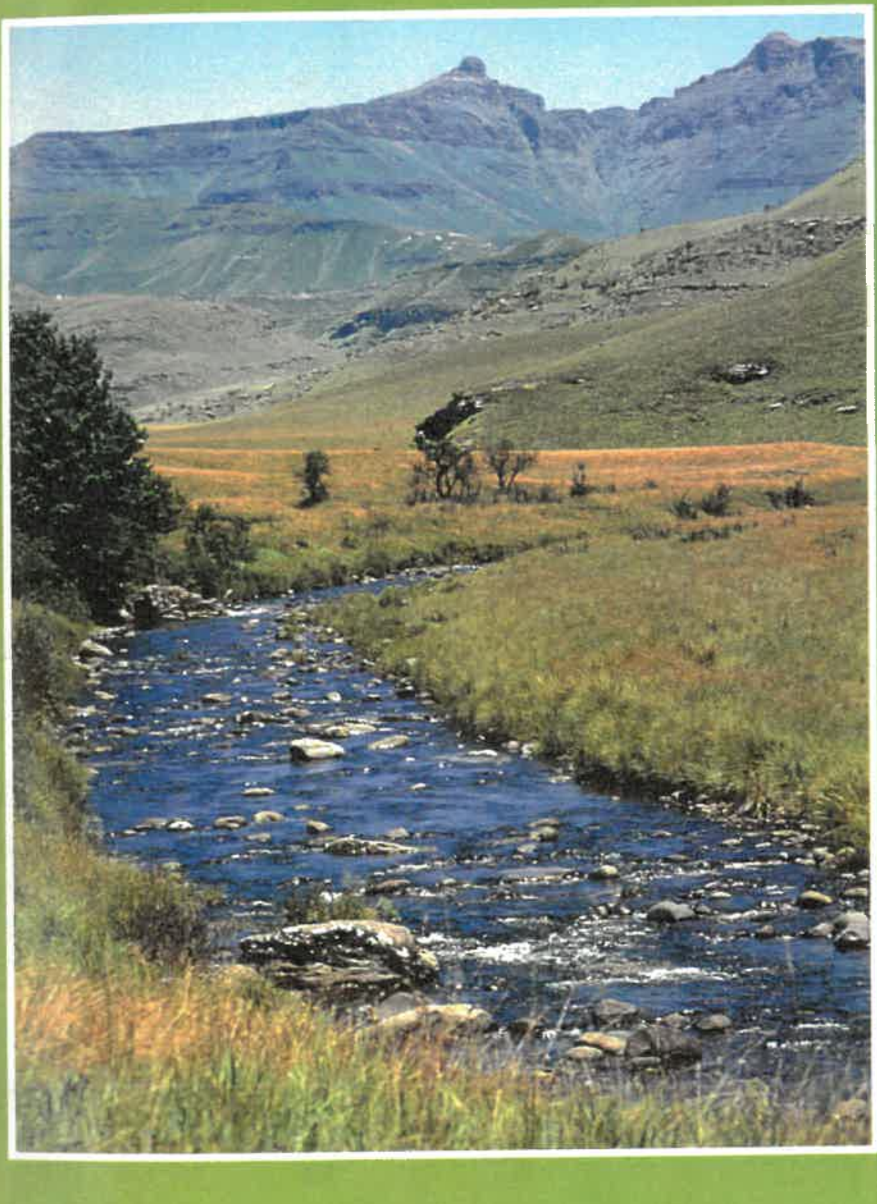
An Explanation of the 1:500 000 General Hydrogeological Map

Durban 2928



By G.M. King

May 2002

DEPARTMENT : WATER AFFAIRS AND FORESTRY
REPUBLIC OF SOUTH AFRICA

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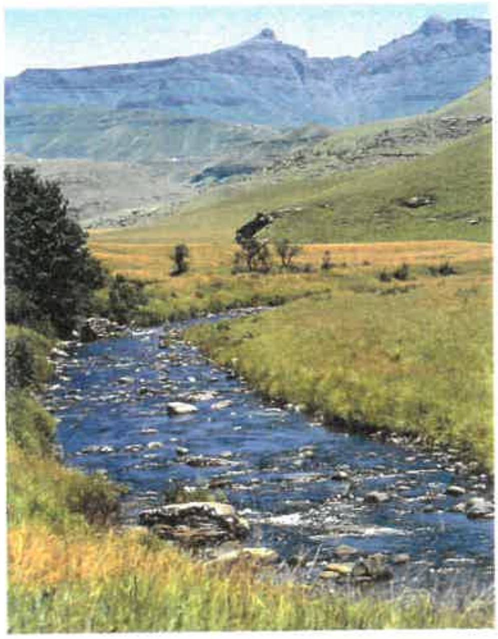

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Cover photograph: The Drakensberg mountains are an impressive feature of the province of KwaZulu-Natal. The mountain range comprises Karoo sandstone underlying spectacular flood basalts of the Drakensberg Group, which give the various peaks their unique forms. This photograph shows Hodgson's Peak in the background with the Pholela River in the foreground.

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DEPARTMENT : WATER AFFAIRS AND FORESTRY
REPUBLIC OF SOUTH AFRICA

Foreword

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

A major obstacle to the realisation of this prosperity is that insufficient information about groundwater is reaching the planners, decision makers, users and other affected parties. In an attempt to rectify this situation, groundwater information locked away in experts' minds and computer data bases is being made available on maps. The first step in this programme at the regional level is the preparation of "General Hydrogeological Maps" at the scale of 1:500 000.

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

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

EBERHARD BRAUNE

DIRECTOR: GEOHYDROLOGY

DEPARTMENT : WATER AFFAIRS AND FORESTRY

PRETORIA

Preface

Groundwater is rapidly growing in importance in South Africa but not enough information concerning this resource is reaching planners, decision-makers and users. Although groundwater is a reliable resource when properly managed, ignorance of its existence or character commonly results in it being used as a second option to more expensive and less reliable surface water schemes. In order to address the problem of a lack of groundwater knowledge, the Directorate: Geohydrology launched a regional mapping programme whereby South African groundwater resources will be portrayed at a scale of 1:500 000. The Durban map this brochure is accompanying, is one of twenty-three similar such maps to be produced.

This mapping exercise is intended to bring together all the information concerning the resource for analysis – thereby determining any regional scale variations in the aquifer and groundwater characteristics. The findings are displayed on the map while more detailed information not readily portrayed on the map is given in this brochure.

The main theme displayed on the General Hydrogeological Map is the groundwater occurrence and flow regime. For example, aquifers in which flow is intergranular (usually unconsolidated material) are distinguished from aquifers in which flow is through fissures (fractures). In addition, the borehole productivity (dependent on rock permeability) is also ranked.

Settling on a legend for the South African 1: 500 000 scale general Hydrogeological Maps series entailed much debate and revision between 1991 and 1996 with inputs coming from parties within and outside Directorate; Geohydrology. The legend used is an adaptation of what is commonly known as the UNESCO legend – published jointly in 1983 by the IAH (International Association of Hydrogeologists), IAHS (International Association of Hydrological Sciences) and UNESCO (IAH, 1983).

Classification of fissured (fractured) groundwater occurrence is particularly important in the South African context because this type underlies at least 90% of the country. A modification to the UNESCO classification was considered necessary in order to incorporate a semi-quantitative expression of storage capacity of the rock interstices into the classification – distinguishing between "fractured" and "fractured and intergranular" groundwater occurrence. The latter is applicable where weathering has imparted intergranular properties to the residuum overlying the fractured bedrock. This weathered zone can provide significant groundwater storage, which can be transmitted to the underlying bedrock.

The South African approach to distinguish groundwater occurrence requires the identification and comparison of "hydrogeological units". These are being defined as "reasonably homogenous groundwater units which possess some degree of internal lithologic homogeneity and similarities in rock properties that impact on groundwater conditions and on groundwater quality" and are "described in terms of lithology, stratigraphy and a combination of mode of occurrence and typical yields of boreholes" (DWAF, 1994).

The groundwater occurrence classification adopted for the South African situation is thus as follows:

- Intergranular
- Fractured
- Karstic
- Fractured and Intergranular

A maximum of five productivity ranges could be accommodated – this is the maximum number of distinguishable shades of colour. The ranges accommodate yields for the country as a whole – based on an analysis of the yield frequency distribution of all the boreholes on the National Groundwater Data Base.

The General Hydrogeological Map gives an indication of where the groundwater resources are most accessible and the quality of the resources, but there is another important aspect – the volume of groundwater abstractable on a sustained basis. A first attempt at quantifying the resource at a regional scale is therefore included in this brochure. Areas most vulnerable to over-exploitation are also identified.

Acknowledgements

The following people, Departments and organisations are thanked:

Department: Water Affairs and Forestry

Editorial Board

Provided guidance to the Mapping Management Team thereby ensuring that the General Hydrogeological Maps conform to their required standard.

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The above consultants were all involved in the mapping project during 1993/94. Their work, being the basis of this map and brochure, is gratefully acknowledged.

Mr R.J. Vegter and Prof F.G. Bell

Reviewers of the KwaZulu-Natal Hydrogeological Mapping Project.

Dr R. R. Maud

Project Co-ordinator and author of the initial explanation for the hydrogeological map. General information and assistance.

University of Natal

The late Dr M. von Veh – Structural geology analysis.

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The Drakensberg mountains are an impressive feature of the province of KwaZulu-Natal. The mountain range comprises Karoo sandstone underlying spectacular flood basalts of the Drakensberg Group, which give the various peaks their unique forms. This photograph shows Hodgson's Peak in the background with the Pholela River in the foreground.

Abbreviations

CSIR	Council for Scientific and Industrial Research
DTH	Down the hole hammer
DWAF	Department: Water Affairs and Forestry
EC	Electrical conductivity
F	Fluoride
GIS	Geographic Information System
NGDB	National Groundwater Data Base
NWQDB	National Water Quality Data Base
NO_3	Nitrate

Units

a	annum
km	kilometre
km^2	square kilometre
ℓ/s	litres per second
m	metre
m^3	cubic metre
m/day	metres per day
mg/ℓ	milligram per litre
$m^3/km^2/a$	cubic metre per square kilometre per annum
mm	millimetre
mS/m	milli-Siemens per metre
°C	degrees centigrade

FACT SHEET

Durban 1:500 000 General Hydrogeological Map

Purpose of this document

The Durban 1:500 000 map provides an overview of the geohydrology of the area. The accompanying brochure provides supplementary information. The purpose of this document is to provide a summary of the map and brochure.

Methodology

Any map on the potential of underground water relies on the information obtained from the drilling of boreholes. Such information includes the different depths where water was struck, the geological formations penetrated and the water yield and quality obtained from the borehole. This information, combined with information which can be obtained on the surface, like topography, geology and rainfall of the mapped area, can, in the hands of the experienced geohydrologist, provide a first estimate of the groundwater potential of the area as a whole. In the case of the Durban map sheet the information from 6 615 boreholes was available on the National Groundwater Data Base (NGDB) of the Department of Water Affairs and Forestry.

In the past there had been a lack of attention to groundwater in KwaZulu-Natal; the province being considered to be well watered with adequate supplies of surface water. The severe droughts of 1982–83 and 1991–93 changed this perspective and major drilling programmes were undertaken in the attempt to alleviate the water shortages. A lot of this information was secured for the NGDB during a special borehole survey in 1993.

Physical Environment

Elevation ranges from sea level to 3 314 m in the Drakensberg escarpment. Mean annual precipitation ranges from about 700 mm to about 1 300 mm.

Hydrogeology

Aquifer types are either intergranular, fractured, karstic or intergranular and fractured. These categories refer to the voids in the rock through which water is transmitted. On this map sheet the following geological groupings and yield classes are associated with these aquifer types:

INTERGRANULAR	FRACTURED	KARSTIC	INTERGRANULAR AND FRACTURED
Maputaland Group **(coastal sediments)**	Msikaba Formation **(sandstone)**	Natal Metamorphic Province **(calcite and dolomite marble)**	Karoo dolerit **(dolorite)**
Alluvium	Natal Group (sandstone)		Drakensberg Group **(basalt)**
	Dwyka Group (diamictite)		Karoo Supergroup sedimentary rocks **(sandstone, shale, mudstone, siltstone)**
			Natal Metamorphic Province **(granite, granite gneiss, gneiss, calsilicate roks, granulite, charnokite, amphibolite and marble)**
RANGE OF YIELD CLASSES (*l*/s)			
0.5 – 2.0	0.0 – 5.0	0.5 – 2.0	0.0 – 5.0

Groundwater levels

Groundwater levels were generally in the 12–25 m range, and averaging 18 m below ground level. However, occasional groundwater levels of up to 140 m below surface were recorded.

Groundwater quality

Groundwater quality is generally good with only isolated areas having an Electrical Conductivity (EC) of greater than 300 mS/m (approximately 1 800 mg/*l* of Total Dissolved Solids). The pH value of the groundwater is mostly in the 7,3 to 8,1 range. Nitrate levels are usually of the order of 0,1 mg/*l* or less, but are as high as 25 mg/*l* where local pollution occurs.

Springs

Springs have a widespread occurrence throughout the map area. The average yield of springs is about 0,05 *l*/s. Mt. Ayliff gets all its water from springs. Kokstad is partially dependant on spring water. A vast number of springs are used as a source for domestic and stock water in the southern rural areas. Seepages, with yields in the order of 0,005 *l*/s, are widely used in the rural areas as a source of domestic water. Thermal springs, indicating deeper groundwater, are found at Lilani (41,1 °C) and at Kinira Drift (29,3 °C).

Groundwater use

It is estimated that total groundwater use in the map area is some 120 million m³/a. Many of the rural communities are dependant on groundwater as are many farms. The generally low yields of the boreholes in this area limit the use of groundwater. However some small urban communities such as Blythdale Beach and Zinwazi Beach rely totally on groundwater, while larger towns such as Gingindhlovu, Greytown, Richmond and Harding use groundwater to augment surface supplies.

A number of high-yielding boreholes in the Richmond area are used for horticultural irrigation. The industrial use of groundwater is prevalent in the Pinetown area where the Natal Group sandstone is exploited. The deep sand aquifers in the upper estuarine portions of major rivers are also used a source of water for industries.

Development potential

Groundwater use as a percentage of natural recharge to groundwater varies from about 1% in the north of the map area to about 9% in the south, suggesting there is considerable scope for the further development of groundwater without detrimental effect to the prevailing natural conditions. However throughout most of the map area the storage capacity of the aquifers is unable to absorb all the potential recharge. Thus the sustainable yield will be less than the average annual recharge. The generally low yields of the boreholes may also make it impractical to abstract groundwater at its sustainable yield.

Borehole siting

Higher borehole yields are generally associated with geological discontinuities. The most satisfactory method of siting boreholes on these discontinuities is by direct geological observation. Where this is not possible air photo interpretation can be used with considerable success. Geophysical methods are required to significantly improve success rates and a good scientific basis already exists on the most appropriate techniques in different geological settings.

Recommendations for further studies:

i. The long-term monitoring of groundwater level behaviour and quality in representative or significant locations to establish estimates of natural recharge to groundwater;

ii. The investigation of the effect of intensive afforestation, especially by *Eucalyptus*, on the groundwater regime;

iii. The effects on the quality of groundwater underlying areas of intensive urban or peri-urban informal settlements;

iv. Exploratory hydrogeological and stratigraphic borehole drilling, including very deep boreholes (300 m), in specific target sites suggested by regional structural analysis, particularly extensional features, or other lithologic indications such as Karoo dolerite contact zones, faults and joints, and inland areas of deep alluvium such as Cedarville Flats;

v. The investigation of the role of fracture density and orientation on groundwater occurrence and borehole yields;

vi. The investigation of Karoo dolerite intrusions as targets for the siting of boreholes; and

vii. The investigation of the groundwater production potential of springs and their usefulness as sources of rural domestic water supply.

INIMININGWANE

Ibalazwe Lasethekwini 1:500 000 Elichaza Umumo Wamatshe Namanzi

Injongo yaleli pheshana

Ibalazwe laseThekwini 1:500 000 libonisa ubunjalo besimo samatshe namanzi kule ndawo. Incwajana ehambisana nalo yona inokwazi inokwaziswa okwenezelwe. Injongo yaleli pheshana ukubukeza okuqukethwe yibalazwe kanye nencwajana.

Indlela Yokwenza

Noma yiliphi ibalazwe elikhomba ukuba khona kwamanzi angaphansi komhlaba, lisebenzisa ulwazi olutholakele ngokumba amapitsi. Lolu lwazi luhlanganisa amabanga ahlukahlukene okujula lapho amanzi etholakala khona, uhlobo lwamatshe agujiwe nenani lamanzi atholakele kula mapitsi nobunjalo bawo.

Lolu lwazi, uma sekuhlangene nokwaziswa kwangaphezulu komhlaba njengokuchazwa kwesimo somhlaba (topography), ucwaningo lwamatshe (geology) nendlela yokuna kwemvula kuleyo ndawo echazwa yibalazwe, okungasiza uma kusetshenziswa ngumakadebona kachwepheshe wezamatshe namanzi (geohydrologist) luyisilinganiso sokuqala sobungako bamanzi angaphansi komhlaba kuleyo ndawo. Maqondana naleli balazwe laseThekwini, kuye kwatholakala ulwazi emapitsini angu- 6 615 ku- National Groundwater Data Base (NGDB) yoMnyango weZamanzi namaHlathi.

Phambilini abenganakwa amanzi angaphansi komhlaba KwaZulu-Natal; lesi sifundazwe besicatshangelwa njengesinamanzi aphezu komhlaba (emifuleni) anele.

Isomiso esikhulu sika- 1982–83 no-1991–93 siye sakushintsha lokhu kucabanga. Kwaqalwa izinhlelo zokumba iziphethu nampitsi kuzanywa ukuqeda ukuntuleka kwamanzi. Luningi ulwazi olwatholakala ngenkathi kuhlolisiswa iziphethu ngo-1993. Lolu lwazi lwagcinwa kwi-NGDB.

