

Study Name: Orange River Integrated Water Resources Management Plan

Report Title: Review of Groundwater Resources in the Orange River Catchment

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Current Analytical Methods and Technical Capacity of the four Orange Basin States
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Summary Report

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LIST OF ABBREVIATIONS

BCC	Borehole Completion Certificate
BHN	Basic Human Needs
BNWMP	Botswana National Water Master Plan
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
CSIR	Council for Scientific and Industrial Research
CSO	Central Statistics Office
DGS	Department of Geological Survey
DRWS	Department of Rural Water Supply
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electric Conductivity
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GMU	Groundwater Management Unit

GPS	Global Positioning System
GOB	Government of Botswana
GRDM	Groundwater Resource Directed Measures
GRES	Groundwater Recharge Estimation Study
GRU	Groundwater Resource Unit
GWC	Groundwater Consultants BEEPEE
GWD	Groundwater Division
IAH	International Association of Hydrogeologists
ICM	Integrated Catchment Management
IGS	Institute for Groundwater Studies
ISARM	Internationally Shared Aquifer Resources Management Project
ITCZ	Inter Tropical Convergence Zone
IWRMP	Integrated Water Resource Management Plan
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
NAMPAD	National Master Plan for Agricultural Development
NBA	National Borehole Archive
NGDB	National Groundwater Database
MAMSL	Metres Above Mean Sea Level
MCM/a	Million (Mega) cubic Metres per annum
MBGL	Metres Below Ground Level
NWA	National Water Act
NWQDB	National Water Quality Database
NWRS	National Water Resource Strategy
ORASECOM	Orange – Senqu River Commission
RDM	Resource Directed Measures

RQO	Resource Quality Objective
RVWSDM	Rural Village Water Supply Design Manual
SWA	South West Africa
S	Storativity
SADC	Southern African Development Community
T	Transmissivity
TDS	Total Dissolved Solids
TMG	Table Mountain Group (Sandstone Aquifer)
VES	Vertical Electrical Soundings
WAB	Water Appointment Board
WARMS	Water Use Authorisation and Registration Management
WASA	Water and Sanitation Authority
WMA	Water Management Area
WMS	Water Management System
WRC	Water Research Commission

1 INTRODUCTION

1.1 Background

The Orange River Basin extends into four countries; Republic of Botswana, The Kingdom of Lesotho, the Republic of Namibia, and the Republic of South Africa. It includes the total land area of Lesotho, most of the central part of South Africa and reaches to the southern part of Botswana as well as draining most of the southern half of Namibia. The Orange-Senqu River Commission (ORASECOM) came into existence on 3rd November 2000 by agreement among the four basin member states in terms of the SADC Protocol on Shared Watercourse Systems, with one of the primary aims being the integrated development and management of the water resources of the Orange River to the mutual and equitable benefit of all parties.

At the stage that ORASECOM was founded, extensive developments had already taken place with respect to water resource infrastructure and utilisation of the resource. Amongst others, large inter-basin transfer schemes have been developed which transfer water from several other basins into the Orange River Basin as well as from the Orange River Basin to other adjoining river basins. Plans have also been developed by some of the co-basin countries with respect to possible further developments and aspects pertaining to the future management and utilisation of the resources of the Orange River Basin. To facilitate the integrated development and management of the resources of the Orange River jointly by the four basin member countries, it is essential that common ground exist among the basin countries with respect to the principles and objectives salient to the joint management and that appropriate strategies and plans be developed to achieve this. A key component and common reference base being the development of an Integrated Water Resources Management Plan (IWRMP) for the Orange River Basin. This report deals with the review of the groundwater resources and relevant groundwater issues as they relate to the Orange River Basin.

1.2 SADC Protocol

The Protocol on Shared Watercourse Systems in the SADC Region contains amongst others, the following fundamental principles :

- It recognises the relevant provisions of the United Nations Conference on Environment and Development, the concepts of environmentally sound

management, sustainable development and equitable utilisation of shared watercourse systems in the SADC Region

- It is desirous of developing close co-operation for judicious and co-ordinated utilisation of the shared watercourse systems
- The utilisation of shared watercourse systems within the SADC Region shall be open to each riparian or basin State, in respect of the watercourse systems within its territory and without prejudice to its sovereign rights, in accordance with the principles in the Protocol
- Member States undertake to respect and apply the existing rules of general or customary international law relating to the utilisation and management of the resources of shared watercourse systems and, in particular, they respect and abide by the principles of community of interests in the equitable utilisation of those systems and related resources
- Member states lying within the basin of a shared watercourse system shall maintain a proper balance between resource development for a higher standard of living for their peoples and conservation and enhancement of the environment to promote sustainable development
- Other Institutions for International Water Management in Southern Africa

1.3 River Basin Commissions

The role of the river basin commissions is to foster sustained dialogue between common countries leading to cohesive and effective co-operative management and optimal utilisation of shared water resources. They will provide focal points for the joint formulation of development plans for the basin, co-ordination of joint basin studies, and collection and sharing of information. The commissions are not water management institutions and the responsibility for project implementation will normally remain with the local domestic institutions.

1.4 Objectives and Methodology of ORASECOM Task 6 Groundwater Issues

The objective of the current phase (Phase One) is essentially a desktop study with minimum, if any, fieldwork. During this phase, the focus will be on :

- To give an overview of the available data on groundwater
- To give an overview of the state of groundwater
- To assess the level of groundwater development

- To assess the level of stress on the groundwater development
- To assess the capacity for further groundwater development

The review of groundwater resources involved the identification of information sources within the four countries involved. Format of the information (hard copy or digital, projection, file type, database package, etc.) as well as information status (complete, being developed, planned), the availability thereof and when the information was captured formed part of the investigation. In all cases it will be appreciated that the discussions and observations presented are not intended to be conclusive, but rather to be indicative of the efforts undertaken in this section of the study.

2 BOTSWANA GROUNDWATER OVERVIEW

2.1 Location and Access

The Orange-Senqu River Basin in Botswana or the Molopo (as locally known) covers approximately 71,000km² of the southern section of the southern part of the country with the Molopo River forming the southern boundary and the General Surface Water Divide of southern Botswana forming the northern boundary of the basin. The international border between Botswana and South Africa from Ramatlabama to Maiphitlwane forms the eastern boundary of the basin while the Nossob River defines the southern part of the western boundary of the basin. The international border between Botswana and Namibia defines the northern part of the western boundary.

2.2 Physiographic Setting : Geomorphology

The Molopo River basin transects topographic landforms found in southern Botswana. In the east around Ramatlabama and moving towards Pitshane-Molopo the topography is reminiscent of a complex geological and structural history. The relief is gentle throughout the area with the low north-south trending discontinuous Mosi Ridge. The topographic lows are marked by the broad flat-bottomed dry valleys, which flatten out towards the west. The drainage courses in the area are the Molopo River, Ramatlabama Spruit and the Matletse Dry Valley. The Molopo River seldom has surface flow during the rainy season. Land surface elevation decreases from 1200mamsl in the northeast to 1160mamsl in the southwest in the Molopo River with the regional surface gradient trending southwest. The outcrops of bedrock are restricted to the river valley and the Mosi Ridge.

Sands, loamy sands and occasional clays characterises the area and the vegetation is fairly open grassland savannas with some patches of savannah woodlands and dense stands of trees and shrubs close to the Molopo River valley.

The area between Mabule and Werda is generally flat with a slight increase in elevation to the east. The physical landscape is generally flat to undulating, with topography sloping generally southwards into fossil drainage of the Molopo River Valley. The general relief is towards the south and southwest into the Molopo River Valley. Fossil valleys (palaeo-channels) running from the east to the west are also visible with the Mosebele Fossil valleys being the most prominent. The only other features are numerous pans and remnant dunes. The soils are classified as sandy and sandy loams with a degree of clay

content (luvic arenosol). The predominant vegetation is acacia thorn scrub whereas grassland is generally associated with the pans and similar depressions.

Kalahari type environment is prominent west of Werda and tends to be poorly endowed with surface water. The sandy soils that cover much of the Kalahari sandveld contribute to poor surface water occurrence as a result of their poor retention abilities. However, the Molopo River is occasionally active (ephemeral) and is the principal surface drainage feature in the region. The Molopo River flows sporadically in its upper reaches past Werda and beyond Makopong (sometimes reaching Draaihoek but rarely further). Intermittent fluvial activity has left terraces and fluvial sediments along the river and river margins. These features have been dated to the late Quaternary (DGS 2003 Werda Sekoma TGLP) while the high terraces, beyond the confines of the present valley, are deemed to be older. Flooding occurs infrequently and generally only in response to large-scale precipitation. There are no river gauging stations.

