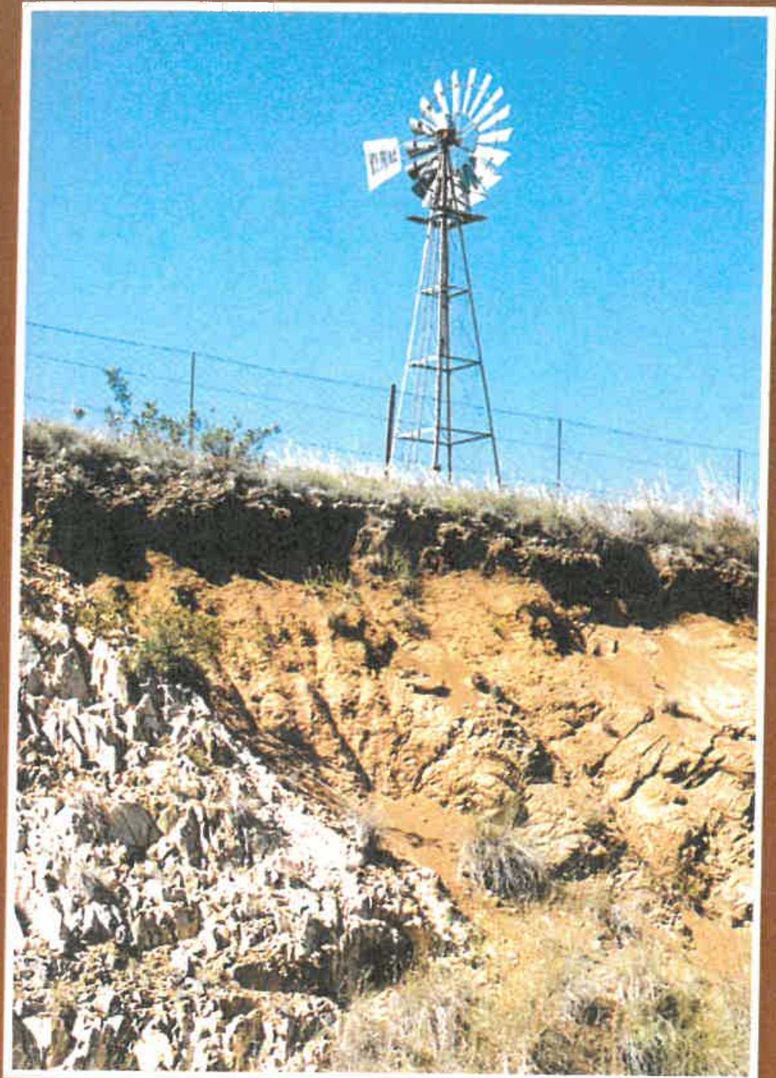
An Explanation of the 1:500 000 General Hydrogeological Map

Queenstown 3126



By: M.C. SMART

October 1998

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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.

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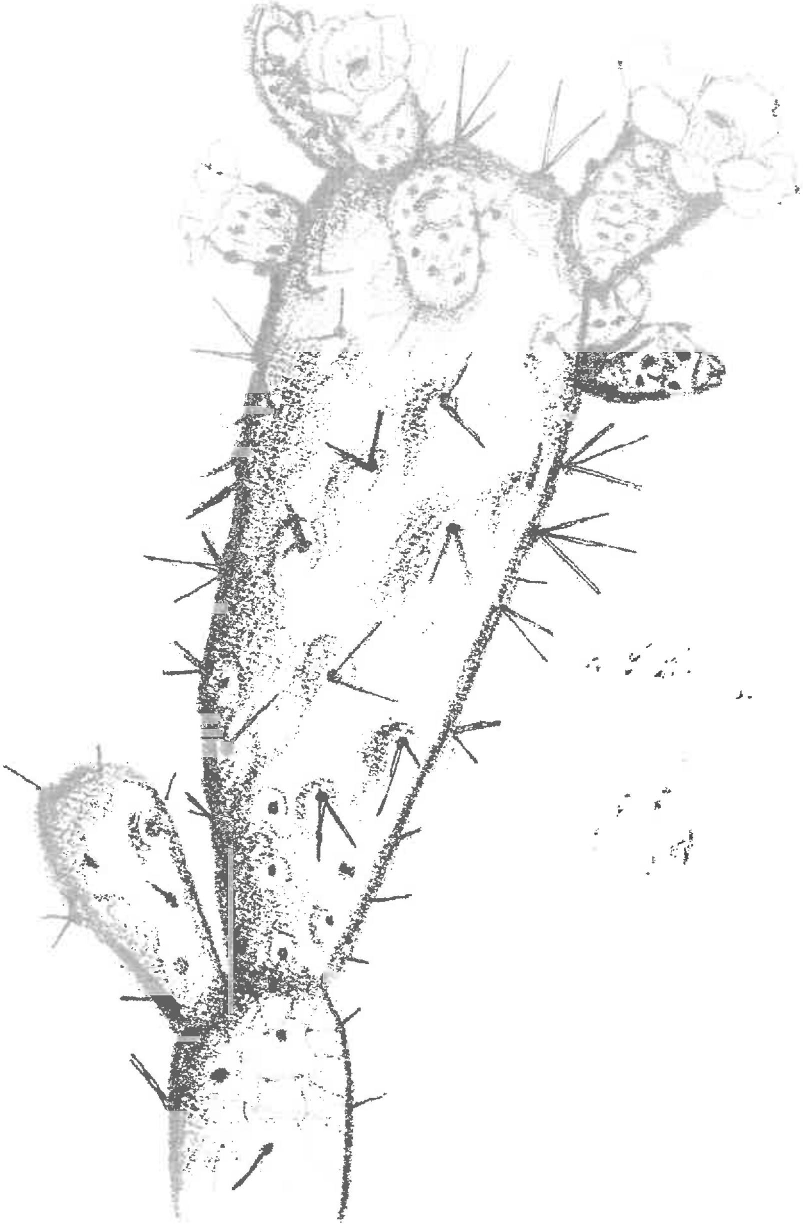


PREFACE

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 second option to more expensive and in places less reliable surface water schemes. In order to address the problem of the 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 Queenstown map accompanying this brochure is one of twenty three similar such maps to be produced.

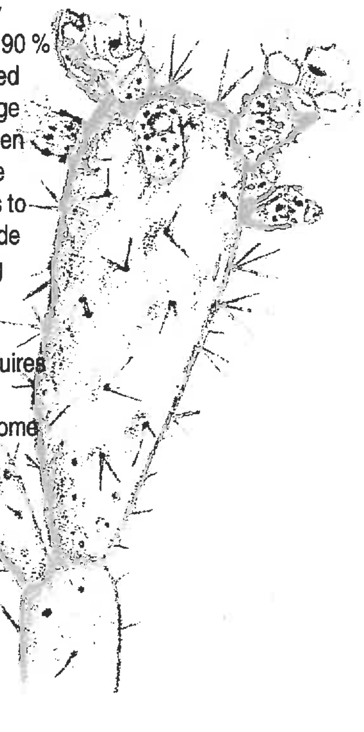
The mapping exercise is intended to bring together all the information concerning the resource for analysis - thereby determining any regional scale variations in the groundwater characteristics. The findings are displayed on the map while more detailed information not readily portrayed on the map is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

The main theme displayed on the General Hydrogeological Maps is the groundwater occurrence and flow regime. For example, intergranular aquifers (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 Map 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 fractured bedrock. This weathered zone can provide significant groundwater storage which can be transmitted to the underlying bedrock.

The South African approach to distinguishing groundwater occurrence requires the identification and comparison of "hydrogeological units". These being defined as "reasonably homogeneous groundwater units which possess some



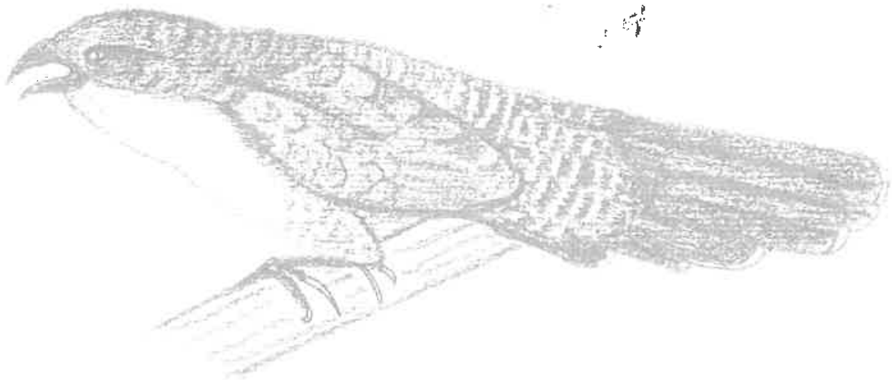
degree of internal lithologic homogeneity and similarities in rock properties that impact on groundwater conditions and on groundwater quality" and is "described in terms of lithology, stratigraphy and a combination of mode of occurrence and typical yields of boreholes" (DWAF, 1994).

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

- Fractured
- Fractured and Intergranular
- Intergranular
- Karst

A maximum of five productivity ranges could be accommodated - this is the maximum number of distinguishable shades of color. The ranges accommodate yields for the country as a whole - based on an analysis of the yield frequency distribution of all 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 sustainable 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.



Editorial Board

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

Surita Hauptfleisch and Heléne Mullin

Cartography on the General Hydrogeological Map

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Encoding of borehole data obtained in the field and from hydrogeological reports.

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GIS support including compilation of data into Arc/Info format for analysis, creation of coverages required for data analysis for the main hydrogeological map, executing the calculations and compiling the drought maps required for determination of the groundwater potential and provided help with cartographic aspects of map compilation.

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Encoding of borehole data obtained in the field and from hydrogeological reports.

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Encoding of borehole data obtained in the field and from hydrogeological reports and digitizing of geological maps.

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Advice on the brochure content and editing of the drafts.

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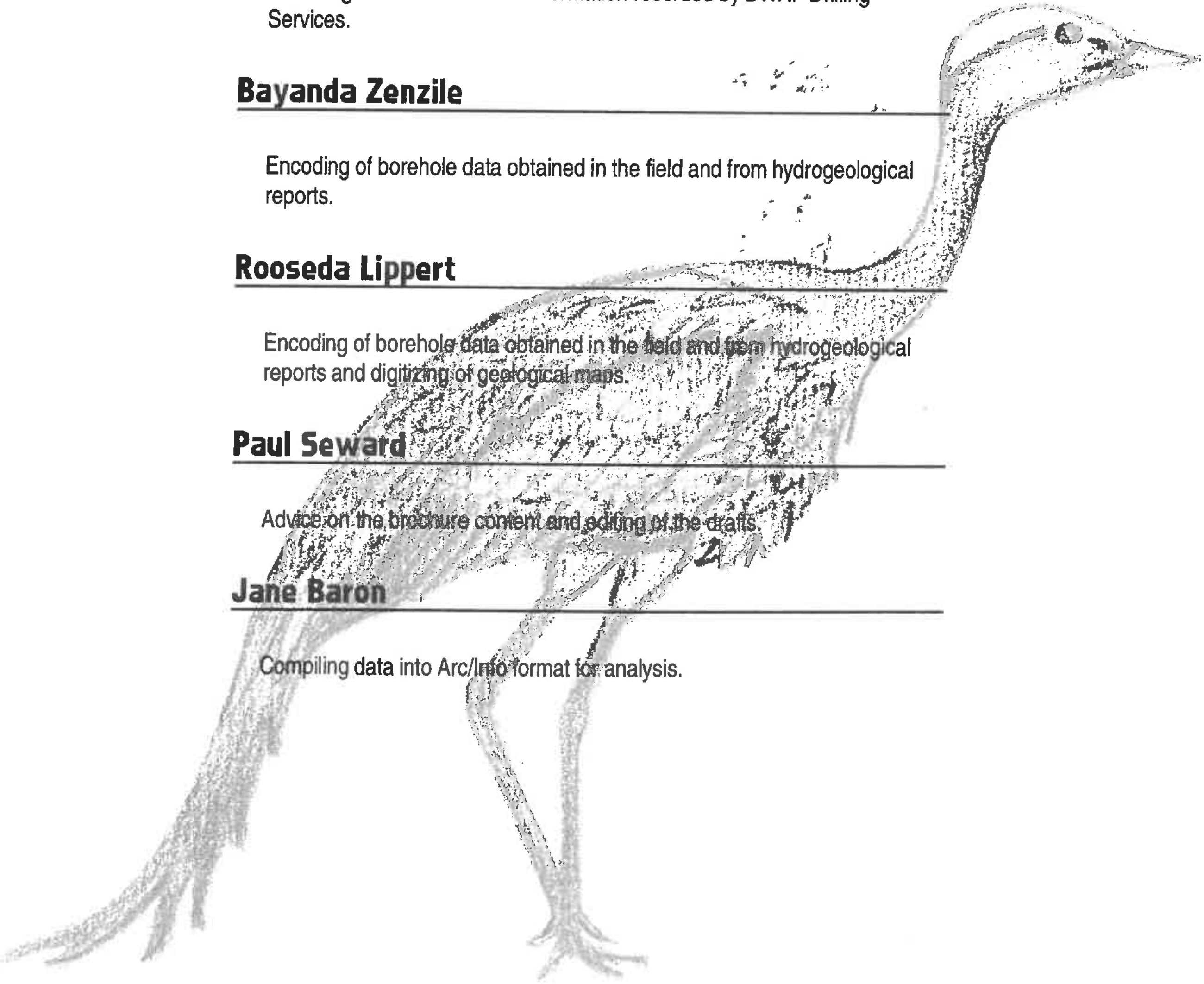
Compiling data into Arc/Info format for analysis.



Paulo Teixeira

Compilation of bar graphs

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

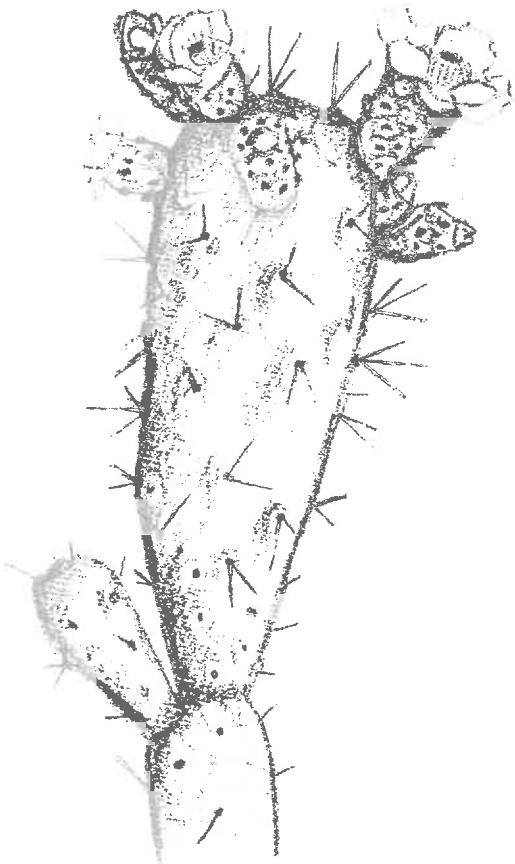
ABBREVIATIONS AND UNITS

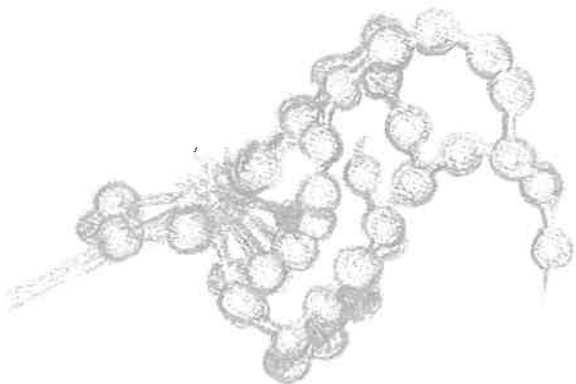
Abbreviations

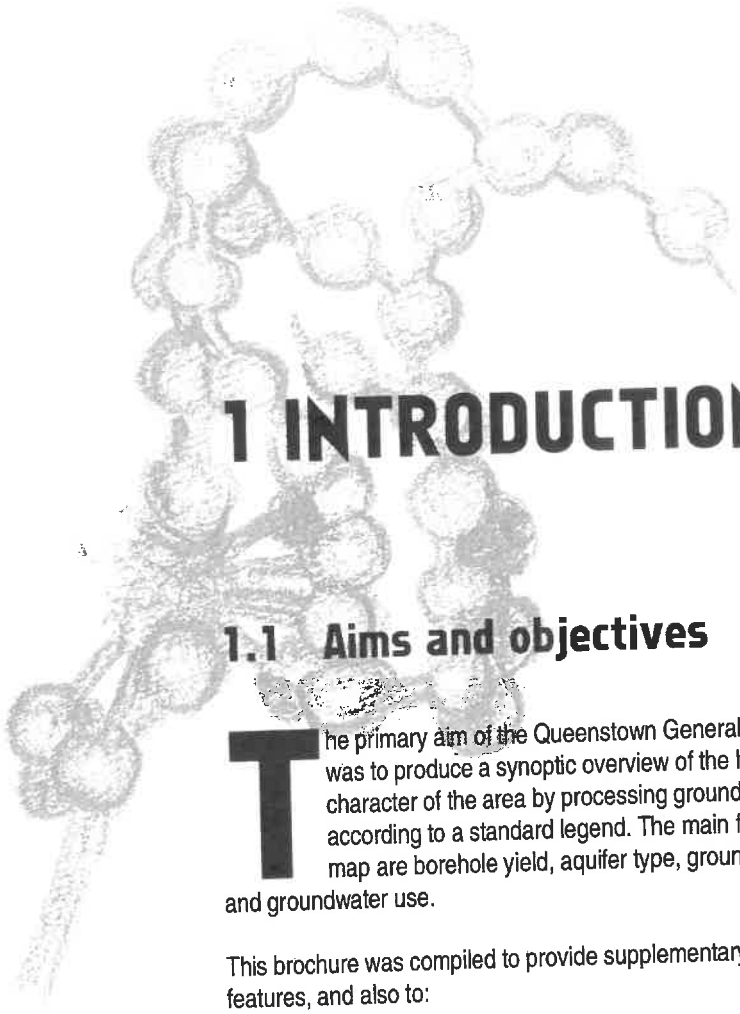
CSIR	Council for Scientific and Industrial Research
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
GIS	Geographical Information Systems
IAH	International Association of Hydrogeologists
IAHS	International Association of Hydrological Sciences
MAP	Mean annual precipitation
NGDB	National Groundwater Data Base
NWQDB	National Water Quality Data Base
SABS	South African Bureau of Standards
UNESCO	United Nations Educational, Scientific and Cultural Organisation

Units

a	annum
km	kilometre
km^2	square kilometre
ℓ/s	litre per second
m	metre
m^3	cubic metre
m^3/a	cubic metre per annum
mg/ℓ	milligram per litre
mm	millimetre
mS/m	milliSiemens per metre
°C	degrees centigrade







1 INTRODUCTION

1.1 Aims and objectives

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

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

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

1.2 Previous hydrogeological investigations

1.2.1 Ciskei National Water Development Plan

This project, carried out between 1986 and 1990, included the identification of groundwater resources (Hill Kaplan and Scott (HKS), 1991). A National Map for the Ciskei at 1:250 000 scale was produced distinguishing areas of "poor", "moderate" and "good" groundwater potential based on a combination of lithology, geological structure, groundwater quality, and recharge potential (precipitation). Six hydrogeological regions were identified and each was described in terms of aquifer type, borehole yield, groundwater quality and target features for groundwater exploitation.

1.2.2 Transkei National Groundwater Plan

A hydrogeological overview was obtained from existing borehole information and published geological maps (Steffen Robertson and Kirsten (SRK), 1993). The expected ranges of borehole yield per lithological unit, as well as expected groundwater quality and potential drilling targets, were briefly described. A computerised database (*Hydrocom Version 4.0*) was compiled from existing borehole data, supplemented by hydrocensus information. The Natal Group Sandstones were selected for more detailed investigations to determine their hydrogeological potential.

1.2.3 Local groundwater assessments and supply schemes

A portion of the Swart Kei River catchment to the west of Queenstown was investigated by the Department of Water Affairs and Forestry (DWAF) (Vandoolaeghe, 1980) to evaluate the groundwater supply potential. The study entailed an extensive hydrocensus and a geophysical survey, followed by detailed drilling of hydrogeological target features and aquifer testing. Much was learnt about how dolerite intrusions influence groundwater occurrence.

Small scale groundwater development investigations at various towns, *inter alia*: Bedford (Simonis, 1987), Jamestown (SRK, 1992), Tarkastad (Groundwater Consulting Services (GCS), 1992), Sterkstroom (SRK, 1993), Komga (Venables *et al*, 1985), Dordrecht (Meyer, 1984) have also provided some insight into groundwater occurrence.

