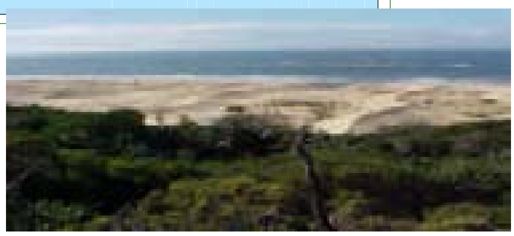
P WMA 15/000/00/0408

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Directorate: National Water Resource Planning

ALBANY COAST SITUATION ASSESSMENT STUDY



Groundwater Resource

Final

December 2004

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DIRECTORATE: NATIONAL WATER RESOURCE PLANNING

PROJECT NAME	:	Albany Coast Situation Assessment Study
TITLE	:	Groundwater Resource – Final
AUTHOR	:	E Mouton
REPORT STATUS	:	Final
DWAF REPORT NO	:	P WMA 15/000/00/0408
DATE	:	December 2004

Submitted on behalf of WSM Leshika (Pty) Ltd by:

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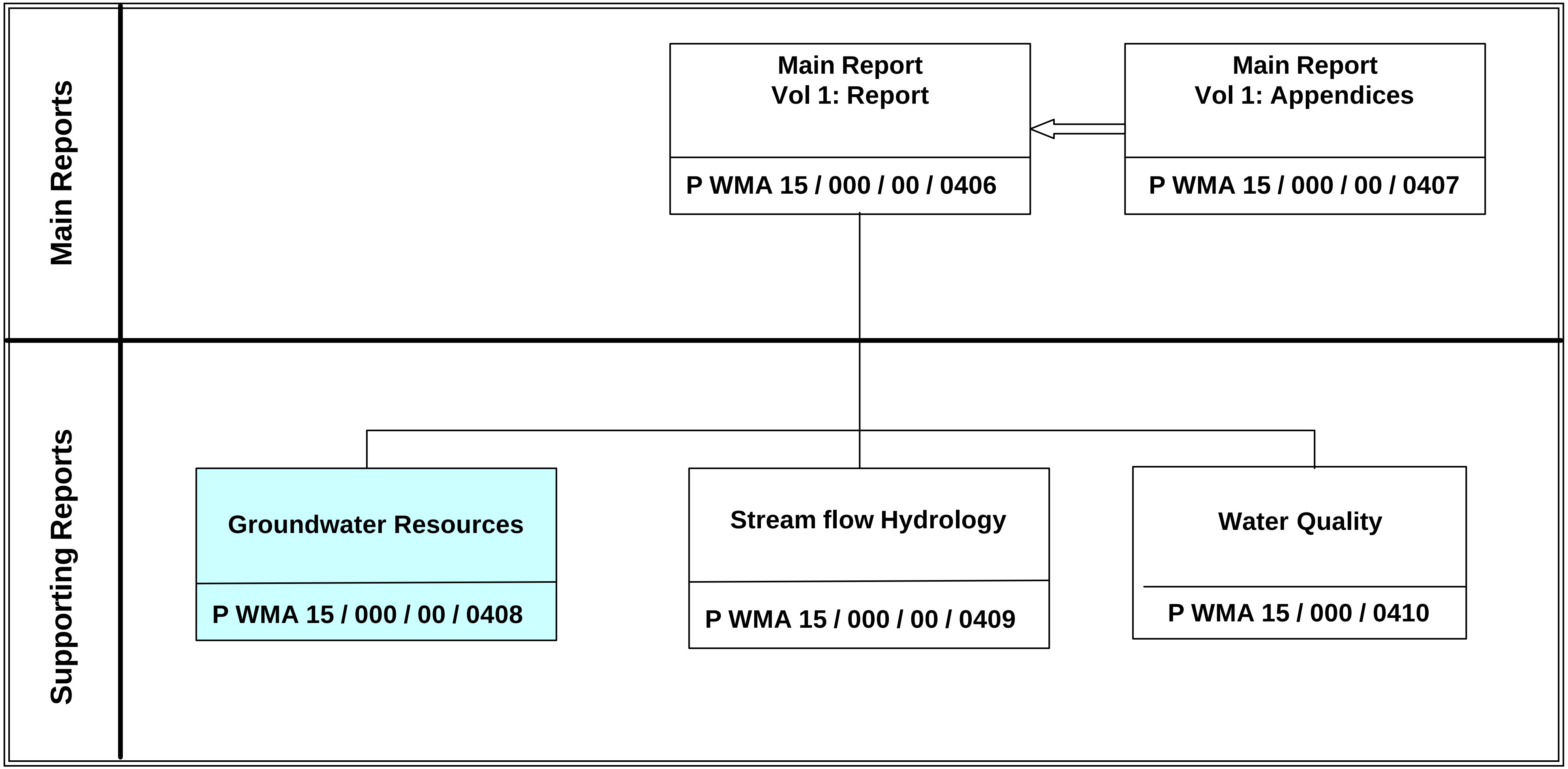
ALBANY COAST SITUATION ASSESSMENT STUDY

Structure of Reports



EXECUTIVE SUMMARY

INTRODUCTION AND RESEARCH OBJECTIVES

The Albany Coast drainage region (‘P’) falls under the jurisdiction of the Cacadu District Municipality, and includes the entire administrative area of Ndlambe Local Municipality, where all the affected towns are located. Essentially all the coastal and inland towns situated within Ndlambe experience serious, periodic water supply problems, mainly because of inadequate resources, poor water quality and insufficient capacity of their bulk supply infrastructure. These towns are Port Alfred, Seafield/Kleinemonde, Kenton-on-Sea, Bushmans River, Boknes, Cannon Rocks and Alexandria. DWAF appointed UWP Consulting Engineers as a lead consultant to conduct a Water Situation Assessment for the coastal zone of the Albany Coast Basin, corresponding roughly to Ndlambe. Due to the multi-disciplinary nature of the project, UWP Consulting invited DMM and ***WSM*** to offer specialist services in the fields of surface hydrology and hydrogeology respectively.

WSM were asked to evaluate the groundwater resources of which the development potential will be conducted in two scales viz., regionally as a desk study and locally as a hydrocensus. This report serves primarily to define the hydrogeological characteristics of Ndlambe on a regional scale in order that planning can be undertaken by DWAF. More specifically, the availability of groundwater in terms of spatial distribution, quality and quantity needs to be evaluated where the resources can serve as a primary water supply or augment surface water.

HYDROGEOLOGY

The geology is dominated by the sedimentary deposits of the Cape Supergroup, which underlie almost the entire area. Some Karoo Supergroup sediments are preserved in he Fish River floodplain. Rocks of the Algoa Group and Quaternary form a thin veneer along the coastal zone, but are nevertheless, an important component of the geology.

The Cape Supergroup rocks are represented by the Bokkeveld Group shales and the Witteberg Group shales and quartzites. Whereas the former is largely undifferentiated, the latter comprises the basal Weltevrede Formation (largely shale); the central Witpoort Formation (largely orthoquartzite), which is in turn overlain by the Lake Mentz Formation (largely shale). Although orthoquartzites of the Witpoort Formation, have much in common with the Table Mountain Group Rocks, its aquifer potential has been largely ignored - mainly because of the ease (and low-cost) in developing coastal aquifers.

The Algoa Group 'limestone's' constitute near shore, marine, fluvial and aeolian sediments. Their formation and distribution was related to sea-level changes during the recent past. These rocks generally young towards the present-day coastline and are represented by the Bathurst, Alexandria, and Nanaga formations. The Quaternary (10 000 years to present) is represented by the Schelmhoek Formation and comprises modern beach and dune sand and found along the entire 75-Km long Ndlambe coastline. These fossil and modern dune aquifers combine to act as primary aquifers and are responsible for groundwater targets where optimally developed.

The entire southern Cape region, originally part of southern Gondwanaland, was subject to increasing compression from a southerly direction – some 290 million years ago. This resulted in folding and uplift of mainly Cape Supergroup rocks to form the east-west trending Cape Fold Belt. During the Mesozoic period, the fragmentation of Gondwanaland began to process of marginal rift faulting. Cape Supergroup rocks within Ndlambe are folded into asymmetric folds and faulted, including thrust, normal and strike-slip varieties.

Prevailing stress conditions have a significant impact on the water bearing potential of a fault, as it determines whether the structure will be open or closed, thereby affecting permeability. Structural mapping and geodynamics analysis from this study suggests that south-southeast and east-northeast trending structures form the most suitable drilling targets for high yielding boreholes. This was complemented by a first-pass lineament analysis, which showed similar directions.

Borehole data exists in the national Groundwater Database (NGBD) and 755 boreholes are listed for the area. The NGDB is nether comprehensive or complete and it is estimated that less than half the actual boreholes drilled and/or utilized are reflected. Nevertheless, the NGDB has been able to provide a regional assessment of background hydrogeological conditions. Limited hydrocensus work was also conducted around each of the affected towns in Ndlambe. An additional 24 boreholes have been appended to the NGDB. The vast majority of these boreholes are low-yielding and serve rural communities.

In fractured aquifers, the sand:clay ratio plays a noticeable role both quantitatively and qualitatively in the occurrence of groundwater, causing borehole yields and chemistry to vary widely. A high proportion of clays resulted in these rocks deforming without inducing secondary fracturing. Clay-rich rocks also impart a marine (or sodium chloride) character to the groundwater, giving it a brackish taste.

The Bokkeveld, Weltevrede and Lake Mentz aquifers, which make up 56 % of the surface geology of Ndlambe, cannot be economically exploited as they generally possess low to moderate yields and are mostly saline.

Of the fractured aquifers, the Witpoort orthoquartzites have the highest potential of an assumed 2.55 Mm^3/a. The Witpoort Formation is present as three discrete, southeast trending belts, which make up 25 % of the surface geology. These three belts have a cumulative strike length of 45 Km, which fortuitously, arcs behind each of the affected towns.

Targets for exploitation in these belts are restricted to major fault zones. Thirty percent of scientifically boreholes sited and drilled are expected to yield between ~ 5 ℓ/s of Class I and Class II quality groundwater. Poorer quality groundwater is expected where marine shales bound faults. Water strikes can be expected as deep as 70 m bgl, and deep drilling will be required to accommodate the high expected draw downs

The western belt trends behind Kenton-on-Sea/Bushmans River i.e., the area of greatest need. Up to 1 Mm^3/a could be exploited from this belt. Obvious targets are situated in and around the farms Bushfontein, Merville, Barville Park and Glendower. Recent drilling on Merville by DWAF on the farm Merville produced very encouraging results viz., a 100 % success rate with 4 boreholes with a cumulative blow yield of ~ 36 ℓ/s. Some of these boreholes are artesian.

A thrust fault bisects the central belt and coincides with a cluster of high-yielding boreholes. Farms in and around Grove Hill, Fords Party and Tharfield are obvious targets for groundwater to benefit Bathurst, Port Alfred or the Seafield/Kleinemonde respectively. Potentially, another 0,3 Mm^3/a could be abstracted from the central belt.

Up to 1.28 Mm^3/a could be exploited from the Eastern Belt, which trends from the Fish River Lighthouse to Grahamstown and beyond. Potential targets occur in and around farms corresponding to Palmietheuval, Southseas and The Grove. The Seafield/Kleinemonde communities could benefit by as much as 3 507 Kℓ/day from this groundwater resource.

With respect to the much younger, coastal aquifers, which occur as a narrow strip along the 75 Km long Ndlambe coastline. Here, approximately 75 % of boreholes drilled are expected to yield ~ 2 ℓ/s of Class I and Class II quality groundwater. Water strikes can vary from 5 to 10 m bgl with a maximum borehole depth of ~ 20 m.

The exploitation potential of the modern dune aquifer were calculated separately for areas where the dune cordon is sufficiently wide to exploit sustainably. These aquifers are composite in nature and are recharged directly from MAP and benefit from lateral inflow from the back dune area. Targets of high potential are presented from the west to the east.

The under utilized Cape Padrone/Fishkraals aquifer could contribute 0.83 Mm^3/a, whereas the undeveloped Apies River aquifer an additional 0.76 Mm^3/a to benefit the Alexandria, Cannon Rocks/Boknes communities.

For the greater Kenton-on-Sea/Bushmans River communities, development of the Kwaaihoek aquifer (0.12 Mm^3/a) makes sense as groundwater from this source would make use of the under optimised Dias Cross pipeline, which passes nearby. Drawing groundwater from this source will do much to reduce the seasonal peak demands. The Dias Cross (0.22 Mm^3/a) and the Bushmans River Mouth (0.07 Mm^3) well fields are fully developed.

All the above-mentioned coastal aquifers are developed in ground managed by SanParks, who do not sanction further exploitation of coastal aquifers. SanParks's jurisdiction extends only as far as the west bank of the Bushmans River.

Port Alfred could benefit by augmenting their East Bank well field (0.12 Mm^3) by considering the Sunshine Coast Nature Reserve (0.28 Mm^3/a); Rufanes River (0.12 Mm^3/a) and Riet River (0.11 Mm^3) aquifers, all of which are undeveloped. By utilizing these resources, Port Alfred could improve water quality by blending and cope with peak demands.

The Seafield/Kleinemonde community could develop the Clayton's Rocks (0.11 Mm^3/a) and/or the Fish River Lighthouse (0.11 Mm^3/a) coastal aquifers to help cope with their peak demands.

CONCLUSIONS AND RECOMMENDATIONS

Existing borehole use is low and it is favourable to develop well fields in both the Witpoort fractured aquifer and the coastal, intergranular aquifer. No other aquifers need to be considered. The groundwater abstracted will augment by conjunctive use, the severe water supply problem in the coastal towns. Areas of high potential within these aquifers have been identified close to affected towns. Although the groundwater quality will be largely marginal, it will be significantly better that water derived from most dams. The TDS is currently 2 500 mg/ℓ at the Sarel Hayward dam.

Initial exploration drilling done in the Witpoort aquifer was encouraging and needs to be expanded to all three belts. All towns (with the possible exception of Bathurst at this stage) can benefit from exploiting this aquifer. Follow-up hydrogeological work is recommended for the proposed sites ahead of the requisite EIA's for any possible groundwater development.

Under optimal conditions, the coastal aquifer can be relied upon to bring relief to each of the coastal towns, almost without exception. Detailed hydrogeological feasibility studies are recommended for the area in and around the proposed sites in support of the EIA's, which will confirm acceptability. Issues regarding developing groundwater resources in the ecologically sensitive coastal zone need to be resolved.

No other aquifers need to be considered as a potential groundwater resource.

It is accepted that groundwater resources will not be sufficient in the long term and ultimately, a surface water scheme will be required for Ndlambe.

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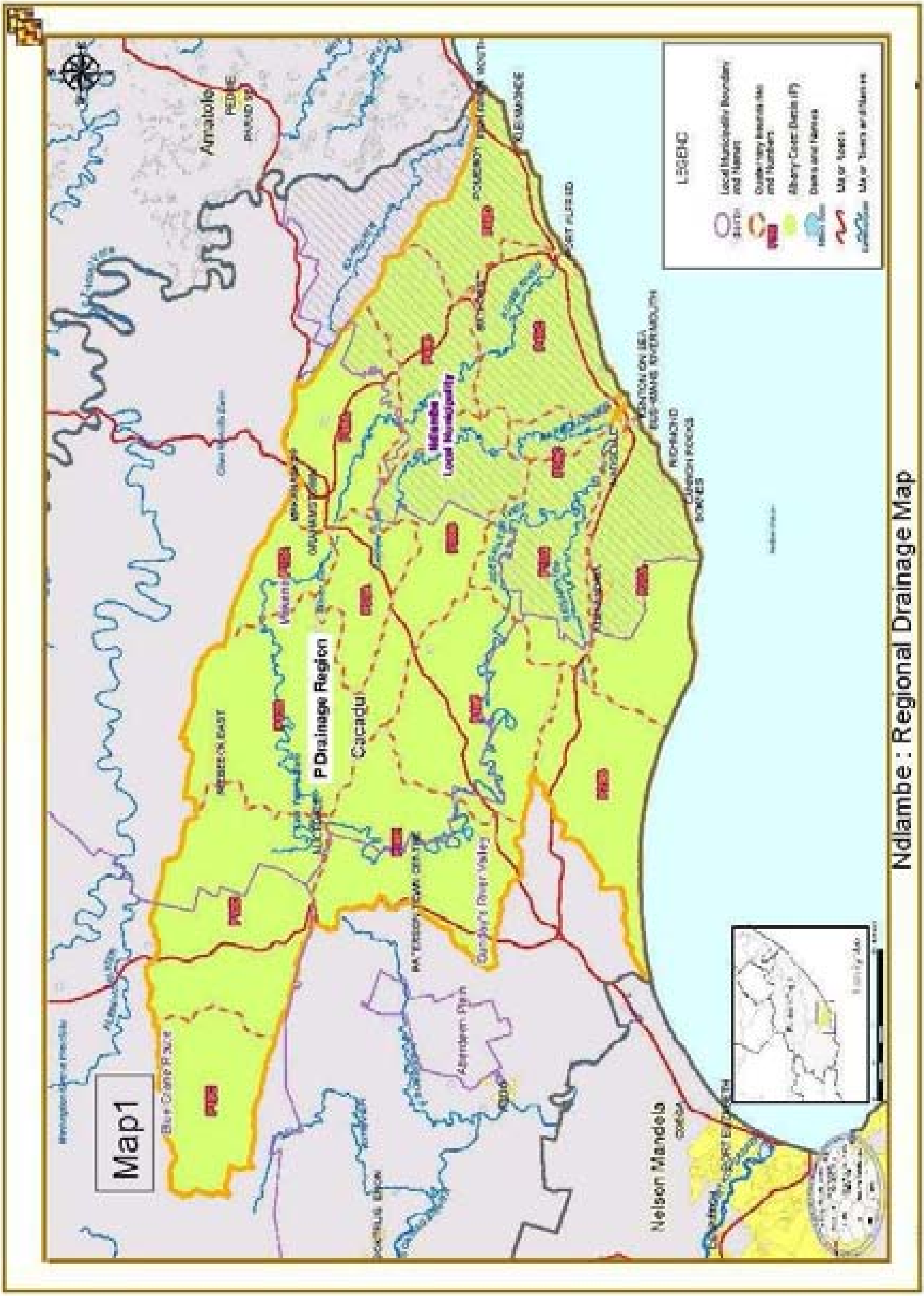
ADDENDUM TO REPORT

1. INTRODUCTION

The Albany Coast primary drainage region ('P') falls under the jurisdiction of the Cacadu District Municipality, and includes the entire administrative area of Ndlambe Local Municipality, where all the affected towns are located (Map 1). For the sake of brevity, the study area will be referred to as 'Ndlambe' hereafter. The study area is situated between the catchments of the Great Fish River, the Sundays River and the Indian Ocean and covers ~ 2 006 Km². The main rivers in the study area are the Bushmans, Kariega and the Kowie, with the Fish River (and its tributary, the Kap River) forming the eastern boundary with primary drainage region 'Q'. These drainage regions were defined in the Water Research Commission Report No.298 of 1994.

Funding has been made available through DWAF's National Resources Planning sub-directorate to undertake a Water Situation Assessment of Ndlambe. A number of coastal and inland towns situated within Ndlambe experience serious periodic water supply problems, mainly because of inadequate resources, poor water quality and insufficient capacity of their bulk supply infrastructure. These towns are Port Alfred, Bathurst, Kleinemonde, Kenton-on-Sea, Bushmans River Mouth, Boknes, Cannon Rocks and Alexandria (Map 1).

At present, the Ndlambe Municipality is the water service authority and service provider for all affected towns, except for Bushmans /Kenton and Alexandria. The Albany Coast Water Board (ACWB) is the service provider for the former towns whereas P&S Consulting is a support services agent for the latter town and the resorts of Boknes and Cannon Rocks.


Map1
Ndlambe : Regional Drainage Map
P Drainage Region
Cacadu
Nelson Mandela
Amatole
LEGEND

Map 1

2. TERMS OF REFERENCE

DWAF appointed UWP Consulting Engineers as a lead consultant to conduct a Water Situation Assessment for the coastal zone of the Albany Coast basin, corresponding roughly to Ndlambe. Due to the multi-disciplinary nature of the project, UWP Consulting invited DMM and ***WSM*** to offer specialist services in the fields of hydrology and hydrogeology respectively. In addition, a specialist sub-consultant – Geospatial and Remote Sensing Specialists, were co-opted to undertake remote sensing interpretation.

Background to the study is contained in the Albany Coast Situation Assessment (Tender No.: 2003-123) and the subsequent Inception Report, both compiled by UWP Consulting.

WSM were asked to evaluate the groundwater resources of which the development potential will be conducted in two scales – regionally as a desk study and locally as a hydrocensus. This report serves primarily to define the hydrogeological characteristics of Ndlambe on a regional scale in order that planning can be undertaken by DWAF. More specifically, the availability of groundwater in terms of spatial distribution, quality and quantity needs to be evaluated where the resources can serve as a primary water supply or augment surface water resources.

3. MAIN AIMS AND OBJECTIVES

The purpose of the study is to investigate, at a reconnaissance level, the water supply problems of the area, with specific reference to the afore-mentioned towns, through a broad review of existing information, and to consider possible solutions that may present themselves for ready implementation. The study will also produce a situation overview from which, if necessary, DWAF can draw up a framework for further studies and infrastructure development.

The study included consultations with officials from DWAF, consulting engineers and local authorities in order to obtain a full understanding of the water supply situation. The primary focus is to identify resources to resolve water supply problems for the specified towns (urban sector) with due consideration given to rural domestic, agricultural, afforestation, ecological Reserve etc.

The purpose of the hydrogeological investigation is to provide an overall assessment of the situation, to identify readily available solutions, and based on this, to refine the scope for the successive phase(s). The following approach was followed:

Regional Scale – Desk Study: A literature study was conducted for all relevant geological and hydrogeological information and maps available for Ndlambe. The groundwater resources included an overall assessment of the resources within Ndlambe, based on available data. This phase drew heavily on interrogating the NGDB.

Local Scale – Hydrocensus: Here detailed, site-specific investigations targeted affected towns. This phase was largely field-based and included remote sensing, hydrocensus and sampling. From this work, the exploration potential of the groundwater resources of the towns was assessed.

The final product will be compiled into a single report.

4. NETWORKING

The study is reliant on the interaction and networking between various organizations including: various DWAF departments, ACWB, agricultural extension officers, consulting engineers, municipal officials, nature conservation officials (including SanParks), rate-payers associations, Chamber of Business, commercial farmers and unions and tertiary institutions. This is required in order that all data is received for the study area, enabling an inclusive overview of the groundwater resources to be put forward. Reference is made to all data received and source(s) of this data. In summary, the following organizations, technical reports and networking activities are listed below:

Interaction with ongoing Projects:

- GRIP (EC) – Groundwater Resources Information Project
- DWAF Directorate Geohydrology –Witpoort Research Drilling
- ACWB: Bulk Water Supply Upgrades, Bushmans/Kenton
- P&S Consulting: Bulk Supply Upgrades – Boknes/Cannon Rocks

Technical Reports:

- Refer References

Liaison and Meetings:

- Ndlambe Municipality (Mr. George Ngesi, Mr. Bill Patterson and Mr. Anton Gouws)
- ACWB (Mr. Ron Ball)
- P&S Consulting (Mr. Paul Fick and Mr. Stephen Fick)
- Bathurst and Alexandria Agricultural Extension Officers (Mr. Ray Hageman and Ms Jenny Potgieter)
- DWAF Directorate Geohydrology – Ms Jane Baron and Mr. Herman Goossens
- Rhodes University (Prof Julian Marsh and Prof Etienne Nel)
- Chamber of Business Kenton – Mr. Walther Kitkat
- Kleinemonde Ratepayers – Mr. Des Forward and Mr. Christo Bezuidenhout
- Various commercial/game farmers and farmers' representatives and unions
- SanParks and Nature Conservation officials

5. SITE LOCALITY AND DESCRIPTION

5.1 LOCATION

The study area is located in the southwestern portion of the Eastern Cape Province and is situated more or less midway between Port Elizabeth and East London and about 50 Km south of Grahamstown (Map 1).

5.2 CLIMATE

On the basis of the Koppen system of climate classification, the coastal zone is regarded as sub-tropical, all months having temperatures of between 10 and 22.2 ºC and having at least 60 mm of rainfall. The temperature is mild in both winter and summer, with wind reducing both the heat and humidity.

The area receives a bi-modal rainfall distribution with a larger peak in spring and a somewhat smaller peak in autumn. This is a transitional zone, as further east, the pattern changes to a more abundant summer rainfall, whereas further west, the pattern changes to mainly winter rainfall.

Table 1: Mean Monthly and Mean Annual Precipitation

Monthly Rain	Alexandria Forest Stn	Bathurst	Bushmans/ Kenton	Seafield/ Kleinemonde	Port Alfred
January	61	55	42	44	41
February	58	59	45	53	52
March	78	80	68	71	69
April	66	55	49	52	53
May	77	43	54	62	58
June	72.5	40	50	48	44
July	69	41	48	37	39
August	73	57	53	43	41
September	91	55	63	50	63
October	97	76	65	61	66
November	86	79	64	58	57
December	61	61	45	42	44
MAP (mm)	**885**	**703**	**636**	**621**	**627**

The Mean Annual Precipitation (MAP) for the region varies around 640 mm (± s = 140) and decreases in a northerly (inland direction). The area around the Alexandria Forest Station benefits from rain-bearing clouds being orographically uplifted, inducing higher rainfall over a localized area.

The most rain that fell in Port Alfred was 175 mm in 24 hours. This event coincided with above average rainfall in 2003.

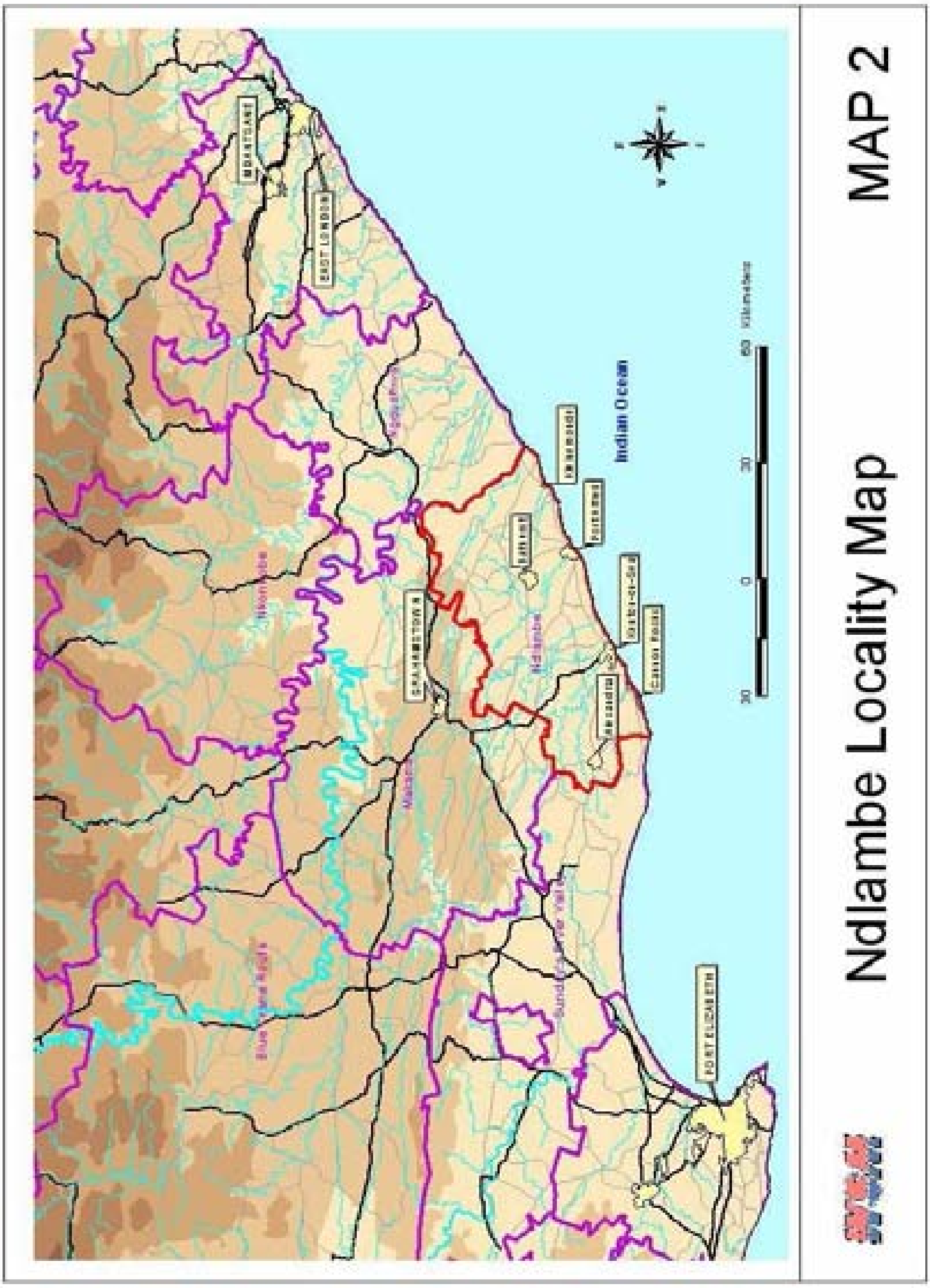
The average monthly evaporation rates for the region ranges seasonally from 104.5 mm in winter to 210.7 mm in summer, following a similar trend to the mean temperatures. Runoff volumes can be estimated from rainfall and evaporation data, and indicate that the maximum runoff should occur in the summer months. Rainfall runoff never exceeds evaporation in this region. According to DWAF criteria, runoff should be managed where rainfall runoff exceeds evaporative water loss for more than 20 % of the time. The annual relative humidity in the area shows seasonal fluctuations and ranges from a maximum of 80 % to a minimum of 40 % for summer and winter, respectively. The mean relative humidity of the air is 72 %.

