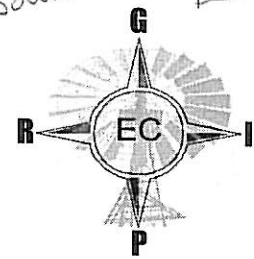


**GROUNDWATER RESOURCE INFORMATION PROJECT
EASTERN CAPE PROVINCE**

*Resource Evaluation
EC*

GROUNDWATER INFORMATION SOURCE REFERENCE SHEET



SOURCE REF NR:	SR207	Own Archive		Copy attached	<input checked="" type="checkbox"/>
		Sourced	<input checked="" type="checkbox"/>	Copy at source	

A: SOURCE DESCRIPTION

District Municipality:	Amatole	<input checked="" type="checkbox"/>	Chris Hani		O.R Tambo	
	Ukhahlamba		Cacadu		Alfred Nzo	
Local Municipality:	COVERS FORMER CISKEI					
Institution where Information is held:	SRK CONSULTING					
Branch of Institution:	JOHANNESBURG					
Contact details:	Contact person:	SUE KING				
	Contact Tel:	011-44 111 11				
	Contact Email:	sking@srk.co.za				

B: TYPE OF INFORMATION

Information format:	Hard copy	<input checked="" type="checkbox"/>	Data Summary		Electronic Report	
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Report / Info Title:	GROUNDWATER RESOURCE EVALUATION AND DEVELOPMENT IN THE REPUBLIC OF CISKEI					
Report Nr:	KP 5109/4	Date:	Jan-87			
Author Details:						
Author's Qualification:	Hydrogeologist	<input checked="" type="checkbox"/>	Govt Dept		Project Manager	
	Engineer		Technician		Other	
	Specify Other:					
Captured by:	PS. Nel	Date:	18/03/2004	Signed:		

C: GEOHYDROLOGICAL CATEGORIZATION

Project Type	Source development		Feasibility Study		Sanitation Study:	
	Specify Other: RESOURCE EVALUATION					
Reference Co-ordinate:	Latitude		Longitude			
	32°52'00"		27°00'00"			
Lithological & Construction Logs	Yes	No	Complete	Incomplete		
Hydrocensus Data		<input checked="" type="checkbox"/>				
Pump Testing Data		<input checked="" type="checkbox"/>				
Chemical Water Analysis Data	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>			
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Remote Sensing Data		<input checked="" type="checkbox"/>				
Map Data	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>			
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CISKEI DEPARTMENT OF PUBLIC WORKS

GROUND WATER RESOURCE EVALUATION AND
DEVELOPMENT IN THE REPUBLIC OF CISKEI

REPORT KP.5109/4

JANUARY 1987



CISKEI DEPARTMENT OF PUBLIC WORKS

GROUND WATER RESOURCE EVALUATION AND
DEVELOPMENT IN THE REPUBLIC OF CISKEI

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JANUARY 1987

PHASE I

PART 1 OF 2 - SUMMARY REPORT

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GLOSSARY

The following technical terms may not be familiar to the reader:

- Anticline : A fold of fold system in the form of an arch.
- Aquifer : A saturated geological formation capable of transmitting significant quantities of water.
- Artesian borehole : A free flowing borehole.
- Colluvial deposits : Weathered material transported by gravity.
- Confined aquifer : A completely saturated aquifer whose upper and lower boundaries are impervious layers.
- Fold hinge : The position of maximum curvature on a fold.
- Joint : A fracture in a rock between the sides of which there is no observable relative movement.
- Orographic : Connected with the presence of mountains.
- Permeability : The rate of flow of groundwater through a porous medium.
- Piezometric level : The level to which groundwater will rise after penetration of a confined or semi-confined aquifer.
- Storage coefficient : The volume of water that an aquifer releases from storage per unit surface area of the aquifer per unit decline in hydraulic head.
- Sodium absorption ratio : Ratio of sodium to calcium and magnesium ions.
- Tectonic : Related to the geological stress regime in the rock mass.
- Transmissivity : The product of the average permeability and thickness of the aquifer.
- Unconfined aquifer : A saturated aquifer whose upper limit is the water table.

C O N T E N T S

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2	INVESTIGATION APPROACH	
3	GEOLOGY	
4	HYDROGEOLOGY	
5	HYDROGEOLOGIC REGIONS	
6	HYDROGEOLOGICAL MAPPING	
7	CONCLUSIONS	



STEFFEN, ROBERTSON AND KIRSTEN (KAAP) ING

Reg. No. 78/03709/07

GEOTECHNICAL, CIVIL AND WATER ENGINEERS AND ENGINEERING GEOLOGISTS • GEOTEGNIESE-, SIVIELE- EN WATERINGENIEURS EN INGENIEURSGELOE

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REPORT KP.5109/4

January 1987

GROUND WATER RESOURCE EVALUATION AND DEVELOPMENT IN THE REPUBLIC OF CISKEI

PHASE I

SUMMARY REPORT

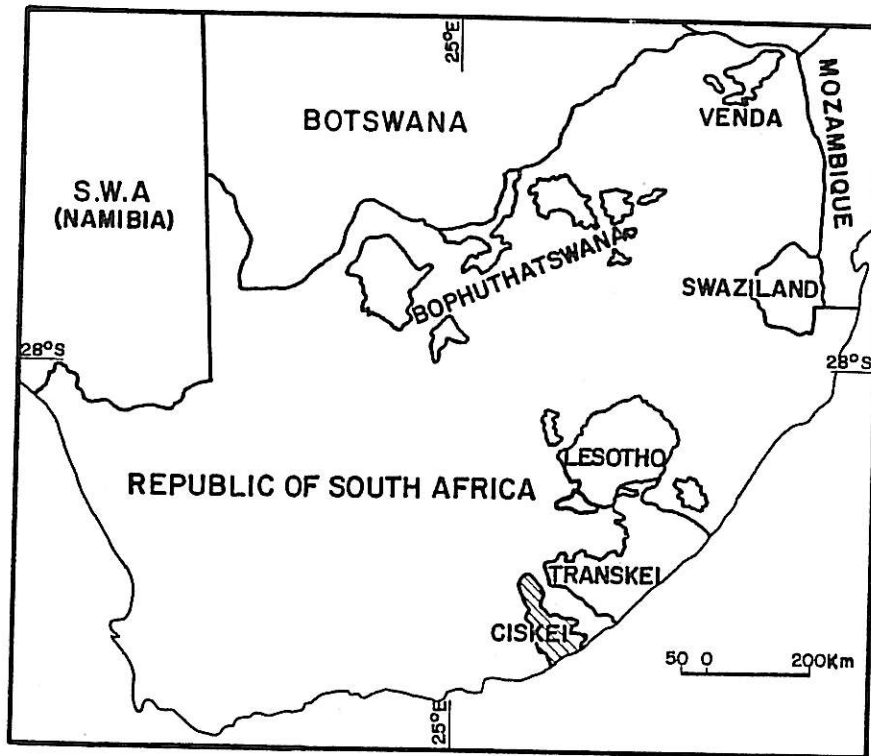
1 INTRODUCTION AND TERMS OF REFERENCE

The Ciskei Government is preparing a National Water Development Plan to ensure the effective development, utilization and management of the country's water resources. Steffen Robertson & Kirsten (KAAP) Ing were appointed as specialist consultants to undertake the ground water investigation for the Department of Public Works, in a project funded by the Development Bank of South Africa.

Broadly, the investigation is to evaluate the quantity and quality of the ground water resources of the entire Republic of Ciskei and establish criteria for its exploitation.

Target areas for borehole siting are to be defined and hydrogeological maps at a scale of 1:50 000 produced.





LOCALITY MAP



JOB N^o
KP 5109

CISKEI GROUND WATER INVESTIGATION

FIG N^o
I

2 INVESTIGATION APPROACH

The project has been split into 2 phases for ease of management. Phase I comprised:

- . Desk Study
- . Field investigation

The desk study involved review and analysis of all existing data relevant to ground water in Ciskei, i.e reports, geological and aeromagnetic maps, borehole data and original interpretation of air photographs and satellite imagery.

The field investigation involved a borehole survey, surface geophysics and aquifer tests.

3 GEOLOGY

Ciskei is underlain by sedimentary rocks ranging in lithology from quartzite through sandstone and tillite to shale. A narrow belt of sand dunes parallels the coast.

The quartzite and tillite lithologies are confined to the southwestern part of Ciskei, between the Great Fish River and Peddie.

Shale is the dominant lithology over the remaining coastal and central parts of Ciskei, up to the Amatole Mountains.

The Amatole Mountains and most of the area further north are underlain by a thick sandstone formation, with shale again occurring in the far north of Ciskei.

These sediments have been intruded by dykes, sills and sheets of dolerite. These intrusions are absent in the coastal belt, rare in the central areas and become common to abundant in the Amatole Mountains and foothills. In the shale lithologies, intrusions are mainly sills and sheets, while dykes become the dominant form in the sandstones.

The sedimentary rocks are folded and steeply dipping in the south-western part of Ciskei. Dips decrease to the north, where strata are gently dipping to horizontal in attitude.

4 HYDROGEOLOGY

Hard rock formations occupy about 97% of the surface area of Ciskei. These rocks contain few if any primary openings and owe their water bearing properties to secondary openings, such as bedding and joint planes, faults and weathered zones. Such aquifers are termed secondary aquifers.

Primary aquifers, in which intergranular porosities are retained from the time of deposition, are confined to a coastal dune belt and, possibly, narrow strips of alluvium developed along the major rivers.

Within this broad framework the main aquifer types recognised are:

- **dolerite intrusions**

These include dykes, sills and sheets with the aquifer zones being the fractured contact zones and fractures within the dolerite itself, especially the inclined sheet-type intrusion. Optimum thicknesses for productive aquifers are more than 5m for dykes and 30m to 50m for sheets.

- **fractured sedimentary rock**

Fractures are liable to be more common and open to greater depth in competent sandstones rather than in shales. A favourable area for fracture development is the south-western part of Ciskei, situated as it is on the eastern margin of the Cape Fold Belt.

- **weathered zone**

Weathered zone development concerns the degree of erosion resistance of rocks. In this respect shales would be more susceptible than sandstones. Fractures provide access for agents of weathering

to more rock surface area. In the Hamburg area a weathered zone up to 44m thick is present.

- coastal dune deposits

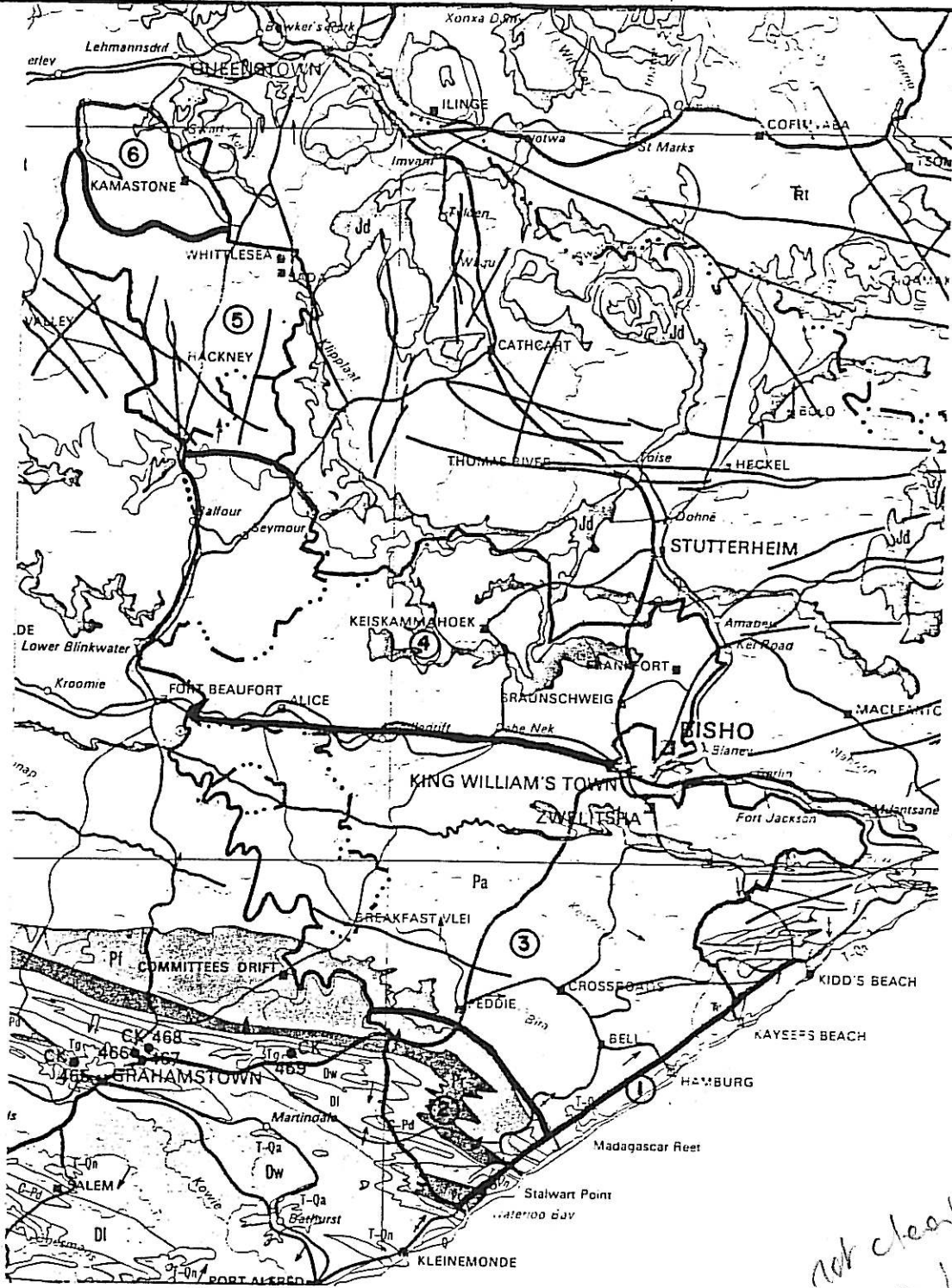
These deposits are fairly extensive locally but little is known regarding saturated thickness or yield potential. Due to the primary nature of this aquifer type ground water potential could be high.

Alluvial deposits are not expected to be productive aquifers due to their very limited extent. They could be locally important in providing recharge by leakage to underlying secondary aquifers.

The transmissivity of the various aquifers is generally low. Fractured sedimentary rock aquifer types gave values of about $30\text{m}^2/\text{day}$. Somewhat higher transmissivities were obtained from fractured dolerite, with a range of $36\text{m}^2/\text{day}$ to $63\text{m}^2/\text{day}$. Dyke /sill contact zone aquifer types gave variable transmissivities of $8\text{m}^2/\text{day}$ to $77\text{m}^2/\text{day}$.

The Amatole Mountains receive the highest rainfall in Ciskei. However, the steep topography here will promote run off rather than infiltration. This area therefore acts as a 'water shedder', transmitting water to the lower lying foothills area, where the main recharge to aquifers will take place.

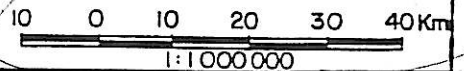
The best quality ground water is obtained from boreholes in the northern parts of the country eg. Hewu and Keiskammahoek Districts. Here, Total Dissolved Solids (TDS) are mostly less than 500mg/l . The TDS of the ground water tends to increase in a southerly direction, with TDS of 1000mg/l to 2000mg/l and isolated 'highs' of over 3000mg/l in places eg. Peddie, Mdantsane and Zwelitsha Districts.



- 1 COASTAL BELT
- 2 CAPE FOLD BELT
- 3 CENTRAL PLATEAU
- 4 AMATOLE MOUNTAIN FOOTHILLS
- 5 AMATOLE MOUNTAINS
- 6 INLAND PLATEAU

*not clear
Ciskei border
region margins*

HYDROGEOLOGIC REGIONS



JOB N^o
KP 5109

CISKEI GROUND WATER INVESTIGATION

FIG N^o
2

5 HYDROGEOLOGIC REGIONS

Ciskei has been provisionally divided into 6 hydrogeological regions based mainly on geology and aquifer types. The regions recognised are:

- 1 Coastal Belt
- 2 Cape Fold Belt
- 3 Central Plateau
- 4 Amatole Mountain Foothills
- 5 Amatole Mountains
- 6 Inland Plateau

The regions are shown on Fig 2 and described briefly below.

. Coastal Belt

This region contains the coastal dune belt which extends up to 7 Km inland. The dunes are underlain by sedimentary rocks which provide 'local' fractured aquifers. Borehole yields are mostly less than $10\text{m}^3/\text{h}$ with isolated yields up to $30\text{m}^3/\text{h}$ eg. Hamburg.

Ground water quality is variable in both the dune and fractured rock aquifers, ranging from about 300 mg/l to over 2000 mg/l TDS. The main target feature for further ground water exploitation would be the dune sand aquifer.

. Cape Fold Belt

The dominant aquifer type here is fractured sedimentary rock. Borehole yields are generally less than $5\text{m}^3/\text{h}$ with isolated yields of up to $48\text{m}^3/\text{h}$. Ground water quality is good in the central part of the region, with TDS of less than 1000 mg/l. Elsewhere, TDS is in the range 2000 mg/l to 3000 mg/l. Target features for ground water exploitation are the crests of anticlinal folds in quartzites.

- **Central Plateau**

Aquifers in this region are predominantly of the fractured/weathered sedimentary rock type. A few dolerite sills occur and the contact zones may be productive aquifers.