1.2.4 Upper Kei Basin Study

The Upper Kei Basin is about 11 500 km^2 in extent and centred around Queenstown. The basin study was initiated by DWAF to gain a holistic view of the water-related issues so as to facilitate the integrated management of scarce water resources (Kei Basin Consulting Engineers (KBCE), 1993).

Part of the investigation was the provision of an overview of groundwater resources based on a review of the literature. Hydrogeological regions were identified and expected aquifer types, borehole yields, target features and groundwater quality were assessed. Groundwater exploitation potential was evaluated, based on recharge and storage estimates extracted from the literature on Karoo aquifers.

1.2.5 Groundwater exploitation potential

This project attempted to demonstrate the use of Geographic Information Systems (GIS) for determining an overview of groundwater exploitation potential in $m^3/km^2/a$ of the Queenstown map sheet (Seward *et al*, 1996). The main elements considered were recharge, storage and transmissivity. Exploitation potential was taken as the lesser of recharge, storage required to tide across drought periods, and abstraction potential limited by transmissivity. It was found that aquifer matrix transmissivity was the limit to groundwater exploitation for most of the area.

1.3 Data collection

The first step in the data collection was to gather all available information from files, reports, maps, and databases for analysis. Much of the existing borehole data were fragmented, mostly on hardcopy in government files and reports, and were housed with three different governments. The Republic of South Africa, and the former homeland of Ciskei possessed extensive hardcopy drilling records most of which needed to be captured on a computerised database. The data of the former homeland of Transkei were already computerised.

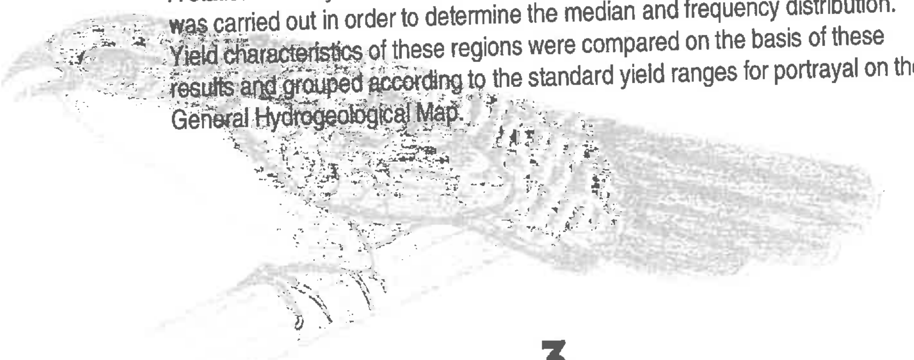
This information was collated and reviewed to allow the identification of areas of data scarcity requiring additional data and field surveys.

1.4 Methodology

1.4.1 Borehole yield

The area was subdivided into 25 relatively homogeneous, hydrogeological "yield regions" within each of which the properties affecting borehole yield are considered to be similar (Table 1). These were initially delineated on the basis of lithology and geological structure, climate, and topography. Some of these areas were further subdivided by taking into account borehole yield information. Concentrations of distinctly higher yielding boreholes than the surroundings were assigned to individual hydrogeological "yield regions".

A statistical analysis of the borehole yields within each of the identified regions was carried out in order to determine the median and frequency distribution. Yield characteristics of these regions were compared on the basis of these results and grouped according to the standard yield ranges for portrayal on the General Hydrogeological Map.



For the map series the median borehole yield determines the productivity range for a particular data set. Data for dry boreholes are available for the study area but were excluded in order to conform to the national mapping standards. The reason for excluding dry boreholes is that this map had to be consistent with maps covering other parts of the country that do not have sufficient records of dry boreholes. Dry boreholes are however included in the yield frequency histograms compiled for this brochure because they form an important part of the data set, enabling distinctions to be made between regions that would not have been otherwise evident.

1.4.2 Aquifer type

For the purposes of the 1:500 000 map series aquifers are divided into four types namely:

- intergranular
- fractured
- fractured and intergranular
- karst

In this way the voids in the rock through which water is transmitted are classified. These types refer to the nature of aquifer that may be found, rather than the boundaries of individual aquifers.

The aquifer type mapped was not necessarily the shallowest, but the **principal** aquifer. i.e. **the shallowest aquifer with the highest borehole yields and the best quality water.** Thus a surface layer of unconsolidated saturated silt with an insubstantial yield of water would not be mapped as the aquifer if the deeper bedrock provides higher borehole yields.

In principle, a "fractured and intergranular" aquifer should transmit water through both the fractures and through the overlying intergranular medium. In practice some fudging of this definition was permitted to allow for the case when the intergranular voids were primarily an important storage, rather than a transmitting, medium. This is a common feature in South Africa and occurs when weathered rock (Plate 1) stores significant quantities of water in the intergranular voids, but the water can only be economically abstracted via fractures in the underlying bedrock through a process of vertical drainage of groundwater from above.

The standard procedure adopted for this map series was to classify the aquifers as "fractured and intergranular" when the water level was in the weathered zone, and as "fractured" only when the water level was below the weathered zone. This approach was not possible for this map sheet because of insufficient information on depths of weathering and water level. Instead the National Saturated Interstices Map (Vegter, 1995), and a map of weathering of basic igneous rocks (Weinert, 1974) were used to separate the aquifers into the "fractured" and the "fractured and intergranular" categories.

Plate 1: *Weathered dolerite - capable of intergranular groundwater storage*

Weinert's N = 5 contour, indicating the transition from predominantly chemical to predominantly mechanical weathering, and Vegter's division between purely fractured interstices and fractured plus porous interstices correlate closely for the study area. The Weinert and Vegter maps were thus jointly used to determine the transition from "fractured" to "fractured and intergranular" for the map sheet.

The "intergranular" aquifer class is not depicted since there are no areas within the Queenstown map sheet where unconsolidated deposits yield significant amounts of water. The "karst" aquifer class is also not depicted.

1.4.3 Lithology

On the General Hydrogeological Map a background ornament depicts lithologies which were derived from the 1:250 000 geological maps published by the Council for Geoscience for the area. The lithology is shown in a highly simplified form highlighting the variations likely to have a significant effect on groundwater occurrence (e.g. presence or absence of dolerite intrusions, predominance of sandstone over mudrocks etc). It is not possible to portray the abundant dolerite intrusions individually without creating an overcrowded map. Therefore dolerite dykes are not displayed on the map at all, and only selected larger dolerite sheets and sills of possible hydrogeological significance are shown in a simplified form. A mixed ornament containing the dolerite symbol and that of the host lithology is used for areas in which dolerite intrusions occur but are not individually portrayed. Only in instances where dolerite is totally absent (e.g. the extreme south-western corner of the map) is the ornament not mixed. Because of the gross generalisation of the lithology it is not possible to use the General Hydrogeological Map as a tool for local borehole siting. The reader interested in the geological details is thus referred to the 1:250 000 geological maps obtainable from the Council for Geoscience.

1.4.4 Groundwater quality and hydrochemistry

Groundwater quality data points were contoured to distinguish regional-scale trends. The presence of selected hydrochemical constituents, which could pose a threat to health, is highlighted. In addition results of hydrochemical analyses were used to determine regional variations in groundwater character as defined by ionic ratios.

1.4.5 Groundwater potential

In this brochure two facets of groundwater potential are considered – Harvest Potential and Abstraction Potential.

Harvest Potential provides an estimate of the theoretical volume of groundwater which can be abstracted from an area on a sustainable basis. It was determined from groundwater storage and recharge without any consideration of socio-economic factors (which includes *inter alia* the cost of bringing groundwater to the point of demand, the value of the water and legal and environmental issues) and water quality. A rainfall / recharge relationship obtained from the literature (Bredenkamp *et al*, 1995) was used to make empirical estimates of recharge at the regional scale. Typical aquifer storativity ranges were also obtained from the literature (Bredenkamp *et al*, 1995). Variations in the storativity assigned to various portions of the area was based on mode and intensity of weathering of the rock.

Abstraction Potential, on the other hand, provides an estimate of the quantity of groundwater that can be practically abstracted. It is determined from aquifer transmissivity, which was estimated from borehole yields, and an assumed borehole density. Abstraction Potential might not be sustainable in some cases because it can exceed Harvest Potential.

1.4.6 Major groundwater use

Areas in which agricultural irrigation from groundwater is practised were identified by interviewing officers of the Department of Agriculture, and by gleaning data from existing reports. Abstraction estimates were made from information on the areas under groundwater irrigation, crop type and the irrigation requirements to sustain that crop.

Information on large-scale domestic groundwater abstractions was obtained from a variety of sources, including the literature, Departmental and consultants reports and interviews with personnel responsible for groundwater supply schemes.

2 PHYSICAL ENVIRONMENT

2.1 Topography and surface hydrology

The Great Escarpment (Fig. 1) comprises the Bamboesberg, Stormberg and Drakensberg mountain ranges which rise from about 1 500 m to between 2 000 and 2 600 m above sea level. On the seaward side of the Great Escarpment drainage is generally south-easterly. In the eastern half of the area the often deeply dissected terrain slopes gradually toward the Indian Ocean. Northward draining tributaries of the Orange River traverse the landward side of the escarpment in the north-west corner of the map. At the western edge of the map tributaries of the Great Fish River drain to the south-west.

2.2 Climate

2.2.1 Precipitation

The lowest mean annual precipitation (MAP) occurs in the west of the area typically 400 mm (Fig. 2). In the eastern area MAP is typically around 800 mm. The highest MAP (ranging from 1 000 - 1 400 mm) occurs along the coastal belt and against mountain ranges comprising the Great Escarpment and the Amatola range.

Rainfall maxima generally occur in late summer, but in the northern parts the rainfall is relatively evenly spread throughout summer (October to March). In the coastal area in the vicinity of East London it is more evenly spread throughout the year. Snow falls on the mountain ranges during winter.

2.2.2 Temperature and evaporation

Mean annual surface temperatures (Fig. 3) are highest along the coastal belt in the south-east, decreasing inland towards the north-west due to the higher altitude and greater distance from the moderating influence of the sea. Over most of the area mean annual temperatures range from 15.0 to 17.5 °C. Along the coastal belt the range is 17.5 to 20.0 °C while in the north-west it declines to between 12.5 and 15.0 °C.

The average annual potential evaporation (Fig. 4) ranges from less than 1 200 mm in the more humid areas near the coast, to 1 800 mm in the drier inland areas to the north-west.

FIG 1: TOPOGRAPHY AND SURFACE HYDROLOGY

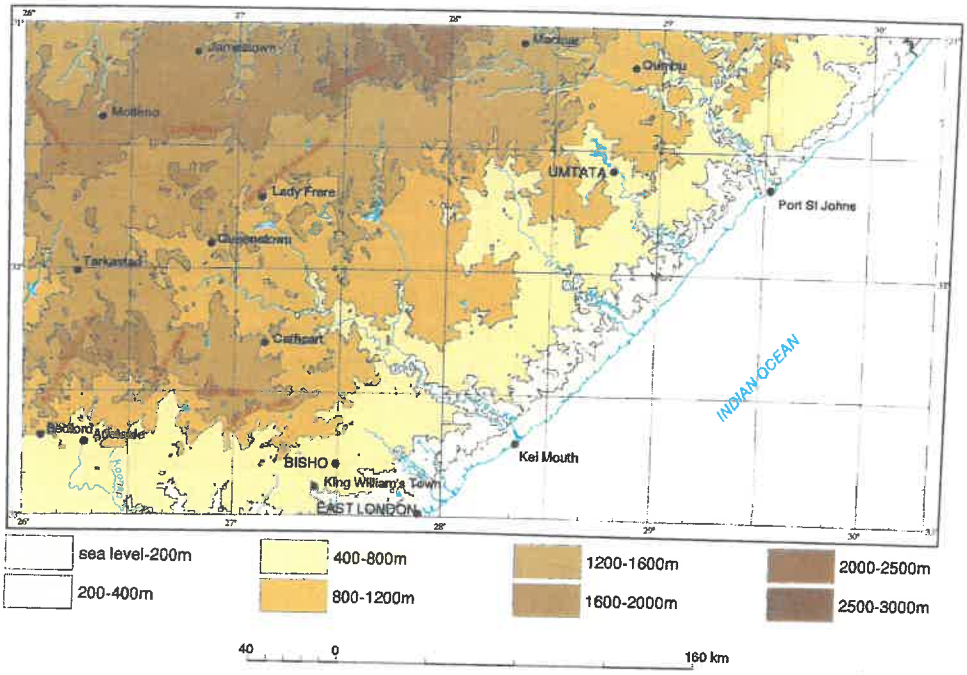


FIG 2: MEAN ANNUAL PRECIPITATION

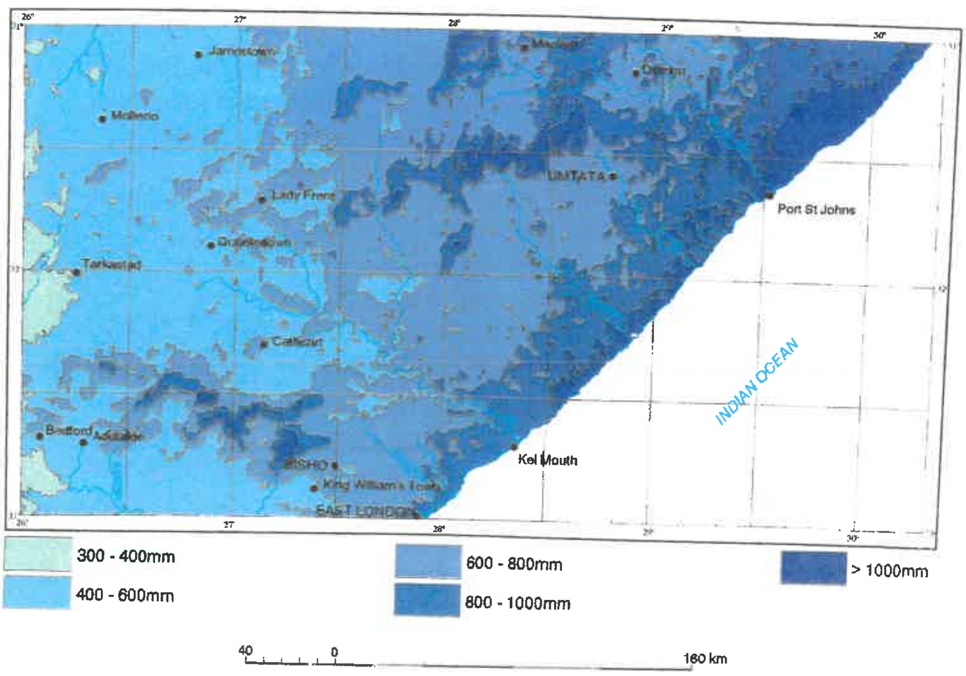


FIG 3: MEAN ANNUAL SURFACE TEMPERATURE FOR SOUTH AFRICA

Modified after DWAF 1986

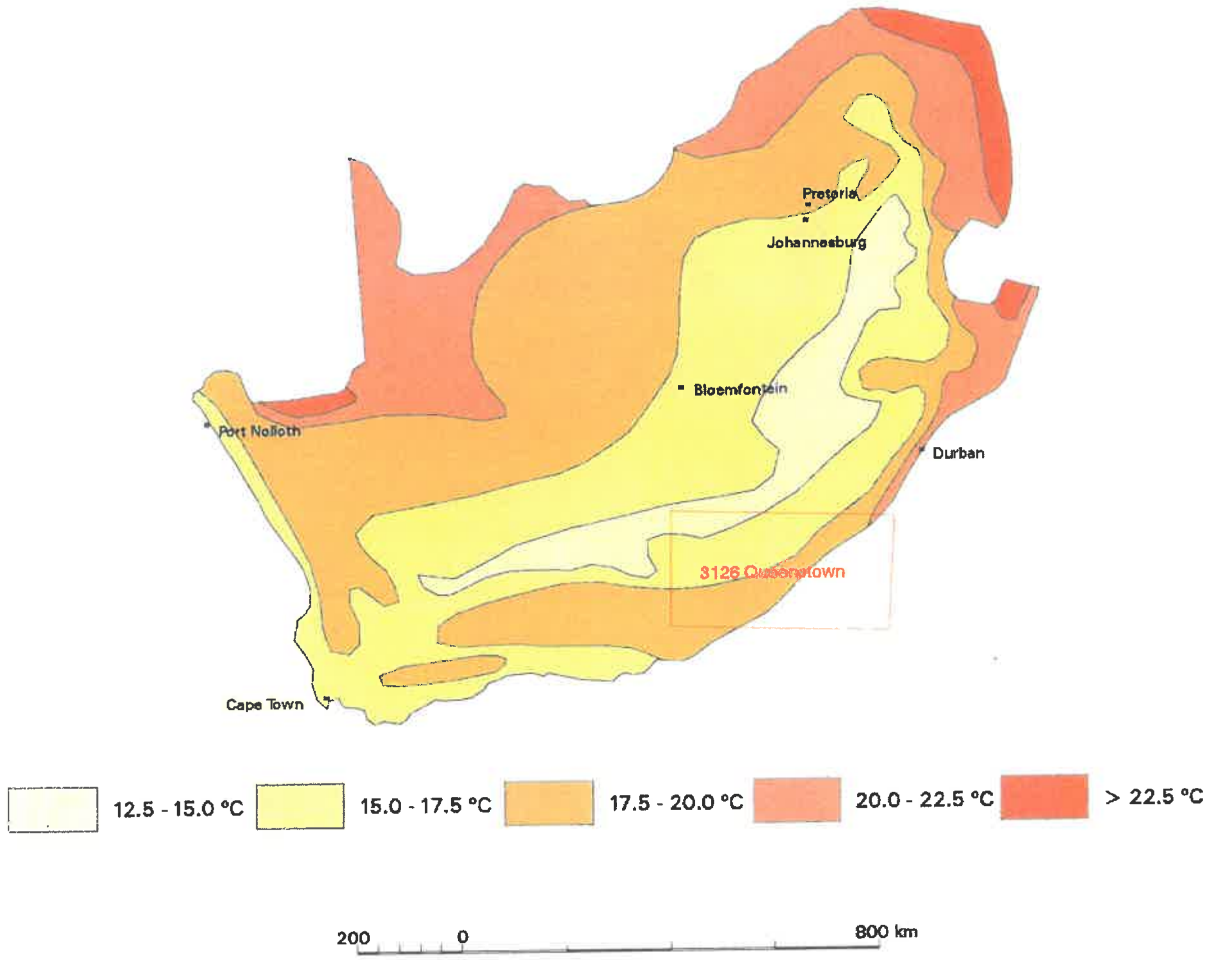
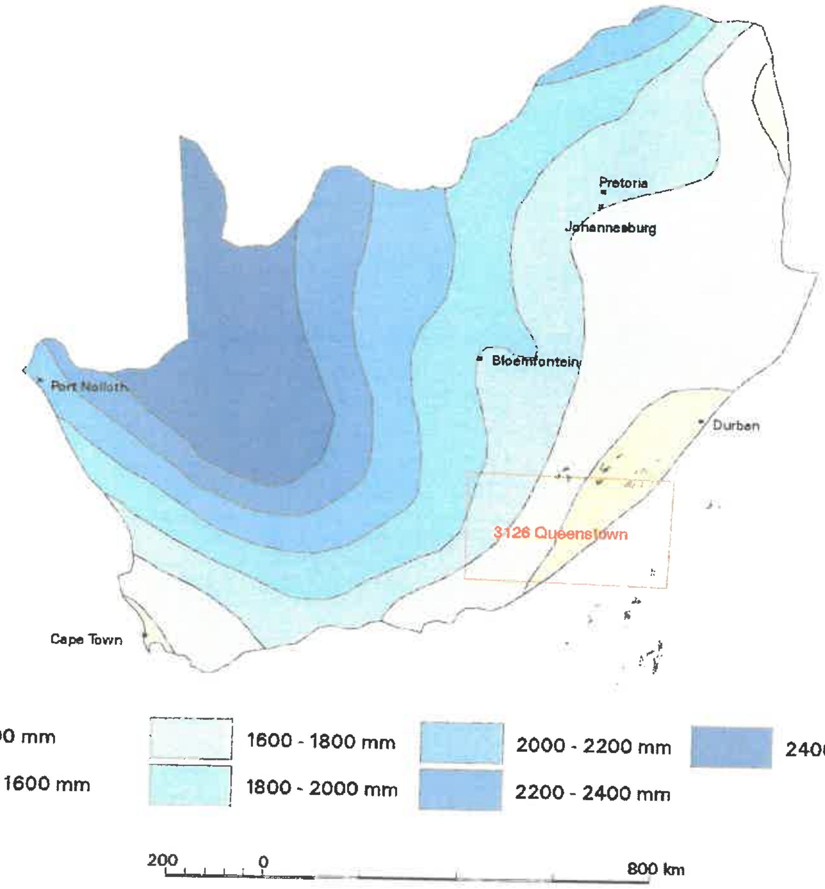


FIG 4: MEAN ANNUAL POTENTIAL EVAPORATION FOR SOUTH AFRICA

Modified after DWAF 1986



3 GEOLOGY

3.1 Pre-Karoo rocks

The Natal Metamorphic Province basement rocks (Fig. 5), exposed only along the coast in the north-eastern corner of the map, comprise mainly granite, gneiss and charnockite.