Further to the west beyond Tsabong, the area has a gentle relief with pans and sand dunes constituting major topographic features that are clearly visible on aerial photographs and satellite images. There are no major surface drainage features in the area except for the Molopo and Nossob fossil river systems marking the southern and western boundaries of the basin respectively.

The southern part of the Gemsbok National Park covers most of the northwestern portion of the Molopo River Basin. This is a flat and relatively featureless semi arid sand and dune savannah region in which pans and associated dunes constitute the major topographic features. Elevations are greatest in the northeast at approximately 1070mamsl with the regional gradient being to the south and southwest i.e. towards the Molopo and Nossob valleys that lie at elevations of around 890mamsl. Insufficient topographic data is available to detail pans and the associated sand dunes. Pan floor levels are up to 15m below the general land level, whilst dunes rise up to 30m above general land elevations. The dunes are of two types viz. Barchan, crescent shaped dunes which are generally rare in the study area and Seif dunes with a much more subtle relief which are often difficult to identify on the ground. The Barchan dunes trend NNW whereas the Seif dunes trend in a NNE direction.

Numerous pans are located in this part of the study area, ranging in size from the elongate pans (5km in length by about 1km wide), to innumerable small 'incipient' pan features of less than 100m in diameter. The larger pans show a distinct trend being elongate in a

north-south direction. The elongate pan direction generally parallels that of the sand dunes.

Van Straten (1955) divided the Kalahari Pans into three categories :

- Grassed pans – pan sediments consist of dark sandy clays, which support a dominantly grassy cover. Saline concentrations are low and calcrete generally not well developed
- Ugrassed pans – pan sediments again consist of dark sandy clays, which support sparse halophyllic (natural salt loving) vegetation
- Saline pans – pan sediments consist of saline and highly alkaline sandy clay with no plant growth. The pans are commonly eroded into calcrete or a calcareous sandstone deposit

All three types appear to be present within this part of the study area. The main phase of pan deepening is likely to be an in-situ process. The present day climate gives rise to sporadic pan flooding and evaporation in an environment in which chemical dissolution and reprecipitation might be expected. Wind erosion (deflation) of the fine-grained clays, salts and carbonates is likely to occur during each drying out phase.

The sand dunes are more prevalent in the western portion of Botswana and they form a linear pattern in the northeasterly direction, indicating the predominant wind direction at the time of formation. The pans in the area show a wide size range, distribution and shape. Over 90% of the dunes in the region are linear, varying in height from 2m to greater than 30m above the interdunes, with some of the highest dunes occurring immediately adjacent to the fossil valleys.

The Kalahari sands form poorly structured and infertile soils of low moisture retaining capacity. As a result, there is no permanent surface drainage in the Kalahari and little or no run-off. The soils of the southern Kalahari can be divided into red, pink and white sands (DGS, 2002) with more than 90% sand fraction and fine soils like sandy clays, usually found in riverbeds and pan floors. The red sand is most common and found on the plains and dunes. The much less common pink sand (intermediate between red and white) occurs in some dune slacks and around pans. It is richer in lime than the red sand. The white sand is the least common type and is mainly found in riverbeds and pans. The soil is richer in minerals than the other types.

The southern part of the Gemsbok National Park is botanically classified as dune savannah. Structurally, dune savannah is open savannah with scattered shrubs and trees. In part the area is covered by Seif dunes where trees and dunes are commoner on the dune slopes than on the crests or in the streets (areas) between. In those areas covered by Barchan dunes the interdune streets are a much smaller component of the landscape and woody species are much more prominent.

2.3 Physiographic Setting : Climate

The synoptic systems controlling Botswana's climate are dominated by a combination of the seasonal movement of the large tropical and temperate zonal systems over Southern Africa and their interaction with localised convective processes. North of 20° latitude, primarily the Inter Tropical Convergence Zone (ITCZ) and the Zaire Air Boundary (ZAB) complex influence the zonal system. The ITCZ attains its most southern position in January when it approaches the northern border of Botswana. The ZAB lies over central Zambia during the mid summer period when the low pressure also troughs into the extreme south of the continent. The rainfall weakens south of latitude 20° as the drought producing sub-tropical anticyclones (high pressure systems) become more dominant. This is reflected in the more meridional alignment (airflow patterns) of rainfall isohyets across South Africa, Botswana and Namibia with drier areas in the west and wetter areas to the east. The latter reflects the differential in rates of subsidence of the air masses between the east and west coasts of Southern Africa. Off the western coast, stronger subsidence occurs as a result of the interaction between the almost stable Atlantic Ocean anticyclone and cold waters of the Benguela Current. To the east, warm waters of the Agulhas Current, more numerous rain producing disturbances and the marked eastward displacement of the Indian Ocean anticyclone during summer result in weaker subsidence.

The climate in the basin area is semi arid with hot days and warm nights during the summer months and warm days and cold nights during the winter months. Extreme diurnal ranges are typical. Winter nights are very cold with the village of Tsabong averaging 72 days of ground frost annually, compared to 26 days in Gabarone.

2.3.1 Rainfall

The eastern part of the basin receives over 500mm mean annual rainfall. The annual rainfall decreases towards the west where Bokspits receives below 300mm annually. Rainfall is predominately convective and comprises instability showers and thunderstorms.

This low rainfall is both spatially and temporally very variable and highly localised. Almost all of the rainfall occurs during the summer period (October to April) with the winter period accounting for only 5% of the annual total. The Department of Meteorological Services has a synoptic weather office at Tsabong. However, rainfall figures are available from most of the villages in the basin area and **Table 2-1** provides some detailed information in this regard.

Table 2-1: -Annual Rainfall Figures of Some Villages in the Study Area

Year	Sekoma	Mabutsane	Khakhea	Tsabong	Werda
1981	N/a	91.2	N/a	327.7	278.9
1982	518	107.6	454.8	245.7	354.5
1983	294.2	119.5	294.1	366.7	N/a
1984	169.7	N/a	95.7	175.2	251.4
1985	272.8	130.1	136.7	144.4	206.9
1986	215.9	136.1	280.8	390.6	284
1987	N/a	N/a	260.3	262.6	279
1988	N/a	236.4	267.4	458.3	304.4
1989	N/a	N/a	400.4	226.6	290.7
1990	N/a	N/a	241.6	223.7	258.3
1991	695.8	116.3	306.5	389.3	629.5
1992	185.2	N/a	122.4	53.6	189.8
1993	263.8	239.7	269.3	252.7	291.5
1994	N/a	N/a	353.9	179	69.5
1995	N/a	N/a	N/a	230.4	297.7
1996	N/a	N/a	N/a	285.8	443
1997	319.8	N/a	524.5	331.9	N/a
1998	372.1	N/a	N/a	406.4	N/a
1999	N/a	N/a	N/a	327.3	N/a
2000	N/a	N/a	680.1	390	N/a
2001	N/a	N/a	609.3	508.4	N/a
2002	N/a	N/a	N/a	278	N/a
Average	331	147	409	326	295

N/a - Not available or Incomplete Record, Source: Department of Meteorological Services, Gabarone

A list of rainfall measuring stations in the basin area is presented in **Table 2-2**.

Table 2-2: -Rainfall Gauging Stations in the Molopo River Basin

Molopo River Basin – Rainfall Gauging Stations	
Arnadale Farm	Sedibeng
Bogogobo Primary School	Sekoma Primary School
Bokspits Primary School	Sekoma (He' s Farm)
Bray Border Post	Struizendam Primary School
Dalyspan	Tsabong Airport
Digawana Shop	Tsatsu Camp
Dipotsana Primary School	Twee Rivers Limpopo
Gakhibane Primary School	Werda Primary School
Gasita Primary School	Ditlharapeng
Gathwane Primary School	Papatlo Primary School
Goodhope Agric Research Station	Pelotshetlha Primary School
Hildavale Primary School	Phepheng Trading Store
Inverness	Phitshane Molopo Primary School
JM31 Farm	Pitsane BDF
Keng Primary School	Ramatlabama bull Stud
Khakhea Primary School	Ramatlabama Police Station
Khawa health Post	Lorolwana Primary School
Khisa Primary School	Mabule Primary School
Khuis Primary School	Makopong Primary School
Kincross	Masokwe
Kokotsha Primary School	Maubelo Primary School
Kolonkwaneng Primary School	Metlobo Primary School
Mogojwejwe	Middlepits Primary School
Mokatako	Mmathethe South
Mokhomma	Omaweneno Primary School