Yields are generally less than $5\text{m}^3/\text{h}$ especially in the southern part of the region. Higher yields up to $54\text{m}^3/\text{h}$ are obtained in the northern parts of the region. This may be attributed to the more common occurrence of dolerite intrusions. Ground water generally has an elevated TDS of between 1000 mg/l and 2000 mg/l , exceeding 3000 mg/l in the central and eastern areas. Target features for borehole siting in this region would be fracture intersections and contact zones of dolerite intrusions.

- **Amatole Mountain Foothills**

This region is characterized by abundant dolerite intrusions, mainly sills and sheets, in a predominantly shale host rock. Aquifers will include contact zones and fractures within thick dolerite sheets. The northern part of this region benefits from the 'water shedding' effect of the Amatole Mountains as described in Chapter 4. Boreholes are higher yielding on average than those in regions 1 to 3. Yields of up to $54\text{m}^3/\text{h}$ are attained and yields of more than $15\text{m}^3/\text{h}$ are not exceptional. Ground water quality is good in this area, being less than 500 mg/l TDS in the north and generally less than 1000 mg/l in the southern parts. Dolerite intrusions are so numerous in this area that there will be no shortage of target features.

- **Amatole Mountains**

This region is characterized by abundant dolerite dykes intruded into a thick sandstone host rock. The main aquifer type will be the contact zones of thick dolerite dykes. Yields of existing boreholes are low, less than $5\text{m}^3/\text{h}$ with one or two exceptions.

Ground water quality is excellent with TDS in the range 250 mg/l to 500 mg/l. Target features will be the contact zones of thick dolerite dykes. This is one of the main regions where it is considered that improved borehole siting techniques will result in higher yields being attained.

- Inland Plateau

Dolerite intrusions are again abundant but the dominant form is the sheet/sill in a largely shale host rock. Information on yields is very sparse and inconclusive. In the Queenstown area, which is part of the same hydrogeological region, yields of 16m³/h to 34m³/h were obtained from exploration boreholes. Ground water quality is again excellent with TDS mostly below 500 mg/l. Target features for borehole siting features will be thick, low lying dolerite sheets.

6 HYDROGEOLOGICAL MAPPING

To obtain an overall picture of ground water in Ciskei a ground water potential map has been drawn up (Fig 3). The principle is to take as many factors as possible that affect ground water occurrence and exploitability and assign them an arbitrary index. The index is weighted according to the relative influence each factor is considered to have on the ground water potential.

A grid is superimposed on the area of interest and at each node the various factors are assessed and the appropriate index assigned. These are then summed and the resulting values contoured. Areas with the highest 'score' then correspond to areas with the highest ground water potential.

The factors considered for compilation of the ground water potential map of Ciskei were:

- mean annual precipitation
- lithology
- dolerite intrusions

- . structure
- . ground water quality

The areas with the highest ground water potential are the Amatole Mountains and surrounding foothills, to the north and south, and the coastal belt. The areas in between are generally of poor potential with one or two zones of moderate potential.

A start has been made on production of detailed hydrogeological maps of Ciskei at a scale of 1:50 000. A literature survey was carried out to ensure that the methodology employed was 'state of the art' as far as possible. The guidelines laid down by a United Nations working committee have largely been adopted, with some modifications. One map has been produced so far, sheet 3327 AC PRUDHOE, to both experiment and illustrate the type of presentation planned.

The basic 1:50 000 topographic sheet has been taken as the base map. Superimposed on this are geological details such as lithology and stratigraphy, from which aquifer types can be ascertained. These details are then toned down so as not to obscure the detailed hydrogeological data. The latter includes borehole locations, with symbols representing different yields and water quality, ground water flow directions (arrows) and contours of iso-TDS values.

7 CONCLUSIONS

The main conclusions to be drawn from Phase I of this investigation are:

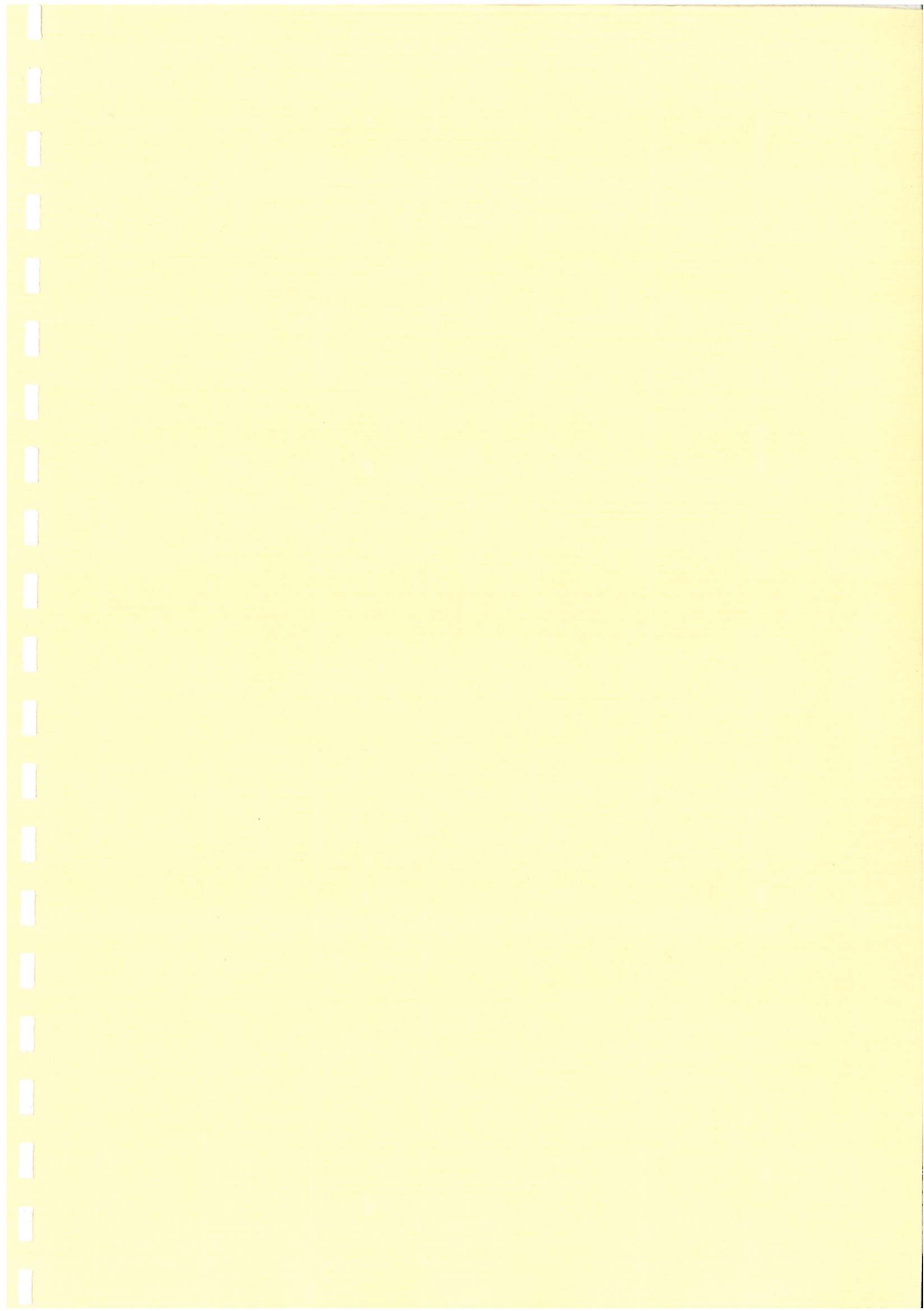
- . ninety seven percent of Ciskei is underlain by secondary aquifers.
- . secondary aquifer types include fractured/weathered sedimentary rocks, fractured dolerite sheets and dyke/sill contact zones.
- . primary aquifers are found in a narrow coastal belt of sand dunes.
- . extensive use is made of ground water on a local scale

- . individual borehole yields are generally low with 85% of boreholes yielding less than 10m³/h. Most boreholes are equipped with windpumps, a further reflection of low yields
- . ground water quality is variable, ranging from less than 500 mg/l TDS in northern Ciskei to between 1000 mg/l and 2000 mg/l TDS in the central and coastal areas. Locally, TDS exceeds 3000 mg/l in the latter areas.
- . the main area of recharge is the Amatole Mountain foothills
- . Ciskei can be divided into 6 hydrogeologic regions, namely Coastal Belt, Cape Fold Belt, Central Plateau, Amatole Mountain Foothills, Amatole Mountains and Inland Plateau. Regions 1, 4, 5 and 6 are considered to have the best potential for increased exploitation of ground water, utilizing target features identified during this investigation.

P N ROSEWARNE, Sci Nat

M SMART

STEFFEN ROBERTSON & KIRSTEN (KAAP) Ing



CISKEI DEPARTMENT OF PUBLIC WORKS

GROUND WATER RESOURCE EVALUATION AND
DEVELOPMENT IN THE REPUBLIC OF CISKEI

REPORT KP.5109/4

JANUARY 1987

PHASE I

PART 2 OF 2 - TECHNICAL REPORT

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(enclosed at the back of the report)

<u>No</u>	<u>Description</u>
5109/1	GROUND WATER POTENTIAL MAP
5109/2	HYDROGEOLOGICAL MAP : SHEET 3327 AC PRUDHOE

T A B L E S

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B	CHEMICAL DATA



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REPORT KP.5109/4

January 1987

GROUND WATER RESOURCE EVALUATION AND DEVELOPMENT IN THE REPUBLIC OF CISKEI

PHASE I

TECHNICAL REPORT

1 INTRODUCTION

The Ciskei Government is preparing a National Water Development Plan to ensure the effective development, utilization and management of Ciskei's water resources. A key element in compiling the plan is the identification of ground water resources.

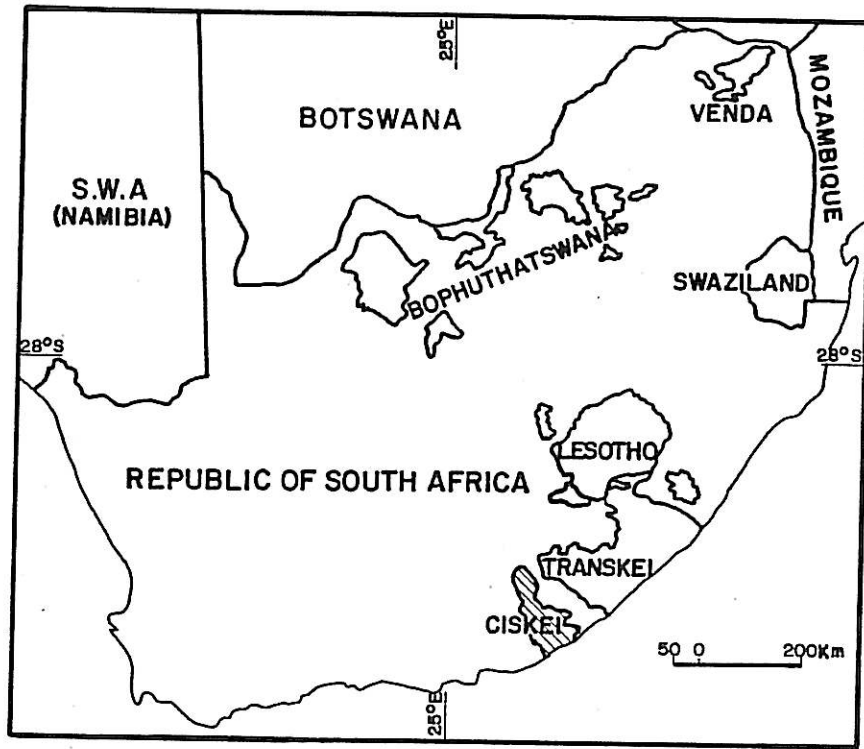
Boreholes are an important source of water supply in Ciskei and ground water is seen to offer great potential for economic water supply schemes. Very little is however known about the ground water potential on a regional or national basis.

Steffen Robertson & Kirsten (KaaP Ing) were appointed as specialist consultants to undertake the ground water study for the Department of Public Works. The project is being funded by the Development Bank of South Africa.

2 TERMS OF REFERENCE

Detailed terms of reference as defined by the Ciskei Department of Public Works are presented in Appendix A. To summarize, the main aspects to be addressed during the investigation are :





LOCALITY MAP



JOB N^o
KP 5109

CISKEI GROUND WATER INVESTIGATION

FIG N^o
1

- . evaluation of the quantity and quality of the ground water resource of the entire Republic of Ciskei and establish criteria for its exploitation.
- . definition of target areas for borehole siting on the basis of interpretation of available information, remote sensing, field borehole and spring census, surface geophysics and test pumping of existing boreholes.
- . determination of hydraulic parameters of representative aquifers and assess the validity of borehole siting criteria by means of exploratory drilling and test pumping.
- . assessment of the suitability of ground water for domestic or agricultural use.
- . preparation of regional hydrogeological and hydrogeochemical maps at a scale of 1:50 000.
- . definition of aquifer distribution, hydraulic properties and likely range of borehole yields, management requirements, ground water balance and recommended exploitable quantities.

3 INVESTIGATION APPROACH

An investigation approach was outlined in SRK's technical proposal KP5109/1, which was accepted by the Department of Public Works in their letter of appointment, ref no. 1/5/4-1, of 19 June 1986. The scope and duration of the project indicated that the work could best be tackled by a 2 phase approach. This report documents the activities and findings of Phase I and involved a desk study and preliminary field investigation.

The desk study comprised a review of all available information in the form of geological/geophysical maps, reports, borehole data and original interpretation of air photographs and Landsat imagery.

The field investigation comprised a hydrocensus of existing boreholes, ground water sampling, limited surface geophysics and aquifer tests.

Interpretation of these data has generated a sound data base on which to form a preliminary assessment of the ground water resources and potential of Ciskei.

The Phase I report is structured in the following way:

- . Chapters 4 and 5 outline the general physiographic and geologic features.
- . Chapters 6 and 7 document the activities carried out during the desk study and field investigation respectively.
- . Chapter 8 presents data analysis and interpretation with discussion on general hydrogeology. Following on from this, chapter 9 discusses the division of Ciskei into hydrogeologic regions. Hydrogeologic mapping is dealt with in chapter 10 with a preliminary map presentation.

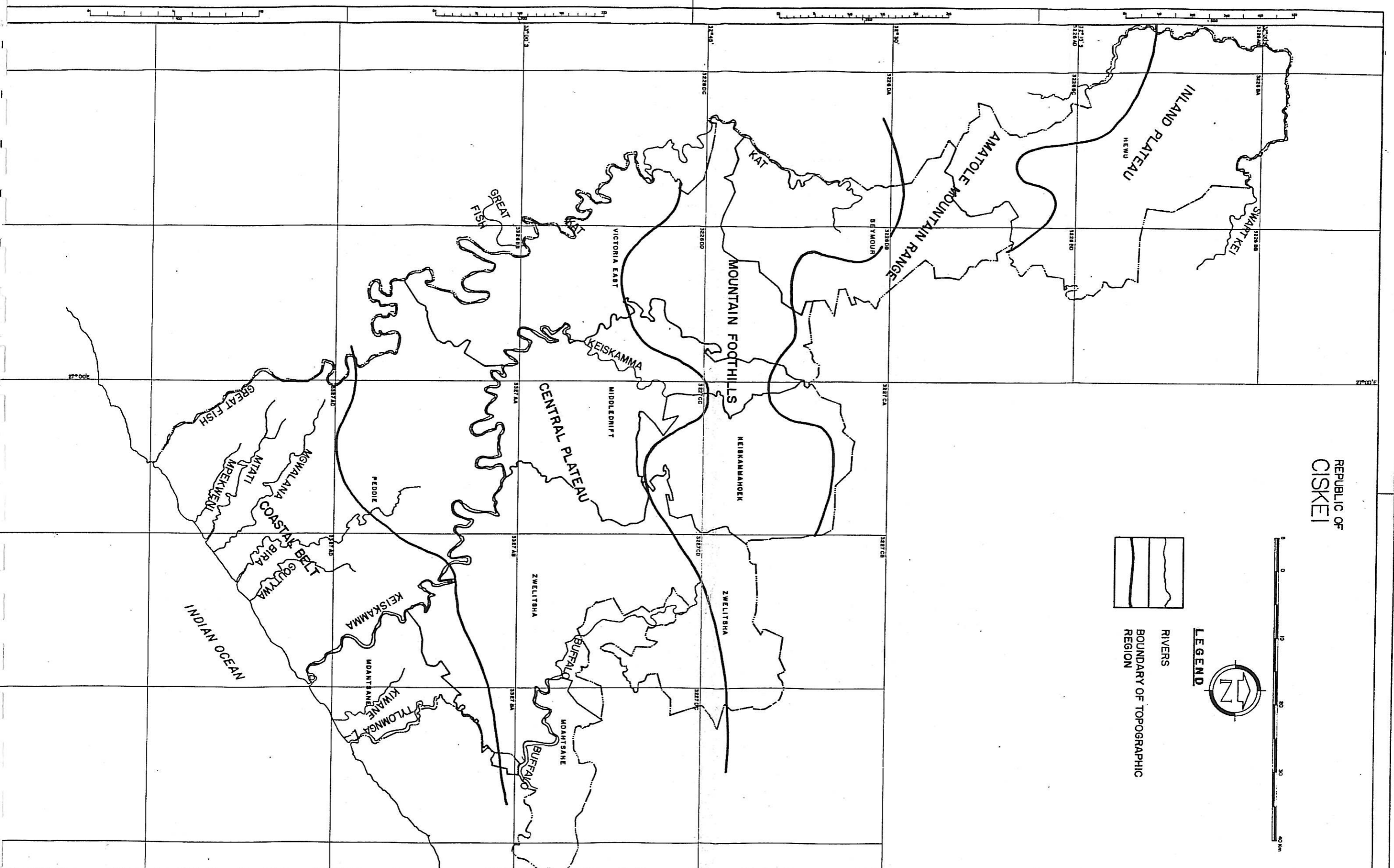
Overall conclusions and recommendations for further work in Phase II, are given in chapters 11 and 12 respectively.

