		
771	VES	8X			7.85	38.3	352	26	180	7.9	1.5	81	0.1	11	2		6.9	0.7	0.01		
772	EM	260			9.37	66	573	7	339	3	1	162	5.1	10	10	0.71	0.29	2.55		0.1	3.3
773	geology				7.29	22	149	50	75	20	10	11	3.2	18	1	0.06	2.33	0.1		0.1	10.6
774	MAG	150																			
775	MAG	150																			
776	EM	250	MAG	250	8.38	86	694	197	376	79	58	35	5.4	34	51	0.013	2.83	1.22		0.1	19
777	geology				8.17	126	1031	212	612	85	66	131	4.1	62	28	0.826	0.48	0.76		0.1	6.8
778	MAG	110																			
779	MAG	110																			
780	EM	130	MAG	130																	
781	EM	130	MAG	130	8.51	157	1210	10	609	4	3	363	5.1	174	1	0.671	0.02	1.32		0.1	5
782	EM	80	MAG	80	7.85	178	1061	180	243	72	18	254	3.5	439	2	1.02	0.69	2.53		0.1	10.5
783	geology				6.6	304	1688	95	20	38	1	581	1.2	985	2	1.393	0.27	3.99		0.1	4
784	EM	130	MAG	130																	

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
785	B303338 B	Ladysmith	30.2236	-28.4436	150	2.30	42			0.08	0.10	Ecca sandstone	dolerite	0	fractured
786	B303340	Ladysmith	30.2108	-28.4917	97	0.00	16			1.20	1.00	Ecca sandstone	Ecca sandstone	1	fractured
787	B303342 A	Ladysmith	30.2247	-28.4717	150		-999			0.00		Ecca sandstone	Ecca sandstone/dolerite		contact
788	B303342 B	Ladysmith	30.2244	-28.4725	101	1.00	16	39		0.20	0.15	Ecca sandstone	Ecca sandstone/dolerite	1	contact
789	B303343 A	Ladysmith	30.2131	-28.4281	150		-999			0.00		Ecca sandstone	Ecca sandstone/dolerite		contact
790	B303343 B	Ladysmith	30.2128	-28.4281	150	13.90	42			0.19	0.10	Ecca sandstone	Ecca sandstone	0	fractured
791	B303344	Ladysmith	29.7922	-28.4200	138	9.40	36	60		0.71	0.40	Ecca sandstone	dolerite	1	fractured
792	B303345	Ladysmith	29.6186	-28.3775	120	0.00	54	86		0.45	0.30	Ecca sandstone	Ecca sandstone/dolerite	2	contact
793	B303347 A	Ladysmith	29.7500	-28.3903	150		-999			0.00		Ecca sandstone	Ecca sandstone/dolerite		contact
794	B303347 B	Ladysmith	29.7500	-28.3903	150	9.48	100			0.02	0.00	Ecca sandstone	Ecca sandstone	3	fractured
795	B303349	Ladysmith	29.8606	-28.6689	132	11.16	24			0.44	0.30	Ecca sandstone	dolerite	1	fractured
796	B303350	Ladysmith	29.7192	-28.3044	102	5.90	11	49		0.11	0.20	Ecca sandstone	Ecca sandstone/dolerite	1	contact
797	B303351 A	Ladysmith	30.0892	-28.5783	127		-999			0.00		dolerite	Ecca sandstone/dolerite		contact
798	B303351 B	Ladysmith	30.0878	-28.5803	121		-999			0.00		dolerite	Ecca sandstone/dolerite		contact
799	B303354	Ladysmith	29.8933	-28.5764	138	6.76	101			0.01	0.15	Ecca sandstone	dolerite	2	fractured
800	B304235	Bergville	29.2011	-28.8092	120	2.14	25	102		0.40	0.20	Ecca sandstone	Ecca sandstone	1	fractured
801	B304235 A	Bergville	29.2039	-28.8094	120		-999			0.00		Ecca sandstone	Ecca sandstone		fractured
802	B304237	Bergville	29.2108	-28.8078	120	0.54	96			0.50	0.40	Ecca sandstone	Ecca sandstone	0	fractured
803	B304237 A	Bergville	29.2094	-28.8250	150		-999			0.00		Ecca sandstone	Ecca sandstone/shale		contact
804	B304237 B	Bergville	29.2106	-28.8081	114		-999			0.00		Ecca sandstone	Ecca sandstone/shale		contact
805	B304239	Bergville	29.1583	-28.7158	90	13.31	22			1.60	0.90	Ecca sandstone	Ecca sandstone	0	fractured
806	B304241	Bergville	29.1919	-28.7667	120	5.84	42			2.00	1.10	Ecca sandstone	Ecca sandstone	0	fractured
807	B304242	Bergville	29.1978	-28.7800	84	8.62	19	36	62	3.80	3.00	Ecca sandstone	Ecca shale/sandstone	1	contact
808	B304243	Bergville	29.1947	-28.7956	132	28.30	45	94		2.20	1.50	Ecca sandstone	Ecca sandstone	0	fractured
809	B304244	Bergville	29.1786	-28.7697	144	14.57	33			0.70	0.40	Ecca sandstone	Ecca sandstone	0	fractured
810	B304245	Bergville	29.1831	-28.7642	102	4.36	36	52		20.00	3.30	dolerite	dolerite	0	fractured
811	B304246	Bergville	29.2150	-28.7511	92	6.61	35	75		0.17	0.10	Ecca sandstone	dolerite/Ecca sandstone	0	fractured
812	B304248	Bergville	29.1319	-28.6914	116	1.86	20			0.50	0.40	Ecca sandstone	Ecca sandstone	1	fractured
813	B304249	Bergville	29.1311	-28.6839	120	2.89	12	85		1.60	0.70	Ecca sandstone	Ecca shale/sandstone	2	contact
814	B304250	Bergville	29.1575	-28.6892	75	3.86	21			0.70	0.50	Ecca sandstone	Ecca sandstone	3	fractured
815	B304251	Bergville	29.1497	-28.6861	120	2.85	24			0.30	0.20	Ecca sandstone	Ecca sandstone	0	fractured
816	B304252	Bergville	29.1594	-28.7328	120	13.27	36			1.00	0.80	Ecca sandstone	Ecca shale/sandstone	1	contact