Wind is dominated by a southwesterly and to a lesser extent, a southeasterly – which predominate in winter and summer respectively. In the winter months, occasional berg winds blow. Winds with a velocity of > 30 m/s occur most frequently in the summer months.

5.3 PHYSIOGRAPHY AND DRAINAGE

The study area extends from sea level along the coastal belt, with elevations increasing inland to ~ 550 m amsl in the vicinity of Grahamstown and the Kap River mountain range (Map 2).

The region consists of a gently undulating coastal plain, through which at least 10 significant rivers and estuaries flow in a southeasterly direction. Adjacent to the coastline, the area is bounded by high, vegetated dunes. The primary drainage regions in the area are indicated on Map 1 and Table 2:


MAP 2
Ndlambe Locality Map
Indian Ocean
PORT ELIZABETH
GRAHAMSTOWN
EAST LONDON
Ndlambe

Map 2

Table 2: Primary Drainage Regions and Associated Rivers

Drainage Region	Primary River
Q93	Great Fish
P40	Kowie
P30	Kariega
P10	Bushmans
P20	Boknes

5.4 SOILS AND VEGETATION

There is a gradation from coastal fynbos to coastal thicket and Ultimately coastal forest as the rainfall changes from a winter to a summer pattern, with the temperatures becoming more moderate.

- **Fynbos**: Although dominant in the southwest, Cape fynbos occurs in the study area as occasional pockets at Woody Cape, Port Alfred and as far as the Fish River Mouth. Proteas are particularly abundant on the acid soils developed on the Witpoort quartzites.

- **Coastal Thicket**: Thicket vegetation is the dominant vegetation and consists of woody shrubs and trees, which are fairly impenetrable. Dune thicket is common along the coastline, whereas valley bushveld penetrates into the interior up the river valleys.

- **Coastal Forest**: In areas of high orographic rainfall, coastal forests are developed and are predominantly Afromontane.

- **Coastal Grassland and Savannah**: Interior to the coastal thicket or forest, sour grassland is common, which is particularly well developed on the Witpoort quartzite. These farms mainly support dairy and beef cattle.

5.5 DEMOGRAPHICS

Ndlambe is home to some 80 000 people residing in 5 main urban areas, 5 coastal resorts and 21 rural settlements. It is primarily an agricultural area, but also has a strong tourism base (Map 2). Almost half the population resides in and around Port Alfred. The rural areas account for close to 17 000 people. The twin resorts of Bushmans/Kenton (9 500) and the agricultural communities of Alexandria (9 000) and Bathurst (6 200) have significant populations. According to DWAF's national database, there are 14 701 people in greater Bushmans/Kenton. The balance is spread in the resorts of Seafield/Kleinemonde and Cannon Rocks/Boknes.

The popularity of the coastal resorts is clearly evident as a major influx of people occurs during the summer holiday periods. The additional seasonal population is estimated at around 35 000, with 15 000 visiting both Port Alfred and Bushmans/Kenton respectively. The balance visits the resorts of Seafield/Kleinemonde or Boknes/Cannon Rocks.

5.6 WATER SERVICES OVERVIEW

There are six local water supply schemes, which service the settlements within the area. Port Alfred, Seafield/Kleinemonde and parts of Bathurst are supplied from surface water schemes, whilst the balance of the area (viz., 45 % of the population) is reliant on groundwater. There is a component of conjunctive utilization of groundwater in both Port Alfred and Seafield/Kleinemonde. Bushmans/Kenton augment their groundwater supplies with desalinated water via the reverse osmosis process. The rural areas, private coastal resorts (e.g. Kasouga and Riet River) and parts of Bathurst (e.g. 'Monkey Town' adjacent to the commonage) are generally serviced through private supply systems (rain water tanks and boreholes).

The reliability of the yields and the quality of the water from the respective water sources is in general inadequate. Furthermore, the capacity of the bulk infrastructure of many of the schemes is in general inadequate, especially to meet peak season demands. Many of the households in the area therefore augment the municipal supplies by rain water harvesting and rain water storage tanks. This is currently a prerequisite for new developments stipulated by the former Western District Council.

5.7 SANITATION

The bulk of Alexandria and portions of Port Alfred and Bushmans/Kenton (primarily the former townships of the latter areas) all have reticulated sewer systems; whilst the balance of the coastal resorts all have soak away or conservancy tanks. The rural settlements tend to have pit latrines of sub-RDP standard.

6. GEOLOGICAL DESCRIPTION

6.1 INTRODUCTION

This section deals with geological and geomorphologic aspects of the study area. Following geological tradition, the oldest rock formations are described first, the youngest last. The same will apply to the various landforms that make up the landscape. The standard geological map of the area is the 1:250 000 Grahamstown 3326 which covers the area between Alicedale and East London. Map 3 is a cropped geological plan of the area whereas a schematic cross section is presented as Figure 1. A generalized stratigraphic column is included as Table 3.

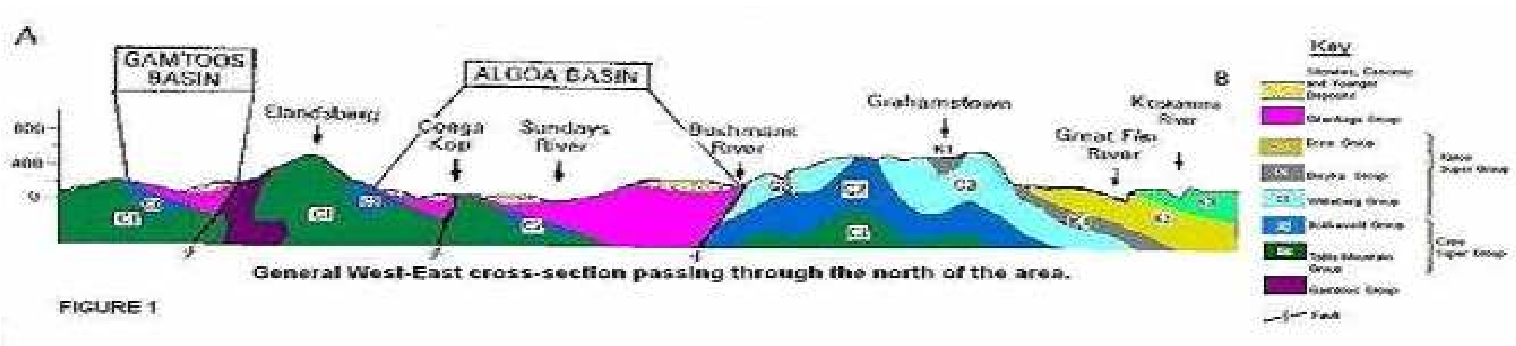


Figure 1: East-West section across the Eastern Cape

Table 3: Stratigraphic Table

Era	Epoch/Period Age (million years)	(Super)Group	Formation	Rock Type
CENOZOIC	HOLOCENE **0.01**	Algoa	Schelmhoek	modern dunes
CENOZOIC	PLEISTOCENE **2**	Algoa	Nahoon Salnova	aeolianite,beach deposits
CENOZOIC	PLIOCENE MIOCENE **25**	Algoa	Nanaga Alexandria	aeolianites beach deposits
MESOZOIC	OLIGOCENE EOCINE PALAEOCENE **65**	Algoa	Bathurst	sandy limestone, marine mud
MESOZOIC (GONDWANA	CRETACEOUS BREAK-UP) **140**	Uitenhage	Sundays River Kirkwood Enon	marine mud fluvial sand conglomerate
MESOZOIC	JURASSIC **210**	Karoo S'Gp	Suurberg Intrusives	basalt, dolerite
MESOZOIC	TRIASSIC **250**	Karoo S'Gp	'Stormberg'	'red beds'
PALAEOZOIC	PERMIAN **290**	Karoo S'Gp	Beaufort Ecca	shale, mud, sandstone
PALAEOZOIC	CARBONIFEROUS **360**	Karoo S' Gp	Dwyka	tillite, shale
PALAEOZOIC	DEVONIAN **410**	Cape S' Gp	Witteberg Bokkeveld	quartzite, shale
PALAEOZOIC	SILURIAN **440**	Cape S'Gp	Table Mountain	quartzite, shale
PALAEOZOIC	ORDOVICIAN **500**	Cape S'Gp		
PALAEOZOIC	CAMBRIAN **590**		Cape Granite	Granite
PALAEOZOIC	PRE-CAMBRIAM **800**	Pre-Cape	Kaaimans Kango Gamtoos	quartzite, marble, skarn

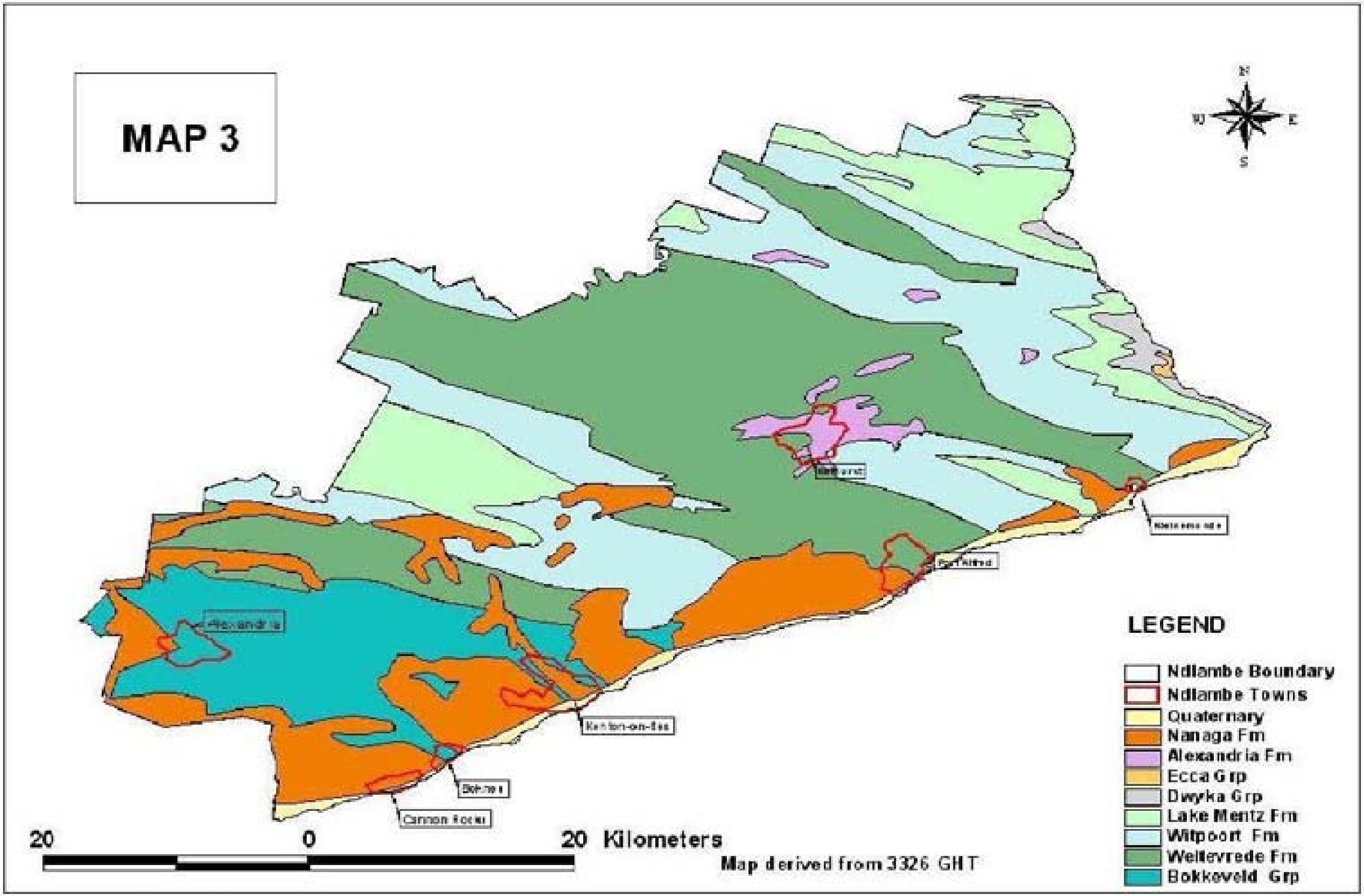
The geology is dominated by the sedimentary deposits of the Cape Supergroup, which underlie almost the entire area. Some Karoo Supergroup sediments are preserved in the Fish River floodplain. Rocks of the Algoa Group (i.e., Cenozoic) and Quaternary form a thin veneer along the coastal zone, but are nevertheless an important component of the geology. No igneous rocks whatsoever occur in the area.

Two major features control the structural fabric, viz., the Cape Fold Belt (CFB) and the fracture system formed during the break-up of Gondwanaland – 140 to 160 million years ago. Sea level fluctuations and erosion has peneplained the fringes of these ancient rocks, unconformably depositing fossil and modern dunes adjacent to the present-day coastal zone.

6.2 CAPE SUPERGROUP

The Cape Supergroup is the backbone of the CFB and is divided into the Table Mountain, Bokkeveld and Witteberg Groups. Outcrops are limited to narrow stretches of the coast, riverbanks and naturally eroded steep cliffs. Artificial exposures are in quarries and road cuttings. These rocks become younger towards the interior.

The **Table Mountain Group** is a thick succession of mostly orthoquartzite. Although there are no outcrops within the study area, Bird Island (off Woody Cape) consists of Table Mountain quartzite. These rocks have attracted much interest as hard rock, fractured aquifers with significant groundwater potential. Only recently, towns such as Jeffreys Bay, Oudtshoorn, Plettenberg Bay, Bredasdorp and Citrusdal have benefited by exploiting this deep, groundwater resource. The Table Mountain Group will not be discussed further in this report.



Ndlambe Geological Map

The Bokkeveld Group is composed largely of black shales, compact siltstone and subordinate sandstones, representative of an ancient deltaic environment of deposition (Plate 1). Minor sandstone units constitute roughly 10 % of the entire sedimentary package. These rocks are restricted to the area west of the Kasouga River. Bokkeveld rocks weather away relatively rapidly, forming valleys and low rolling hills. The Bokkeveld shales occur as a low amplitude, southeast plunging anticline in the southwestern portion of Ndlambe. Dip is variable and can, over short distances, alternate from vertical to shallow dipping. Outcrop is poor and as a result of the absence of marker beds, no attempt has been made to sub-divide the Bokkeveld Group into discrete formations.

Plate 1: Exposure of Bokkeveld Shale in the Kariega River.

The **Witteberg Group** comprises the basal Weltevrede Formation (predominantly black shale), the central Witpoort Formation (predominantly quartzites) overlain by the uppermost Lake Mentz Formation (predominantly shale). Through a combination of folding, faulting and erosion, rocks of the Witteberg Group occur as three discrete, southeast trending belts in Ndlambe.

The Weltevrede Formation consists of a series of greyish-black phyllite grading upwards into buff-coloured quartzite (Plate 2). The former shows a pronounced cleavage and often weathers into a red-grey or olive-grey colour.

Plate 2 : Exposure of Weltevrede Shales near the Wellington Dam.

The Witpoort Formation has a high proportion of arenaceous rocks interbedded with lesser phyllite beds (Plate 3). Quartzite rocks consist mainly of recrystallised, polygonal-shaped quartz grains with minor feldspar and biotite. Beds have variable dips and display a well-developed joint pattern. Although the Witpoort has much in common with the Table Mountain Group rocks, its aquifer potential has been largely ignored - mainly because of the ease (and low-cost) in developing coastal aquifers.

Plate 3 : Exposure of highly veined Witpoort Quartzites.

The Lake Mentz Formation overlies the Witpoort Formation. Its lower and upper contacts are composed largely of argillaceous (or clay-rich) units, some 200 and 340 m thick respectively. The central portion is an 80 m thick arenaceous unit, which may have moderate aquifer potential due to its thickness.

6.3 KAROO SUPERGROUP

Karoo Supergroup rocks unconformably overlie those of the Cape Supergroup and only have a very limited occurrence in the extreme eastern portion of Ndlambe.

The **Dwyka Group** is an approximately 600 m thick mass of diamictite, which contains a dark grey argillaceous matrix. Subordinate lenses of shale and sandstone occur sporadically. Due to their dense, impervious nature, the rocks of the Dwyka Group generally offer limited groundwater potential. These rocks have an extremely limited sub-outcrop distribution in the area, being limited to the floodplain of the Fish River in the extreme east.

The **Ecca Group** consists predominantly of laminated and platy argillaceous rocks and subordinate inter-bedded sandstones.

Rocks of the Dwyka and Ecca Group are not considered as potential aquifers in Ndlambe area and will not be discussed further.

6.4 ALGOA GROUP

These Cenozoic deposits form a discontinuous veneer of variable but generally thin thickness in the coastal zone and constitute near shore, marine, fluvial and aeolian sediments. The major driving force controlling their formation and distribution was sea-level changes during the recent past. The interaction between landscape development and contemporary sedimentary record is complex and poorly understood. These rocks generally become younger towards the present day coastline.

The **Bathurst Formation** occurs roughly 300 m amsl and is a 65 million year old (fossiliferous) limestone with a negligible sub-outcrop distribution. It will not be discussed further.

The **Alexandria Formation** (24.6 to 1.8 million years old) is well represented in the area. It is mostly of marine origin, deposited during intermittent regressions of sea level after an initial high stand at about 250 m above present sea level. Sediments of this formation were deposited on wave-cut platforms. The base is marked by a thin (0 to 2 m), discontinuous conglomerate, whereas the overlying coarse-grained 'limestone' makes up the balance of its ~ 7 m thickness (Plate 4). The Alexandria Formation typically forms bench-like cliffs, e.g. at Cape Padrone and Woody Cape. Being a limestone, the Alexandria Formation is a good aquifer and is responsible for some karst topography in the coastal zone.

Plate 4 : Exposure of Alexandria Conglomerate in Port Alfred.

The aeolian deposits of the **Nanaga Formation** overlie the marine deposits of the Alexandria Formation. The oldest deposits are found as far inland as Paterson. These wind-derived deposits take the form of fossil dune cordons (i.e., parallel to the present coast line) that developed successively along an old shoreline (Plate 5). The Nanaga (and Alexandria) sediments are better developed in the western portion of Ndlambe. The preferential erosion of the Bokkeveld basement rocks governs their thickness and distribution.

Plate 5 : Exposure of Nanaga Aeolanite in Port Alfred.

The **Nahoon Formation** (1,8 to 0,01 million years old) is a younger, semi-cemented aeolianite, with spectacular cross beds marking the slip faces of the fossil dunes. A distinctly textured rock, which forms isolated rocky headlands (or promontories) all along the present coast, such as Dias Cross, Kwaaihoek, Three Sisters and Bats Cave at Fish River. The present-day Alexandria coastal dune field is a modern-day equivalent of the Nahoon and Nanaga Formations. The Nahoon Formation has a very limited sub-outcrop distribution and shall not be discussed further.

6.5 QUATERNARY

The **Schelmhoek Formation** (10 000 years old to present) represents modern beach and dune sands (Plate 6). It is composed largely of well-sorted quartz grains and may contain 30 to 35 % shell and algal fragments. Typically these sediments contain sand, which may be interbedded with mud and lenses of calcrete. Depending on the palaeo-topography of the basement rocks, a highly transmissive shell conglomerate (or ‘shingle’) may be developed at its base.

Plate 6 : Exposure of Schelmhoek (Quarternary) Coastal Sands.

These are the youngest deposits and are still currently being deposited. The Schelmhoek Formation forms a strip of variable thickness (0 to 40 m) and width (100 to 1 000 m) above the high tide mark. This, along with the Alexandria and Nanaga Formations, constitutes the coastal aquifer, which is exploited intermittently along the 75 Km-long Ndlambe coastline.

6.6 STRUCTURE AND GEODYNAMICS

The presently exposed structure of the region can be attributed to two major tectonic events: thrusting that occurred during the Permo -Triassic Cape Orogeny and extension resulting from the fragmentation of southwestern Gondwanaland during Mesozoic times. The Cape Orogeny tectonically thickened the rock sequence of the CFB by thrusting, while the later, extensional faulting disrupted the sequence. As a result, the region displays northeasterly verging, first order folds sliced by thrusts and shears and extensional normal faults, all striking roughly southeast.

6.6.1 Regional Structure

The entire southern Cape region, originally part of southern Gondwanaland, was subject to increasing compression from a southerly direction - some 290 million years ago. This resulted in folding and the uplift of (mainly) Cape Supergroup rocks, to form the east-west trending Cape Fold Belt (CFB). Subsequent erosion, especially of the weak shales of the

Bokkeveld Group produced broad valleys, whereas the resistant sandstones of the Table Mountain and Witteberg Groups formed the longitudinal east-west mountain ranges.

During the Mesozoic period, the fragmentation of Gondwanaland began with the extrusion of the Drakensburg basalts and injection of the Karoo dolerites due to the initiation of tensional stresses. These did not intrude into the CFB region due to the prevailing compressional stresses, and the occurrence of dolerites is restricted to the region north of 33° S. The southern portion of Gondwana subsequently began to break-up by a process of marginal rift faulting. The structure of the coastline of the Eastern Cape was determined by the Agulhas-Falklands fracture zone – essentially a linear tear-fault, which extends offshore from the Eastern Cape coast and along the southern margin of the Agulhas Bank. With the break-up of Gondwanaland, the sea flooded into the new margins of the subcontinent and thus marine rocks of the Cretaceous age (i.e., 144 to 65 million years ago) are found fringing the continental margin in places. In the Eastern Cape Province, these are rocks belonging mainly to the Uitenhage Group.

After the break-up of Gondwana, erosion commenced on the newly formed high and steep margins of the newly formed subcontinent and operated to base level of the newly formed ocean. It was the continuance of this head-ward working erosion, which has given rise to the ‘escarpment’ as we know it today.

6.6.2 Local Structure

Rocks of the Witteberg Group, in the vicinity of Port Alfred, are folded into asymmetric folds and thrust faulted. Medium-sized folds are prevalent with the majority being close folds (i.e., interlimb angle 54 º). Further inland, these folds plunge shallowly to the northwest, whereas closer to the coast, they plunge southeast. Vergence, based on the asymmetry of folded limbs, is from the southwest.

Bedding parallel thrusting, duplexing and piggy back trusting have disrupted strata, giving rise to variable bed thickness and stacking of beds one upon another. These complexities make the correlation of rock units in the field extremely dubious. Problems of correlation are compounded where thrusting, folding and normal faulting occurs together. Furthermore, it is difficult to distinguish between the Weltevrede and the underlying Bokkeveld Group.

Northwest-striking normal faults are commonly developed in the proximity of the Kowie River, forming horst and graben structures. Strike-slip faults occur approximately parallel to the strike of normal faults. The normal and strike-slip faults are the product of the break-up of Gondwanaland. At least four pulses of tectonics took place with the style of folding and thrusting showing a decrease in deformation northwards.

Deformation and metamorphism is imprinted on the Cape Supergroup rocks and interpreted to have reached greenschist facies i.e., low-grade regional metamorphism. Granoblastic polygonal textures are commonly developed in arenaceous rocks, whereas chlorite/stilpnomelane assemblages occur in metapelites.

The conflicting interpretations regarding the stratigraphic positions of the rocks in the area may be attributable to the lack of appreciation of the significant deformation, including thrust, normal and strike-slip faulting recorded in these rocks.

6.6.3 Geodynamic Analysis of Faulting

Faults can be divided into normal or dip-slip (extensional), thrust-slip (compressional) and strike-slip (shear) categories, depending on the orientation of rock movement. The direction of movement is dependent on prevailing stress conditions at the time the fault was formed. It is also important to note that stress conditions change over geological time so that faults formed under one stress-regime, such as shear stress, can be rejuvenated as another type of fault, such as normal faults, if stress conditions change.

The prevailing stress conditions have significant impact on the water bearing potential of a fault, as it determines whether the structure will be open or closed, thereby affecting permeability. Prevailing stress conditions can only be determined by seismic data, but where this is lacking, faults and resulting conjugate fracture sets can be used to interpret stress conditions that occurred at the time the structures were formed. The assumption is then made that the stress condition that prevailed at the time that the most recent structures were formed is similar to those of the present day.

Faults can be categorised either by field observations of rock movement and slickenside orientations, or alternatively by their dip angle. Due to the stress conditions under which rocks break in combinations with Coulomb's law of rock failure, strike-slip faults are predominantly vertical, normal faults dip at ~ 60^0 and thrust-slips dip at approximately 30^0. The dynamic analysis of faults and/or conjugate fracture sets allows the stress conditions under which they formed to be predicted. Therefore, from the orientation of fractures and slip directions, the orientation of their causal stresses can be predicted. By determining the age relationship of faults, variations in stress conditions over time can also be determined. For hydrogeological investigations, present day stress conditions, or the most recent stress conditions, and their impact on existing structures are the most relevant.

Joint sets are similar to faults, except a fracture is classified as a joint when there is no observed rock movement. Joints commonly occur parallel to conjugated fault planes. Secondary joint sets, known as Mode 1 tension joints, may also develop perpendicular to the direction of principal stress, however at a much steeper dip, resulting in a network of intercepting fractures. In the dip-slip and strike-slip settings these are sub-vertical.

During field structural investigations, a plunging anticline in a zone not disturbed by faulting was observed with a dip direction and dip of $166^{\circ}/18^{\circ}$, suggesting that folding and thrusting occurred due to stresses from the west-southwest. The folds and thrusts within the CFB are attributable to compression and uplift during the Cape Orogeny.

The observed presence of regional southeast to south-southeast trending normal faults implies that the thrust-slip, compressional setting present during the Cape Orogeny, was subsequently altered to a dip-slip setting. Thrusts were subsequently inverted to normal faults due to the initiation of tensional stresses. This shift in the stress regime can be attributed to tensional stresses that prevailed during the early Mesozoic break-up of Gondwanaland.

Tension was probably caused by extension of the Southern Outeniqua Basin and the related rotation of the Falkland Platform due to wrench or transform faulting that developed offshore along the Aghulhas Marginal Fracture Zone, which forms the boundary between continental and oceanic crust.

This east-southeast trending wrench fault resulted from right-lateral shear stresses. Associated stresses from wrenching would have resulted in northeast oriented maximum extensional stress (southeast trending normal faults); northwest oriented maximum compressional stress (northeast trending thrusting, and east-southeast and south-southeast to south shearing (Figure 2).