4 PHYSIOGRAPHY

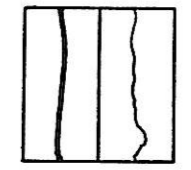
4.1 Topography

Five topographic regions can be recognised in Ciskei. A coastal belt, central plateau, mountain foothills, Amatole mountain range and an inland plateau/plain (Fig 2).

The coastal belt consists largely of low rounded hills. The elevation rises from sea level at the coast to approximately 300m (all elevations relative to mean sea level).



REPUBLIC OF
CISKEI




LEGEND
 RIVERS
 BOUNDARY OF TOPOGRAPHIC REGION



REV NR	DR GET	CH NAG	DATE DATUM	DESCRIPTION / BESKRYWING	REV NR	DR GET	CH NAG	DATE DATUM	DESCRIPTION / BESKRYWING

NOTES/AANTEKENINGE


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TITLE / TITEL		BY / DEUR		DATE / DAT	CH / NON
PHYSIOGRAPHIC FEATURES		DESIGNED ONTWERP			
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The central plateau is in the region of 50 km wide, with elevations varying between 300m and 600m. Although more deeply dissected than the central plateau the topography remains gently undulating, with occasional remnant pediplain surfaces.

The mountain foothills begin at an elevation in the region of 600m. The Fort Beaufort to King William's Town main road approximates the southern boundary of this zone. The northern boundary, although not well defined, can be taken approximately as the 1000m contour line. The Kat River System in the west, and Keiskamma River System in the east deeply incise the otherwise subdued topography.

The generally south-east trending Amatole mountain range rises steeply from the mountain foothills. The escarpment rises to approximately 1600m. Peaks vary between 1739m and 1963m in height. The terrain is deeply dissected forming a rugged topography.

The inland plateau, bounded by the Amatole Mountains in the south slopes gently to the north-east, descending to approximately 900m.

4.2 Surface drainage

Ciskei is drained by 5 major river systems, namely the Great Fish, Kat, Keiskamma, Buffalo and Swart Kei (Fig 2).

The mean annual runoff and catchment areas for the river systems are shown in Table 1.

River	Mean Annual Runoff ($m^3 \times 10^6$)	Catchment Area (km^2)
Swart Kei	117	2 828
Buffalo	82	1 906
Keiskamma	133	2 751
Kat	61	1 750
Great Fish	479	30 427

TABLE 1 : DETAILS OF MAJOR RIVER SYSTEMS

These rivers are in the process of rejuvenation, and as a result have deeply incised mature meandering configurations for the larger part of their lengths.

The geology exerts some control on the course of the rivers which in some cases parallel the regional geological strike, and in others coincide for part of their length with major lineations.

The Swart Kei drains the inland plateau north of the Amatole Mountains. The remainder of the rivers drain the area south of the Amatolas.

The Great Fish has the major portion of its catchment outside the borders of Ciskei, originating near Middleberg and Steynsberg in the Karoo. The Great Fish, and its major tributary, the Kat form the south-western boundary of Ciskei from Fort Beaufort to the coast.

The Kat River rises in the Amatole Mountains, draining the larger part of the Seymour District. The river flows southwards, joining the Great Fish River about 23 km south of Alice.

The Keiskamma River has its entire catchment within Ciskei. The river system drains the Keiskammahoek and Middledrift Districts as well as parts of Victoria East, Zwelitsha and Peddie Districts. The river flows into the Indian Ocean at Hamburg.

The Buffalo river rises in the Amatole Mountains and drains the larger portion of Zwelitsha District. The river flows into the Indian Ocean at East London.

The Swart Kei forms part of the Ciskei boundary in Hewu District and eventually joins the Great Kei River.

A number of minor perennial rivers cross the coastal plateau, draining in a south-easterly direction to the sea. These rivers are, from south-west to north-east, the Mpekweni, Mtati, Mgwalana, Bira, Gqutywa, Kiwane and the Tyalomnga.

4.3 Climate

4.3.1 Precipitation

Ciskei lies within the summer rainfall region, with more than 70 per cent of the annual precipitation occurring between October and March. Precipitation along the coastal area is slightly more evenly distributed throughout the year.

The pattern of precipitation is strongly orographic, with mean annual precipitation (MAP) varying from more than 1200mm on the Amatole mountains to less than 500mm in the Hewu District to the north (Fig 3). To the south of the Amatole range, MAP decreases sharply to approximately 600mm.

The larger portion of the central plateau and coastal belt/plain receives MAP of between 500mm and 700mm. Part of the Great Fish River catchment south of Fort Beaufort receives MAP of less than 500mm, and a strip along the northern coastline receives MAP of 700mm to 800mm.

Rains normally associated with cyclonic movements can cause rainfall of high intensity. This type of rainfall forms a large proportion of late summer rainfall. Thunder storms are a frequent occurrence and occur 20-30 days per annum. Gentler rains are normally associated with anticyclonic movements.

Infrequent snowfalls occur on the Amatole Mountains, mainly in July. The snow normally melts within a day or two.

4.3.2 Evapotranspiration

Mean annual evaporation (Symons pan) increases in a north-westerly direction from about 1350mm in the Hamburg area to 1700mm in the far north of Ciskei (Middleton et al, 1981). It can be seen that on an annual basis, evaporation exceeds rainfall over the whole country.

Potential evapotranspiration can be calculated by applying a pan factor to the monthly Symons pan readings. This factor varies from 0,8 to 1,0. For the purposes of this report the figures for evaporation can be taken as a near enough approximation to potential evapotranspiration.

5 GEOLOGY

5.1 Sedimentary formations

The stratigraphic divisions represented in Ciskei are the Cape Supergroup and Karoo Sequence, of Devonian to Triassic age, and Quaternary to Recent sediments. The major geological features are shown in Fig 4.

5.1.1 Cape Supergroup

Rocks of the Cape Supergroup are confined to a narrow strip along the south-western border of Ciskei and are represented by the Witteberg Group. They consist of quartzitic sandstones and shale.

5.1.2 Karoo Sequence

These rocks occupy the remainder of Ciskei and comprise the Dwyka Formation, Ecca Group and Beaufort Group.

. Dwyka Formation

The Dwyka follows on conformably from the Witteberg Group and consists of tillite, a sandy mudstone containing boulders and shale.

. Ecca Group

The Ecca consists essentially of dark grey shales with subordinate sandstone.

. Beaufort Group

This Group is subdivided into a lower Adelaide and upper Tarkastad Subgroup. The latter is distinguished by a greater abundance of sandstone than in the former.

The lowermost member of the Adelaide Subgroup is the Middleton Formation, comprising grey and red mudstones and subordinate sandstone. It attains a thickness of 1600m (+ 300m) south of Fort Beaufort. The overlying Balfour Formation is distinguished by a general absence of red mudstone. The contact is difficult to follow in the field but approximately parallels the King William's Town - Fort Beaufort road. The Formation comprises grey mudstone and subordinate sandstone. A thickness of 2150m (+ 300m) has been measured north of Fort Beaufort.

The lowermost member of the Tarkastad Subgroup is the Katberg Sandstone Formation which is up to 900m thick. This resistant sandstone forms the mountainous northern part of Seymour district, and a large portion of the Hewu district.

In the Hewu District, sandstone still comprises 90% - 95% of the total thickness with mudstone constituting the remainder. The top of the Katberg Sandstone Formation is arbitrarily taken as a plane below which sandstone is more abundant than mudstone.

In the down-faulted block north of East London this unit consists almost entirely of pale reddish-grey fine to medium grained sandstone.

The Burgersdorp Formation consists of mudstone (about 70%) and fine grained sandstone (about 30%) and is confined to the northern extremity of Ciskei.

5.1.3 Quaternary to Recent deposits

The coastal Quaternary to Recent deposits consist of consolidated sand (dune rock and fixed dunes) and unconsolidated sand (dunes and beach sand). The consolidated sands are usually calcareous. The coastal strip of unconsolidated sand is up to 2 km wide and grades into the older consolidated sand deposits, which extend up to 6 km inland.

Further inland are alluvial and colluvial deposits. Alluvial deposits are of relatively limited extent due to the incised nature of the major river courses. Extensive but thin colluvial deposits, formed by sheetwash, occur in northern Hewu District.

5.2 Dolerite Intrusions

North of latitude 33°15', the sedimentary rocks have been intruded by dykes, sills and sheets of Jurassic-age dolerite.

Dolerite is absent in the Witteberg, Dwyka and Ecca rocks. Dolerite is rare in the Middleton Formation, with 2 main sills and a few scattered outcrops north of Hamburg. In the Balfour Formation dolerite becomes increasingly common, consisting of extensive sills and sheets.

In the Katberg Sandstone Formation the pattern of intrusion changes, with dykes becoming the dominant type. Dominant trends are N-S and NW-SE. Major dykes can be traced for up to 30 km. Presumably the more competent nature of the sandstone has given rise to a more jointed/fractured medium which favours dyke emplacement.

In the Burgersdorp Formation sills and sheets are again the dominant form of intrusion.

5.3 Structure

The most important structural feature is the eastern extension of the Cape Fold Belt. Rocks of the Witteberg, Dwyka and Ecca Groups have been folded into a series of anticlines and synclines. These trend WNW-ESE and plunge to the east. Dips of up to 55° are encountered in this area, between Peddie and the Great Fish River.

Dip angles decrease progressively northwards and over most of Ciskei are 1° to 3° to the north.

Normal faults trending E-W occur in the Chalumna area. Extensive jointing was noted in the mudstones and sandstones of the Adelaide Subgroup during field reconnaissance.

6 DESK STUDY

This part of the investigation was carried out during July to September 1986 inclusive and involved review of available information and remote sensing.

6.1 Review of available information

Only those data reviewed that have direct relevance to ground water occurrence in Ciskei are listed here. These are:

. Reports

- 1 Chalumna River Basin Study
for Ciskei Directorate of Planning, by Loxton Venn & Associates. Rep no A58/84.
- 2 Soils and Agricultural Potential of Chalumna Farms
for Dept of Cooperation and Development by Loxton Venn & Associates. Rep no A52/84.
- 3 Fish/Kat River Basins Study
for Ciskei Dept of Agriculture and Forestry, by Loxton Venn & Associates. Rep no TS122/79.

4. Keiskamma River Basin Study
by Hill Kaplan Scott.
5. Feasibility Report on Wesley Regional Water Scheme
for Ciskei Dept of Public Works, by Bosch and Associates.
6. Investigation for Groundwater Supplies for Wesley
Regional Water Scheme
for Ciskei Dept Public Works, by Gombar and Gombar.
7. Queenstown Geohydrological Investigation
M A C Vandoolaeghe, SA Dept Water Affairs. Rep no Gh 3153.
This report is of great relevance to understanding the role
of dolerite intrusions in ground water occurrence, in a
similar hydrogeological environment to that existing in
Ciskei.
8. Ground water Resources in Wesley Rural Area
for Ciskei Dept of Public Works by Tahal (Israel) 1986.
9. Recommended Standardized Procedures in Hydrogeological
Mapping in Southern Africa
Unpub PhD thesis, E Martinelli. UOFS.

. Papers

1. The Influence of Karoo Geology on the Groundwater Quality
of Part of the Great Fish River Basin.
by E A W Tordiffe et al. Groundwater '85.
2. Current Status and Future Plans for Water Supply and
Sanitation in Ciskei.
by T I Balzer. Seminar on Technology Transfer in Water
Supply and Sanitation in Developing Areas, February 1985,
Kingwilliam's Town.
3. International Legend for Hydrogeological Maps, UNESCO 1983.

- 4 Hydrogeological Reconnaissance Mapping in the Republic of Botswana at scale 1:500 000, G Goldberg and C Hr Neumann Redlin. Groundwater 1980. Conference.

. **Maps**

- 1 1:50 000 scale geology, (12 maps) open file Geological Survey SA (GSSA), covering all of Ciskei north of lat 33°S.
- 2 1:125 000 geology 'Grahamstown' GSSA, Sheet 136
- 3 1:125 000 geology Kidds' Beach, Sheet 3327B
- 4 1:250 000 geology 'King Williams Town' GSSA, Sheet 3226.
- 5 1:50 000 aeromagnetic, (20 maps) open file GSSA, covering all of Ciskei.

. **General information**

- 1 Borehole Register Data : Ciskei Depts Public Works and Planning, M Lundstrom and Associates.

In addition valuable discussions were held with Mr O Gombar, of Gombar and Gombar, Hydrogeological Consultants with extensive experience of Ciskei ground water conditions.

6.2 Remote sensing

This activity covers the study and interpretation of air photographs and Landsat (satellite) imagery.

Remote sensing provides an invaluable tool in initial assessment of a region, as large areas can be covered in a relatively short time. Important linear structures such as faults, joints and dykes can be traced and their regional significance assessed.

The following data were obtained and original interpretation carried out:

. Air-photos, 1:50 000 scale:

Job no 721, Strips 1-7 (partial) 90 photographs.

Job no 732, Strips 1-14 (partial) 151 photographs.

Attention was concentrated on the area below latitude 33°S as no detailed geological maps were available for this area. A stereoscope was used to aid interpretation.

. Landsat imagery, 1:150 000 scale colour composite image (bands 4, 5 and 7) and black and white single band images for bands 4 and 7, July 1984.

The abundance of dolerite intrusions in northern Ciskei resulted in a rather 'confused' image. Individual lineations were more easily interpreted below latitude 33°S.

Four main sets of lineations occur in the Ciskei. Two sets of lineations are present across the entire Ciskei, and a further two sets are of a more restricted nature.

The orientations, extent and distribution of the major sets are listed in Table 2.

Orientation	Maximum length	Distribution
NNE-SSW	60km	Present throughout.
NW-SE	40km	Present throughout.
NE-SW	40km	Restricted to within 30km of the coast.
WNW-ESE	45km	Sporadically developed N of 33°S.

TABLE 2 : DETAILS OF MAJOR LINEATIONS IDENTIFIED BY REMOTE SENSING

Dolerite occurrences often coincide with lineations. In the East London area dolerite dykes parallel the NE-SW coastal set, and may represent intrusions into continuations of these features.

The NNE-SSW and NW-SE sets, where developed in the Katberg Sandstone Formation, appear to be intruded by dolerite.

Further lineations of varying orientation are locally developed giving rise to more complex patterns and increased intensities. These may result from variations in local stress patterns.

The straight nature of the lineations indicates that they are essentially vertical.

7 FIELD WORK

Field work was carried out between September and November 1986, and involved a hydrocensus, limited surface geophysics and aquifer tests.

7.1 Hydrocensus

aims?
objectives?
no!

A census of as many water points (boreholes, springs, etc) as time will allow normally marks the first field phase of a hydrogeological investigation. In the present study an 'office hydrocensus' was first carried out as there was much existing data on record for Ciskei boreholes. In this way 862 located boreholes were documented to varying degrees of detail. For example, data on yields were available for 476 boreholes and chemical data for 138 boreholes.

of?

In general the range of data includes: borehole number, locality, depth, yield, water intersections, water-level, geological profile, water quality and borehole equipment.

These borehole locations were all plotted on the published 1:50 000 topographic maps so that field work could be planned.

The field work had 2 aims; firstly to obtain borehole data where existing data were sparse or non-existent, and secondly to update and expand existing records.

Areas where information was sparse were Seymour, Victoria East, Keiskammahoek, northern Zwelitsha and Mdantsane. A further 80 boreholes were thus located. Field measurement of Total Dissolved Solids (TDS) was carried out for 51 boreholes and selected water samples taken and submitted to the Department of Public Works laboratory for chemical analysis. Some of these boreholes could be correlated with data on file for which no locality had previously been available.

Some statistics on depths and yields of boreholes in the 8 Magisterial Districts of Ciskei are given in the following tables.

Magisterial District	Depth range (m)				Number of boreholes
	50	50-100	100-150	150	
	Percentage boreholes				
Hewu	30	64	5	1	306
Mdantsane	7	80	13	0	56
Zwelitsha	32	54	13	1	392
Victoria East	24	69	7	0	132
Peddie	23	70	6	1	227
Middledrift	24	57	13	6	99
Kieskammahoek	25	57	13	5	53
Seymour	No information				
TOTAL %	24	64	10	2	1265

TABLE 3 : BOREHOLE DEPTHS

The table shows that out of 1265 boreholes, 88% or 1113 are less than 100 m in depth.

Magisterial District	Yield range (m ³ /h)				Number of boreholes
	50	50-100	100-150	150	
	Percentage boreholes				
Hewu	58	19	15	8	217
Mdantsane	75	14	8	3	37
Zwelitsha	74	14	10	2	175
Victoria East	64	23	7	6	88
Peddie	69	19	6	6	182
Middledrift	32	20	10	4	108
Kieskammahoek	70	20	6	4	60
Seymour	No information				
TOTAL %	66	19	10	5	867

TABLE 4 : BOREHOLE YIELDS

really represents minimum yields

usually just relates water supply related yields

The table shows that 85% of boreholes for which data are available have yields of less than 10m³/h. The reason for the relatively poor yields is not necessarily that aquifers in Ciskei have poor potential. If a supply of say 5m³/h is required for a village and this yield is obtained after 80m of drilling, drilling will most probably be stopped at this depth. It could well be that additional water strikes would be made if drilling were continued to say 150m and a higher yield therefore obtained.

explain!