817	B304253	Bergville	29.1594	-28.7328	120	10.70	27	90		5.00	3.00	Ecca sandstone	Ecca sandstone	1	fractured
818	B304256	Bergville	29.0933	-28.6269	152	12.57	20			0.50	0.20	Ecca sandstone	Ecca shale/sandstone	0	contact
819	B304256 A	Bergville	29.0933	-28.6269	122		-999			0.00		Ecca sandstone	Ecca sandstone/shale		contact
820	B304257	Bergville	29.0842	-28.6308	122	1.20	12			0.50	0.45	Ecca sandstone	Ecca sandstone	3	fractured
821	B304257 A	Bergville	29.0839	-28.6317	120		-999			0.00		Ecca sandstone	Ecca sandstone/shale		contact
822	B304258	Bergville	29.3531	-28.6833	122	9.42	18			0.13	0.13	Ecca sandstone	Ecca sandstone/shale	3	contact
823	B304259	Bergville	29.0486	-28.6794	80	3.17	17			0.15	0.10	dolerite	dolerite	0	fractured
824	B304262	Bergville	29.3406	-28.6817	102	13.21	27	67		6.60	3.30	dolerite	dolerite	2	fractured
825	B304263	Bergville	29.3453	-28.6778	122	14.55	70			0.20	0.15	Ecca sandstone	Ecca sandstone	2	fractured
826	B304265	Estcourt	29.6874	-29.1207	73	18.10	16			0.44	0.10	Karoo argillaceous	dolerite	3	secondary porous/featureless
827	B304266	Estcourt	29.6816	-29.0982	63	3.47	18			2.00	0.85	dolerite	dolerite/Karoo argillaceous	3	contact
828	B304267	Estcourt	29.6751	-29.1084	123	25.90	75			2.50	0.70	dolerite	Karoo argillaceous	3	fractured
829	B304268	Estcourt	29.6304	-28.9471	102	8.98	18	55	77	0.60	0.30	Karoo argillaceous	Karoo sandstone/shale	3	contact
830	B304269	Estcourt	29.5789	-28.9622	120	13.46	33	39	99	3.40	1.00	Karoo argillaceous	Karoo argillaceous	3	fractured
831	B304270	Estcourt	29.5637	-28.9971	120	1.85	21	72		0.60	0.20	Karoo argillaceous	Karoo sandstone/shale	0	contact
832	B304271	Estcourt	29.5213	-29.0119	120	9.88	15	18	99	1.10	0.50	Karoo argillaceous	Karoo argillaceous/sandstone	0	contact
833	B304272	Estcourt	29.5628	-28.9961	120	8.90	31	56		0.40	0.20	Karoo argillaceous	Karoo argillaceous	2	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
785	EM	130	MAG	130	6.58	54	386	110	155	44	21	37	2.3	46	38	0.129	5.1	0.25		0.1	6.7
786	EM	210	MAG	210	8.01	90	739	175	423	70	36	95	3.8	40	30	0.374	0.04	0.56		0.1	18.1
787	EM	25	MAG	115																	
788	EM	25	MAG	115	8.08	62	506	125	307	50	30	54	1.9	19	21	0.012	0.05	0.63		0.1	7.1
789	EM	95																			
790	EM	95			7.7	40	328	82	192	33	16	36	0.9	11	11	0.065	0.26	0.82		0.1	18.9
791	EM	150	MAG	150	7.93	68	568	87	378	35	11	113	1.9	10	1	1.29	0.06	0.23		0.1	5.6
792	geology				9.26	42	359	2	213	1	1	102	0.9	1	1	0.194	0.03	2.77		0.1	5.1
793	EM	100																			
794	EM	100			8.33	540	3208	337	265	135	9	979	4.5	1761	2	0.387	0.08	1.33		0.1	3.8
795	EM	140			7.4	68	588	182	329	73	41	29	1.1	16	26	0.026	2.69	0.24		0.1	21.1
796	EM	200			9.34	33	316	20	170	8	3	71	0.9	5	2	0.542	1.08	0.28		0.1	14.2
797	geology																				
798	geology																				
799	MAG	130			8.6	63	497	15	274	6	2	138	1.6	33	8	0.463	1.1	2		0.1	4.7
800	EM	270	MAG	270	5.75	5	29	7	7	3	1	4	0.9	7	1	0.155	0.39	0.02		0.1	1.2
801	EM	250	MAG	250																	
802	EM	70	MAG	70	6.9	14	116	27	54	11	3	17	0.9	10	2	0.09	1.74	0.26		0.1	1.8
803	EM	230	MAG	230																	
804	EM	70	MAG	70																	
805	EM	290	MAG	300	7.92	23	198	30	120	12	1	43	0.1	3	8	0.065	0.05	0.28		0.1	5.1
806	EM	310	MAG	300	6.28	13	94	30	33	12	3	11	0.9	9	2	0.142	4.07	0.04		0.15	3.8
807	EM	210	MAG	220	5.59	6	37	7	5	3	2	5	1	7	1	0.09	3	0.02		0.1	1.7
808	EM	170	MAG	180	7.99	21	191	15	109	6	1	45	1.7	3	6	0.31	0.03	0.34		0.1	7
809	EM	190	MAG	200	6.67	7	58	12	29	5	1	10	0.9	2	1	0.077	1.35	0.06		0.111	3.7
810	EM	330	MAG	350	6.87	10	99	27	52	11	3	8	2	3	1	0.219	1.7	0.07		0.1	10.4
811	EM	300	MAG	300	6.91	20	156	30	84	12	2	30	0.9	15	1	0.04	0.75	0.6		0.1	3
812	EM	290	MAG	300	6.02	11	86	20	13	8	4	8	0.9	8	1	0.013	9.02	0.04		0.1	3.8
813	EM	110	MAG	120	6.68	18	148	15	72	6	2	35	0.9	16	1	0.052	0.17	1.69		0.1	6.9
814	geology				6.94	31	228	70	19	28	8	16	1.8	29	1	0.052	26.1	0.05		0.1	5
815	MAG	160			6.98	18	114	32	40	13	4	12	2.3	14	5	0.155	3.42	0.1		0.1	3.1
816	MAG	70			7.74	21	178	17	103	7	1	42	0.9	7	7	0.219	0.63	1.33		0.1	5
817	MAG	150			8.75	20	190	12	100	5	1	43	1.1	3	6	0.168	0.01	1.45		0.1	8.1
818	EM	120	MAG	120	7.11	13	92	30	41	12	4	10	1.8	10	12	0.245	0.21	0.3		0.1	5.1
819	EM	120	MAG	120																	