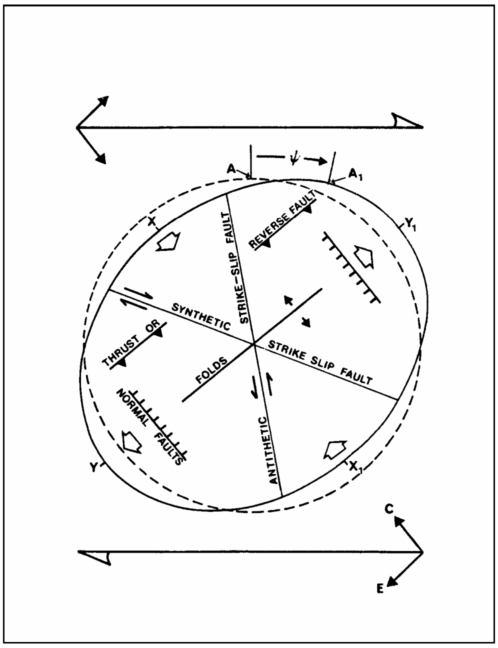


Figure 2: Strain ellipse arising from wrench or transform faulting

It is possible that subsequent uplift of the coastal margin could have resulted in tensional stresses oriented perpendicular to the coast line (i.e., northwest) and reactivated some of the existing structures since late-Mesozoic times.

6.6.4 Local Structure and Field Observations

A total of 18 outcrops were mapped with 7 fault orientations and 121 joint orientation measured (Figure 3). The following faults were observed in the field and classified as follows:

Thrust-slip setting (Dip direction/dip of fault planes)

- 23°/33°: Back-thrust – Kowie Quarry, Port Alfred
- 44°/40°: Back-thrust - Kowie Quarry, Port Alfred
- 234°/13°: Low-angle thrust – Marselle Quarry, Kenton-on-Sea

Thrusts generally strike northwest to southeast and represent stresses that arose from thrusting from the southwest during the Cape Orogeny.

Dip-slip setting (Dip direction/dip of fault planes)

- 66º/78º
- 229º/73º
- 67º/48º
- 249/79º
- 266º/70º

The normal faults strike northwest to southeast to north-northwest to south-southeast and opposing dips suggest a horst and graben structure developed. However, this cannot be observed on an outcrop scale. The faults 229°/73° and 67°/48° represent a conjugate set recorded on one outcrop. The relatively steep dip of southwest dipping fault and the shallow dip of the northeast dipping fault may be the result of tilting that occurred during continental uplift subsequent to faulting.

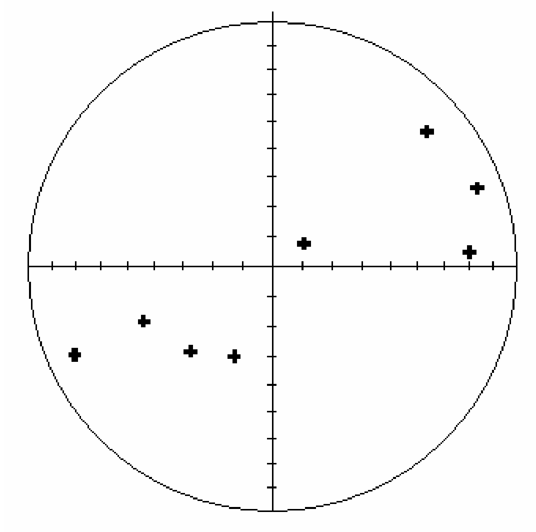


Figure 3: Equal area stereonet of poles of faults

The joint sets mapped are shown in Figures 4 and 5. Several prominent joint sets can be observed:

1. The most obvious features in the study area are sub-vertical joints dipping at more than 70° to the north or south and striking east-northeast to east-southeast. These could be associated with shear stresses related to east-southeast wrenching, or could represent Mode 1 tension joints due to north-south extension.

2. A second prominent set can be observed striking south-southeast to north-northwest and dipping at 60° - 80°, predominantly to the northeast. These indicate extension to the west-southwest resulting from east-southeast wrenching.

3. Low-angle thrust related joints are predominantly oriented to the north-northwest to south-southeast and can be attributed to thrusting during the Cape Orogeny.

The pattern of faulting and jointing indicates a dip-slip fault setting with shear stresses related to wrench faulting. The primarily northeast dip of joints appears to indicate that the northeast side of the faults is commonly the downthrown side.

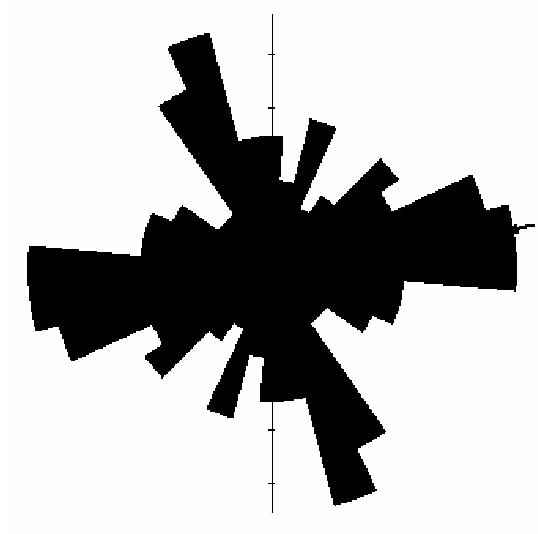


Figure 4: Rose diagram of frequency of strike orientations of joints

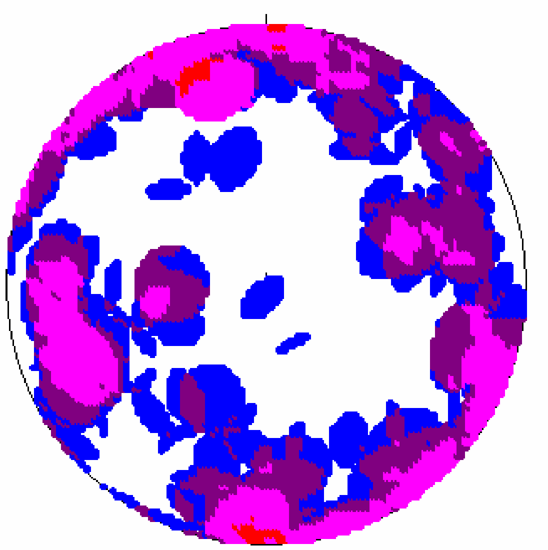


Figure 5: Equal area stereonet plot of pole of all fractures

To identify the different stress fields responsible for the observed fracture pattern, fractures were plotted into dip degree categories of:

- 90º-80º
- 80º-61º
- 60º-46º
- <45º

<u>Fractures dipping 90-80°</u>

The cluster of fractures dipping steeper than 80^0 can be considered to be shear related or Mode 1 tension joints, related to dip-slip or strike slip stresses and are expected to be parallel to the strike of potential faulting. Consequently, joints are expected to range from east-southeast to south-southeast striking. However, the dominant orientation observed is south-southwest to north-northeast to west-east striking (Figure 6), parallel to the coastline.

This suggests that north-south to northwest-southeast tensional forces have been present, which cannot be explained by wrenching on the Aghulas Fracture Zone, since structures with a northeast orientation would have been subject to maximum compressional stress.

Northwest tension could be attributable to coastal uplift, since this orientation is sub-perpendicular to the coastline, however no corresponding northeast striking normal faulting has been observed.

Another explanation may be that oblique or divergent movement was created on the Aghulas Fracture Zone due to the change in orientation of movement on the Master Transform Fault, resulting in transtension. The increasingly southwest to westerly trend of the Transform Fault as it curves around the coast of the Eastern Cape, suggests that such stresses may have taken place. In a transtensile regime, divergent movement results in a combination of tensional and transcurrent faulting perpendicular to the axis of tension. Oblique shear motion is taken up by high angle strike-slip faults that curve away from normal faults until they strike almost perpendicular to the normal fault (Figure 7).

Transtension would result in extension oriented to the northwest and maximum transtensional stress being located between the Algoa Basin and East London. Very limited lateral displacement is usually observed on transcurrent faults; hence they appear as high-angle normal faults.

The high observed dip angles of northeast to east trending joints and the large variation in strike in these joints suggests they may have a transtensile origin and may represent tension features with a shear origin.

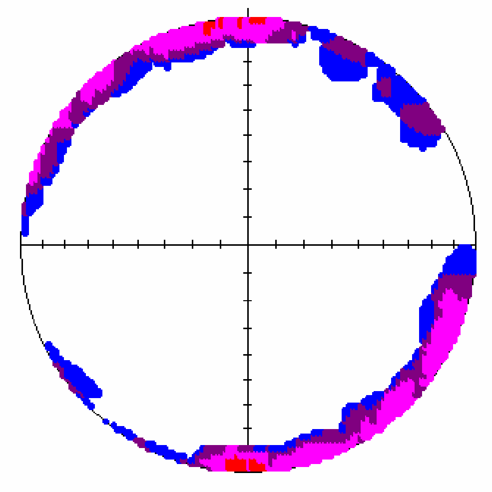


Figure 6: Stereonet plot of all fractures dipping >80^0

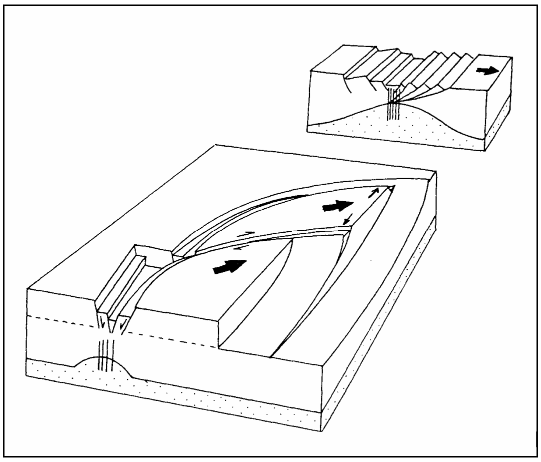


Figure 7: Block diagram of transtension

The stresses responsible for the observed joint sets are shown in Table 4.

Table 4: Orientation of stresses responsible for observed fracture sets

Dip (degrees)	Setting	Orientation Strike°/dip°	Compression Strike°/dip°	Neutral Strike°/dip°	Extension Strike°/dip°
80° - 90°	Dip-slip	198/86 24/90	199/85	213/71	109/-5
	Dip-slip	225/86 50/89	228/89	224/37	138/-1
	Dip-slip	251/85 75/89	73/90	231/71	343/0
	Dip-slip	272/85 90/89	272/89	92/10	182/-1
	Dip-slip	326/80 143/85	143/88	144/6	53/2
	Dip-slip	117/82 296/87	117/86	296/14	27/4
61° - 80°	Dip-slip	337/70 163/70	337/81	337/3	247/-9
	Dip-slip	360/71 179/69	360/80	179/3	270/-10
	Dip-slip	275/68 90/71	90/86	91/19	360/4
	Dip-slip	69/75 234/68	67/80	242/27	337/10
	Dip-slip 3D	338/69 1/70 303/62 119/65 143/73 165/68	340/82	157/20	250/-8
45° - 60°	Dip-slip	161/50 338/56	161/63	340/2	71/27
<45°	Thrust slip	353/34 162/41	266/-67	169/1	353/16

Fractures dipping between 80-60^0

These fracture sets are considered to be related to dip-slip stresses (Figure 8). Prominent sets strike east-northeast, east-southeast, south-southeast, south-southwest, southwest, west, and north-northwest respectively. The most prominent conjugate sets are those striking north-northwest and east-northeast, which suggests two dominant extension orientations at perpendicular angles: one to the north-northwest and one to the east-northeast. These stresses confirm a model of west-southwest oriented tension arising from wrenching on the Aghulas Fracture Zone, and uplift or transtension causing northwest to southeast oriented tension. The stresses responsible for these fractures are shown in Table 4.

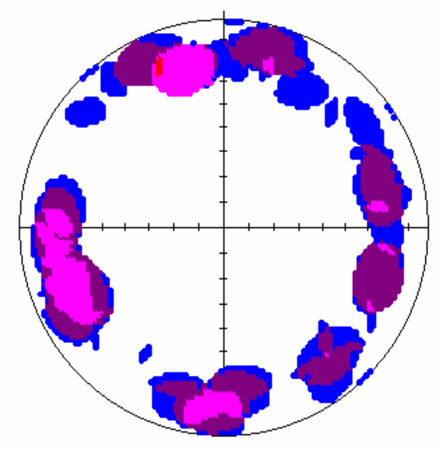


Figure 8: Stereonet plot of all fractures dipping 60-80^0

Fractures dipping between 60-45°

Only one conjugate set strikes to the north-northwest to south-southeast (Figure 9). These can be attributed to dip-slip stresses, or joints with a thrust slip origin that have subsequently been tilted.

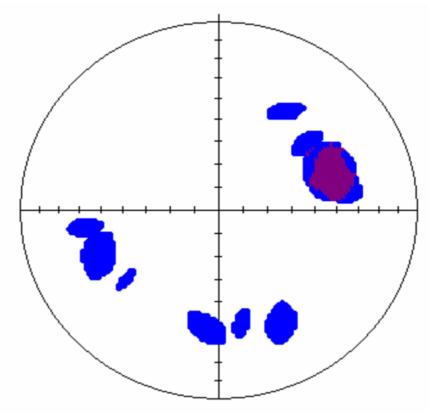


Figure 9: Stereonet plot of all fractures dipping 45-60^0

Fractures dipping less than 45°

The orientation of thrust-slip fractures is shown in Figure 10. The most prominent set strikes north to south and dips to the east. In general, few fractures with a thrust-slip origin can be observed.

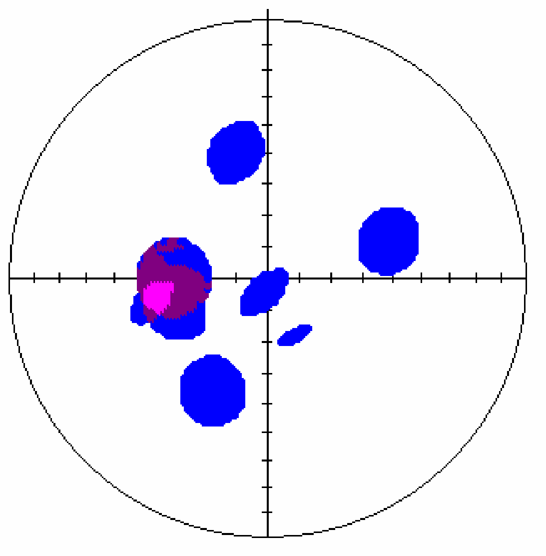


Figure 10: Stereonet plot of all fractures dipping <45^0

6.6.5 Orientation of stress fields

Dip-slip setting

Figure 11 shows the stereonet of the direction of maximum extension for the dip-slip setting based on the data in Table 1. Extension structures generally strike at 140 -160°, dipping steeply to the southwest (Figure 12). Another cluster strikes from 70 - 90° and dip steeply southward. This suggests tension stresses oriented to the west-southwest and to south-southeast to south.

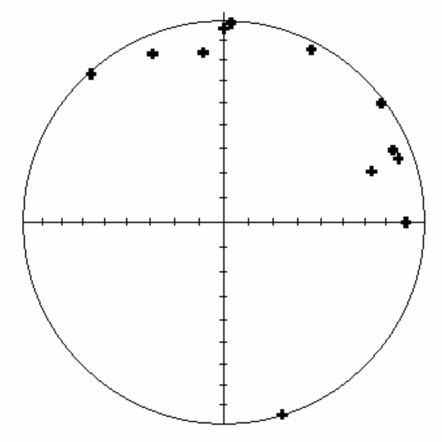


Figure 11: Directions of maximum extension for the dip-slip setting

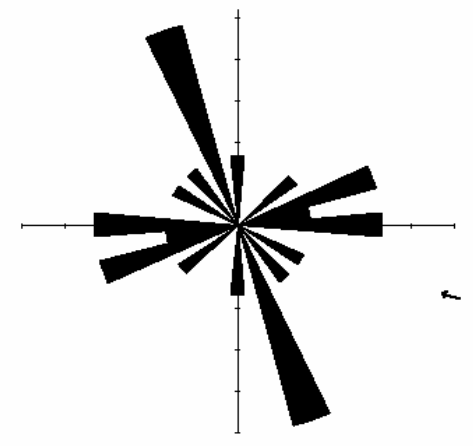


Figure 12: Rose Diagram of the orientation of maximum extension

6.6.6 Structural Interpretation

Analysis of joint orientations suggest that structures oriented to the south-southeast and dipping steeply to the west-southwest have a tensional origin, however, available seismic data has not been able to confirm that this stress orientation exists today due to the low density of seismic stations in the region.

East-northeast to east striking and south dipping structures also have a tensional origin, however the nature of this stress cannot be confirmed. North-northwest tensional stress may have originated from transtension related to movement on the Aghulas Fracture Zone, or due to differential stresses resulting from continental uplift.

The present day drainage network follows a south-southeast orientation, with significant east-northeast kinks on major rivers. This confirms that these orientations represent zones of major weaknesses in the rock, exploited by major river channels.

South-southeast and east-northeast trending structures therefore form the most suitable drilling target for high yielding boreholes. A lineament analysis is required to identify the location of these structures.

6.7 EROSION SURFACES

Sea level fluctuations and erosion has peneplained the fringes of the Cape Supergroup rocks, unconformably depositing fossil and modern dunes in the present-day coastal zone.

The African erosion surface, which was developed both above and below the escarpment, was initiated by the break-up of Gondwanaland. The escarpment was pushed progressively further into the interior by head-ward erosion of rivers, a broad plain developed in the coastal margin, while offshore, a marine cut bench developed on the more resistant rock-types. This erosion persisted to 'Old Age' and caused the Bushmans and Fish Rivers to meander in their upper reaches. Because of the resistance to erosion, sandstone and quartzite rocks of the CFB have always stood high above younger erosion surfaces developed on surrounding softer rocks.

The development of silcrete on the African erosion surface: Deep weathering caused silica to migrate into the upper portions of the soil profile that underlay low points in the landscapes. Nevertheless, because of the resistance of silcrete to erosion and the later dissection of the African erosion surface by younger erosion, silcrete remnants now usually form the highest points of the landscape. Consequently, an inversion of the topography has taken place as far as silcrete deposits are concerned. This has positive implications with respect to groundwater potential, as drilling will invariably be restricted to valleys.

Development of the early Post-African erosion surface: About 18 million years ago, epeirogenic uplift of some 100 to 200 m took place in the Eastern Cape. The axis of uplift was parallel to and ~ 70 Km inland of the coastline. As a result, the coastal areas were tilted seaward. This initiated a new cycle of erosion as rejuvenated rivers cut down to new erosion base levels. The seaward tilting of the proto-Eastern Cape on the coastal side of the axis of uplift led to an invasion of the land by the sea. A major embayment formed between Port Elizabeth and Port Alfred – similar to the present day Algoa Bay. Limited coastal areas northeast of Port Alfred were also submerged.

Sedimentary deposits associated with submergence now form beach deposits, comprising the Alexandria Formation, in which large fossil oysters predominate.

Development of the later Post-African erosion surfaces: The early erosion cycle was terminated by major uplift and seaward tilting of the coastal hinterland about 4 million years ago. This uplift raised the Alexandria Formation beach sediments to an altitude of some 300 m at Paterson. The later erosion surface developed mainly as a valley incision cycle as there has not been enough time to reduce the land to a plain. Where the later erosion cycle has penetrated into the interior, it has operated to local base levels resulting from variations in rock hardness and resistance to erosion.

Recent events: These lasted from 1,8 million to 10 000 years ago and were characterized by sea level movements, resulting from worldwide climate fluctuations. In overall terms, the sea level declined. These fluctuations in sea level gave rise to a number of well-developed marine terraces. During this time, sandy limestone of aeolian origin, corresponding to the Nahoon Formation, were deposited. About 18 000 years ago, during the peak of the world wide Last Glacial stage, sea level was about 120 m below its present level. As a result the lower courses of rivers in the Eastern Cape, such as the Bushmans, Kowie and Fish rivers, became deeply incised. Subsequent rises in sea level some 5 000 years ago have caused alluvial infilling of these incised valleys to depths of up to 40 m or more.

Modern events: During the last 10 000 years, climatic changes and sea level movements gave rise to extensive dune fields around Algoa Bay, producing the Alexandria dune fields. Sea level rose about 2 m above its present level some 5 000 years ago, as evidenced by raised beach deposits near the mouths of many rivers. By 3 700 years ago sea level had reached its present level.

6.8 REMOTE SENSING

The principle objectives of using remote sensing are to:

- To define geological boundaries

- To identify on a regional scale internal tectonic structures that represent potential groundwater targets
- To undertake the pattern of fracture orientation and density over a range of characteristic length scales

Aster images, including digital elevation and topographic data, were acquired for the project. The reader is referred to the comprehensive digital dataset entitled 'Ndlambe Geospatial Digital Atlas' compiled by Tyson (2004), which has been included as Addendum A to this report.

6.8.1 Digital Elevation Model Analysis

Using the DEM and elevation modelling procedures the following data sets were created:

- slope and aspect raster as well as a sun-shaded DEM data set
- drainage vector and basins/catchment areas and raster for flow directions and flow accumulations.

Utilising 1: 50 000 Topographical sheets covering Ndlambe, the following infrastructure and ancillary data was incorporated: Municipal boundary, roads, railway line and towns.

6.8.2 Satellite Image Processing

Two ASTER Image Maps were acquired to provide satellite coverage of the region. The images were received in geotiff format and the following procedures were run on the data in order to make it suitable for processing:

- Accurate georeferencing and resampling to fit the 1:50 000 Topographical sheets and other data.
- Image decomposition to separate the image into three bands representing the original data. These bands cover the green, red and near-infrared portions of the electromagnetic spectrum and have a 15 m pixel size
- Hue/Intensity/Saturation analysis to enhance the details visible on the image
- Principal Components Analysis to enhance information available in the image dataset and to search for anomalies
- A Normalized Difference Vegetation Index (NDVI) to highlight vegetation cover and patterns

- A Lap Lace edge enhancement filter was run on the red and infrared bands of the image to highlight linear features within the dataset.

A script was also run to try and de-vegetate the red and near-infrared bands. These attempts were conducted to strip the image of vegetation and emphasize the ground below. This script was designed for semi-arid/sparsely vegetated regions, and in this case, Ndlambe is fairly heavily vegetated – in particular farmland, forests and grasslands. Although the procedure was not as successful as in other areas, it did reveal some additional patterns in the landscape.

6.8.3 Lineament Mapping and Interpretation

Many landform patterns are visible from both the DEM and ASTER image datasets. The additional analyses provide valuable support information in mapping out the drainage networks and catchment's areas; assessing the pour points between basins and flow accumulations along the drainage network; assessing the slopes and aspects of sites of interest; assessing relationships between existing boreholes and potential sites; assessing distances and access routes; and many other features.

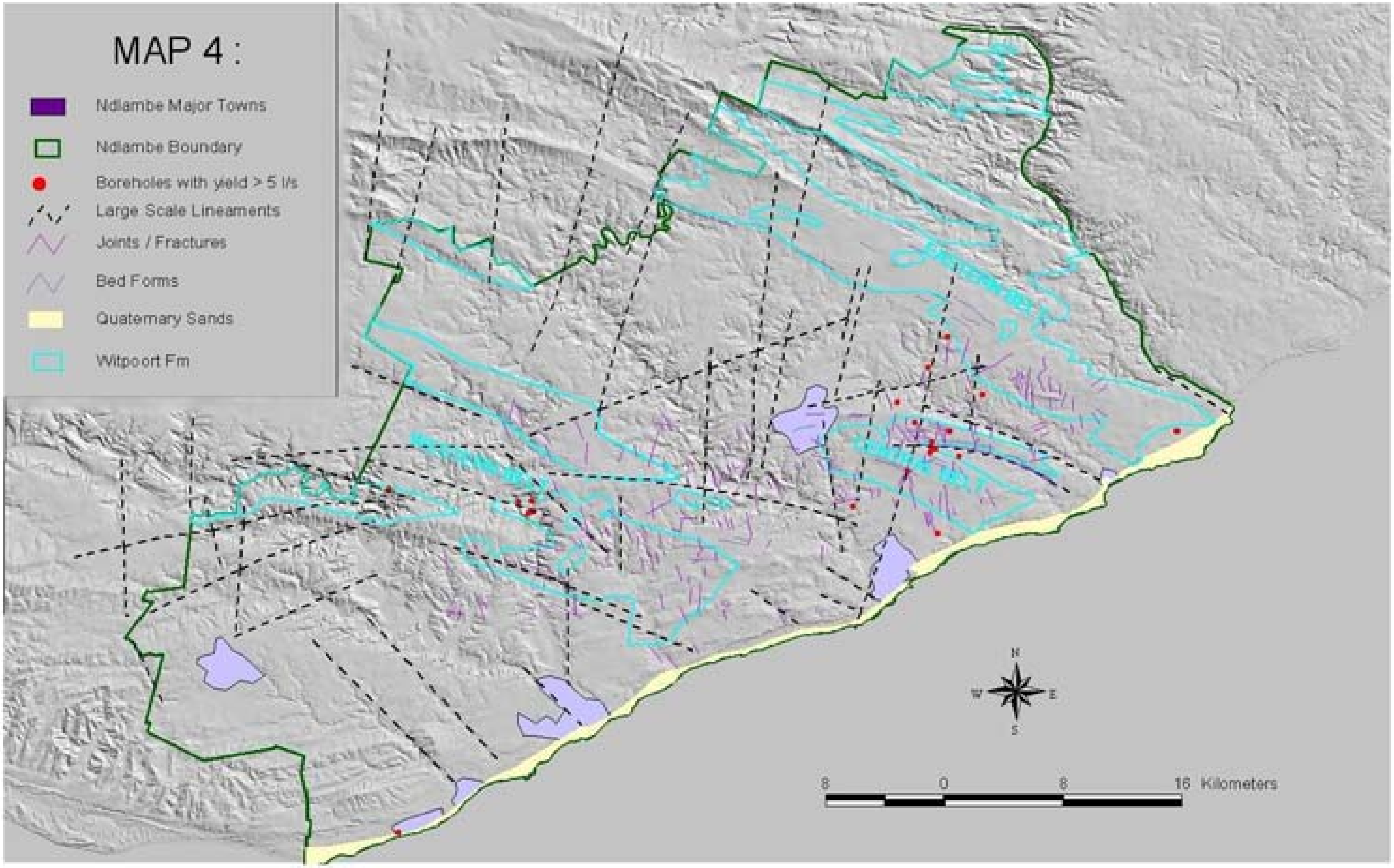
The Digital Atlas (Addendum A) contains all the data specified above with styled and annotated legends. These have been produced to provide easy access to view and explore the entire dataset. Many tools are included for the user to conduct further interpretations of the data. These tools include querying databases, measurements, drawing cross-sections, sketching and annotating and printing displays. Also included are instructions on how to use the Atlas. The data has been exported to ArcView and geotiff files for use by a range of GIS software packages.

The present day drainage network follows a south-southeast orientation, with significant east-northeast kinks on major rivers. This confirms that these orientations represent zones of major weaknesses in the rock resulting from tensional stress that have been exploited by major river channels (Map 4). Other obvious lineaments include the north-northeast to south-southwest and southeast to northwest directions. This could represent conjugate strike-slip structures associated with the south-southeast normal faulting.

There is a general paucity of data in the coastal zone owing to the blanketing effect that fossil and modern dunes have on the Cape Supergroup rocks. It was concluded that the scale of the dataset is such that large/medium scale structures become very clear and are highlighted by many of the data layers. However, small-scale features are not visible due to the resolution of the datasets. In order to produce detailed fracture maps of the small areas requested, high-resolution aerial photography would be required in combination with field investigations.

6.8.4 Aerial Photographs

Limited aerial photographs (in stereo-pairs) have been purchased to cover select areas of interest to this study and the concomitant Witpoort drilling project and include Bushmans/Kenton, Merville farm and Port Alfred. Stereoscopic interpretation of the area around the farm Merville located a strong structural fabric trending southeast-northwest. This feature was ground-truthed and found to be a significant fault, with a 5 m thick crush zone separating vertical dipping rocks (north) from horizontal dipping rocks (south).



NDLAMBE: LINEAMENTS, JOINTS AND BEDDING FROM SUN-SHADED DEM

7. HYDROGEOLOGICAL DESCRIPTION

7.1 BOREHOLE INFORMATION AND STATISTICS

Borehole data exists in the National Groundwater Database (NGDB) and 755 boreholes are listed for the area. The NGDB is neither comprehensive nor complete. It is estimated that less than half the actual boreholes drilled and/or utilized are reflected in the NGDB (pers. obs. and pers. comm. Walter Penny, Agricultural Extension Officer, Grahamstown). Nevertheless, the NGDB can be used to perform a regional assessment of background hydrogeological conditions.