A further comment on yields. Most are based on a standard 8 hour test and the yield assigned to each borehole is that recorded at the end of the test. This is frequently up to 50% less than the initial yield at the start of the test, which illustrates the necessity of carrying out this type of test to ascertain a realistic yield in fractured rock aquifers. *(no really, who says the yield went down another 50% after an additional 8hrs drilling?)*

Boreholes are mostly equipped with windpumps, possibly a further indication of the generally low yields and also the remoteness of many of the borehole locations.

Ground water is mainly used for domestic and stock watering purposes.

7.2 Surface geophysics

Surface geophysics was carried out to firstly assess the applicability of the ground magnetic method and secondly to identify the nature of lineaments from the magnetic response. ✓

The ground magnetic method is one of the quickest and cheapest of surface geophysical techniques. The method involves measurement of the local geomagnetic field (in this case by a proton magnetometer) and detecting variations or anomalies. Such anomalies may be caused by a number of features including dykes, fractures and faults, which can be favourable zones for ground water occurrence.

The magnetic method was successfully employed by Gombar (1983) in the location of structural features in the Wesley area, and by Vandoolaeghe (1980) in the mapping of dolerite intrusions and borehole siting in the Queenstown area.

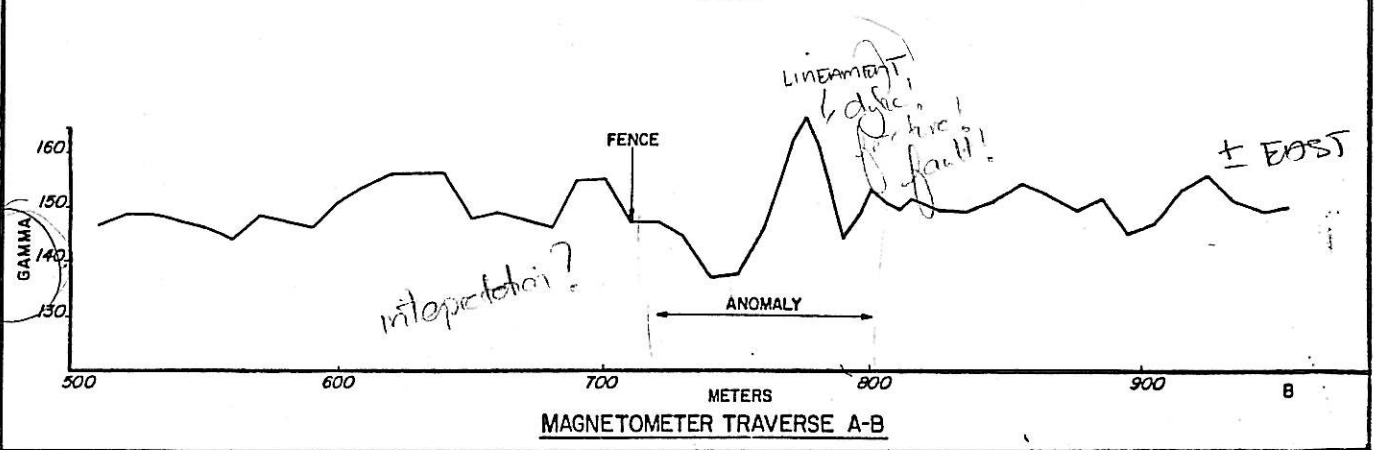
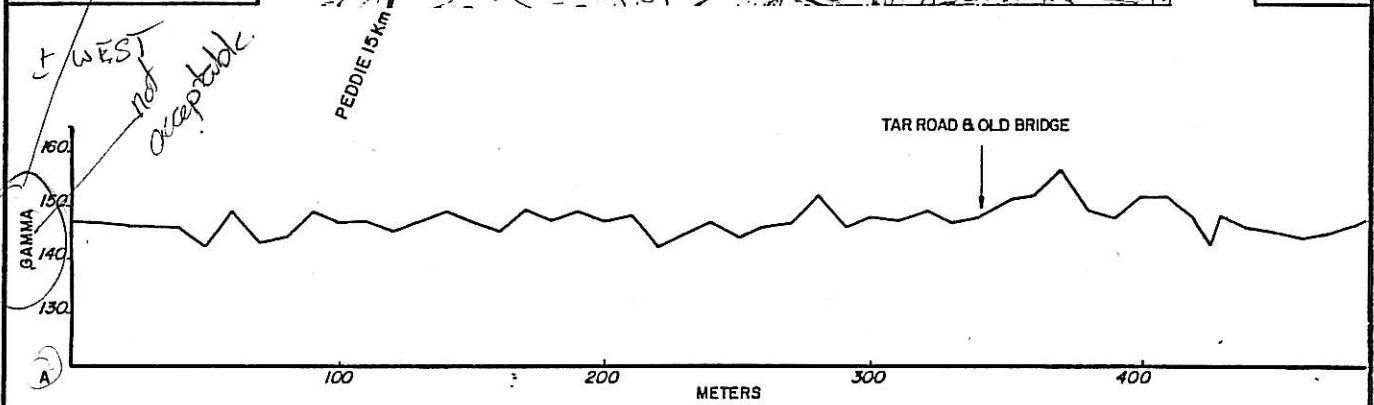
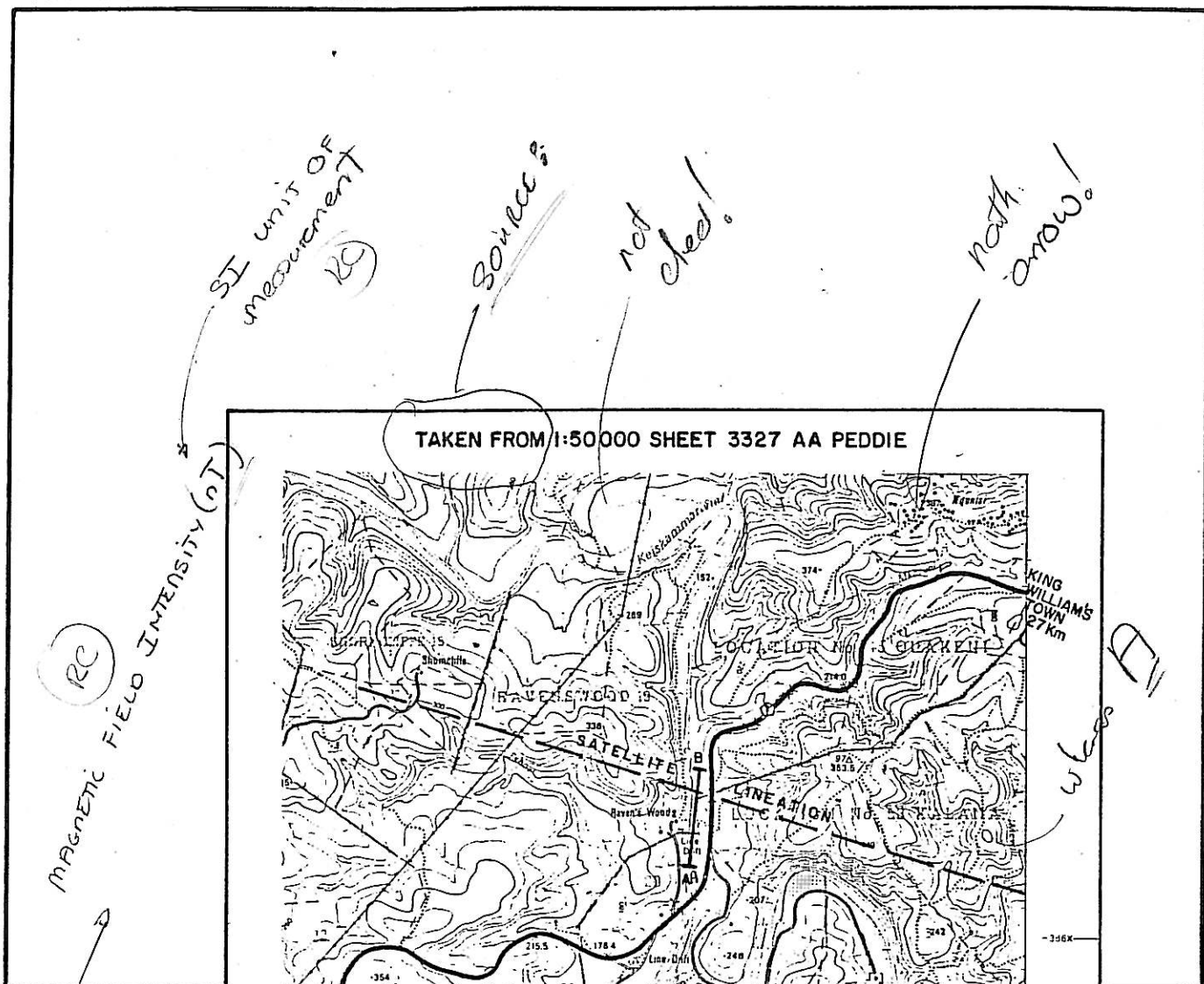
(A total of) ^{confusing} 13 magnetometer traverses were carried out across selected lineations identified by remote sensing and 5 across known dolerite occurrences. The purpose of the former traverses was to try and confirm the existence and the nature of a linear feature, although the absence of a magnetic anomaly would not necessarily preclude the existence of a fault or fracture. The latter traverses were carried out in order to define a dolerite intrusion at a site where an aquifer test was planned.

Readings were taken at 10m intervals, shortened to 5m intervals where anomalous responses were obtained. Of the 13 magnetometer traverses carried out across lineations, anomalies were obtained for only 3, the variations being in the region of 30 gamma. An example of such a response is presented in Fig 5. The responses obtained by Gombar (1983) were also in the region of 30 gamma, the maximum variation being 45 gamma. At this stage it is thought that the anomalies obtained are related to fracture zones rather than dolerite intrusions.


I don't think
gammas are acceptable!

indicate on
map.

to what? RC



MAGNETOMETER TRAVERSE A-B

	<p>JOB NO KP 5109</p>	<p>MAGNETIC INVESTIGATION CISKEI GROUND WATER INVESTIGATION</p>	<p>FIG NO 5</p>
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new circle: client is not referred to any more, ∴ MAGNETIC INVESTIGATION

FIG 5

7.3 Aquifer tests

Aquifer tests may be carried out to satisfy two main objectives; firstly, to test the performance of the pumped borehole, and secondly, to obtain information on aquifer hydraulic properties.

The first type of test, known as a step drawdown test, involves increasing the pump rate in a borehole in a step-wise fashion over equal time increments whilst measuring the accompanying fall in water level in the pumped borehole. Appropriate analysis of the drawdown/discharge data allows differentiation of the two components of the total drawdown in a pumped borehole, namely aquifer losses and well losses. The well loss calculation is essential in the analysis of constant discharge aquifer tests on pumping boreholes with no observation boreholes. Calculation of transmissivity in solitary boreholes ignoring the well loss leads to underestimation of transmissivity. The step drawdown test also allows selection of the optimum pumping rate for the constant discharge test.

The second type of test involves pumping a borehole at a constant rate, while measuring the decline in water-level in nearby observation boreholes, as well as the pumped borehole. Appropriate analysis of these data allows computation of the aquifer hydraulic properties, principally transmissivity and storage. Water-level recovery is usually measured after the pump is shut off at the end of a constant discharge test. The data so obtained provide a check on the transmissivity computed from the drawdown data and are often more reliable as fluctuations in pumping rate are eliminated.

In Phase I, use had to be made of existing boreholes and as most boreholes were equipped, existing pumping equipment too. This immediately cut down the number of sites to choose from as the majority of boreholes are equipped with windpumps.

Criteria for selecting test sites were therefore:

- . suitability of existing equipment
- . geological environment
- . borehole data available eg. yield, depth water intersections

Within these constraints and the time and budget constraints of the project, only 2 aquifer tests could be carried out. These were on boreholes CZB 114 and CQB 2512B (Fig 11).

It was not possible to step-test CZB 114 as the existing pumping equipment could not be regulated to give differing discharge rates. A 413 minute constant rate test was carried out, with a discharge of 12,60 m³/h, followed by recovery measurements for 210 minutes. No observation borehole was available at this site.

It was possible to step-test CQB 2512B as Department of Public Works pumping equipment was installed on this borehole. A discharge range of 4,76 m³/h to 8,35 m³/h was obtained over 4 steps. However, 8,35m³/h proved to be excessive and as a result a pumping rate of 6,53 m³/h was selected for the 480 minute constant discharge test. Recovery was monitored for 120 minutes after the pump was shutdown. There was no observation borehole at this site either.

Fortunately, a number of aquifer tests have been carried out in previous investigations by the Vandoolaeghe (1980), Gombar (1983) and Taha1 (1986) and these data have been combined with the present tests to expand the data base.

8 HYDROGEOLOGY

8.1 Aquifer types

8.1.1 General

Aquifers can be divided into two broad categories, namely primary and secondary types.

Primary aquifers are those in which intergranular porosities and permeabilities are dominant. In Ciskei this type of aquifer is limited to Quaternary to Recent dune and alluvial deposits and possibly the colluvial deposits of the Hewu region.

Older, so-called hard-rock formations, ranging in age from Devonian to Jurassic, occupy about 97% of the surface area of Ciskei. These rocks contain few if any primary openings and owe their water bearing properties to secondary openings caused by tectonic deformation, weathering and unloading. These openings comprise bedding and cleavage planes, joints, fissures, faults and disintegrated and decomposed rock. Such aquifers are termed secondary aquifers.

8.1.2 Aquifer types occurring in Ciskei

The following aquifer types have been identified as occurring in Ciskei. Their distribution will be outlined in Chapter 9 where hydrogeological regions are discussed.

. Dolerite intrusions

Vandoolaeghe (1980) concluded that the optimum target features were dolerite dykes and inclined sheets, with strongest yields being obtained on or near the curved segments of dolerite sheets. Ground water is contained in fractures in the dolerite itself and the adjacent bedrock. In the Queenstown area the fractures were mostly horizontal to sub-horizontal in attitude.

A dyke contact zone aquifer type is illustrated in Fig 6.

Ground water potential was found to be related to thickness of the intrusion, with optimum thickness for dykes being more than 5m and for sheets, 30m to 50m.

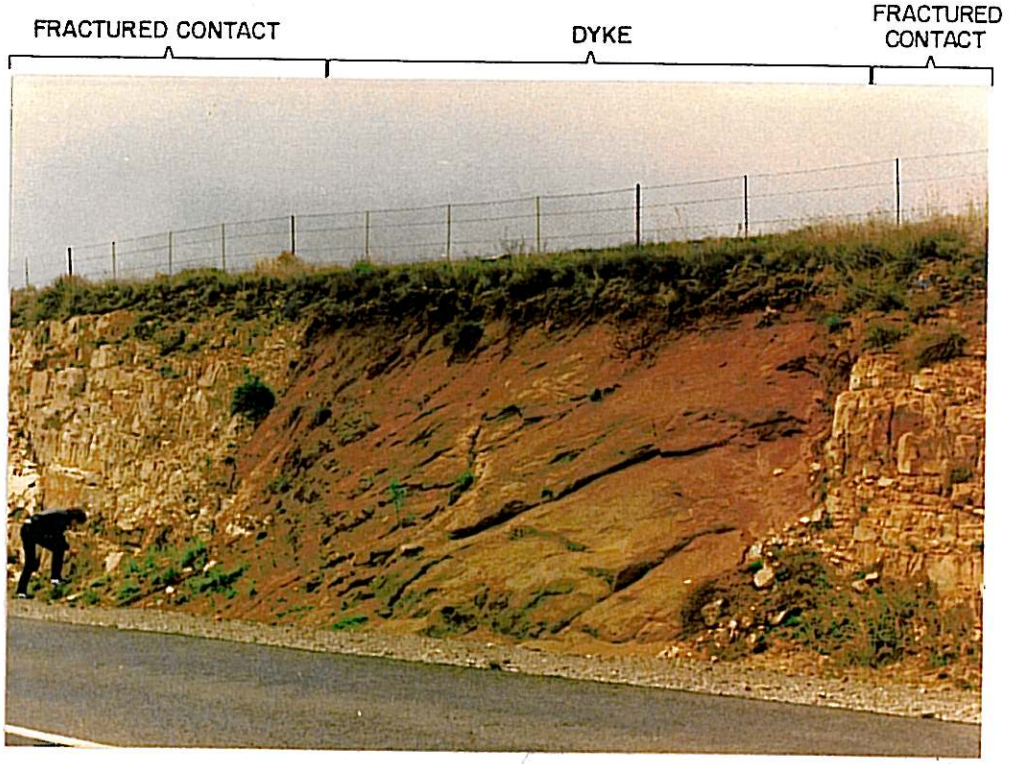


FIG. 6 a
EXAMPLE OF DYKE
CONTACT ZONE
AQUIFER TYPE



FIG. 6 b
DETAIL OF CONTACT
ZONE



JOB Nº
KP 5109

CISKEI GROUND WATER INVESTIGATION

FIG Nº
6

Dolerite intrusions in thick sandstone, eg Katberg Sandstone Formation, should have higher ground water potential than with a shale eg. Balfour Formation, due to increased fracturing of the contact zone in the more competent host rock.

An optimum environment would be where a fractured dolerite/contact zone is overlain by saturated alluvium or crossed by a perennial water course, as this would promote recharge.

- **Fractured sedimentary rock**

This aquifer type excludes dolerite contact zones.

The degree of fracture zone development will depend on a number of factors, such as sedimentology and tectonics.

Sedimentological considerations include the scale of rock competence, which will govern the degree of fracture development, i.e. sandstones more favourable in this respect than mudstones and shales.