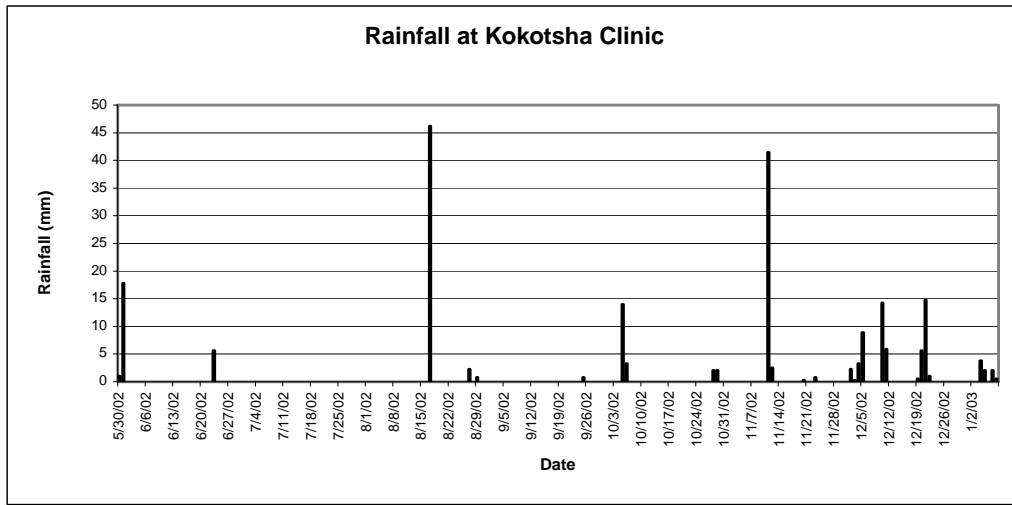


Figure 2-1: Histogram of Automatic Rainfall Gauge at Khokhotsha Clinic

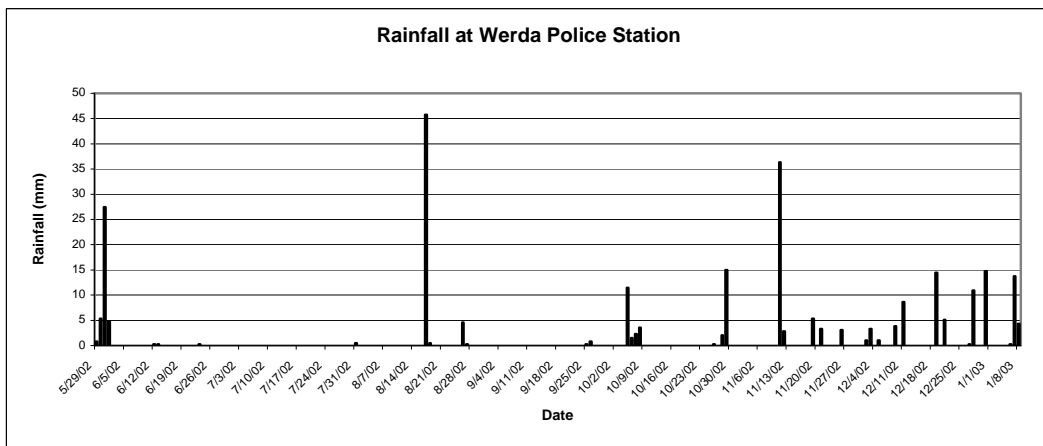


Figure 2-2: Histogram of Automatic Rainfall Gauge at Werda Police Station

2.3.2 Temperature

The warmest period at Tsabong is mid summer with a mean annual temperature of 34.8°C and the coolest month is July with a mean minimum temperature of 4°C. Mean monthly maximum temperature in the Tsabong area varies from 22.1°C in June to 34.8°C in December. The mean monthly minimum temperatures vary from 4°C in July to 19.7°C in January. Highest temperatures are recorded for November, December and January with minimum temperatures occurring during June and July (occasionally sub zero).

2.4 Population

Some 2.8% of Botswana's population lives within the Molopo Basin area. Population centres include Goodhope, Gathwane, Mogojogojowe, Mmathethe, Digawana, Thareselele, Ramatlabama, Mokatako, Phitshane-Molopo Mmakgori, Tshidilamolomo, Mabule, Selokolela, Metlobo, Magoriapitse, Sekoma, Khakhea, Makopong, Khisa, Omaweneno, Maleshe, Tsabong, Werda, Maralaleng, Struizendam, Rappelspan, Khuis, Bogogobo, Middlepits, Khawa, Gakhibane and Bokspits. Southern Botswana hosts a very low rural population density confined to the sparsely populated Kgalagadi District and the moderately populated Southern District. The Botswana Central Statistic Office (CSO) carries out a national population census every ten years. Population statistics derived from the CSO 2001 census and the associated 2010 and 2020 population projections for the Molopo River Basin are presented in **Table 2-3**.

Table 2-3: Summary of Population Statistics Molopo River Basin Area

LOCALITY/TOWN	POPULATION		
	2001	2010	2020
Goodhope	2934	3300	3414
Gathwane	922	927	928
Bogogobo	341	336	335
Sekoma	1033	1151	1188
Magoriapitse	969	1107	1151
Makopong	1501	1577	1600
Khakhea	2035	2096	2114
Omaweneno	1068	1127	1166
Khisa	423	455	464
Khonkhwa	473	490	495
Keng	931	1007	1031
Leporung	582	587	588
Werda,	1961	2108	2153
Tsabong	6591	7546	7848
Maleshe,	389	403	407
Maralaleng	487	567	625
Struizendam	313	318	335
Rappelspan	278	315	327

LOCALITY/TOWN	POPULATION		
	2001	2010	2020
Khuis	755	791	802
Khawa	517	538	544
Gakhibane	501	515	519
Bokspits	499	528	537
Thareseleele	767	778	781
Selokolela	1188	1296	1329
Metlobo	925	942	947
Mabule	1589	1631	1643
Tshidilamolomo	673	1783	1851
Mokatako	967	978	961
Mmakgori	742	834	863
Ramatlabama,	1174	1179	1180
Phitshane-Molopo	1569	1783	1851
Mogojogojowe	603	654	670
Kokotsha	1021	1053	1062
Kolonkwaneng	591	594	595
Vaalhoek	346	377	387
Dikhukhung	288	279	276
Bray	899	927	936
Sedibeng	616	701	728
Mmathethe	4415	4809	4930
Middlepits	657	707	722
Maubelo	453	491	516
Digawana	2675	2832	2879
Population in Molopo River Basin area	47661		
Total population in Botswana	1680863		
Population outside Molopo River Basin area	1587038		
% Population in study area	2.8		

Source – CSO 2001 Population Census

2.4.1 Impact of HIV / AIDS Pandemic

Over the last ten years, the demographics of the country have changed significantly with increasing numbers concentrated around the urban centres. Botswana's population is becoming increasingly urbanised. The traditional way of life of people moving between the village home, the fields, lands and cattle kraals is in decline with more people having additional town domiciles. Both education and health care continue to be priority areas for Botswana. The Government of Botswana (GOB) continues to improve and expand the education system, consuming over a fourth of the 2000-2001 allocated expenditure budget. The health care system has also received substantial inputs resulting in about 85% of the rural population living within 15km of a health facility. Public health expenditure averaged 5-8% of the national budget between 1980 and 1999.

Between the 1974/75 and 1999/2000 financial years, the Gross Domestic Product (GDP) of Botswana grew at an average rate of 9.1% increasing from (in Pula) P228 million to P26 billion in 1999/2000. This expansion was fuelled primarily in the structure of the economy from agriculture and financial services to mining and public sector. Mining is now the leading sector in the national economy, constituting more than 50% of Government revenues and nearly 80% of foreign exchange earnings. Through diversification efforts by the GOB and shifts in the global economy, the mining sector now represents about one third of GDP.

The HIV / AIDS epidemic continues to deepen in Botswana. The overall, adjusted HIV prevalence rate for pregnant women aged 15-49 has increased from 33.6% in 2000 to 36.2% in 2001. This increase is reflected across nearly all age groups. The trend of HIV prevalence from 1993 to 2001 indicates that the prevalence rates for 2001 are double those for 1993. Population growth structure continues to be altered as a result of the HIV and AIDS epidemic. Mortality across age groups is on the rise in Botswana and life expectancy has begun a steady decline, from a GOB estimated high of about 66.2 years to a projected low of 47.4 years (1999 & 2000 GOB Human Development Reports). It is estimated that by the year 2010 life expectancy could reach a staggering low of 29 years. Additionally, if nothing is done to halt the deepening of the epidemic, 30% of Botswana's adult population could be lost over the next eight to ten years.