Umumo Wendawo

Kukhona ukuphakama okusukela ezingeni lolwandle kuze kufinyelele ku- 3 314 m oKhahlamba (Drakensberg). Kube khona imvula esuka ku- 700 mm kuze kufinyelele cishe ku- 1 300 mm.

Umumo Wamanzi Namatshe (Hydrogeology)

Lezi zinhlobo zamatshe agciana amanzi, zivame ukuba mahhadlahadlana, zichachambe, zibe wuqweqwe noma zihlanganise amahhadlahadlana nokuchachamba. Amanzi angaphansi komhlaba avamise ukutholakala egcineke amatsheni amahhadlahadlana, anezinhlamvu zesihlabathi, aqhekekile noma anakho konke lokhu. Kuleli balazwe amatshe ahlukaniswe ngezindawo lapho kutholakala khona amanzi.

AMAHHADLAHADLANA	ACHACHAMBILE (AQHEKEKILE)	AWUQWEQWE	AHLANGANISE AMAHHADLAHADLA NOKUCHACHAMBA
Uhlobo lwase Maputaland **(coastal sediments)**	Ukwakheka kwawase-Msikaba **(sandstone)**	Uhlobo lwawaseNatali anguqunguqu **(calcite and dolomite marble)**	Idolerite yase Karoo **(dolorite)**
I- Aluviyamu	Uhlobo lase Natali **(sandstone)**		Ukwakheka kwawasoKhahlamba **(basalt)**
	Uhlobo lwe-Dwyka **(sandstone)**		Uhlobo oluvelele lwase Karoo olunamadwala agugulwe ngamanzi **(sandstone, shale, mudstone, siltstone)**
			Uhlobo lwawaseNatali anguqunguqu **(granite, granite gneiss, gneiss, calsilicate roks, granulite, charnokite, amphibolite and marble)**
UHLA LWEMIKHAKHAEK HIQIZIWE (*l*/s)			
0.5 – 2.0	0.0 – 5.0	0.5 – 2.0	0.0 – 5.0

Izilinganiso zamanzi angaphansi komhlaba

Amazinga amanzi angaphansi komhlaba abevame ukuba ngu- 12–25 m ukujula, ngokwesilinganiso abe wu- 18 m ukujula. Nokho, bekuke kwenzeke kuqoshwe ukujula okuze kufinyelele ku- 140 m ngaphansi komhlabathi.

Ubunjalo Bamanzi Angaphansi Komhlaba

Amanzi angaphansi komhlaba avamise ukuba mahle ngaphandle kwezindawo ezithile lapho ake atholakale engakwazi ukuhambisa ugesi (EC) lokhu okungaphezu kuka- 300 mS/m (okungase kube ngu- 1 800 mg/*l* yawo wonke amagaqana ancibilikile). Inani le-PH kula manzi angaphansi kimhlaba livame ukuba phakathi kuka- 7,3 no 8,1. Amazinga e-Nitrate wona avame ukuba ngu- 0,1 mg/*l* noma ngaphansi, kodwa aze afinyelele ku- 25 mg/*l* ezindaweni ezinokunukubezeka okuthile.

Iziphethu

Iziphethu zithe chithi – saka kuyo yonke indawo ekhonjwa yileli balazwe. Amanzi akhiqizwa isiphethu ngasinye alinganiselwa ku- 0,05 *l*/s. I-Mt. Ayiliff ithola onke amanzi ayo eziphethwini. I-Kokstad yona iwasebenzisa laphaya nalaphaya amanzi eziphethu. Iningi leziphethu lisetshenziselwa ukuphakela abemizi nemfuyo yabo nokuwagcina kulo lonke elisemakhaya asezansi nezwe. Amanzi adonswayo alinganiselwa ku- 0.005 *l*/s asetshenziswa emakhaya nasempahleni. Iziphethu zamanzi afudumele, linani (41,1°C) nase Kinira Drift (29,3°C).

Ukusetshenziswa Kwamanzi Angaphansi Komhlaba

Alinganiselwa ku- 120 m³/a amanzi angaphansi komhlaba asetshenziswayo. Imiphakathi eminingi yasemapulazini nasemakhaya isebenzisa la manzi Ukumfimfa kwalezi ziphethu kunqinda ukusetshenziswa kwamanzi.

Nokho kukhona eminye imiphakathi emincane yasemadolobheni njengakoBlythedale Beach naseZinkwazi Beach ethembele kula manzi angaphansi komhlaba. Kanti amadolobha amakhudlwana njengoGingindlovu, Greytown, Richmond kanye neHarding, asebenzisa la manzi ukwenezela kwakangaphezu komhlaba.

Idlanzana leziphethu ezikhiqiza kakhulu eRichmond zisetshenziselwa ukunisela emasimini. La manzi angaphansi komhlaba asetshenziswa kakhulu ezimbonini ePinetown, ngokukhiqizwa ematsheni ohlobo lwaseNatali. Kanti amanzi aphuma esihlabathini esijulile esisezizalweni zemifula emikhulu ayasetshenziswa ezimbonini.

Intuthuko Enokuba khona

Ukusetshenziswa kwamanzi angaphansi komhlaba ngokulinganiswa ngokwamaphesenti kusukela ku- 1% enhla naleli balazwe kuze kufike ku- 9% ezansi nalo, lokho kubonisa ukuthi asemaningi amanzi angasetshenziswa eziphethu ngaphandle kokuphazamisa izimo ezikhona zemvelo. Nokho kulo lonke leli balazwe amatshe akhona awakwazi ukugcina amanzi emvula ashona phansi emhlabathini. Ngaleyo ndlelake, inani lamanzi elingakhiqizwa minyaka yonke lingaba ngaphansi kwamanzi avela emvuleni engena ematsheni. Nakho ukumfimfa kwalezi ziphethu kungase kube nzima ukuthola amanzi eziphethwini.

Ukukhetha Indawo Yokumba Isiphethu

Iziphethu ezikhiqiza amanzi amaningi zivame ukuhambisana nalapho amatshe eqhekeke khona noma lapho kuhlangana izinhlobo ezimbili ezahlukene zamatshe. Indlela enconywa kakhulu yokukhetha indawo yesiphethu kulezi zindawo ezinemifantu ukulandela ubuchwepheshe bamatshe. Uma kungalungi lokhu, ukuhunyushwa kwesithombe sasemkhathini kungasiza kakhulu. Ulwazi lomumo wamatshe luyadingeka ukwenza ngcono impumelelo yalezi ziphethu kanti nobuchwepheshe namakhono aphathelene nokumbiwa kwazo asekhona ngokwezimo ezahlukene zamatshe.

Imibhalo Engakusiza Ngolwazi Oluthe Xaxa/Thuthu

i. Ukuqashelwa kwesikhathi eside komumo wamanzi eziphethu nobunjalo bawo ezindaweni ezingoqobo Noma ezicatshangelwayo ukuze kuqagelwe ukuthi aphinde abuye nini ngokwemvelo yawo,

ii. Ukucwaninga imiphumela yokutshalwa kwamahlathi, ezindaweni zeziphethu ikakhulukazi I-*Eucalyptus,*

iii. Imiphumela ebonakala emanzini iziphethu asezindaweni ezingamadolobha anezimboni impela Nezingamadobhana omahambe – hlala,

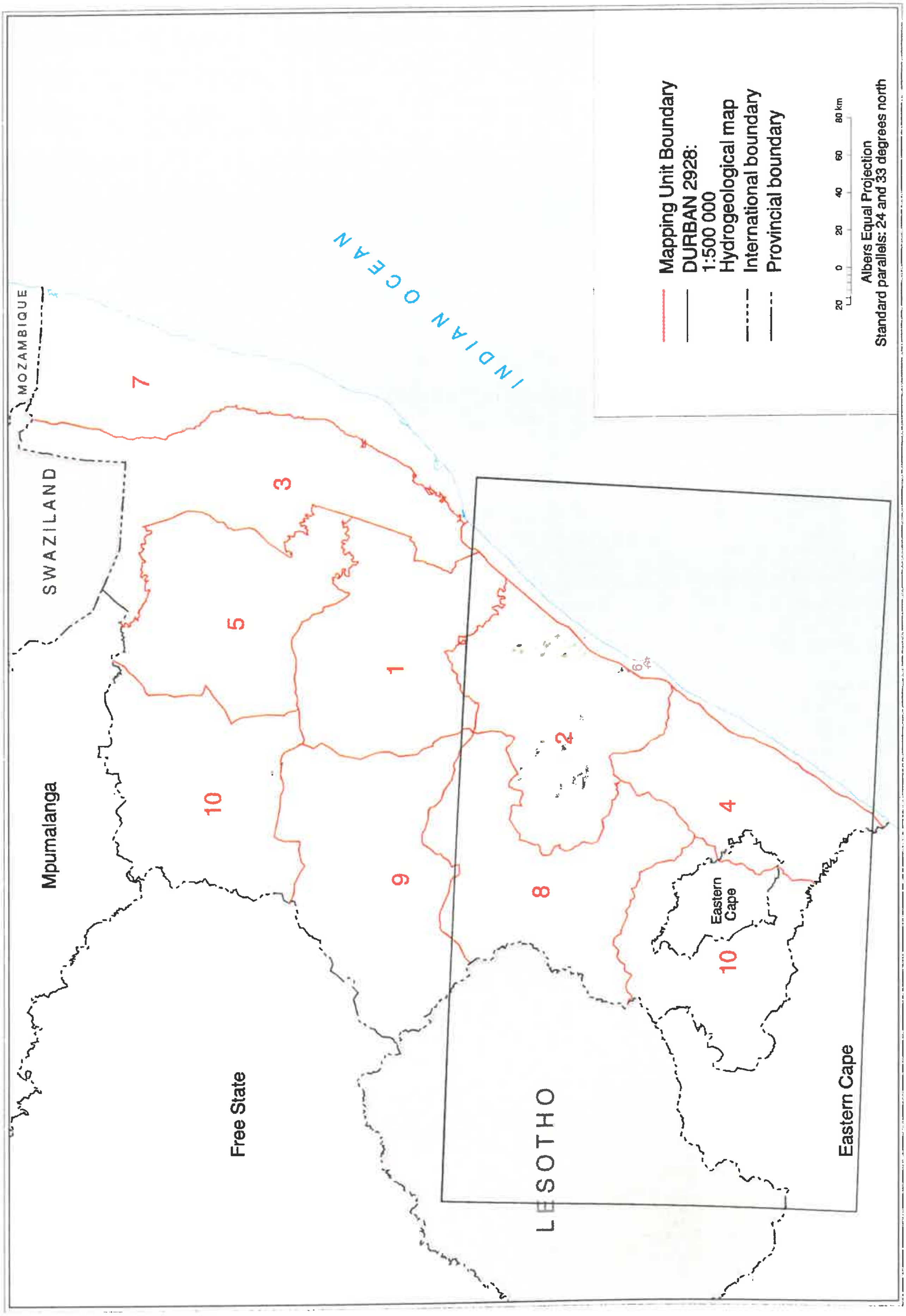
iv. Ukuhlolwa kewndlela yokumbiwa kweziphethu ngokulandela umumo wamatshe namanzi kuleyo Ndawo, ngisho nezijulile impela iziphethu... (300 m), izindawo ezikhethwayo zikhethwa ngesimo Sangaphandle saleyo ndawo, ikakhulukazi izimo zangaphezulu, noma ke ngokulandela imibhalo Ye lithology echaza umumo onjengowezindawo ze dolerite yase Karoo, ukunqamuka noku xhumeka kochungechunge lwamanzi zasezindaweni ezivundile ezimaphakathi nezwe njenge Cedarville Flats;

v. Ukuhlolisisa kwemiphumela ebangwa ubungako boqhekeko lwamadwala nomkhondo wamanzi Angaphansi komhlaba nokuthi iziphethu zingakhiqiza kanganani,

vi. Ukuhlolisiswa kwemingenela ye dolerite yase Karoo njengekacatshangelwa ekumbiweni kweziphethu,

vii. Ukuhlolisisa kwamandla okukhiqiza amanzi eziphethu nokuthi angasiza kanjani ekubeni umthombo wamanzi ase khaya ezindaweni sazemaphandleni.

Figure 1. KwaZulu-Natal Hydrogeological Mapping units



1 Introduction

1.1 Aims and objectives

The primary aim of the Durban general Hydrogeological Map was to produce a synoptic overview of the hydrogeological character of the area by processing data according to a standard legend. The main features shown on the map are borehole yield, aquifer type, groundwater quality, groundwater use, and lithology.

This brochure was compiled to provide supplementary information on these features, and also to:

- determine the hydrogeological parameters to consider in siting boreholes,
- describe the hydrochemical character of the groundwater,
- make a preliminary estimate of maximum and optimum sustainable abstraction rates,
- facilitate the focus of future research directions by identifying knowledge gaps.

1.2 Previous hydrogeological investigations

1.2.1 KwaZulu-Natal Hydrogeological Characterisation and Mapping Project

KwaZulu-Natal has traditionally been considered a well-watered province with adequate surface water to meet local needs. Prior to 1980, groundwater was rarely considered an important natural resource and this resulted in neglect of its utilisation, evaluation and management. The severe droughts of 1982–83 and again of 1991–93 changed this perspective when water use restrictions were imposed and attention was diverted to groundwater as a possible alternative source of water. During these periods, both public and private organisations undertook major groundwater drilling and spring protection programmes in an attempt to alleviate the shortages of potable water, particularly in the rural areas. Unfortunately, much of the hydrogeological data generated by these projects were never formally collected and analysed.

In 1993, the Department of Water Affairs and Forestry (DWAF) together with the Water Research Commission, the KwaZulu Government, the Water Services Advisory Board, and the former Joint Services Boards of Port Natal-Ebhodwe, Midlands, Zululand, Southern Natal, East Griqualand, Tukhela, Umgeni Water and Mhlatuze Water funded the KwaZulu-Natal Hydrogeological Characterisation and Mapping Project.

Due to a shortage of trained personnel within DWAF's Directorate: Geohydrology in KwaZulu-Natal and paucity of readily available groundwater and related data it was decided to appoint a number of groundwater consultants in order to accelerate the project. The aim of this project was to expand the hydrogeological data base as contained in both the National Ground Water Data Base (NGDB) and the National Water Quality Data Base (NWQDB) by the verification of existing NGDB borehole data, collection of new data and groundwater sampling. The final products of the project were eleven 1:250 000 scale hydrogeological maps and accompanying brochures characterising the groundwater resources and depicting its occurrence, recharge potential and ambient quality. The distribution of the project mapping areas covered the Province and area shown in Figure 1.

To assist the consultants in their work, DWAF also commissioned an expert structural geologist from the University of Natal to produce a report on the structural geological conditions prevailing in the region and their likely effect on the groundwater regime. Hydrogeological maps and reports of the individual Mapping Units were reviewed by two external expert reviewers, Professor F.G. Bell and Mr J.R. Vegter, who reported on their adequacy to DWAF. The project was directed by Dr R.R. Maud acting as Project Co-ordinator because of his extensive local hydrogeological knowledge, and it was managed by two Project Managers from the Directorate: Geohydrology, Mr Z.M. Dziembowski and Mr W.R.G. Orpen.

It must be emphasised that the purpose of the project was not to conduct a full hydrocensus of every borehole in the area, but rather to obtain information regarding a sufficient number of boreholes, so that statistically reliable characterisation could be made of the groundwater conditions prevailing in the project area. The project resulted in an increase in the number of boreholes on the NGDB, covered by the Durban 1:500 000 map sheet from 2 929 to 6 615 borehole records.

1.2.2 1995–96 Crisis intervention programme

The most recent drought in 1995–96 expedited the drilling of 993 boreholes in rural areas of KwaZulu-Natal which were deemed to be in a critical water supply situation. The purpose of the programme was to drill and equip boreholes with hand-pumps for the immediate relief of the affected communities. Private consultants were employed to carry out borehole siting, drilling supervision, pumping tests, groundwater sampling and finally to give recommendations as to the use of each borehole.

The data generated during the programme were of high quality and were further used by King (1997) in her M.Sc. thesis entitled "The Development Potential of KwaZulu-Natal Aquifers for Rural Water Supply". This thesis examined the potential yield and groundwater quality of individual aquifers in rural areas of KwaZulu-Natal.

1.2.3 Others

The KwaZulu-Natal Hydrogeological Characterisation and Mapping Project has been the only formal large-scale hydrogeological investigation carried out in the province. Umgeni Water has recently taken its own initiative to improve on groundwater characterisation in its area of interest but as yet results have not been finalised (pers. comm. Umgeni Water, 1997).

1.3 Data collection

The borehole data used in the production of this hydrogeological map were primarily collected by consultants contracted during the KwaZulu-Natal Hydrogeological Characterisation and Mapping Project. Existing data on the NGDB were first verified because it was recognised that the quality of the data on the database suffered from poor co-ordinate accuracies and other deficiencies. Other records from the Department of Agriculture, the KwaZulu Department of Agriculture and KwaZulu Department of Works were captured from hardcopy drillers' completion forms. Other data were collected from academic and industrial organisations in digital format.

Recent data extracted from consultants' reports from the Crisis Intervention Programme were entered into a local database for analysis but also added to the overall database for the purposes of the hydrogeological map.

1.4 Data limitations

The data collected and used in the compilation of this map was limited by a number of factors. A primary problem being the poor quality of the data available. Typical examples of these types of problems are very poor co-ordinate accuracies, many in excess of 1 000 m and a lack of basic hydrogeological information such as yield, strike depths and static water levels. The method of borehole siting, for which there are data, is often questionable. It is estimated that approximately 40% of the boreholes were sited non-scientifically. This means that the boreholes have not always been sited in the most optimum hydrogeological location. Compounding this problem, is the fact that many boreholes have also been sited in particular places because it is close to the demand, again not in the most favourable hydrogeological location. Difficulties in obtaining access to the most favourable sites, due to dense vegetation and difficult terrain also means the boreholes are not drilled in their optimum locations.