820	MAG	100			8.46	41	316	55	105	22	4	62	1.5	5	87	0.142	0.11	4.28		0.1	2.1
821	EM	80	MAG	90																	
822	EM	110	MAG	110	8.42	30	249	22	130	9	1	65	1.5	8	1	0.052	0.03	7.33		0.1	3.6
823	none				6.88	14	117	47	50	19	2	7	0.9	6	3	0.026	3.6	0.04		0.1	9
824	MAG	120			7.76	26	210	60	132	24	6	29	0.9	5	2	0.039	0.04	1.57		0.1	6.7
825	geology				8.99	29	259	5	142	2	1	71	1.4	6	1	0.142	0.04	2.88		0.1	4.2
826	EM	370	MAG	370	7.61	69	422		63	33	11	67	4.6	75	8		183	0		0	
827	MAG	250			7.69	15	84		18	9	3	6	8.9	12	0		35	0		0	
828	EM	260	MAG	260	8.18	31	180			23	11	2	8.5	70	22		62.7	2		0	
829	EM	180	MAG	180	8.11	47	277		185	29	10	54	0.7	28	5		33	4.9		0	
830	EM	180	MAG	180	8.71	42	290		213	30	6	52	14.6	11	1		43	1.4		0	
831	EM	190	MAG	200	8.03	17	105		50	19	3	8	17.4	9	12		4.8	0		0	
832	EM	140	MAG	160	7.38	14	72		40	11	2	11	0.2	8	11		4.2	0		0	
833	EM	70	MAG	70	7.02	34	147		108	13	4	13	4.5	21	11		14.7	0		0	

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
834	B304272 A	Estcourt	29.5636	-28.9970	102		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
835	B304273	Estcourt	29.5848	-28.9973	120	14.98	53	77		1.20	0.20	Karoo argillaceous	Karoo sandstone/shale	0	contact
836	B304273 A	Estcourt	29.5848	-28.9973	120	-1.00	98	109		3.00		Karoo argillaceous	Karoo sandstone/shale		fractured
837	B304274	Estcourt	29.6856	-28.9906	120	9.22	53	83	103	5.50	2.00	Karoo argillaceous	Karoo argillaceous	2	fractured
838	B304274 A	Estcourt	29.6856	-28.9906	120		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
839	B304275	Estcourt	29.6973	-29.1140	101	-1.00	64			1.10		Karoo argillaceous	Karoo sandstone/shale		contact
840	B304275 A	Estcourt	29.6973	-29.1140	101		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
841	B304275 B	Estcourt	29.6995	-29.1162	90		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
842	B304276	Estcourt	29.5886	-29.1452	91	5.50	38	74		0.60	1.00	Karoo argillaceous	Karoo argillaceous/dolerite	3	contact
843	B304277	Estcourt	29.6720	-29.0779	101	15.80	38	63		0.10	0.33	Karoo argillaceous	dolerite/Karoo argillaceous	3	contact
844	B304278	Estcourt	29.6854	-29.1057	121	15.76	108			4.00	2.00	Karoo argillaceous	Karoo argillaceous/dolerite	0	contact
845	B304279 A	Estcourt	29.5826	-28.9748	96		-999			0.00		Karoo argillaceous	Karoo argillaceous/dolerite		contact
846	B304279 B	Estcourt	29.5874	-28.9767	72		-999			0.00		Karoo argillaceous	Karoo argillaceous/dolerite		contact
847	B304280	Estcourt	29.5219	-29.0148	102	10.65	15	42	65	1.10	0.50	Karoo argillaceous	dolerite/Karoo argillaceous	0	contact
848	B304280 A	Estcourt	29.5283	-29.0115	120		-999			0.00		Karoo argillaceous	dolerite/Karoo argillaceous		contact
849	B304280 B	Estcourt	29.5283	-29.0115	120		-999			0.00		Karoo argillaceous	dolerite/Karoo argillaceous		contact
850	B304281	Estcourt	29.5196	-29.0499	125	-1.00	88			0.10	2.30	Karoo argillaceous	Karoo sandstone/shale	0	contact
851	B304281 A	Estcourt	29.5248	-29.0314	120		-999			0.00		Karoo argillaceous	dolerite/Karoo argillaceous		contact
852	B304282 A	Estcourt	29.7120	-29.1120	123		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
853	B304282 B	Estcourt	29.7118	-29.1118	121		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
854	B304282 C	Estcourt	29.7118	-29.1118	91		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
855	B304283 A	Estcourt	29.7060	-29.1393	123		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
856	B304283 B	Estcourt	29.7076	-29.1409	120		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
857	B304283 C	Estcourt	29.7076	-29.1409	72		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
858	B304283 D	Estcourt	29.7076	-29.1409	36		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
859	B304284 A	Estcourt	29.6968	-29.1147	121		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
860	B304284 B	Estcourt	29.6968	-29.1147	121		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
861	B304284 C	Estcourt	29.6920	-29.1096	61		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
862	B304285	Estcourt	29.7369	-29.0976	111	38.28	85			2.40	1.00	Karoo argillaceous	dolerite/Karoo argillaceous	2	contact
863	B304286 A	Estcourt	29.7010	-29.0710	13		-999			0.00		Karoo argillaceous	dolerite		secondary porous