The Natal Group rocks outcropping in the north-eastern corner of the map comprise predominantly quartz arenites but other rock types (conglomerates, coarse-grained sandstones, siltstone, mudstone and diamictite) are also represented. This succession is between 900 and 1 300 m thick. The base of the Natal Group is exposed in the east where it lies unconformably on the basement rocks of the Natal Metamorphic Province.

3.2 Karoo Supergroup

3.2.1 Dwyka Tillite Group

The massive and structureless 500 m thick Dwyka Tillite Group outcrops near the coast to the north-east of the map and unconformably overlies the Natal Group rocks. This diamictite consists of angular clasts (up to 250 mm diameter) set in a fine to very fine-grained matrix.

3.2.2 Ecca Group

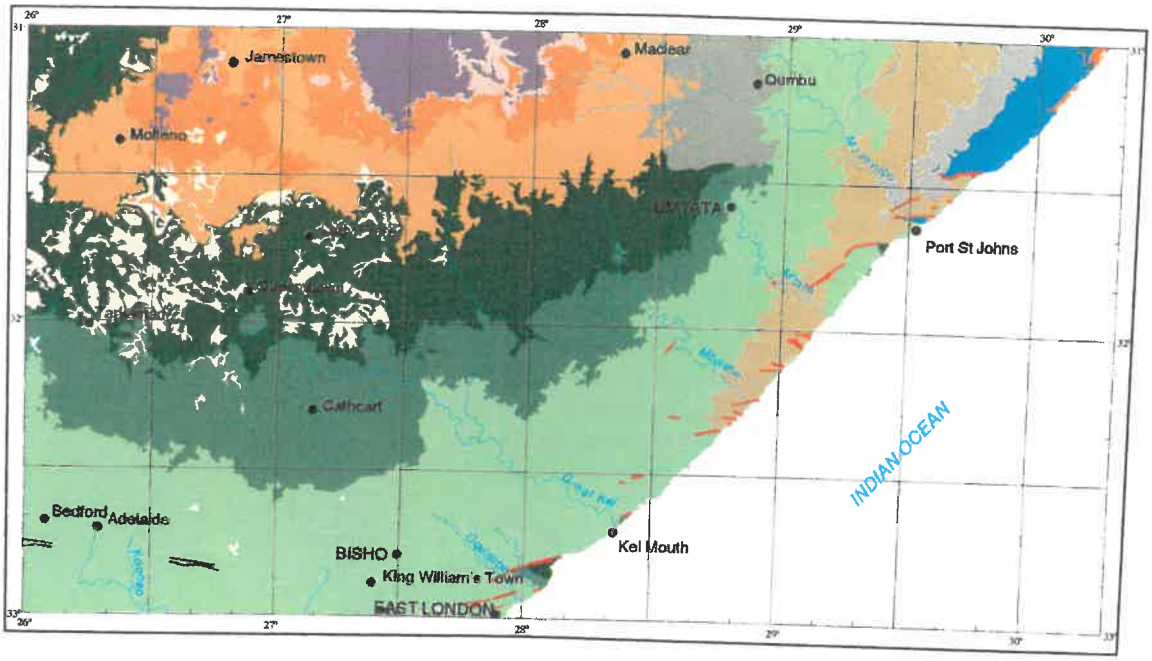
The Ecca Group (Fort Brown and Ripon Formations) which conformably overlies the Dwyka Tillite Group consists of a 1 000 m thick succession of rhythmically bedded and laminated shales and minor sandstones.

3.2.3 Beaufort Group

3.2.3.1 Middleton Formation

In the study area the Middleton Formation is approximately 1 900 m thick and comprises greyish-green mudrock interspersed with multi-layered river channel sandstones. The sandstone to mudrock ratio is of the order of 1:2 (Rubidge, 1995).

FIG 5: LITHOSTRATIGRAPHY AND STRUCTURE



	GROUP	SUBGROUP	FORMATION	LITHOLOGY
				alluvium, sand
			Mbotyi, Mgazana	conglomerate, sandstone
KAROO SUPERGROUP	DRAKENSBERG			basaltic lava
KAROO SUPERGROUP			Clarens	sandstone
KAROO SUPERGROUP			Elliot	mudstone, sandstone
KAROO SUPERGROUP			Molteno	mudstone, shale, sandstone
KAROO SUPERGROUP	BEAUFORT	Tarkastad	Burgersdorp	mudstone, sandstone
KAROO SUPERGROUP	BEAUFORT	Tarkastad	Katberg	sandstone, mudstone
KAROO SUPERGROUP	BEAUFORT	Adelaide	Balfour	mudstone, sandstone
KAROO SUPERGROUP	BEAUFORT	Adelaide	Middleton	mudstone, sandstone
KAROO SUPERGROUP	ECCA		Fort Brown	shale, mudstone, sandstone
KAROO SUPERGROUP	ECCA		Ripon	shale, mudstone, sandstone
KAROO SUPERGROUP	DWYKA			tillite
	NATAL			quartzitic sandstone
	NATAL COMPLEX			granite, gneiss, charnockite

—— fold axis

—— fault

40 0 160 km

3.2.3.2 Balfour Formation

The Balfour Formation is approximately 2 000 m thick. At its contact with the underlying Middleton Formation this formation is relatively sandstone rich, although overall mudrock still predominates.

3.2.3.3 Katberg Formation

This sandstone-rich formation is 500 to 1 000 m thick. Fine-grained to medium-grained horizontally laminated, cross-bedded or massive sandstone comprises about 90% of the total thickness on average.

3.2.3.4 Burgersdorp Formation

The Katberg Formation is overlain by the Burgersdorp Formation, which reaches a thickness of 600 m in the Queenstown-Lady Frere area. This Formation is relatively mudstone rich (70-80%). Sandstone layers are typically 2 to 3 m thick but can reach thicknesses of 10 m.

3.2.4 Molteno Formation

A low angle unconformity exists between the underlying Burgersdorp Formation and the Molteno Formation. Mudstone and sandstone are the dominant rock types with sandstone content ranging from 30 - 50% but in some instances (for example west of the town of Molteno) the sandstone component reaches 75%. Minor rock types are shale (2 - 10%), coal and conglomerate (each less than 1%). Sandstone lithosomes generally range from a few metres to 20 m in thickness with a maximum of 60 m. The Molteno Formation is some 250 m thick in the west, the thickness increasing to about 450 m in the east.

3.2.5 Elliot Formation

The Elliot Formation overlies the Molteno Formation and is between 300 and 500 m thick. It consists of interbedded fine-grained sandstone (30% of the succession) and mudstone. The lenticular sandstone horizons are between 3 and 15 m thick.

3.2.6 Clarens Formation

The contact with the underlying Elliot Formation is gradational. This Formation is fine-grained (sandstone) to very fine-grained (mudrock), predominantly massive and structureless. The thickness varies from 20 to 300 m and the unit commonly forms sandstone cliffs.

3.2.7 Drakensberg Group

This Group is made up of a 1 400 m thick succession of basalt flood-lava fed by a complex of igneous intrusives known as the Karoo Dolerite (Fig. 6). The thickness of the lava flows varies from 0,5 to 50 m. In the basal one third of the sequence, the lavas are interlayered with pyroclastics and thin lacustrine sandstone, mostly less than 10 m thick.

Two main categories of dolerite intrusion are recognised, namely vertical dykes, and sheets of varying inclination and curvature. Dolerite sheets, which approximately conform to bedding dip, are termed sills. Dolerite dykes (Plate 2) of the study area usually range between 1 and 10 m wide and can be tens of kilometres long. Their orientations are variable but with a north-westerly strike prominent over much of the area. In the Butterworth area dykes strike almost exclusively east-west. Here two prominent dykes up to 300 m wide are traceable for over 100 km. Sills and sheets are usually between a few metres and 100 m thick but can be well in excess of this in some instances. For example the Andriesberg north of Queenstown (300 m), and Tabankulu north-west of Flagstaff (500 m).

Plate 2: *A dolerite dyke (light yellowish brown in foreground) forms a topographic ridge extending into the distance*

The regional variations in intrusive style across the study area appear to be related to the stratigraphic level of the intrusions (Figs. 7 and 8). Dolerite is rare in the older lithologies toward the base of the Karoo succession while the Balfour Formation of the Beaufort Group is characterised by massive dolerite sheets. From this stratigraphic level up to and including the basal parts of the Molteno Formation a combination of dykes, sheets, and sills occur. Ring-shaped intrusions are most common in the upper levels of the Beaufort Group (Burgersdorp Formation) and the lower Molteno Formation. Above this stratigraphic level dykes are most common, sheets become rare and volcanic vents/diatremes appear.

FIG 6: DOLERITE INTRUSIONS

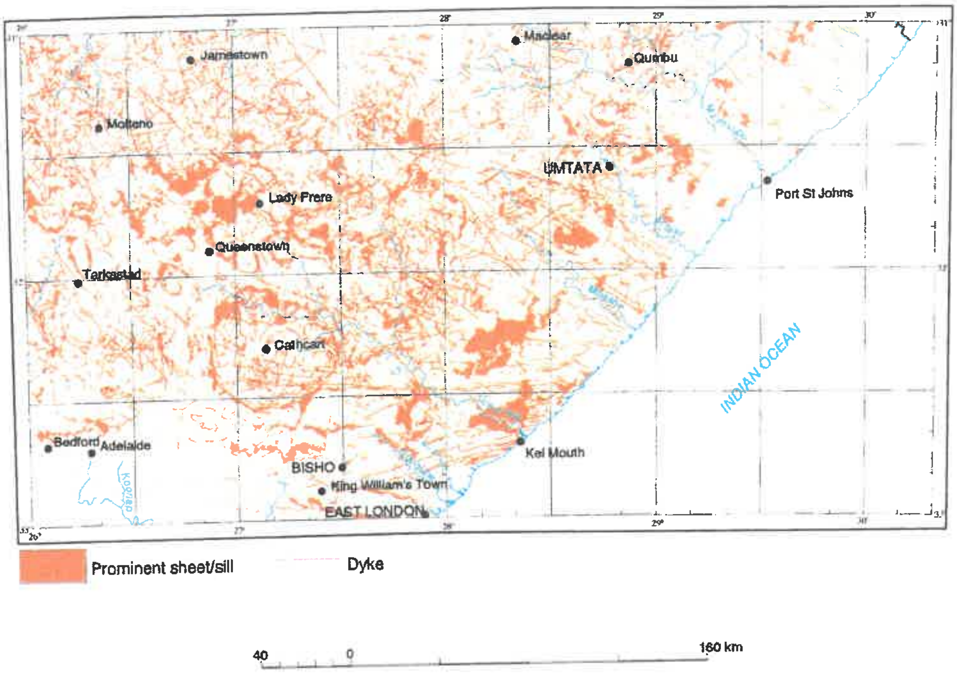


FIG 7: IDEALIZED S-N SECTION SHOWING STRATIGRAPHIC RELATIONSHIPS OF DRAKENSBERG INTRUSIVE AND EXTRUSIVE VOLCANIC ROCKS IN THE MAIN KAROO BASIN

(After Dingle *et al*, 1983)

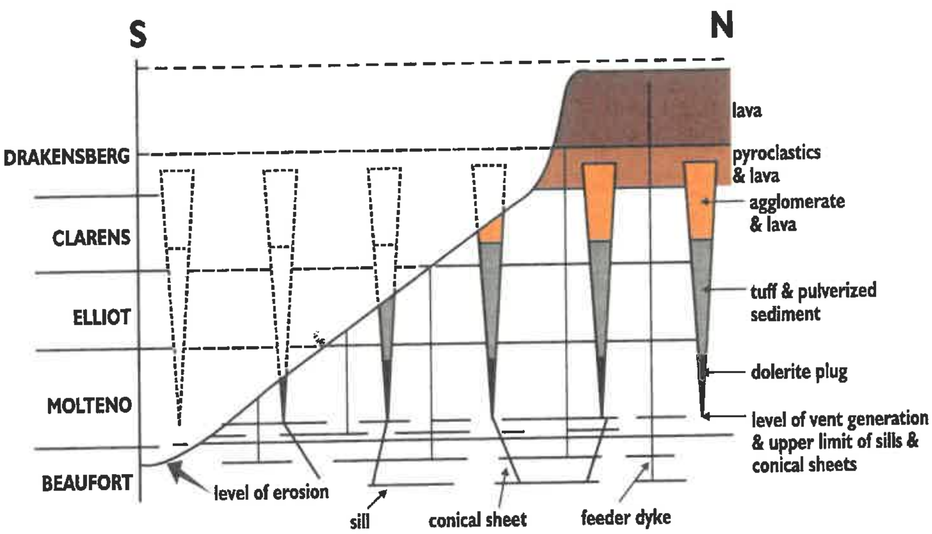
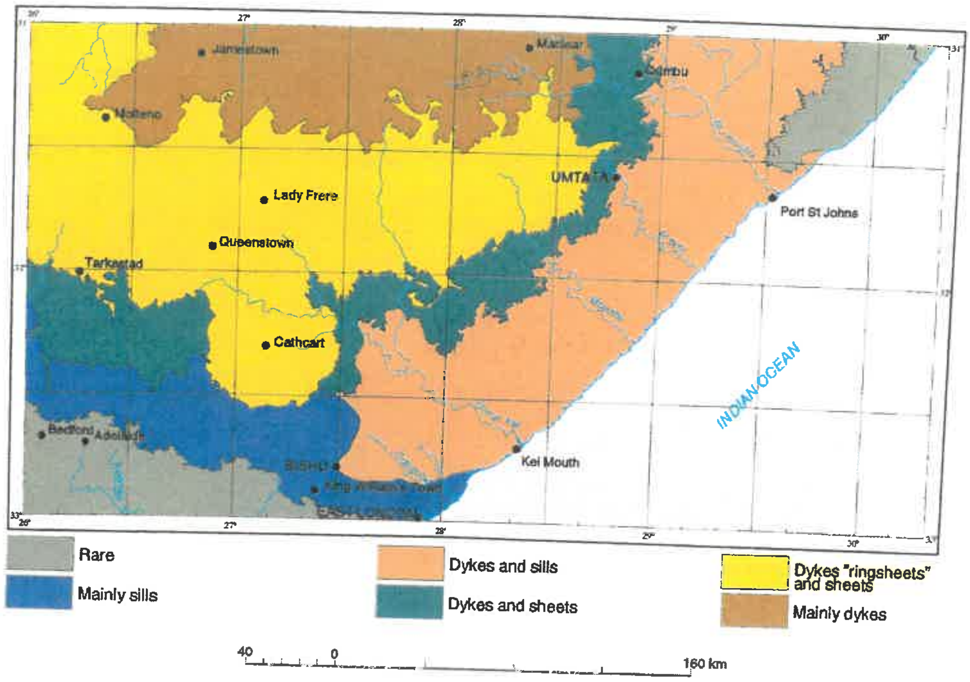


FIG 8: ABUNDANCE AND PREDOMINANT STYLE OF DOLERITE INTRUSIONS



3.3 Post-Karoo lithologies

3.3.1 Cretaceous rocks

A 300 m thickness of Mbotyi Formation is present in a downfaulted area at Mbotyi on the coast. It consists of conglomerate and subordinate coarse sandstone, resting unconformably on Karoo sequence rocks.

3.3.2 Quaternary unconsolidated deposits

Alluvium is generally limited in thickness in most of the study area, rarely exceeding 2 m, and is most extensive in the north-western quarter of the study area, in particular in the area underlain by Burgersdorp Formation rocks where alluvium thickness of the order of 10 m are attained. Deposits of colluvium up to 2 m thick may also be found. Unconsolidated coastal deposits of regional significance are not found.

3.4 Structure

3.4.1 Faulting

According to the 1: 250 000 published geological maps and accompanying explanations, major faults occur only along the coast of the study area. There are several of these east-west striking faults, the downthrows (as much as 3 000 m) being mainly to the south. They are hinge faults with downthrows diminishing inland - for example a fault immediately to the south of Port St. Johns has a displacement of about 3 000 m at the coast but dies out within 16 km inland. Although movement on these faults predominated in the Cretaceous, seismic evidence indicates some recent movement (e.g. an earthquake north of Port St. Johns reported by Krige and Maree, 1951).

3.4.2 Folding

The southern edge of the study area is close to the northern limit of the Cape Fold Belt and very localized dips of up to 30° (a result of folding) are encountered, for example in the Bedford vicinity. The generally northward dip decreases progressively northwards, and in most of the map area these dips vary between 1° and 5°.

Variations in dip steepness and direction occur locally next to some intrusions. Dips also increase in the faulted areas at the coast where eastward dips of up to 20° occur.

3.4.3 Fracturing

Localised fracturing associated with dolerite intrusions occurs in both the host rock and in the dolerite itself. Open fractures, not necessarily associated with dolerite, also form as a result of tectonic forces, weathering and stress release on unloading by denudation. Lithological boundaries often represent zones for development of openings when there is local flexure and rock competence contrast (e.g. at sandstone-mudrock contacts (HKS), 1991).

3.5 Weathering

Climatic conditions and rock type influence the intensity and mode of weathering that can be expected in a particular area. Weinert (1974) derived a weathering index (climatic N value) for basic igneous rocks based on temperature and moisture considerations and produced a set of contours for South Africa ranging from 1 to 50. Where the N value is greater than 5 (roughly west of 25° longitude) disintegration due to physical weathering is predominant, while decomposition due to chemical weathering prevails in the more humid areas (lower N value) to the east of this. The weathered zone rarely exceeds 30 m in depth.

3.6 Stress regime

Andreoli *et al* (1996) conclude from research into neotectonic activity in Southern Africa that there is a NW-SE trending maximum horizontal compression from southern Angola to off the Transkei coast. Because the study area falls within this zone the same stress direction can be expected. In this stress regime NW-SE trending structures are likely to be in tension (open) and those at right angles to this in compression (closed).

A comparison of vertical to horizontal stresses across South Africa was made by Gay (1975) who concluded that horizontal stresses tend to be larger than vertical stress at shallow depths, but at greater depths the vertical stress is nearly twice those acting horizontally. Under these circumstances horizontal fractures are more likely to be open at shallow depths but closed deeper down due to increasing load pressure. The NW-SE trending (vertical) fractures are most likely to be open at depth given the NW-SE maximum horizontal stress.

4 HYDROGEOLOGY

4.1 Conceptual model of groundwater occurrence

For the bulk of this area groundwater occurs in dual porosity aquifers, comprising large but infrequent principal transmissive fractures with relatively low storage capacity, and secondary but numerous microfissures with higher storativity but lower transmissivity. The microfissures are mainly concentrated in a near-surface upper zone usually less than 30 m thick, possessing a higher storage capacity than the rocks encountered at deeper levels. The upper and lower zones are hydraulically linked. The groundwater stored in the shallower section replenishes, by downward leakage, groundwater abstracted from deeper fractures via boreholes, or groundwater issuing from springs and seepages. The deeper fractures often have a higher transmissivity but lower storativity than the shallow zone fractures.

4.2 Influence of local geology on borehole yield

4.2.1 Aquifers associated with dolerite intrusions

4.2.1.1 Introduction

The conceptual illustration beneath the main map illustrates styles of dolerite intrusion and associated fracturing. Associated with these intrusions are "fractured" or "fractured and intergranular" aquifers. The fractures occur within the dolerite as a well as in the host rock, and are often concentrated toward the margins of the dolerite intrusion (Plate 3). Weathering generates the intergranular property of these aquifers. The dolerite is commonly weathered as a combined result of the fractures providing weathering agents access to the rock as well as the susceptibility of the dolerite minerals to weathering.

Plate 3: *A borehole targeting a highly fractured sandsone aquifer at the margin of a dolerite dyke (weathered light yellowish brown)*

4.2.1.2 General trends

The following general trends were revealed on analysis of the groundwater-related data from the map sheet:

- yields associated with dolerite intrusions are higher than those associated with sedimentary rocks only,

- yield characteristics of dykes and sheets are broadly similar,
- yields associated with dolerite intrusions are highly variable at both the local and regional scale,
- regions that have higher yields than average in the sedimentary rocks will also have correspondingly higher than average yields in the dolerite associated aquifers.