The hydrogeological map produced is only as good as the data from which it is generated. It is acknowledged that there are some flaws in the data, but only by ensuring that new borehole data are included in the NGDB can there be confidence that the information portrayed on the hydrogeological map, and any future maps, is as true a reflection of the hydrogeology as possible.

1.5 Mapping methodology

1.5.1 Lithology

The basis of the hydrogeological map is the underlying lithology, as it is primarily the nature of the rocks that dictates the occurrence of groundwater. Therefore, rocks with similar lithological characteristics have been grouped for the purposes of the map (hydrolithological unit). For example, there are numerous different types of argillaceous rocks within the Beaufort Group and these have been grouped into one hydrolithological unit called P-Trb. The various groupings of Formations are discussed further in chapter 3.

The lithological boundaries of the map area were obtained by digitising the geology from the Council for Geoscience 1:250 000 geological maps. Thereafter the Formations of similar lithology were grouped together. Sometimes it was necessary to smooth out intricate lithological boundaries to make the map more readable at a 1:500 000 scale. In cases where there were small "islands" of lithology, these were also excluded for the sake of readability. These changes mean that some lithological boundaries of the map area will not correspond exactly to the 1:250 000 geological maps. Geological faults were also digitised from the same 1:250 000 geological maps. Some faults have also been removed in order to increase readability of the map.

1.5.2 Borehole yield

The lithology map was further subdivided or grouped into areas, which were delineated on the basis of geological structure, groundwater recharge and topography. These are important aspects that are considered to have an effect on the yield of boreholes. The resultant areas, therefore, represent areas of different hydrogeological characteristics.

A database of all borehole records with yield data was created. Dry boreholes or those with no data were excluded from analysis because it was impossible to distinguish on the NGDB which were dry or which had no data. This fact is unfortunate, as information regarding dry boreholes can be beneficial in determining the potential yield of an area. Use of only successful boreholes means that the map therefore portrays the likely yield to be expected of successful boreholes only. Yield data when it was available was usually the blow yield of the borehole. It is estimated that less than 10% of the borehole yield data were obtained by controlled pumping tests.

Using a geographic information system (GIS), the borehole records were overlain on each hydrogeological area, and statistics returned on the number of boreholes, standard yield deviation, median yield, maximum and minimum yield for each area. The results of this analysis were compared to the 1:250 000 hydrogeological maps produced by consultants during the KwaZulu-Natal Hydrogeological Characterisation and Mapping Project. Further refinements were made by checking each area for clusters of abnormally high or low yielding boreholes.

The borehole yield boundaries on the map generally follow the lithology boundaries. There are some cases where the borehole yield boundary does cut across the lithology, thereby reflecting distinct areas of higher or lower yield compared to the rest of the hydrolithology.

1.5.3 Aquifer type

For the purposes of the 1:500 000 map series, aquifers are divided into:

- intergranular
- fractured
- karst
- intergranular and fractured

These aquifer categories classify the voids in the rock through which water is transmitted. The categories refer to the type of aquifer present, rather than the actual boundaries of individual aquifers, since individual aquifers may be too small to be mapped at a 1:500 000 scale.

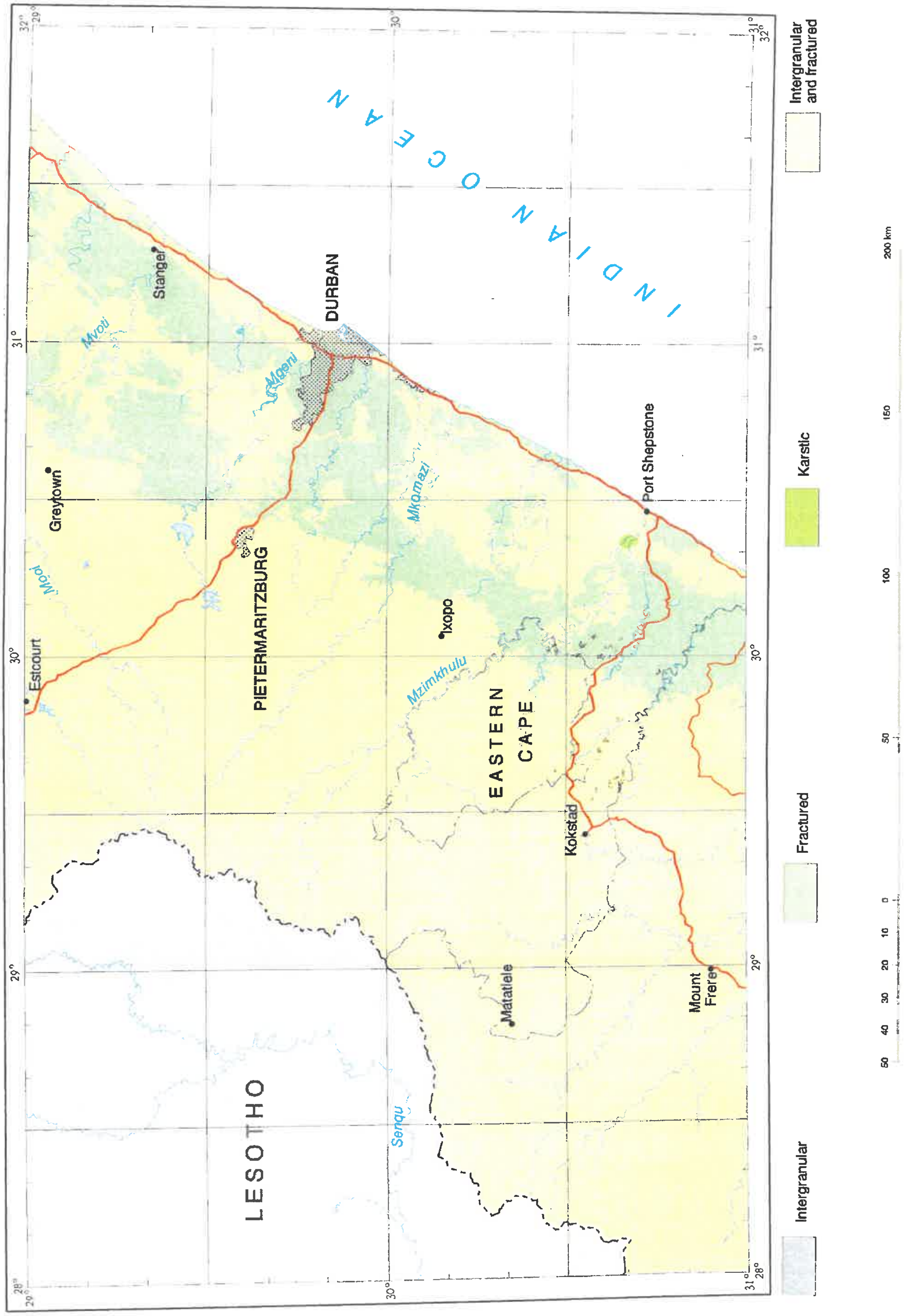
The aquifer mapped was not necessarily the shallowest, but the principal aquifer. In other words, the principal aquifer is the shallowest aquifer with the highest yield and the best quality water. Thus a surface layer of sand with an insignificant groundwater yield would not be mapped as the aquifer if the deeper bedrock provides higher yields.

Intergranular aquifers are those which transmit groundwater in the voids between individual grains. The formation of these grains may either be a result of primary sedimentation, e.g. unconsolidated coastal sands, or secondary process such as weathering of crystalline or sedimentary rocks.

Those rocks in which groundwater flow is mainly within fractures are classified simply as fractured aquifers. It is generally aquifers in competent rocks which fall into this category. However, many competent rocks also exhibit some weathering that may confuse one into believing that the aquifer should be classed as intergranular and fractured. The weathered or intergranular zones may store important quantities of groundwater in their voids, but the water can only be economically abstracted from fractures in the underlying bedrock. Thus it is mainly from the fractured hard rock that groundwater is obtained.

The small karst aquifer found in the map area is defined as such due to its carbonate nature. Solution weathering of these rocks form passages that enhances the transmission of groundwater.

Figure 2. Distribution of aquifer types



Where the intergranular zone does contribute significantly to the transmission of groundwater in conjunction with fractures, the aquifer is classed as intergranular and fractured. This is often the case in crystalline rocks, which tend to be susceptible to weathering in hot humid climates. It is both within the intergranular weathered zone and fractures that groundwater can be obtained, with the intergranular zone also acting as a storage zone for downward percolating groundwater.

The distribution of the four different aquifer types found in the map area is shown in Figure 2.

1.5.4 Groundwater quality and hydrochemistry

Data points containing electrical conductivity (EC) readings were contoured, using inverse distance weighting, to distinguish regional-scale trends. The quality parameter of EC was chosen because it is the most commonly measured water quality variable, it reflects high salinity and/or is a good indicator of pollution. Lithologies with known influences on EC were contoured separately.

1.5.5 Major groundwater use

The locations of large-scale groundwater abstraction points were obtained through the experience of both the map author, the KwaZulu-Natal Hydrogeological Characterisation and Mapping Project consultants, and Dr R.R. Maud. An estimate of the abstraction rate was determined from abstraction reports or from the owners of the schemes.

2 Physical environment

2.1 Physiography

The topography of the area rises fairly steeply inland from the coast to the base of the Drakensberg escarpment. The elevation of the top of the Drakensberg escarpment varies from over 3 000 m in the north at Giant's Castle (3 314 m) to about 2 500 m in the Qachas Nek area, northwest of Matatiele. It's highest point rises to over 2 800 m in the extreme southwest corner of the map. A number of elevated interfluve ridges of varying width are present between much lower, frequently deeply incised river valleys, which traverse from the high ground in the west in a southeasterly direction towards the sea. In the interior the river valleys broaden out into fairly large shallow basins, such as those of the Thukela (Estcourt-Bergville), the Mzimkulu (Underberg), and the Mzimvubu (Matatiele).

The resistance to erosion of some of the rock types that are present, such as sandstone and dolerite, modifies the overall general physiographic environment. For example, the Kloof escarpment west of Durban and the Town Hill escarpment west of Pietermaritzburg, as well as the scenic 300 m deep Oribi Gorge, inland of Port Shepstone in the south. Conversely, where less erosion-resistant rock types are exposed, such as granite-gneiss, erosion has produced such major scenic features as the Valley of a Thousand Hills inland of Durban.

2.2 Climate

2.2.1 Precipitation

Rainfall is strongly orographically related, except along the coast. Most rainfall falls in the summer months as a result of seaward-moving convective thunderstorms, other rainfall being frontal and associated with the passage of cold fronts from the southwest. Representative average annual rainfalls are shown in Table 1 (right). In the winter, rainfall may occasionally be replaced (about 6–10 times per year) by snowfalls on the higher ground associated with the Drakensberg escarpment. A place with one of the highest average annual rainfalls is the Karkloof escarpment, north of Pietermaritzburg, with 1 328 mm, and one of the lowest is Matatiele with 686 mm. A mean annual precipitation map is included as an inset map on the hydrogeological sheet.

Table 1. Representative average rainfalls

CITY/TOWN	AVERAGE ANNUAL RAINFALL (mm)
Karkloof	1328
Cathedral Peak	1269
Port Shepstone	1114
Stanger	1078
Durban	1013
Giant's Castle	1038
Underberg	933
Pietermaritzburg	929
Estcourt	766
Kokstad	758
Matatiele	686

2.2.2 Evaporation

Mean annual evaporation (Symons Pan) over the map sheet area varies from <1 200 to about 1 400 mm (Midgley *et al.*, 1994). Evaporation rates increase inland from < 1 200 mm per annum to 1 400 mm per annum, but decrease again on the highest parts of the Drakensberg to between 1 200–1 300 mm per annum. Figure 3 shows the distribution of evaporation.

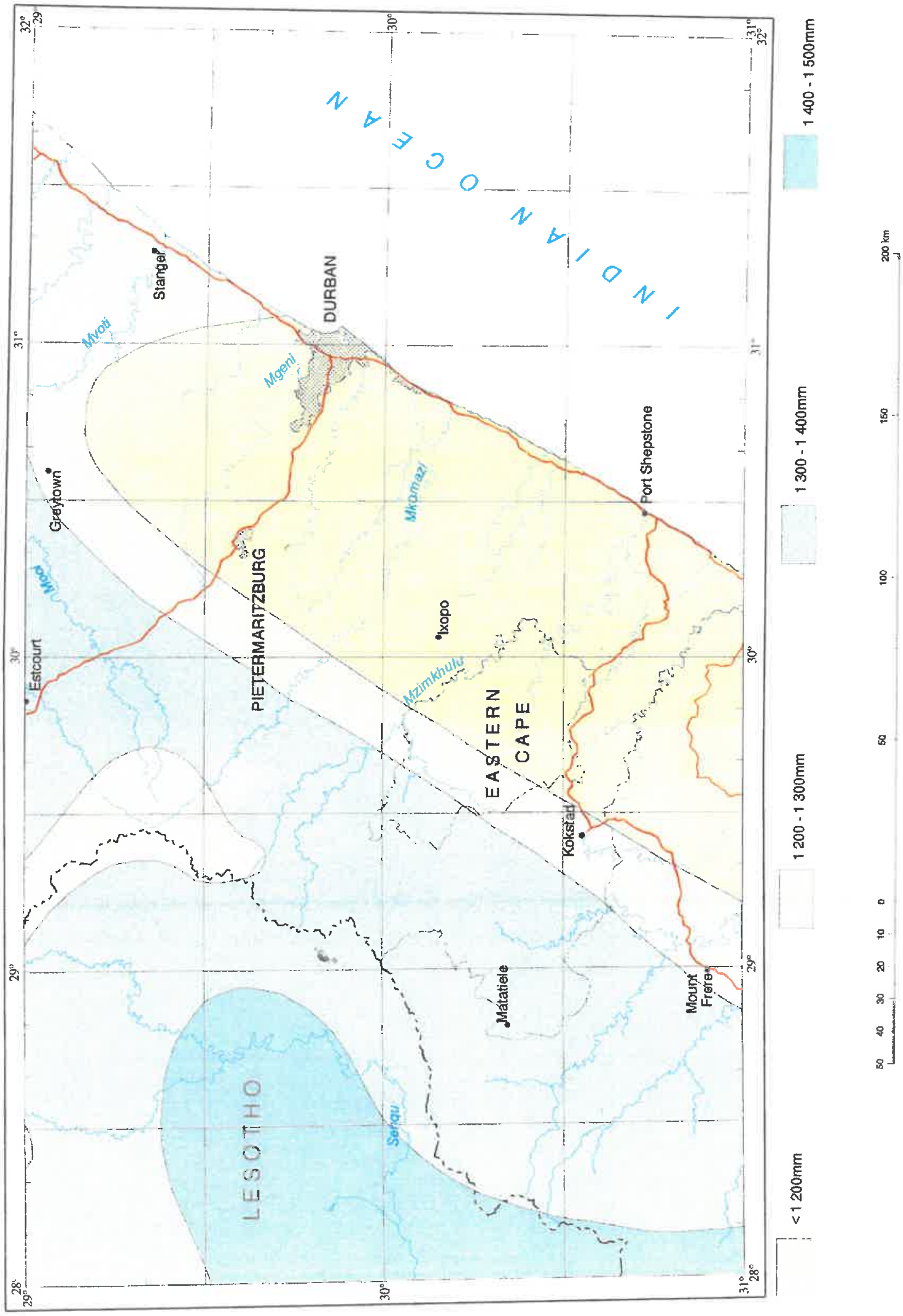
2.3 Surface hydrology

All the larger rivers, such as the Bushmans, a major tributary of the Thukela in the north, the Mkomazi, the Mzimkulu and the Mzimvubu and its major tributaries in the south, have their sources on the high Drakensberg escarpment in the west. Intermediate-size rivers such as the Mvoti, Mgeni and the Mtamvuna rise in the highlands of the interior, while the smaller rivers have their sources in the coastal hinterland. Rivers are characterised by a very marked seasonal variation in flow dependent on rainfall.

The greatest number of major surface water impoundments are located on the Mgeni River to supply water to the Durban-Pinetown-Pietermaritzburg development axis. The major dams on the Mgeni River successively in a downstream direction are Midmar, Albert Falls, Nagle and Inanda dams with a total full supply capacity of 733 x 10^6 m^3. Other significant water supply dams on the map sheet are the Wagendrift, Craigieburn and Hazelmere dams. There are no dams at present on either the Mkomazi or Mzimkulu Rivers, although a pumping transfer scheme to transfer water from the Mkomazi to the Mgeni to further augment that system is proposed. There are abundant minor farm water storage and conservation dams throughout the region.

A transfer scheme pumping surface water from the Mooi River in the Thukela catchment to the catchment of Midmar Dam is in operation during low flow periods in the Mgeni system.

Figure 3. Mean annual evaporation



3 Geology

3.1 Introduction

The geology depicted in the map area incorporates the most recent proposals (1996) and decisions by the S.A. Committee for Stratigraphy and will thus differ with earlier published geological literature and maps.

In many instances it has been possible in the lithological legend to combine a number of stratigraphic units at Formation level within the major stratigraphic units at Group or Supergroup level. This is possible, even for rocks and unconsolidated material of different geological age because they may have the same hydrogeological properties. Two examples of this are the argillaceous sedimentary rocks such as shales and mudstones of the various Formations of the Karoo Supergroup, and the unconsolidated coastal sediments. The generalised lithology legend shown on the map sheet is therefore a product of the grouping of similar lithologies and does not reflect the actual stratigraphy of the rock formations. A summary of the groupings is given in Table 2 and a simplified lithology map (Figure 4) shows the distribution.