864	B304286 B	Estcourt	29.7010	-29.0710	15		-999			0.00		Karoo argillaceous	dolerite		secondary porous
865	B304286 C	Estcourt	29.7010	-29.0710	16		-999			0.00		Karoo argillaceous	dolerite		secondary porous
866	B304287 A	Estcourt	29.5557	-29.0281	120		-999			0.00		Karoo argillaceous	Karoo sandstone/shale		contact
867	B402001	Vulamehlo	30.3106	-30.1469	150	110.00	123			0.00		NGS	NMP granite		featureless
868	B402002	Vulamehlo	30.3078	-30.1467	136	102.70	121			1.00	0.60	NGS	NGS/NMP granite	0	contact
869	B402003	Vulamehlo	30.3039	-30.0756	150		-999			0.00		dolerite	Dwyka tillite		featureless
870	B402004	Vulamehlo	30.3050	-30.0753	105	62.70	91			1.00	0.50	Ecca shale	Dwyka tillite	1	fractured
871	B402005	Vulamehlo	30.3269	-30.1089	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
872	B402006	Vulamehlo	30.3211	-30.1072	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
873	B402007	Vulamehlo	30.3283	-30.1003	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
874	B402008	Vulamehlo	30.3311	-30.1089	102		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
875	B402009	Vulamehlo	30.3189	-30.1036	102		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
876	B402010	Vulamehlo	30.3314	-30.1092	102		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
877	B402011	Vulamehlo	30.3339	-30.0853	102		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
878	B402012	Vulamehlo	30.3564	-30.2650	102		-999			0.00		NMP	NMP granite		fractured
879	B402013	Vulamehlo	30.4231	-30.2578	102	63.00	93			0.50	0.15	NMP	NMP granite	1	fractured
880	B402014	Vulamehlo	30.3569	-30.2664	90	23.00	73	84		0.30	0.40	NMP	NMP granite	3	fractured
881	B402015	Vulamehlo	30.5103	-30.2606	84	30.00	66	79		10.00	10.00	NMP	NMP granite	0	fractured
882	B402016	Vulamehlo	30.5364	-30.3100	102		-999			0.00		NMP	NMP granite		featureless

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
834	EM	70	MAG	70																	
835	EM	130	MAG	130	7.69	9	44		18	3	1	13	0.8	15	1		0.3	0.9		0	
836	EM	90	MAG	90																	
837	MAG	250			8.57	41	244		212	22	9	56	1.9	9	1		15.7	0.8		0	
838	MAG	250																			
839	MAG	250																			
840	MAG	155																			
841	MAG	155																			
842	MAG	400			8.41	38	215		128	21	9	39	1.7	28	15		21.4	0.1		0	
843	MAG	400			8.45	38	207		95	16	24	18	0.9	40	27		23.1	0		0	
844	MAG	400			8.28	20	110		105	8	0.4	33.1	0.4	1.1	0.6		2.9	0.26		0	
845	EM	60	MAG	60																	
846	EM	110	MAG	110																	
847	EM	60	MAG	60	7.82	9	47		38	9	1	7	0.9	5	1		1.1	0.1		0	
848	EM	60	MAG	60																	
849	EM	60	MAG	60																	
850	EM	150	MAG	150	7.43	5	30		18	5	1	1	1.5	4	1		1.5	0		0	
851	EM	200	MAG	200																	
852	EM	200	MAG	200																	
853	EM	100	MAG	100																	
854	EM	100	MAG	100																	
855	EM	105	MAG	105																	
856	EM	105	MAG	105																	
857	EM	105	MAG	105																	
858	EM	105	MAG	105																	
859	EM	120	MAG	120																	
860	EM	120	MAG	120																	
861	EM	120	MAG	120																	
862	EM	200	MAG	200	8.08	20	104		70	11	1	24	0.4	8	1		15.6	0		0	
863	EM	65	MAG	65																	
864	EM	65	MAG	65																	
865	EM	65	MAG	65																	
866	MAG	150																			
867	EM	200	MAG	200																	
868	EM	400	MAG	400	7.5	38.1	277	123	127	28	13	31	2.8	36	4		1.8	0.3		0.02	15.8
869	EM	250	MAG	250																	
870	EM	250	MAG	250	7.8	57.3	471	209	250	41	26	46	1.4	13	19		4.6	0.5		0.008	19.1
871	EM	120	MAG	120																	
872	EM	285	MAG	285																	
873	EM	300	MAG	300																	
874	EM	300	MAG	300																	
875	EM	285	MAG	285																	
876	EM	300	MAG	300																	
877	EM	650	MAG	650																	
878	EM	200	MAG	200																	
879	EM	200	MAG	200	6.8	37.2	234	81	60	11	13	37	4	47	12		8.37	0.5		0.008	19.9
880	EM	200	MAG	200	6.9	65.4	399	102	47	21	12	82	2.8	107	3		25.78	0.7		0.007	14.9
881	EM	130	MAG	130	7.9	27.3	169	44	60	6	7	31	5.4	36	9		0.04	0.7		0.028	23.3
882	EM	150	MAG	150																	

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
883	B402017	Vulamehlo	30.4847	-30.3556	72	7.00	46			0.30	0.15	Ecca shale	Ecca shale/NGS	0	contact
884	B402018	Vulamehlo	30.5372	-30.3006	102	78.00	96			1.30	0.80	NMP	NMP granite	1	fractured