The structure of the population will shift to increasing numbers of both the very young and very old. Household income levels are expected to drop at least 8% due to HIV and AIDS, pushing the number of household below the poverty line up by around 5%. Ever

decreasing household resources may be increasingly channelled to medical and care expenses, with less going to education and social amenities. The impact of HIV / AIDS is keenly felt in the social sector in particular education and health. A high incidence of morbidity and mortality among teachers reduces the number of classroom hours being taught. At home, ill health among family reduces the time children spend at school or attending to schoolwork. Similarly, the nation's health system is stretched to the limit as the sheer magnitude of the epidemic threatens to consume both health resources and facilities. The massive burden of caring for and treating HIV and AIDS in Botswana will increasingly limit the health care system to deliver even the most basic care to the rest of the population.

The epidemic is having a catastrophic impact on the economy with an HIV prevalence of some 36% among the workforce. The number and quality of people available to work will decline over the next five to ten years. The loss of skills, institutional memory and experience will create a vacuum in the labour market. Labour costs will rise along with recruitment and retraining costs in order to meet the need of business and industry. Add to that the costs of meeting expected medical and support costs may seriously reduce corporate earnings, savings and investment levels, depressing the economy. It has been estimated that the HIV / AIDS epidemic will cause a contraction of GDP by 1.5% over the next 20-25 years resulting in an economy at least 31% smaller than would otherwise be projected without the impact of the epidemic. The impact of the epidemic in respect of water demands has not as yet been quantified by the GOB.

2.5 Water Demand

The economic success of the Republic of Botswana has translated into improved infrastructure nationwide and increased household per capita income in rural villages. This new buying power enables more households to have water connections. These connections have proved to encourage high water consumption per capita as compared to public standpipes. As such there is increased demand for a reliable and convenient potable water supply. Rural village water demand calculations are based on the DWA (1989) Rural Village Water Supply Design Manual (RVWSDM). Rural water supply schemes are designed for the water demands shown in following table :

Table 2-4: Rural Village Water Demand Design Criteria

Connection Type		% Served
Private connections	House connection	15%
	Yard connection	20%
Public standpipe		65%

Source – DWA 1989 Rural Village Water Supply Demand Manual

The design criteria are:

- Standpipe (30 litres/day/person)
- Yard connection (60 litres/day/person)
- Household supply (150 litres/day/person)

The last decade has seen rapid infrastructural developments at rural village level, which makes many of the RVWSDM water demand calculation formulae obsolete. There has been a large increase in the number of housing developments at village level, which now exceeds the 15% stated in the RVWSDM. Waterborne sewage systems are being emplaced in the larger villages. Primary and junior Secondary Schools (JCSS) nationwide are being equipped with waterborne sanitation facilities. The Ministry of Health is establishing a network of primary hospitals located at sub-district HQ and major villages. This combined with the many new developments (businesses, shopping malls etc.) in the larger villages and the resulting urban life style (modern housing) of the population results in a much higher water demand.

For major villages supplied from wellfields separate water demand studies are implemented (as is the case in the Molopo River Basin). The studies are also based in the consumption statistics given the RVWSDM and the Botswana National Water Master Plan (BNWMP) planning documents.

Water demand forecasts contained in the BNWMP (1991) are presented below in **Table 2-5**. The BNWMP is currently being revised.

Table 2-5: Settlement Water Demand Forecasts (Nationwide)

Year	1990	2000	2010	2020
Population (10 ³)				
Urban Centres	262	437	647	949
Major Villages	294	431	597	816
Rural Villages	289	386	498	629
Minor Settlements	444	515	593	641
Domestic Demands (10 ⁶ m ³)				
Urban Centres	8.1	17.0	26.6	41.9
Major Villages	3.1	8.8	15.1	24.4
Rural Villages	1.8	3.2	5.1	6.8
Minor Settlements	2.4	2.8	3.3	3.5
Overall Demands (10 ⁶ m ³)				
Urban Centres	19.6	41.3	68.2	107.2
Major Villages	7.4	17.5	27.9	43.3
Rural Villages	3.6	6.3	9.5	12.6
Minor Settlements	3.3	3.8	4.4	4.7

Source – 1991 BNWMP

The 1991 BNWMP identifies five main water demand users : Domestic, Mines & Energy, Livestock, Irrigation & Forestry and Wildlife. Percentage usage figures for the different categories are presented in **Table 2-6** and **Figure 2-3** and **Figure 2-4**. Water demand projections for the categories are presented in **Table 2-7**.

Table 2-6: Percentage Water Demand Usage Nationwide

Year Demand Category	1990	2000	2010	2020
Settlements	28.6	38	45	51
Mines & energy	19.3	18.6	21.4	17.9
Livestock	30.7	22.7	14.3	14
Irrigation/forestry	16.4	17.4	16.9	15
Wildlife	5	3.3	2.4	2

Source BNWMP, 1991

Table 2-7: Water Demands (all units x 10⁶m³/annum)

Year Demand Category	1990	2000	2010	2020
Settlements	33.7	68.8	109.9	167.8
Mines & energy	22.9	33.6	52.2	58.7
Livestock	36.5	41	34.8	46.7
Irrigation/forestry	19.5	31.6	41.3	49.8
Wildlife	6	6	6	6
Total	118.6	181	244.2	329

The domestic water demand for settlements increases with time to a projected total of 51% of the total national water demand in 2020 as shown in **Figure 2-5**. In comparison the percentage proportion of other users remains static or even declines with time (as in the case of livestock).

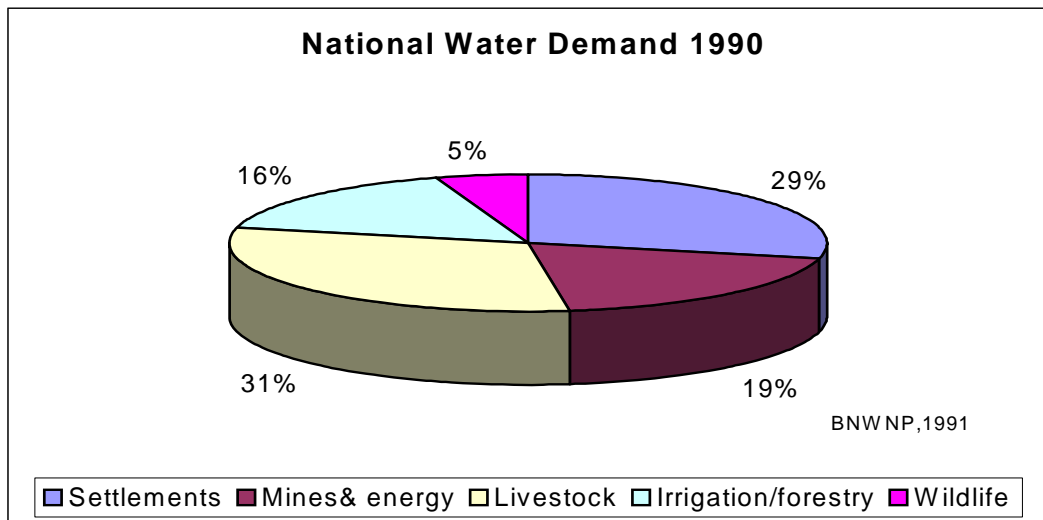


Figure 2-3: National Water Demand and Usage for 1990

These water demand figures have been calculated using a range of water consumption between 15 - 130 litres/day/person.