Tectonic forces may well be important for fracture development in the south-western part of Ciskei, situated as it is on the eastern margin of the Cape Fold Belt. Here the geological formations are folded and steeply dipping (30° - 60°), giving rise to a favourable environment for fracture development. A favourable zone is also the contact between a competent sandstone and a more easily deformed shale. Openings frequently develop parallel to the bedding planes along this contact zone in folded rock.

A large number of lineaments were detected by remote sensing in and adjacent to this area. These presumably reflect joint and other fracture development associated with the folding.

- Weathered zone

Weathered zone development concerns the degree of erosion resistance of rocks. In this respect, shales would be more susceptible than sandstones to in-situ weathering processes. A further factor in this respect is the climate, especially rainfall and thus surface water availability as an agent of weathering. Fractures provide access for agents of weathering to more rock surface area. In this respect, the more fractured areas would promote weathering processes.

In some cases, weathered zones may not be aquifers in themselves. Decomposition of shales and sandstones to clay may produce low permeability but high storage potential (up to 30%). Fractured zones underlying such a weathered layer may receive indirect recharge by leakage.

- Coastal dune deposits

These deposits are fairly extensive locally and possess primary porosity. If sufficient saturated thickness is available, storage potential would be high. Little is known in this regard at this stage of the investigation. Gombar (1983) reported on 2 shallow hand-dug wells in the dunes at Hamburg. Tests carried out indicated a low transmissivity. Ground water abstractions from this aquifer type is an important source of supply in Port Alfred and Bushmans River Mouth, for example.

- Alluvial deposits

This aquifer type is considered to be relatively unimportant in Ciskei as deposits are limited in extent due to the incised nature of the major river channels. Deposits are limited to narrow terraces bordering the river channels. Examples can be found in the lower reaches of the Great Fish River.

- **Colluvial deposits**

There are extensive colluvial deposits in the northern Hewu area. These are described as thin in the explanation to sheet 3226 King Williams Town and this fact, coupled with the low rainfall and high potential evapotranspiration in this area, suggests that these deposits are likely to be unsaturated.

8.2 Aquifer hydraulic parameters

Aquifer tests carried out by Vandoolaeghe (1980), Gombar (1983), Taha1 (1986) and SRK (1986) cover a fair range of the aquifer types and hydrogeologic regions (discussed in Section 9) of Ciskei. The aquifer types include:

- fractures in dolerite sheets
- dyke/sill contact zones
- fractured/weathered sedimentary rock
- dune sand

Test results in these aquifer types are discussed below.

- **Fractured dolerite dyke/sheet aquifer**

Tests were carried out in this aquifer type in the Queenstown area (Vandoolaeghe, 1980). Transmissivity values of $36\text{m}^2/\text{day}$ to $63\text{m}^2/\text{day}$ were obtained, with one exceptionally high value of $343\text{m}^2/\text{day}$. The latter was obtained from a step drawdown test however. The average storage coefficient was 3×10^{-4} , which is indicative of a confined aquifer.

- **Dyke/sill contact zone.**

The 2 aquifer tests carried out during this investigation were on existing boreholes in this aquifer type. Borehole CZB114, located 11 km south-west of King Williams Town (see Fig 11) is drilled into sandstone of the Middleton Formation adjacent to

a major dolerite sill. A transmissivity of $77\text{m}^2/\text{day}$ was calculated here. A storage coefficient could not be determined as there was no observation borehole available. The second site tested, CQB2512B, is located north of Keiskammahoek in Balfour Formation sandstone/dolerite. A very low transmissivity of $8\text{m}^2/\text{day}$ is computed for this site. A step drawdown test was carried out but gave anomalous results, so correction for well losses could not be made. In fractured rock aquifers well losses are usually small compared to aquifer losses (Vandoolaeghe 1980) so correction for well losses may not significantly improve the situation.

*Dubious
reference*

Two aquifer tests on boreholes in the contact zone of Burgersdorp Formation shale and dolerite in the Queenstown area (Vandoolaeghe 1980) gave transmissivities of $15\text{m}^2/\text{day}$ and $258\text{m}^2/\text{day}$. A storage coefficient of 2×10^{-4} was derived indicating confined aquifer conditions.

- **Fractured/weathered sedimentary rock aquifers**

Tests on boreholes in the Middleton Formation of the Hamburg area gave an average transmissivity of $28\text{m}^2/\text{day}$. Tests carried out in the Prudhoe/Mpekweni area (Tahal 1986) gave an average transmissivity of $30\text{m}^2/\text{day}$. This was for Dwyka Tillite and Ecca shales/sandstone. These are very low figures, indicating that individual borehole yields will generally be low also. A low transmissivity gives rise to a steep and local cone of depression around a pumping borehole. Gombar (1983) concluded that the Hamburg aquifer was semi-confined and computed an average storage coefficient of $1,1 \times 10^{-3}$.

- **Dune sand**

Tests carried out on shallow hand-dug wells in the Hamburg area (Gombar 1983) gave a permeability of $2\text{m}/\text{day}$ (transmissivity = permeability x aquifer thickness). This is a low figure, probably influenced by the somewhat crude test method

and the shallow penetration of the aquifer zone. The thickness of saturated sand is not known. A saturated thickness of 10m would give a transmissivity of $20\text{m}^2/\text{day}$ for example. No storage coefficient could be computed.

8.3 Recharge

The maximum volume of water which may be abstracted from an aquifer on a continuous basis is limited to its recharge. Estimation of recharge is therefore a very important aspect of a ground water resource evaluation, especially in predicting long-term yield potential.

Recharge may be of direct or indirect origin. Direct recharge comes from rainfall infiltration. Sources of indirect recharge include throughflow from adjacent areas, surface water seepage (influent seepage), irrigation return flow and leakage from semi-confining formations.

At this stage of the investigation, speculation as to recharge will be confined to qualitative discussion. It is possible to map direct recharge (and discharge) areas on the basis of field observation (Freeze and Cherry 1979). There are 5 basic types of indicators :

- . topography
- . piezometric levels
- . water quality
- . environmental isotopes
- . land and vegetation features

The simplest indicator is topography. Recharge areas are topographically high. The highest topography in Ciskei is developed on the Amatola Mountains and surrounding foothills. This area receives the highest MAP in Ciskei. However, the steep topography will promote run off rather than infiltration. The mountains are therefore 'water shedding' and this run off will recharge the surrounding lower lying areas which contain the productive aquifers.

Piezometric levels can indicate recharge areas in a similar way to topography, with piezometric 'highs' indicating recharge areas. Such a zone exists in the Cape Fold Belt area.

In general terms, the TDS of ground water increases along the flow path. Ground water from recharge areas is relatively low in TDS. Evidence of this type backs up the first two indicators discussed above, with ground water of lowest TDS being associated with the Amatole Mountains and foothills and parts of the Cape Fold Belt.

Environmental isotopes include tritium (^3H) and carbon (^{14}C). The distribution of ^3H in ground water can be used to identify areas where water younger than 1953 occurs, this being the year when atmospheric testing of nuclear weapons began.

The last indicator listed is more a reflection of discharge areas with features such as springs, salt precipitates and salt tolerant plants that can live with their roots below the water table occurring. The latter are termed phreatophytes. These areas are generally low lying. In humid areas, which applies to much of Ciskei, saline areas and phreatophyte vegetation are not prominently developed.

From consideration of the above indicators, for which data are available, it is apparent that the Amatole Mountains and foothills should be the main areas of direct recharge in Ciskei.

Elsewhere the main source of recharge is probably indirect and via throughflow.

8.4 Ground water quality

To assist with an initial assessment of water quality in Ciskei, Table 5 and Fig 7 have been drawn up. Table 5 gives the range of TDS for ground water from 480 boreholes distributed through all the Magisterial Districts, excluding Seymour for which no data are available. Fig 7 is a contour plot of iso-TDS for the same data.

Magisterial District	TDS range (mg/l)				Number of boreholes
	1000	1000-2000	2000-3000	3000	
	Percentage boreholes				
Hewu	100	0	0	0	156
Mdantsane	28	36	0	36	14
Zwelitsha	29	36	19	16	72
Victoria East	30	60	10	0	30
Peddie	18	37	24	21	183
Middledrift	26	68	0	6	19
Kieskammahoek	83	17	0	0	6
Seymour	No information				
TOTAL %	44	36	8	12	480

TABLE 5 : GROUND WATER QUALITY

To put the above values in perspective, the SABS 271-1971 maximum allowable limit for TDS of domestic water supplies is 2000 mg/l (recommended limit is 500).

Table 5 shows that Hewu District has the best quality ground water. In this respect the table is a bit misleading as most ground water in this District has TDS of less than 500 mg/l, let alone 1000 mg/l.

Keiskammahoek also has good quality water, although this observation is based on comparatively few sampling points.

Victoria East and Middledrift Districts also have reasonably good water quality, with 90% and 94% respectively of boreholes sampled having TDS of less than 2000 mg/l.

Poorer quality ground water is obtained from the Mdantsane, Zwelitsha and Peddie Districts with 36%, 35% and 45% respectively of boreholes sampled having TDS of more than 2000 mg/l.

Referring to Fig 7 an overall regional picture of ground water quality distribution can be obtained, as well as some insight into reasons for the observed variations.

The northern parts of Ciskei stand out as having the best quality ground water, with TDS of less than 500 mg/l. The reasons for this are firstly the water shedding effect of the Amatole Mountains and secondly the nature of the aquifers in this area.

The former was discussed in section 8.3. This same effect is seen in the Western Cape, where mountainous areas of Table Mountain Group sandstones receive some of the highest precipitation in South Africa. The resulting run off is also transmitted to lower lying aquifers and results in low TDS ground water in geological formations normally regarded as relatively poor quality aquifers eg Bokkeveld Group.

The regional influence of this phenomenon can be seen in the southerly extension, for tens of kilometres, of the 1000 mg/l TDS contour.

The northern part of Ciskei is also largely underlain by the Katberg Sandstone Formation with numerous dolerite intrusions. This aquifer type is relatively low in mineral species that contribute to salinity eg Na, Cl and SO₄ and is also of relatively higher permeability, thus allowing freer circulation of ground water, preventing stagnation and build up of salts.

Further south in Ciskei, shale is the dominant aquifer and dolerite becomes scarce. The MAP also decreases. These factors result in an increase in TDS as permeability is reduced, soluble salts become more abundant and there is less water available for 'flushing' of the aquifers. This results in elevated TDS of generally 1000 mg/l to 2000 mg/l, with isolated 'highs' of over 3000 mg/l (much higher in places).

Chemical analyses of 28 ground water samples are shown in Appendix B and have been plotted on a modified Durov diagram to

illustrate the various water types (Figs 8 and 9). This graphical treatment allows the plotting of a composite chemical analysis as a single point, from which certain deductions regarding chemical evolution of the ground water can be made.

Referring to the central plotting field, recently recharged ground waters tend to plot in the top left hand rectangle and have a $\text{Ca}^{++}/\text{Mg}^{++} (\text{HCO}_3^-)_2$ and low TDS character. As ground water evolves it tends to take on a Na^+Cl^- character with an increase in TDS. These ground waters plot in the lower right hand rectangle. Base exchange, whereby Ca^{++} and Mg^{++} ions dissolved in ground water are exchanged for Na^+ ions absorbed on soil/rock surfaces, can lead to an $\text{Na}^+\text{HCO}_3^-$ water type. This water type plots in the upper right hand rectangle.

All three of the above water types are represented by the Ciskei analyses. The lower TDS waters show a $\text{Ca}^{++} (\text{HCO}_3^-)_2$ and $\text{Ca}^{++}/\text{Na}^+ (\text{HCO}_3^-)_2$ character, while the higher TDS ground waters tend towards a Na^+Cl^- character. About 50% of the samples fall into the latter category.

Discussion up to now has revolved around general water quality and the contributing environmental factors.

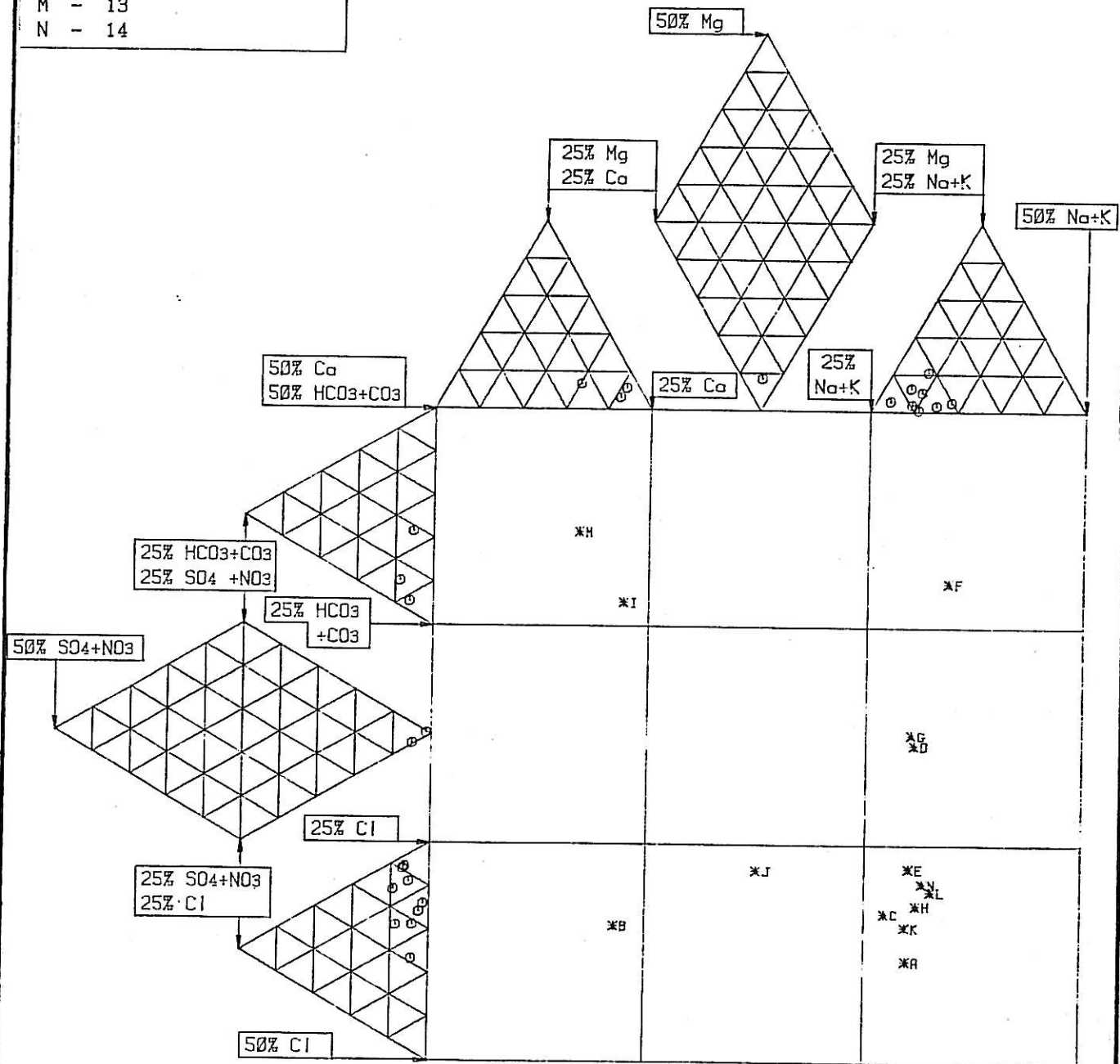
This initial study would not be complete without looking at the relationship of water quality to use. The main categories here are domestic, agricultural and industrial water use.

. Domestic use

Limits are laid down in SABS 241-1971 with regard to constituents in water for domestic supply. Some of these are shown in Table 6. With regard to TDS, 80% of ground waters sampled fall within the maximum allowable limit of 2000 mg/l. Only the Hewu and Keiskammahoek Districts have ground waters with TDS less than the recommended limit of 500 mg/l.