885	B402019	Vulamehlo	30.5861	-30.1694	102		-999			0.00		NMP	NMP granite		featureless
886	B402020	Vulamehlo	30.5922	-30.1586	102		-999			0.00		NMP	NMP granite		featureless
887	B402021	Vulamehlo	30.5811	-30.1603	102		-999			0.00		NMP	NMP granite		featureless
888	B402022	Vulamehlo	30.5958	-30.1600	102		-999			0.00		NMP	NMP granite		featureless
889	B402023	Vulamehlo	30.5814	-30.1714	96		-999			0.00		NMP	NMP granite/dolerite		contact
890	B405057	S.Coast	30.5260	-30.4225	101	32.90	66			0.10	0.10	Dwyka tillite	NGS	0	fractured
891	B405058	S.Coast	30.0292	-30.4818	101		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
892	B405059	S.Coast	30.0193	-30.4832	101		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
893	B405061	S.Coast	30.0057	-30.5123	101		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
894	B405062	S.Coast	30.0378	-30.4778	151		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
895	B405517	Izingolweni	30.3542	-30.7411	84	57.00	70			0.10	0.10	NGS	NGS	2	featureless
896	B405518	Izingolweni	30.1683	-30.6819	84	19.00	60			0.25	0.40	NGS	NGS	2	fractured
897	B405519	Izingolweni	30.1658	-30.6744	102	55.00	72			0.20	0.15	NGS	NGS	3	featureless
898	B405520	Izingolweni	30.1553	-30.6711	102		-999			0.00		Dwyka tillite	NGS		featureless
899	B405521	Izingolweni	30.1536	-30.6683	108	92.00	98			0.10	-1.00	NGS	NMP granite	3	fractured
900	B405522	Izingolweni	30.1533	-30.6875	114	38.00	12	73		2.50	-1.00	Dwyka tillite	NGS/NMP granite	2	contact
901	B405523	Izingolweni	30.1450	-30.6811	102		-999			0.00		Dwyka tillite	NGS		featureless
902	B405525	Izingolweni	30.0908	-30.7672	102	50.00	54	66		0.10	-1.00	Dwyka tillite	Dwyka tillite	1	featureless
903	B405526	Izingolweni	30.0028	-30.7328	102		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
904	B405527	Izingolweni	30.0989	-30.7278	84	22.00	30			0.10	-1.00	Dwyka tillite	Dwyka tillite	1	featureless
905	B405528	Izingolweni	29.9911	-30.8114	150		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
906	B405529	Izingolweni	29.9914	-30.7894	138		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
907	B405530	Izingolweni	29.9883	-30.8153	120	56.00	90			2.50	1.00	Dwyka tillite	Dwyka tillite	1	fractured
908	B405531	Izingolweni	29.9792	-30.8289	144		-999			0.00		Dwyka tillite	Dwyka tillite/NMP granite		featureless
909	B405532	Izingolweni	29.9911	-30.7947	144		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
910	B405533	Izingolweni	29.9975	-30.8053	60	20.00	30			0.10	-1.00	Dwyka tillite	NMP granite	1	secondary porous
911	B405534	Izingolweni	29.9878	-30.8206	84	55.00	60			0.05	-1.00	Dwyka tillite	Dwyka tillite	1	featureless
912	B405535	Izingolweni	29.9947	-30.7711	90	25.00	30			0.10	-1.00	Dwyka tillite	Dwyka tillite	0	featureless
913	B405536	Izingolweni	29.9917	-30.7694	102	48.00	60			0.10	-1.00	Dwyka tillite	Dwyka tillite	0	featureless
914	B405537	Izingolweni	29.9931	-30.7811	102	54.00	72			0.05	-1.00	Dwyka tillite	Dwyka tillite	0	featureless
915	B405538	Izingolweni	29.9947	-30.7544	84		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
916	B405539	Izingolweni	29.9900	-30.7339	150		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
917	B405540	Izingolweni	29.9653	-30.7294	150	85.00	108			0.10	-1.00	Dwyka tillite	Dwyka tillite	0	fractured
918	B405541	Izingolweni	29.9961	-30.7350	120	85.00	110			0.15	-1.00	Dwyka tillite	Dwyka tillite	1	featureless
919	B405542	Izingolweni	29.9961	-30.7344	126		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
920	B405543	Izingolweni	29.9931	-30.7311	84	10.00	66			4.00	-1.00	Dwyka tillite	Dwyka tillite	0	fractured
921	B405544	Izingolweni	30.0264	-30.7647	120	80.00	96			0.25	-1.00	Dwyka tillite	Dwyka tillite	1	fractured
922	B405545	Izingolweni	30.0219	-30.7875	120		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
923	B405546	Izingolweni	30.0361	-30.7844	150	85.00	106			0.10	-1.00	Dwyka tillite	Dwyka tillite/NMP granite	2	featureless
924	B405547	Izingolweni	30.0192	-30.7803	102	65.00	82			1.00	-1.00	Dwyka tillite	Dwyka tillite	1	fractured
925	B405548	Izingolweni	30.0322	-30.7917	120		-999			0.00		Dwyka tillite	dolerite/Dwyka tillite		featureless
926	B405549	Izingolweni	30.0306	-30.6153	144		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