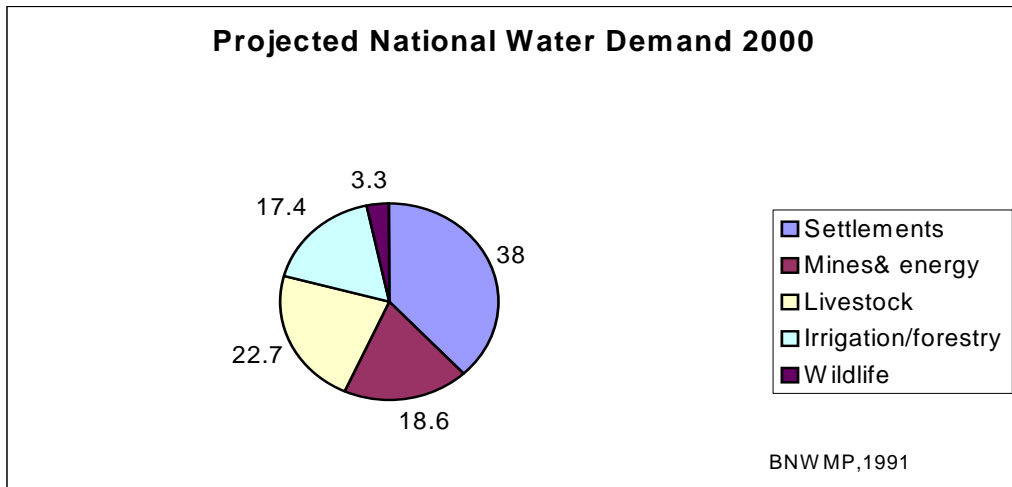


Figure 2-4: Projected 2000 National Water Demand

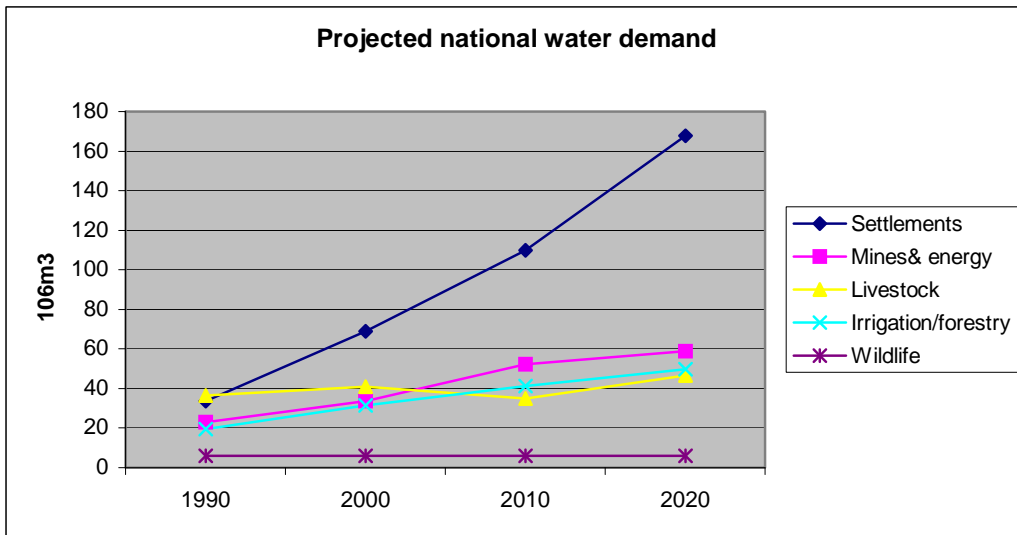


Figure 2-5: Projected National Water Demand & Usage for Year 2020

2.5.1 Water Demands for the Molopo (Orange) River Basin

Tsabong, Goodhope, Mmathethe, Digawana and Khakhea are considered major villages in the Molopo River Basin. These villages thus have the highest water demand as compared to other minor villages. The water demands of these villages are presented in **Table 2-8**.

Table 2-8: Water demands

Village	POPULATION			Water Demand (m ³ /d)		
	2001	2010	2020	2001	2010	2020
Goodhope	2934	3300	3414	220.05	247.50	256.05
Gathwane	922	927	928	69.15	69.53	69.60
Bogogobo	341	336	335	25.58	25.20	25.13
Sekoma	1033	1151	1188	77.48	86.33	89.10
Magoriapitse	969	1107	1151	72.68	83.03	86.33
Makopong	1501	1577	1600	112.58	118.28	120.00
Khakhea	2035	2096	2114	152.63	157.20	158.55
Omaweneno	1068	1127	1166	80.10	84.53	87.45
Khisa	423	455	464	31.73	34.13	34.80
Khonkhwa	473	490	495	35.48	36.75	37.13
Keng	931	1007	1031	69.83	75.53	77.33
Leporung	582	587	588	43.65	44.03	44.10
Werda,	1961	2108	2153	147.08	158.10	161.48
Tsabong	6591	7546	7848	494.33	565.95	588.60
Maleshe,	389	403	407	29.18	30.23	30.53
Maralaleng	487	567	625	36.53	42.53	46.88
Struizendam	313	318	335	23.48	23.85	25.13
Rappelspan	278	315	327	20.85	23.63	24.53
Khuis	755	791	802	56.63	59.33	60.15
Khawa,	517	538	544	38.78	40.35	40.80
Gakhibane	501	515	519	37.58	38.63	38.93
Bokspits	499	528	537	37.43	39.60	40.28
Thareseleele	767	778	781	57.53	58.35	58.58
Selokolela	1188	1296	1329	89.10	97.20	99.68
Metlobo	925	942	947	69.38	70.65	71.03
Mabule	1589	1631	1643	119.18	122.33	123.23
Tshidilamolomo	673	1783	1851	50.48	133.73	138.83
Mokatako	967	978	961	72.53	73.35	72.08
Mmakgori	742	834	863	55.65	62.55	64.73
Ramatlabama,	1174	1179	1180	88.05	88.43	88.50
PhitshaneMolopo	1569	1783	1851	117.68	133.73	138.83
Mogojogojo	603	654	670	45.23	49.05	50.25
Kokotsha	1021	1053	1062	76.58	78.98	79.65
Kolonkwaneng	591	594	595	44.33	44.55	44.63
Vaalhoek	346	377	387	25.95	28.28	29.03
Dikhukung	288	279	276	21.60	20.93	20.70

Village	POPULATION			Water Demand (m ³ /d)		
	2001	2010	2020	2001	2010	2020
Bray	899	927	936	67.43	69.53	70.20
Sedibeng	616	701	728	46.20	52.58	54.60
Mmathethe	4415	4809	4930	331.13	360.68	369.75
Middlepits	657	707	722	49.28	53.03	54.15
Maubelo	453	491	516	33.98	36.83	38.70
Digawana	2675	2832	2879	200.63	212.40	215.93
Totals	47661	52417	53678	3574.58	3931.28	4025.85

It has to be noted, however, that these demands are based on current life trends and infrastructure. There are planned new developmental projects that will be highly water intensive and it should be noted they have not been catered for in these water demands as it remains currently unclear in the relevant policy documents how the provision of water for these projects is going to be addressed.

2.6 Land Use, Infrastructure and Communications

It has only been recent that the GOB's Department of Town and Regional Planning have made land use plans for the entire country. These plans updated and modernised the old land tenure where land use policy was vague or in some cases nonexistent. The infrastructural developments in the Molopo River Basin have been progressing very slowly due to the low population and the simple vastness of the area.

2.6.1 Land Use

Due to the low rainfall characteristic of the Molopo River Basin, most of the area is devoted to pastoral farming, both commercial pastoral farming or ranching and communal cattle farming. Commercial ranches in the Molopo River Basin are located in the following areas: Sekoma, Sekutlane, Middelpits, Makopong and Bokspits. The rest of the area is characterised by clusters of boreholes and associated cattle posts. As one moves west past Werda, the intensity of cattle posts and farms is reduced since adequate potable water supplies are often difficult to locate and develop.

About 20% of the Molopo River Basin area forms part of the Mabuasehube Game reserve and The Gemsbok Transfrontier Park. These areas have been reserved for wildlife management and tourism activities. Commercial arable agriculture is active in the eastern section of the basin in the Barolong farms and Mosi areas. Very large fields are cultivated

for rain fed crop production. Small-scale subsistence arable agriculture is practised in the vicinity of most of the villages of the Molopo River Basin.

2.6.2 Communications

In an effort to foster expansion of economic activity and thus hopefully implementing Botswana's National Socio-Economic Policy, the GOB developed a road network in the country through a series of National Development Plans. The study area was no exception to this initiative. In the east there is the Ramatlabama to Lobatse tarred road (a strategic route) linking southeastern Botswana with neighbouring South Africa. Ramatlabama is also connected to Mmathethe via Goodhope with another tarred road. The Sekoma to Tsabong tarred road links the central Molopo River Basin with the eastern part of the country via the Trans Kalahari Highway. In the extreme south there is a tarred road from Goodhope to Tshidilamolomo linking most of the southern villages to the national road network. A tarred road linking Tsabong and Bokspits is to be built to replace the current gravel road (already commissioned?). The rest of the villages in the study area are linked with gravel roads. Middelpits is linked to Struizendam via Bokspits with gravel, which runs mostly along the Molopo River from Kolonkwaneng in the east. The road from Middelpits to Khawa is a cleared sandy road and may be difficult to traverse at Matlalo cattle post where it runs across cattle ranches and thus maintenance is kept at a minimum to reduce pasture degradation.

There is a stretch of railroad in the east linking Ramatlabama and Lobatse. Due to the well-established road network in the east, the railroad is used mainly for goods transport. Several airstrips have been constructed in the study area; the most frequently used being the Tsabong airstrip. These airstrips have been used for light aircraft transporting government officials and the flying medical doctor service.