Limited hydrocensus work has also been conducted around each of the affected towns in Ndlambe. Initially this fieldwork involved visits to DWAF officials, consulting engineers, municipal staff, ratepayers, agricultural extension officers and commercial farmers to obtain an overview of groundwater resources and potential problems. Subsequent visits were geared at collecting hard hydrogeological and geological data. An additional 24 boreholes have been appended to the NGDB for statistical analysis. All the borehole information is tabulated in Appendix A and summarized in Table 5. Map 5 shows borehole localities and yields of boreholes within Ndlambe. These boreholes are superimposed over Topographical sheets in much more detail as Appendices B to G.

Table 5: Median borehole data from the NGDB for Ndlambe

Aquifer	(n)	Depth (mbgl)	SWL (mbgl)	Water Strike	Yield (ℓ/s)	Max Yield		EC (mS/m) (n)	Remarks (Area)
						ℓ/s	Location		
FRACTURED									
Bokkeveld	41	76.5	25	49.07	0.07	2.71	Ghio	405 (15)	223 Km²
Weltevrede	224	73.15	30.2	56.5	0.37	25	Mansfield	244 (9)	661 Km²
Witpoort	272	65.5	22.2	55.6	0.49	25	The Grove	305 (21)	502 Km²
Lake Mentz	51	73.15	30.0	56.0	0.55	25	Pinelands	364 (7)	220 Km²
Dwyka & Ecca	1	44	19	23.0	0.81	0.81	Spanish Reeds		21 Km²

INTERGRANULAR									
Alexandria	17	91.4	20.0	43.0	0.7	3.4	Bathurst	307	35 Km²
Nanaga	145	87.1	25.6	50.9	0.29	76.8	Palmiet	(43)	306Km²
Schelmhoek	4	8	2.5	6.0	1.5	5.0	Dias	213 (8)	39 Km²
TOTAL	**755**								**2007 Km²**

7.2 BOKKEVELD AQUIFER

The sand:clay ratio plays a noticeable role both quantitatively and qualitatively in the occurrence of groundwater, causing borehole yields and chemistry to vary widely. A high proportion of clay results in these rocks deforming without inducing secondary fracturing. Within Ndlambe, the Bokkeveld aquifer (n=41) produces a median yield of 0.07 ℓ/s, while a maximum yield of 2.71 ℓ/s has been recorded on the farm The Ghio, north of Kenton. Figure 13 shows the distribution of borehole yields in the Bokkeveld aquifer.

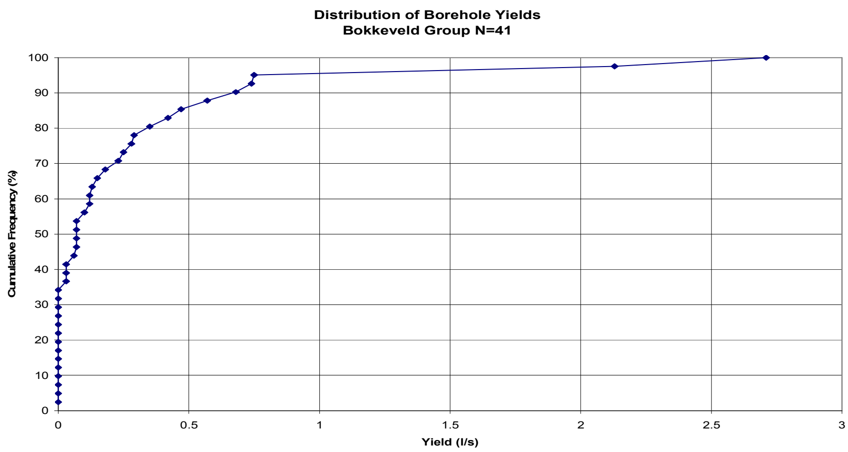


Figure 13: Distribution of borehole yields-Bokkeveld Group

A spring, which supplies water to the development of Natures Landing, is reputed to yield ~ 2.5 ℓ/s (pers. comm. K Wilmot) of Marginal (Class II) quality water. According to Meyer (1980), where sandstone units have been targeted, 5 % of boreholes yield > 5 ℓ/s. This phenomenon may be responsible for the high yield recorded in the centre-pivot equipped borehole on the farm Boschfontein, immediately west of Cannon Rocks.

Water strikes are encountered from 5 -100 m (Figure 14), but few strikes occur below 85 m. The median water strike is 49 m. The highest yielding water strikes occur above 40 m (Figure 15).

Static water levels (Figure 16) are variable and range from 5 - 95 m, with a median of 25 m. This reflects the varied topography of the region.

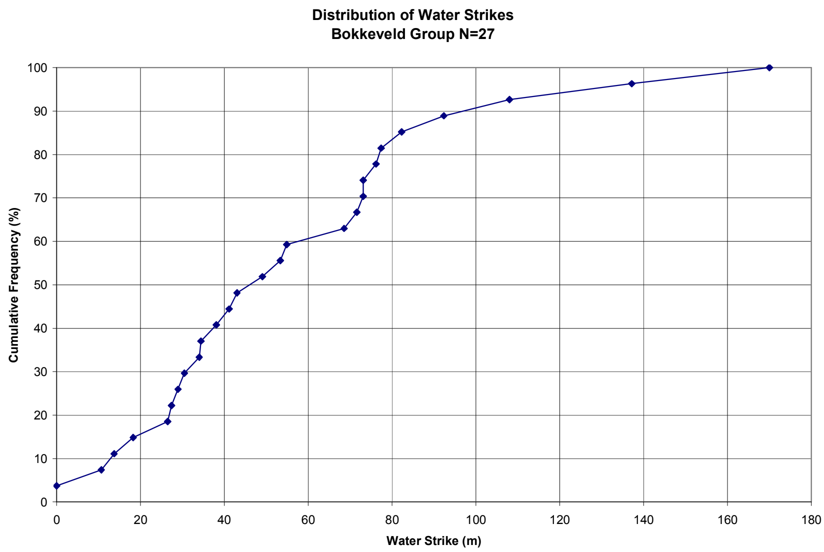


Figure 14: Distribution of water strikes-Bokkeveld Group

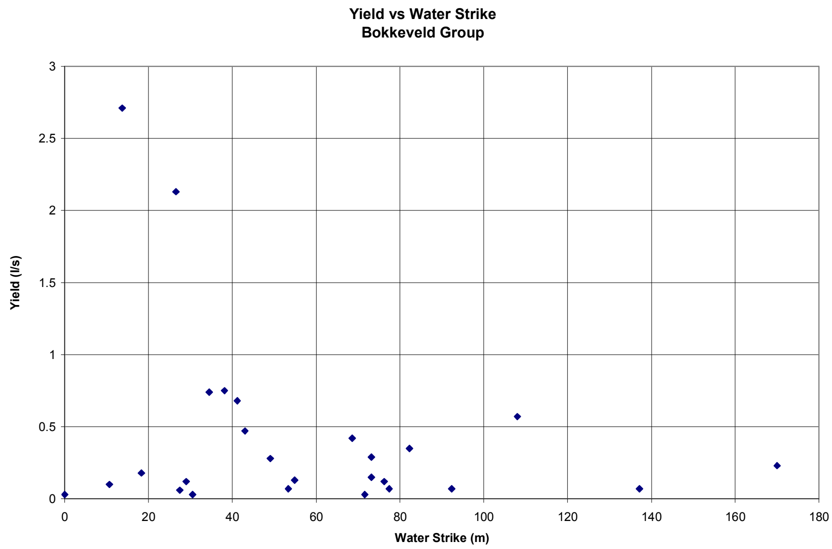


Figure 15: Water strike depth versus yield-Bokkeveld Group

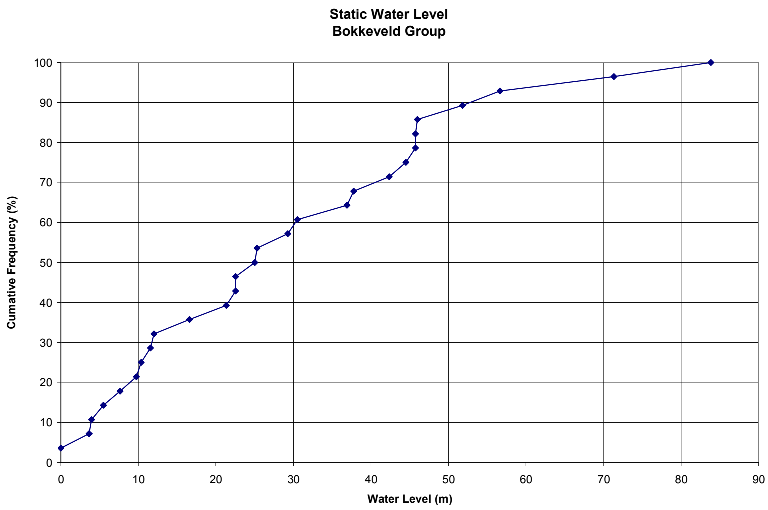
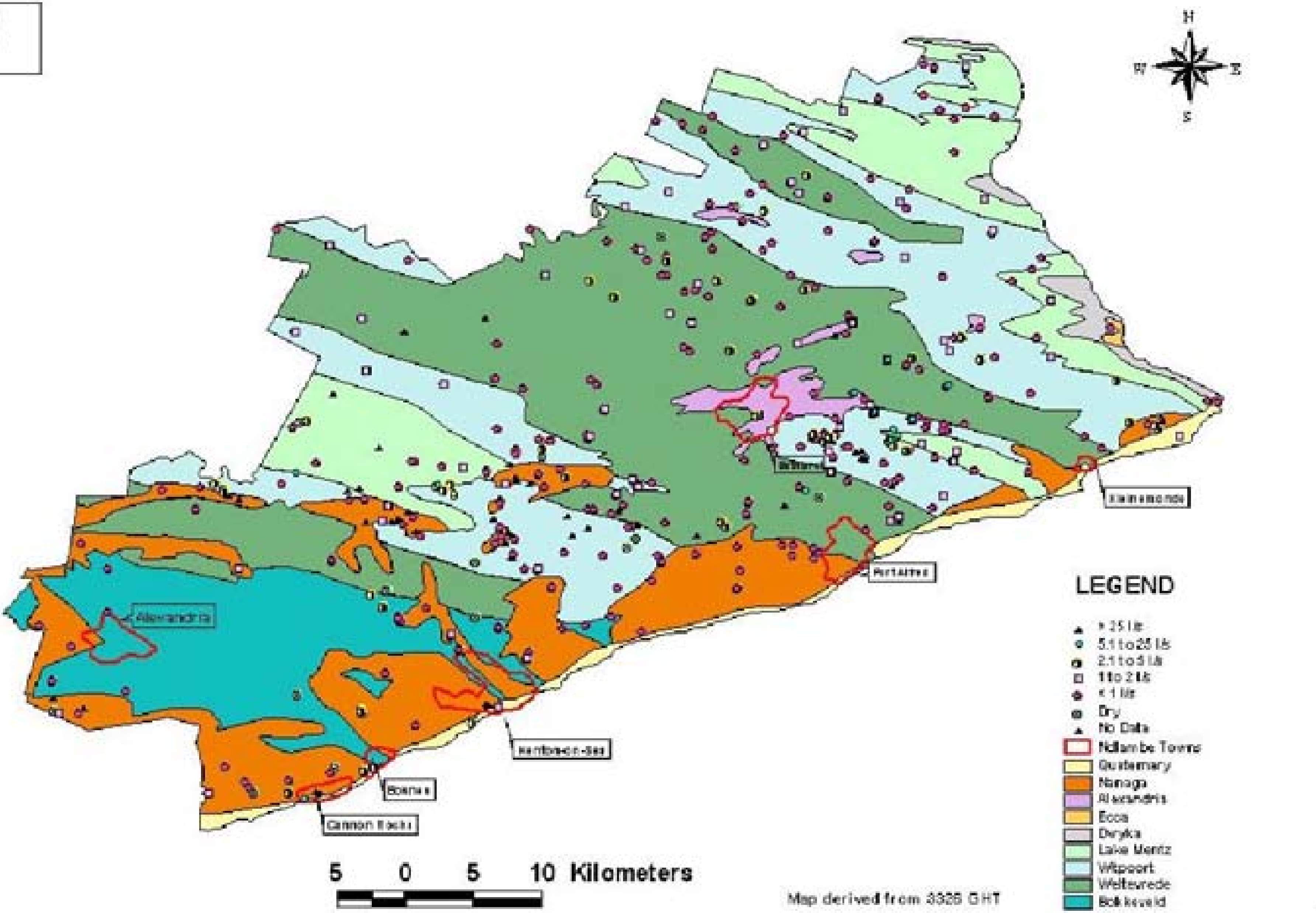


Figure 16: Distribution of static water level-Bokkeveld Group

Map 5



Ndlambe : Borehole Localities & Yields

Bokkeveld shale is associated with poorer water quality and electrical conductivities (EC's) commonly exceed 200 to 400 mS/m i.e., Marginal (Class II) water quality to Poor (Class III) water quality. Sodium, chloride and sulphate often exceed maximum recommended and/or allowable limits. Groundwater in the Bokkeveld is generally of a sodium-chloride nature with its character taking on the chemistry of the ancient environment of deposition.

Through the preferential erosion of the Bokkeveld shale, an irregular, impermeable basement to a thin succession of recent and modern dune sands has developed. This basement (or wave-cut platform) slopes seaward at ~ 1.5º and controls the specific flow of groundwater towards the sea. An understanding of the trends in the buried landscape is important in the exploration of water in the coastal environment. Obvious targets are ancient, buried depressions or valleys, which are in turn blanketed by large, permeable catchment areas. These buried structures can be mapped or located geophysically.

The importance of the Bokkeveld is not for its aquifer potential - but rather for the role it plays as an aquiclude. The aquifer can be developed locally to serve domestic water to small homesteads, stock watering and smaller water supply schemes.

The Bokkeveld aquifer makes up 12 % of the surface area of Ndlambe, yet accounts for less than 6 % of recorded boreholes – suggestive of a low groundwater potential.

7.3 WELTEVREDE AQUIFER

The Weltevrede Formation consists of shale and subordinate sandstone. A median borehole yield of 0.37 ℓ/s was determined (n=224). The distribution of borehole yields is shown in Figure 17. Of this sub-population, six boreholes recorded yields > 5 ℓ/s. High yields have been recorded on the farms of Mansfield (25 ℓ/s), Port Alfred Park (16 ℓ/s) and Sweet Fountain (10 ℓ/s), which may have intersected sandstone units. These boreholes are also located topographically below prominent Witpoort Formation outcrop, which may also help explain the high yields encountered.

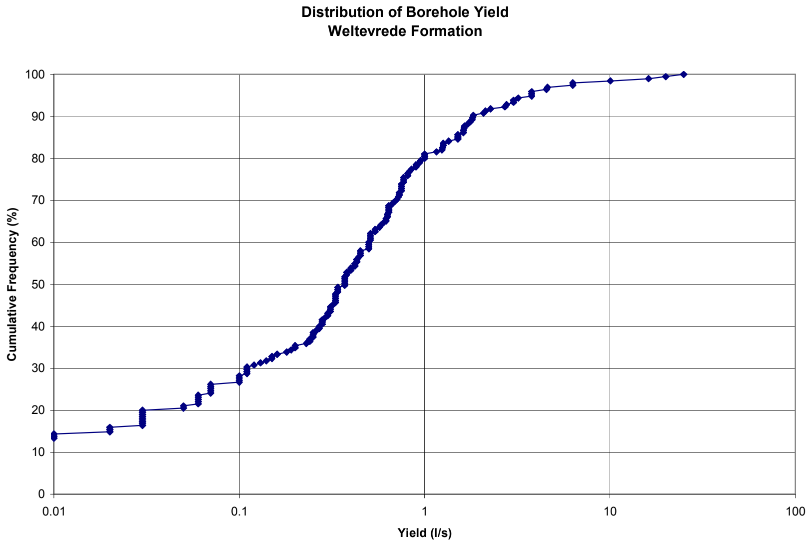


Figure 17: Distribution of borehole yields-Weltevrede Formation

Water strikes generally occur down to 100 m, suggesting that prevalent tectonic related fracturing occurs (Figure 18). No relationship exists between yield and water strike depth due to the tectonic nature of fracture zones. This implies fracture zones are not weathering related (Figure 19).

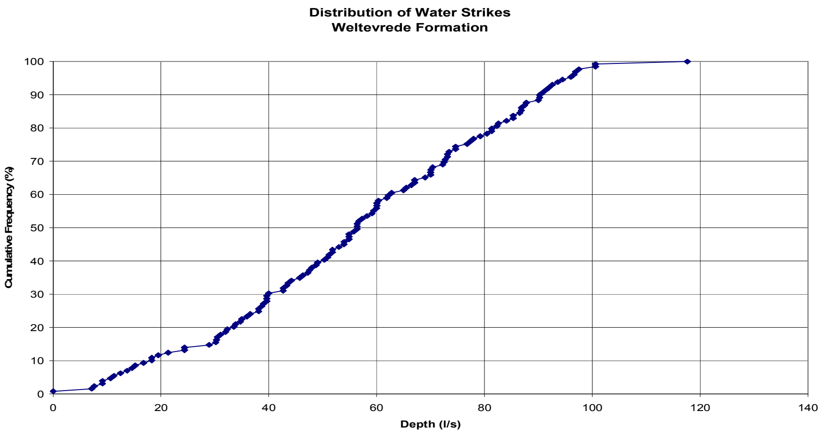


Figure 18: Distribution of water strikes – Weltevrede Formation

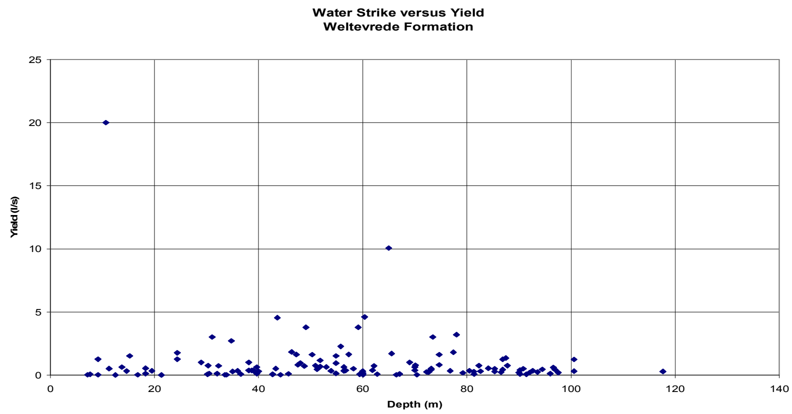


Figure 19: Water strike versus yield – Weltevrede Formation

Static water levels range form 0-70 m, and are generally topographic position dependent (Figure 20).

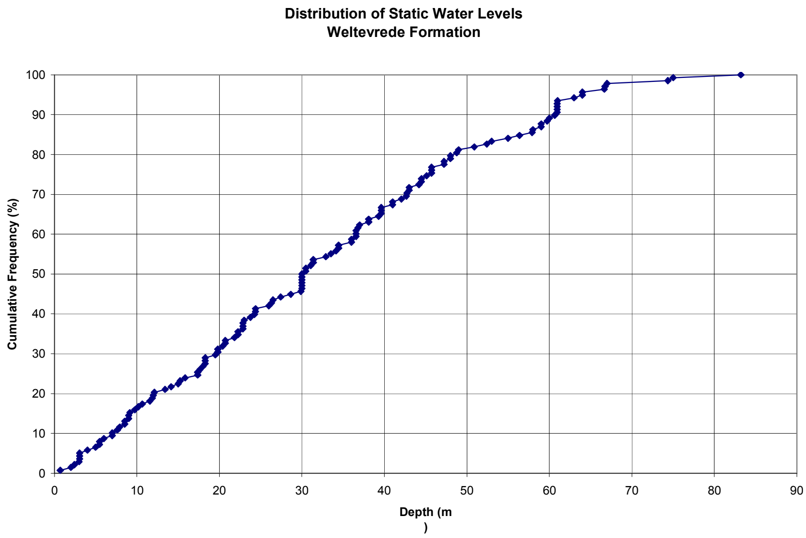


Figure 20: Distribution of static water levels – Weltevrede Formation

Brackish groundwater, with EC's ranging between 40 - 1 400 mS/m can be expected, with higher salinities from the shale components. Some 50 % of the water quality is Class II and 25 % is Class III (Figure 21).

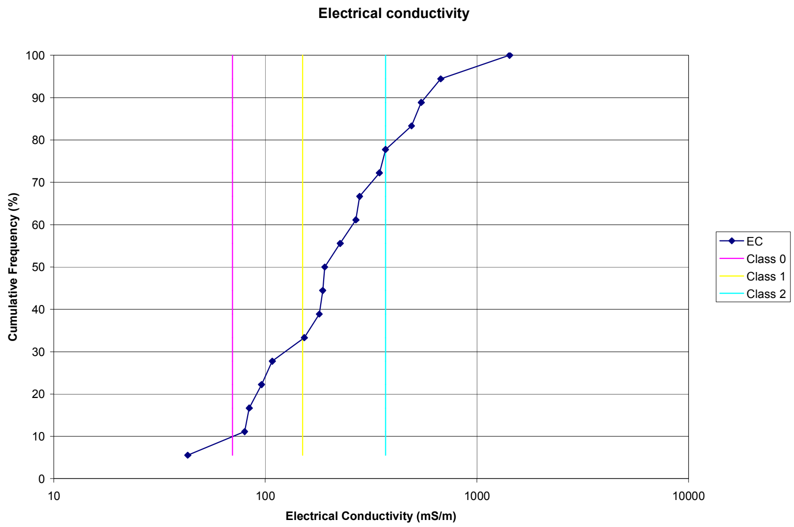


Figure 21: Electrical conductivity of borehole water – Weltevrede Formation

The following determinants often exceed the maximum allowable limits in the shale's viz., sodium, magnesium, chloride and sulphate. Groundwater in the shale is generally of a sodium-chloride nature. Groundwater associated with the Weltevrede sandstone is expected to be of better quality.

The Weltevrede Formation posses a moderate groundwater potential, with 55 % of boreholes yielding 0.2 – 2 ℓ/s and 35 % yielding less than 0.2 ℓ/s. Hence the aquifer can only be used for small water schemes.

The Weltevrede aquifer makes up 33 % of the surface area of Ndlambe, and accounts for 30 % of recorded boreholes.

7.4 WITPOORT AQUIFER

The ~ 300 m thick Witpoort Formation is an orthoquartzite unit, which overlies the Weltevrede Formation. A borehole analysis (n = 272) indicates that the median yield is 0.49 ℓ/s (Figure 22). Of this sub-population, 10 % yield more 2.8 ℓ/s. Of these 21 boreholes, 4 of them were drilled at Merville during this investigation. This suggests that the database may under represent the potential of the Witpoort, since most of the boreholes did not target high yielding structures and/or were to shallow.

High yields have been recorded in each of the three belts within Ndlambe viz., at The Grove (2 x 25 ℓ/s), Merville (7 & 20 ℓ/s) and Dundas (15 ℓ/s). The spectacular yields (viz., an unconfirmed 77 ℓ/s) recorded at Palmietheuwel, behind the Fish River Lighthouse, should be defaulted to the Witpoort, despite being collared in Nanaga Formation.

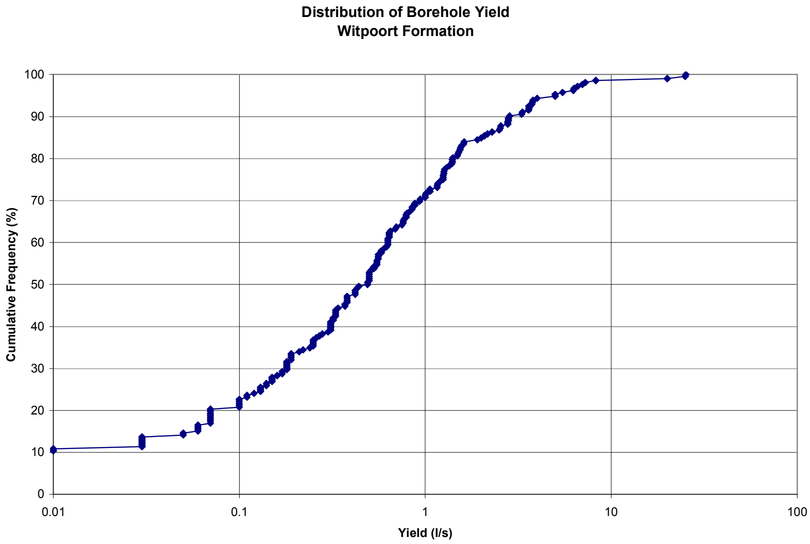


Figure 22: Distribution of borehole yield- Witpoort Formation

Water strikes generally occur down to 90 m (Figure 23). However, it can be noted that the distribution of drilling is only approximately 10 m deeper than water strikes, suggesting in many cases boreholes have not been drilled deep enough to encounter additional water strikes. It is also significant to note that the average water strike depths (viz., 74 m) recorded under very favourable conditions at Merville exceeds the median drilling depth recorded in the NGDB.

No relationship exists between yield and water strike depth due to the tectonic nature of the water bearing fracture zones (Figure 24).

The Witpoort can also be exploited through the presence of many springs. One such spring, the Kariega Spring, on the farm Merville is thought to be tapping a southeast-northwest fracture. This spring has been estimated by Reynders (1987) to yield between 15 to 20 ℓ/s. The reported strategy was to pump the spring for 18 hours at 20 ℓ/s, followed by a period of recovery of 6 hours, to produce 473 040 m³ per annum of marginal quality (i.e., Class II) water. This volume is 1.5 times greater than the production of the Dias Cross well field and is of a similar quality. As the upper reaches of the Kariega River flows through weathered rocks with a marine origin, runoff and leaching from these rocks is responsible for introducing salts into the spring. Depending on seasonal rainfall, the EC's of the Merville Spring can vary between 160 and 320 mS/m.

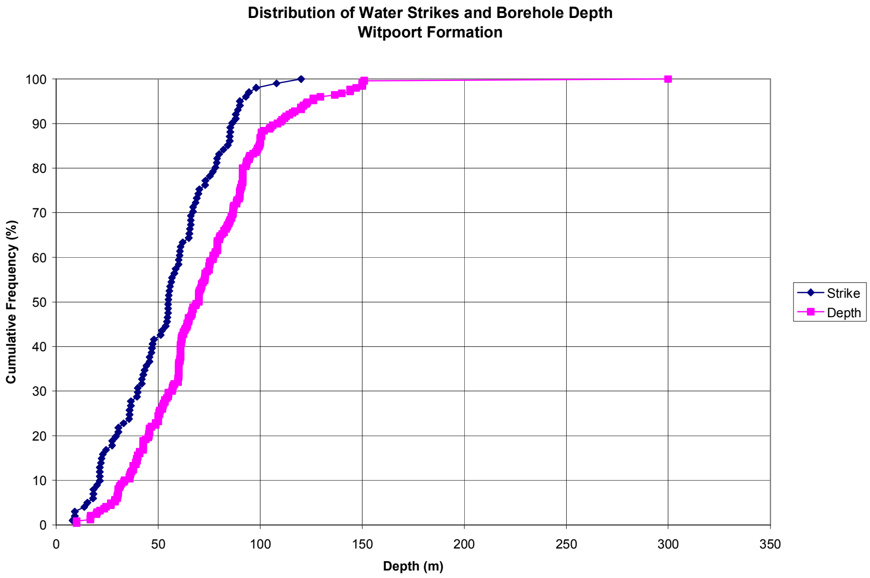


Figure 23: Distribution of water strikes and borehole depth – Witpoort Formation

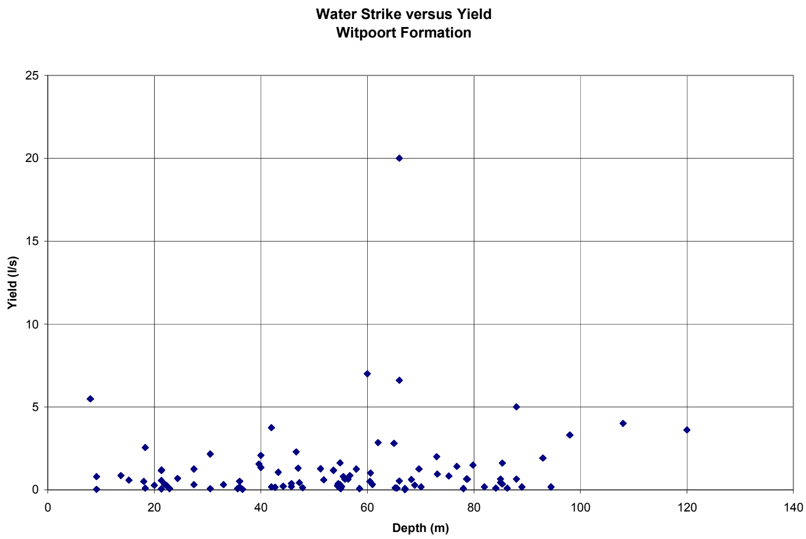


Figure 24: Water strike depth versus borehole yield – Witpoort Formation

Static water levels generally range from 0 – 50 m depending on topographic setting (Figure 25).