927	B405550	Izingolweni	30.0339	-30.6175	108		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
928	B405551	Izingolweni	30.0328	-30.6153	126	100.00	114			0.10	-1.00	Dwyka tillite	Dwyka tillite	1	featureless
929	B405552	Izingolweni	30.0333	-30.6144	150		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
930	B405553	Izingolweni	30.0261	-30.6300	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
931	B405554	Izingolweni	30.0194	-30.6417	132		-999			0.00		Dwyka tillite	Dwyka tillite		fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
883	EM	800	MAG	800	6.5	12.8	85	13	34	2	2	17	2.2	15	4		0.1	0.6		0.019	17.9
884	EM	150	MAG	150	7.7	37.3	259	85	120	21	8	38	3	31	7		0.79	1.4		0.01	22.8
885	EM	700	MAG	700																	
886	EM	165	MAG	165																	
887	EM	900	MAG	900																	
888	EM	165	MAG	165																	
889	EM	270	MAG	270																	
890	VES	7X																			
891	VES	1X																			
892	VES	1X																			
893	VES	4X																			
894	VES	5X																			
895	EM	300	MAG	300	8.1	184	1062	329	199	51	49	237	4.6	435	42		0.04	0.6		0.032	1.8
896	EM	300	MAG	300	7.2	150	990	360	26	65	48	188	3.2	326	32		0.7	0.8		0.021	5.5
897	EM	330	MAG	330	6.1	250	1425	514	46	71	82	318	4.1	821	49		5.2	0.6		0.026	6.5
898	EM	740	MAG	740																	
899	none				8	852	5109	1644	229	242	253	1268	28.4	2880	156		0.05	1.3		0.022	2.3
900	none				8	240	1299	450	168	75	64	298	4.2	586	39		6.28	1.1		0.054	5.3
901	EM	450	MAG	450																	
902	EM	160	MAG	160	7.7	86.4	641	221	261	34	33	102	5.6	108	8		7.11	0.8		0.029	3.1
903	EM	300	MAG	300																	
904	none				7.9	67.3	515	183	229	29	27	76	4.5	65	11		5.29	0.7		0.035	8.2
905	EM	370	MAG	370																	
906	EM	540	MAG	370																	
907	EM	370	MAG	370	7.7	90.9	671	306	252	60	38	84	2.1	144	5		6.7	0.7		0.033	8.7
908	MAG	370																			
909	EM	1280	MAG	640																	
910	EM	370			7.6	70.7	533	237	208	47	29	63	2.7	108	8		4.33	0.6		0.044	7.6
911	EM	600	MAG	600	7.4	34.9	262	52	95	11	6	48	7.2	26	6		9.18	1.2		0.044	10.4
912	EM	400	MAG	400	7.4	49.3	364	152	162	28	20	42	3.2	56	4		2.77	0.6		0.027	11.8
913	EM	200	MAG	200	8	50.6	400	188	192	34	25	38	6.4	59	4		0.11	0.4		0.026	8.7
914	EM	300	MAG	300	8.1	38.6	323	105	154	19	14	41	8.9	32	4		3.28	0.7		0.036	5.6
915	EM	150	MAG	150																	
916	EM	450	MAG	450																	
917	EM	160	MAG	160	8.3	55.3	408	137	177	22	20	57	9.4	60	4		3.95	0.7		0.045	2.5
918	EM	300	MAG	300	7.9	76.8	583	232	262	47	28	75	3	76	4		6.83	0.6		0.022	7.1
919	EM	600	MAG	600																	
920	none				8.2	27.5	211	70	103	15	8	25	5.1	21	4		2.13	0.6		0.03	14.8
921	EM	800	MAG	800	7.7	76.1	542	224	223	42	29	71	4.2	104	4		3.63	0.7		0.024	5
922	EM	380	MAG	380																	
923	EM	400	MAG	200	8.3	71.3	575	122	258	16	20	122	4.4	78	18		0.05	1.8		0.036	6.4
924	none				7.4	55.7	446	193	218	41	22	47	2.1	33	4		6.65	0.7		0.012	10.1
925	EM	280	MAG	280																	
926	EM	150																			
927	EM	250	MAG	250																	
928	EM	250			7.5	49.6	376	142	147	34	14	44	4.6	53	17		6.7	0.6		0.04	9.6
929	EM	340	MAG	240																	
930	EM	600	MAG	600																	
931	EM	240	MAG	240																	

No.	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
932	B405555	Izingolweni	30.0219	-30.6378	132	70.00	76			0.10	-1.00	Dwyka tillite	Dwyka tillite	2	featureless
933	B405556	Izingolweni	30.0256	-30.6397	126		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
934	B405557	Izingolweni	30.0411	-30.6364	120	58.00	79			0.25	-1.00	Dwyka tillite	Dwyka tillite	1	featureless
935	B405558	Izingolweni	30.0478	-30.6431	108		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
936	B405559	Izingolweni	30.0447	-30.4914	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
937	B405560	Izingolweni	30.0469	-30.6622	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
938	B405561	Izingolweni	30.0622	-30.6414	108		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
939	B405562	Izingolweni	30.0486	-30.6619	150		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
940	B405563	Izingolweni	30.0919	-30.6825	150		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
941	B405564	Izingolweni	30.5058	-30.6531	102		-999			0.00		Dwyka tillite	Dwyka tillite/dolerite		featureless