Major villages in the Molopo Basin are connected to both fixed landline telephone and cellular phone service. Some villages in the extreme southwest like Bokspits do not have both services and some rely on overlap of cellular phone services from neighbouring South Africa.

2.6.3 Infrastructure

Both Tsabong and Goodhope have primary hospitals, which are used as referral services for the sub-districts. All other villages have a clinic, health post or mobile stops for the very small settlements and outlying cattle posts. All villages within the study area have a

primary school and some major villages have Community Junior Secondary Schools. Water reticulation tends to be generally well established in most, if not all the villages. There is usually a reservoir, which may be supplied from a wellfield or from a water bowser. Water from the storage facility is gravity fed reticulation and access to the supply would either be through centrally located public standpipes or yard connections.

Tsabong and Goodhope have planned waterborne sewage systems and this development is anticipated to substantially increase the water demand for these villages. There are plans to harness wastewater from the system for re-use in agriculture. This concept may pose some cultural barriers, which would need to be addressed by the implementing agents. The remainder of the study area generally has dry sewage systems (pit latrines). There are exceptions as some schools have waterborne systems.

2.7 Regional Geology

Mapping and remote image sensing indicate that the Kalahari sand cover obscures most of the hard rock geology. Aeolian sand deposits have produced a landscape characterised by WNW to NW trending longitudinal sand dunes. Some rock exposures are found along the Molopo River in Khuis, Werda and Phitshane Molopo. Outcrop of the pre-Kalahari Group rocks is limited to the exposures of the Volop Group quartzites, with minor shales and ironstones around Maralaleng, Omaweneno and Tsabong. The extent of the outcrop areas can be readily mapped from aerial photography and have also been mapped in detail by the GOB Geological Survey.

2.7.1 Basement Rocks

Most of the study area falls within an environment where bedrock is almost entirely concealed by a veneer of Tertiary to Quaternary sediments known as the Kalahari Group or Sequence. The bedrock geology is deduced from borehole and exploration drilling records and from aeromagnetic surveys. As a result, there are many uncertainties regarding the regional geology. A number of boreholes around the Tsabong area have intersected granitic rocks, leuco-gabbros and gneissose-structured rocks. The full nature of these rocks and their relationship to the other Supergroups remain yet to be determined.

The area around Werda lies in an area of sub-outcropping Proterozoic rocks of the Upper Transvaal Supergroup and the somewhat younger Olifantshoek Formation (Waterberg Group). In the north of the study area, the rocks fall within a basement high which projects westwards into the western Kalahari and can be followed eastwards to the bedrock

outcrop zones of eastern Botswana. The basement high is generally devoid of Karoo Supergroup cover and the Kalahari Group tends to be thin (generally less than 30m) but thickens considerably in the direction of the Molopo River Basin in the south of the project area. Both the Transvaal and Waterberg rocks consist of quartzites, sandstones, shales and siltstones. The Upper Transvaal Supergroup includes some volcanic units, the most common lithologies being andesite and felsite.

The Waterberg Supergroup rocks include red beds (the oldest rocks in Southern Africa) that are absent from the Transvaal Supergroup. However, by no means all of the Waterberg rocks are red and some Transvaal sandstones have a secondary red colouration. It is acknowledged that distinguishing between Transvaal and Waterberg clastic sediments is difficult, even in outcrop or where relatively long cored sections are available. In percussion drilled boreholes, which tend to make up the vast majority of data points within the study area, it is virtually impossible to assign rocks to one of these units with any degree of certainty.

2.7.2 Olifantshoek Supergroup

This unit unconformably overlies the Griqualand West Supergroup, which is exposed to the east in South Africa. Whereas the latter is an essentially marine succession of carbonates, ferruginous sediments and argillites with minor arenites, the Olifantshoek Supergroup is comprised mainly of coarse arenites including red beds. Quartzites of the Volop Group outcrop near Tsabong and the hills between Omaweneno and Khisa.

The Olifantshoek rocks are tectonised by the Kheis Orogenic Belt that strikes north south from the Orange River to the Okwa Valley in western Botswana. At Okwa, the strike appears to swing to the northeast and it is possible that the Kheis Orogen is contiguous with the Magondi Belt of Zimbabwe. The project area is on the eastern edge of the Kheis Orogen and the rocks show various degrees of deformation. The exposures at Tsabong, which are thought to belong to the Verwater Formation close to its transition to the white ortho-quartzites of the Top Dog Formation, lack any penetrative fabric and form the eastern limb of a synform which plunges gently to the south. The western limb of the synform is exposed in a straightened zone north of Khweyane. The white, recrystallised quartzites of the Omaweneno – Khisa area are tightly folded about a mainly north south axis that can be mapped from aerial photography.

Along the Molopo River from Kolonk in the east to Khuis in the west, the Volop Group quartzites are seen to become progressively more deformed until at Khuis outcrops display tight folding. Some thrust faults have been mapped in the area as well. Further south towards the Korannaberg hills in South Africa, the Olifantshoek Supergroup rocks display isoclinal recumbent folding and shallow angle north south striking thrust planes on which movement has occurred from west to east. Almost certainly the thrust planes continue north of Korannaberg into Botswana.

Faults oriented NE – SW passing to the north of Tsabong appear to have dextral strike slip movements with the southern fault passing between the quartzite outcrops of Tsabong and Maleshe. The northern fault is seen to displace magnetic bands within the Kheis zone. The two parallel NW – SE faults south of the project area are considered to be a graben filled with rocks of the Dwyka Group. A strong geophysical gravity gradient over the northern fault indicates a change in the pre-Karoo lithologies across the fault, as a thickening of Karoo rocks cannot itself explain the observed gravity anomaly.

The relationship between the Olifantshoek Supergroup and the Waterberg rocks of eastern Botswana remains uncertain but it is likely they are chronostratigraphic equivalents. The Olifantshoek rocks possibly represent a continental margin facies of the essentially intra-continental Waterberg sediments.

2.7.3 Karoo Supergroup

Dwyka Group

The Dwyka Group unconformably overlies the Olifantshoek Supergroup rocks, which is the lowermost group of the Karoo Supergroup. The Dwyka is a sequence of glaciogenic sediments consisting of diamictites succeeded by fluvioglacial sandstones and argillites. The basal tillites were deposited on a glaciated landscape, remnants of which can be seen in the quartzite hills (well exposed in the Molopo Valley west of Khuis). The Dwyka Group has been divided into a lower formation of essentially structureless diamictite – the Malogong Formation – and an upper heterolithic formation of diamictites, shales and sandstones of the Khuis Formation. The area of Dwyka east of Tsabong appears to be contiguous with a large NE – SW palaeovalley infilled with Dwyka rocks. A NW – SE trending trench to the south Logaganeng is infilled by Dwyka sediments.

Ecca Group

The Ecca group is divided into two formations. These are the lower Kobe Formation of slightly carbonaceous mudstone followed by the Otshe Formation of cyclical mudstones, siltstones, sandstones and coals. The Otshe Formation is the equivalent of the Auob Sandstone of Namibia and the Middle Ecca and Mea Arkose of eastern Botswana. The underlying Kobe Formation is mainly a black mudstone that is easily pulled apart by hand. Thin sand lenses are seen with sandstone bands becoming more frequent towards the bottom of the unit. At the base of the Kobe Formation, overlying the Dwyka rocks is a 2m unit of pink to light brown, coarse well sorted sandstone with a 2cm conglomerate at its base. This sandstone is classified as the Nossob Member of the Formation and is believed to correlate with the Nossob Sandstone of Namibia.

Beaufort Group

The Beaufort Group is composed of greenish-red, non-carbonaceous, shales belonging to the Kwetla Formation.

2.7.4 Post Karoo Dolerites

Post Karoo dolerite dykes and sills are common in the southern Kgalagadi. Further west within the Karoo basin, a number of sills are emplaced into the Karoo succession. The stratigraphic level of the Ecca-Beaufort Group contact appears to be favoured for sill intrusion. The dolerites are correlated with the Jurassic Drakensberg basalts. The presence of the dolerite sills has been confirmed by drilling logs from boreholes and exploration holes. The age of the sills are unknown as they occur at various stratigraphic levels but are generally thought to be post-Karoo age. Other intrusives are norites and ultrabasics of the Molopo Farms Complex as well as Archean granites and felsites.