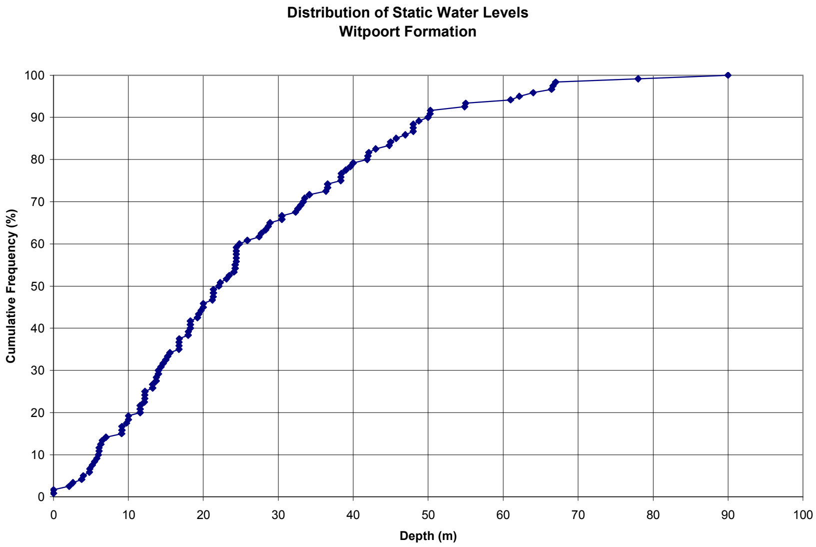


Figure 25: Distribution of static water levels – Witpoort Formation

EC's of groundwater from these quartzite's ranges between 5 – 314 mS/m i.e., Ideal (Class 0) or Marginal (Class II) quality water. Some 50 % of the water quality samples are of Class II, but only 5 % are of Class III (Figure 26).

The following determinants might occasionally exceed maximum recommended limits: sodium, chloride and total alkalinity. Groundwater from the sandstone and orthoquartzite units is invariably of a magnesium-chloride nature. Poorer quality water is associated with unfavourable recharge conditions and/or abundant black phyllite encountered during drilling. The phyllite acts as a conduit, drawing in poorer quality water from the enclosing shale formations.

Some of the highest yielding boreholes, such as the artesian boreholes at The Grove, in close proximity to the Cuylerville Cricket Club, have EC values in the range 60 mS/m.

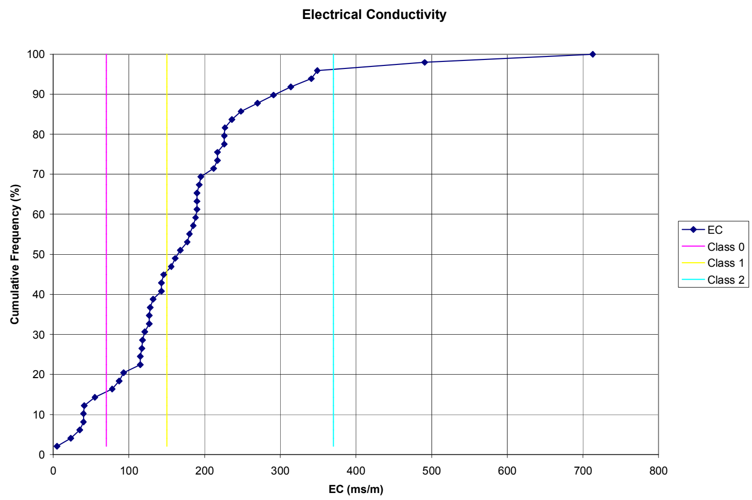


Figure 26: Distribution of borehole water quality - Witpoort Formation

A characteristic of groundwater derived from the Witpoort aquifer is that it is often sweet to taste, slightly acidic and iron-rich. Once a borehole is functional, the action of iron bacteria can set in under certain circumstances, due to the iron titanium oxides present on cross-bed foresets in the quartzite matrix. Iron bacteria problems often occur when formations with substantial levels of iron and manganese are exposed to oxidising conditions due to pumping. Slimy material is created which may plug screen pores and perforated slotted casing and may even retard fracture permeability, rendering a once productive borehole much less effective. Borehole rehabilitation is possible with chemical treatment, however, controlling fluctuations in draw down is preferable to avoid the problem.

The low pH of the groundwater is also a problem due to the consequent corrosive action that makes relatively inexpensive steel unsuitable for well screens and casing. The use of uPVC can be used to overcome these problems.

DWAF recently undertook drilling in Ndlambe to test the potential of the Witpoort aquifer as a groundwater resource. Drilling started on the farm Merville on a southeast to northwest trending fault with encouraging results, with the third borehole drilled among the best ever drilled in Ndlambe. The structure of the locality is complex and represents a significant tectonically deformed zone. A Rhodes University honours (geology) student is currently mapping the structure of the general area.

Subsequent drilling took place in the vicinity of Kleinemonde, behind the Fish River lighthouse. The results (up to end March 2004) are summarized in the Table 6.

Table 6: Summary of Witpoort Drilling on Merville & Kleinemonde

Borehole Number	Depth (mbgl)	Water Strike	SWL (mbgl)	Blow Yield (ℓ/s)	EC (mS/m)	TDS (mg/ℓ)
ECP 3001	151	88	Artesian	5.0	127	636
ECP 3002	150	98	Artesian	3.3	118	603
ECP 3003	91	66	2.1	20.0	314	1906
ECP 3004	147	60		7.0	212	1090
ECP 3005	126	108		4	92.9	604
ECP 3006	71	40	14.34	1.35	156.0	1014
ECP 3007	123	47		1.3	87.1	566

Another southeast-northwest trending fault was mapped in Potgieter Quarries, immediately south of Merville. This fault displays a 5 m thick crush zone, which separates vertical beds from horizontal beds in the north and south respectively. This fault trends towards the farm Bushfontein, which has a gorge 2 Km long and 240 m deep, through which the Bushmans River flows. Geological structures, observed in the sheer walls, can be utilized to site boreholes with confidence (Plate 7). While the terrain is relatively flat, accessibility, owing to extremely thick vegetation, would pose a problem. The same gorge has been mooted by DWAF to be a potential dam site. An extremely high yielding borehole (viz., an unconfirmed 76 ℓ/s) is mentioned in the NGDB on the farm Ettrick, north of the gorge, but is immediately outside the Ndlambe municipal boundary and not reflected in Figure 21. This gorge is ~ 15 Km from each of the following towns: Alexandria, Boknes/Cannon Rocks and Bushmans/Kenton and represents an obvious groundwater target for these communities and should be considered in conjunction with Merville.

Plate 7 : Gorge on the farm Harvestvale/Boschfontein

In summary, the Witpoort aquifer has high groundwater potential and is largely undeveloped, except by private individuals. Two centre-pivot irrigation systems are known to exist in the vicinity of the Cuylerville Cricket Club, on the Eastern Belt. At least one derives its water from a borehole. The Witpoort Formation has much in common with the Table Mountain Group aquifer that supplies significant groundwater to Jeffreys Bay, where seven boreholes (130 to 150 m deep) and yielding 11 to 28 ℓ/s, supply roughly 50 % of the bulk supply during peak season. Out of season, their contribution is higher as this borehole water is cheaper than piped water from the Churchill Dam.

Large groundwater schemes can be developed within this aquifer although the water may be slightly acidic and aggressive. Some high yielding boreholes also experience salinity problems due to leakage of poor quality water from surrounding formations, especially when marine sediments bound faults.

Access to potential targets may also be problematic, particularly in densely vegetated ravines and valley gorges. In addition, some of the land is occupied by private game reserves not amenable to the development of groundwater within their property. The following game reserves are developed on the Witpoort Formation in Ndlambe: Western Belt – Emlanjeni, Kariega, Sibuya; Central Belt – Nyala Valley and Oceana; Eastern Belt – Kap River, Round Hill/ Oribi and Safari Park/ Fort D'Acre.

DWAF plans to drill additional boreholes to further test the Witpoort aquifer, for the benefit of all towns within Ndlambe.

The Witpoort aquifer makes up 25 % of the surface area of Ndlambe, and accounts for 36 % of recorded boreholes – suggesting high groundwater potential.

7.5 LAKE MENTZ AQUIFER

The Lake Mentz aquifer occurs as three discrete belts within Ndlambe (Map 3). An analysis of NGDB data suggests a median yield of 0.55 ℓ/s. Figure 27 shows the distribution of borehole yields in the Lake Mentz aquifer. Less than 5% of boreholes yield more than 2 ℓ/s. In theory, the Lake Mentz aquifer should not be a prolific producer of groundwater. While this is largely true, some boreholes yield as much as 25 ℓ/s, which can be attributed to the fact that the Lake Mentz rocks overlie those of the Witpoort Formation. While some boreholes may have been collared in the former, they may have intersected groundwater in the latter. Alternatively, the 80 m thick quartzite in the central portion of the Lake Mentz may have aquifer potential. An example of a prolific borehole, which supplies groundwater to the centre-pivot irrigation system, occurs on the farm Goodwoods, roughly 20 Km north of Kenton.

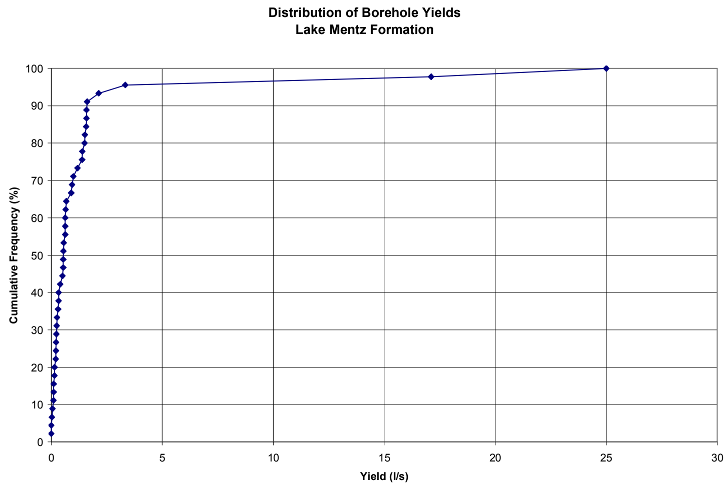


Figure 27: Distribution of borehole yields - Lake Mentz Formation

The competency contrast between the two formations also appears to be a productive groundwater target. Map 5 shows several high yielding boreholes drilled on the geological contact between the Witpoort and the Lake Mentz Formations especially in the central belt. A southeast trending thrust fault has been mapped in this locality (pers. comm. Marc Goedhardt).

Water strikes in the Lake Mentz Formation range from 15 – 110 m, with a median of 56 m (Figure 28). Water strikes are uniformly distributed with depth and water strike frequency does not decline with depth. Yield is also not correlated with depth (Figure 29), suggesting that water bearing horizons are primarily fractured and not related to weathering. Static water levels range from less than 5 m to 100 m, reflecting topographic controls (Figure 30).

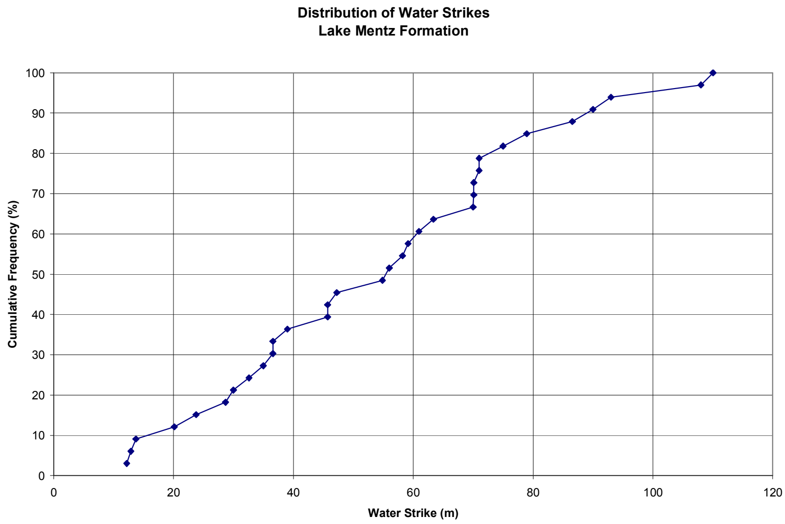


Figure 28: Distribution of water strikes – Lake Mentz Formation

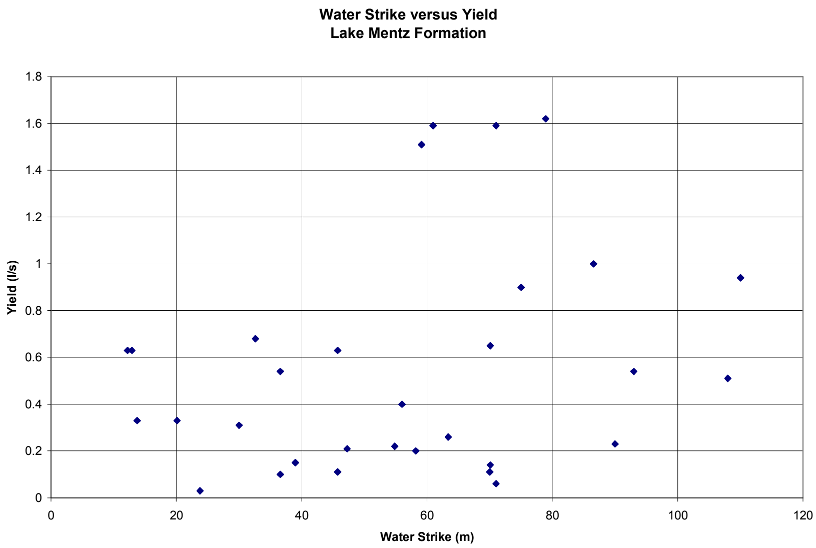


Figure 29: Water strike depth versus yield – Lake Mentz Formation

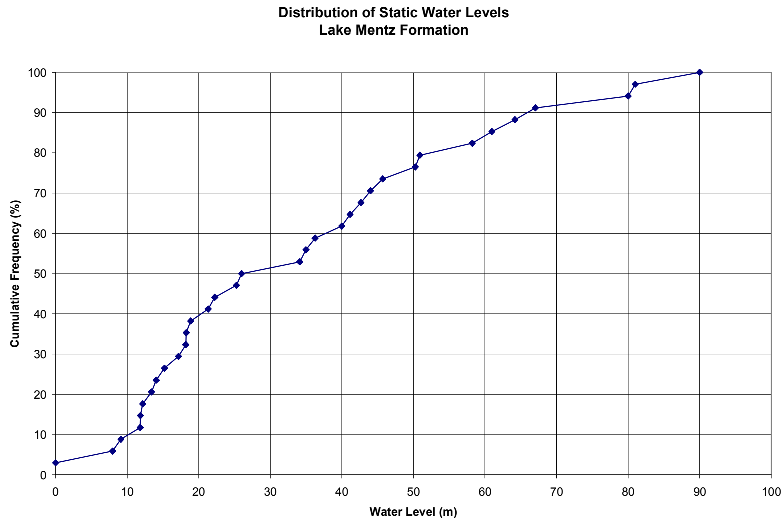


Figure 30: Distribution of Static water levels – Lake Mentz Formation

Groundwater quality is significantly worse than the lithologically similar, Weltevrede aquifer. Groundwater EC's range from 100-400 mS/m (Figure 31) and are generally Class II.

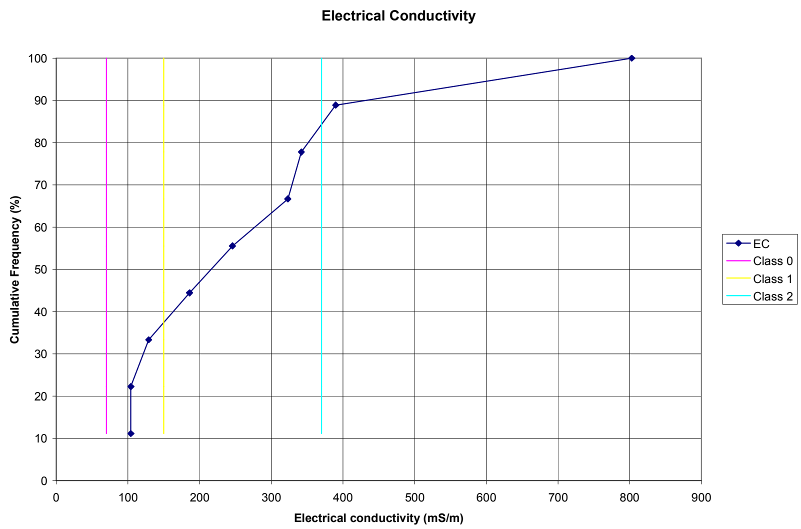


Figure 31: Distribution of borehole water quality – Lake Mentz Formation

The Lake Mentz aquifer makes up 11 % of the surface area of Ndlambe, yet accounts for 7 % of recorded boreholes – suggesting low groundwater potential.

7.6 ALEXANDRIA AND NANAGA AQUIFERS

Coastal primary aquifers are geological formations adjacent to the coastline comprising sufficient water-saturated permeable material to produce significant volumes of water in boreholes and wells. The underlying material may be semi-consolidated (i.e., fossil dunes) to unconsolidated (i.e., modern dunes) belonging to the Nanaga and Schelmhoek formations respectively. Porous rocks account for 19 % of all lithologies within Ndlambe. Relevant NGDB data is summarized in Appendix A, whilst Map 5 shows localities and yields of boreholes in Ndlambe. These boreholes are superimposed over Topographical sheets in much more detail as Appendices B to G.

Collectively, fossil dunes corresponding to the Alexandria and Nanaga Formations form a unique intergranular aquifer. The Nanaga can be considered an aquitard; it stores a significant volume of water but does not transmit water at an economic rate due to its relatively low permeability. In general, the Nanaga drains via springs that emerge at the contact with underlying low permeability formations. When the underlying formation is relatively permeable and is pumped, it can transmit water via vertical leakage to the underlying aquifer.

The basal Alexandria Formation conglomerate is not laterally persistent – its occurrence is governed primarily by the ancient topography of the underlying Cape Supergroup. The conglomerate is best developed in ancient depressions where it contains and transports significant quantities of water. From a hydrogeological perspective, the Alexandria Formation is a thin transmissive zone overlying the Post-African erosion surface through which groundwater draining from the Nanaga Formation flows towards the sea, frequently emerging as springs near sea level (e.g. Cape Padrone).

At Cape Padrone, three wells produce 7 ℓ/s of water on a near continuous basis for the partial requirement of the Alexandria community (Plate 8). A spare borehole is held as a reserve for times of peak demand and produces 3 ℓ/s over a 12-hour pump cycle. These springs have been providing Class 0 and Class I water to Alexandria since 1967 via a 20 Km pipeline. Shutdowns are restricted to routine maintenance and those occasions where spring high tides are accompanied by gale force on-shore winds, causing waves to break over the wells. Abstraction continues as soon as the wind has abated.

Recharge conditions are favourable for the springs at Cape Padrone and are related to a large catchment area of porous Nanaga 'limestone' and generous orographic rainfall.

The distribution of borehole yields is shown in Figure 32. The median yield is 0.3 ℓ/s however, it is often uncertain whether the yield is obtained from the Nanaga and Alexandria Formations, or from an underlying aquifer. The high yielding borehole immediately behind the Fish River Lighthouse with an unconfirmed yield of 76 ℓ/s is almost certainly related to underlying Witpoort quartzite. For this reason, the yield of boreholes collared in the Nanaga and Alexandria Formations must be seen in light of the underlying geology.

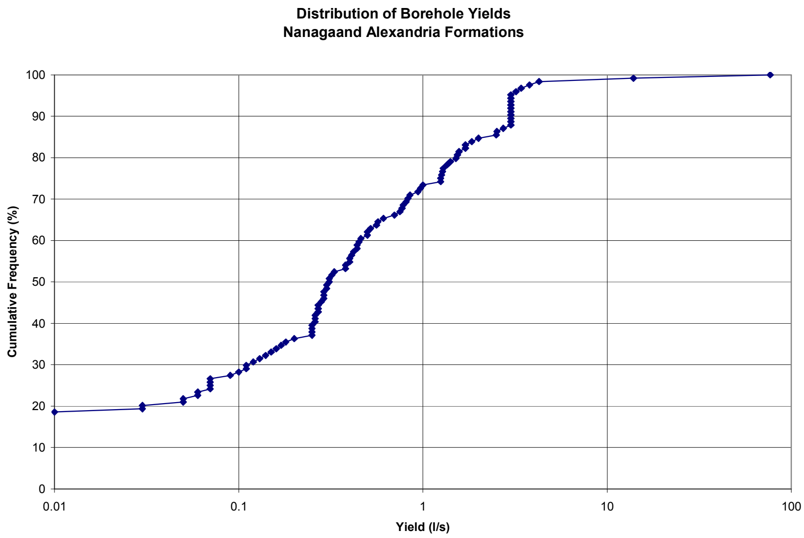


Figure 32: Distribution of Borehole Yields – Nanaga and Alexandria Formations

Additional untapped springs occur beneath the limestone cliffs of Woody Cape and are well known by recreational fishermen. Both the Cape Padrone and Woody Cape springs occur in the Alexandria Forest Reserve – now part of the Addo Elephant Park.

Another high yielding borehole, which derives its yield and favourable water chemistry from similar aquifer conditions, is the centre-pivot equipped borehole on the farm Boschfontein owned by Mr. Christo Potgieter. This borehole is on the western periphery of Cannon Rocks and has been considered as a potential source of bulk water for this community. This borehole has been registered with DWAF and has been licensed to abstract 70 200 m³/annum for irrigation of pasturage for dairy cattle. This borehole struck water at 36 m, which corresponds to the Bokkeveld sandstone/Alexandria conglomerate contact. This borehole is currently pumped at 10 ℓ/s for three to four days and then rested for a week during late autumn-early spring with no ill effects according to the owner. Recently this borehole was subjected to a constant rate test (72-hours at 10.47 ℓ/s) and reached 1.65 m draw down on completion of the test. Recovery reached 93.3 % after 72-hours. The test indicated that a sustainable rate of 2.5 ℓ/s on a 24-hour cycle could be pumped from this borehole – equivalent to 216 Kℓ/day. This borehole has, in the Ndlambe context, a fairly spectacular yield. The water quality is Marginal (Class II), with a TDS analysis of 1 820 mg/ℓ.

Water strikes generally range from 2 – 90 m, reflecting the variable thickness of this composite aquifer (Figure 33). Water strikes above 1 ℓ/s can occur at any depth, depending on the thickness of the Nanaga Formation (Figure 34).

Static water levels range from less than 1 to 60 m below ground (Figure 35).

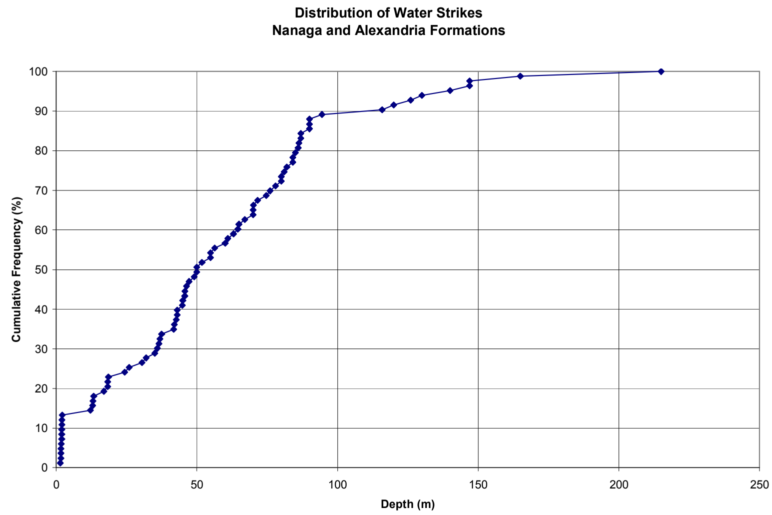


Figure 33: Distribution of Water strikes – Nanaga and Alexandria Formations

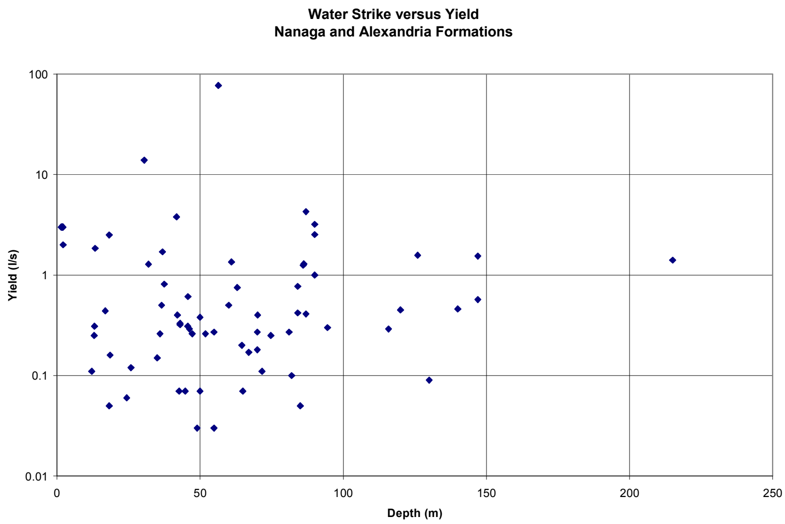


Figure 34: Water strike depth versus yield – Alexandria and Nanaga Formations

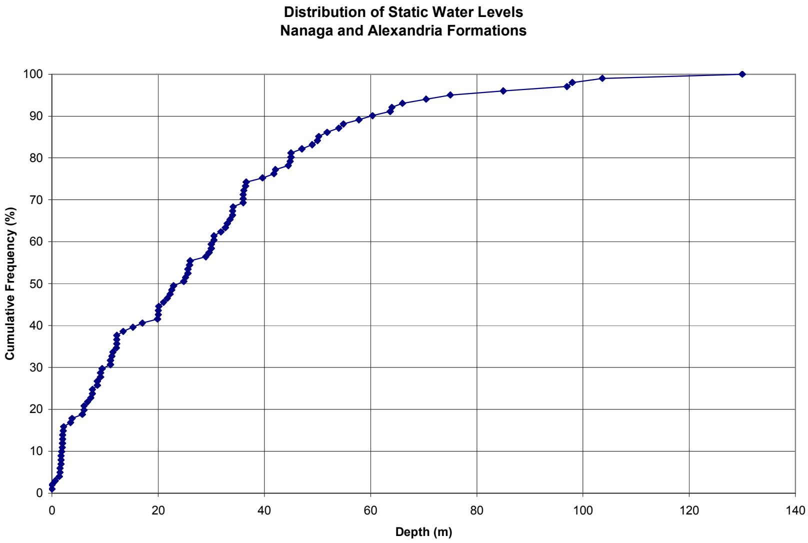


Figure 35: Distribution of static water levels – Alexandria and Nanaga Formations

Plate 8 : Cape Padrone Well Field.

Water quality ranges from 100 – 400 mS/m (Figure 36) and is generally Class II or Marginal quality water. Sodium, calcium and chloride may exceed maximum recommended limits. Groundwater from the Alexandria and Nanaga aquifers frequently displays a sodium–chloride-calcium nature.