942	B405565	Izingolweni	30.1022	-30.6858	54		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
943	B405566	Izingolweni	30.1000	-30.6872	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
944	B405567	Izingolweni	30.1106	-30.6892	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
945	B405568	Izingolweni	30.0786	-30.5236	138		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
946	B405569	Izingolweni	30.0542	-30.5211	132		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
947	B405570	Izingolweni	30.0689	-30.5222	132		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
948	B405571	Izingolweni	30.0492	-30.5247	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
949	B405572	Izingolweni	30.0331	-30.5231	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
950	B405573	Izingolweni	30.0294	-30.5317	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
951	B405574	Izingolweni	30.0239	-30.7014	120		-999			0.00		Dwyka tillite	Dwyka tillite		featureless
952	B405575	Izingolweni	30.0408	-30.4775	108		-999			0.00		Dwyka tillite	NMP granite		fractured
953	B406014	Vulamehlo	30.4331	-30.3558	132		-999			0.00		NMP	NMP granite		fractured
954	B406015	Vulamehlo	30.4300	-30.3547	132		-999			0.00		NGS	NMP granite		fractured
955	B406016	Vulamehlo	30.4742	-30.3336	102		-999			0.00		NGS	NMP granite		featureless
956	B406032	S.Coast	30.0667	-30.5237	101		-999			0.00		Dwyka tillite	NMP gneiss		fractured
957	B406033	S.Coast	30.5207	-30.4228	71	0.80	37			0.10	0.07	NMP	NMP gneiss	2	fractured
958	B406034	S.Coast	30.5223	-30.4275	101	6.12	47			0.10	0.06	NMP	NMP gneiss		fractured
959	B406035	S.Coast	30.4805	-30.5682	101	1.34	24			1.00	0.50	NMP	NMP gneiss	2	fractured
960	B406036	S.Coast	30.4933	-30.5643	101	9.32	27			1.10	0.70	NMP	NMP gneiss	0	fractured
961	B406037	S.Coast	30.5003	-30.5697	121	2.89	15			0.90	0.22	NMP	NMP gneiss	1	fractured
962	B406039	S.Coast	30.5237	-30.4832	101	1.69	65			0.10	0.08	NMP	NMP granite	1	fractured
963	B406040	S.Coast	30.5200	-30.4777	101		-999			0.00		NMP	NMP granite		fractured
964	B406041	S.Coast	30.5638	-30.4490	96	0.85	70			0.80	0.55	NMP	NMP granite	1	secondary porous
965	B406042	S.Coast	30.5823	-30.4558	101	1.20	61			0.80	0.42	NMP	NMP granite	0	fractured
966	B406043	S.Coast	30.5815	-30.4480	51	0.00	29			0.80	2.22	NMP	NMP granite	0	fractured
967	B406045	S.Coast	30.1180	-30.5008	121		-999			0.00		Dwyka tillite	NMP gneiss		fractured
968	B406046	S.Coast	30.1828	-30.5212	101		-999			0.00		Dwyka tillite	Dwyka tillite		fractured
969	B406047	S.Coast	30.1795	-30.5088	121	5.01	110			0.40	0.14	Dwyka tillite	Dwyka tillite	0	fractured
970	B406049	S.Coast	30.1323	-30.5605	91	7.60	40			6.67	3.89	NMP	NMP diorite	2	fractured
971	B406050	S.Coast	30.1063	-30.4372	101		-999			0.00		Dwyka tillite	NMP diorite		fractured
972	B406051	S.Coast	30.0883	-30.4545	126	35.80	106			0.14	0.06	Dwyka tillite	NMP diorite	0	fractured
973	B406052	S.Coast	30.1128	-30.4485	121	31.52	63	115		0.14	0.06	Dwyka tillite	NMP diorite	0	fractured
974	B406053	S.Coast	30.3142	-30.0755	121		-999			0.00		NMP	NMP diorite		fractured
975	B406054	S.Coast	30.3115	-30.0752	71		-999			0.00		NMP	NMP diorite		fractured
976	B406055	S.Coast	30.4578	-30.3707	101	0.45	5			1.25	1.53	NMP	NMP granite	1	secondary porous
977	B406056	S.Coast	30.4573	-30.3635	106	2	4	83		0.50	0.22	NMP	NMP diorite		secondary porous
978	B406057	S.Coast	30.4905	-30.3797	101	54.92	66			0.14	0.08	NGS	NGS	0	fractured
979	B406058	S.Coast	30.4772	-30.3852	101	8.73	56			0.11	0.11	NGS	NGS		fractured
980	B406059	S.Coast	30.4740	-30.3893	101	30.40	56			0.33	0.56	NGS	NGS	1	fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
932	EM	420	MAG	210	8.5	43.2	381	49	195	10	6	81	11.1	19	14		0.08	2.2		0.05	2.9
933	EM	300	MAG	300																	
934	EM	200	MAG	200	7.8	72.5	548	201	251	41	24	81	4.4	79	13		0.04	0.4		0.039	8.1
935	EM	230	MAG	230																	
936	EM	510	MAG	510																	
937	EM	180	MAG	90																	
938	EM	1150	MAG	1150																	
939	EM	90	MAG	90																	
940	EM	600	MAG	300																	
941	EM	200	MAG	200																	
942	EM	1000	MAG	500																	
943	none																				
944	EM	540	MAG	340																	