2.7.5 Post Karoo Kimberlites

A major cluster of kimberlite intrusives consisting of at least 60 separate intrusions lies to the north, south and west of Tsabong. All of the intrusions are covered with Kalahari Group sediments but their presence was revealed by the widespread occurrence of widespread kimberlite indicator minerals in the soils. This was recognised by De Beers Prospecting circa 1970 but the discoveries were made later by Falconbridge Explorations Botswana between 1978 and 1981 using low level aeromagnetic surveys. Although diamonds have been found, none of the Tsabong kimberlites carries sufficient grade to be exploited. There

are clear signs of structural control in the emplacement of some of Tsabong Kimberlites. The kimberlites are believed to be all of Cretaceous age.

2.7.6 Kalahari Group

The Kalahari Group is a unit of continental sediments of Palaeocene to Recent Age with a complex history in which the stratigraphy and age of the deposits are not well understood. Low fossil content, limited exposure, the ubiquitous cover of surficial Aeolian sand and a limited understanding of the extensive duricrusts make reconstruction of Kalahari stratigraphy difficult. It is evident, however, that recurring cycles of erosion and deposition have re-worked the same sediment. It is also difficult to separate primary depositional effects from secondary modifying processes.

Broadly, the Kalahari Group consists of a layer of Aeolian sand up to 20m thick that may display relict dune structures, mainly Barchans. At the present time, the sand is fixed by vegetation and the dunes are fossil. The sand is generally underlain by a duricrust of silcrete and calcrete that must represent an unconformity within the succession. Poorly consolidated sandstones that are often calcareous underlie the duricrust. Where a full succession is present, red marls and a basal clayey gravel of undoubted fluvial origin underlie the sandstones. The thickness of the Kalahari succession is largely a function of pre-Kalahari Group topography, with the gravels being largely confined to palaeovalleys and channels.

The palaeo-drainage system represents a post Waterberg elongate southwest trending basin infilled with Karoo Supergroup, Dwyka Group and tillites. During the post-Karoo period, a drainage system was cut into the soft Dwyka sediments that in turn were infilled by Tertiary Kalahari Group sediments.

The maximum known thickness of this unit is 120m (north of McCarthy's Rust) but in excess of 220m is proven in the Bray area and in adjoining Northern Cape Province. The surface Aeolian sands, named the Gordonia Sand Formation, are up to 20m thick and are underlain by a duricrust horizon of silcrete and calcrete. Fine-grained sandstones with a carbonate or silica cement matrix and containing lenses of clayey material underlie the cretes. The Budin Clay Formation (a red clay) is restricted to valleys or depressions in the pre-Kalahari surface and may be fluvial or lacustrine in origin. It grades into a basal gravel (Wessels Gravel Formation) that is a coarse alluvial deposit restricted mainly to palaeovalleys.

The thickness and distribution of the Kalahari Group is largely a function of the pre-Kalahari topography. Some of the buried channels, in which the clays and gravels were deposited, follow the approximate alignment of Palaeozoic pre-Dwyka valleys. There may thus be a local correspondence between the distribution of the thickest developments of the Kalahari Group and Dwyka group, in particular the Malogong Formation. This may be the case for the pre-Kalahari valley that appears to trend NW-SE to the northeast of Tsabong. The Kalahari sandstones (Eden Formation) have a much wider distribution than the clays and gravels and may have been in part deposited in a braided river system.

In Quaternary times, major rivers such as the Molopo and Kuruman have incised the Kalahari Group, which may now be exposed in cliffs overlooking the valleys. This is well seen in the Molopo Valley around Middelpits. Recent alluvial gravels are found in the present and sometimes earlier courses of these rivers but are now often buried by wind blown sands. Gravels, possibly deposited on old terraces of the Molopo River, cover an extensive area north of Middelpits and recent gravels are known in the present bed of the Molopo at McCarthy's Rust.

2.7.7 Structure

The Molopo River Basin lies between the Kaapvaal Craton in the east until a few kilometres west of Tsabong. At Tsabong, early Proterozoic rocks of the Kheis and Mangodi Orogenic Belts are encountered. In the west there is the Nossob-Ncojane Basin of the Damara Orogenic Belt. Most of the study area has been tectonically stable since the end of the Achaean, approximately 2700 million years ago. Kheis Orogenic Belt occurred approximately 1900My the core of which lies to the west along the margin of the Kaapvaal Craton, as conventionally defined. Two major igneous complexes have been intruded into Kaapvaal Craton namely the Molopo Farms Complex and the Gabarone Granite. Lack of exposure in the study area limits any detailed structural analysis. However evidence from outside the study area shows that gentle to moderate bi-directional folding (E-W and NNW-SSE), associated with faulting (NW-SE), and took place between the deposition of the Transvaal and Waterberg Supergroups. It is clear that the rocks are extensively faulted, and are most probably within the area affected by the Kheis Orogenesis. It is likely that the basement rocks of the project area are at least affected by thrust faults with west to east translation, and recent high quality aeromagnetic data points to ductile deformation. There is no evidence for post-Waterberg folding in the area, therefore the Waterberg deposition was almost certainly controlled by pre-Waterberg

folding and faulting. Most faults are inferred from geophysical surveys, LandSat and aerial images. Such interpretation suggests NE-SW is predominant.

Post Waterberg faulting seems mainly to be parallel to the dolerite dykes in the area, which trend WNW, NW or NNW. The geological structure of Botswana is contained in **Figure 2-6**.

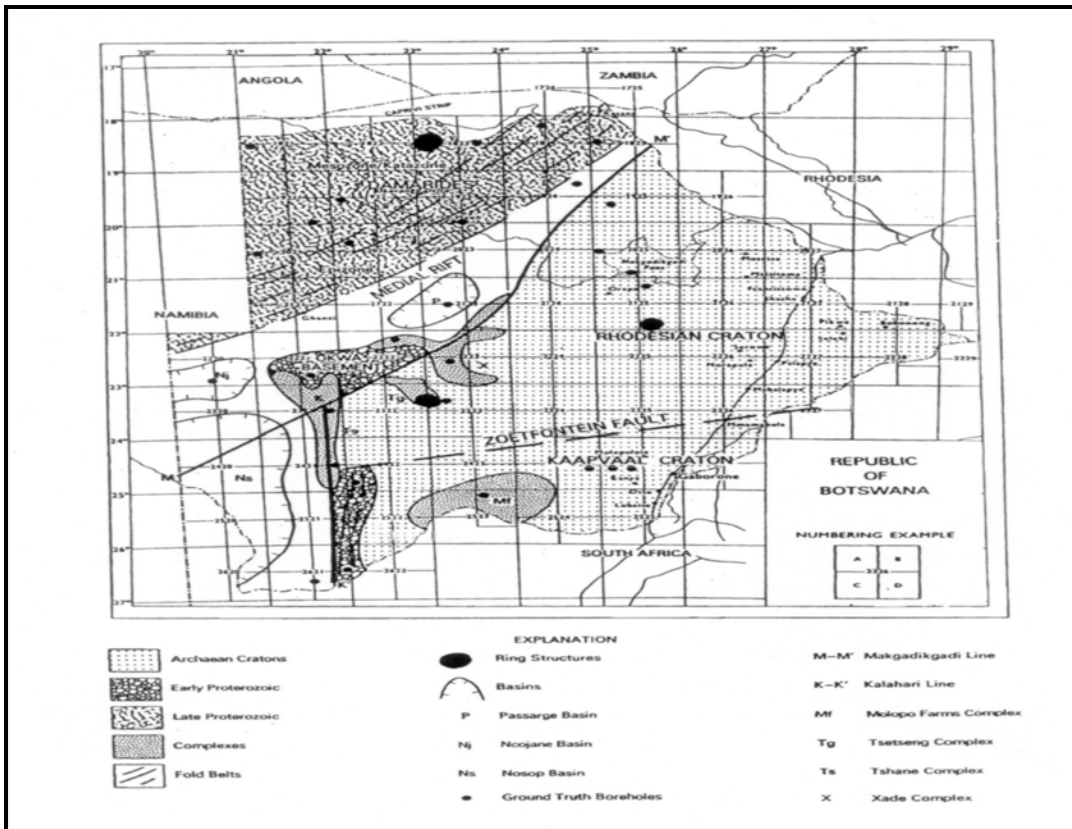


Figure 2-6: Structural Geology of Botswana

2.8 Regional Geohydrology

The Molopo River Basin encompasses all of the known aquifer units in Botswana. These include :

- Basement Aquifers
- Transvaal and Waterberg Aquifers
- Upper Proterozoic Aquifers
- Karoo Aquifers

- Kalahari Group Aquifers
- Sand River Alluvial Aquifers

The Botswana National Water Master Plan sub-divided the various aquifers in Botswana into the following four categories :

- Fractured porous – Dual porosity system whereby water is released from a porous matrix via a series of transmissive interconnected fractures
- Fractured – Aquifer whose material has limited porosity due to the rocks' solid fracture or to subsequent metamorphic changes. In this case fracturing, jointing and weathering provide the storage and transmissive properties of the aquifer
- Porous – Aquifers that store and transmit water via the interstitial pore space in the sedimentary formation
- Karstic Fractured – Aquifers in carbonate rocks where solution-weathering joints, fractures and bedding have enhanced the water-bearing properties of the rock.