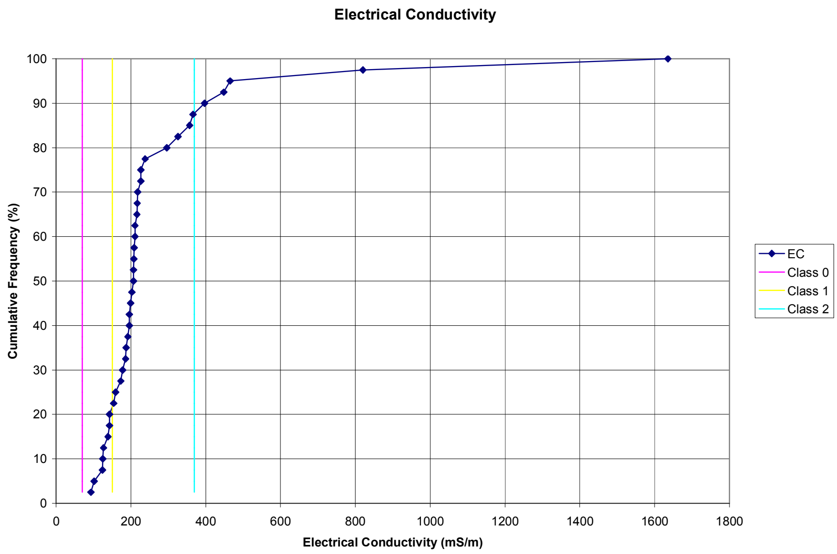


Figure 36: Distribution of borehole water quality – Alexandria and Nanaga Formations

The combined Alexandria/Nanaga aquifers makes up 17 % of the surface area of Ndlambe, and account for 22 % of recorded boreholes – indicative of its moderate groundwater potential.

7.7 SCHELMHOEK AQUIFER

This Quaternary (modern) sand aquifer occurs sporadically along the coast and is exploited at the Fish Kraals, Dias Cross, Bushmans River Mouth, Port Alfred (Freshwater Estates and East Bank) and Kleinemonde. The Apies River sand aquifer (immediately west of Cannon Rocks) is currently being investigated as a possible source of bulk water for this community (Mouton, 2004).

Borehole yields are generally 1 – 2 ℓ/s but can reach 5 ℓ/s, depending on aquifer thickness. Test pump data from available reports suggest transmissivity values ranging between 150 and 180 m²/day. Storativity values are in the order of 2.8×10^{-1}. Porosity in the upper saturated sand is in the order 12 % and in the lower shingle considerably higher at 26 %.

Boreholes situated within the modern sand aquifers are recharge dependent and their exploitation must be adjusted accordingly to prevent degradation through salt water intrusion. Ideally they must be developed where the sand cordon is thick, broad, and free of pockets of highly salinized mud and associated with favourable recharge conditions.

The locality where the Schelmhoek aquifer is exploited is discussed from west to east.

The Fish Kraals: The Fish Kraals West and East well fields are situated between Cape Padrone and Cannon Rocks and currently produce a combined 12 ℓ/s (over a 24 hour pump cycle) of Good/Marginal quality water (Class I/II). This groundwater augments the Cape Padrone springs, which supply bulk water to Alexandria. These were established in 2002 and, according to the DWAF license agreement, the full quota is utilized. The manifold-type abstraction points utilize a strong suction to draw fresh water from ~ 4 m of dune sand – some 200 m from the high tide mark (Plate 10).

Plate 10 : Fish Kraals Well Field.

This well field is managed by P & S Consulting Engineers who have an agreement with the Ndlambe municipality to deliver bulk water to the storage reservoirs outside Alexandria. The current daily demand of Alexandria is 1 350 m³/day (equivalent to 15.6 ℓ/s) with the current capacity of the system just coping with the peak demand of 1 500 m³/day (equivalent to 19.1 ℓ/s).

Additional groundwater is available for exploitation in the modern dune sands between Fish Kraals East and Cannon Rocks. The Apies River aquifer has high groundwater potential and feasibility study has just been completed. Plate 9 is a false colour infrared image of the area around the Apies River aquifer.

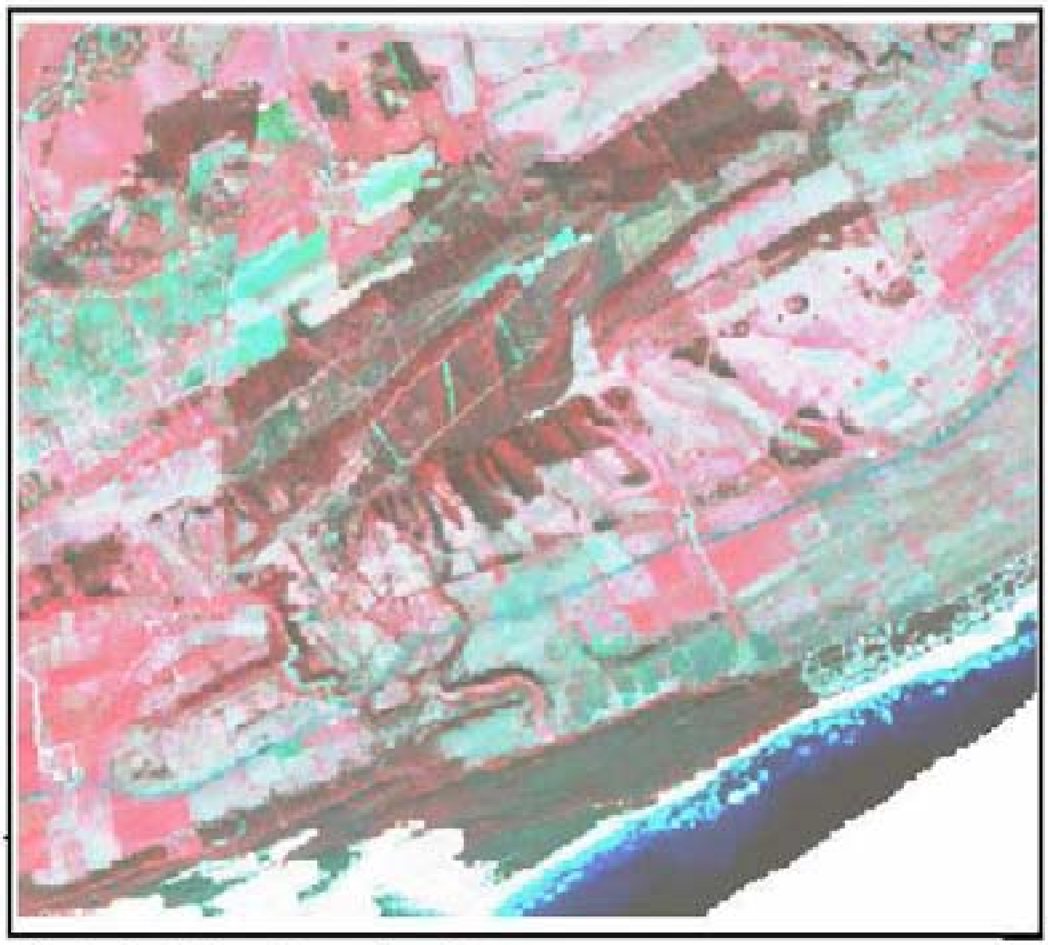


Plate 9 : Apies River Aquifers.

This environmentally sensitive land forms part of the Alexandria Forest Reserve and is managed ultimately by the Addo Elephant Park. SanParks have intimated that they will not consider any new well field development in ground under their jurisdiction.

Dias Cross: The Dias Cross well field is situated midway between the resort towns of Boknes and Bushmans River (Plate 11). In 1984, a Water Affairs investigation identified the area behind the Dias Cross rock promontory suitable for development as a production well field for the greater Bushmans/Kenton communities. The long term safe yield of this 1250 m (long) x 800 m (wide) aquifer was set at 300 000 m^3/annum. Recharge by direct rainfall was calculated at 60 % for rainfall events exceeding 10 mm – which may be an over estimation.

The Dias Cross well field is currently producing 19 ℓ/s over a 12-hour pump cycle, equivalent to 821 m³/day. The water from the Dias aquifer is pumped via a 9 Km pipeline (rated at 25 ℓ/s) to 2 x 2 Mℓ storage reservoirs overlooking Ekuphumleni Township to the north of Kenton. Groundwater from Dias Cross (@ R0.70/m³) is blended in the ratio 63:37 with better quality Reverse Osmosis water (@ R4.85/m³) to produce an end product of an acceptable quality and cost profile.

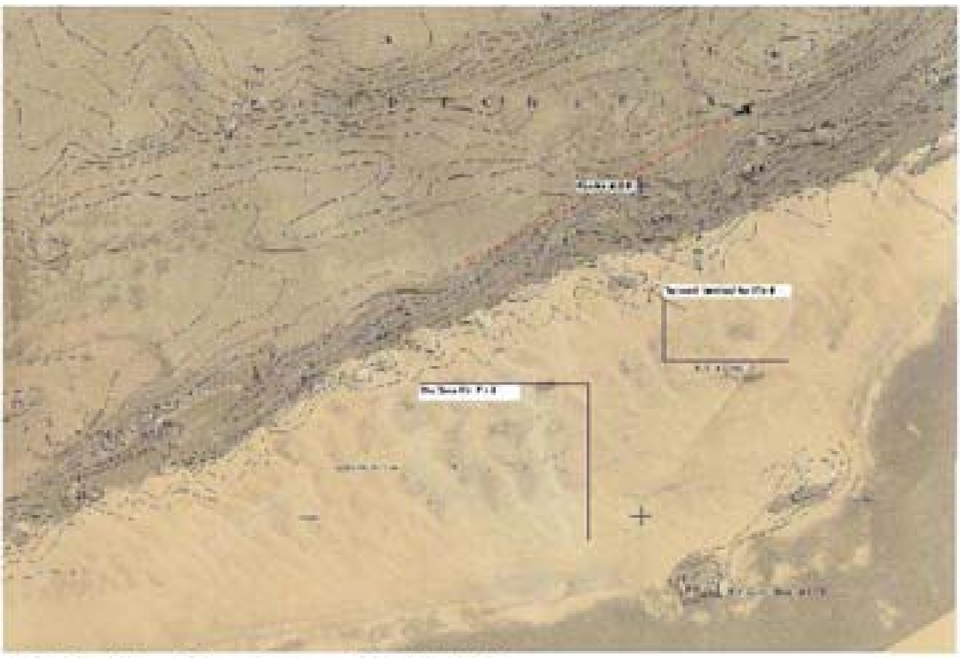


Plate 11 : Dias Cross Well Field.

Any demand for bulk water in excess of 1 900 m³/day results in a decline in the level of the storage reservoirs. During the 2003/04 Xmas holiday season, demand peaked at 2 800 m³/day, causing the water level in the storage reservoirs to drop for 14 consecutive days.

The stressing of the Dias Cross aquifer has caused the EC's to degenerate from around 100 mS/m (initial production 1990), to 200 mS/m (late 2003) to 250 mS/m (early 2004). Despite the many reversals in water quality based on seasonal rainfall patterns, the overall trend has seen a steady decline in the groundwater quality. This is due to the ACWB not being able to reduce abstraction during times of stress and drought conditions. In the absence of spare capacity, the ACWB has little option but to draw water from this stressed source. Locally the water table is depressed with the result that the pumps in the production boreholes began sucking air intermittently on the 18 March 23, 2004, interrupting the supply of bulk water. ***Due to the drought conditions, over 60 % of the bulk supply to the greater Bushmans/Kenton is extremely vulnerable at present.***

Based on the influx of people into the surrounding townships and current developments in the Bushmans/Kenton, soon the ACWB will face serious shortfalls in the delivery of bulk water. It is proposed to develop an additional well field in the modern dunes behind Kwaaihoek, some 800 m east of the existing Dias Cross well field. A linear array of approximately 6 additional boreholes (ø = 10 to 12”) will be required to produce an additional 12 ℓ/s over a 12-hour pump cycle. The groundwater can be reticulated through the existing pipeline, located in close proximity to the envisaged expansion. As a result, the unit cost of producing this water will be low. Outside the peak holiday season, pumping schedules from Dias and the proposed Kwaaihoek aquifer can be rotated to prevent degradation of water quality and ensure the longevity of both well fields. However, SanParks have stressed that they will oppose the development of any new well fields in ground under their jurisdiction.

Direct recharge of the depleted Dias Cross well field by the Boknes lagoon (EC’s of 100 – 200 mS/m) in the back dune area, may result in hyper-saline water migrating down hydraulic gradient to degrade the groundwater quality. It is likely, that intrusion of salt water from the south is also down grading the Dias Cross well field.

Bushmans River Mouth: Here groundwater has historically been abstracted from shallow boreholes situated in the dunes in close proximity to the mouth of the Bushmans River (Plate 12). In 1983, the Bushmans Municipality and the ACWB were abstracting 104 000 m³/annum from five boreholes for the Bushmans/Kenton bulk supply. On average, these boreholes yielded 2 – 3 ℓ/s each. Ten years later, supply had essentially doubled to 202 726 m³/annum. In 1984, Water Affairs were commissioned to conduct a detailed hydrogeological investigation from the mouth of the Bushman River up to and including the state land immediately west of Dias Cross. Their investigation condemned this area due to low yield and poor quality, due to pockets of mineralized mud in the sand profile.

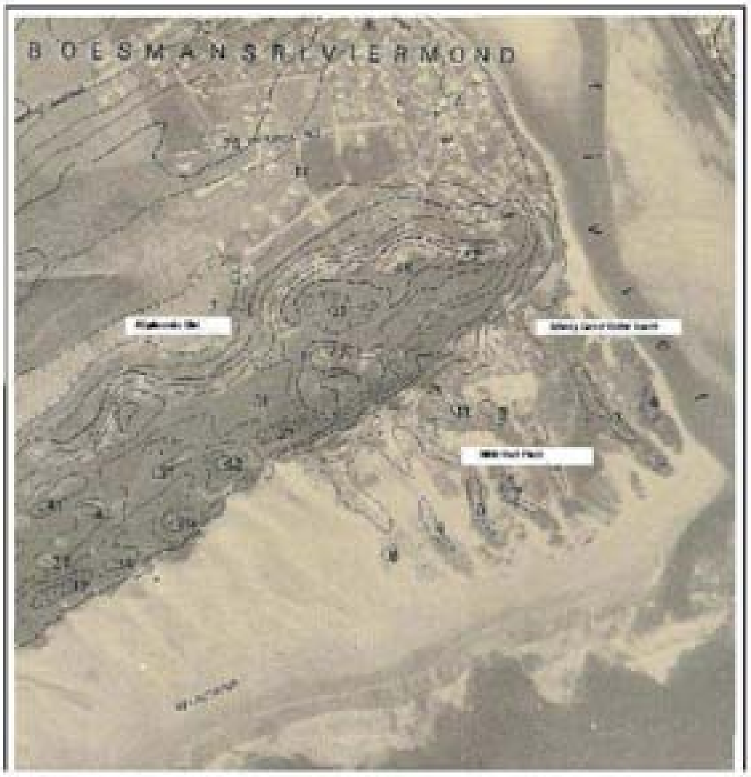


Plate 12 :Bushman 's River Mouth Well Field

Direct recharge from the aquifer beneath the Klipfontein Vlei in the back dune area (EC's ranging from 300 to 400 mS/m) resulted in brack water migrating down the hydraulic gradient to degrade the water quality over time. Later in 1986, it was noted that yields and water quality had deteriorated significantly. The Bushmans River well field was abandoned in favour of the newly commissioned Dias Cross well field in 1990.

Four brackish boreholes are currently being pumped and provide around 20 % of the raw input water to the ACWB's desalination plant.

Fresh Water Estates, Port Alfred: Numerous shallow wells and springs characterize this secluded, low density development on the western peripheries of Port Alfred (Plate 13). Historically, the general area served as a camping ground with holidaymakers exploiting the shallow water table for domestic use. This aquifer consists of unconsolidated coastal sand (0 to 10 m thick) overlying relatively impervious Witpoort quartzite.

Plate 13 : Spring on Fresh Water Estates.

The development of the Forest Downs suburb (hydraulically up-gradient) and the popularity of these sea-fronting properties, poses a risk of sterilizing this groundwater resource. DEAT are currently looking at the environmental implications of further developments in the area.

The general area to the west of Fresh Water Estates, viz., the Sunshine Coast Nature Reserve, possesses all the salient characteristics of having high aquifer potential.

East Bank, Port Alfred: Here water is also abstracted at a low-rate on an almost continuous basis from this coastal aquifer on the East Bank of the Kowie River (Plate 14). The scheme was devised and implemented by Water Affairs in 1985. The cumulative yield is in the order of 130 000 m³/annum. Five boreholes have been developed in a line mid-way between the high-tide mark and the vegetated, back dunes. The dune cordon is 800 m's wide at this location. The aquifer consists of recent coastal sands (4 to 5 m's thick) in contact with impermeable Weltevrede shale. Current field measurements of the water quality reveal the EC's to be 230 mS/m i.e., Class II or Marginal quality water. This water is used conjunctively with water from the Sarel Hayward dam.

Plate 14 : East Bank Well Field at Port Alfred.

Recharge conditions are not ideal at this location owing to the East Bank suburb being located nearby and hydraulically up gradient of this well field.

7.8 WATER QUALITY

The main phenomenon affecting the quality of the water is the mineralisation or salinization of groundwater in the main catchments due to the marine origin of the geology in the region. Shale-dominated lithologies account for 56 % of the surface area by outcrop, whereas 'limestones' make up an additional 17 %. Together these two 'marine' lithologies account for 73 % of the surface area by outcrop, whereas chemically inert quartzites make up only 25 %. The underlying Weltevrede shales and overlying Lake Mentz shales enclose the Witpoort quartzites. In the near coastal zone, the Nanaga limestones often blanket the Witpoort. Leakage from these rocks introduces a marine character to the groundwater in the Witpoort aquifer.

Other factors affecting the natural chemistry of groundwater include:

- Volume and rate of recharge
- Exchange of water between the bedrock and the overlying sediments
- Residence time/response time (varies with saturated thickness, spatial extent, specific yield)

- Depth to water table (aquifers with shallow water tables tend to have a close correlation between groundwater quality and climate)
- Abstraction
- Evapo-transpiration.
- Seawater intrusion (either close to the sea as a natural condition, or farther inland through over-exploitation).
- Salt leaching (most of the sediments of coastal aquifers are of marine origin and have both a high calcareous content and a high alkalinity. The calcareous component is derived mainly from shells and calcareous algal fragments. Leaching and dissolution of these compounds into groundwater produces a high salt content. Deposition of salt by sea spray is a factor in the near, marine environment
- Weathering and erosion of the parent material, especially Bokkeveld shales, have been shown to release large quantities of salts on leaching
- Selective retention of salts by plants, e.g. Tamarisk, which concentrates the salts in leaves. When the leaves fall off annually, the salts leach out with the following rains causing a relocation of the salt in the profile.

As water moves from the recharge area to the discharge area, various geochemical processes alter the quality of the water. When rain water enters the unsaturated zone it is pure (very low TDS) and is slightly to moderately acidic. The water also has a high carbon dioxide and oxygen content. Interactions of the water with mineral constituents and organic matter bring about active leaching and transport of dissolved salts. As the groundwater moves through the sand, plant root reactions decrease the oxygen and increase the carbon dioxide content. This results in the formation of carbonic acid, making the groundwater more acidic. Furthermore the TDS content increases as water moves away from the recharge area.

A total of n = 103 groundwater samples from the NGDB, were clipped according to the various lithologies within the Ndlambe municipal boundary. These are listed along with their analyses in Appendices H along with additional groundwater samples collected during the course of this study. The following is a generalized description of the expected groundwater chemistry.

Fifty-two groundwater analyses are presented to describe groundwater from the various fractured aquifers and a further 51 from the two intergranular aquifers. Median concentrations per lithotype for both classes of aquifer are presented in Table 7.

pH is consistently and comfortably in the ideal (Class 0) category for all aquifers. Slightly more acidic water (viz., ph of 6.2) is often associated with the Witpoort Formation rock-types. The low pH of the groundwater and consequent corrosion makes relatively inexpensive steel unsuitable for well screens and casings. The use of uPVC can be used to overcome these problems.

Electrical Conductivity is, as expected, poor quality (Class III) for groundwater derived from the Bokkeveld Group. Here the median value is 405 mS/m. Groundwater emanating from the Lake Mentz Formation narrowly escapes the poor quality classification by falling just within the upper limits of marginal quality classification with an EC value of 364 mS/m. The median concentration for all the other lithotypes, plots essentially in the middle of the marginal quality (Class II) category. Anomalously, groundwater from the Weltevrede Formation (EC = 244 mS/m) appears to be significantly better than that derived from the Witpoort Formation (EC = 305 mS/m). In general, EC's from the modern coastal sands are the best with median values around 213 mS/m.

Total Dissolved Salts for all lithotypes span the range of marginal water quality (Class II), with the Bokkeveld Group defining the worst (TDS = 2 333 mg/ℓ) and anomalously, the Weltevrede Formation the better with a TDS = 1 245 mg/ℓ. It is apparent that there is significant leakage between the aquifers in the various lithotypes. As the Witpoort Formation occurs stratigraphically and topographically above the Weltevrede Formation, the latter may be benefiting from the 'leakage' of higher quality groundwater generally anticipated in the former. Further work should be done to establish the generally disappointing water quality of the Witpoort Formation.

Table 7: Median Hydrochemistry of the various aquifers

ANALYSES	UNIT	Fractured Aqufers				Primary Aquifers		CLASSIFICATION			
		Bokkeveld Group	Weltevrede Fm	Witpoort Fm	Lake Mentz Fm	Alexandria & Nanaga Fm's	Schelm Hoek Fm	Class 0	Class I	Class II	Class III
(n = x)		15	9	21	7	43	8	Ideal	Good	Marginal	Poor
pH								5.5 - 9.5	4.5 - 10	4 - 10.5	3 - 11
Conductivity	mS/m	405	244	305	364	307	213	< 70	70 - 150	150 - 370	370 - 520
TDS	mg/l	2333	1245	1745	1976	1633	1342	< 450	450 - 1000	1000 - 2400	2400 - 3400
Sulphate	mg/l	181	102	110	103	122	71	< 200	200 - 400	400 - 600	600 - 1000
Nitrate (N)	mg/l	0.5	0.34	0.29	0.68	1.06	0.3	< 6	6 - 10	10 - 20	20 - 40
Chloride	mg/l	1089	644	828	981	747	542	< 100	100 - 200	200 - 600	600 - 1200
Fluoride	mg/l	0.26	0.39	0.29	0.35	0.36	0.43	< 0.7	0.7 - 1	1 - 1.5	1.5 - 3.5
P - Alkalinity		273	245	295	292	275	284				
M - Alkalinity											
Carbonate											
Bicarbonate		333	299	360	356	336	346				
Total Hardness	CaCo3	697	381	543	282	470	408	< 200	200 - 300	300 - 600	> 6
Ca - Hardness											
Mg - Hardness											
Calcium	mg/l	159	78	133	170	112	114	< 80	80 - 150	150 - 300	> 3
Magnesium	mg/l	79	41	53	79	42	30	< 70	70 - 100	100 - 200	200 - 400
Sodium	mg/l	590	365	429	438	473	348	< 100	100 - 200	200 - 400	400 - 1000
Potassium	mg/l	9.06	4.62	8	9.37	7.41	6.2	< 25	25 - 50	50 - 100	100 - 500
Iron	mg/l	0.02	0.02	0.02	0.02	0.02	0.02	< .5	.5 - 1	1 - 5	5 - 10
Manganese	mg/l	0	0	0	0	0	0	< .1	.1 - .4	.4 - 4	4 - 10

Drinking Water Quality Criteria (WRC, 1988)

Class 0: Ideal water quality - suitable for lifetime use
Class I: Good water quality - suitable for use, rare instances of negative impact.
Class II: Marginal water quality - unsuitable for use without treatment.
Class III: Poor water quality - unsuitable for use without treatment. Chronic effects may occur.
Class IV: Dangerous water quality - totally unsuitable for use. Acute effects may occur.

Sulphate is variable and generally plots in the middle of ideal (Class 0) water quality. The concentration of sulphate in the Bokkeveld Group generally tests the good (Class I) classification.

Nitrate concentrations are generally low with most values comfortably within ideal (Class 0) water quality. The highest values (viz., up to 10.10 mg/ℓ corresponding to Class II) occur within the Alexandria/Nanaga Formations and appear to be associated with intensive dairy farming in the near coastal zone of western Ndlambe.

Chloride, with the exception of marginal (Class II) quality water associated with the modern, sands, reports largely to poor water quality (Class III). Groundwater from the Bokkeveld Formation, is often unacceptably close to dangerous quality water classification (Class IV), with a median value of 1 089 mg/ℓ.

Fluoride is consistently and comfortably within ideal (Class 0) water quality for all aquifer and lithotypes.

Hardness covers the range in classification from good (Class I) water quality for the Lake Mentz formation to poor (Class III) water quality for the Bokkeveld Group rocks. The rest, viz., the Weltevrede, Witpoort, Alexandria/Nanaga and Schelmhoek Formations, all default to marginal (Class II) water quality. On average, most groundwater will have a 'brack' after taste. Where recharge conditions are favourable, Class 0 and/or Class I water quality is known to exist e.g. the artesian borehole at 'The Grove.' Some farmers sell this water commercially as 'whiskey water'.

Calcium spans the range from ideal (Class 0) for the Weltevrede aquifer to marginal (Class II) for the Bokkeveld and Lake Mentz aquifers. The Witpoort, Alexandria/Nanaga and Schelmhoek aquifers on average, all report to good (Class I) water quality.

Magnesium, on average, either reports to ideal (Class 0) or to good (Class I) water quality.

Sodium defaults largely to poor (Class III) water for the Bokkeveld, Witpoort, Lake Mentz and Alexandria/Nanaga lithotypes. Marginal (Class II) water quality, on average characterizes the Weltevrede and Schelmhoek formations.

Potassium is consistently and comfortably well within the ideal (Class 0) water quality classification for all lithotypes.

Iron is, on average, falls well within the ideal (Class 0) water quality classification. Problems do occur with individual boreholes within the Witpoort Formation, where concentrations consistent with poor (Class III) water quality are recorded e.g. high-yielding borehole on Merville has a Fe concentration of 8.59 mg/ℓ.

Manganese concentrations, on average, report largely to the ideal (Class 0) and good (Class I) water quality classification. Occasionally, some boreholes in the Witpoort Formation may be elevated to marginal (Class II) water quality with respect to Mn.

Different graphical techniques are presented to characterize the groundwater occurring within each of the lithotypes making up the hydrogeology of Ndlambe. These are Shoeller, Piper and Expanded Durov diagrams and are presented as Figures 37, 38 and 39 respectively.

The Shoeller diagram (Figure 37) represents different types of water in a quick and easy manner.

For the Piper diagrams (Figure 38), the major cations (Ca, Mg and Na+K) are plotted in one trilinear diagram by calculating the percentage contribution that each represents of the major cations. The same is done for the major anions (Cl, SO_4 and HCO_3 + CO_3) and the results are plotted as one point in the anion trilinear field. These two points are then extended into the main diamond –shaped field of the Piper diagram to plot as one point. The water is classified depending on the position of this point. Piper diagrams can be used to imply certain chemical processes such as mixing, chemical evolution along a flow path or ion exchange. Piper diagrams can also be used to identify certain types of water.

Expanded Durov diagrams (Figure 39) use similar ratio techniques to plot the concentrations of the major ions, however six triangular diagrams are used, three for the anions and three for the cations, on each triangle the sum of the ions add up to 50 % and the ions are plotted in different combinations. The result is nine fields for classification, giving better splitting than the Piper diagram.