Table 2. Summary of lithological groupings and their symbols on the hydrogeological map

SYMBOL ON MAP	GENERALISED LITHOLOGY	HYDROGEOLOGICAL MAP GROUPING	MAJOR STRATIGRAPHIC UNIT
Q T-Qm	alluvium coastal sediments	Fluvial deposits Maputaland Group	Quarternary Tertiary-Quarternary
Jdr	basalt	Drakensberg Group	Karoo Supergroup
Jd	dolerite	Karoo Dolerite	
Trc Tre Trm	sandstone shale, mudstone, siltstone sandstone and shale	Clarens Formation Elliot Formation Molteno Formation	
P-Trb	shale, mudstone, siltstone	Beaufort Group	
Pe	mostly shales, carbonaceous shales and mudstone with the exception of the Vryheid Formation sandstones	Ecca Group	
C-Pd	diamictite	Dwyka Group	
Dms	sandstone	Msikaba Formation	Cape Supergroup
On	sandstone	Natal Group	Natal Group
Nmp	granite, granitic gneiss, gneiss, calc-silicate rocks, granulite, charnockite, amphibolite and marble	Natal Metamorphic Province	Natal Metamorphic Province

3.2 Natal Metamorphic Province (Nmp)

Extensive occurrences of largely crystalline rocks of Mokolian age, collectively known as the Natal Metamorphic Province stretch approximately south to north from south of Margate to the northern boundary of the map east of Greytown. The Nmp is structurally complex and features like folds, faults, thrusts, nappes and various intrusions abound in this unit. Many of the rocks tend to be strongly foliated and jointed in a prevailing southwest – northeast to west – east major structural trend direction. A variety of lithologies occur within the Nmp and the following sub-units and their respective lithologies have been recognised:

Oribi gorge Suite: porphyritic granite
Sezela Suite: quartz syenite, granite and quartz monzonite
Margate Suite: augen gneiss and leuco-granite
Humberdale Granite: grey and pink granite
Glenmore Granite: garnet-biotite augen gneiss
Mahlongwa Granite: pink granite
Mkomazi Gneiss: augen gneiss
Mzumbe Suite: Gneiss
Buhleni Gneiss: quartz-feldspar gneiss
Mapumulo Group: gneiss and granulite
Mzimkulu Group: marble, dolomite and granulite
Ntingwe Group: conglomerate, mudstone, limestone and schist
Tugela Group: amphibolite, gneiss, schist, quartzite, dolomite and limestone

3.3 Natal Group and Msikaba Formation (On and Dms)

The Natal Group rocks occur both in the coastal hinterland and along the faulted coastline. The Group thickens from north to south and from west to east. The western limit of the rocks is about 80 km from the coastline north of Durban. The thickness of the Natal Group can be up to 600 m. It comprises erosion-resistant pinkish well-bedded arkosic sandstone and quartzite with some minor shale (Plate 1). The grey well-bedded sandstone of the Msikaba Formation is found exclusively south of Hibberdene and reaches a thickness of about 600 m.

The Msikaba Formation has recently been separated from the Natal Group as a result of isotopic dating which showed the southern rocks to be younger than the Natal Group sandstone and to be the likely equivalent of the Witteberg Group of the Cape Supergroup.

3.4 Karoo Supergroup

3.4.1 Dwyka Group (C-Pd)

This basal member of the Karoo Supergroup generally rests unconformably on the rocks of the underlying Natal Group. It mainly comprises massive unbedded but jointed diamictite (tillite) with subordinate fine-grained sandstone and shale horizons in places. The diamictite rock comprises a dark coloured fine mudstone matrix in which are set erratic clasts of various older resistant rock types such as gneiss, quartzite and chert that vary in size from pebbles up to large boulders. This Group also occurs as a fairly broad north-south trending band in the coastal hinterland as well as in the faulted coastal portion of the region. The diamictite thickens in a north to south direction, its thickness varying from about 100 m in the north to about 400 m in the south.

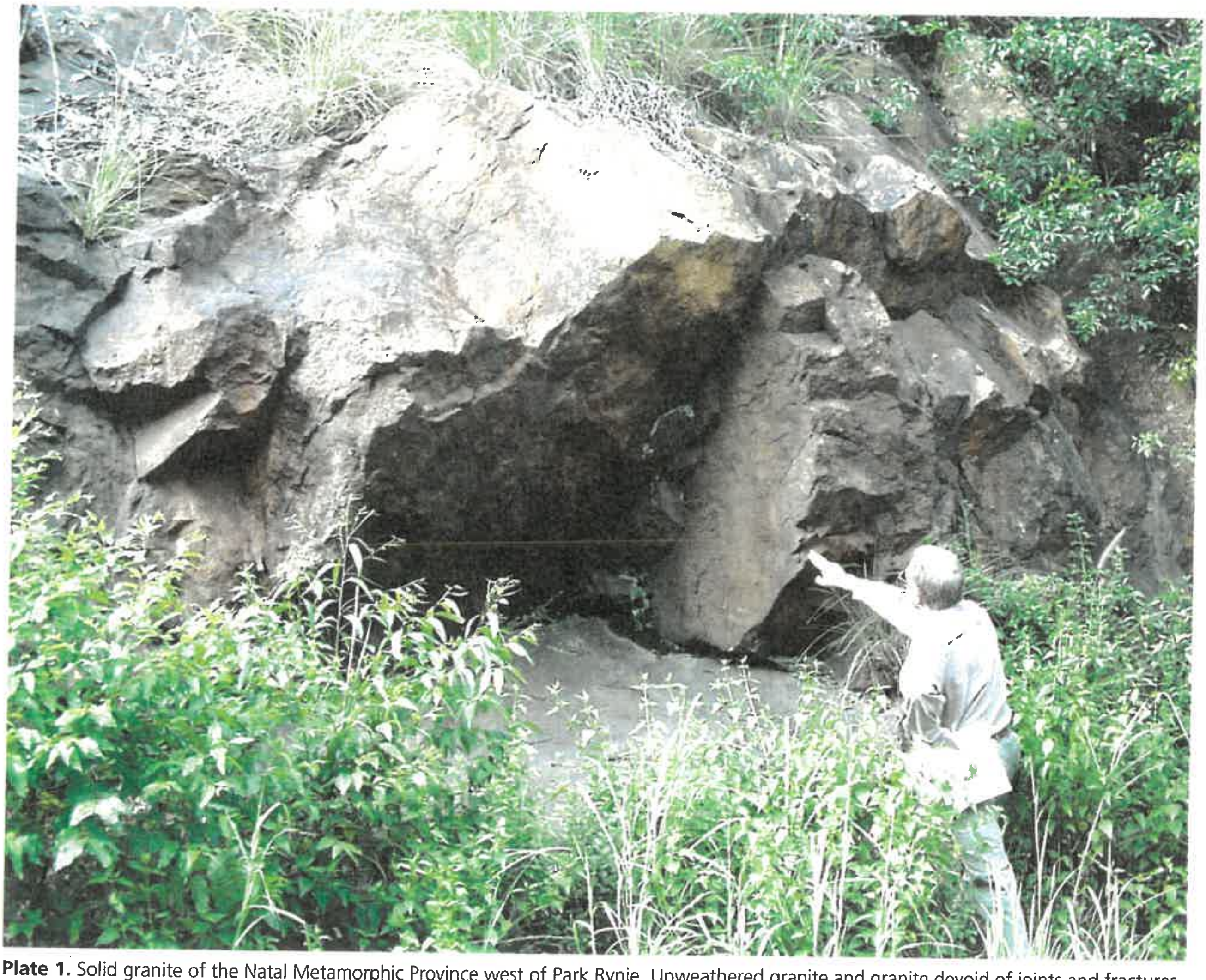
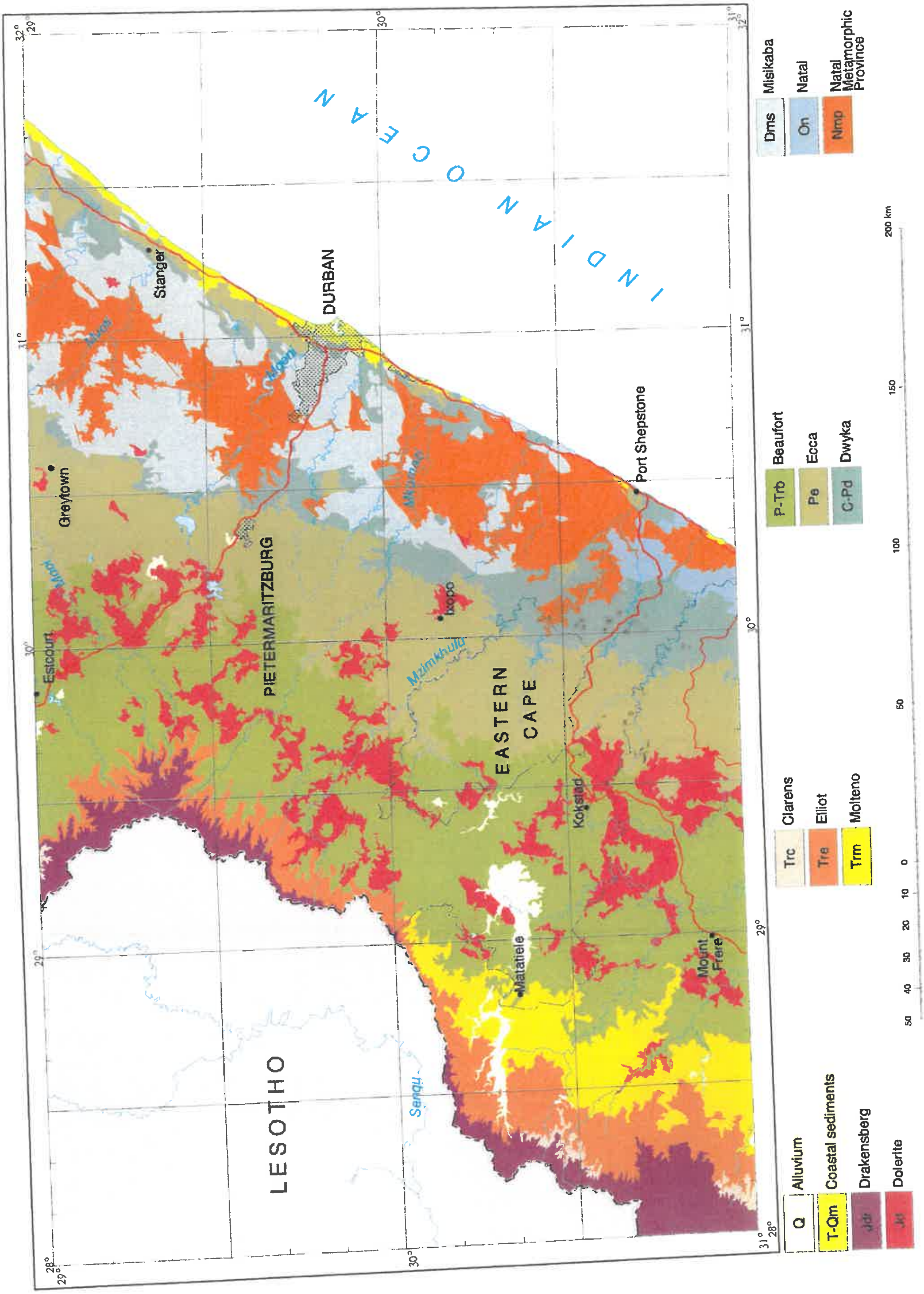


Plate 1. Solid granite of the Natal Metamorphic Province west of Park Rynie. Unweathered granite and granite devoid of joints and fractures offer little scope for groundwater development and yields of less than 0.5 *l*/s can be expected.

Figure 4. Principal geological units



3.4.2 Ecca Group (Pe)

This grouping contains three Formations, two with very similar lithologies and one with a distinctly different lithology. The two argillaceous Formations (Pietermaritzburg and Volksrust Formations) occur as a fairly broad band in the coastal hinterland, as well as in places along the faulted coast. Its thickness is about 250 m in the north and thickens to about 400 m in the south. The rocks comprise dark-coloured, well-laminated shales and mudstones, with interlayers of fine-grained sandstone. Many of the shales are characteristically fissile due to fine jointing, often as a result of unloading. Secondary mineralisation by iron pyrite is common in fractures.

The distinctly different Formation in the Ecca Group is the arenaceous Vryheid Formation, which occurs stratigraphically between the Pietermaritzburg and Volksrust Formations. These arenaceous rocks occur as a narrow band through the centre of the mapped area where they are associated with a series of escarpments. They also occur in the faulted coastal zone north of Durban. The Formation thins north to south, thus its occurrence is much less in the south than in the north. In the north its thickness is nearly 300 m, but this thins virtually to zero some distance from the southern boundary of the map area. The lithology comprises an alternating succession of micaceous shale and medium- to coarse-grained arkosic sandstone, the shale frequently also being carbonaceous.

3.4.3 Beaufort Group (P-Trb)

The two Subgroups (Tarkastad and Adelaide) contained within this Group comprise similar lithologies. These are an alternating succession of fine-grained sandstone, shale, siltstone and mudstone with an overall thickness of about 1 000 m. The Group has extensive occurrence over much of the western or interior portion of the map area.

Plate 2. Massive, unbedded tillites of the Dwyka Group generally have limited groundwater potential due to matrix storage values of less than 0.0001 and low permeability. When fractured, the tillites can however yield up to 10 *l*/s.

3.4.4 Clarens, Elliot and Molteno Formations (Trc, Tre, Trm)

These Formations comprising mainly sandstone, with some subordinate interlayered shale and mudstone, outcrop from underneath the Drakensberg basalt in the west where they give rise to the erosion resistant feature of the 'Little Berg'. The overall thickness of these Formations varies from about 150 m in the north to about 300 m in the south.

3.4.5 Karoo Dolerite (Jd)

Intrusive into the consolidated rocks of the mapped area are dykes and sills of Karoo dolerite. Dykes varying in width from about 1 to 8 m are common in the interior but are fairly rare in the coastal and coastal hinterland areas. Most dykes are vertical or have a near-vertical dip. Dolerite sheets or sills vary in thickness from about 1 to 50 m and more, becoming much more frequent in the upper portions of the overall stratigraphic succession in the interior (Figure 5). This is the case particularly in the sediments of the Ecca and Beaufort Groups. The reason for this is probably due to both increased ease of injection into well-bedded sedimentary rocks of the upper portion of the succession, and the lower overlying rock loading, permitting easier injection of the molten dolerite rock, with increasing elevation in the succession. The dolerite sills vary in attitude from horizontal to inclined, but most are sub-horizontal in terms of the bedding of the host sediments.

3.4.6 Drakensberg Group (Jdr)

These extrusive basaltic rocks occur only in the extreme west of the area. On account of their resistance to erosion, the basalt forms the high escarpment of the Drakensberg, as well as underlying most of the high-standing portion of Lesotho to the west. The maximum thickness of the horizontal layered basalt lava flow succession in the Drakensberg is about 1 500 m.

3.5 Quaternary and Tertiary sediments

3.5.1 Maputaland Group (T-Qm)

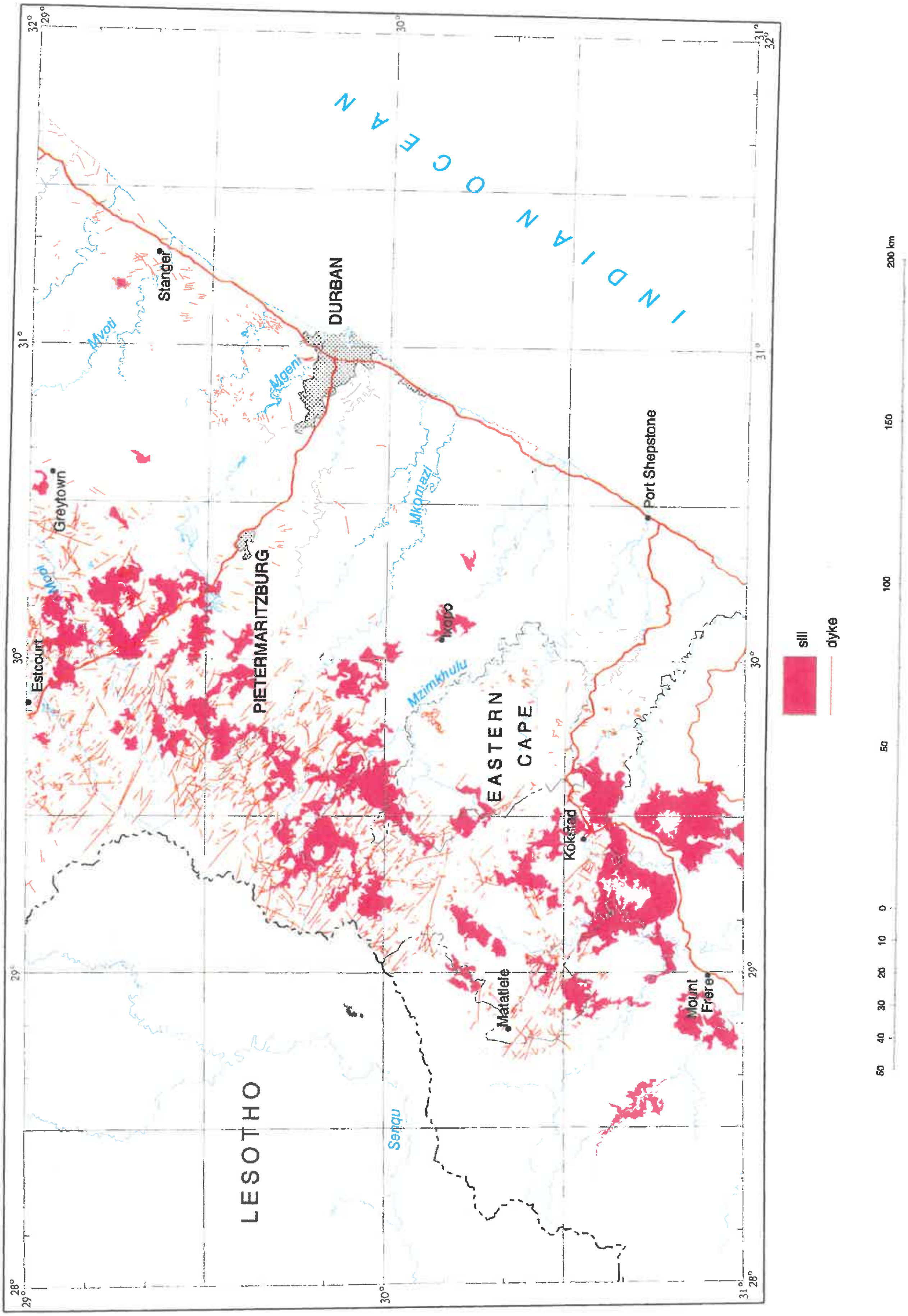
This is a provisional lithostratigraphic group of sediments (pers. comm. Botha, 1997) which has recently been used to describe the sediments along the coastal zone of KwaZulu-Natal. On the mapped area, these sediments occur in a zone of less than 8 km from the coast, north of Amanzimtoti. The distribution of the sediments lessens south of Amanzimtoti to isolated patches found only on high ground. A number of Formations make up the Maputaland Group but these will not be individually discussed. A short description of the Group as a whole is given instead.