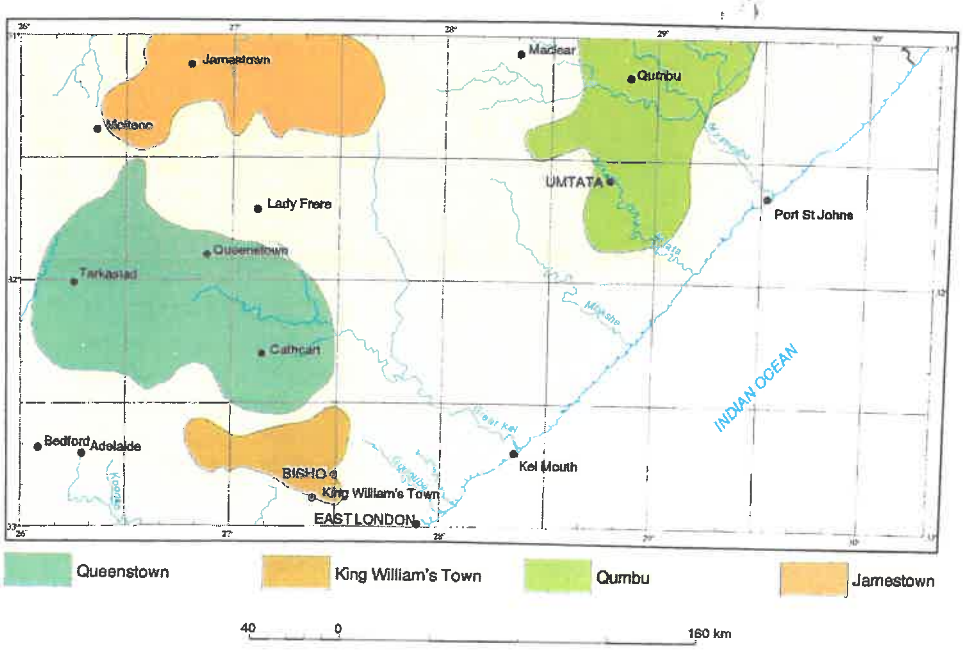
These trends show that regional-scale fracturing affects all the rock types in a particular structural domain (i.e. both the dolerite and as well as the sedimentary host rocks remote from the intrusion). But at the local-scale dolerite contact zones provide competent rock in which these fractures are likely to remain sufficiently open to be the highest yielding. This relationship/ phenomenon is clearly illustrated in the area underlain by the Burgersdorp Formation where higher than average yields are obtained in the Burgersdorp Formation sedimentary rocks as well as the dolerite, but the fractures associated with dolerite are still the highest yielding.

4.2.1.3 Type areas

In order to better illustrate and explain the variations in groundwater occurrence associated with dolerite some "type areas" were selected (Fig. 9). These areas were somewhat loosely selected taking into account the distribution of available information as well as intrusive style and relative abundance of dykes, sheets and sills namely;

- Queenstown – predominantly dykes, "ringsheets" and sheets
- King William's Town – mainly sills
- Jamestown – mainly dykes
- Qumbu - "dykes and sills" and "dykes and sheets"

FIG 9: TYPE AREAS



Borehole yield frequency histograms for these type areas are given in Figs. 10 and 11.

4.2.1.4 Queenstown type area

The dolerite-related aquifers typifying this type area are more productive than in all the other type areas (although yields are still lower than the folded aquifers near Bedford area where dolerite is rare to absent). The presence of abundant dykes and sheets indicate that significant regional structural disturbances must have taken place during intrusions. What makes this area stand out as being different from the other areas though is the presence of ring-shaped dolerite intrusions (Plate 4) as well as the abundance of irregular intrusions displaying sharp variations in thickness and dip along their length. (Note that the colours in Plate 4 are unnatural because the reflective–infrared portion of the spectrum was used. The colour variation therefore is rather an indicator of plant health/density.)

The intrusion of the ring structures are likely to cause extension and fracturing of the overlying host rock, and could be responsible for a generally higher incidence of fracturing than in the other areas. The irregularity of the dolerite sheet intrusions of this area provide an abundance of curved portions which Vandoolaeghe (1980) found to be the most productive drilling targets.

Another factor is the abundance of dolerite intrusions, which provide plentiful potential drilling sites. In addition the relatively flat terrain, particularly to the west of Queenstown, makes drilling access easier than the other areas, allowing more flexibility in the optimal positioning of a drill rig.

4.2.1.5 King William's Town type area

The King William's Town type area is characterised by massive, shallow-dipping dolerite sheets, while dolerite dykes are rare. The contact zones of the massive sheets are notoriously unproductive, with more dry boreholes than in unaltered sedimentary rock. Dolerite-related yields of more than 3 ℓ/s are extremely rare. The dolerite sheet contact zone normally only yields water if a structural feature is present.

Best results are obtained for boreholes drilled away from the influence of dolerite. The prospects for success are seemingly greater in topographic lows away from the rigid sheets. The reason for the poor results on these sheets is uncertain, but may be related to lack of tectonic activity and associated fracturing, and the rarity of dykes along which structural movements/ adjustments could have occurred.

4.2.1.6 Qumbu type area

The style of intrusion, especially in the Burgersdorp Formation in the Qumbu type area, is very similar to that of the Queenstown type area, with dykes and sheets both abundant. However drilling associated with dolerite intrusions is far less successful than in the Queenstown type area, with yields seldom exceeding 3 ℓ/s.

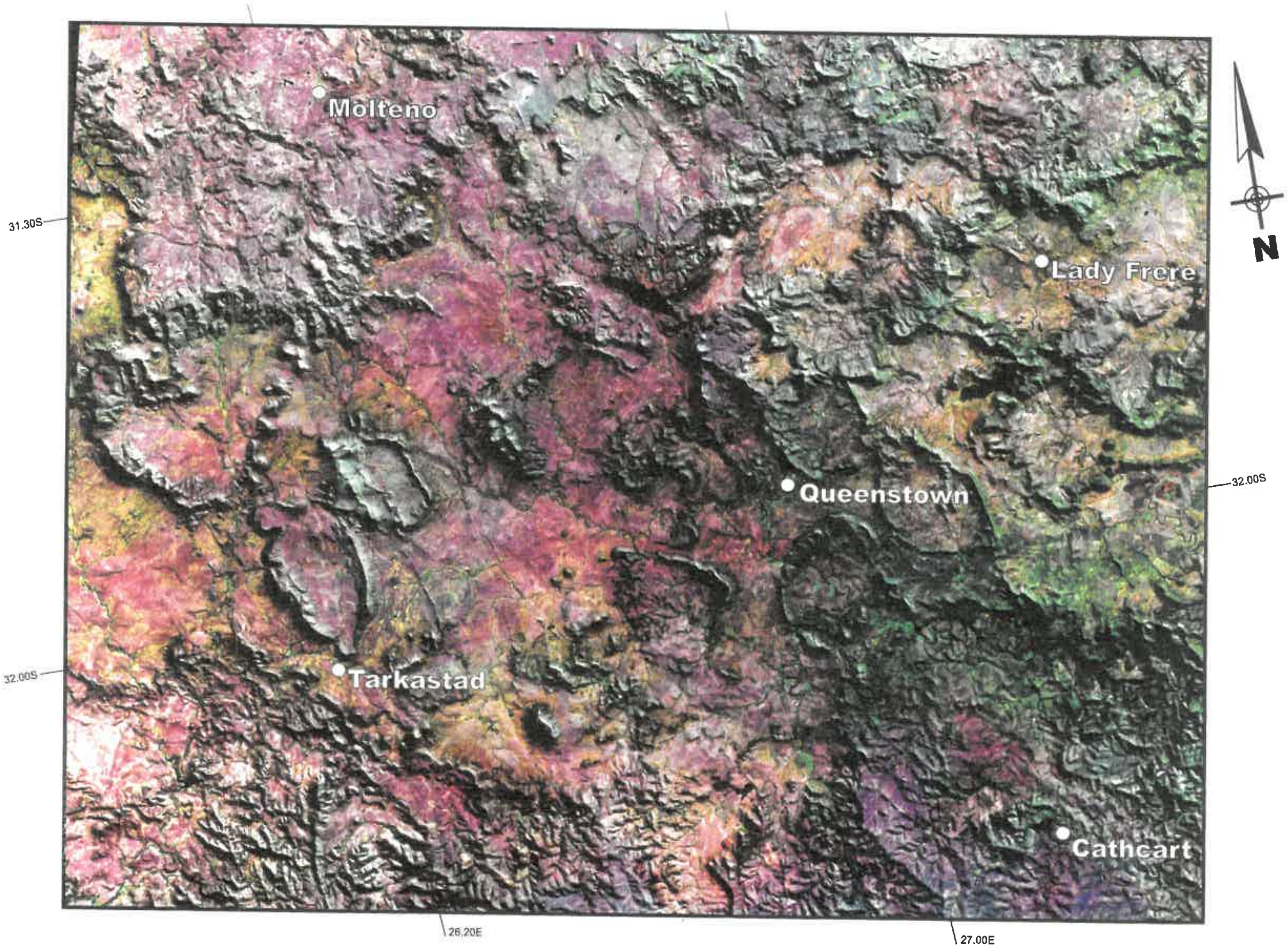


Plate 4: *A satellite image of the Queenstown area (Landsat - 5 TM Band 745)*

FIG 10: COMPARISON OF BOREHOLE YIELD: DOLERITE VERSUS NON-DOLERITE TARGETS

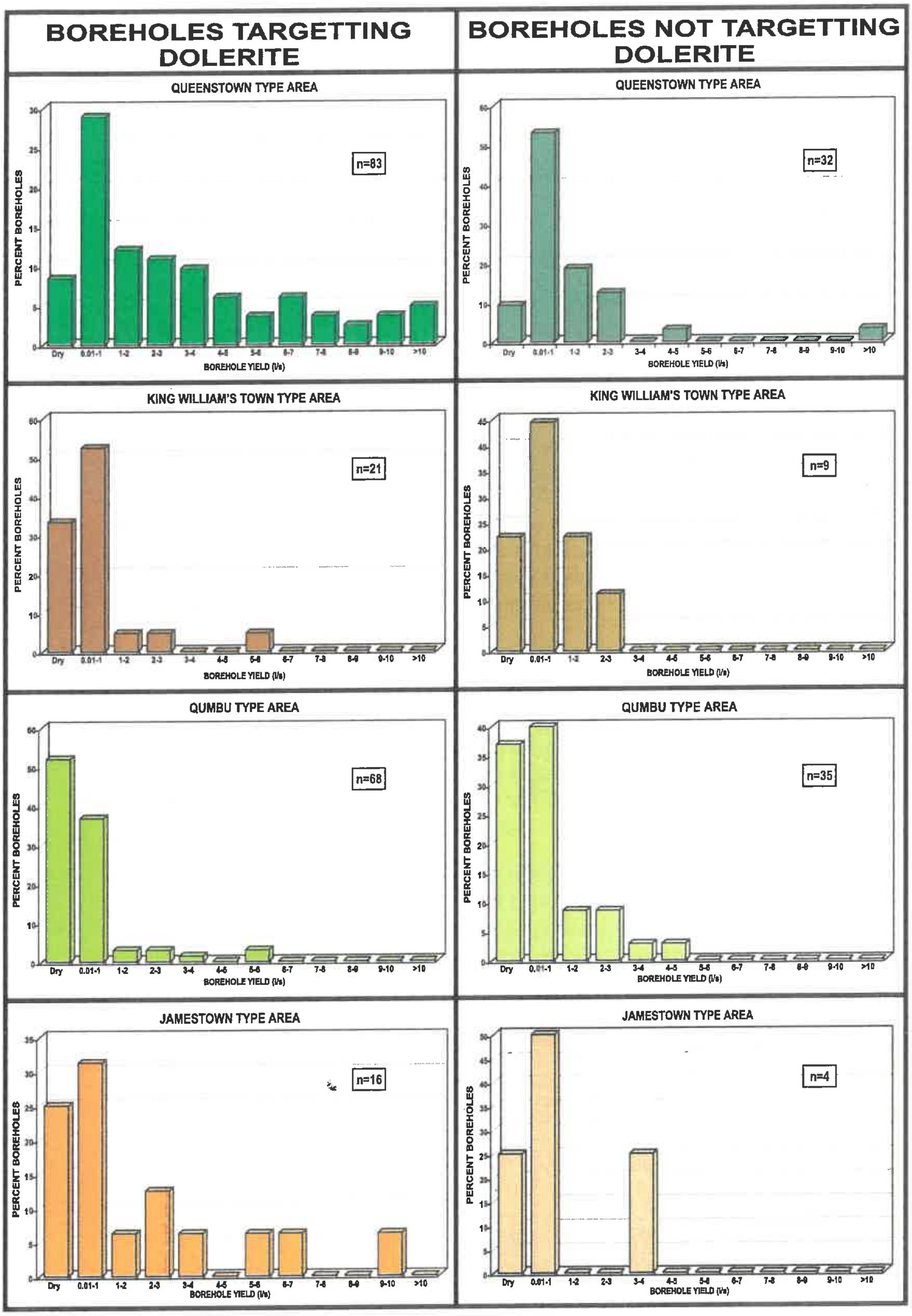
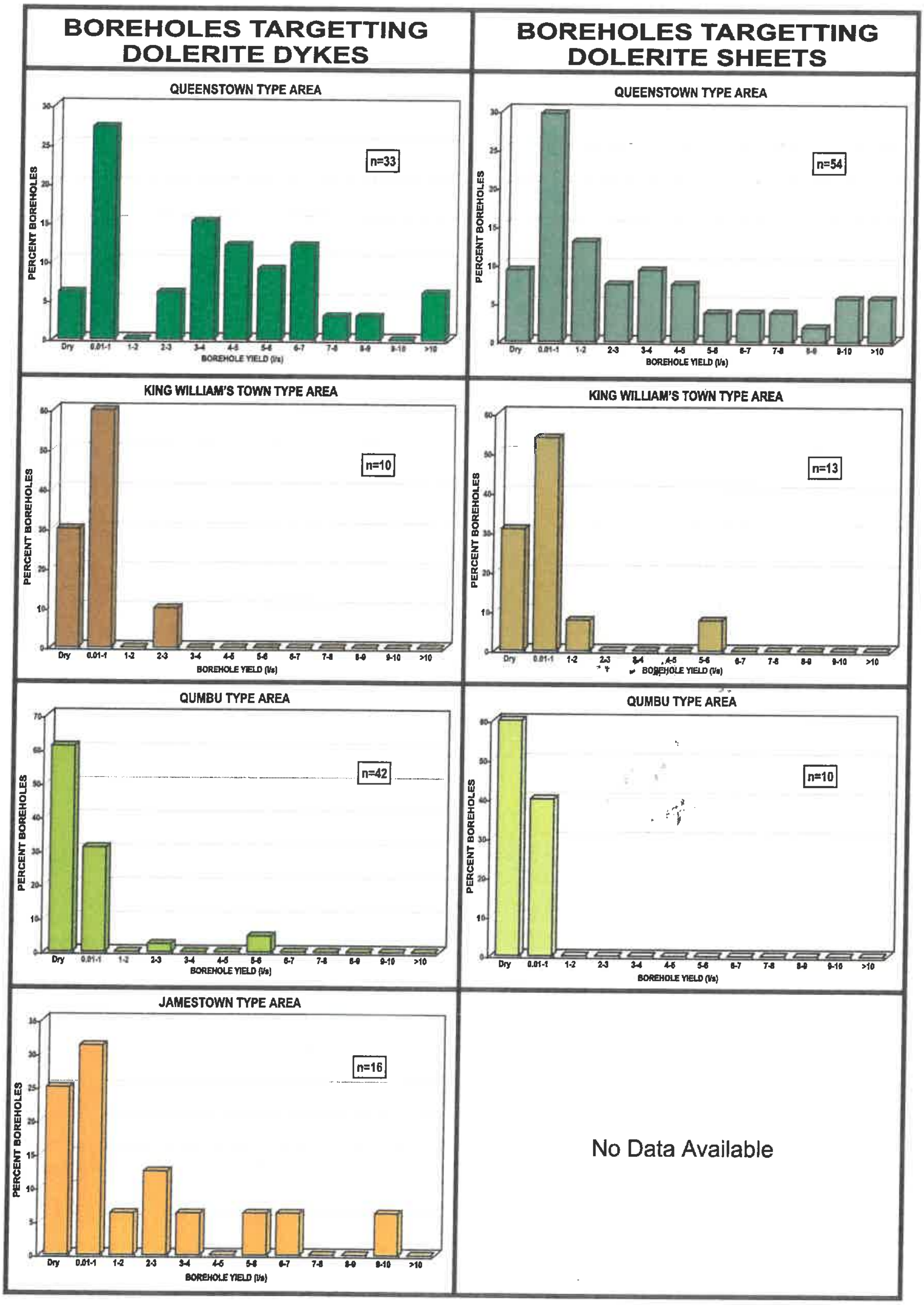


FIG 11: COMPARISON OF BOREHOLE YIELD: SHEETS VERSUS DYKES



The reason for this low success rate has probably more to do with economics than hydrogeology. Limited financial resources have often precluded the optimal siting of boreholes. Historically, drilling has taken place in or very close to the villages, generally situated on hilltops, which is far from ideal from topographic considerations, and gives no choice in selecting the best site from geological considerations.

There is no apparent reason why similar yields to the Queenstown type area cannot be obtained, given optimal borehole siting. Clay products from the more intense weathering in the more humid eastern parts of the study area could result in reduced fracture transmissivities, but only at shallow depths.

From the yield frequency histograms (Fig. 11) dykes appear to be more productive than dolerite sheets. However, in the same way that dolerite in general has not been adequately tested in this area, it is even more likely that dolerite sheets in particular have not been properly explored.

4.2.1.7 Jamestown type area

Dolerite dykes are common in this area and sheets/sills are rare. In the Dordrecht area, Meyer (1984) found the topographically up-gradient sides of dykes to be most productive. Yields in excess of 2 ℓ/s are rare but up to 9 ℓ/s are obtained in some instances. These results are much higher than the yields obtained from dykes in the King William's Town and Qumbu type areas which rarely exceed 3 ℓ/s, but not as high as the Queenstown type area where approximately 5% of boreholes targeting dolerite yield in excess of 10 ℓ/s.

4.2.1.8 Discussion

Dykes are generally longer and more abundant in the higher yielding Queenstown and Jamestown type areas than in the other two areas. This correlation could indicate that the abundance and length of dyke intrusions reflect the degree of associated structural disturbance / fracturing resulting in higher borehole yields.

Assuming the study area is subject to regional compression from the south-east, dykes with a north-west trend will be in tension and associated fractures more open as a result. This could also partly explain the better results obtained in the Queenstown and Jamestown type areas where this trend is more prominent.

However, with the current level of information it is only possible to speculate as to the reasons for the borehole yield variations associated with dolerite. Detailed research-orientated drilling investigations in the individual type areas are required to better explain such variations. Such a drilling programme would entail drilling traverses through typical dolerite intrusions to determine their structure, obtain detail on the distribution of associated fractures, including their orientation and yield.

Until such information is obtained it would be wise not to be too dogamtic, or to make sweeping generalisations, about the relation between groundwater occurrence and dolerite intrusions. This is especially true in areas that appear to have little groundwater potential associated with dolerite. This could well be due to the lack of scientifically-sited boreholes, rather than any lack of potential associated with the dolerite.

4.2.2 Aquifers associated with fracturing unrelated to dolerite intrusions

In general fractured sedimentary rock (not influenced by dolerite intrusion) yields less than 1 ℓ/s. Higher yields are obtainable up to 3 ℓ/s but can be as high as 5 ℓ/s in exceptional cases (Fig. 10). Virtually all these boreholes yield less than 5 ℓ/s whereas approximately 20% of yields exceed 5 ℓ/s in boreholes targeting dolerites in the same area.

Tectonically induced fracturing of sedimentary rock is particularly important in the dolerite-scarce folded terrain in the Bedford vicinity in the south-western corner of the study area. High yields, mostly less than 4 ℓ/s but up to 20 ℓ/s, are obtained and there are relatively few dry boreholes (only 17% of boreholes are dry in this folded area whereas elsewhere in undeformed dolerite-rich areas between 23 and 45 % of boreholes are dry). This region was influenced by compressive stresses from the south during the Cape Orogeny resulting in folding. Enhanced fracturing of the affected sedimentary rocks is noted in association with the more intensely folded portions, in particular at anticline hinges (Simonis, 1987).

Lithological boundaries represent favourable zones for development of openings where there is local flexure and rock competence contrast e.g. mudrock-sandstone contacts (HKS, 1991). Unconformities at lithological contacts are likely to be more productive due to weathering effects at the contact. For example two boreholes drilled to test the lithological unconformable boundary between the Natal Sandstone and Dwyka Tillite Group (SRK, 1993) yield approximately 6 ℓ/s , which are abnormally high yields for these two lithological units.

Another lithological boundary which can be singled out as a potential target is the contact between the Drakensberg Group basalt and the underlying Clarens Formation Sandstone (in the north of the mapped area). High yields (as high as 10 ℓ/s) are reported at this contact, which is also a relatively common site for spring emanations.