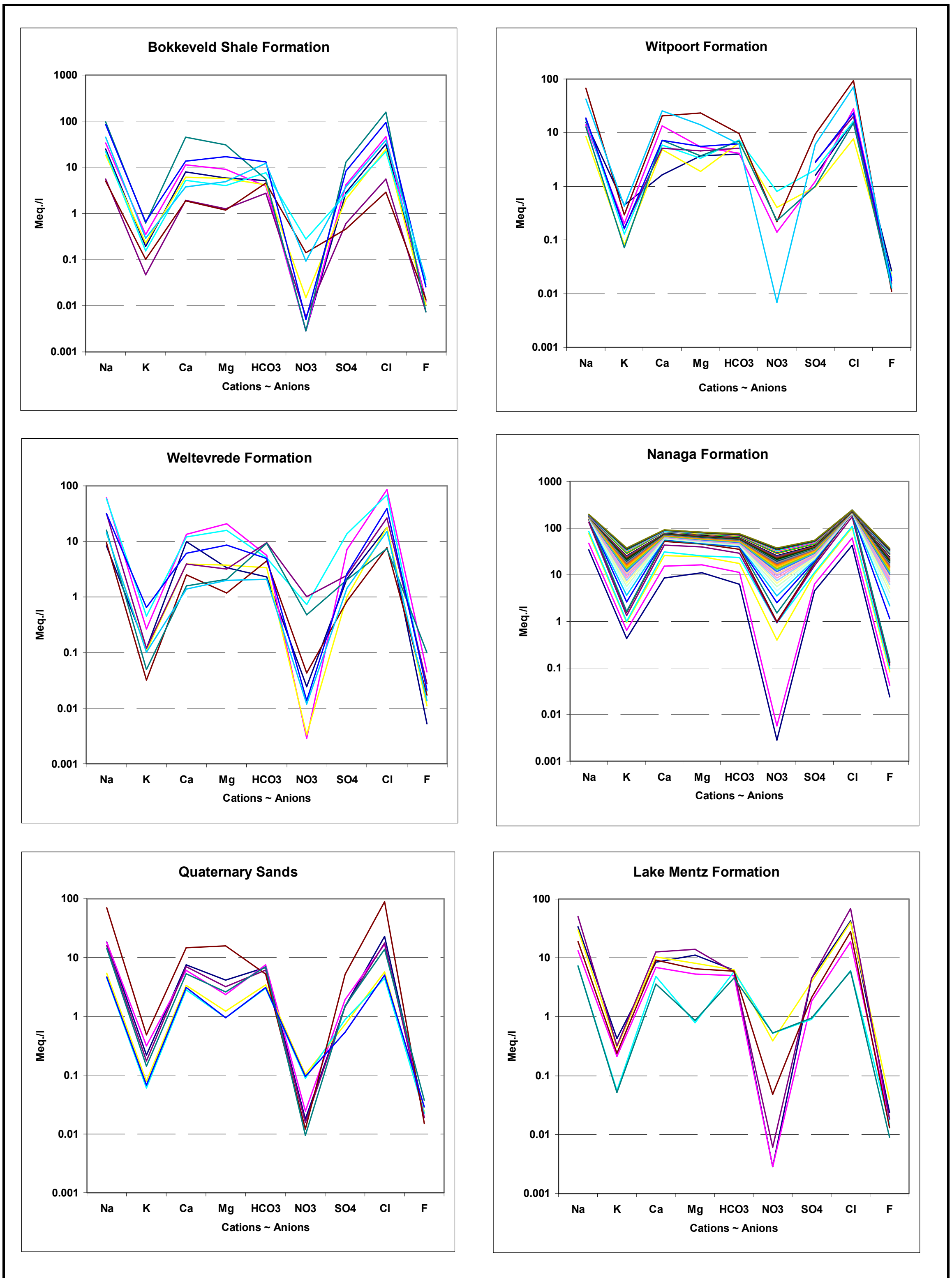


Figure 37: Schoeller Diagrams

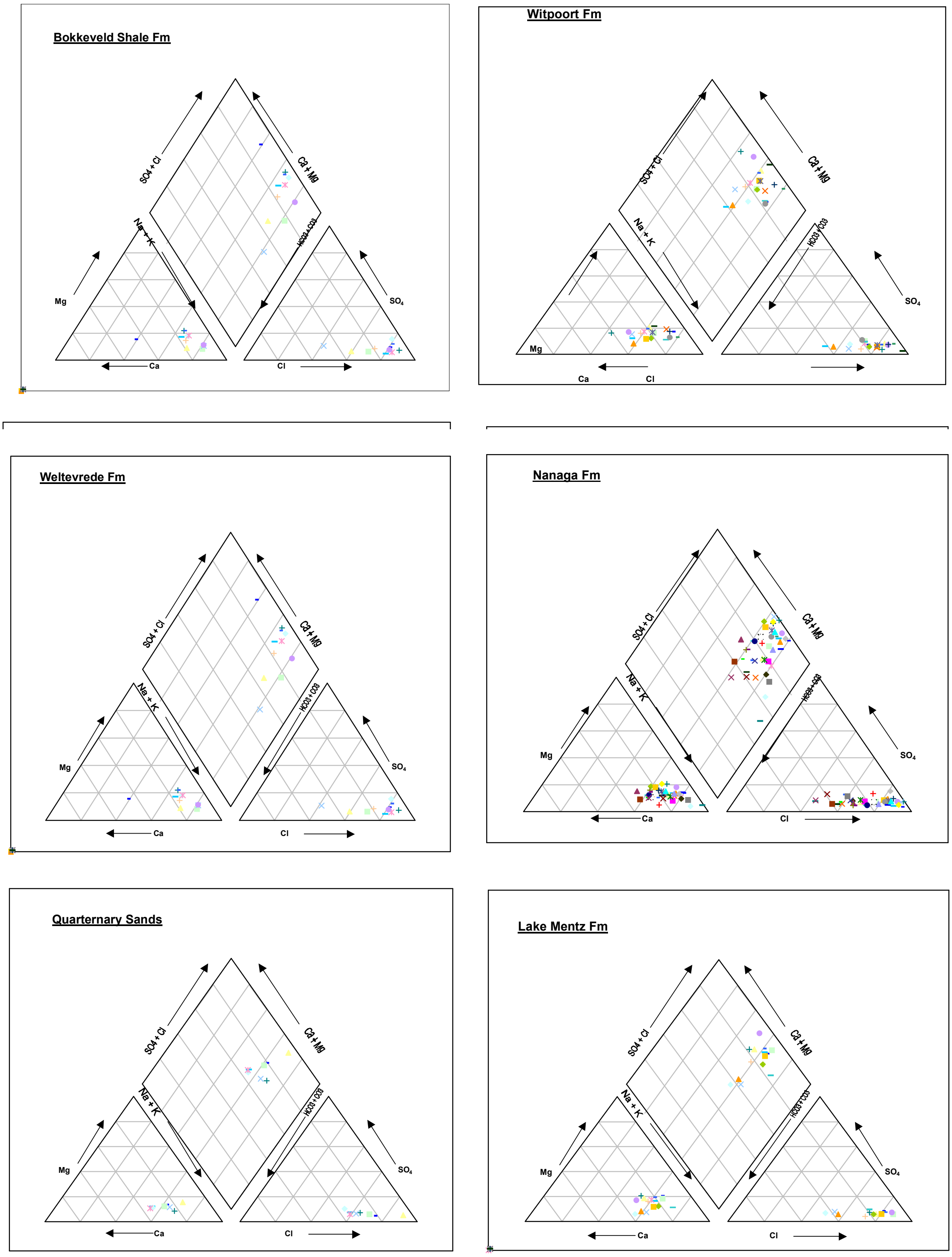


Figure 38: Piper Diagrams

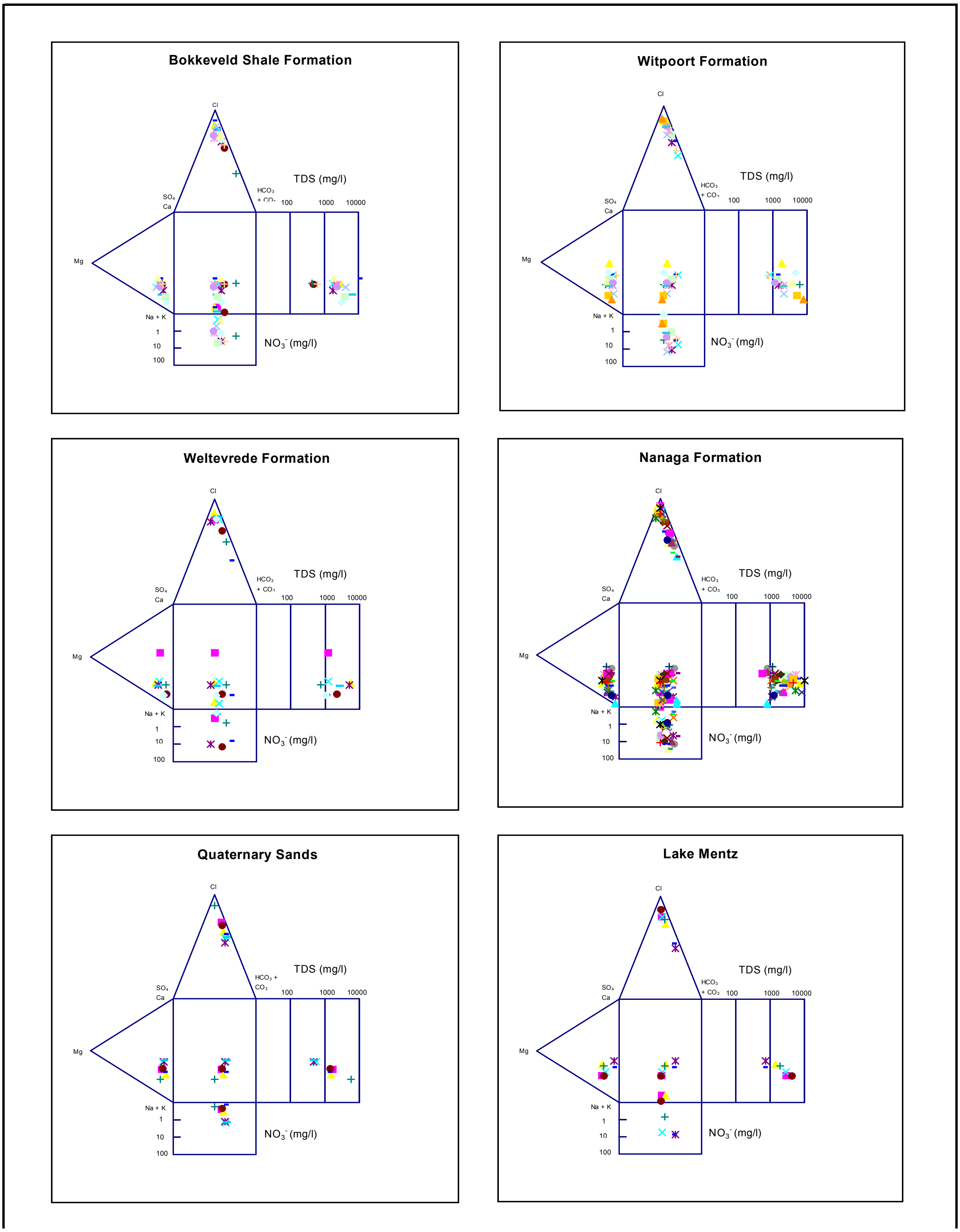


Figure 39: Durov Diagrams

The marine imprint on the groundwater in the study area is clearly indicated on all three hydrochemical representations i.e., Schoeller, Piper and Expanded Durov. The hydrochemical signatures of the various aquifer units are very similar and are suggestive of leakage from shales, which dominate the geology.

7.9 CONTAMINATION AND POLLUTION

For the purposes of this report, contamination is considered to be due to natural causes, whereas pollution refers to human influences. The following natural sources of contamination may affect the quality of groundwater:

- Groundwater/surface water interactions
- Natural leaching
- Saline intrusion
- Brackish water up-coning

These sources may be created and/or exacerbated by human activity.

Pollution occurs as a result of deleterious substances and waste products produced by humans adversely affecting aquifers. Some examples include:

- Discharge of substances into the earth by wastewater treatment plants and/or septic tanks.
- Unplanned release by sources designed to store, treat and/or dispose of substances. These may be landfills and waste disposal sites, illegal dumping, graveyards, materials stockpiles, storage tanks and storm water detention centres.
- Transport or transmission of substances, viz., pipelines and materials transport operations.
- Discharging of substances as a consequence of planned activities, viz., animal wastes, irrigation, fertilizer application, urban runoff and percolation of atmospheric pollutants.
- Inducing discharge by altered flow patterns or conduits, viz., boreholes and wells and construction excavation.
- Uncontrolled development hydraulically up-gradient of existing well fields and/or potential aquifers should be avoided as a matter of routine.

7.10 SEA WATER INTRUSION

Groundwater input to coastal waters has been shown to account for as much as 65 % of the total fresh water inflow (Campbell et. al., 1992). Alteration of this groundwater flow through abstraction can result in salt water intrusion into wells, which also affects the salinity status of the whole aquifer system, and ultimately the ecological stability of the area. Under natural conditions, salt water intrusion must be very rare.

The most important and immediately apparent source of contamination is that of saline water intrusion. Salt water has a higher density than fresh water, so salty water always occurs below fresh water. The salt wedge below and along coastlines prevents downward mixing of low salinity water, so that fresh groundwater discharges closer to the shore.

Saline intrusion occurs when coastal aquifers are in direct contact with the sea and when over pumping reverses the normal seaward flow of fresh water. The presence of a salt wedge has important implications since deepening wells for increased abstraction will increase the danger of intrusion of salt water. This is not a factor in Ndlambe as boreholes in the coastal aquifer are only drilled as deep as the Cape Supergroup contact.

Classical salt water intrusion from the south has been mentioned as the reason for the steady degradation in water quality of the Bushmans River and Dias Cross well fields over time. However, it is more likely, given the impermeable Bokkeveld 'basement' and the salinities of groundwater in the back dune area, that this degradation has an inland source. Long-term and comprehensive monitoring is required to resolve the issue unambiguously.

7.11 ACCESSIBILITY AND DRILLING

In general, accessibility is not a problem. However problems may arise in attempting to place a drilling rig on a known geological fault – the surface expression of which may be a steep, thickly, wooded ravine. Mobilizing drilling rigs onto modern sand dunes also poses problems, as light, 4 x 4 driven vehicles are required. Drilling in the Apies River, Kwaaihoek and/or Sunshine Coast Nature Reserves will have to be cleared with DEAT and SanParks. The latter have indicated, that in future, no new well fields may be developed in ground under their management or control. SanParks have agreed to allow maintenance drilling to repair or replace existing boreholes under strict conditions. This decision has effectively sterilized all untapped groundwater resources in the coastal zone west of the Bushmans River mouth.

Boreholes in the Witpoort aquifer should be cased throughout with uPVC casings and screens. This is necessary to stabilize the brittle formation and to prevent corrosion of metal casings by aggressive (acidic) groundwater.

Drilling in unconsolidated sand requires more advanced methods to penetrate without disrupting the aquifer. Despite its relatively high cost, mud rotary drilling, ODEX or Simcase is recommended.

Borehole construction is important and must take cognisance of unique aquifer characteristics.

Most of the drilling terrain in fractured aquifers will comprise private farmland, whereas drilling in the coastal aquifers will involve DEAT, SanParks and/or Nature Conservation.

8. OVERVIEW OF AQUIFER POTENTIAL

In broad terms, the physiological, geological and hydrogeological characteristics of the area have been described. These are based on existing borehole data, literature surveys, technical reports and local experience of the area. The ensuing sections provide an interpretation of this data to ensure effective development and exploitation of the groundwater resources.

8.1 HARVEST POTENTIAL

The quantification of the groundwater resources is probably one of the most difficult aspects to assess. Information on recharge to the groundwater systems, storage capacity of the groundwater systems, the hydraulic conductivity and thickness of these groundwater systems, the interaction with surface water and water quality is required. Once the groundwater resources are quantified a groundwater balance is established, comparing the resource with the existing use, to determine areas of over exploitation and identify areas that have a potential for further groundwater exploitation.

The Groundwater Harvest Potential (Seward and Seymour, 1996) was used as the basis for the evaluation. The Harvest Potential is defined as the maximum volume of groundwater that is available for abstraction without depleting the aquifer systems, and takes into account recharge, storage and drought periods. The minimum groundwater harvest potential along the coastal zone varies between 25 000 – 100 000 $m^3/a/Km^2$, depending on whether the underlying geology is comprised of fossil or modern dunes. Farther inland, harvest potential decreases sharply, to vary between a minimum of 10 000 – 15 000 $m^3/a/Km^2$, depending on whether the underlying geology is comprised of shale or quartzite. For the purpose of this study, the following estimates of harvest potential have been used and tabulated in Table 8 below.

Table 8 : Estimates of Minimum Harvest Potential

AQUIFER	Dimension Km^2	Harvest Potential $m^3/a/Km^2$	Supply Mm^3/a	Supply/Day M^3/day
UNCONSOLIDATED				
Schlemhoek Formation	39.17	100 000	3.92	10 700
SEMI-CONSOLIDATED				
Nanaga & Alexandria Fms	340.27	25 000	8.51	23 300
ARENACEOUS FRACTURED ROCKS				
Witpoort Formation	501.55	15 000	7.52	20 600
ARGILLACEOUS FRACTURED ROCK				
Bokkeveld, Lake Mentz, Weltevrede, Ecca, Dwyka Fm	1125.72	10 000	11.26	30 800
TOTAL	**2006.71**		**31.21**	**85 500**

It must be noted that the water resource volumes noted in Table 8 might not be economically exploitable due to water quality limitations, low yields, limited aquifer extent in outcrop areas, and land ownership issues:

- The argillaceous aquifers are generally of poor quality and low yielding, hence their exploitation potential is extremely limited.
- The semi-consolidated dunes can only be exploited where underlain by a permeable horizon, such as the Alexandria Formation. Consequently, a large fraction of this resource is not economically exploitable.
- The unconsolidated dunes can only be exploited where accessible, and where a sufficiently wide dune cordon exists to provide recharge and storage.
- Significant portions of the arenaceous Witpoort Formation are rugged and difficult to access due to adverse topography and the existence of Nature and Game Reserves. In addition, sufficient permeability is restricted to major fault zones.

Consequently, economically accessible groundwater reserves are restricted to portions of the unconsolidated modern dunes and the arenaceous Witpoort Formation.

8.2 EXPLOITATION POTENTIAL

It is generally not possible to abstract all the groundwater considered available in the Harvest Potential concept. This is mainly due to economic and/or environmental considerations. The main contributing factor is the hydraulic conductivity or transmissivity of the aquifer systems. As no regional information on transmissivity is available, borehole yield information was used, as there is a good relationship between borehole yield and transmissivity.

The groundwater resources were estimated using Harvest Potential data from WSAM (Table 9) in order to quantify exploitable groundwater resources. These Harvest Potential values are based on gridded median Harvest Potential values, accounting for rainfall variability and variations in geological exposure, hence are more spatially integrated than those in Table 8.

The Harvest Potential was reduced by an exploitation factor, determined from borehole yield data, to obtain an exploitation potential i.e. the portion of the Harvest Potential that can practically be exploited. Where average yields were above 1.5 ℓ/s, an exploitation factor of 0.6 was utilized, where average yield was 0.7-1.5 ℓ/s a factor of 0.5 was utilized, and where yield was 0.3-0.7 ℓ/s a factor of 0.4 was utilized.

This factor was multiplied by the Harvest Potential of each quaternary catchment to obtain the exploitation potential. The Exploitation Potential is considered to be a conservative estimate of the groundwater resources available for exploitation.

The interaction of the groundwater and the surface water was assessed by evaluating the base flow component of the surface water, or more specifically the contribution of the Harvest Potential to base flow. From this, the extent to which groundwater abstraction will reduce base flow component of the surface water was evaluated and the Exploitable Portion was calculated in order to avoid impacts on the Environmental Reserve.

Where the contribution of groundwater to the base flow component of the surface flow is zero the impact will be negligible. Where the contribution is less than 30 % of the base flow the impact will be low, where the contribution is between 30 % and 80 % of the base flow the impact will be moderate, and where the contribution to base flow is more than 80 % the impact will be high.

Existing groundwater use was also estimated and the balance of the Exploitation Potential was calculated. The portion of the groundwater resources considered potable (Class 0, I and II) was utilized to account for the portion of Exploitation Potential that cannot be utilized for water supply due to poor quality in order to determine maximum utilisable groundwater resources (Table 9).

The Exploitation Potential is 19.7 Mm^3/a, however, it is estimated that the maximum utilisable groundwater is 7.3 Mm^3/a due to the prevalence of poor water quality. Current use is approximately 20 % of these utilisable resources.

Quat Catch	A Km^2	Harvest Pot m^3/Km^2/a	Harvest Potential x10^6 m^3/a	Ave yield Bh's ℓ/s, 8hrs/d	Expl Factor	Exploitation Potential x10^6 m^3/a	Total Use x10^6 m^3/a	Contribution to Base flow (10^6 m^3/a	Gwater only portion (10^6 m^3/a	Exploitable Portion x10^6 m^3/a	Balance Harvest Potential x10^6 m^3/a	Balance Exploitation Potential x10^6 m^3/a	Use % Exp. Pot	Portion Potable	Max Utilize Gwater x10^6 m^3/a
P10G	256	15116	3.87	1.40	0.5	1.93	0.0822	0.00	3.87	1.93	3.79	1.85	4.25	0.00	0.00
P20A	270	35206	9.51	1.17	0.5	4.75	0.4954	0.06	9.45	4.72	9.01	4.26	10.49	0.39	1.87
P30B	195	12700	2.48	0.88	0.5	1.24	0.0532	0.00	2.48	1.24	2.42	1.19	4.30	0.13	0.15
P30C	68	29229	1.99	1.02	0.5	0.99	0.0163	0.00	1.99	0.99	1.97	0.98	1.64	0.50	0.50
P40A	51	12700	0.65	0.59	0.4	0.26	0.0406	0.12	0.53	0.21	0.61	0.22	19.33	0.30	0.08
P40B	257	12700	3.26	0.90	0.5	1.63	0.0623	0.00	3.26	1.63	3.20	1.57	3.82	0.70	1.14
P40C	342	38324	13.11	0.69	0.4	5.24	0.4118	0.03	13.08	5.23	12.69	4.83	7.87	0.39	2.04
P40D	246	12779	3.14	1.76	0.6	1.89	0.2038	0.03	3.12	1.87	2.94	1.68	10.90	0.33	0.63
Q93D	321	11842	3.80	1.09	0.5	1.90	0.0825	0.00	3.80	1.90	3.72	1.82	4.34	0.47	0.89
TOTAL	**2006**		**41.80**			**19.84**	**1.45**	**0.24**	**41.56**	**19.73**	**40.35**	**18.39**			**7.31**

Table 9: Groundwater Resources of Ndlambe by Quaternary Catchment

8.3 RECHARGE

To confirm the Exploitation Potential of individual geological formations, recharge was estimated. Recharge is the portion of rainfall that contributes directly to aquifer replenishment on an annual basis. A figure of 2 % has generally been regarded as a conservative estimate for ancient fractured aquifers, however, recharge to quartzites of the Cape Supergroup has been estimated at 15 – 25 %. These estimates are primarily derived from regions with winter rainfall, hence are probably an overestimate for the Witpoort quartzites. Consequently, a recharge value of 5 % has been tentatively used.

According to Reynders (1987), recharge to the coastal sands can be as high as 30 %. Sami (2004) calculated recharge of over 35 % based on steady state flow conditions at the Bushmans River Mouth and Dias Cross dune well fields. Recharge into the fossil dunes of the Nanaga Formation was estimated by Sami (2004) at around 3.6 % of MAP based on hydraulic gradients and permeabilities of the back dune areas. An estimate of groundwater recharge is given in Table 10.

AQUIFER	Dimension Km^2	Recharge % @ 640 mm MAP	Supply/Annum Mm^3/a
UNCONSOLIDATED			
Schlemhoek Formation	39.17	35	8.77
SEMI-CONSOLIDATED			
Nanaga & Alexandria Formations	340.27	3.6	7.84
ARENACOUES FRACTURED ROCK			
Witpoort Formation	501.55	5	16.05
ARGILLACEOUS FRACTURED ROCK			
Bokkeveld, Lake Mentz, Weltevrede, Ecca, Dwyka	1125.72	2	14.41
TOTAL			**47.06**

The estimates of recharge are slightly higher than Harvest Potential as the latter is based on drought rainfall. Recharge must also be reduced by an exploitation factor to determine Exploitation Potential.

8.4 AQUIFER UNITS AND UTILISABLE GROUNDWATER

An attempt has been made to subdivide the broad aquifer units into discrete aquifers or well fields (Table 11) where these are within economic distance to towns and communities.

Estimated aquifer storage was calculated by multiplying the area of outcrop by aquifer thickness and storativity. Aquifer thickness was determined from the difference in the median values of water strike and static water level for each aquifer.

Exploitation Potential was calculated as the exploitable fraction of recharge using exploitation factors in a similar manner to Table 9. Exploitation Potential therefore only considers recharge and aquifer permeability. For the Witpoort aquifer, potential recharge is higher than the storage potential, hence a fraction of recharge is lost as base flow, discharge to springs, and evapo-transpiration. In addition, during years of less than average recharge, storage limits exploitation potential. For this reason, Exploitation Potential was calculated as the product of the exploitation factor and storage.

Maximum utilisable groundwater resources were calculated by multiplying recharge or storage capacity, which ever is least, by the fraction of boreholes yielding more than 2 ℓ/s and the fraction of boreholes of water quality Class 0 and I (Exp. Factor * Class I), and the fraction of boreholes of Class II (Exp. Factor * Class II). These data attempt to exclude poor quality water and potential low yielding portions of aquifers that cannot be economically exploited.

For the intergranular coastal dune aquifer, the exploitation factor was also multiplied by the fraction of the area where the dune cordon is sufficiently wide to exploit (71 %).

Table 11 : Utilisable Groundwater Resources by Aquifer

Lithology	Area (Km^2)	Aquifer thickness (m)	Storativity	Storage (Mm^3)	Recharge (%)	Recharge (Mm^3/a)	Exploitation Factor	Exploitation Potential	Exp. Factor * Class 1	Util. Resources (Mm^3/a)	Exp. Factor* Class 2	Util. Resources (Mm^3/a)
Witpoort Fm Western Belt	190.47	30	0.001	5.71	5%	6.10	0.50	2.86	0.080	0.46	0.170	0.97
Witpoort Fm Central Belt	59.22	30	0.001	1.78	5%	1.90	0.50	0.89	0.080	0.14	0.170	0.30
Witpoort Fm Eastern Belt	251.77	30	0.001	7.55	5%	8.06	0.50	3.78	0.080	0.60	0.170	1.28
Weltevrede Formation	660.97	25	0.005	82.62	2%	8.46	0.30	2.54	0.033	0.28	0.075	0.63
Bokkeveld Group	222.7	20	0.005	22.27	2%	2.85	0.20	0.57	0.000	0.00	0.000	0.00
Lake Mentz Formation	220.33	30	0.005	33.05	2%	2.82	0.30	0.85	0.027	0.08	0.044	0.12
Nanaga & Alexandria Formations	340.27	25	0.01	85.07	4%	7.84	0.30	2.35	0.033	0.26	0.127	1.00
Karoo Super Group	21.72	20	0.005	2.17	2%	0.28	0.30	0.08	0.020	0.01	0.075	0.02
Schlemhoek Formation	39.17	5	0.1	19.59	35%	8.77	0.65	5.70	0.090	0.79	0.360	3.16
TOTAL	**2006.62**			**259.81**		**47.07**		**19.61**		**2.61**		**7.49**

Groundwater resources are approximately 7.5 Mm^3/a, of which 1.45 Mm^3/a is already being exploited, primarily from the coastal intergranular and Witpoort fractured aquifers. Over 42 % are found in the coastal dune belt. A total of 2.55 Mm^3/a can be exploited from the Witpoort aquifers. Portions of the Witpoort western and eastern belts are also too far removed from population centres, hence will not be economically exploitable. Other portions are either difficult to access or occupied by National Parks and/or private game reserves. To take into account these factors, exploitable resources in the Witpoort would have to be reduced by as much as 50 % Mm^3/a.

8.5 LOCAL AREAS OF HIGH GROUNDWATER POTENTIAL

Areas of high groundwater potential occur throughout Ndlambe and their occurrences are given on Map 6. The description pertaining to each area gives generalisations of expected conditions such as expected yield, drilling success and anticipated water chemistry. These should be used for planning purposes only.

8.5.1 Witpoort Fractured Aquifers

With respect to the Witpoort fractured aquifer, areas of high groundwater potential shall be discussed for each of the three main areas of outcrop: the western, central and eastern belts. Targets for exploitation in these belts are restricted to major fault zones. Thirty percent of scientifically–sited boreholes drilled are expected to yield between 5 and 10 ℓ/s of Class I or Class II quality groundwater. Poorer quality water is expected where marine shales bound faults. The main water strikes can be expected as deep as 70 m bgl. Since fracture zones are tectonic in origin, fracturing at depth is expected and boreholes can be drilled to 150 m to increase yield and the available draw down of boreholes. However, it must be noted that deep-water strikes are only high yielding due to the effect of the hydraulic pressure head as the fracture For the intergranular coastal dune aquifer, the exploitation factor was also multiplied by the fraction of the area where the dune cordon is sufficiently wide to exploit (71 %).

are generally low. As a result, deep-water strikes generally incur high draw downs when pumped at high rates, resulting in high pumping costs. Large available draw downs are required to accommodate the high-expected draw downs arising from low fracture permeabilities.