The Maputaland Group mainly comprises calcareous coastal dune sand of aeolian origin, which can reach a thickness of 150 m. The older sediments of the Group are often variably calcified, cemented and consolidated. The weathered products of these sediments are known as Berea-type red sands which, depending upon the degree of weathering undergone, can vary in texture from sands to sandy clays. In general, the profile gets sandier and less weathered with depth, which may be as much as 100 m. A basal boulder bed of waterworn erosion-resistant sandstone cobbles and boulders may be present in places overlying older marine-cut terraces on the underlying bedrock.

3.5.2 Alluvium (Q)

Alluvium of late Pleistocene and Holocene age is associated with the rivers and streams of the region. The alluvium is unconsolidated and varies in nature from sand to clay. Sands are usually associated with the beds of existing rivers or stream channels, with the more clayey sediments being associated with the higher flood plains and adjoining river terraces. Clayey and silty sediments frequently occur in the estuarine or lower lagoon portions of the river courses. Thickness of alluvium varies from a metre or less to as much as 60 m at the mouths of the major rivers. In the southwest of the area, up to about 30 m of mainly clayey sediments underlies the extensive Cedarville Flats, and the Kinira Flats to the west of Matatiele.

Figure 5. Dolerite dyke and sill distribution

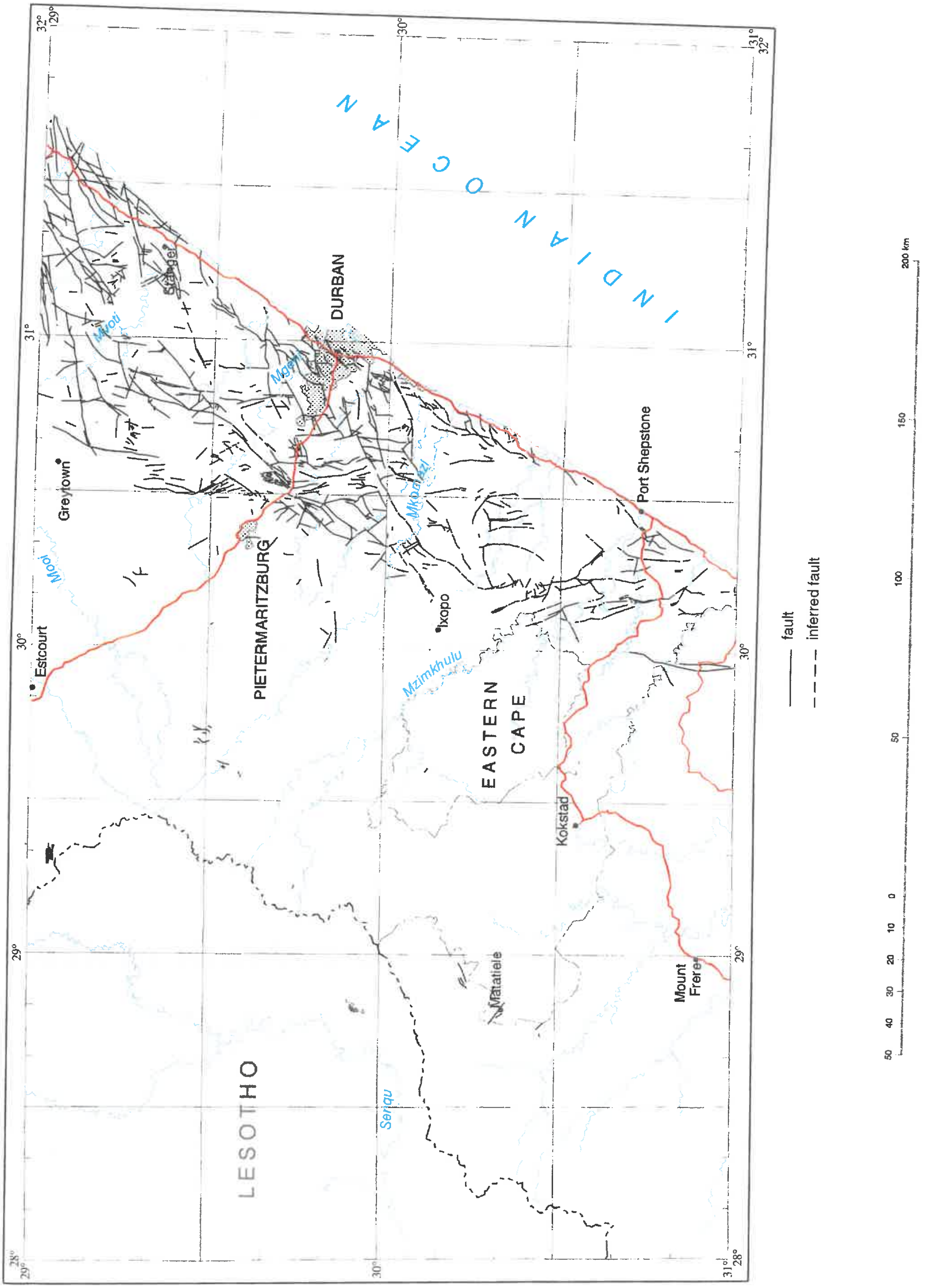


3.6 Structural geology and tectonics

The coastal and coastal hinterland portions of KwaZulu-Natal are part of the rifted margin of the continent. These areas are intensely faulted, the structure being one of fault-tilted blocks with some associated horst and graben structures. Most of the blocks are tilted in a seaward direction at angles of between about 5 and 12°, but on the coast north of the Tugela River and around Port Shepstone the tilted blocks dip in an inland direction. It is evident from the cross-section on the General Hydrogeological Map that the elevation of the Natal Metamorphic Province rocks through the central hinterland represents its natural relative elevation. It has not been downthrown relative to the sedimentary rocks on either side. This can be explained by the action of the rifting breakup of the southern super-continent, Gondwana, which caused extensional or normal faulting. This type of faulting caused the rocks overlying the Natal Metamorphic Province to be lowered from their original level and have their gentle dip reversed and steepened. In the interior, the regional bedding dip is usually to the west at about 2 to 3°, but can be locally disturbed by Karoo dolerite intrusions.

The faults of the coast and coastal hinterland form a conjugate shear fracture pattern, the two main trend directions of which are south-north and southwest-northeast (Maud, 1961). All the faulting in the coastal portion of the region, which is of end-Jurassic age and related to the breakup of Gondwana, is of the extensional or normal type. Vertical displacement on faults is up to about 1 000 m. Minor seismic activity, mainly offshore but also in the southern portion of the Province and the adjoining Eastern Cape, continues presently. There is no evidence of any significant movement on the faults in the coastal portion of the region since the major rift-faulting episode of the end-Jurassic. In the central western portion of the Province, however, it is probable that within the last half million years, neotectonic activity in the form of minor localised faulting and warping is responsible for the development of the alluvium-infilled Cedarville Flats between Kokstad and Matatiele and the Kinira Flats farther west. Another probable limited area of neotectonic activity is located in the upper reaches of the Mkomazi River where apparently young fault movements have taken place. Figure 6 illustrates the main tectonic fault features of the map sheet.

Figure 6. Geological fault distribution



4 Hydrogeology

4.1 Introduction

Groundwater occurrence is represented on the General Hydrogeological Map by the various colours overlaying the lithological hatching. These colours represent both the nature of the aquifer and the expected yield ranges of successful boreholes. The nature of the different aquifers is mostly a result of their lithology, structural history and climatic location. The lithological groupings as discussed in the previous section have been re-grouped into intergranular, fractured, karstic or intergranular and fractured aquifer types according to their hydrogeological nature (Table 3).

Table 3. Summary of aquifer types for the Durban Hydrogeological Map

INTERGRANULAR	FRACTURED	KARSTIC	INTERGRANULAR AND FRACTURED
	Natal Group		Drakensberg Group
Maputaland Group	Msikaba Formation	Natal Metamorphic Province	Karoo dolerite
	Dwyka Group		Karoo Supergroup sedimentary rocks
			Natal Metamorphic Province

Each aquifer type and its occurrence of groundwater is briefly discussed in the following sections. The yield histograms presented were constructed using only records with values. Due to it being impossible to distinguish between dry boreholes or boreholes with no data on the database, these have not been included. The exclusion of these boreholes does affect the overall appearance of the graphs, often giving the impression that a particular aquifer does not have low yields, when in fact, it may have a greater number of dry boreholes than any other yield category. In order to present a more realistic figure, the approximate success rate is also given. Success, for this purpose, is defined as a borehole that is not dry. A trilinear plot for each aquifer type is presented to show the average chemical composition of the groundwater.

4.2 Intergranular aquifers

4.2.1 Maputaland Group (T-Qm)

The only intergranular aquifer depicted on the map sheet is found immediately south of Durban harbour. This is a small area that comprises predominantly sands but also some estuarine clay and silty material. Due to average hydraulic conductivities of 5 m/day and storativity values of approximately 0.18, borehole yields in excess of 50 *l*/s have been reported. Groundwater levels are shallow, usually between 2 and 7 m below ground level or even artesian, depending on topography. Figure 7 shows the distribution of yield frequencies to be fairly uniform, with few < 0.1 *l*/s boreholes. This is because boreholes drilled into these primary formations are almost always successful.

Groundwater quality in this aquifer is influenced by the sedimentary depositional environment, proximity to the coast and industrial activities. These factors have given rise to electrical conductivities that are more elevated than surrounding aquifers, i.e. averaging 100 mS/m. The chemical characteristic of the groundwater is a sodium-chloride type which verifies its saline nature (Figure 8).

The Berea-type red sands that are common around the Durban area are not regarded as true aquifers. Groundwater is usually only present at the base of the red sands, at the interface with the underlying bedrock. This being due to its high permeability that allows a rapid lateral drainage of infiltrating water.

4.2.2 Alluvium (Q)

Numerous wide riverbeds contain large amounts of sand which constitute reliable intergranular aquifers. These aquifers have not been depicted on the map due to their limited size, which could not be reflected on a 1:500 000 scale map. The Mvoti and Fafa Rivers are examples of such aquifers. Storativity of these sands is usually in the range of 0.15 to 0.17, with the hydraulic conductivity on average being 120 m/day. Yield ranges are similar to that of the Maputaland Group aquifers, but do not have such a large percentage of > 2 *l*/s boreholes (Figure 7). Groundwater derived from the alluvium does not usually exhibit any dominant type of chemical characteristic but rather takes on the chemical characteristic of its associated surface water.

Figure 7. Yield frequencies of boreholes in intergranular aquifers
(39 and 84 boreholes analysed respectively)

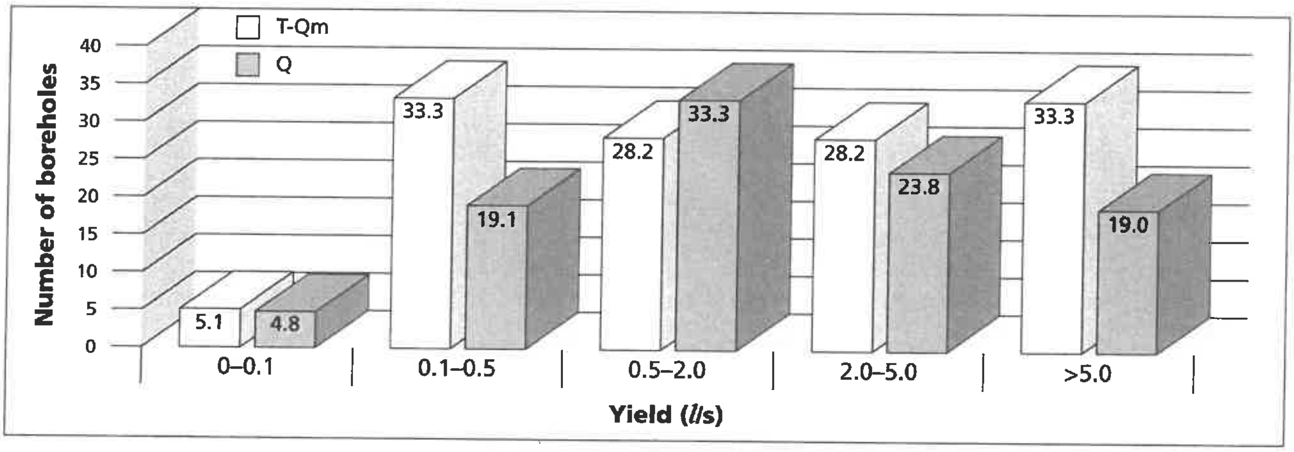
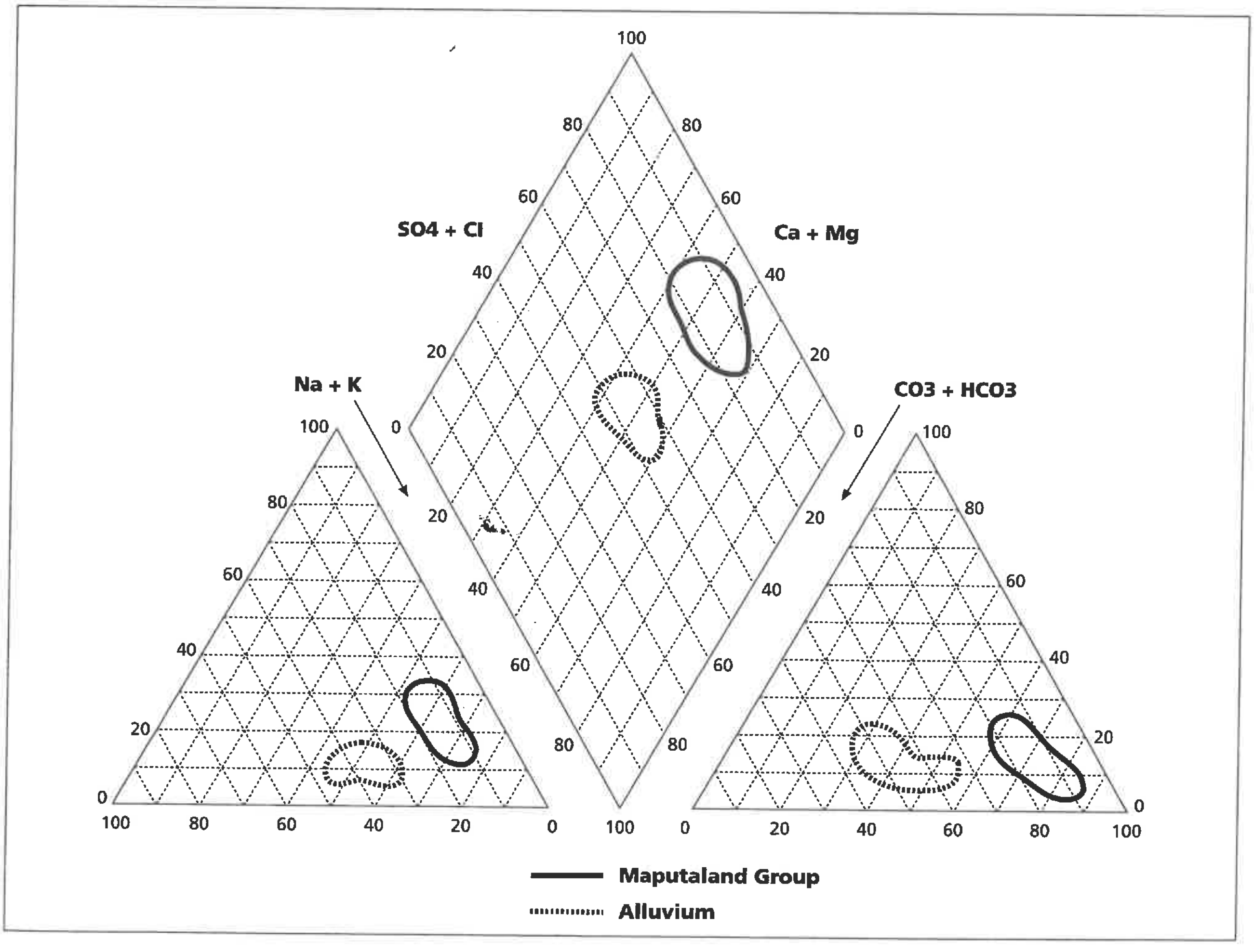


Figure 8. Composite Piper diagram for intergranular aquifers



4.3 Fractured aquifers

Rocks that behave in a brittle manner under tectonic forces and have limited intergranular properties have been grouped as fractured aquifers. Rock fracturing has its greatest expression in the faults along the coastal zone, thereby including the Msikaba Formation, Natal Group and Dwyka Group. Jointing in the rocks is far more common than true fracturing. The above mentioned rocks respond favourably to jointing and fracturing because of their petrography, which due to their competency tend to allow the joints and fractures to remain open. Dolerite intrusions into these rocks are also not very common because of the lack of discontinuities, which would allow for extensive intrusion of sills. A few dolerite sills do occur, but dolerite dykes are more common as feeder structures to intrusions into the argillaceous sediments above.