Faults Very limited borehole yield data are available for faults but indications are that these structures represent poor targets for groundwater (all 7 boreholes known to have targeted faults are dry). By way of illustration a 116 m deep borehole sited by the author drilled into a major (3 000 m throw) east-west trending fault situated to the south of the study area. Although outside the study area it is typical of the major faults along the coast within the study area. The rock material was very soft and highly friable, and the borehole produced only seepage, although it became weakly artesian a few hours after completion of the borehole.

Based on this experience it is speculated that the material infilling fault planes in the study area is of low permeability. A number of factors could jointly be responsible for this low permeability. The generally incompetent nature of the sedimentary rocks and the large-scale movement could result in formation of rock flour as opposed to a highly transmissive breccia with angular rotated fragments. In addition, intense weathering (decomposition) associated with the high rainfall areas where major faults are concentrated could further limit breccia fragment size and transmissivity.

4.2.3 Intergranular aquifers

These aquifers are unconsolidated sedimentary deposits where groundwater occupies interconnected pore spaces. Consolidated rocks with a significant intergranular porosity or transmissivity are not found in the study area. Boreholes drilled into alluvial aquifers in general yield less than 1,5 ℓ/s. Isolated coarser and thicker occurrences yield in excess of 5 ℓ/s. Higher yields may be obtained in these aquifers by constructing large diameter wells.

Extensive unconsolidated colluvial and fluvial deposits are found only in the north-west quarter of the map in the vicinity of Queenstown. For the remainder of the area uplift resulted in a relatively young, deeply incised, eroding landscape with little scope for deposition, hence isolated unconsolidated fluvial deposits are found only in some few sections of river channels.

The alluvial and colluvial inland deposits investigated by DWAF (Vandoolaeghe, 1980) in the Queenstown vicinity were found to have much lower yields than the underlying fractured rock aquifers. The explanation for the low yields is that the grain size is very fine resulting in very low permeabilities.

In general, these aquifers are considered to have a relatively low storage capacity because the deposits are relatively thin with a limited saturated thickness (usually less than 5 m). During dry periods bedrock is commonly exposed in river channels. Under these circumstances groundwater will drain into the river channels and as a result the alluvial deposits will not be permanently saturated.

Coastal deposits also provide aquifers of only local importance due to their limited extent. Sporadically developed coastal dunes are restricted to a very narrow zone within 2 km of the coast. An investigation at Bonza Bay (Boehmer, 1969) showed the underlying fractured rock to be more productive than the dunes, while the dunes have some value as a storage medium, a situation similar to the inland alluvial deposits.

4.3 Regional variation in borehole yields

Hydrogeologically distinct regions were identified to allow borehole yields from areas of differing character to be compared. The hydrogeological regions

Table 1: Characteristics of the hydrogeological regions

Hydrogeological region	Dole rite		Host rock (in order of abundance Mdst = Mudstone Sst = sandstone	Dominant structure and trend	Fractured (F) or fractured and intergranular (F+I)	Statistics of borehole yield (ℓ/s)							Total boreholes
	Dyke	Sheets and sills				Median	75% tile	25% tile	Mean	Standard deviation	Upper standard deviation	Lower standard deviation	
1	Common	Common	Mdst, Sst	NNW dykes	F	1.06	2.52	0.40	0.9	0.64	3.92	0.21	267
2	Common	Common	Sst, Mdst	NNW + EW dykes	F	1.06	5.80	0.25	0.86	0.78	5.13	0.15	86
3	Common	Rare	Mdst, Sst	NW + NE dykes	F+I	0.06	1.28	0.18	0.45	0.71	2.23	0.38	177
4	Common	Common	Mdst, Sst	NW + NE dykes	F+I	0.63	1.58	0.23	0.59	0.63	2.52	0.14	474
5	Common	Rare	Sst	WNW + NNE dykes	F+I	1.22	2.56	0.68	0.95	0.57	4.83	0.35	19
6	Common	Rare	Basalt	WNW dykes	F+I	0.64	1.83	0.14	0.5	0.75	2.83	0.09	147
7	Common	Common	Sst, Mdst	NNW + NNE dykes	F+I	1.23	2.25	0.45	1	0.45	2.85	0.35	94
8	Common	Common	Mdst, Sst	NW + NE dykes	F+I	0.62	1.00	0.3	0.62	0.38	1.5	0.57	52
9	Rare	Common	Shale	NW dykes	F+I	1.17	1.78	0.55	0.16	0.35	0.36	0.07	80
10	Rare	Rare	Tillite	NW dykes	F+I	0.30	0.65	0.14	0.02	0.53	0.07	0.01	55
11	Rare	Rare	Sst	NW dykes	F+I	0.50	1.04	0.18	0.47	0.04	1.22	0.19	28
12	Common	Common	Mdst, Sst	NW dykes	F+I	1.88	4.43	0.75	1.74	0.6	6.91	0.44	709
13	Common	Common	Mdst, Sst	NW dykes	F+I	1.80	3.00	0.65	1.3	0.45	2.9	0.36	310
14	Common	Common	Sst, Mdst	NW + ENE dykes	F+I	1.01	2.50	0.32	0.84	0.52	2.76	0.25	248
15	Common	Common	Mdst, Sst	NW + ENE dykes	F+I	0.50	1.26	0.3	0.58	0.42	1.53	0.22	61
16	Common	Common	Sst, Mdst	NW dykes	F	0.61	2.54	0.1	0.49	0.82	3.3	0.07	98
17	Common	Common	Sst, Mdst	NW + EW dykes	F+I	0.85	2.50	0.33	0.77	0.59	2.99	0.2	249
18	Common	Common	Sst, Mdst	NW + NNE dykes	F+I	0.89	2.15	0.28	0.65	0.65	3.41	0.17	268
19	Common	Common	Mdst, Sst	NW + NS dykes	F+I	0.49	1.36	0.11	0.53	0.73	2.84	0.1	389
20	Rare	Common	Mdst, Sst	----------	F+I	0.70	1.55	0.1	0.48	0.75	2.76	0.08	122
21	Rare	Common	Mdst, Sst	----------	F	0.59	1.55	0.07	0.4	0.82	2.69	0.06	85
22	Rare	Common	Mdst, Sst	----------	F+I	0.60	1.83	0.21	0.57	0.67	2.68	0.12	676
23	Rare	Rare	Mdst, Sst	Folding (EW)	F	5.00	8.00	1.4	3.62	0.53	12.03	1.09	81
24	Rare	Rare	Mdst, Sst	Folding (EW)	F+I	0.63	1.98	0.28	0.66	0.61	2.7	0.16	379
25	Rare	Common	Mdst, Sst	Faults (ENE)	F+I	0.25	1.51	0.06	0.29	0.79	1.79	0.05	35
													5 189

identified for this study are given in Fig. 12 and their characteristics are given in Table 1. Factors taken into account when delineating these areas included:

- ❑ Dolerite abundance and style of intrusion
- ❑ Lithology
- ❑ Geological structure (faults, folding, dyke orientations)
- ❑ Intensity and mode of weathering
- ❑ Catchment boundaries

Instances occurred where groups of higher yielding boreholes were identified without there being an obvious hydrogeological explanation for that area being superior. Despite this these areas were assigned to separate hydrogeological regions for statistical analysis e.g. the higher yielding boreholes around Queenstown were analysed separately from those in the hydrogeologically similar Burgersdorp Formation further to the east. This was done to avoid extrapolating unrealistically high borehole yields to the eastern area. The results of the statistical analyses for each region are included in Table 1.

The following examples demonstrate that what one sees on a regional map depends on how the data are analysed and presented. It must be pointed out that the one method is not necessarily better than another, but rather the use of a variety of methods serves to highlight aspects which otherwise go unnoticed.

Example 1

The borehole yield ranges adopted for the standard legend for the General Hydrogeological Map are not sensitive enough to adequately distinguish yield variation across the study area, because virtually the whole study area falls in a single yield range category (0.5 - 2 ℓ/s). A better indication of yield ranges for this area can be obtained from Fig. 13 compiled using narrower yield ranges for the legend.

Example 2

Focusing on the incidence of dry boreholes reveals the lowest incidence of dry boreholes in the west and south-west of the region (latter affected by the Cape Orogeny) as well as the Natal Group Sandstone in the extreme north-east (Fig. 14). This figure was compiled by determining the percentage of dry boreholes within each of the 25 hydrogeological regions. Those regions with less than 15% dry boreholes were assigned a "low" incidence and those exceeding 15% dry boreholes a "high" incidence. The median percentage of dry boreholes for the hydrogeological regions comprising the area of "low" incidence is 12% whereas the median percentage of dry boreholes for the area of "high" incidence of dry boreholes is 38% and can reach 60 %.

Example 3

An examination of the areal distribution of higher yielding boreholes (in the 3 - 10 ℓ/s range) reveals the pattern highlighted in Fig. 15. The area with higher yielding boreholes is affected by folding in the extreme south-west

FIG 12: HYDROGEOLOGICAL REGIONS

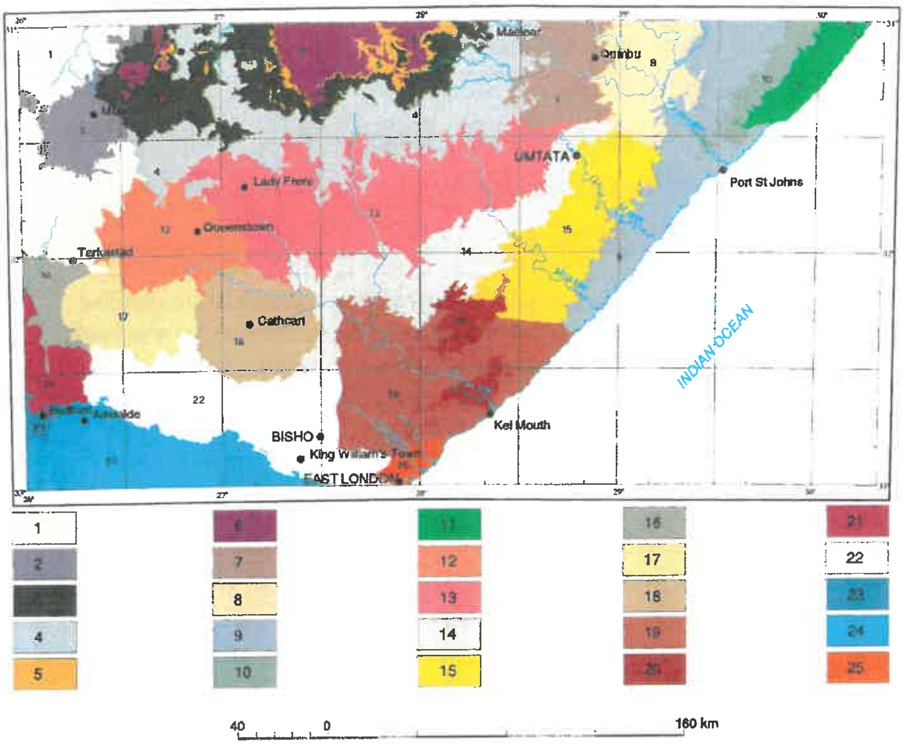


FIG 13: HYDROGEOLOGICAL MAP USING ALTERNATIVE YIELD CLASSES

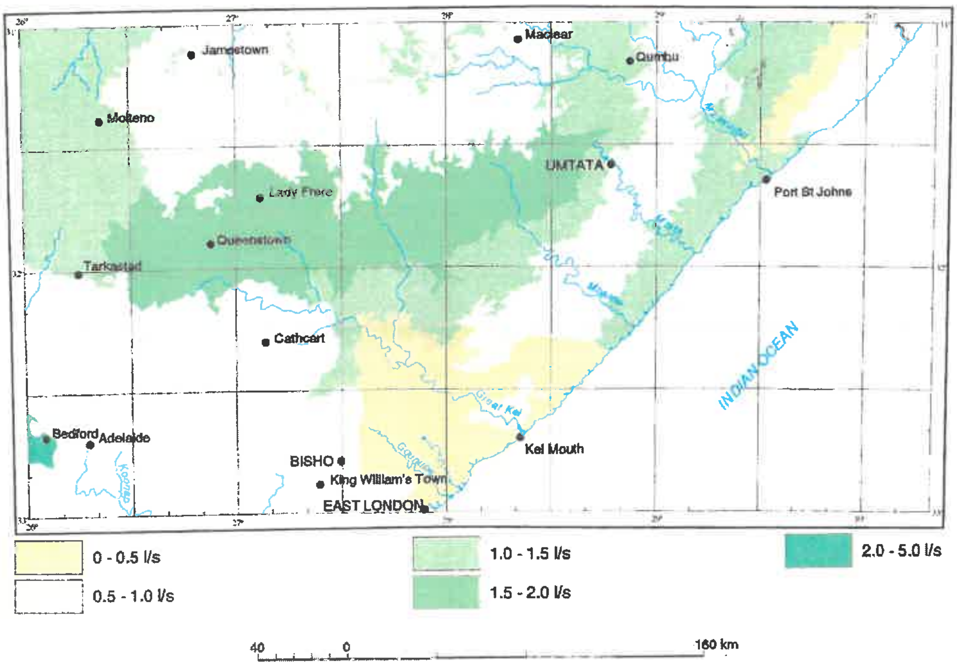


FIG 14: RELATIVE INCIDENCE OF DRY BOREHOLES

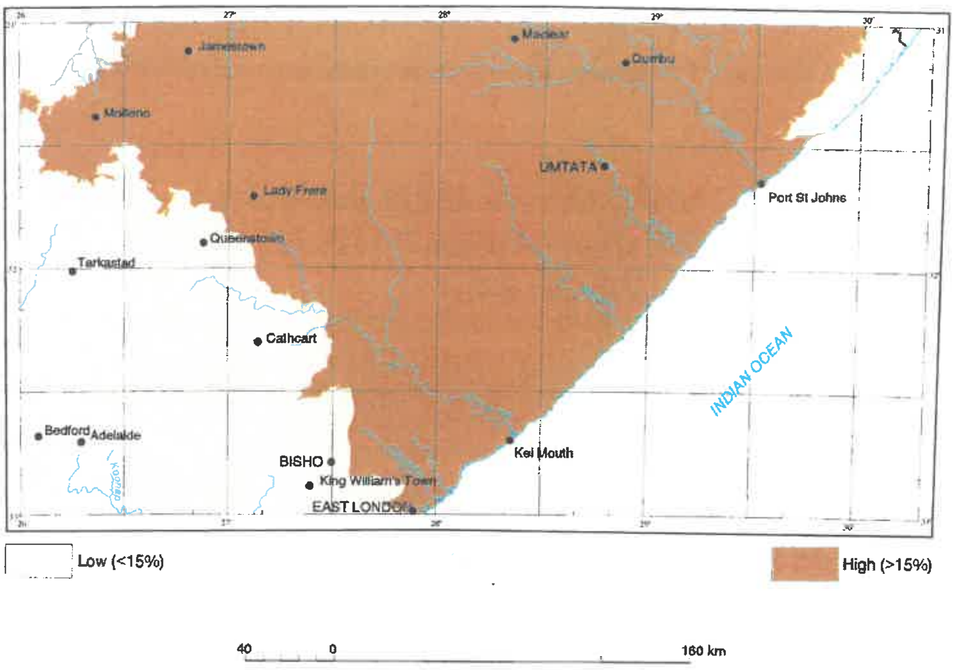
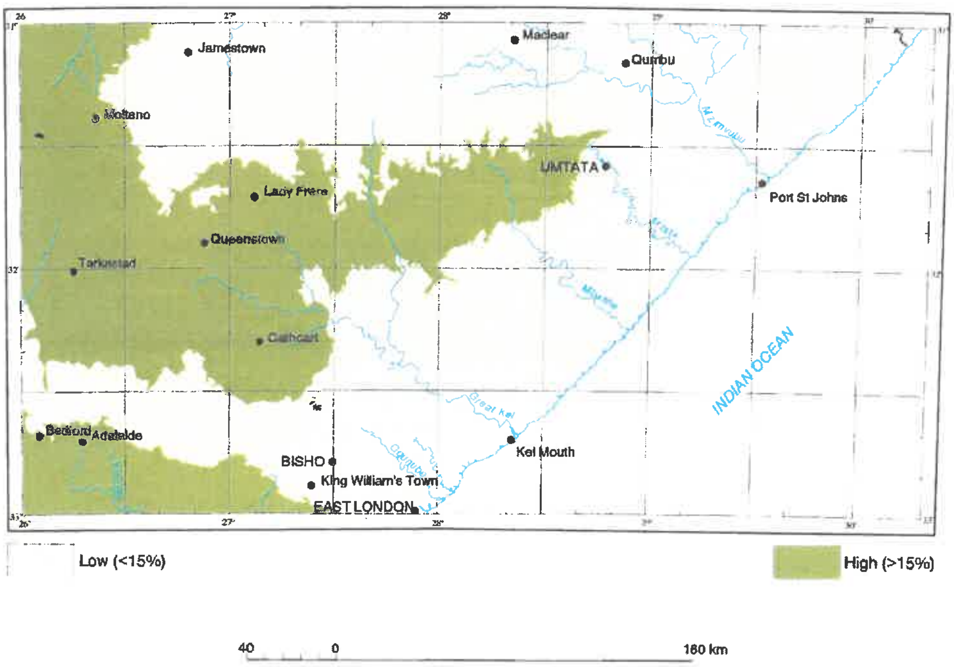


FIG 15: RELATIVE INCIDENCE OF HIGH-YIELDING BOREHOLES IN THE 3-10 ℓ/s RANGE



(Bedford area) as well as in a centrally situated east-west trending zone in the Queenstown area coinciding with ring-shaped dolerite intrusions into the Burgersdorp Formation.

A discussion of the observed borehole yield variations in the study area follows:

4.3.1 Low incidence of dry boreholes in the west (regions 1, 12, 16, 17, 21, 22, 23, 24)

The relatively low incidence of dry boreholes in the western portion of the study area indicates a generally higher degree of fracturing of the rock matrix in this area.

This could possibly be related to a higher degree of tectonism affecting the western part of this area, the intensity dissipating towards the east. This could well be the case if the abundance of dolerite dykes is taken as a reflection of the intensity of tectonism affecting the study area. Dolerite dykes are abundant in the western parts becoming progressively less frequent toward the east (Fig. 6).

Mode of weathering could play a role in the observed change in incidence of dry boreholes across the study area from east to west. Clay minerals generated by weathering by decomposition in the eastern parts may result in lower transmissivities of near surface fractures (and higher incidence of "dry" boreholes) than in the west where weathering by disintegration will not generate clay minerals. A higher density of fractures associated with folding in the south-western part of the area could explain the low incidence of dry boreholes in regions 23 and 24.

4.3.2 High yields in the Bedford vicinity (regions 23 and 24)

These result from fracturing associated with folding related to the Cape Orogeny. The fact that the lithology is relatively competent (sandstone-rich) probably results in fractures being more open than if it were mudrock-rich (fractures tend to squeeze closed under load pressure in the softer, more mudrock-rich lithologies).

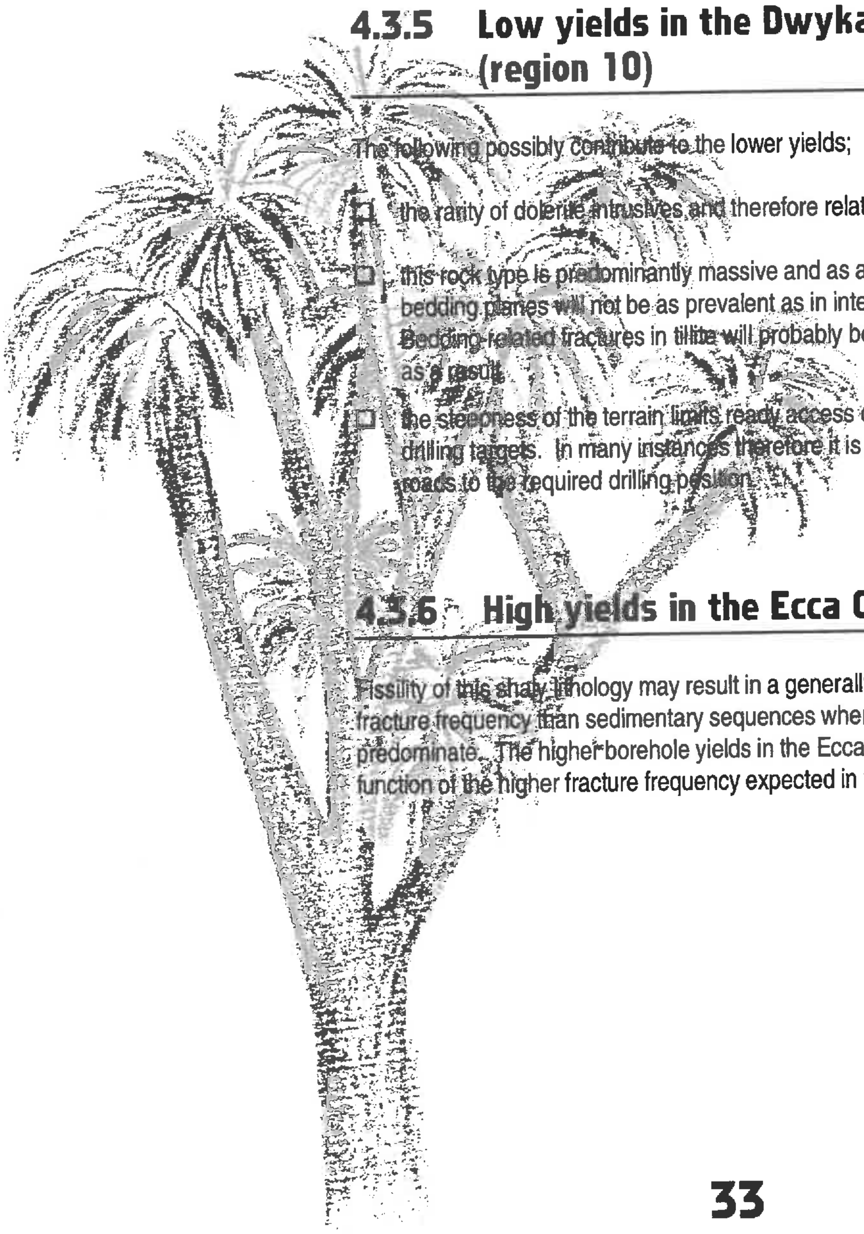
4.3.3 High yields in the Queenstown vicinity (regions 1, 2, 12, 13, 16, 17 and 18)

Ring-shaped dolerite intrusions and irregular sheets are concentrated within these regions indicating that deformation related to their emplacement may have resulted in more intense fracturing than surrounding areas. It could be argued that better yield statistics obtained for region 12 results from this area being the focus of an intensive scientific drilling programme (Vandoolaeghe, 1980). This argument does not hold however because the median yield is virtually identical to that obtained for region 13 where no such programme was undertaken.