Deep fracture zones also contain water in a reduced geochemical environment, hence when these fracture zones are exposed to oxidation resulting from draw down, iron bacteria clogging results due to the iron-rich matrix of the quartzites.

No reliable pump testing data is available to determine potential sustainable yields from boreholes, however, it can be assumed that yields could be 30 – 50 % of blow yields. Based on assumed exploitation potential of 2.55 Mm^3/a, 50 % of which can be accessed economically, a yield of 40 ℓ/s would be achieved, which would require blow yields of 133 ℓ/s.

Target regions consist of brittle fracture zones associated with major south-southeast and east-northeast trending fault structures. These have not been thoroughly documented as yet. Figure 40 shows the orientation and length of identified lineaments. Long regional lineaments appear to be oriented north-northeast and east-northeast.

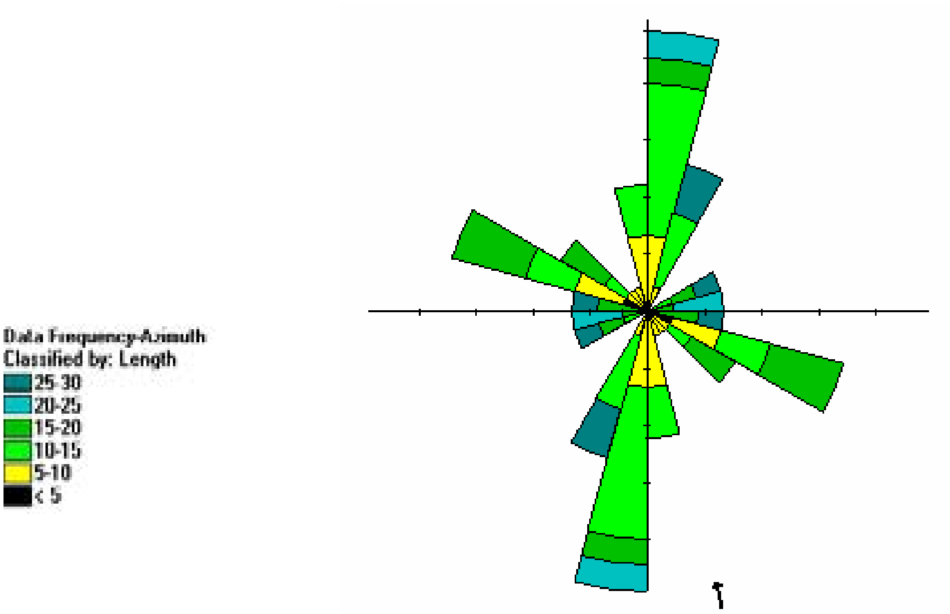


Figure 40 : Classified Rose Diagram of Lineaments According to Length (Km)

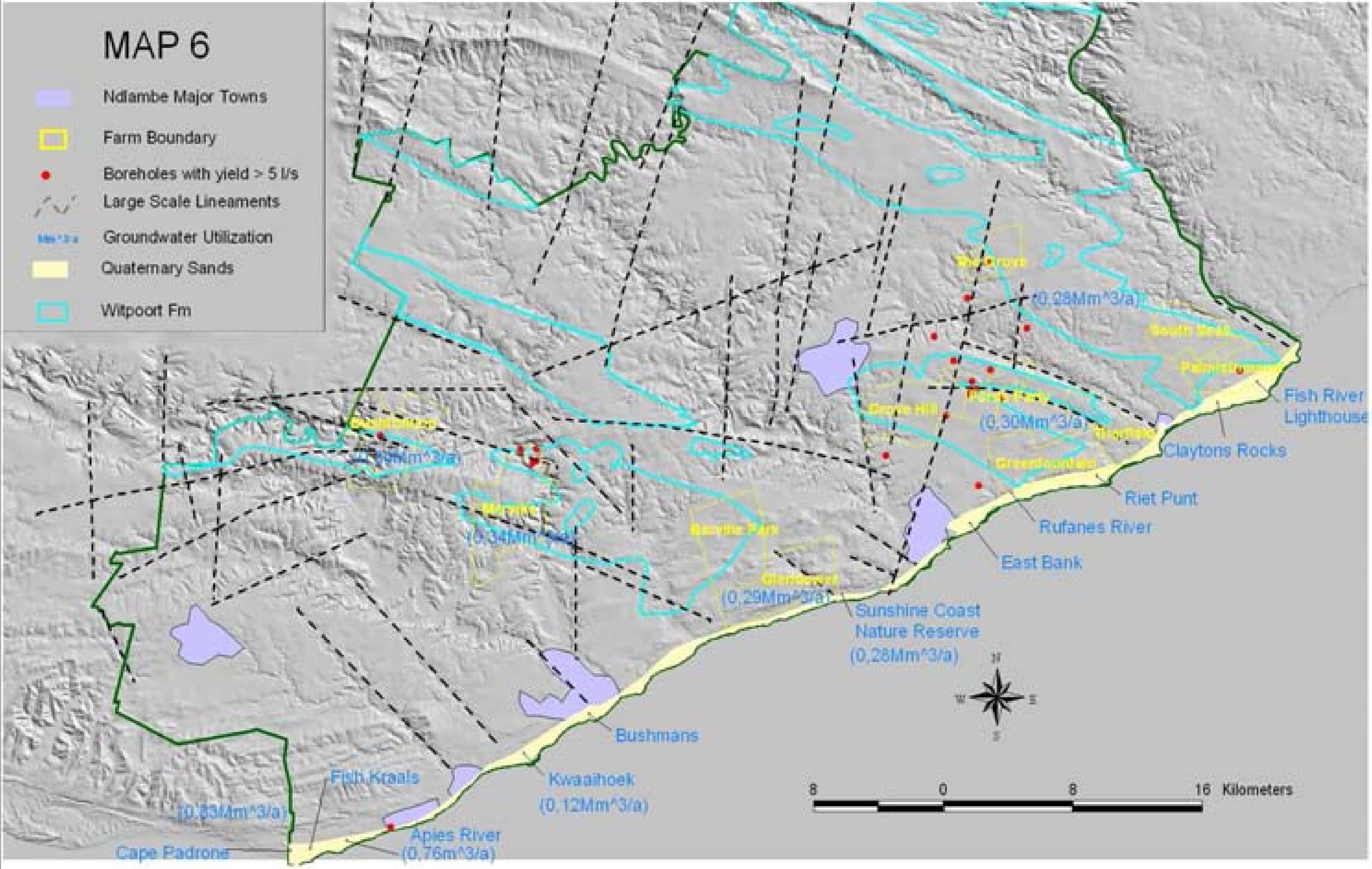
Western Belt: Up to 1 Mm^3/a could be exploited from this belt, however a significant portion may occur too far away from population centres to be economically viable. This belt corresponds to the area of greatest need and fortuitously arcs behind Kenton-on-Sea/Bushmans River and ultimately, behind Alexandria.

Obvious targets in the western belt are found in and around the farms Bushfontein, Merville, Barville Park and Glendower. Groundwater (and spring water) resources have been proven on Merville, which could be utilized to augment the bulk supply of Bushmans/Kenton. DWAF drilled exploration boreholes on Merville with very encouraging results viz., a 100 % success rate with 4 boreholes having an average blow yield of ~ 9 ℓ/s. These boreholes alone could provide 900 m^3/d, or 0.34 Mm^3/a.

The gorge on Bushfontein has many of the salient characteristics of Merville (i.e., lithology, structure, topography etc.) with obvious groundwater potential. Bushfontein is equidistant (~ 15 Km) from Alexandria, Boknes/Cannon Rocks and Bushmans/Kenton. Bushfontein has also been mooted as a potential dam site by DWAF. Potentially, another 900 m^3/d, or 0.34 Mm^3/a could be obtained from this target.

The recharge potential at Glendower is particularly attractive as blind rivers bring surface runoff into the back of fossil dunes, which in turn overlie the Witpoort aquifer. Here geophysics would be required to site boreholes with confidence. Glendower is 5 Km west of Port Alfred and immediately inland of the Sunshine Coast Nature Reserve coastal aquifer. Potentially another 0.32 Mm^3/a could be abstracted from this target.

Central Belt: Conveniently, this belt arcs behind Port Alfred and terminates at Bathurst. A large southeast trending thrust bisects the northern portion of this belt and this portion coincides with a cluster of high yielding boreholes. Farms in and around Grove Hill, Fords Party and Tharfield are obvious targets for groundwater for the Bathurst, Port Alfred and Seafield/Kleinemonde communities respectively. Potentially 0.3 Mm^3/a could be exploited from this belt.



NDLAMBE: AREAS OF HIGH GROUNDWATER POTENTIAL (CLASS I/II)

Eastern Belt: This belt outcrops neat the fish River Lighthouse and trends towards Grahamstown and beyond. Up to 1.28 Mm^3/a could be exploited. Potential groundwater targets occur in and around the farms Palmietheuval, Southseas and The Grove, where up to 1.28 Mm^3/a could be exploited The Seafield/Kleinemonde community would benefit from boreholes drilled on these farms. DWAF drilled three boreholes behind the Fish River lighthouse with moderate success.

8.5.2 Lake Mentz, Weltevrede and Bokkeveld aquifers

The Bokkeveld, Weltevrede or Lake Mentz Formations cannot be economically exploited as they generally possess a low to moderate potential and are mostly saline with respect to water quality. Up to 0.75 Mm^3/a can be exploited if sufficiently high yielding fault structures are present in sandstone beds.

These formations may serve to supply local homesteads, stock watering and small local supplies schemes.

8.5.3 Intergranular Aquifers

With respect to the intergranular coastal aquifers, areas of high potential will be discussed from west to east. Approximately 75 % of boreholes drilled are expected to yield 2 ℓ/s of Class I and Class II quality groundwater. The main strikes can vary between 5 and 10 m bgl with a maximum borehole depth of ~ 20 m.

The exploitation potential of the dune intergranular aquifers was calculated separately for zones where the dune cordon is sufficiently wide to exploit economically (Table 12). These aquifers are composite in nature and are recharged by direct recharge into the coastal dunes and lateral inflow from the back dune area. Recharge to these aquifers was assumed to be 35 % of rainfall for the area coastal dunes, and 3.6 % for the back dune area (Table 10). The exploitation factor utilized was 0.54, based on borehole yields of 1.5 – 3 ℓ/s and 90 % of boreholes having a water quality of Class II or better. For Cape Padrone and Apies River the exploitation factor was reduced to 0.3 since it is unlikely the large areas involved can be fully exploited.

Table 12 : Groundwater Availability in Dune Aquifer Systems

Well field / Aquifer	Area Km²		Storage Capacity Mm³	Recharge	Utilisable Groundwater		Current Status	Priority Status
	Dunes	Back Dune		Mm³/a	Factor	Mm³/a		
Cape Padrone - Fish kraals	11	13	12.00	2.76	0.30	0.83	Under Developed. ± 50% spare capacity	High Priority. Supply to Alex & Can Rocks
Apies River	9.7	15.3	6.25	2.53	0.30	0.76	Under Developed. ± 80% spare capacity	High Priority. Supply to Can Rocks/Boknes
Dias Cross	1.08	7	4.00	0.40	0.54	0.22	Fully Developed	High Priority. Supply to BRM/KOS
Kwaaihoek	0.52	4.5	2.5	0.22	0.54	0.12	Undeveloped. 100% spare capacity	High Priority. Augment Dias Cross supply
Sunshine Coast Nature Reserve	1.3	10.2	3.0	0.53	0.54	0.28	Undeveloped. 100% spare capacity	High Priority. Supply for Port Alfred.
Bushmans River Mouth	0.42	1.2	0.81	0.12	0.54	0.07	Fully developed	Water supply to ACWB
Port Alfred East Bank	0.8	1.76	1.28	0.22	0.54	0.12	Limited Spare Capacity	Low Potential
Rufanes River	0.8	1.65	0.61	0.22	0.54	0.12	Undeveloped	Moderate Potential
Riet River	0.8	1.3	0.52	0.21	0.54	0.11	Undeveloped	Moderate Potential
Claytons Rocks	0.8	0.95	0.43	0.20	0.54	0.11	Undeveloped	Moderate Potential
Fish River Lighthouse	0.8	1.15	0.49	0.21	0.54	0.11	Undeveloped	Moderate Potential
TOTAL	**28**	**58**	**31.89**	**7.61**		**2.84**		

The aquifers at Cape Padrone, Fishkraals, Kwaaihoek and Apies River are largely in the control of SanParks, who do not sanction further exploitation.

Pump testing data suggests the aquifers are leaky, with a thin transmissive basal conglomerate overlain by fine sands. Optimum pumping schedules would require long duration pumping at low rates due to the limited available draw down.

Apies River: Serious consideration should be given to developing the Apies River aquifer, immediately west of Cannon Rocks. Favourable recharge conditions suggest a groundwater Harvest Potential of around 2 000 m³/day. This assumption is based on the thick occurrence of both fossil and recent dunes, a wide dune cordon of around 1 000 m, generous orographic recharge (MAP = 788 mm) and flushing received from the Apies

River. As this area forms part of the Addo National Park, any bush clearing and access roads will first have to be cleared with DEAT and SanParks.

The resources at Apies River are sufficient to meet the current peak demand of the combined Boknes/Cannon Rocks communities.

Alternative options are to approach the landowner of the farm Boschhoek (Mr. Christo Potgieter) regarding the use of his borehole to the benefit of the Boknes/Cannon Rocks community. This borehole, licensed for 70 200 m³/annum and would be able to provide Class II water at a rate of 2.5 ℓ/s over a 24-hour pump cycle. This augmentation would also serve to upgrade the existing poor quality of water by blending with higher quality water.

Kwaaihoek: The modern dune aquifer (800 m east of Dias Cross) has moderate groundwater development potential and should be considered to augment the Dias Cross well field. Approximately 6 wide diameter boreholes, each estimated at 14 m deep, would be sufficient to supply an additional 300 m^3/d of Class II quality water towards the bulk supply of ACWB. Water from this source could conveniently utilise the existing pipeline, which passes directly behind this aquifer. Developing this well field could resolve the peak demand crisis often experienced by the Bushmans/Kenton communities over holiday periods. This well field can be pumped below capacity on a rotational basis with the Dias Cross well field.

Both DEAT and SanParks need to be informed of the urgency to develop this aquifer.

Sunshine Coast Nature Reserve: This aquifer west of Port Alfred, coincides with the eastern portion of the Sunshine Coast Nature Reserve, has a high groundwater development potential. A well field developed in these coastal sands could provide 750-1000 m³/d for the western suburbs of Port Alfred. This water could be utilized to cope with the peak demand. Alternatively, this water could be judiciously blended with the bulk supply from the Sarel Hayward dam, on a continual basis, to upgrade the existing poor quality water endured by the residents of Port Alfred.

This aquifer is served by a pristine catchment area and also has a blind river focusing recharge into the back dune area, enhancing the sustainability of the resource. This aquifer has much in common with the Apies River aquifer.

DEAT should be informed of the need to develop this aquifer.

Rufanes River: Consideration should also be given to augment the East Bank well field with a new well field developed on the west bank of the Rufanes River. This area is undeveloped, has a broad dune cordon and is periodically recharged by the Rufanes River, which introduces runoff into the back-dune area.

Riet River: Here, a broad dune cordon is developed on a plunging anticline of Witpoort quartzites, at Riet Punt, immediately west of Riet River. Although some distance from Port Alfred, this source can deliver potable water to the local residents, if required.

Clayton's Rocks: The ongoing development and expansions at Seafield/ Kleinemonde has resulted in water shortages that will be compounded in the future. An option is to develop the modern dune cordon, located immediately behind Clayton's Rocks in preference to the current coastal borehole, which supplies poor quality water to a small portion of the community.

Fish River Lighthouse: At this locality, a broader zone of fossil dunes, hydraulically up-gradient, complements a broad expanse of modern dunes, thus providing additional significant storage potential to the latter aquifer. This option should be investigated further as the Kleinemonde community requires additional water to cope with peak demand.

8.5.4 Anticipated Hydrogeological Conditions and Costs

Anticipated hydrogeological drilling conditions and costs are presented in Tables 13 and 14 respectively.

Table 13 : Anticipated Hydrogeological Conditions

Locality Farm/Area	Tot. Yield (12 hours) (kℓ/day)	Yield per borehole (ℓ/s)	No. of bh's	Average drill depth (m bgl)	Metres drilled	Cost per (m)	Av. Dynamic Water Level (m)	Drill Success Rate (%)	Assumptions/Remarks
HIGH POTENTIAL: FRACTURED									
Harvestvale/Bushfontein	800	7.5	10	150	1 500	400	30	50	Boreholes near artesian.
Merville	800	4	10	150	1 500	400	35	50	Boreholes near artesian, excludes contribution from spring.
Barville/Glendower	1 000	5	12	180	2 160	400	50	35	Witpoort fractured will receive vertical leakage from the overlying, intergranular Nanaga aquifer.
Tharfield/Greenfountain	1 000	4	12	150	1800	400	40	30	
Fords Party	1 000	4	12	150	1 800	400	40	30	
South Seas/Palmietheuval	800	3	12	150	1 800	400	40	30	
The Grove	800	5	10	150	1 500	400	35	50	Has potential but fairly remote.
HIGH POTENTIAL: INTERGRANULAR									
Cape Padrone/Fish Kraals	1 100	2	15	12	180	1 200	8	60	Excludes current abstraction (~ 19ℓ/s)
Apies River	2 000	3	20	20	400	1 200	10	70	Blind river feeding dune cordon
Kwaaihoek	300	2	5	12	60	1 200	8	60	Satellite well field to Dias Cross
Sunshine Coast Nature Reserve	750	2	12	20	240	1 200	10	70	Blind river feeding dune cordon
TOTAL (kℓ/day)	**9 350**	**37.5**			**11 140**				

Table 14 : Anticipated Borehole Costs

Locality Farm/Area	Scoping/ EIA	Water Licences	Hydrogeo Study	Test Pumping	Sub Total	Contingencies	VAT	TOTAL	Cost/m³/d	URV/m³/d
HIGH POTENTIAL: FRACTURED										
Harvestvale/Bushfontein	45 000	35 000	25 000	100 000	805 000	80 500	123 970	885 500	1 106.88	0.28
Merville	35 000	25 000	17 500	100 000	777 500	77 750	119 735	855 250	1 069.06	0.27
Barville/Glendower	35 000	25 000	17 500	120 000	1 061 500	106 150	163 471	1 167 650	1 167.65	0.30
Tharfield/Greenfountain	35 000	20 000	17 500	120 000	1 070 000	107 000	164 780	1 341 780	1 341.78	0.34
Fords Party	30 000	20 000	17 500	120 000	907 500	90 750	139 755	998 250	998.25	0.26
South Seas/Palmietheuval	30 000	20 000	17 500	120 000	907 500	90 750	139 755	998 250	1 247.81	0.32
The Grove	25 000	17 500	17 500	100 000	760 000	76 000	117 040	836 000	1 045.00	0.27
HIGH POTENTIAL: INTERGRANULAR										
Cape Padrone/Fish Kraals	45 000	35 000	25 000	150 000	471 000	47 100	72 534	518 100	471.00	0.12
Apies River	45 000	35 000	25 000	200 000	785 000	78 500	120 890	863 500	431.75	0.11
Kwaaihoek	30 000	15 000	17 500	50 000	184 500	18 450	28 413	202 950	676.50	0.17
Sunshine Coast Nature Reserve	45 000	35 000	25 000	120 000	513 000	51 300	79 002	564 300	752.40	0.19
TOTAL (kℓ/day)	**400 000**	**282 500**	**222 500**	**1 300 000**	**7 172 500**	**7 818 100**	**1 269 345**	**9 231 530**	**987.33**	**0.22**

Drilling costs include assumed mobilization, site setup, PVC casing and screens, gravel packs etc.
Site supervision is included in drilling and test costs
URV's are based on 25 year design life and 0.08 discount rate. They include borehole establishment only.

9. CONCLUSIONS

A number of coastal and inland towns situated within the coastal belt of the study area experience serious periodic water supply problems, mainly because of inadequate sources, poor water quality and insufficient capacity of their bulk supply infrastructure.

There is a general lack of understanding of groundwater resources and a lack of capacity and funding to perform basic maintenance and monitoring.

Around 45 % of the population is reliant on groundwater schemes as a source for bulk supply. This is particularly prevalent in the western portion of Ndlambe, which has a thicker succession of fossil and modern dunes, allowing exploitation of primary (porous) aquifers.

The study has identified the potential of several regional aquifers to supplement existing water supply, and has identified several localities that can be targeted for more detailed groundwater investigation.

Conclusions pertaining to the hydrogeological potential of Ndlambe are as follows:

9.1 COASTAL AQUIFERS

- Exploitation of the fossil (Alexandria and Nanaga) and modern (Schelmhoek) coastal aquifers has application in the Ndlambe context. Both these primary aquifers are capable of storing and releasing significant volumes of water. These aquifers are invariably in contact with one another, with the latter occurring down the hydraulic gradient and receiving groundwater from the former. Their optimal development coincides with large, present-day catchments superimposed over ancient channels.
- Intergranular aquifers are best developed along the coast where thicker deposits of Alexandria, Nanaga and Schelmhoek Formation have been preserved. The contact between these rocks and the underlying 'basement' is an obvious target. The permeable Nanaga Formation also plays a significant role in storing significant volumes of groundwater, where leakage occurs to the lower aquifer. The aquifers are

currently exploited at Cape Padrone, Fishkraals, Dias Cross, Bushmans River Mouth and Port Alfred, East Bank.

- Potential target areas where a thick and wide succession of these deposits exist have been identified at Cape Padrone/Fishkraals, Apies River, Sunshine Coast Nature Reserve, Kwaaihoek, Rufanes River, Riet River, Clayton's Rocks and Fish River Lighthouse.
- The potential groundwater resources of these coastal aquifers is 2.84 Mm^3/a.
- The Apies River, Kwaaihoek and the Sunshine Coast Nature Reserve coastal aquifers represent the most attractive to develop due to potential large water resources of suitable quality in the vicinity of population centres. The preferred method of abstraction is from shallow (generally < 15 m) boreholes or caissons. These potential well fields would benefit the Boknes/Cannon Rocks, Bushmans/Kenton and the Port Alfred communities respectively.
- Coastal aquifers are vulnerable to degradation through over pumping and drought conditions – a situation currently affecting Ndlambe and the ACWB in particular.
- Severe draw down causes localized flow gradients, inducing brack water in the back-dune area to surge into the well field. Under certain conditions, sea water is capable of intruding from the south to infiltrate the well field.

9.2 FRACTURED AQUIFERS

- Competent rocks, especially quartzites of the Witpoort Formation underwent brittle failure during the Cape Orogeny and during the break-up of Gondwanaland, resulting in numerous faults, fractures and joints, thus creating secondary fracture porosity. Many of these structures are tensional in nature, hence are potentially high yielding groundwater targets.
- The Witpoort Formation is a potential aquifer due to its proximity to population centres. Conveniently, the Witpoort aquifer arcs behind Bushmans/Kenton, Port Alfred and Seafield/Kleinemonde as three discrete belts.

- The median yield of the Witpoort aquifer is less than 0.5 ℓ/s, unless regional structures are targeted. Recent drilling suggests a moderate to high groundwater potential on fault structures. Drilling on the farm Merville has provided significant yields of 5.0; 3.3, 20.0 and 7.0 ℓ/s of Class I and II quality water – confirming the attractiveness of the aquifer. These boreholes have not, as yet, been subjected to long duration test pumping. The two high yielding boreholes are artesian. Similar structures are located elsewhere in the Witpoort Formation.

- Sustainable groundwater resources of the Witpoort aquifer are approximately 2.5 Mm^3/a.

- South-southeast and east-northeast trending structures form the most suitable drilling target for high yielding boreholes. These can be detected using a combination of Landsat imagery and aerial photography.

- Incompetent rocks (i.e., shale's) are more flexible and less inclined to break, thereby inhibiting fracture porosity. As a possible groundwater resource, the Bokkeveld, Weltevrede and Lake Mentz aquifers generally have a low groundwater potential. Low median yields and the paucity of brittle deformations structures result in few obvious groundwater targets. In addition, water quality is generally poor. Some high yielding boreholes in the Lake Mentz Formation may be related to the underlying Witpoort Formation.

10. RECOMMENDATIONS

A sustainable solution to the perennial bulk water supply problems of Ndlambe needs to be sought as a matter of urgency. The interruptions to supply and poor water quality (often Class II or Marginal) endured by the residents have become an emotive issue. An erosion of business and/or investment confidence (particularly as a retirement location or tourist destination) has been forecast should the situation not improve. The popularity of the area and the upgrading of infrastructure to RDP standards will place additional demands on the suppliers of bulk water.

The following recommendations are made based on the findings and evaluation of the available data and an understanding of the demographics, hydrogeology and economic potential of the region.

- Although the NGDB lists 755 boreholes in Ndlambe, it is estimated that at least half the actual boreholes drilled and/or utilized are not reflected in the NGDB. It is recommended to conduct a thorough hydrocensus over he entire local municipality to confirm borehole densities and actual usage.
- Community and private boreholes make up an important contribution (~ 45 %) to the supply of bulk water in Ndlambe. Boreholes, as much as possible, should not be used in isolation as a source of bulk supply. Rather, they should be used in conjunction with surface water, desalinated water (via reverse osmosis) and/or recycled water to spread the load on the various resources. Water from diverse sources will allow an element of proactive management to reduce risk and to achieve the right cost and quality profiles through judicious blending.
- The Witpoort aquifer has much in common with the heavily exploited Table Mountain Group aquifer in the southern Cape region, however, it is relatively unexploited within Ndlambe. The Bushmans/Kenton communities can benefit from this aquifer, however, the extent of resources remains unproven.
- Target areas within the Witpoort need additional remote sensing to confirm anomalies ahead of ground-truthing properties for the scoping/EIA process.
- The boreholes drilled into the Witpoort by DWAF on Merville should be test pumped and equipped. Groundwater could then be piped 20 Km into the ACWB's storage reservoirs at Ekuphumleni.
- DWAF could extend their drilling programme to test the high groundwater potential in and around the following farms locate on the Witpoort aquifer. Western belt: Bushfontein, Barville Park and Glendower. Central belt: farms corresponding to Grove Hill, Fords Party and Tharfield. Eastern belt: Palmietheuval, Southseas and The Grove. Successful boreholes in these belts would be to the benefit of all towns within the affected area. Mapping and geophysical surveys should precede drilling to increase success rates.

- Geophyisical surveys, utilising the electrical ('Res') and electro-magnetic ('EM') methods should be considered along the gravel roads, developed on Witpoort quartzite, trending towards the interior.

- Satellite telemetry system is required to monitor water quality, water level and flow rate on a continual basis in the coastal aquifers, relaying information to a dedicated computerized data capture system. Although the Dias Cross aquifer has served the area for several years, limited performance data is available which would enable a model to be produced and calibrated to similar aquifers in the Ndlambe. In addition, such data is required as an early warning system of potential aquifer failure. Environmental monitoring of well fields is a requisite by DWAF in terms of their licence agreement to abstract groundwater.

- Given the severe water shortages in Ndlambe, an aggressive 'Water Conservation and Demand Programme' must be instituted without delay. DWAF expect this of municipalities in dire need, as the data produced provides a stimulus for their intervention.

- Agricultural property is widely sought after in Ndlambe and attracts premium prices from individuals (often foreigners) who are keen to develop the land into a housing estate or game reserve. This often makes it difficult to utilize a potential groundwater resource. Ndlambe should consult with affected landowners as soon as possible about its future bulk water requirements and come to a commercial agreement regarding developing well fields and abstraction of groundwater.

- In light of all the developments occurring in Ndlambe, care should be taken to ensure that potential aquifers are not sterilized and/or contaminated through injudicious planning. At present, bulk water resources are severely stretched and any new development is essentially 'fatally flawed' until the situation improves significantly. Alternatively, new developments should develop their own sustainable water source.

- Rain water tanks should be installed as a matter of routine to all future RDP houses. This should be extended with retro-fitting of rain tanks to all older houses in the townships. Rain tanks should be made compulsory in the affluent communities, with the tank capacity based on a sliding-scale according to the roof area.

- DWAF should inform DEAT and SanParks of the bulk water problems of the region and the need to develop coastal aquifers.

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