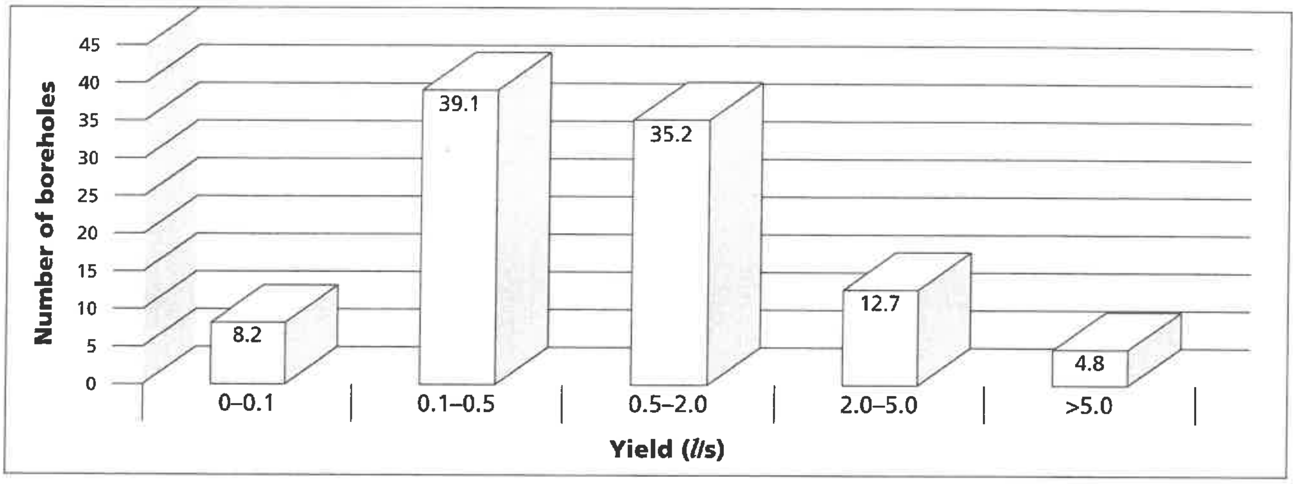
4.3.1 Natal Group and Msikaba Formation (On and Dms)

The Natal Group and Msikaba Formation have a high quartz content which causes them to behave in a brittle manner. These rocks usually have well-developed joints that may be interconnected. Fault zones are very important high yielding areas in these rocks. The faults can be silicified which may decrease the transmissivity of the aquifer and thus restrict its yield. As can be seen in the map area, these sandstones have a higher yield than neighbouring lithologies because of their ability to transmit larger amounts of groundwater. The range of known hydraulic conductivities is from 0.4 – 7.7 m/day and the storativity is estimated to be 0.005. The median borehole yield in the sandstone is 0.5 *l*/s, with yields consistently between 0.1 and 2 *l*/s (Figure 9). A success rate of between 80 and 90% is commonly achieved by scientifically sited boreholes.

The quality of groundwater within these aquifers is usually very good. Figure 11 shows the groundwater to be an alkali chloride to mixed type of groundwater. Elevated electrical conductivity (above 100 mS/m) is not to be expected unless pollution of the aquifer has occurred.

Plate 3. Sandstone with thin shale interbeds of the Natal Group. Up to 2 *l*/s can be obtained in joints and bedding planes and yields in excess of 2 *l*/s can be developed in well-developed fractures and faults in this unit.

Figure 9. Yield frequencies of boreholes in the Natal Group and Msikaba Formation (355 boreholes analysed)



4.3.2 Dwyka Group (C-Pd)

The groundwater yield of the Dwyka Group diamictites are commonly an order of magnitude less than the sandstones of the Msikaba Formation and Natal Group. These low borehole yields are prevalent because of matrix storativity values of less than 0.0001 and low hydraulic conductivity. The massive structureless nature of the rock limits the number of groundwater targets available. Large scale fracturing of the diamictite has provided a few areas where borehole yields of up to 10 *l*/s can be obtained. These types of high borehole yields are, however, rare and the average yield expected of this fractured aquifer is 0.1 *l*/s. Many of the fractures may be kaolinised thereby decreasing the potential yield. A success rate of 30 – 40% confirms this aquifer's poor status. Figure 10 shows there to be < 5 % of boreholes with a yield < 0.1 *l*/s. This can be explained by the exclusion of dry boreholes from the graph.

The quality of groundwater derived from the Dwyka Group is usually good, i.e. suitable for human consumption. The electrical conductivity can range from between 4 to 400 mS/m but averages 90 mS/m. Groundwater along the coastal zone may be more saline, with values commonly reaching 300 mS/m but this decreases inland. There are no other water quality variables that pose any threats to the groundwater quality in these aquifers. Groundwater from the Dwyka Group is characterised as being a sodium, potassium bicarbonate water, however, along the coastal zones the groundwater from this aquifer can be characterised as a calcium, sodium-chloride type water (Figure 11).

Figure 10. Yield frequencies of boreholes in the Dwyka Group (202 boreholes analysed)

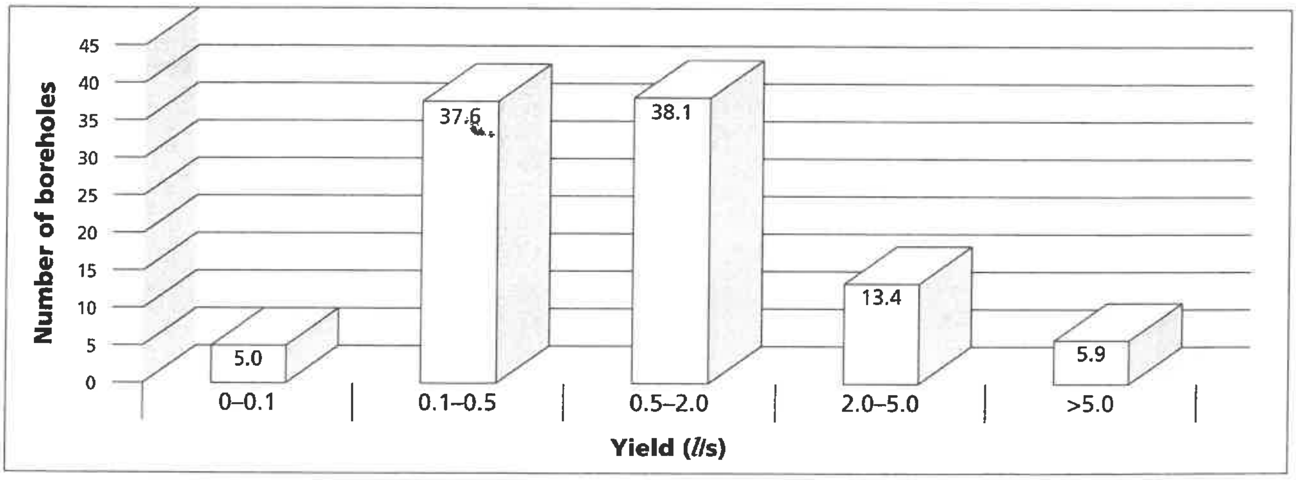
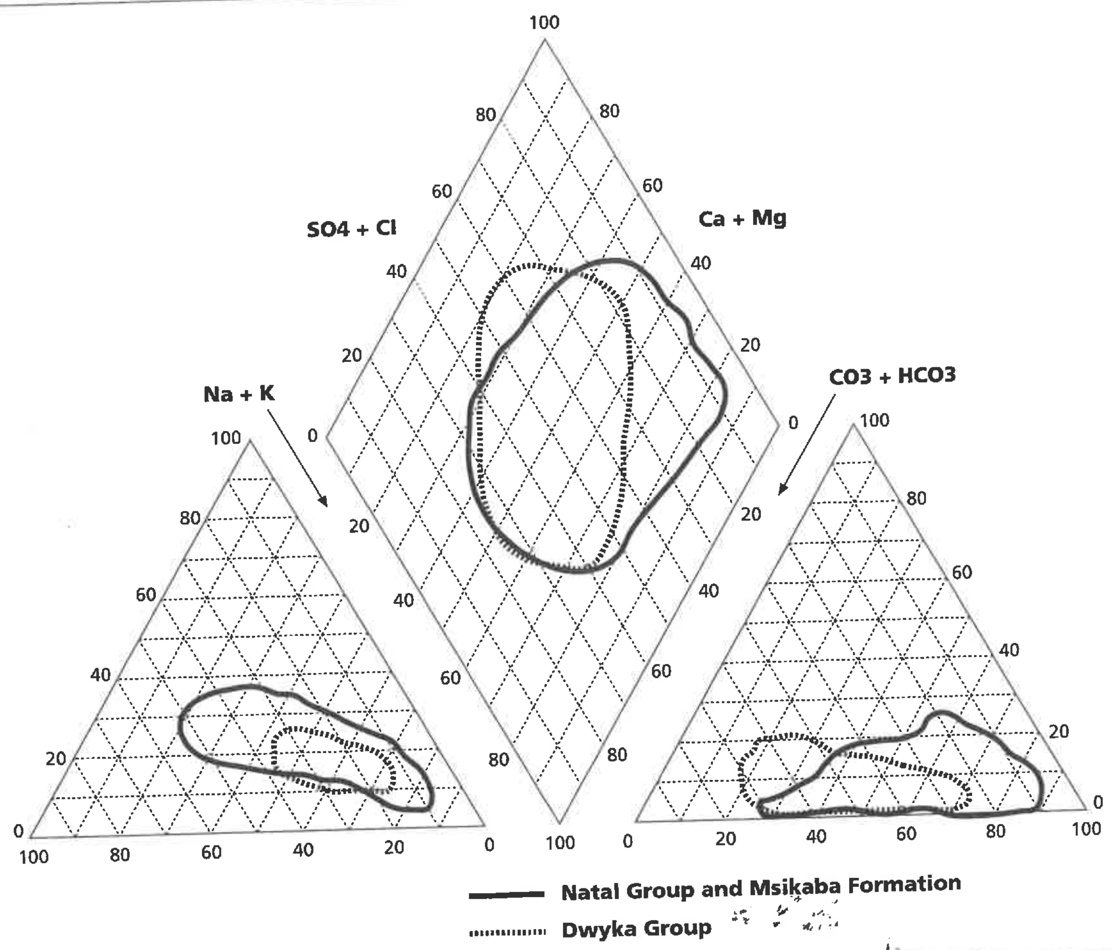


Figure 11. Composite Piper diagram for fractured aquifers



4.4 Karstic aquifers

A marble delta of approximately 20 km^2 is the only karstic aquifer on the map sheet. Only one borehole yield record is available for the aquifer, mainly due to the quarrying activities presently taking place, which have inhibited groundwater development. However, because of the karstitic nature of the rocks forming the delta, borehole yields are expected to be between 0.5 and 2 *l*/s. No groundwater quality information is available for this aquifer type.

4.5 Intergranular and fractured aquifers

4.5.1 Natal Metamorphic Province (Nmp)

The occurrence of groundwater in the predominantly crystalline rocks of the Natal Metamorphic Province is associated with fracturing, near surface weathering processes and dolerite intrusions. It is, however, the fractures that offer the highest borehole yields as these are often well supplied with groundwater from saturated overlying clayey intergranular zones that produced these zones. Weathering of the rocks results in a material that has a high porosity but low hydraulic conductivity due to the clay content derived from the feldspars. The thickness of the weathered zone is usually not more than 25 m. Generally, the weathered, intergranular zone is in hydraulic connectivity with the underlying fractured or solid bedrock. Hence, a borehole drilled below the intergranular zone will draw from the storage above. Analysis of the occurrence of faults shows the Natal Metamorphic Province to have the highest incidence of faults (King, 1997). The susceptibility of these Basement rocks to fracturing is probably because of their brittle nature and greater age, which has exposed it to more tectonic activity, compared to the more ductile argillaceous rocks. Expected borehole yields within the intergranular zones are typically between 0.1 and 0.4 *l*/s, whereas in underlying fractures, borehole yields up to 0.5 *l*/s can be realised. The overall median yield (0.4 *l*/s) in these aquifers is usually less than in surrounding sedimentary rocks. Figure 12 shows a graph of the yield frequencies. The success rate is approximately 70%.

The calcium, magnesium bicarbonate character of the groundwater is typical of recently recharged groundwater (Figure 15). The general quality of the groundwater is normally very good, with only fluoride values of about 2 mg/*l* sometimes found in argillaceous metamorphic rock aquifers.

Figure 12. Yield frequencies of boreholes in the Natal Metamorphic Province (212 boreholes analysed)

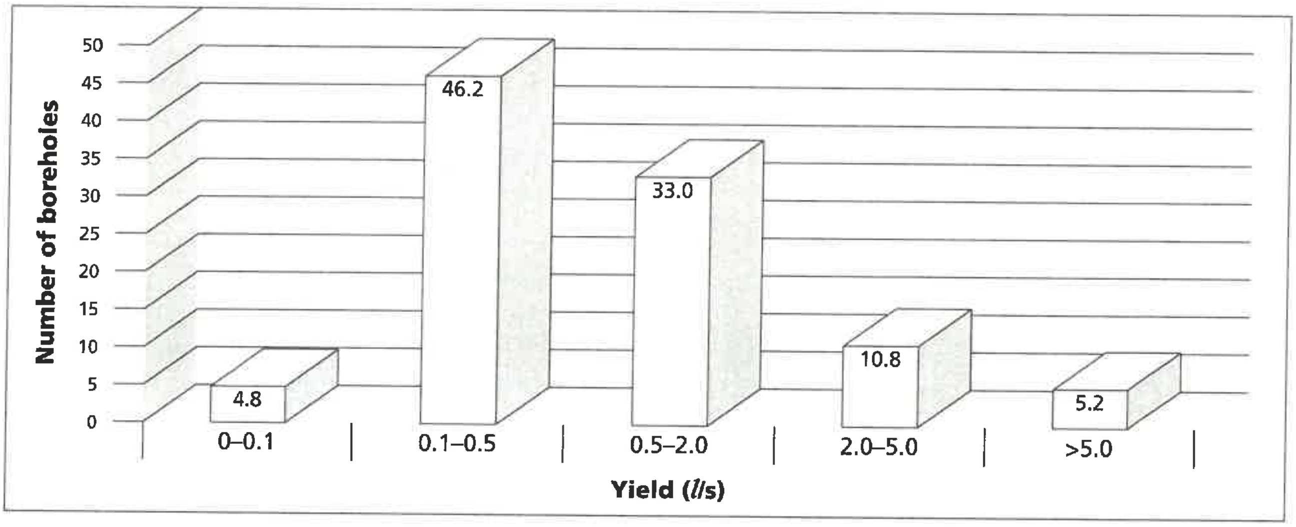


Plate 4. Jointing in decomposed granite of the Natal Metamorphic Province west of Scottburgh. Decomposition is often enhanced along joint freatures. Rock decomposition results in material that often has high porosity but low permeability due to the clay content derived from feldspars.

4.5.2 Karoo Supergroup sedimentary rocks (Trc, Tre, Trm, P-Trb and Pe)

The hydrogeological behaviour of all the argillaceous Karoo Supergroup sedimentary rocks is similar. The hydraulic conductivity can range from 0.05 m/d in solid rocks to 0.5 m/d in fractured rock. Storativity values are estimated to vary from 0.001 for the sandstone lithologies and 0.0001 for mudstone-shale lithologies. Fractures within the rock usually constitute reasonable aquifers, capable of yielding in excess of 0.2 *l*/s (Figure 13). Fractures within the more fine-grained rocks may tend to close once they have been dewatered due to the ductility of the rock. Fractures can also be mineralised with iron pyrite, especially in the Ecca Group. Oxidation of iron pyrite by the groundwater may cause precipitation of iron and produce a sulphur smell as hydrogen sulphide is released. The concentration of iron in the Karoo Supergroup sedimentary rocks can reach 40 mg/*l* but usually does not exceed 0.5 mg/*l*.

Within the Ecca Group (Pe), the arenaceous Vryheid Formation occurs. Yield analysis was carried out separately from the argillaceous rocks in order to determine the difference between them. Figure 13 shows that there is not much difference with respect to yield frequencies, although the median yield in the argillaceous rocks is 0.9 *l*/s and the median yield of the Vryheid Formation is 1.2 l/s. A success rate of between 65 and 80% is common.

An overall classification of these aquifers shows the groundwater to be the bicarbonate, calcium, magnesium type, which indicates that it a young groundwater that has recently been recharged (Figure 15). Electrical conductivity generally tends to be quite variable with local occurrences of values exceeding 300 mS/m, usually in areas of relatively lower rainfall. Fluoride derived from mica can spoil the overall quality of the groundwater, but this occurs sporadically.