4.3.4 Low yields in the East London - Kei Mouth area (regions 19 and 25)

Dolerite dyke orientation in this area differs markedly from the other areas as here the predominant dyke trends are east-west and west-south-west. Assuming that the regional maximum compressive stress is indeed directed from the south-east, structures of this orientation will be under compression. Generally low yields could therefore be expected because the major fractures may be closed.

4.3.5 Low yields in the Dwyka Tillite Group (region 10)



The following possibly contribute to the lower yields;

- the rarity of dolerite intrusives and therefore related targets,
- this rock type is predominantly massive and as a result fracturing on bedding planes will not be as prevalent as in interbedded lithologies. Bedding-related fractures in tillite will probably be discreet/discontinuous as a result.
- the steepness of the terrain limits ready access of drilling rigs to optimal drilling targets. In many instances therefore it is necessary to construct roads to the required drilling position.

4.3.6 High yields in the Ecca Group (region 9)

Fissility of this shaly lithology may result in a generally higher bedding-related fracture frequency than sedimentary sequences where massive mudrocks predominate. The higher borehole yields in the Ecca Group can possibly be a function of the higher fracture frequency expected in the more fractured shale.

4.4 Variations in borehole yield with depth

Two aspects are considered in relation to depth of borehole - the probability of striking water, and the average borehole yield.

To ascertain water strike probability with depth, the total number of groundwater interceptions obtained in each 5 m depth interval was determined. The number of interceptions in each 5 m depth interval expressed as a proportion of the total number of interceptions for the entire depth range of all boreholes was taken as the probability of striking water within that depth interval.

As far as the probability of striking water is concerned, the general trend (Fig. 16) is a decrease in the chances of striking groundwater with depth below the land surface (average water level for the region was 17 m below surface). An inflection point in this trend occurs at approximately 55 m below surface which point marks the bottom limit of a more intensely fractured zone. The probability of striking groundwater decreases more sharply in the zone between groundwater level and 55 m below surface than between 55 and 135 m.

The mean borehole yield obtained at water strikes in relation to depth below surface (Fig. 17) shows little significant variation with depth.

As far as optimum drilling depths are concerned, these statistics can be looked at in two ways. If a large number of boreholes are to be drilled, then 50 m would appear to be the optimum maximum drilling depth. The overall average water yield per metre drilled is certainly not going to increase by drilling boreholes deeper than this. On the other hand, if drilling sites are limited, for example by difficult terrain, it would be unwise to discontinue at 50 m and turn to more expensive alternatives like surface water as additional water strikes may be intercepted at much greater depths.

4.5 Springs

Springs are important groundwater sources in the high rainfall areas (mainly in the east of the area as well as in the mountainous areas). Snowfalls in the Drakensberg enhance recharge to the springs - the slow melting process allowing more time for percolation of the melt to groundwater as opposed to rapid runoff from rainfall.

Springs emanate wherever the water table/piezometric surface coincides with the land surface. Common spring sites include:

- dykes intersecting drainage features,
- contacts of dolerite sills/sheets,

FIG 16: PROBABILITY OF STRIKING GROUNDWATER WITH DEPTH FROM SURFACE

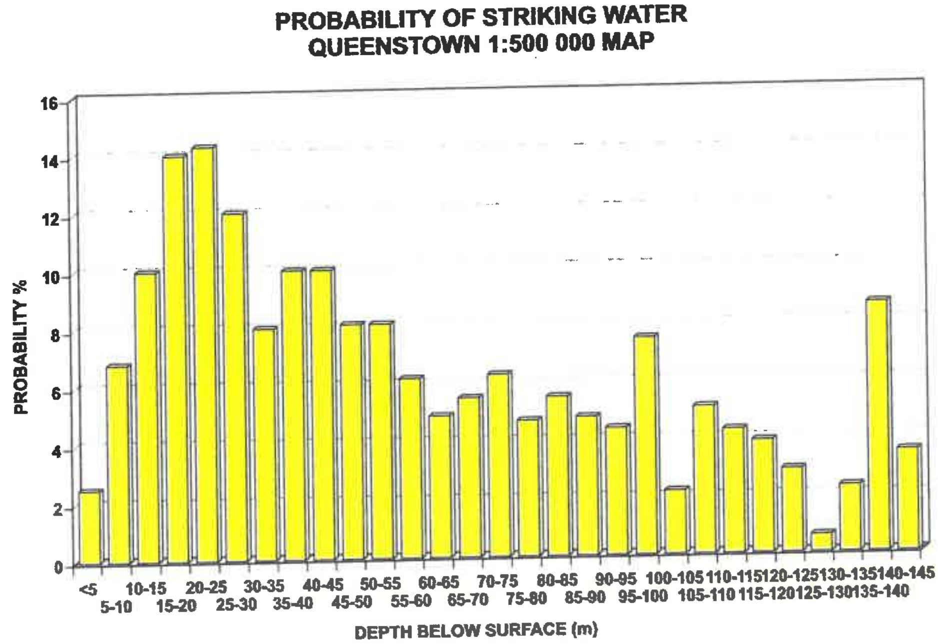
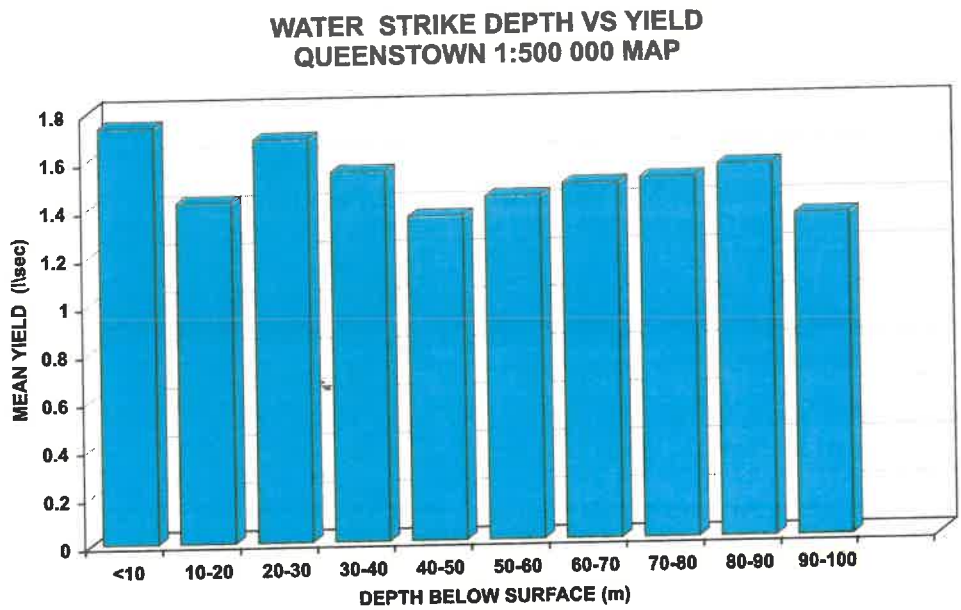


FIG 17: YIELD OBTAINED AT WATER STRIKES IN RELATION TO DEPTH FROM SURFACE



- basal contact of a fractured sandstone with an underlying less permeable mudrock horizon,

- weathered basins (usually weathered dolerite sheets) also known as "sponges".

The yield and sustainability of spring flow depends on an interplay between the recharge rate, the size of the groundwater reservoir, permeability of the aquifer feeding the spring and the hydraulic head above the spring outlet. A perennial high flow rate indicates both large reservoir capacity plus high transmissivity. Flows of short duration after recharge events indicate a low reservoir capacity relative to the transmissivity. In the latter case the relatively high flow rate results in rapid dewatering of the source aquifer. Obviously flow from springs which are more regularly replenished will also be sustained longer, but storage capacity remains the overriding factor.

4.6 Groundwater quality and chemical characteristics

4.6.1 Regional electrical conductivity trends

Regional quality trends are given in Fig. 18. The contour map is based on a relatively sparse distribution of sample points and therefore only depicts general trends. Local quality variations will occur with the result that trends depicted on the map can differ significantly from that found at a point in the field.

In the study area electrical conductivities (ECs) rarely exceed the 300 mS/m i.e. maximum acceptable limit for human consumption (SABS, 1984). The areas where the 300 mS/m limit is exceeded include the extreme south as well as in localised areas such as faulted terrain near Port St. Johns. In the latter case it exceeds 1000 mS/m.

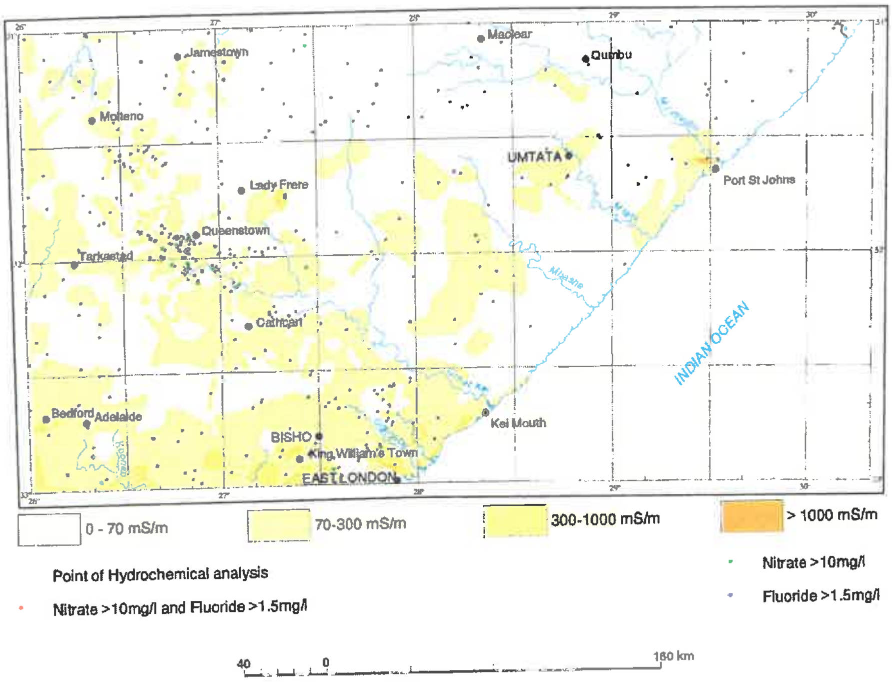
While the water quality for sampled springs and boreholes obtained from the Dwyka Tillite Group diamictite (in the north-east of the study area) is generally less than 300 mS/m, there are indications that deep saline water exists in this rock type. Evidence for this is the saline springs (EC = 1400 mS/m) emanating at the bottom of deep gorges in the Bizana area, 300 m below the surrounding plateau (Bond, 1946).

Anomalously high individual electrical conductivities are obtained near Umtata and Lady Frere. The reason for these high ECs is not known.

In general the lowest ECs are found where the precipitation is highest. Lower ECs are therefore found in the north-eastern half of the map where annual precipitation usually exceeds 600 mm and along mountain ranges e.g. Amatola, Elandsberg, Didima ranges (Fig. 1). The poorer quality water occurs in the topographic depressions where the precipitation is lower.

Comparison of lithology (Fig. 5) with precipitation (Fig. 2), elevation (Fig. 1) and groundwater quality (Fig. 18) shows that the more resistant sandstone-rich formations tend to form topographic highs or escarpment faces which receive higher precipitation and display better quality groundwater e.g. Katberg Formation north of Adelaide and the Molteno Formation east of Lady Frere. The less resistant mudrock-rich lithologies tend to occupy topographic lows. It is evident therefore that lithology influences groundwater quality trends, if only by virtue of its influence on topography and hence precipitation.

FIG 18: GROUNDWATER QUALITY AND SOME HYDROCHEMICAL DETAILS



4.6.2 Local cases of high nitrate and fluoride levels

These two chemical constituents are introduced to give examples of chemical characteristics for the area. In a reconnaissance-type study of this nature it is impossible to map nitrate and fluoride concentrations for the area as a whole. Thus when, say, high nitrate levels are discussed, it should be remembered that the cases discussed are by no means the only cases of high nitrate levels to be found in this map area. Nor should it be implied that fluoride and nitrate are the only two chemical constituents of concern in this area.

Nitrates

Fig. 19 is a frequency distribution histogram of nitrate concentrations from analyses available on the National Water Quality Data Base.

Eight percent of analyses available for the study area exceed the 10 mg/ℓ maximum limit for insignificant risk, and the localities of these elevated nitrates are shown Fig. 18. An investigation by the author into the incidence of high nitrates in groundwater to the north of East London revealed that inadequate precautions in the design of cattle watering points were the likely cause - resulting in faecal pollution of the water (Plate 5). It is likely that similar point pollution sources are responsible for the scattered high nitrates across the area.

Plate 5: *A borehole which had to be abandoned due to nitrate pollution from cattle excrement (the cattle drinking rough is situated too close to the borehole and the borehole itself is inadequately sealed at surface by the too small contrete block)*

In addition downward leaching of nitrogenous fertiliser is a likely nitrate contributor, especially to the group of boreholes of the south-west of Queenstown where intensive crop farming is practised. Another possible nitrate source in the Queenstown area is the treated municipal sewage water, which is used for irrigation.

Fluoride

Fig. 20 is a frequency distribution histogram plot of fluoride concentrations from analyses available in the National Water Quality Data Base, the highest recorded fluoride content being 5.6 mg/ℓ.

Fluoride content exceeds the 1.5 mg/ℓ SABS maximum limit for insignificant risk in seven percent of the available analyses, the localities of which are given in Fig 18. In the northern part of the study area the fluoride highs are most common in boreholes drilled into the Molteno Formation.

High fluoride levels are often related to acidic igneous rocks, and the probable granitic origin of the material which comprises the Molteno Formation sediments (Turner, 1975) could be a source of the elevated fluorides. Gases associated with volcanism are an important source for fluoride in natural water

FIG 19: FREQUENCY DISTRIBUTION HISTOGRAM OF NITRATE CONCENTRATIONS

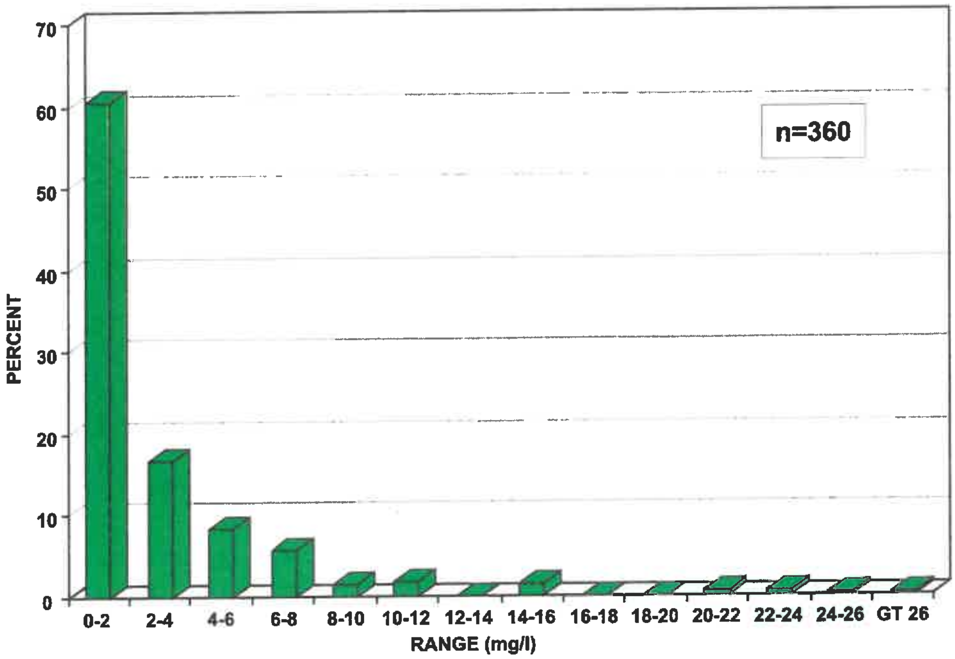
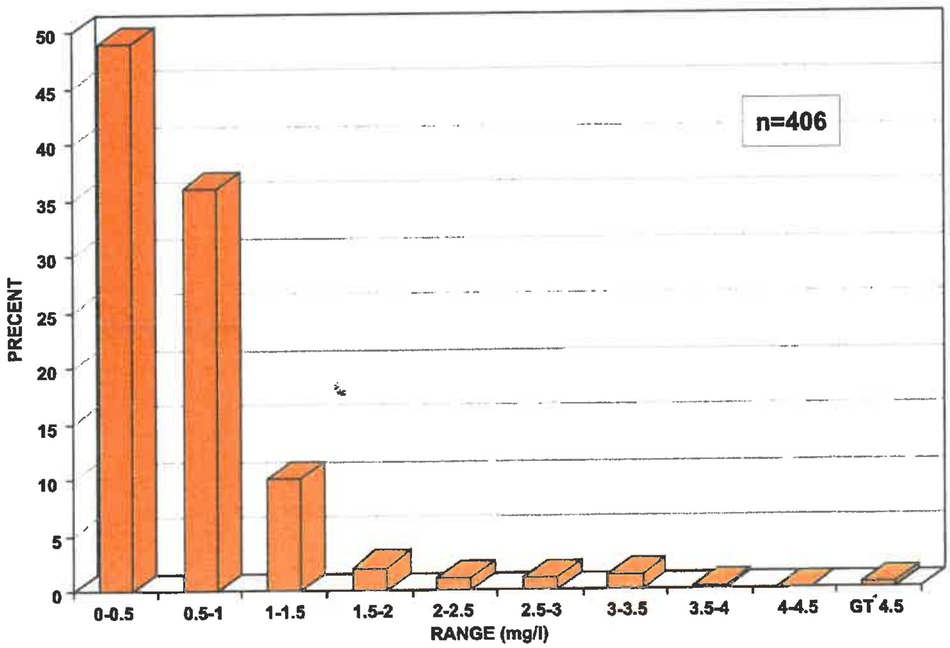


FIG 20: FREQUENCY DISTRIBUTION HISTOGRAM OF FLUORIDE CONCENTRATIONS



(Hem, 1970) and therefore another possible explanation for the fluoride anomalies is the volcanic plugs which are relatively common at the stratigraphic level of the Molteno Formation.

This explanation is supported by a comparison of the distribution of high fluoride values in the Molteno Formation with the 1:250 000 published geological maps of the area, which reveal that the anomalies do indeed occur in the general vicinity of mapped volcanic plugs.

In the south-western part of the study area fluoride in excess of 1.5 mg/ℓ occurs in the Middelton Formation in the area folded during the Cape Orogeny. It is possible that these concentrations are related to the upwelling of deep-seated thermal water sources. The thermal spring associated with a prominent fold structure to the south of Fort Beaufort provides evidence to support this contention. The fluoride concentration of this spring water is 13.2 mg/ℓ (Kent, 1949) and the groundwater temperature 27° C.

4.6.3 Groundwater hydrochemical classification

The hydrochemical character of groundwater from the various lithologies is summarised using the Piper technique in Fig. 21.