945	EM	400	MAG	200																	
946	EM	300	MAG	300																	
947	EM	1250	MAG	1000																	
948	EM	300	MAG	300																	
949	EM	400	MAG	200																	
950	EM	650	MAG	450																	
951	EM	720	MAG	360																	
952	EM	400	MAG	200																	
953	EM	200	MAG	200																	
954	EM	300	MAG	300																	
955	EM	800	MAG	800																	
956	VES	2X																			
957	VES	2X			7.8	136	833		244	71.2	42.6	150	11	277	33	0.3	0.3	1.01		0.05	
958	VES	2X			7.4	58.1	396		155	17.2	12.2	89	6	68	24	0.3	3.1	0.67		0.05	
959	VES	3X			7.5	91.4	537		252	31	22.2	140	4	111	29	0.3	0.3	1.98		0.05	
960	VES	4X			8.3	59.2	424		126	28.7	28.7	21	86	94	49	0.3	0.3	0.59		0.05	
961	VES	7X			7.6	58	366		189	38.3	12.2	76	3	57	19	0.3	1.4	1.2		0.05	
962	VES	3X			7.3	73.5	440		223	37.7	17.2	96	9	92	24	0.3	0.3	0.43		0.05	
963	VES	1X																			
964	VES	1X			7.3	83.1	489		209	47.8	20.8	98	6	127	20	0.3	0.3	0.36		0.05	
965	VES	5X			6.9	58.9	370		187	35.3	15.8	72	4	55	40	0.3	0.3	0.21		0.05	
966	VES	1X			7.3	66.4	392		204	53	17.2	66	4	70	24	0.3	0.3	0.38		0.05	
967	VES	2X																			
968	VES	2X																			
969	VES	3X			7.7	25.1	173		72	21.2	5	24	4	20	5	0.3	4.7	0.2		0.06	
970	VES	8X			8.2	186	1210		311	95	72	240	3	408	54	0.3	15.3	0.65		0.05	
971	VES	5X																			
972	VES	3X			7.2	51.2	306		147	36.8	15.6	52	1	70	6	0.3	0.3	0.06		0.05	
973	VES	6X			7.8	45.6	306		178	48.4	12.9	36	2	23	25	0.3	0.3	0.31		0.05	
974	VES	1X																			
975	VES	1X																			
976	VES	4X			5.9	12.2	84		20	2.2	2.3	14	4	16	9	0.3	1.1	0.17		0.05	
977	VES	5X			7.7	38.1	288		145	13.4	8.1	70	7	23	43	0.3	0.3	0.78		0.08	
978	VES	5X			6.7	20.1	156		20	3.5	7	22	8	35	6	0.3	0.3	0.23		0.05	
979	VES	3X			6	11.2	78		20	1.5	2	14	2	21	5	0.3	2.8	0.05		0.05	
980	VES	2X			5.2	13.1	86		20	2.4	2.3	15	6	27	9	0.3	0.9	0.08		0.08	

	BOREHOLE NUMBER	AREA	LONGITUDE (X)	LATITUDE (Y)	BOREHOLE DEPTH (m)	STATIC WATER LEVEL (m.b.g.l)	DEPTH OF WATER STRIKE 1 (m.b.g.l)	DEPTH OF WATER STRIKE 2 (m.b.g.l)	DEPTH OF WATER STRIKE 3 (m.b.g.l)	BLOW TEST YIELD (l/s)	PUMP TEST YIELD (l/s)	SURFACE LITHOLOGY	LITHOLOGY OF WATER STRIKE	QUALITY CLASS	AQUIFER TYPE
981	B406060	S.Coast	30.4717	-30.3970	101	21.50	37	56		0.47	0.56	NGS	NGS		fractured
982	B406061	S.Coast	30.5147	-30.4110	66		-999			0.00		NGS	NGS		fractured
983	B406062	S.Coast	30.5458	-30.4518	61	1.30	8	45		2.22	2.78	NMP	NMP granite	2	fractured
984	B406063	S.Coast	30.5360	-30.4487	93		-999			0.00		NMP	NMP granite		fractured
985	B406064	S.Coast	30.5352	-30.4452	91		-999			0.00		NMP	NMP granite		fractured
986	B406065	S.Coast	30.5348	-30.4432	91	1.20	8	61		2.22	1.25	NMP	NMP granite	1	fractured
987	B406066	S.Coast	30.6350	-30.3905	101		-999			0.00		NMP	NMP diorite		fractured
988	B406067	S.Coast	30.6387	-30.3922	101	3.12	70			0.10	0.03	NMP	NMP granite	3	fractured
989	B406068	S.Coast	30.6417	-30.3920	101	3.57	16			0.10	0.08	NMP	NMP granite	2	fractured
990	B406069	S.Coast	30.6192	-30.3838	101		-999			0.00		NMP	NMP granite		fractured
991	B406070	S.Coast	30.6513	-30.3487	91	5.50	18	53		1.33	0.56	NMP	NMP granite	2	fractured
992	B406071	S.Coast	30.6448	-30.3493	101	5.80	16	73		2.22	0.78	NMP	NMP granite	0	fractured
993	B406072	S.Coast	30.6437	-30.3455	101		-999			0.00		NMP	NMP granite		fractured

	GEOPHYSICAL METHOD 1	LENGTH OF TRAVERSE METHOD 1 (m)	GEOPHYSICAL METHOD 2	LENGTH OF TRAVERSE - METHOD21 (m)	pH	EC (mS/m)	TDS (mg/l)	Total hardness (mg/l)	Total alkalinity (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	F (mg/l)	Fe (mg/l)	P (mg/l)	Si (mg/l)
981	VES	2X			7.1	26.3	158		92	25.1	7.2	15	4	18	14	0.3	0.3	0.25		0.05	
982	VES	2X																			
983	VES	2X			7.7	121	740		200	64	28.2	180	6	219	147	0.3	0.3	1.21		0.05	
984	VES	1X																			
985	VES	1X																			
986	VES	1X			7.7	107	692		264	62	41.7	110	7	170	40	0.3	0.3	0.53		0.05	
987	VES	1X																			
988	VES	2X			7.7	126	763		216	24.2	12.1	240	3	240	38	0.3	0.3	4.24		0.05	
989	VES	2X			7.9	83.6	503		224	35.3	20.4	120	4	123	14	0.3	0.3	1.96		0.05	
990	VES	4X																			
991	VES	1X			7.4	39.1	269		130	32.6	11.9	38	3	39	11	0.3	0.3	2.34		0.05	
992	VES	2X			8.2	60.3	400		121	26.5	9.2	76	3	90	40	0.3	0.3	0.59		0.05	
993	VES	1X																			