Figure 13. Yield frequencies of boreholes in the Karoo Supergroup
(70 and 977 boreholes analysed respectively)

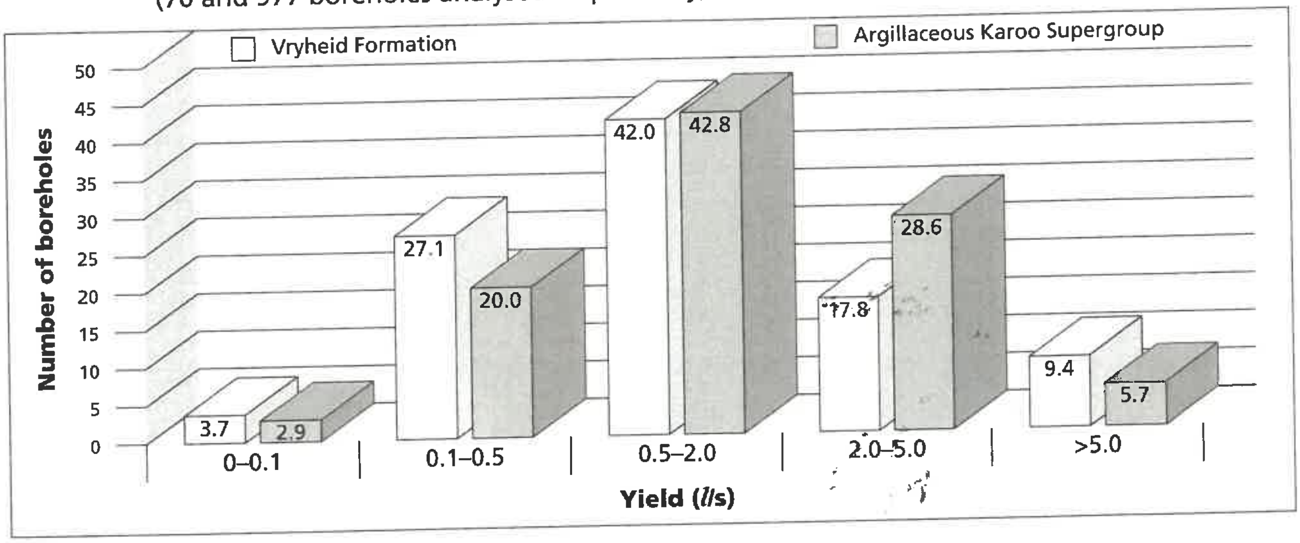


Plate 5. Jointing in shale of the Ecca Group south of Petermaritzburg. Potable groundwater with yields in excess of 0.2 *l*/s and EC-values of less than 70 mS/m can be obtained from these features.

Plate 6. A thick dolerite sill near Ixopo. Decomposed dolerite can be seen in the background and solid dolerite in the foreground. The transitional jointed and partly weathered zone between the decomposed and solid dolerite can be targeted for groundwater development.

4.5.3 Drakensberg Group (Jdr)

The basalt capping the Drakensberg mountain range is very elevated and occurs in areas of extreme relief. This has resulted in a lack of borehole data available for yield and groundwater quality analyses. Only 18 borehole records were available at the time of this analysis. However, it is expected that intrusive dolerite, cooling joints and weathered intergranular zones within the basalt are locations where groundwater would be most likely to occur. Van Wyk (1963) indicated that boreholes drilled in this Group often intersect groundwater at a depth of approximately 20 to 25 m below surface. Springs in these elevated areas are common, especially along the Drakensberg Group / Clarens Formation contact.

4.5.4 Karoo Dolerite (Jd)

A number of different possible aquifers occur in dolerite. The dolerite rock itself not only constitutes an aquifer, but also its contact with the rocks into which it has intruded. The process of dolerite intrusion has resulted in geological features that have the potential to bear water. Intrusion of the dolerite, by means of sills and dykes, causes induration of the contact with its host rock and displacement of rocks around the intrusion, thus increasing the hydraulic conductivity of the zone. The yield associated with contacts with other rocks types varies considerably and is dependent on fracture interconnections. Dolerite contacts with competent rocks such as Natal Group sandstone and granitic basement rock are found to have higher borehole yields than those contacts with argillaceous rocks (King, 1997). Typical borehole yields from successful contact zones can range from 0.2 *l*/s for argillaceous contacts to 1.4 *l*/s for arenaceous or crystalline contacts. Water strikes can occur either at the top contact or bottom contact of dolerite sills. There is no fixed rule as to which is the better target.

Apart from contacts of dolerite with its host rock, the dolerite body may be weathered and also fractured. In the humid conditions of KwaZulu-Natal, weathering of dolerite intrusions to corestones and eventually, deep red clay is common. This fine-grained intergranular material acts as a type of "sponge" in storing groundwater and transmitting it vertically to zones of higher hydraulic conductivity, such as contacts or underlying fractures. Fractures in fresh dolerite tend to be well defined due to the brittle nature of the rock. This often ensures that the fractures will commonly yield in excess of 0.5 *l*/s. The median yield of dolerite associated aquifers is 1 *l*/s, which is supported by the yield frequency plot in Figure 14. It must be highlighted that the close relationship of the intergranular zone of dolerite with underlying fractures may increase the potential yield of the aquifer. There is a 70 – 80% chance that boreholes drilled into dolerite will yield groundwater.

The Piper diagram shows groundwater from dolerite aquifers to be of the recently recharged bicarbonate, calcium, magnesium type (Figure 15). EC of the groundwater may be greater than 90 mS/m. Elevated concentrations of sodium, chloride, magnesium and calcium may be found in areas of lower rainfall.

Figure 14. Yield frequencies of boreholes in Karoo dolerite (335 boreholes analysed)

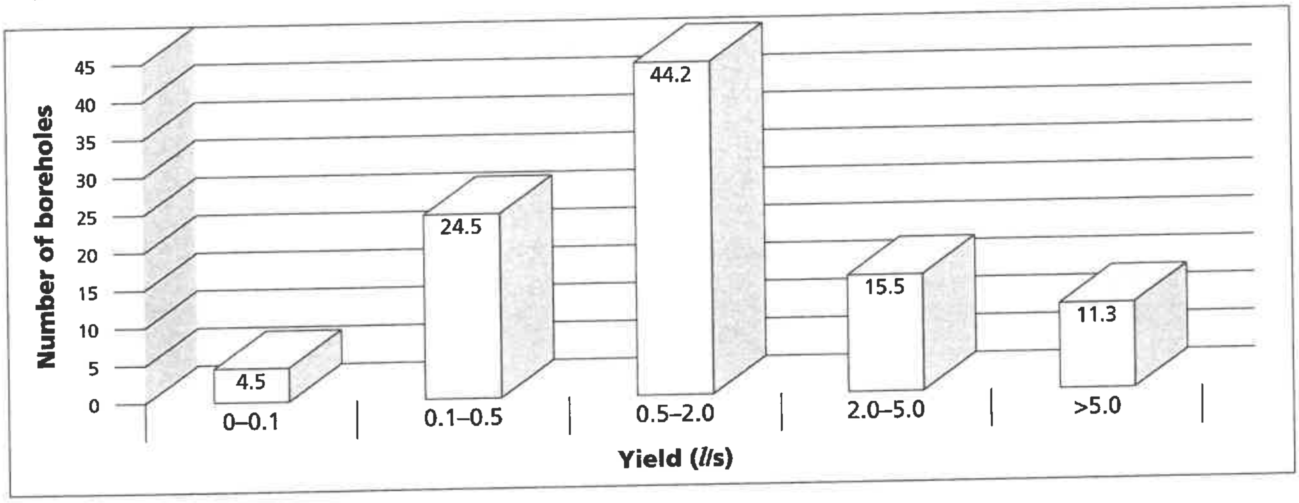
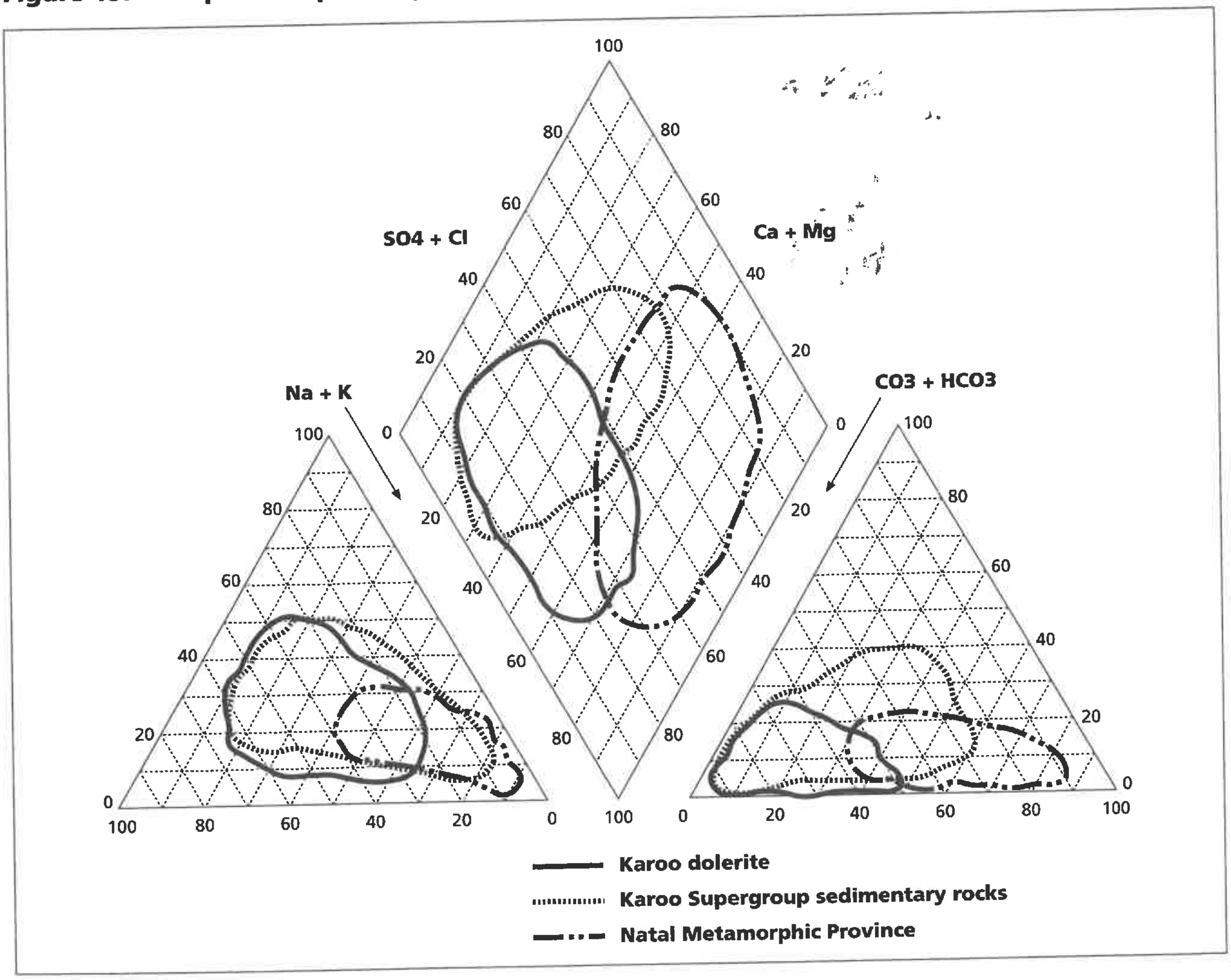


Figure 15. Composite Piper diagram for intergranular and fractured aquifers



4.6 Regional groundwater levels

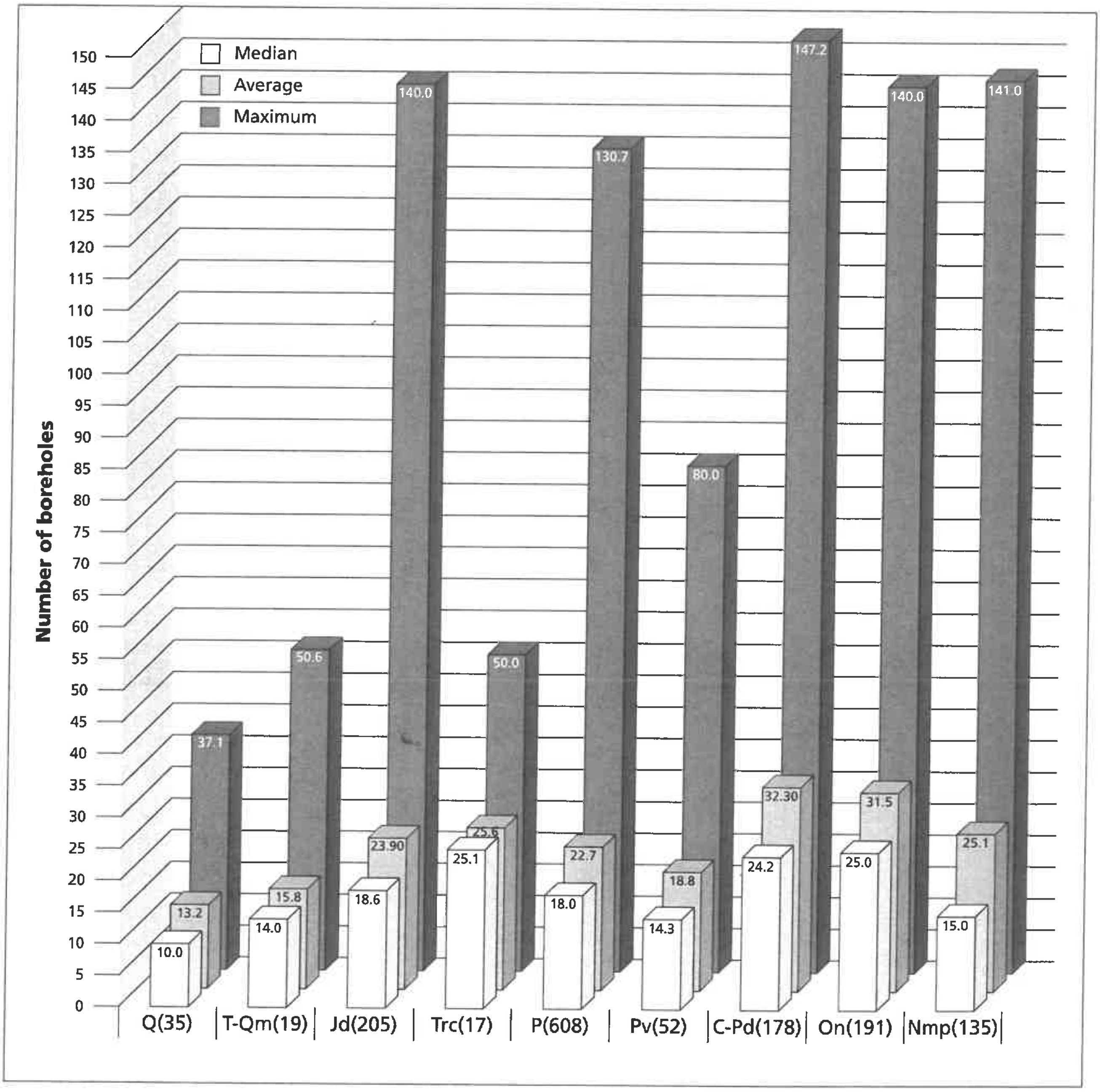
The depth of the groundwater table below ground level in the area covered by the map is variable and strongly influenced by local topographic conditions. In steep terrain the groundwater level depth is extremely localised and variable, but in flatter terrain, as in the interior river basins, more clearly defined groundwater tables exist. As such, a contour plot of depth to the groundwater table cannot be produced for the area. In many boreholes, groundwater struck at depth (e.g. 45 m) rises piezometrically to a shallower rest level (e.g. 20 m) in the borehole.

Static groundwater levels in boreholes have only been recorded for 30% of the available records. Groundwater levels in boreholes are generally in the range 12 to 25 m, averaging 18 m, below ground level. There is not much variation in the average groundwater level between the various hydrogeological units (Figure 16). The exceptions are the primary sediments (Q and T-Qm) which are unconfined aquifers with shallow groundwater tables.

In the case of springs and seepages, the groundwater level, even if temporary on a seasonal basis intercepts the ground surface. In the interior of the region, the slopes immediately below the bases of major Karoo dolerite sheets in the regional Karoo Supergroup sedimentary rocks are usually characterised by spring lines.

Artesian flow of groundwater from boreholes in the region is uncommon. Artesian flow from boreholes, where it occurs, is usually associated with Natal Group sandstone or the breccia zones of faults in the coastal zone.

Figure 16. Graph showing statistics on depth to the groundwater table per lithological grouping (The figures in brackets are the number of records used in the analysis)



4.7 Regional groundwater quality

4.7.1 General trends

The sulphate anion is not present to any significant extent in any of the groundwater in the region. The dominance of the bicarbonate anion in almost all of the groundwater suggests that the prevailing hydrogeological regime represent a dynamic system with a rapid turn over or short residence time.

The pH value of groundwater in the various hydrogeological groups varies in the range 6,7 to 8,8 but most groundwater have pH values in the range 7,3 to 8,1.

Nitrate (NO_3) levels in groundwater are usually of the order of 0,1 mg/*l* or less, but levels as high as 25 mg/*l*, as a result of pollution from domestic or agricultural sources, have been found to occur very locally. Fluoride (F) levels in groundwater are also usually less than 0,1 mg/*l*, but they can be as high as 4 mg/*l* very occasionally. High fluoride is usually related to granitic type rocks in the Natal Metamorphic Province or in shale of the Karoo Supergroup.

4.7.2 Pollution sources

Potential pollution sources of groundwater in urban areas include industrial facilities such as oil refineries, chemical works, etc., and solid waste disposal sites of various types such as ash dumps, and industrial and urban landfills. Many of these sites are monitored by DWAF.

The potential for pollution in the rural areas can not be dismissed. Here, because of faulty or unsatisfactory borehole head-works construction, bacteriological (faecal) pollution of the groundwater occurs frequently as a result of contaminated surface water gaining entrance to the borehole, and the local groundwater. Similar contamination can also occur from any nearby pit latrine and stock enclosures. Locally, fertilisers used for agricultural production may cause some limited groundwater pollution, especially in respect to nitrate.

4.7.3 Aquifer vulnerability to pollution

Primary, unconfined aquifers are the most vulnerable to pollution. These types of aquifers usually have a shallow groundwater table, within 2 – 10 m of the ground surface. The relatively high permeability of these sediments and the shallowness of the groundwater gives rise to short travel times of contaminants to the aquifer body. Examples of areas where these types of sensitive aquifers occur are the alluvial and estuarine sediments south of Durban harbour and riverbed alluvium.