MODIFIED DUROV DIAGRAM

- A - 1
- B - 2
- C - 3
- D - 4
- E - 5
- F - 6
- G - 7
- H - 8
- I - 9
- J - 10
- K - 11
- L - 12
- M - 13
- N - 14



PERCENT OF TOTAL MILLIEQUIVALENTS PER LITRE

HYDROCHEMICAL PLOTS



JOB Nº
KP 5109

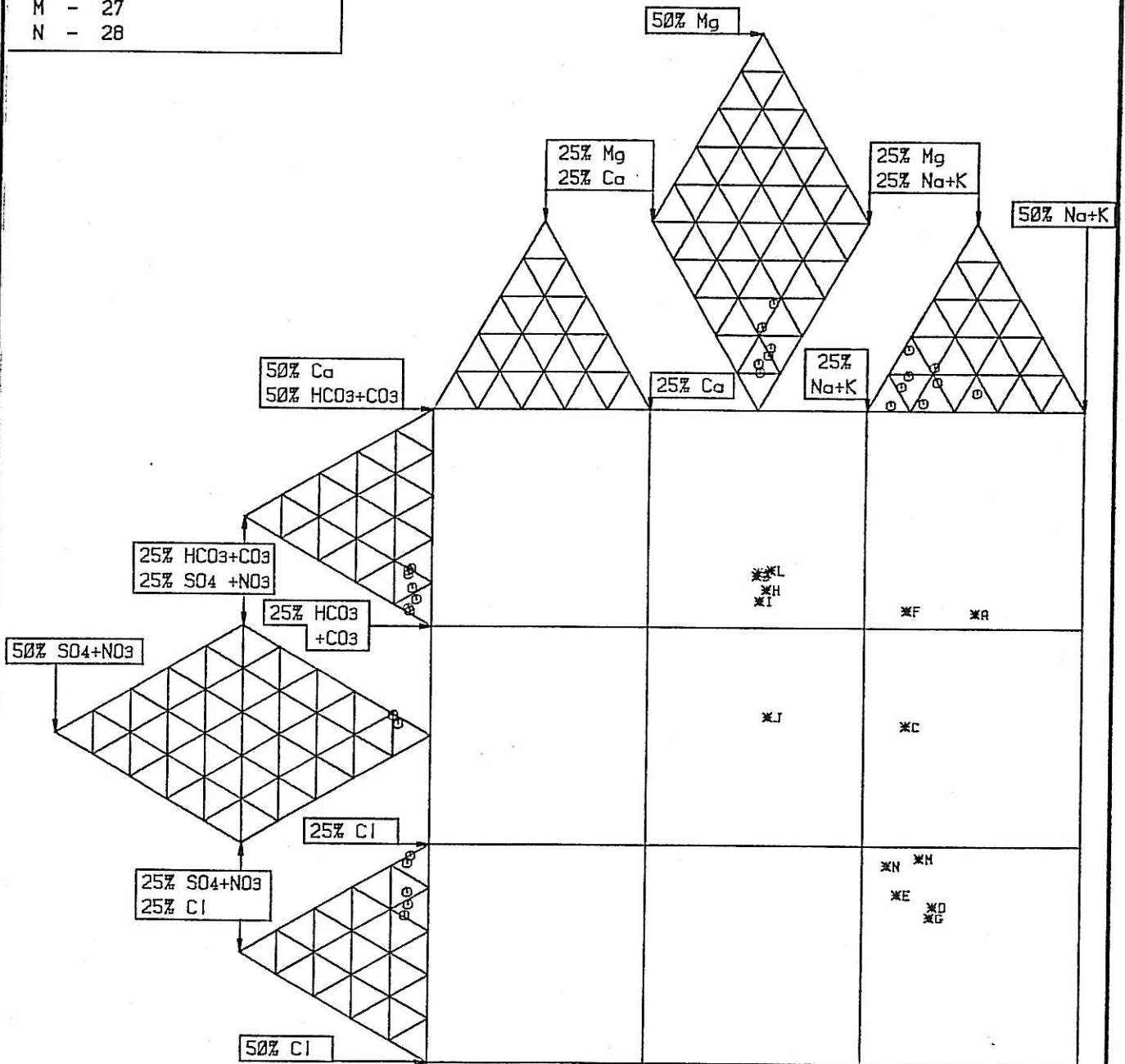
CISKEI GROUND WATER INVESTIGATION

FIG Nº

8

MODIFIED DUROV DIAGRAM

- A - 15
- B - 16
- C - 17
- D - 18
- E - 19
- F - 20
- G - 21
- H - 22
- I - 23
- J - 24
- K - 25
- L - 26
- M - 27
- N - 28



PERCENT OF TOTAL MILLIEQUIVALENTS PER LITRE

HYDROCHEMICAL PLOTS



JOB Nº
KP 5109

CISKEI GROUND WATER INVESTIGATION

FIG Nº
9

The majority of ground waters exceed the recommended limits for Na^+ and Cl^- . However, with only one or two exceptions, the ground waters fall within the maximum allowable limits for the constituents analysed for. It should be emphasised that the SABS limits are a guideline only and really more applicable to urban water supplies. For the generally low density rural use in Ciskei the water quality is acceptable.

. Agricultural use

This includes stock watering and crop irrigation. Quality limits for stock watering vary in the literature. Figures of 5000 mg/l to 6000 mg/l TDS seem most widely quoted but ground water with TDS up to 10000 mg/l does not appear to have a detrimental effect on sheep and cattle. Ciskei ground waters are thus suitable for stock watering.

Water quality criteria for irrigation are very varied, depending on the tolerance of particular crops to salinity. Sensitive crops include citrus fruits and grapes. Tolerant crops are lucerne and potatoes, for example.

To provide an initial assessment of suitability of the ground water for irrigation, Fig 10 has been drawn up. This is a graph of conductivity (salinity) against sodium absorption ratio (sodium hazard). Most of the ground waters plot in the high salinity and low to medium sodium hazard fields. This indicates that the waters are not ideal for irrigation and that care should be taken in selecting suitable crops for any planned irrigation with ground water.

. Industrial use

Quality requirements for industrial use are so varied that it is not really possible to generalise. A few examples are given below for interest's sake:

- brewing : TDS up to 1000 mg/l
- paper and pulp : TDS limits of 100 mg/l to 300 mg/l depending on grade of product
- tanning : hardness (as CaCO_3) 50 mg/l to 135 mg/l.

A, B ETC. CORRESPONDS TO ANALYSIS 1, 2 ETC. FROM APPENDIX B

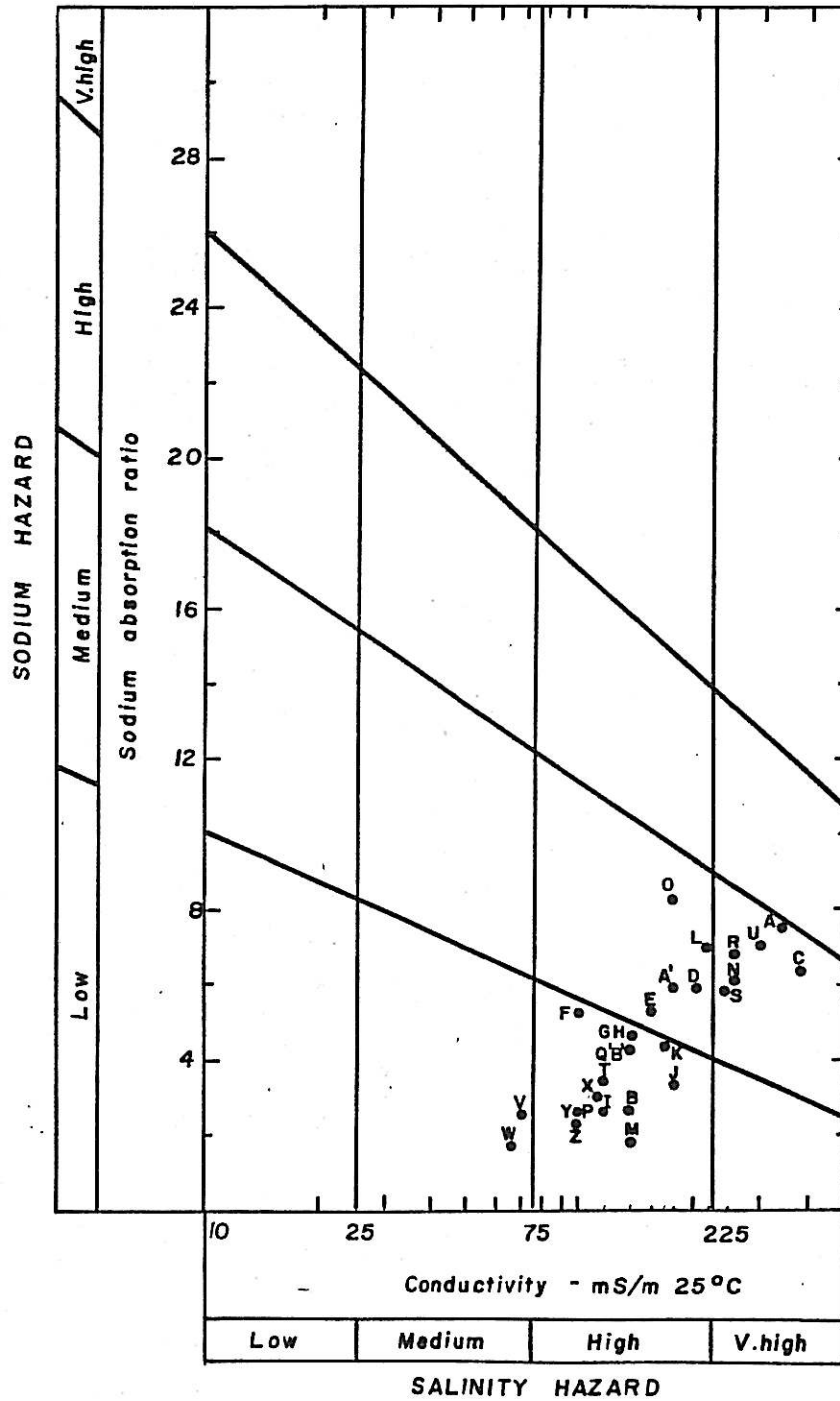


DIAGRAM FOR CLASSIFICATION OF IRRIGATION WATER



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CISKEI GROUND WATER INVESTIGATION

FIG Nº
10

9 HYDROGEOLOGIC REGIONS

The division of Ciskei into hydrogeologic regions is an attempt to simplify the description of ground water occurrence over an otherwise rather large area of 7760 km².

The division into 6 hydrogeologic regions is based on geology and aquifer types. The boundaries do not coincide with major surface water drainage basins, for example.

The regions are described in the following sections under the headings aquifer types, ground water potential, target features for borehole siting and siting techniques. The boundaries of the regions are shown in Fig 11.

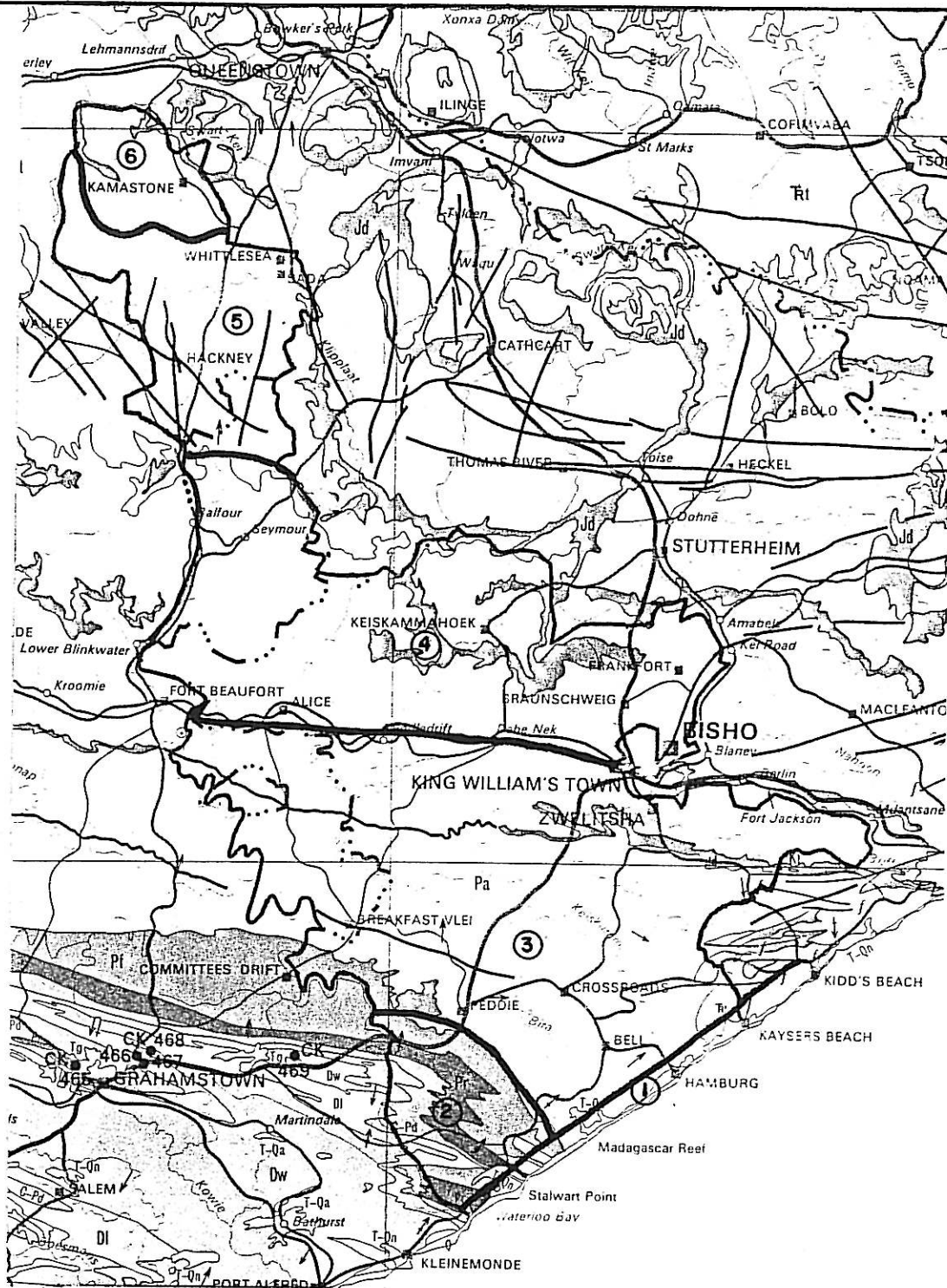
The regions recognised at this stage are :

- Region 1 : Coastal Belt
- Region 2 : Cape Fold Belt
- Region 3 : Central Plateau
- Region 4 : Amatole Mountain Foothills
- Region 5 : Amatole Mountains
- Region 6 : Inland Plateau

9.1 Region 1 : Coastal Belt

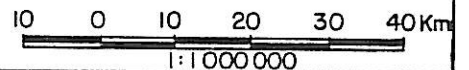
. Aquifer types and distribution

Primary aquifers in the form of coastal dune deposits are present along the coastal belt and are expected to be the most important aquifer in this region. Dune deposits consist of recent windblown sand, older sand, fixed dunes and dune rock. Deposits are most extensive to the west of the Gqutywa River mouth, extending up to 7 km inland and mostly occupying elevated areas between coastal rivers. To the east of the Gqutywa River mouth, deposits generally do not extend further than 2 km inland.



- 1 COASTAL BELT
- 2 CAPE FOLD BELT
- 3 CENTRAL PLATEAU
- 4 AMATOLE MOUNTAIN FOOTHILLS
- 5 AMATOLE MOUNTAINS
- 6 INLAND PLATEAU

HYDROGEOLOGIC REGIONS



JOB N^o
KP 5109

CISKEI GROUND WATER INVESTIGATION

FIG N^o
11

Fractured sedimentary rock may form aquifers of limited extent west of the Mtati River where fractures associated with folding are likely to be present.

Tectonic features are documented (Gombar 1983) and exploited in the Hamburg area. Interpretation of Landsat images indicates that these features are present along the entire length of the coast.

- **Ground water potential**

Recharge to this area will mainly be effected by direct surface infiltration of rainfall on the sand dunes. MAP ranges from 600 mm in the south-west to 800 mm in the north-east. A recharge rate of 165 mm/year has been calculated for the Hamburg area (Tahal 1986). Recharge to the fractured sedimentary aquifer will come mostly from underflow from the adjacent hydrogeological regions 2 and 3 and possibly by leakage from the dunes.

About 90% of boreholes in this region have yields of less than 10m³/h. Isolated yields of up to 30m³/h are obtained at Hamburg, from Lower Beaufort sediments.

Ground water from dune sand in the Mpekweni and Bira River mouth areas may have TDS in excess of 2000 mg/l. More favourable qualities are recorded in the Hamburg area, with TDS of 754mg/l to 1112 mg/l, and Tyalomnga River mouth, with TDS of 315 mg/l. Ground water from the fractured rock aquifer shows a similar range of TDS.

- **Target features**

The main target features present are the sand dunes and, to a lesser extent, the fractured rock aquifer.

The extensive dune deposits west of the Gqutywa River makes this area potentially favourable for investigation. Target

features would include old river channels, marked by depressions in the bedrock.

Fractured rock may underly dunes in the coastal belt southwest of Mpekweni, further enhancing the attractiveness of this area for ground water exploitation.

The linear tectonic features investigated by Gombar (1983) may warrant further investigation, as these features are extensive.

- **Borehole siting**

Holes would ideally be sited where substantial thicknesses of saturated dune sand occur. Here the electrical resistivity geophysical method could provide information on sand thicknesses, as well as giving an indication of expected water quality. The ground magnetic method was successfully employed by Gombar (1983) to detect tectonic features in the fractured rock aquifer.

9.2 Region 2 : Cape Fold Belt

- **Aquifer types and distribution**

Fractured or possibly weathered zone sedimentary rock aquifers are expected to dominate in this region. Tectonic forces responsible for folding should give rise to increased fracturing, especially along fold hinge zones, particularly anticlines.

- **Ground water potential**

The exposed and fractured nature of the rock in this area should promote recharge. A negative factor in this respect however is the relatively low MAP of 600 mm and fairly steep topography, which will promote run-off. Ground water flow directions (Tahal 1986) indicate a N-S trending recharge zone in this area.

Yields are generally low, less than $5\text{m}^3/\text{h}$, but one or two boreholes are reported to give up to $48\text{ m}^3/\text{h}$ (Tahal 1986) from Dwyka and Ecca sediments.

Ground water quality is good in the central part of this region, with TDS less than 1000 mg/l , corresponding to the recharge zone mentioned above. Elsewhere TDS is generally between 2000 mg/l to 3000 mg/l .

- **Target features**

The most favourable target features are the fold hinge zones where the degree of fracturing should be highest. Antiforms often prove more favourable than synforms, as open tension fractures form on the 'outside' of the fold hinge. The relative importance of the fold type will depend on the base level of erosion however. As quartzite is the most competent lithology, anticlinal hinges in this rock type should provide the greatest potential for open fractures at depth.

- **Borehole siting**

Field mapping and aerial photo/Landsat interpretation is required in order to determine the position of fold hinges, the plunge of the relevant folds and fracture zones. The position of the fold hinge will influence borehole siting, whereas the plunge will give an indication of depth of drilling required to intersect the fold hinge. Access for drilling equipment may be difficult in places due to the steep topography.