Based on the Piper (1944) classification two main groundwater types are present in the mapped area, namely;

- Sodium Chloride / Na HCO3 type occurring in the Middelton Formation at the southern margin and along the coast, and
- Calcium Magnesium Bicarbonate groundwater for the remainder of the study area.

Sodium Chloride / Na HCO3 waters

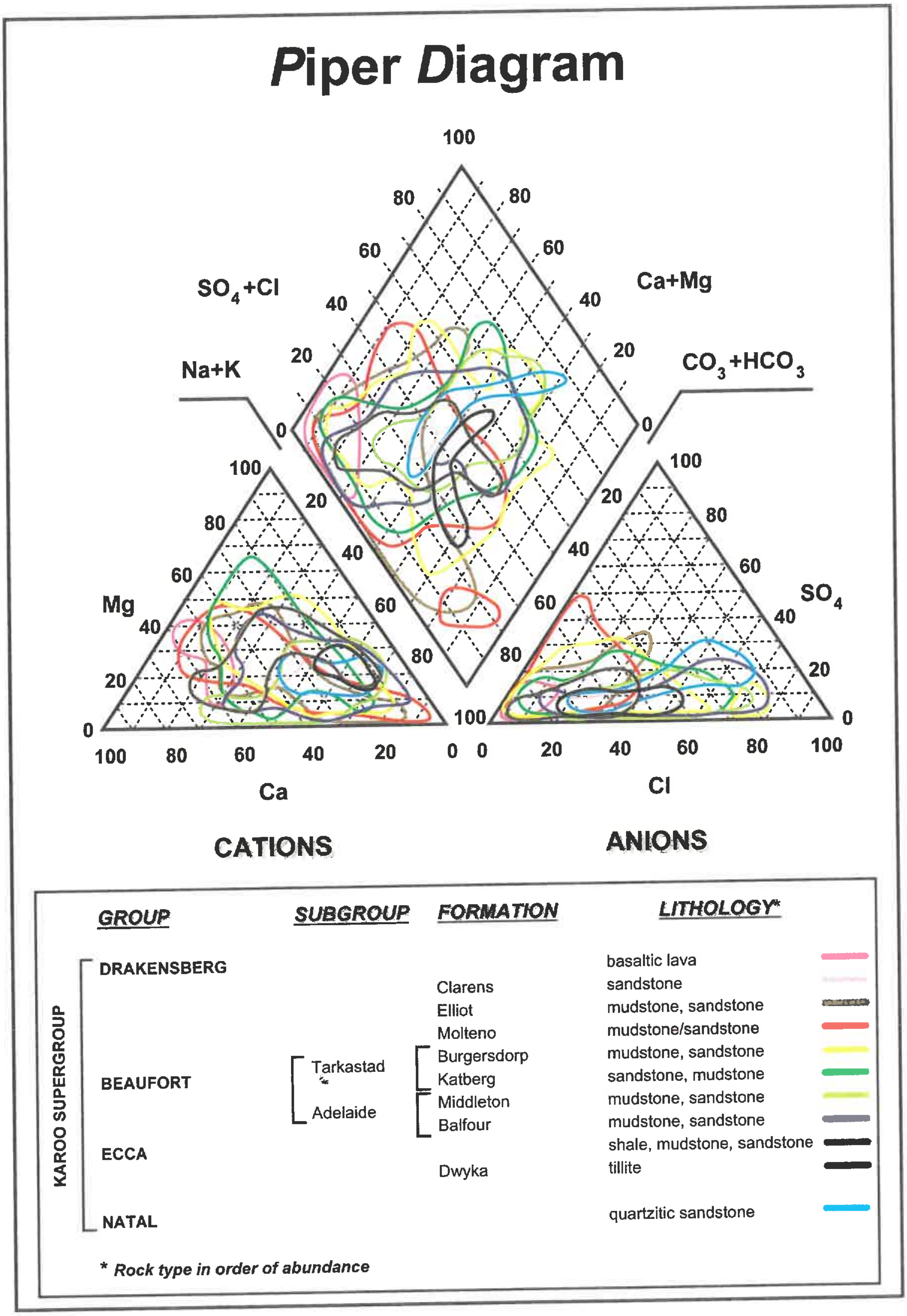
Proximity to the coast with accompanying atmospheric fall-out is most likely responsible for elevated sodium and chloride ionic concentrations along the coast and in the Middleton Formation along the southern margin of the study area.

An investigation of chloride and isotopic relationships (Sami, 1992) in the Bedford vicinity revealed that the chloride ions are indeed of meteoric origin, and that the process was one of a period of evaporative enrichment of meteoric salts at or near the soil surface followed by periodic leaching of these accumulations into the groundwater during storm/recharge events.

Calcium Magnesium Bicarbonate waters

With the exception of the Middelton Formation and the north-eastern coastal margin, groundwater of the study area is predominantly of a calcium-magnesium bicarbonate type with some sodium and chloride enrichment.

FIG 21: COMPOSITE PIPER DIAGRAM



This enrichment is most prevalent in the Burgersdorp, Katberg and Balfour Formations. These bicarbonate waters are indicative of active groundwater circulation (Johnson, 1974), the sodium and chloride enrichment occurring through ionic exchange in the groundwater flow paths.

5 GROUNDWATER DEVELOPMENT

5.1 Existing utilisation

The General Hydrogeological Map shows areas of major groundwater abstraction using a circular symbol to denote total abstraction for a given quaternary catchment. Major abstraction includes agricultural irrigation mainly in the Queenstown area (Plate 6), and municipal supplies e.g. Tarkastad, Sterkstroom, Jamestown, Bedford, Komga.,

Groundwater is also used for domestic supplies and stockwatering in the rural areas. The use of groundwater by rural communities is relatively low per unit area as a result of the widely scattered population and low per capita consumption necessitated by distances from dwelling to water source.

5.2 Exploitation Potential

5.2.1 Introduction

Exploitation Potential is a generic term for describing aquifer rather than borehole yields, and encompasses factors such as the availability of groundwater, the cost of groundwater development, and the desirability of using groundwater. It is not a fixed parameter like, for example storage capacity, but can change according to the intended use of the groundwater.

In this brochure two facets of Exploitation Potential are examined:

- HARVEST POTENTIAL = what can be abstracted if storage and recharge are the only limiting factors,
- ABSTRACTION POTENTIAL = what can be abstracted if transmissivity is the only limiting factor.

Harvest Potential thus represents the maximum **sustainable** abstraction, while Abstraction Potential gives an indication of what can be practically, economically or feasibly abstracted. The Abstraction Potential (according to the definition used in this brochure) is not necessarily sustainable.

Plate 6: *Flood irrigation from boreholes in the Queenstown area*

5.2.2 Harvest Potential

Harvest Potential can be defined as the maximum annual volume of water which is available for abstraction on a long-term basis without exhausting the resource. It was calculated using methods broadly similar to the National Harvest Potential Map (Seymour *et al*, 1996) but with refinements to take into account local knowledge and more extensive data availability.

The Harvest Potential is between 2 000 and 80 000 $m^3/km^2/a$ (Fig. 22). The parameters used were estimates, so the values depicted should be seen more as order of magnitude estimates, rather than as assured maximum supplies.

5.2.3 Abstraction Potential

The Abstraction Potential (Fig. 23) for the various hydrogeological regions was calculated by assuming that it is possible to establish a borehole yielding the median yield every km^2 and that this borehole is pumped for 12 hours per day. Although the logic behind such a generalisation may be questioned, it does allow a broad overall picture to be constructed, and enables one region to be compared with another.

5.2.4 Possibilities for additional development

The lesser of Harvest Potential and Abstraction Potential was taken as the Development Potential (Fig. 24). The Development Potential is probably as close as one can get to what might actually be abstracted, given the limitations of such crude "broad brush" estimates.

FIG 22: GROUNDWATER HARVEST POTENTIAL ($m^3/km^2/a$)

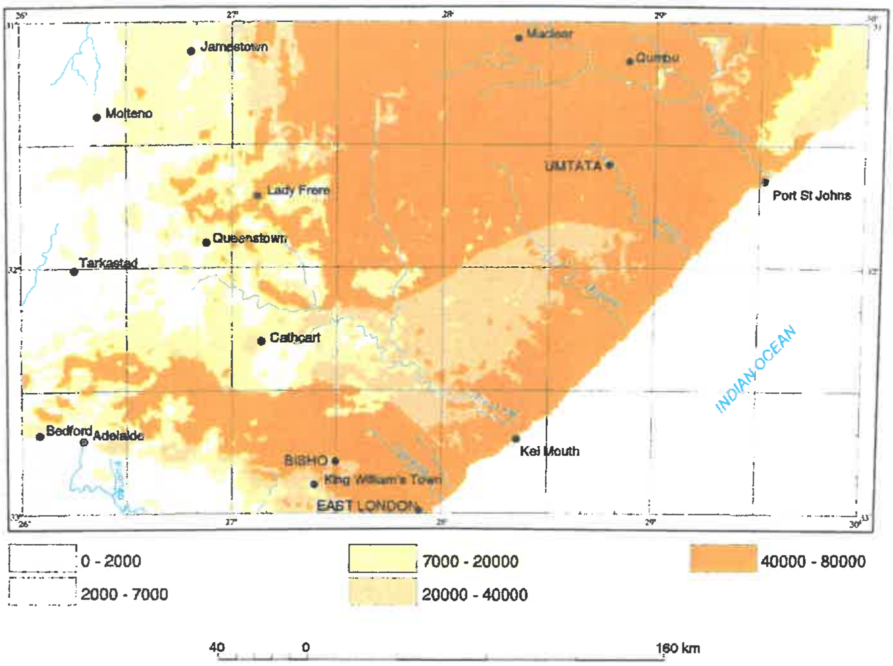


FIG 23: GROUNDWATER ABSTRACTION POTENTIAL ($m^3/km^2/a$)

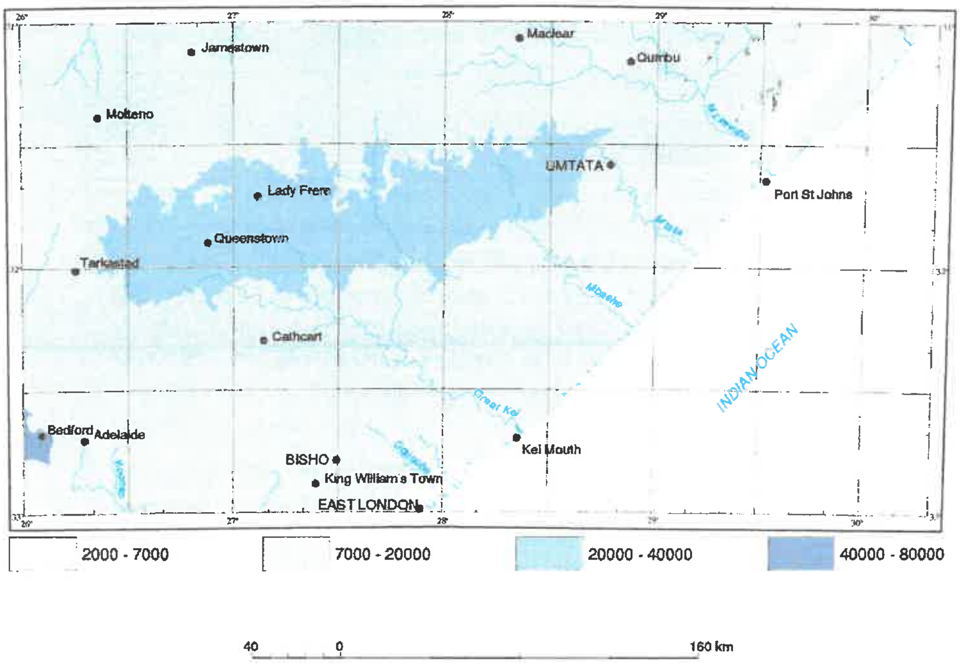
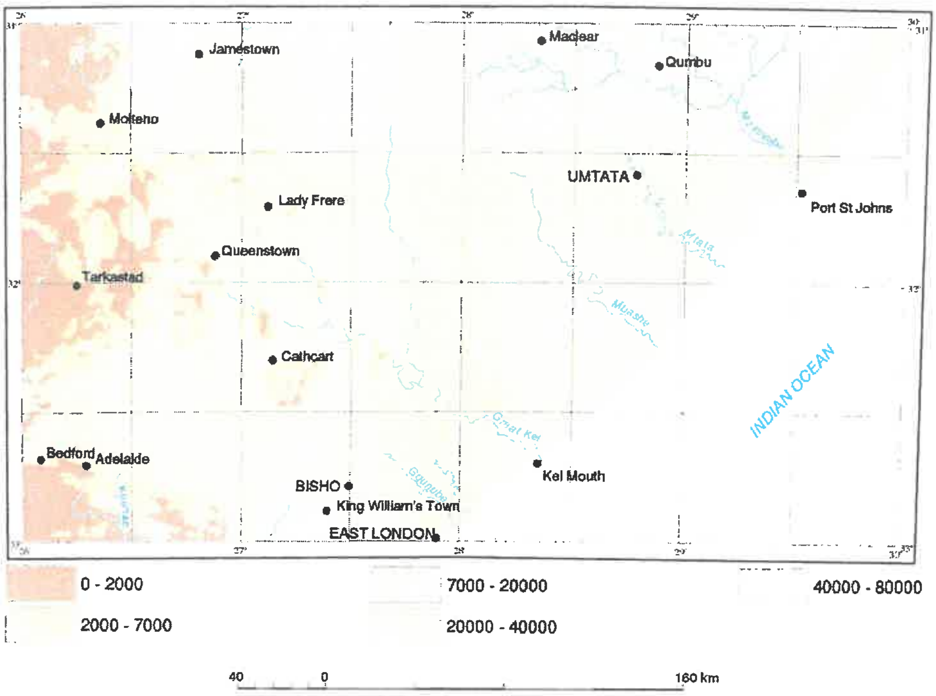


FIG 24: GROUNDWATER DEVELOPMENT POTENTIAL
($m^3/km^2/a$)



The population support capacity, a term used by planners for the number of people that can be supplied with water per km^2, assuming a particular consumption rate, is given for rural and urban supply in Figs. 25 and 26 respectively. For the rural situation a water requirement of 25 ℓ/person/day is assumed and 200 ℓ/person/day is assumed for urban populations.

5.2.5 Risk of over-exploitation

Although as a general rule over-exploitation is possible in any area where potential demand exceeds supply, it is a particularly high-risk scenario where the Abstraction Potential (what may be withdrawn practically or economically) exceeds the Harvest Potential (what may be withdrawn sustainably).

The south-western part of the map (Bedford area) is such an example (Fig. 27). Here the boreholes yields are among the highest for the mapped area, with a median of 5 ℓ/s (or 79 000 $m^3/km^2/a$ assuming one borehole is established per km^2 pumping 12 hours per day) but the Harvest Potential is lowest for the area (2 000 $m^3/km^2/a$).

Areas such as the Bedford area are thus in more urgent need of groundwater management advice or intervention than areas where Abstraction Potential is much less than Harvest Potential - the bulk of the area. In these areas of low Abstraction Potential the low transmissivities are, in effect, the groundwater abstraction controllers since they make over-abstraction on a regional scale both difficult and unlikely. It would require too many low-yielding, closely spaced boreholes to over-exploit the low transmissivity areas - a scenario that is highly improbable given the economics of drilling and equipping so many boreholes.

From the available evidence it is not absolutely clear whether groundwater is being over-exploited for agricultural irrigation at Queenstown. However, given the high Abstraction Potential of this area, there is a real risk of over-exploitation, and steps to ensure that this area is managed as an integrated unit are urgently recommended.

5.2.6 Discussion

In order to better understand the complex interplay of factors involved in quantifying the available groundwater resource some of the key issues, as they apply to this map area, are discussed below:

- **Transmissivity/interconnectivity of fractures.** The extent to which a groundwater resource can be developed depends on the rate at which boreholes can abstract the groundwater on a long-term basis (abstractable volume). This volume is limited by the rate at which groundwater can flow toward points of abstraction, and is proportional to the interconnectivity of fractures or extent to which fractures are supplemented from the porous matrix of microfissures.

- **Borehole density.** This also influences the proportion of the Harvest Potential which will be abstractable. For a given matrix transmissivity low-yielding, closely spaced boreholes permit a higher recovery than high yielding, widely spaced boreholes (Seward *et al*, 1996). The lower recovery in the latter instance results from local dewatering in the vicinity of the borehole (causing the borehole to "dry up") while there is little drawdown in the aquifer at some distance from the borehole. In this way only part of the groundwater available for abstraction can be recovered. Closely spaced low yielding boreholes on the other hand result in a more even lowering of the water level throughout the aquifer and a higher groundwater recovery.

- **Density of drilling targets available in the area**. An abundance of targets evenly distributed across an area will represent a favourable situation for full development of the resource because the possibilities for capturing the resource are greater. Lower recovery is expected if there are a limited number of targets or if they are closely concentrated within a small portion of the area.

- **Accessibility for drilling equipment**. As a rule, the more rugged the terrain the lower the development potential due to the smaller proportion of the area which can be practically accessed for drilling. This can be offset by the greater number of springs expected in rugged terrain receiving high precipitation.

FIG 25: RURAL POPULATION SUPPORT CAPACITY (persons / km^2)

assumes 25 ℓ / person / day required

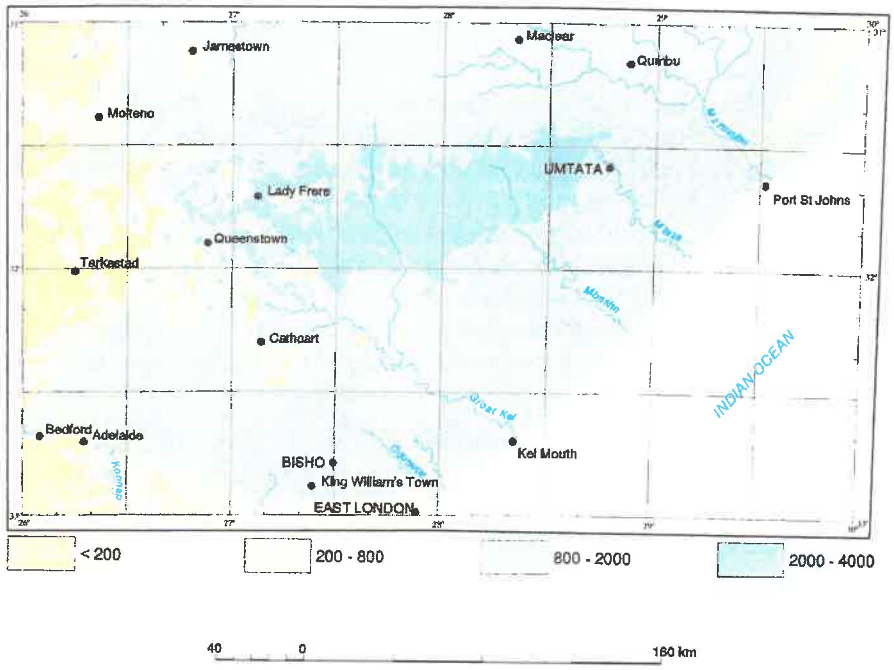


FIG 26: URBAN POPULATION SUPPORT CAPACITY (persons / km^2)

assumes 200 ℓ / person / day required

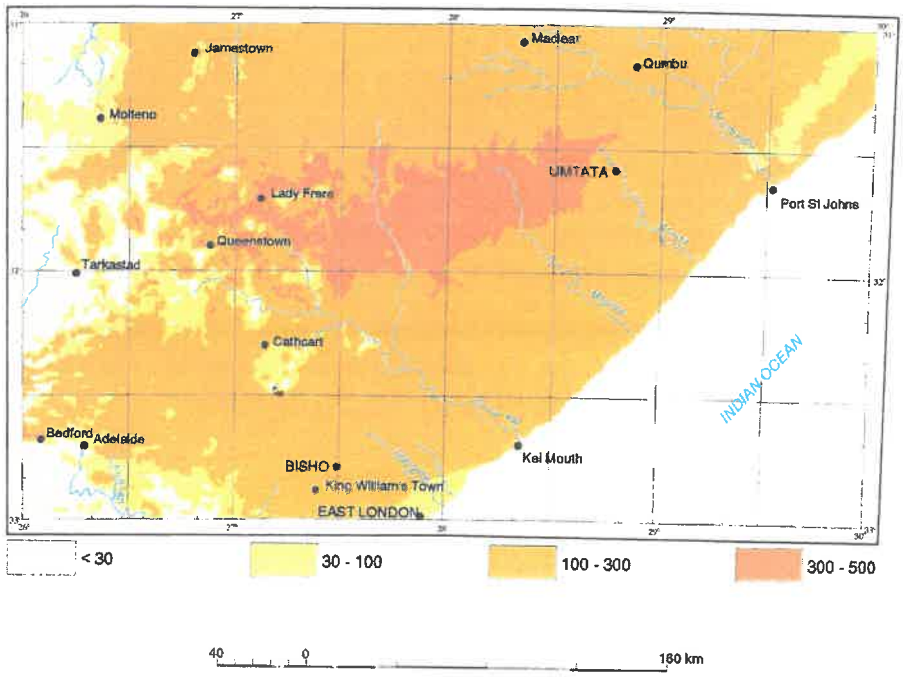
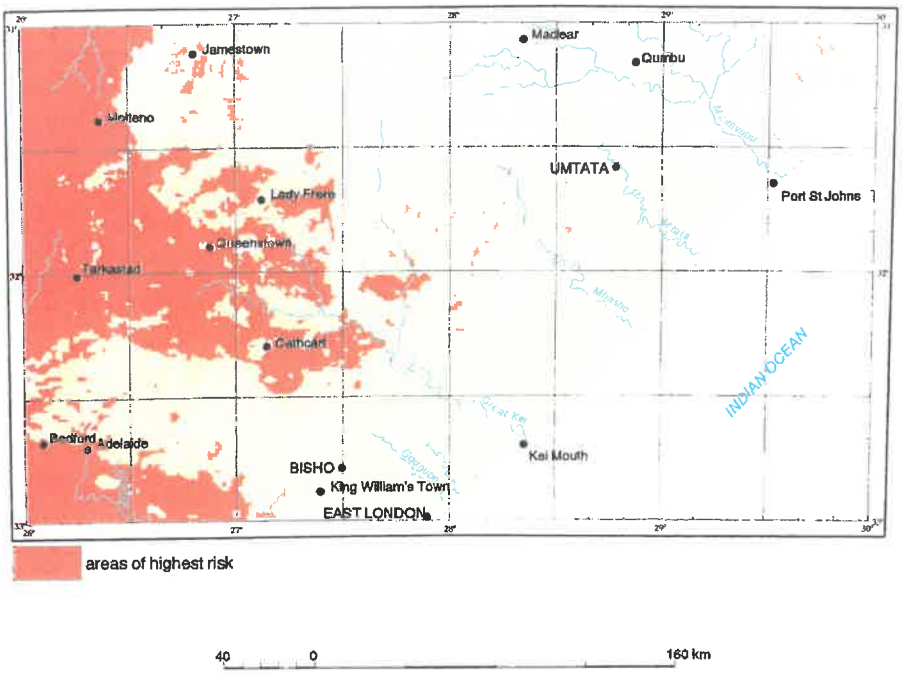


FIG 27: GROUNDWATER OVER-EXPLOITATION HAZARD



- **Economic factors (forces of supply and demand).** The recovery of all the available groundwater on a regional scale is dependent on financial resources to establish the required number of boreholes. The more profitably groundwater can be used the more finance is likely to be available for establishing a greater number of abstraction points - thereby permitting higher recovery. For example an abundance of arable land will permit crop production and a return on the capital outlay, this can then be invested in further development of the resource. Low financial returns on supply established for purely subsistence purposes will on the other hand limit further development.