Secondary aquifers are more complex to describe in terms of their vulnerability to pollution. The potential pathways from the ground surface to the aquifer itself are not always clearly defined or recognisable. A description of the most likely route contaminants may take is the best method of hypothesising over aquifer vulnerability in fractured and/or intergranular rocks.

The unsaturated or vadose zone overlying secondary, confined or semi-confined, aquifers provides the protection of the underlying aquifer against pollution. The nature of this protection layer is very important when determining vulnerability. The permeability or hydraulic conductivity is influenced by the characteristics of the geological formation, i.e. clay content of unconsolidated material, jointing pattern and fracture frequency in rocks, infilling of fractures and joints. Contaminants will take the same travel path to an aquifer, as would normal recharge water. It is thus vital that potentially polluting activities do not take place in areas of known groundwater recharge.

The situation for the majority of the secondary aquifers portrayed in the map area is that all the aquifers have the potential to become polluted. Only, a site-specific hydrogeological investigation to determine preferential pathways from the surface to the aquifer will establish how vulnerable to pollution each aquifer is. The occurrence of less vulnerable rocks is usually due to their massive or structureless character. An example of a rock type that has a relatively lower vulnerability to pollution is the Dwyka Group diamictite. The exception is when the Dwyka Group diamictite is fractured. These fractures are then the only pathway for contaminants to move down below the surface. Fractures such as these often have an even greater hydraulic conductivity than primary sediments.

All the factors mentioned above must be taken into consideration when determining aquifer vulnerability. An understanding of the geological nature of the rocks and unconsolidated sediments, recharge, groundwater flow and hydrochemistry will provide information on the vulnerability of aquifers on a local scale.

5 Springs

5.1 Common springs

Springs have a widespread occurrence throughout the map area, and especially in areas with higher rainfall. The average yield of springs is 0,05 *l*/s, with a maximum yield being about 2 *l*/s. A vast number of springs are utilised as a source of domestic and stock watering supply in the southern rural areas (Figure 17). It must be noted that the springs represented in Figure 17 do not represent all the springs on the map sheet, but they are only those that have been surveyed. The most favourable locations for springs has been found to be at the base of high-standing thick Karoo dolerite sills intruded into the Karoo Supergroup sedimentary rocks in the interior, and the lower portions of slopes underlain by sandstone of the Natal Group in the coastal zone. Springs can also occur in lower slope and valley bottoms at differing rock type contacts, faults, joints, etc.

Kokstad is partially dependent on spring water for its urban water supply, and Mt Ayliff, is entirely dependent on spring water. In the case of Kokstad, a town of 50 000 inhabitants, the 'Crystal Springs', issuing from the contact of an inclined Karoo dolerite sill in the regional Karoo Supergroup shale, mudstone and sandstone, yields of at least 25 *l*/s.

The yield of springs, especially those of low yield, fluctuates seasonally, some of them drying up completely during the winter months. In recent years, a programme of spring protection has been implemented in a number of rural areas. Spring protection involves effectively covering and sealing the spring source and piping the groundwater under gravity to a storage tank down slope from where the water is tapped as required.

Seepages with yields of the order of 0,005 *l*/s are also of widespread occurrence throughout the area. They are widely used in the rural areas as a source of domestic water supply. These seepage flows are very markedly seasonal and frequently dry up completely in the winter months, especially in years of below-average rainfall. Seepages are frequently shallow phenomena associated with perched water table conditions, the groundwater being perched within the base of sandy permeable topsoil overlying relatively impermeable clayey subsoil or weathered rock. Seepages are usually exploited by means of small pits in which the groundwater accumulates and from which it is drawn as required.

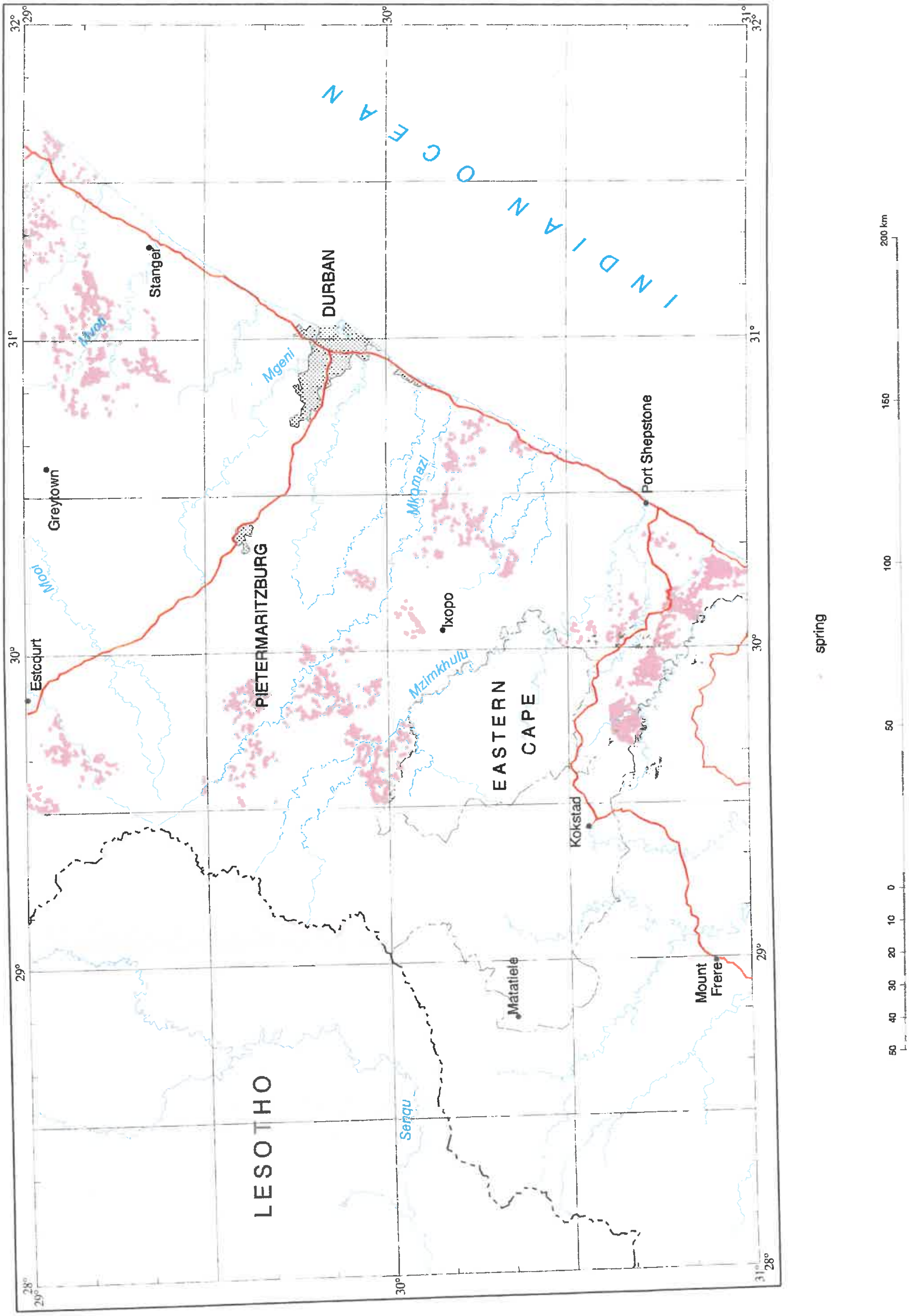
5.2 Thermal springs

Two thermal springs that have a year round temperature in excess of 25°C exist in the area covered by the map sheet. These are at Lilani , 25 km east of Greytown, where six springs on fractures in the Natal Metamorphic Province rocks have a combined yield of 3,4 *l*/s, and a temperature of 41.1°C; and at Kinira Drift, southwest of Matatiele, with a yield of about 1 *l*/s and a temperature of 29.3°C (Kent, 1969). The chemical composition of the groundwater of the latter thermal spring is significantly different to that of the normal groundwater in the adjoining area due to its lower salinity.

5.3 Other spring types

Of interest is the Bongwan Gas Fault in the south of the map which discharges carbon dioxide at intervals along its length. At Bongwana, 15 km southeast of Harding, the gas was formerly exploited on a commercial basis. The gas discharges, mainly in Dwyka Group diamictite, are associated with springs of highly saline groundwater of normal temperature. Saline springs are associated with the fault farther south in the valley of the Mtamvuna River, (Gevers, 1941). Similar saline springs occur on the banks of the Mzimkulu River 7km southwest of Creighton, but these do not appear to be associated with a fault.

Figure 17. Distribution of mapped springs



6 Groundwater development

6.1 Existing utilisation

Many of the rural areas covered by the map sheet are dependent on groundwater for domestic and stockwatering purposes. These rural communities abstract groundwater by means of handpumps and springs. The majority of boreholes occurring in the area are equipped with handpumps and have been drilled by government departments and non-governmental organisations.

Many formal rural farms are also dependent upon groundwater boreholes for domestic and stock watering supply, but these tend to be motorised boreholes. From existing records, it is estimated that less than 30% of all boreholes are equipped with motorised pumping units, the rest are equipped with handpumps or windpumps.

The use of groundwater in the region is constrained by the generally low yield of boreholes drilled into secondary 'hard rock' aquifers, which underlie almost all of the area. Nevertheless, groundwater from boreholes is used as the sole source of water supply to some of the smaller urban communities such as Blythedale Beach and Zinkwazi Beach, and to augment surface supplies in the case of some larger towns such as Gingindhlovu, Greytown, Richmond and Harding. For the same reason of low yields, groundwater is not used to any great extent for irrigation purposes in agriculture, although in the Richmond area a number of high-yielding boreholes are used for irrigated horticultural production.

In the major urban areas, a few industries exploit groundwater by means of boreholes. This practice is particularly prevalent in the Pinetown area, underlain by the favourable secondary aquifer of the Natal Group sandstone. In a number of other locations, industries exploit the groundwater contained in the deep primary sandy alluvial aquifers in the upper estuarine portions of major rivers. Examples of this are an oil refinery at Wentworth in Durban, and a paper mill on the Mvoti River near Stanger, where relatively large supplies of groundwater are obtained from a number of screened wells in the sandy alluvium

It is estimated that total groundwater usage in the region covered by the map area is currently some 120 million m^3/a. (For comparison, the capacity of the Midmar dam on the Mgeni River is 178 million m^3). Within the area covered by the Durban map sheet, current groundwater usage as a percentage of annual recharge varies from an estimated 1% in the north to about 9% in the south, exclusive of the former-Transkei portion of the Eastern Cape Province. Thus, nowhere does the current groundwater abstraction rate approach that of the annual recharge and considerable scope therefore exists for further utilisation of the groundwater resources without detriment to the prevailing natural conditions, provided the resource is judiciously managed.

6.2 Development potential

The groundwater development potential of the region covered by the map sheet is considerable. The overall groundwater resource potential is about 37 $000m^3/km^2/a$. Regional variations of between 15 000m3/km2/a in the south to about 50 $000m^3/km^2/a$ in the coastal and northern areas of the map sheet do occur (Seymour and Seward, 1996). Locally, the potential may be much lower.

Seymour and Seward (1996) have introduced the concept of a harvest potential. This term can be defined as the maximum annual volume of water, which is available for abstraction on a long term basis without exhausting the resource. To calculate the harvest potential, the recharge and groundwater storage were determined on a national scale. These two factors were further used to ascertain whether storage or recharge was the limiting factor for the purposes of calculating the harvest potential.

Where recharge is a limiting factor, the size of the aquifer exceeds the annual recharge volume. This phenomenon typically controls the development potential of coastal and alluvial aquifers.

Areas where recharge is not consistent and where recharge has a marked impact on the development potential of aquifers are prone to drought. Where there is limited aquifer storage together with variable recharge, the harvest potential is limited by the storage capacity to bridge droughts. This condition is commonly found in the lower rainfall areas (< 500mm/a) which are underlain by argillaceous Ecca and Beaufort Group rocks.

The third limiting factor, according to Seymour (1997), is the available volume of effective storage. This means that even though there is enough recharge, the aquifer storage is not large enough to take in all the recharge water. The majority of the aquifers on the map sheet fall into this category. This is evident, in KwaZulu-Natal, by the occurrence of many perennial streams, which are the recipient of surface run-off water that cannot be contained in aquifer storage. Another additional constraint on the utilisation of groundwater is the low transmissivity of many of the aquifers. Both transmissivity and lack of aquifer storage are the most frequent limiting factors in developing the groundwater resource.

Other aspects to be considered in determining the development potential of groundwater are:

- Access for drilling equipment – many promising borehole locations are not accessible by regular drilling rigs. Much of the inland areas of the southern portion of the map area have extremely high relief, which restricts the number of drilling sites available. Recent drilling programmes have, however, been improved by the use of earth moving equipment to push access roads to areas that normally could not be accessed.

- Water quality – can affect the suitability of the groundwater for use. Hydrochemical analysis should be carried out on all groundwater to establish whether concentrations of the various elements comply with SA Water Quality Guidelines (1993) for the intended use.

6.3 Borehole siting

Borehole siting is primarily concerned with the location of geological discontinuities, as higher borehole yields are generally associated with such features. Apart from direct geological observation, which is the most satisfactory method of borehole location where it can be practised, potential groundwater-bearing discontinuities can be located either by remote sensing methods or surface geophysical methods. In the case of the remote sensing methods, air photo interpretation has been used with considerable success, with satellite imagery not having been used to any significant extent as yet on account of its large perspective.

Geophysical methods are techniques that measure the physical properties of the earth's materials, such as density, electrical conductivity, magnetic susceptibility, electrical potential. Table 4 below shows the recommended geophysical methods to use for the different rock types found in the map area.

Table 4. Recommended geophysical methods to use in different rock types

HYDROLITHOLOGY	RECOMMENDED GEOPHYSICAL METHOD
Karoo argillaceous rock	EM, magnetics
Karoo arenaceous rock	EM, magnetics
Ecca Group shale	Resistivity, EM
Vryheid Formation sandstone	EM, magnetics
Natal Metamorphic Province	Resistivity profiling, magnetics
Dwyka Group diamictite	VLF, resistivity, FDM
Karoo dolerite	Magnetics, EM
Natal Group sandstone	Resistivity, EM
Drakensberg Group basalt	EM, magnetics

VLF = very low frequency electromagnetics
FDM = frequency domain electromagnetics (MAX-MIN)

6.4 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.

6.5 Groundwater management

Groundwater is "mined" or over-exploited when the amount of groundwater being abstracted exceeds recharge to the aquifer. This means that the groundwater level in boreholes will be drastically lowered, pump suction will occur and eventually the borehole will dry up, and even collapse. For proper management of an aquifer, it is necessary to determine the storage capacity of the aquifer, in addition to estimating recharge, as well as any other inputs, e.g. effluent disposal, artificial recharge, baseflow, and outputs, e.g. springs flows, evapotranspiration, baseflow and other abstraction boreholes. The National Water Act (Act 36 of 1998) has initiated the concept of a reserve. The Act states that the human and ecological reserve for all catchments must be determined before allocations on the remaining portion of water, including groundwater, can be made. This concept will ensure that there is enough water for basic human needs and the needs of the environment. The task of reserve determination is the responsibility of DWAF and must be seen as a tool through which the national groundwater resource can be equably managed.

On a different scale, it is up to the individual user of groundwater to ensure that over-abstraction does not occur in local boreholes. The user must adhere to initial recommendations made by the hydrogeologist and the following records on boreholes must be kept:

- water level measurements (weekly/monthly);
- recording of daily rainfall (if possible) and
- volume of water pumped (daily/weekly).

The above information can be used for long term management of the resource and for adjusting pumping rates to sustainable levels. This may include reducing the rate if a continuous declining trend in water levels is detected, or even increasing abstraction rates if trends indicate the impact is limited.

It is important to note that the evaluation of sustainable yield and groundwater management options is a specialised task requiring the expertise of a professional hydrogeologist.

Apart from managing groundwater in terms of its quantity, it is very important to manage and protect its quality. Septic tanks, landfill sites, cemeteries, application of fertilisers, accidental chemical and hydrocarbon spills are all artificial sources of potential groundwater contamination. Contamination of an aquifer can also be caused if poorer quality groundwater is drawn into a borehole during pumping. This can be the case when coastal aquifers are overpumped, thus causing the landward migration of the freshwater and salt-water interface. This is called salt-water intrusion.

Another issue, receiving attention in South Africa, is the effect of afforestation on groundwater. There have been reports of newly forested areas causing shallow springs, wetlands and even deeper boreholes to dry up. This is a conflict situation that needs careful consideration before permits for afforestation are granted. DWAF's Water Conservation campaign concentrating on the removal of alien vegetation is an example of successfully addressing the impacts on water resources.

The Water Act outlines the government's responsibility for monitoring of water resources. Monitoring is a management tool that aims to obtain quantitative information on changes in groundwater storage and changes in the physical, chemical and biological characteristics of the groundwater. A groundwater monitoring network, of dedicated boreholes throughout the province of KwaZulu-Natal, will be implemented by the end of 2000. These boreholes shall be used to monitor the ambient or background groundwater quality and levels for the various hydrogeological regions.

7 Recommendations for further studies

i. The long term monitoring of groundwater level behaviour and quality in representative or significant locations to establish recharge estimates,

ii. The investigation of the effect of intensive afforestation, especially by Eucalyptus, on the groundwater regime,

iii. The effects on groundwater quality underlying areas of intensive urban or peri-urban informal settlement,

iv. Exploratory hydrogeological and stratigraphic borehole drilling, including very deep boreholes (300m), in specific target sites suggested by regional structural analysis, particularly extensional features, or other lithologic indications such as Karoo dolerite contact zones, faults and joints, and inland areas of deep alluvium such as Cedarville Flats,

v. The investigation of the role of fracture density and orientation on groundwater occurrence and borehole yields,

vi. The investigation of Karoo dolerite intrusions as targets for the siting of boreholes, and

vii. The investigation of the groundwater production potential of springs and their usefulness as sources of rural domestic water supply.

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