A major antiform in quartzite is present in the vicinity of Prudhoe, and appears to be the most favourable target site. Previous boreholes drilled in this area (Tahal 1986) are low yielding and would appear from the geological map to have been drilled to the north of the fold hinge or to be too shallow.

9.3 Region 3 : Central Plateau

. Aquifer types and distribution

Aquifers in this area will dominantly be of the fractured/-weathered sedimentary rock type. As the dominant rock type is shale, which is relatively incompetent, fractures are likely to be closed at shallow levels. For this reason aquifers are probably not extensive. Locally more competent sandstone lenses are present which may form isolated aquifers.

Dolerite is not common in this area. However, where present, contact zones and/or fractured zones within the dolerite may form aquifers.

. Ground water potential

Recharge by direct infiltration of rainfall is not expected to be significant owing to the low MAP, 450 mm to 700 mm and high potential evapotranspiration. Main recharge is probably derived by throughflow from adjacent areas eg Region 4.

Yields are generally low, less than 5 m³/h, especially in the southern part of the region. A tendency for the percentage of boreholes with high yields, ie more than 15m³/h and up to 54m³/h, to increase in a northerly direction is apparent. This may be due to the more common occurrence of dolerite intrusions here.

The ground water in this region generally has an elevated TDS of between 1000 mg/l and 2000 mg/l, exceeding 3000 mg/l in the central and eastern areas.

- **Target features**

Fractured shale/sandstone/dolerite constitutes the most favourable target features for this area. Linear features have been detected by remote sensing and these may represent such fracture zones. The northern part of the region appears to be more favourable for exploitation from both yield and quality considerations.

- **Borehole siting**

Fracture zones can be identified by remote sensing and located in the field by geological mapping and possibly ground magnetic traverses. The major dolerite sills/sheets are marked on the published geological maps.

9.4 Region 4 : Amatole Mountain Foothills

- **Aquifer types and distribution**

This region is characterised by the presence of abundant dolerite intrusions, mainly sills and sheets in Balfour Formation shale and subordinate sandstone. Aquifers in this area will be predominantly fractured zones within the dolerite itself, and adjacent contact zones.

- **Ground water potential**

The MAP increases sharply from 600 mm to 1200 mm in a northerly direction due to the orographic effect of the Amatole Mountains. As discussed in Section 8.3, the rugged northern area will act as a 'water shedder' promoting recharge of the lower lying mountain foothills.

Boreholes in this region appear higher yielding on average than those of Regions 1 to 3. Yields of up to 54 m³/h are obtained and certainly yields of more than 15 m³/h should not be regarded as exceptional. An artesian borehole,

CZB151, is located in this region (Fig 11). This borehole is 100m in depth and drilled into a major dolerite sill, apparently on an air-photo lineation, (Gombar, pers comm). The yield is 36m³/h.

Ground water quality is good in this area, being lower than 500 mg/l TDS in the north and generally less than 1000 mg/l in the southern parts.

- **Target features**

Dolerite intrusions are so numerous in this area that there will be no shortage of potential target features. The aim will be to select the optimum structure(s) with regard to type and thickness of intrusion, lithology of the sedimentary host rock and position relative to the water table. A point to be borne in mind is accessibility of sites for drilling. The rugged topography in the northern parts of Region 4 may preclude the drilling of boreholes.

- **Borehole siting**

Techniques will include field mapping and air photo interpretation, backed up by magnetometer traverses. Landsat interpretation will not be of much use here due to the small scale of the image and high density of dolerite intrusions.

9.5 Region 5 : Amatole Mountains

- **Aquifer types and distribution**

This region is characterised by abundant dolerite dykes and sheets intruding the Katberg Sandstone Formation. Aquifer types will be largely of the fractured dolerite/sedimentary rock type. Fractures in the sandstone along margins of the dolerite as well as those in the dolerite itself are likely to constitute the major aquifer type.

- Borehole siting

Interpretation of air-photos and geological maps followed up by field geological mapping and magnetometer traverses would be employed here.

9.6 Region 6 : Inland Plateau

- Aquifer types and distribution

Dolerite is again abundant in this region but the dominant form is the sill/sheet intrusion. The host rock is the Burgersdorp Formation, which is largely shale.

Extensive colluvial deposits occur in this region but are reportedly thin (op cit) and are probably unsaturated.

- Ground water potential

The MAP in this region is only 500 mm and potential evapotranspiration is high. Surplus water for recharge to aquifers will be minimal. Main recharge is probably by throughflow from adjacent areas, such as Region 5.

Information on yields is sparse and inconclusive, with 2 boreholes giving 2,7 m³/h each and one borehole 15 m³/h. In the Queenstown area, which is an extension of Region 6, exploration boreholes gave yields of 16m³/h to 34m³/h with an exceptional yield of 70m³/h being obtained from one borehole (Vandoolaeghe 1980). These facts suggest that good yields can be obtained. The boreholes were all sited by a hydrogeologist using geological criteria and surface geophysics.

Ground water quality is again excellent, with TDS mostly below 500 mg/l, increasing somewhat to the west.

- **Ground water potential**

The MAP varies from 1000 mm in the south to 500 mm in the north. The southern parts of the region will benefit from recharge by the 'water shedding' effect of the Amatole Mountains proper.

The yields obtained from boreholes in this region are surprisingly low, mostly below $5\text{m}^3/\text{h}$, with one or two exceptions in the $10\text{m}^3/\text{h}$ to $15\text{m}^3/\text{h}$ range. The combination of Katberg Sandstone with numerous dolerite intrusions, mainly dykes, was expected to be a more favourable environment for ground water exploitation. One reason for low yields may be positioning of the boreholes. Quite a few borehole sites do not appear to be related to any tangible features, such as dykes or fractures. A further factor here could be that there are so many dolerite intrusions that small ground water 'compartments' are formed which can only support low yielding boreholes.

Ground water quality is excellent in this region, TDS being in the range 250 mg/l to 500 mg/l.

- **Target features**

These are expected to be almost entirely confined to dyke contact zones. Dolerite sheets are uncommon and where present are topographically high lying. The dense network of dykes over much of the area will give rise to ground water compartments. Care must be taken not to select features that are of limited extent due to this fact. Regionally extensive dykes more than 5 m thick and traversed by surface drainage channels would be optimum targets. Comments on accessibility made for Region 4 apply here as well.

A grid is superimposed on the area of interest and at each node the various factors are assessed and the appropriate index assigned. These are then summed and the resulting values contoured. Areas with the highest 'score' correspond to areas with the highest ground water potential.

This is a qualitative representation of data and is intended for planning purposes only. Areas that indicate a high potential for ground water exploitation can be readily ascertained and more detailed data obtained from the 1:50 000 scale hydrogeological maps. These maps will back up the potential map with quantitative data on borehole yields and water quality, for example.

The factors chosen for compilation of the Ciskei ground water potential map are shown in Table 6. The map is enclosed at the back of this report (Drwg 5109/1).

The highest ground water potential (14-18) was obtained for the Amatole Mountains where a combination of very high rainfall, presence of dolerite intrusions, and Katberg sandstone give rise to favourable ground water conditions in terms of both quality and yield. To the north, ground water potential decreases slightly as a result of lower rainfall and the presence of shales. However, a reasonably high potential (10-12) is still obtained due to the abundance of dolerite intrusions and the good water qualities present.

To the south of the Amatolas an approximately 30 km wide zone (mountain foothills) has an above average potential (10-14). Although this area is underlain by shale, the water quality is reasonable, there is an abundance of dolerite and good rainfall.

The central plateau is of poorer potential (4-10) with low rainfall, rare dolerite, and shales with shallow dips largely contributing to this. An approximately 25 km long ESE trending zone of higher potential (10-14), coincident with the northern extremity of the Cape Fold Belt, is present.

- Target features

Drawing again on the results of the Queenstown investigation, low lying dolerite sheets, of 30m to 50m thickness, provide optimum features for ground water exploitation. Ninety five per cent of water strikes in the Queenstown area were within 55m of the regional water-level with highest yields between 45m to 55m, on or near the curved segment of the dolerite sheets. Fractures occur both within the dolerite itself and the adjacent bedrock.

- Borehole siting

Techniques will involve air photo and geological map interpretation followed up by field mapping and magnetometer traverses.

10 HYDROGEOLOGICAL MAPPING

Work to date has centred around a literature survey of hydrogeological mapping projects worldwide, production of a ground water potential map of Ciskei at 1:250 000 scale and production of a 1:50 000 hydrogeological map, to both experiment and illustrate the type of presentation planned.

10.1 Ground water potential map

In order to obtain an overall picture of ground water in Ciskei a ground water potential map has been produced at 1:250 000 scale. The technique has previously been employed to assess the potential for ground water inflow to surface and underground mines. In this context it is known as ground water hazard mapping (Connelly 1980).

The principle is to take as many factors as possible that affect ground water occurrence and exploitability and assign them an arbitrary index. This index is weighted according to the relative influence each factor is considered to have on the ground water potential.

In the extreme south-west of the Ciskei an approximately 10 km wide zone bordering on the Great Fish River shows fair potential (10-14) as a result of folded steeply dipping quartzite, good rainfall and reasonable water quality.

The coastal belt has a high potential (up to 16) largely due to the presence of primary aquifers. The zone widens towards the north-east with increasing rainfall.

10.2 Hydrogeological map series, 1:50 000 scale

10.2.1 Literature survey

A literature survey was carried out to ensure that the methodology employed for Ciskei mapping was 'state of the art' and compatible with internationally accepted techniques. Of the many and diverse publications on hydrogeological mapping, 3 were singled out as being of most relevance to this project. One concerns the work of the IAH* and IAHS*, coordinated by UNESCO (1983), and has resulted in a set of guidelines for compilation of hydrogeological maps. These will be used as a basis for the Ciskei map series, with some additional symbols as discussed in section 10.3.

Of particular relevance to the present study were two publications concerning Southern Africa. The first concerns hydrogeological mapping of the Republic of Botswana (Goldberg, 1980), and the second, recommended procedures for hydrogeological mapping in Southern Africa (Martinelli, 1977).

With regard to scale, UNESCO regard 1:250 000 or greater to be small scale maps. Martinelli (1977) recommends a scale of 1:250 000 for regional medium scale mapping and 1:50 000 for detailed large scale mapping.

TABLE 6 : FACTORS USED FOR COMPILATION OF GROUND WATER POTENTIAL MAP

FACTOR	INDEX
<u>MEAN ANNUAL PRECIPITATION (mm)</u> less than 500 . 500 - 1000 more than 1000	0 3 6
<u>LITHOLOGY</u> shale sandstone dune sand/alluvium	1 3 5
<u>DOLERITE INTRUSIONS</u> Absent Rare Common Abundant	0 2 4 6
<u>GROUND WATER QUALITY (TDS, mg/l)</u> more than 3000 2000 - 3000 1000 - 2000 less than 1000	0 2 4 6
<u>STRUCTURE</u> gently dipping (0-10° dip) folded (10-40° dip) highly folded (more than 40° dip)	0 2 4

Hydrogeological mapping of Botswana was carried out at 1:500 000, but this scale was largely dictated to by the availability of suitable topographic base maps and the level of hydrogeological information available.

Ciskei is covered by 1:50 000 scale topographic maps of excellent quality and the level of ground water data over much of the country is also good.

The legend proposed by UNESCO (1983) for hydrogeological maps has been adopted for this study, with some modifications. ^{revised 1963} Martinelli (1977) recommends that point source data eg. borehole yields be omitted, even on large scale maps eg. 1:50 000. This is intended to simplify interpretation of such maps by non-specialists. However, it is felt that a hydrogeological map would be more complete with such data included and at such a large scale would not be too cluttered or unnecessarily complex. Contouring of data will be employed where possible eg. water quality.

UNESCO (1983) and Martinelli (1977) all advocate the use of colour coding to depict different hydrogeological features eg. secondary aquifers coloured green (dark colour indicating an extensive and productive aquifer), ground water symbols in violet. The Botswana maps are also produced in colour.

For the present study, symbols, contours, aquifers etc, will be shown in black. Colour printing is very expensive and has not been considered at this stage. Ground water is also transient and quality and yields are liable to change with time. It is far easier to update a sepia print than to change a multi-colour print.

*International Association of Hydrogeologists

*International Association of Hydrogeological Sciences

As a matter of interest, the scientific compilation work by a hydrogeologist for the 1:500 000 Botswana maps requires almost 9 man-months per sheet (Goldberg, 1980).

10.2.2 Proposed legend

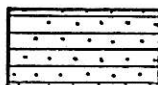
The legend proposed for compilation of the 1:50 000 hydrogeological map series is discussed below. It has been based on the UNESCO (1983) recommendations with some modifications for representation of detailed data eg. borehole symbols and stratigraphic information, to suit local nomenclature.

- **Background information**

This comprises the basic 1:50 000 topographic sheet, which has been screened so as not to obscure the overlying hydrogeological data.

- **Lithology**

The lithology of strata in outcrop is shown by ornament, which has also been screened. Where the ornament indicates recognisably stratified bedrock, the ornament itself is recognisably laminar; when the ornament is arranged horizontally (in an E-W direction on the map) it indicates horizontal or gently inclined strata, when in a vertical position (N-S orientation on the map) it indicates steeply inclined or folded strata. This is illustrated below.

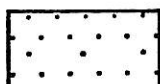


horizontal/gently dipping sandstone



steeply dipping/folded shale

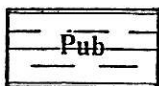
Unstratified deposits such as alluvium and dune sand will be shown as such, as illustrated below.



Alluvium/dune sand

- **Stratigraphy**

This information is not of primary importance on hydrogeological maps but it is useful to indicate the approximate age of the strata depicted. The symbols are printed in black and conform with the Geological Survey of South Africa conventions. An example is given below.



Upper Permian, Balfour Formation

- **Representation of detailed data**

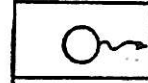
Detailed hydrogeological information is shown by the use of symbols and occasionally lines and ornaments. Numerical figures are only used on contours. The various symbols are shown below.

Borehole and spring data

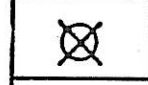
Artesian borehole



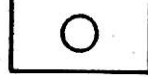
spring



dry borehole

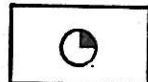


borehole - no information



borehole yield

less than 5m³/h



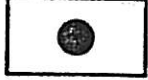
5-10m³/h



10-15 m³/h

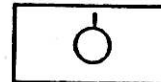


more than 15m³/h

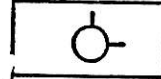


borehole water quality (TDS)

less than 1000 mg/l



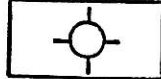
1000-2000 mg/l



2000-3000 mg/l

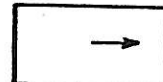


more than 3000 mg/l

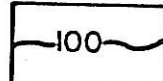


Ground water

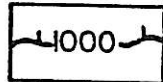
ground water flow direction



ground water level contour



iso-TDS contour



Sheet 3327 AC PRUDHOE has been used as an example to illustrate the hydrogeological mapping technique proposed. The sheet contains a good spread of borehole data, varied geology, structure and aquifer types. The map is presented at the back of this report (Drwg 5109/2). A brief explanation (500 words) of the physiography, geology, hydrogeology and ground water potential is given with the map.

11 CONCLUSIONS

The main conclusions to be drawn from Phase I of this investigation are:

- **Ground water exploitation**

Extensive use is made of ground water on a local scale for domestic use and stock watering. Borehole yields are generally low, with 85 per cent of boreholes having yields of less than 10 m³/h. Most boreholes are equipped with windpumps. Higher yields of 30m³/h to 50m³/h are obtained in places, mainly in the Amatole Mountains and foothills, where there is an abundance of dolerite intrusions. Application of more refined borehole siting and construction techniques will result in generally higher yields being attained.

- **Aquifer types**

About 97 per cent of Ciskei is underlain by secondary fractured rock aquifers. These consist of fractured/weathered sedimentary rocks, fractured dolerite sheets and dyke/sill contact zones. Primary aquifers are restricted to a narrow coastal belt of sand dunes. Transmissivities are low, less than 100m²/day, but not untypical of fractured rock aquifers.

- **Recharge**

The main recharge area is the Amatole Mountain Foothills. This area benefits from the 'water shedding' effect of the Amatole Mountains proper. The effects of this recharge are seen in the excellent water quality of this area which is discussed below.

- **Ground water quality**

In the Amatole Mountains, Foothills and Inland Plateau areas, ground water quality is excellent, with TDS of less than 500 mg/l. Quality deteriorates in a southerly direction, away from the mountain front, with TDS of 1000 mg/l to 2000 mg/l in the central and coastal areas and local 'highs' exceeding 3000 mg/l.

- **Hydrogeological regions**

Ciskei can be divided into 6 hydrogeological regions, namely Coastal Belt, Cape Fold Belt, Central Plateau, Amatole Mountain Foothills, Amatole Mountains and Inland Plateau. Regions 1, 4, 5 and 6 are considered to have the best potential for increased exploitation of ground water, utilizing target features indentified during this investigation.

- **Hydrogeological mapping**

The level of information regarding geology and hydrogeology of Ciskei warrants production of a series of hydrogeological maps covering the country, at a scale of 1:50 000. An example of such a map has been produced in this investigation. Data have been presented using internationally accepted symbols where applicable.