- **Water quality.** This can restrict the use to which groundwater can be used. Hydrochemical analysis should be carried out on all groundwater to establish whether concentrations of the various elements comply with SA Water Quality Guidelines (DWAF, 1993 a and b) for the intended use.

5.3 Borehole siting techniques

Borehole siting should involve firstly a desk study where available geological maps, aerial photographs and satellite images are examined to ascertain the hydrogeological setting and to home in on the most promising drilling sites.

This is followed by field proofing of features identified on aerial photographs and satellite images, and hydrocensus, during which historical degree of success on hydrogeological features in the area is ascertained. This information, plus examination of the geology at the most promising sites will allow prioritisation of possible drilling sites. If necessary additional information can be obtained using geophysical techniques.

Dolerite intrusions / contact zones

Exploratory investigations in the Queenstown vicinity (Vandoolaeghe, 1980) employed a combination of aerial photograph and satellite image interpretation, field mapping, magnetic profiling, resistivity traverses and exploratory drilling in the location of target features. Magnetic profiling proved to be the most suitable because the magnetic properties of dolerite allowed the contacts of these bodies to be delineated. Recent investigations carried out in similar hydrogeological terrain - e.g. Calvinia (Woodford, 1995) indicate that inclined joint zones within dolerite may be located using electromagnetic methods. This option should therefore be considered in future investigations. The resistivity method can be used to detect the thickness of weathered material.

Fractured sedimentary rocks

Weathered zone aquifers are more common in the humid eastern parts of the study area and in particular where the rocks are significantly jointed and overlain by saturated alluvium. The resistivity method can be applicable in detecting the extent of the weathered zone.

Detection of fractures confined to particular lithological units (e.g. sandstone horizons / contacts) is difficult. Because strata are horizontal the fractures do not extend to surface and cannot be predicted - successful boreholes being largely drilled by chance. In general jointing is not likely to be intense and bedding plane joints cannot therefore be considered prime targets. The use of resistivity and electromagnetic methods may be applicable in their detection.

Delineation of vertical fault and joint zones is relatively straightforward, employing a combination of satellite imagery and aerial photograph interpretation, and field mapping. A combination of remote sensing and electromagnetic geophysical methods is most probably a good approach as indicated by relatively high yields obtained in the King William's Town vicinity using this technique (Groundwater Consulting Services (GCS), 1994).

5.4 Drilling methods

Practically all the boreholes are drilled in hard rock, and the rotary percussion method is most commonly utilised. While the cable tool method can be cheaper it is also slower - drilling into dolerite is prohibitively slow with the cable and tool method, and so intercepting water in, or beneath, dolerite intrusions only became a realistic option with the advent of rotary percussion drilling.

5.5 Aquifer management

To ensure that a borehole can be used on a sustainable basis it is necessary to estimate the sustainable yield of the groundwater unit in which the borehole is situated. The storage capacity of this unit needs to be known, as well as all water inputs to and outputs from the unit. Commissioning an additional borehole means that some of the losses from the unit will now be diverted to this borehole. Losses include base-flow, evapotranspiration and abstractions from other boreholes.

Good aquifer management includes ensuring that diversion of losses is acceptable, and ensuring that net losses do not exceed net gains on a long-term basis for the groundwater unit as a whole, i.e. that the groundwater abstraction is balanced by groundwater recharge in the long-term. In addition a practical pumping rate needs to be determined, based on the local hydrogeological conditions.

This is a specialised task requiring the expertise of a geohydrologist, entailing test pumping of the borehole, and an evaluation of the hydrogeology of the aquifer unit. On the basis of this information recommendations on the pumping rate, and correct pump size are made.

The fractured aquifers in the Queenstown map area are highly heterogeneous, making it very difficult to make accurate estimates of sustainable yield. The best way to determine what these aquifers can yield is to monitor groundwater abstractions and water-level behaviour so that the sustainable yields can be refined.

This approach used by groundwater scientists might seem back to front to those who are used to surface water where it is possible to reach greater degrees of certainty before embarking on a supply scheme. In the case of surface water direct water flow measurements can be made beforehand, and this information used to design dams of specific dimension. However, given the very low start-up costs of groundwater schemes the initial lower level of certainty should not and need not be used as an excuse to ignore groundwater.

Armed with this information it is possible to manage the resource, adjusting pumping rates to sustainable levels (reduce the rate if continuous declining trend in water levels is detected, or even increase rates if trend indicates impact is limited).

6 STUDY LIMITATIONS

Some of the major limitations that came to light during the course of this investigation are given below:

- The 1:500 000 map scale is too coarse to show subtle hydrogeological variations at the local scale (topographic influences, dykes etc).

- The borehole yield ranges adopted for the standard legend are too coarse to portray the small yield variations found on the Queenstown map - virtually the whole area being in the 0.5 - 2 ℓ/s category. Smaller yield ranges are necessary to highlight these variations. A revised map was created using these smaller ranges (Fig . 13).

- The division into "fractured" and "fractured and intergranular" aquifer classes was a somewhat academic exercise. It is doubtful if it will better help the map user understand the hydrogeology. The colour palette used in the legend would have been put to better use depicting smaller yield intervals rather than "fractured and intergranular."

- Poor borehole co-ordinate accuracy coupled with geological map coverages of inadequate accuracy precludes use of GIS techniques to overlay borehole information onto linear features (for comparison of borehole yields on dolerite dykes versus those drilled away from dykes for example).

- Numerous Departmental borehole siting reports contain geological descriptions of the drilling targets and a corresponding borehole site "G" number. Upon drilling the site different a "Boring branch" number was recorded for the site but rarely the original borehole site "G" number. As a result numerous drilling results could not be correlated with target descriptions, and detailed comparisons between local geology and hydrogeology were scarcely possible.

7 RECOMMENDATIONS FOR FURTHER WORK

7.1 Research into groundwater occurrence

Much more needs to be known about the relationship between local geological structures and groundwater occurrence. The data collection associated with the compilation of the Queenstown 1:500 000 map underlined this problem, but did not go far enough in solving it.

A host of potential drilling targets exist, such as dykes of various orientation and thickness, sheets of varying structure, diatremes, weathered zones, faults and lineaments, exist throughout the study area. Localities for testing these features should be those requiring establishment of groundwater supplies, and specifically where larger scale supplies are an urgent requirement. For this reason priority drilling targets must be identified in liaison with Chief Directorate: Water Services, which is responsible for the development of water resources for the rural areas. Using this approach the exploratory drilling will have immediate application and suitably located boreholes with adequate yield could even be incorporated into the supply system. Monitoring of exploratory boreholes incorporated into the supply system will provide valuable additional information concerning the performance of these aquifers.

In addition **all** boreholes drilled in this area must be properly documented and records entered onto the National Groundwater Data Base.

7.2 Calibration of exploitation potential

It would be wise to regard the estimates of Exploitation Potential contained in this brochure as the initial output from a model rather than final values. Like any good model it needs to be calibrated. Thus research sites are needed where abstraction data can be collected to calibrate the model. Suitable sites covering the entire precipitation "spectrum" must be identified to allow for extrapolation of the results to the region as a whole. The following sites are recommended:

1 Low rainfall area (500 mm/a)

Bedford area in the south-western corner of the map. Low rainfall coupled with high borehole yields (high transmissivity) increase the risk for over-exploitation because groundwater is readily abstractable but recharge is low. Extensive hydrological and hydrogeological information are already available for this area from research conducted at Rhodes University (Hughes *et al*, 1992).

2 Moderate rainfall area (500 - 600 mm/a)

Area between Tarkastad and Queenstown. Ideal research sites are present with defined groundwater units - including "dolerite ring structures". Springs emanating from these units facilitate measurement of outflow. Quantification of the resource is necessary because groundwater is extensively used for irrigation and the possibility of over-exploitation therefore exists.

3 High rainfall area (600 - 800 mm/a)

The Amatola mountain range receives rainfall of this magnitude and its location between the above two proposed research sites would reduce logistical costs. Additional work is required to identify the exact locality of such a site, which ideally must comprise a well-defined aquifer unit where groundwater is exploited.

REFERENCES

ANON/UNESCO, 1983

International Legend for Hydrogeological Maps, Revised edition, 1983. UNESCO Techn. document, SC-84/WS/7, 51 p., Paris.

ANDREOLI, M.A.G., DOUCOURE, M., VAN BEVER DONKER, J., BRANDT, D. AND ANDERSEN, N.J.B. (1996).

Neotectonics of Southern Africa - a review. Africa Geoscience Review, 3, No 1, 1-16.

BOEHMER, W.K. (1969).

Report on the results of a pumping test on a borehole on the P.S.A. holiday resort at Bonza Bay, District East London. Unpublished Technical Report GH 1414, DWAF, Pretoria, 9pp.

BOND, G.W. (1946).

A geochemical survey of the underground water supplies of the Union of South Africa with particular reference to their utilization in the power production and industry. Mem. **41**, Geological Survey of South Africa, Pretoria.

BREDENKAMP, D.B., BOTHA, L.J., VAN TONDER, G.J. AND JANSE VAN RENSBERG, H. (1995).

Manual on quantitative estimation of groundwater recharge and aquifer storativity. WRC report TT 37/95, Pretoria. pp 363.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1993A).

SA Water Quality Guidelines. Vol.1: Domestic Use. Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1993B).

SA Water Quality Guidelines. Vol.4: Agricultural Use. Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1994).

A recommended map legend and mapping methodology for the compilation of regional hydrogeological maps of the Republic of South Africa at a scale of 1:500 000. Unpublished Technical Report, DWAF, Pretoria.

DINGLE, R., SIESSER, W. G., AND NEWTON, A.H. (1983).

Mesozoic and Tertiary geology of Southern Africa. Rotterdam, A.A. Balkema, 375pp.

GAY, N.C. (1975).
In situ stress measurements in Southern Africa. Tectonophysics, 29, 447-459.

GROUNDWATER CONSULTING SERVICES (1994).
Da Gama Textiles - Results of the Hydrogeological Investigation of the Malakalaka Valley Rep 943 - 025/RP1.

GROUNDWATER CONSULTING SERVICES (GCS) (1992).
Hydrogeological investigation resulting in the establishment of additional groundwater supplies for the Municipality of Tarkastad. 22pp.

HEM, J.D. (1970).
Study and interpretation of the chemical characteristics of natural water (2nd ed.). USGS Water Supply Paper 1473, Washington.

HILL KAPLAN AND SCOTT (HKS) (1991).
Ciskei National Water Development Plan. Groundwater chapter prepared by Steffen Robertson and Kirsten (SRK) on behalf of HKS for the Ciskei Department of Public Works.

HUGHES, D.A., MURDOCH, K. A. AND SAMI, K. (1992).
Hydrological models – development and application. Water Research Commission report 235/1/93, Pretoria.

JOHNSON, J. H. (1974).
Hydrochemistry in groundwater exploration. Groundwater Symposium, Buluwayo, 12 pp.

KEI BASIN CONSULTING ENGINEERS (1993).
Upper Kei Basin Study, prepared for Department of Water Affairs and Forestry, South Africa.

KENT, L.E. (1949).
The thermal waters of the Union of South Africa and South West Africa. Trans. geol. soc. S.Afr., **52**, 231 – 264.

KRIGE, L.J. AND MAREE, B.D. (1951).
Earthquakes in South Africa Bull. geol. surv. S. Afr., **20**, 14pp.

MEYER, P.S. (1984).
Grondwaterondersoek: Dordrecht. Unpublished Technical Report GH 3327, DWAF, Pretoria.

PIPER, A.M. (1944).
A graphical procedure in the geochemical interpretation of water analyses. Am. Geophys. Union Trans., **24**, 914 - 923.

RUBIDGE, B. S. (1995).
Biostratigraphy of the Beaufort Group (Karoo Supergroup). Publication of the South African Committee for Stratigraphy, Biostratigraphic Series No 1, 46 pp.

SABS (1984).
Specification for Water for Domestic Supplies, South African Bureau of Standards (24101984). SABS, Pretoria.

SAMI, K. (1992).
Recharge mechanisms and geochemical processes in a semi–arid sedimentary basin, Eastern Cape, South Africa. Journal of Hydrology, **139**, 27-48.

SEWARD, P., BARON, J.H. AND SMART, M.C. (1996).
Groundwater exploitation potential using a GIS. Proceedings and papers - Groundwater 95 symposium – Groundwater Recharge and Rural Water Supply. Midrand, 5 pp.

SEYMOUR, A. AND SEWARD, P. (1996).
Groundwater Harvest Potential Map of the Republic of South Africa produced for DWAF, Pretoria.

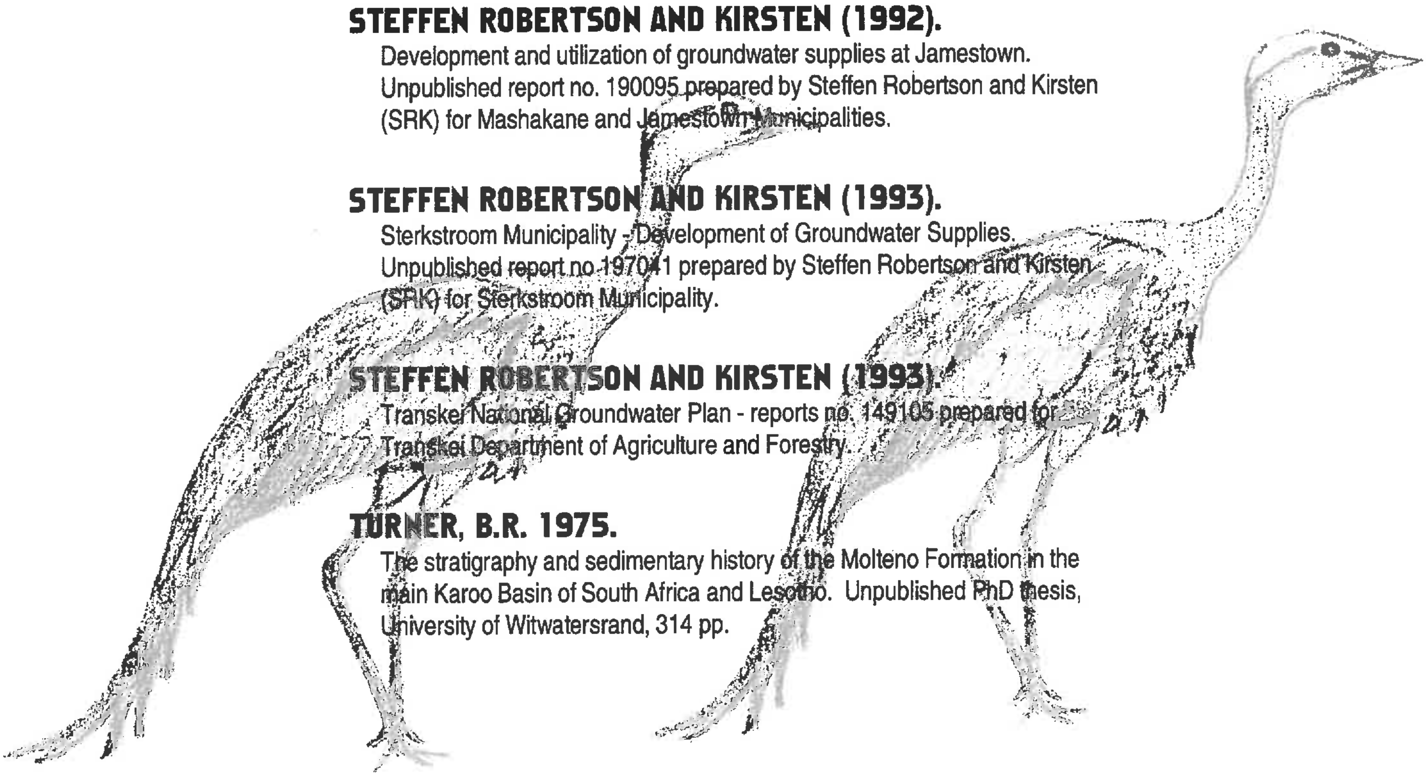
SIMONIS, J.J. (1987).
Addisionele grondwater ontwikkeling in die Bedford omgewing, Oos-Kaapland. Unpublished Technical Report GH 3555, DWAF, Pretoria.

STEFFEN ROBERTSON AND KIRSTEN (1992).
Development and utilization of groundwater supplies at Jamestown. Unpublished report no. 190095 prepared by Steffen Robertson and Kirsten (SRK) for Mashakane and Jamestown Municipalities.

STEFFEN ROBERTSON AND KIRSTEN (1993).
Sterkstroom Municipality - Development of Groundwater Supplies. Unpublished report no 197041 prepared by Steffen Robertson and Kirsten (SRK) for Sterkstroom Municipality.

STEFFEN ROBERTSON AND KIRSTEN (1993).
Transkei National Groundwater Plan - reports no. 149105 prepared for Transkei Department of Agriculture and Forestry.

TURNER, B.R. 1975.
The stratigraphy and sedimentary history of the Molteno Formation in the main Karoo Basin of South Africa and Lesotho. Unpublished PhD thesis, University of Witwatersrand, 314 pp.



VANDOOLAEGHE, M.A.C. (1980).
Queenstown geohydrological investigation. Unpublished Technical Report Gh 3153, DWAF, Pretoria.

VEGTER, J. R. (1995).
An explanation of a set of National groundwater maps. Water Research Commission Report no TT 74/95, Pretoria, 63pp.

VENABLES, A.J. AND WOODFORD, A.C. (1985).
Report on the hydrocensus and borehole testing programme carried out at Komga over the period November - December 1984. Unpublished Technical Report 3369, DWAF, Pretoria.

WEINERT, H.H. (1974).
A climatic index of weathering and its application in road construction. Geotechnique **24** No 4, 475-488.

WOODFORD, A.C. (1995).
Personal communication.

MAP REFERENCES

- SA 1:250 000 geological series sheet 3126, 3128, 3226 and 3228
- SA 1:250 000 topo-cadastral series sheets 3126, 3128, 3226 and 3228.