12 RECOMMENDATIONS

Arising out of the Phase I investigation, recommendations for further work in Phase II centre around 3 main areas, namely ground water exploitation, hydrogeological mapping and data banking. These are discussed briefly below:

- **Ground water exploitation**

A number of target features have been identified as being potentially favourable for siting of 'high' yielding boreholes. These are:

- dolerite sheets
- dolerite dyke/sill contact zones
- sand dunes
- fold axes/fracture intersections in sedimentary rock.

It is recommended that borehole sites be selected on these features in appropriate areas and exploration drilling carried out. Promising boreholes should be tested so that yields and

aquifer parameters can be ascertained. Analysis of the data so obtained will enable guidelines to be drawn up for borehole siting in the different hydrogeological regions of Ciskei.

• **Hydrogeological mapping**

The compilation of the first map in the proposed series of 1:50 000 hydrogeological maps of Ciskei was carried out in Phase I. This exercise has proved the feasibility of producing such maps given the level of hydrogeological data available in Ciskei.

It is considered that such maps will add greatly to the understanding of ground water occurrence in Ciskei and also provide a more accessible form of data presentation.

It is therefore recommended that work should proceed on compilation of the remaining hydrogeological maps in the 1:50 000 scale series.

• **Data banking**

It became apparent as Phase I progressed, that the sheer volume of data on boreholes in Ciskei would make it very time-consuming and cumbersome for the information to be presented by conventional means, eg. a manually compiled and typed appendix. The data are also filed in a number of different places, eg. Departments of Public Works and Planning, Consultants. These problems could be solved by incorporating the information into a single computerised data bank, which, after adoption of a suitable format and capturing of all currently available hydrogeological data, could be maintained by the Department of Public Works.

P N ROSEWARNE

M SMART

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APPENDIX A

TERMS OF REFERENCE

CISKEI WATER DEVELOPMENT PLAN: GROUND WATER RESOURCES STUDY

The objective of the groundwater investigation is to evaluate the quantity and quality of the groundwater resources of Ciskei and to establish criteria for its exploitation. The investigation is required to proceed from a general assessment of hydrogeological conditions to defining specific areas for exploitation and will involve the following:

- Review of relevant reports prepared by Ciskei Government and the SA Department of Water Affairs. Review of published geological and geophysical maps.
- Interpretation of available 1:30 000 scale aerial photographs and LANDSAT satellite imagery and aeromagnetic data.
- Field borehole census, including data on borehole equipment, depth to water table and water sampling to determine water quality. Geology of existing boreholes where possible.
- A detailed inventory of springs including Location, discharges, and water quality.
- Limited geophysical survey of the study area to obtain an initial assessment of the suitability of target areas for borehole siting.
- Test pumping of selected boreholes to determine hydraulic properties of representative aquifers.
- The siting and drilling of exploratory boreholes to test the validity of borehole siting criteria and to define the groundwater resource potential of the target areas. Borehole pump tests to monitor discharges and pressure decline induced by pumping.
- Chemical analysis of selected water samples obtained during aquifer tests and from existing boreholes to assess the suitability of the water for domestic or agricultural use.
- Preparation of regional Hydrogeological and water quality maps at 1:50 000 scale and a full report in which aquifer distribution, general aquifer properties and likely ranges of borehole yields, management requirements, groundwater quality and Regional water balance with recommended exploitable quantities are analysed and discussed.
- The report to be presented in three sections, a summary report giving a condensed non-technical account of the investigation, a technical report providing a detailed discussion of activities and findings, and an appendix giving data produced during the investigation.

APPENDIX B

CHEMICAL DATA

Sample number	pH	Cond	Ca	Mg	Na	K	Total Fe	HCO3	CO3	Oil	Cl	SO4	NO3	F	SiO2	ERROR
Units		µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	%
SARS Max.	5.5-9.5	300		100.0	400.0						600.0	600.0	44.0	1.50		
Rec.	6-9	70		70.0	100.0						200.0	250.0	20.0	1.00		
1	7.70	360.0	283.0	8.0	480.0	3.0		417.0			855.0	70.0	3.0	1.30		4.7
2	7.00	140.0	143.0	5.0	120.0	3.0		233.0			311.0	26.0	2.0	.50		1.3
3	6.90	380.0	313.0	12.0	430.0	5.0		669.0			756.0	40.0	5.0	1.10		3.3
4	7.10	200.0	153.0	1.0	270.0	9.0		599.0			380.0	52.0	1.0	.80		4.8
5	7.10	160.0	132.0	2.0	225.0	7.0		423.0			311.0	52.0	2.0	.70		.4
6	7.30	100.0	59.0	3.0	150.0	1.0		321.0			118.0	38.0	2.5	.50		1.5
7	7.10	140.0	100.0	2.0	175.0	1.0		516.0			296.0	11.0	.5	.20		14.3
8	7.10	140.0	92.0	8.0	175.0	1.0		284.0			296.0	10.0	.5	.20		1.3
9	6.90	120.0	123.0	8.0	110.0	1.0		377.0			173.0	33.0	2.5	.40		.9
10	7.20	180.0	158.0	18.0	180.0	7.0		414.0			311.0	52.0	5.0	.50		1.8
11	7.00	170.0	110.0	11.0	185.0	7.0		257.0			361.0	62.0	5.0	.40		3.8
12	7.10	220.0	143.0	4.0	310.0	1.0		435.0			410.0	90.0	5.0	.60		.7
13	7.50	140.0	182.0	12.0	100.0	1.0		591.0			128.0	34.0	3.0	.10		1.4
14	6.90	250.0	159.0	32.0	330.0	8.0		574.0			488.0	63.0	1.0	1.50		1.1
15	7.10	180.0	83.0	11.0	300.0	20.0		531.0			265.0	47.0	1.0	.90		3.9
16	7.10	100.0	92.0	16.0	105.0	1.0		372.0			128.0	30.0	1.0	.30		.7
17	7.00	140.0	98.0	16.0	170.0	5.0		303.0			198.0	52.0	2.0	.30		2.0
18	6.90	260.0	140.0	22.0	330.0	5.0		545.0			579.0	70.0	1.0	.80		7.0
19	7.00	250.0	205.0	21.0	330.0	3.0		561.0			525.0	70.0	1.0	1.00		1.7
20	7.10	120.0	71.0	22.0	130.0	1.0		393.0			162.0	30.0	3.0	.70		1.4
21	7.40	300.0	178.0	44.0	420.0	6.0		551.0			664.0	90.0	2.0	.80		2.0
22	7.30	70.0	63.0	14.0	80.0	1.0		238.0			95.0	15.0	3.0	.20		5.8
23	7.20	65.0	51.0	18.0	60.0	1.0		163.0			73.0	5.0	6.0	.10		14.9
24	7.10	110.0	100.0	26.0	130.0	2.0		368.0			174.0	57.0	1.0	.50		2.7
25	7.10	100.0	86.0	12.0	100.0	1.0		373.0			124.0	30.0	1.0	.30		3.1
26	7.10	100.0	73.0	39.0	100.0	2.0		368.0			120.0	26.0	1.0	.20		6.0
27	7.60	180.0	134.0	5.0	260.0	9.0		434.0			282.0	38.0	1.0	.30		8.0
28	7.70	160.0	135.0	3.0	184.0	18.0		366.0			256.0	38.0	2.0	.70		4.6

SOUTH AFRICAN BUREAU OF STANDARDS

SPECIFICATION

for

WATER FOR DOMESTIC SUPPLIES
(Metric Units)

1. SCOPE

- 1.1 This specification lays down the minimum physical, chemical, and bacteriological requirements for the purity (as delivered to the consumer) of water for domestic supplies.

NOTE

- a)* Water for domestic supplies includes water for culinary purposes and general household usage, but not necessarily water for hot water systems (for which a special treatment might be required to prevent problems such as scale formation or corrosion or both).
b) The numbers of test methods referred to in this specification are listed in Appendix A.
c) Suggestions for assessing, by chemical tests, the presence or absence of faecal contamination in a water supply are given in Appendix B.
d) Various differential coliform tests are listed in Appendix C.
e) A list of references relating to the chemical tests is given in Appendix D.

2. PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL REQUIREMENTS

2.1 GENERAL

- 2.1.1 Suitability. The assessment of the suitability of a water for domestic supplies shall be based on consideration of its physical and chemical properties and its bacterial content (considered together).
- 2.1.2 Classification of Requirements. The limits specified as "recommended" and "maximum allowable" both represent water fit for human consumption and for domestic purposes.

NOTE: The "recommended" limit should, if possible, be applied to all water supplied for domestic use, and the "maximum allowable" limit should never be resorted to unless the consumer population does not exceed 2 500 persons.

2.2 PHYSICAL REQUIREMENTS

- 2.2.1 Turbidity. The turbidity, determined in accordance with 4.1, and expressed in turbidity units, shall not exceed the following:

Recommended limit : 1 Maximum allowable limit : 10

- 2.2.2 Colour. The colour, determined in accordance with 4.2, and expressed in Hazen (platinum-cobalt) units, shall not exceed the following:

Recommended limit : 20 Maximum allowable limit : not specified

- 2.2.3 Taste and Odour. The taste and odour shall not be objectionable.

2.3 CHEMICAL REQUIREMENTS

- 2.3.1 Potability Properties. The properties that affect the potability of water, determined in accordance with the relevant methods given in Column 4 of Table 1, shall comply with the values given in Column 2 or 3, as relevant.

TABLE 1

1	2	3	4
Property	Recommended limit	Maximum allowable limit	Test method subsection
<i>Content of, mg/litre</i>			
Anionic surfactants (as Manoxol OT)	0,5	0,5	5.2
Chloride (as Cl)	250	600	5.5
Copper (as Cu)	1,0	1,5	5.6
Iron (as Fe)	0,3	0,7	5.10
Magnesium (as Mg)	100	150	5.12
Manganese (as Mn)	0,1	0,4	5.13
Phenolic compounds (as phenol)	0,001	0,002	5.15
Sulphate (as SO ₄)	250	400	5.16
Dissolved solids	500	2 000	5.17
Zinc (as Zn)	5	15	5.18
<i>Total hardness</i>			
min. (as CaCO ₃)	20	Not specified	5.19
max.	200	1 000	
<i>pH value</i>			
min.	6,0	5,5	5.21
max.	9,0	9,0	

- 2.3.2 Content of Toxic Substances. The properties that affect the safety of drinking water, determined in accordance with the methods given in Column 4 of Table 2, shall comply with the values given in Column 2 or 3, as relevant.

TABLE 2

1	2	3	4
Property	Recommended limit	Maximum allowable limit	Test method subsection
<i>Content of, mg/litre</i>			
Arsenic (as As)	0,05	0,05	5.3
Cadmium (as Cd)	0,05	0,05	5.4
Cyanide (as CN)	0,01	0,2	5.7
Fluoride (as F)	1,0	1,5	5.8
Hexavalent chromium (as Cr)	0,05	0,05	5.9
Lead (as Pb)	0,05	0,1	5.11
Nitrates (as N)*	10	Not specified	5.14

* If nitrates (expressed as N) are present in concentrations in excess of 10 mg/litre the water may be unsuitable for use by infants under one year of age, and an alternative source of supply must be found for such infants' use.

- 2.3.3 Other Constituents. The water shall not contain any other constituents in concentrations which may render it unsuitable for use for domestic supplies. Radioactivity, if present, shall be within the limits laid down by the International Commission for Radiological Protection.
- 2.4 BACTERIOLOGICAL REQUIREMENTS. When tested by the methods given in Column 4 of Table 3, the water shall comply with the limits given in Column 2 or 3, as relevant.

TABLE 3 - BACTERIOLOGICAL LIMITS

1	2	3	4
Organism	Recommended limit	Maximum allowable limit	Test method subsection
Coliform organisms, number per 100 ml	*	10	6.2
<i>E. coli</i> 1, number per 100 ml . . .	Nil	Nil	6.3
Total viable organisms, colonies per ml	100	Not specified	6.4

- * a) If any coliform organisms are found in a sample, a second sample shall be taken immediately after the tests on the first sample have been completed and shall be free from coliform organisms, and
 b) not more than 5 per cent of the total number of water samples (from any one reticulation system) tested per year may contain coliform organisms.

3. SAMPLING AND COMPLIANCE WITH THE SPECIFICATION

3.1 SAMPLING. The following sampling procedure shall be applied in determining whether the water complies with the requirements of the specification. The samples so drawn shall be deemed to represent the water for the respective properties.

3.1.1 Samples for Physical and Chemical Tests

NOTE: Samples should be sent to the laboratory as quickly as possible as immediate chemical analysis (or stabilization) of the samples is imperative (see 5.1.2).

3.1.1.1 *Frequency of sampling.*¹⁾ Sampling and testing should be carried out at least four times each year at the following times: at the beginning of the rainy season, in the middle of the rainy season, at the end of the rainy season, and in the middle of the dry season.

3.1.1.2 *Sample containers.* Use glass bottles of approximately 2 litre capacity with close-fitting clean stoppers. Protect the stoppers and necks of the bottles, both before and after sampling, by securely covering them with a cloth or thick paper. Clean the bottles thoroughly before use (the bottles should preferably be washed with a solution of nitric acid and rinsed thoroughly to remove the acid), half-fill with the water being sampled, shake well, empty, and drain. Repeat this procedure three times (i.e. four times in all) before starting to collect the sample.

3.1.1.3 *Collection of sample.*²⁾ Collect at least 10 litre of sample as follows:

a) *Sampling from a tap.* Turn the tap on full and allow the water to run to waste for 2 minutes before the sample is taken. Adjust the tap to only partially open (to avoid unnecessary aeration when taking the sample), remove the covering and stopper, and fill the bottle to within 15 mm of the top of the neck. Replace the stopper, and secure it with the cover.

b) *Sampling from a borehole or well.* When water is sampled from boreholes and wells, it is preferable to sample from the pump outlet pipe (the procedure given in 3.1.1.3 (a) being used) and not direct from the borehole or well. In the case of a new borehole or well, water should be pumped for at least 24 hours before a sample is taken.

c) *Sampling from a stream, lake, or spring.* Remove the covering and stopper and completely immerse the bottle, holding it by the base. Allow it to fill by facing it upstream in flowing water, or by slowly moving it forward in still water (so as to obviate collecting any disturbed sediment). If wading to collect samples, keep moving upstream while collecting a series (for the same reason). To ensure that the sample is as representative as possible, collect it as far from the verge of the water as possible. It will probably be necessary to use a boat to obtain a sample at a suitable depth from a lake or dam. In such cases attach the bottle to a rod or use other appropriate means.

1) Because the results of analyses performed at one time of the year may differ markedly from those obtained at another time of the year, a recommended frequency only has been included in the specification. The frequency actually used should be based on the variations obtained in an initial series of, say, monthly tests, the number of population served, and the nature of the source of supply.

2) A printed form of instructions for the sampler should accompany the prepared (empty) sample bottles dispatched by the laboratory.

3.1.2 Samples for Bacteriological Tests

3.1.2.1 *Sampling points.* The points at which samples are taken shall be such that the samples are as representative as possible of the water throughout the storage and reticulation system(s).

3.1.2.2 Frequency of sampling

a) *Volume and number of samples.* The volume of each sample shall be at least 250 ml, and the minimum number of samples taken at each sampling point shall be as given in Table 4. Not more than one sample shall be taken on any one day.

b) *Special samples.* The samples taken after an unsatisfactory test (see footnote to Table 3 and 3.1.2.3) shall be considered as special samples and are not to be included in the minimum number of samples taken in terms of (a) above.

TABLE 4 - FREQUENCY OF SAMPLING

1	2
Population served	Frequency*, min.
More than 100 000	10 every month per 100 000 of population served
25 000 - 100 000	10 every month
10 000 - 25 000	3 every month
2 500 - 10 000	2 every month
1 000 - 2 500	1 every month
100 - 1 000	1 every two months
Less than 100	1 every three months

* During the rainy season, sampling should be carried out more frequently.

3.1.2.3 *Check samples.* If on testing a regular sample (see 3.1.2.2(a)) the water is found not to comply with the appropriate requirements of 2.4, a check sample shall be taken immediately.³⁾

3.1.2.4 *Sample containers.* Only containers that are supplied by the testing laboratory and that are sterile and fit for immediate use shall be used.

3.1.2.5 Collection of sample

a) *General.* The sampler shall wash his hands thoroughly before taking each sample. Before sampling, a label shall be prepared, giving the name of the sender, the date, the time of sampling, and any special distinguishing mark. This label shall be firmly affixed to the sample container immediately after sampling.

When the sterile sample container is handled, no surface of the closure that can come into contact with the sample or with an inner surface of the container shall be allowed to touch the hand or come into contact with any object; on no account shall the closure be laid down.

b) *Sampling from a tap or pump.* Allow the water to run to waste for long enough to completely flush the pipe supplying the tap, and in any case for 2 to 3 minutes.

Wash the mouth of the tap or pump inside and outside with a suitable cleaning agent. Using a spirit (or other suitable type) burner, apply a flame to the mouth of the tap until well heated, and then allow the water to run to waste until the tap is cool.

c) *Sampling from a stream, reservoir, etc.* Hold the base of the container in one hand, remove the closure with the other hand, and immerse the container at once to a depth of about 300 mm below the surface of the water, allowing it to fill up-stream in flowing water and by forward movement of the container in still water (so as to prevent the collection of any water which has come into contact with the hand). After removing the container from the water, replace and secure the closure, and return the container to the sample box.

3.2 INFORMATION TO BE SUPPLIED WHEN SAMPLES ARE SUBMITTED FOR TESTING.
The following information (as relevant and given as fully as possible) should accompany each sample submitted for testing:

3) If tests on a check sample confirm the original finding, the health authority concerned should be advised, efforts should be made to locate the cause of the contamination, and action should be taken to eliminate the cause.

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