The Molopo River Basin area within Botswana contains all four of the above mentioned aquifer types. These are :

- The fractured porous type, represented by the Karoo sandstones, comprise 37% and are the most common but generally nearly always saline
- The porous aquifers, represented by alluvial and Kalahari bed aquifers, comprise 35% are generally saline or low yielding and occasionally fresh
- The fractured aquifer, which includes the Archaean Basement and Proterozoic aquifers and Karoo Basalts, comprise 27%
- The Karstic fractured aquifers, which are represented by the Transvaal dolomite units, comprise only around 1%

The Hydrogeological Reconnaissance Map published by the Department of Geological Survey (DGS) indicates the groundwater resource potential of the study area tends vary from fair in the northwest to poor in the southeastern section and the area around Tsabong is classified as fair to good. Relevant maps show that the areas of fair to good groundwater potential coincide with areas of quartzitic outcrop.

2.8.1 Basement Aquifers

Generally there are poor prospects of securing groundwater in the Proterozoic rocks of the study area. Groundwater occurrence in these rocks can be wholly attributed to secondary porosity (water contained in fractures and fissures). As such, the resource is controlled by the size of the fractures and their relative interconnectivity. The most significant aquifer is located at Sedibeng where ten boreholes have been drilled with average yields per borehole of around 5m³/hr. These favourable water-bearing lithologies are restricted mainly to the east of the study area and are classified by the National Hydrogeological Reconnaissance Maps as having fair groundwater potential.

2.8.2 Transvaal and Waterberg Aquifers (Olifantshoek Sequence)

Several boreholes were drilled in the areas between Khuis and Kolonkwaneng for village water supply to Khuis, Middelpits, Bogogobo and Kolonkwaneng villages. The quartzites generally outcrop in the area but can be overlain by Kalahari Beds and river alluvials, which can reach a thickness of up to 23m. Water strikes in the fractured quartzites range from as shallow as 10m to as deep as 200m. Borehole yields tend to be highly variable and range from dry to 40m³/hr. The static water levels of boreholes range from 5m to 100m indicating that groundwater in the fractures occurs under unconfined to semi-unconfined conditions (with partial compartmentalisation). In Bogogobo, artesian conditions were reported at Borehole 5898 indicating confinement in the fractured quartzites. Tsabong and Goodhope are the only major supply wellfields within the Molopo River Basin catchment exploiting the Transvaal and Waterberg aquifers.

The Olifantshoek Sequence is dry in the Middelpits area and according to DGS Botswana, the quartzite north of Middelpits may be productive and further groundwater exploration and development programmes are recommended to fully define and delineate the groundwater potential. The GOB, in the absence of alternatives, knowingly mine (wellfield annual abstraction exceeds annual recharge) the groundwater resources from the aquifers at Tsabong (Waterberg Group). Groundwater has long residence times in this area and is classified as fossil (old waters). Long residence times suggest areas of low recharge potential.

2.8.3 Karoo Aquifers

The Dwyka Formation does not constitute an important aquifer in the study area as suggested by the results from boreholes drilled near Gakhibane. These boreholes were

dry (no water strike recorded). In borehole 9423, minor seepage accumulation was noted after drilling. A representative water sample was collected and subsequent water chemistry results indicated highly saline water with an associated Total Dissolved Solids (TDS) of some 7170mg/l. Known borehole yields in this aquifer are generally considered to be low, showing little confining head and poor quality water.

The Eccca Group sediments cover more than 40% of the study area and hence vast majority of boreholes have been drilled in these sediments. The Eccca sediments occur under varying thickness of Kalahari beds ranging from 10m to 55m. The Otshe sandstone of the Eccca Group forms an important aquifer in the study area with localised areas of potable groundwater. It consists of a complex succession of fluvial and deltaic sediments. The sediments consist of multiple interbedded layers coarse-grained sandstone, shales, mudstone, carbonaceous shale and poor coal. Argillaceous units within the formation confine the individual water-bearing sandstone units.

The Otshe sandstone generally provides sufficient yields (2-3m³/hr) for livestock watering in both confined and unconfined conditions. The confined sandstone generally yield very saline water while semi-confined sandstone yield usable brackish water and in some areas the confined Otshe sandstone aquifer contains fluids too saline for any agricultural use. Depths to first water strike in the Eccca sediments are highly variable and range from 30m to 200m. Multiple water strikes have been recorded in several boreholes tapping the Eccca aquifer(s) with the deepest water strike logged at 301m. Borehole yields are variable and range from dry to 60m³/hr.

2.8.4 Kalahari Group Aquifers

The Kalahari Group aquifers consist of a layer of Aeolian sand that may display relict dune structures (mainly Barchans). At the present time, the sand is fixed by vegetation and the dunes are considered to be fossil. A duricrust layer of silcrete and calcrete that must represent an unconformity within the succession generally underlies the sand. Poorly consolidated sandstones that are often calcareous underlie the duricrust. Where a full succession is present, red marls and a basal clayey gravel of undoubted fluvial origin underlie the sandstones. The thickness of the Kalahari succession is largely a function of pre-Kalahari Group topography, with the gravels being largely confined to palaeochannels.

The basal Kalahari gravels can constitute a useful aquifer. The Kalahari Group sediment thickness around Bray in Botswana and Vryburg in South Africa indicate a broad 15-30km wide trough of these sediments (in excess of 180m) forming a palaeovalley. The northern flank shows several tributaries, which drain southwards into the palaeovalley. The palaeovalley crosses the international border and passes into the Molopo Farms area.

There is high borehole density on the South Africa side of the border indicating extensive abstraction of the groundwater resource on this aquifer. Thus the Kalahari aquifer(s) constitute an important water supply source in the region, along with the Molopo and Nossob rivers for both human and livestock populations. The water strikes range from 12m to 72m with yields ranging from $<1.0\text{m}^3/\text{hr}$ to $8.6\text{m}^3/\text{hr}$.

2.9 Water Quality and Chemistry

Water quality is the major constraint on groundwater utilisation in the study area. The groundwater over much of the southern and western Kgalagadi District is excessively saline and large areas of the Otshe Formation sandstone aquifers and Kalahari group aquifers are quite unusable. Salinity stratification is evident in the fracture aquifers of the Olifantshoek Supergroup and pumping has the effect of drawing deeper, more saline fluids into public supplies. The hydrochemistry of groundwater in the southern Kgalagadi has been reviewed by Molebatsi (1994) who concluded that the salinisation is result of dissolution of salt evaporites in the Kalahari Group (similar situation to the northern areas of Namibia in the Ondangwa region).

The water quality in the basin area varies from fresh to hypersaline. The most important ions contributing to the groundwater salinity are chloride, sulphate and sodium. As a result there is good correlation between these ions and Total Dissolved Solids (TDS). Therefore, the spatial distribution of TDS provides a good measure as well of chloride, sulphate and sodium. The highest concentrations are in the boreholes near Khawa, in the northeast section of the study area, just north of Middelpits, Gakhibane, and Rappelspan and between Two Rivers and Tshane-Tshane. The lowest concentrations occur in Middelpits, Khuis and Bogogobo and stretch further northwest to Khotswane.

Other occurrences of relatively low salinity water are in a few sections along the Molopo and Nossob Rivers (around Gafrans and Drie-ertjies). Further east the groundwater quality improves dramatically and few boreholes are reported to be saline east of Mabule. There are a few relatively fresh water borehole samples that exhibit levels greater than the BOS

32:2000 (Botswana Drinking Water Standards) DWA maximum permissible limit (max 100mg/l) supplying drinking water to Khuis, Gakhibane and Middelpits areas. Elevated nitrate levels are usually indicative of organic contamination.

2.10 Transboundary Groundwater Resources

The Internationally Shared Aquifer Resources Management Programme (ISARM) was established in 2000 in direct response to the challenges of shared water resources set out in the Declaration of The Hague Ministerial Conference. The current understanding of transboundary aquifers is poor as is the water resource management plan of such resources. Present international law does not adequately address the issues concerning spatial flow of groundwaters and has limited application. Scientific correlation of the Geohydrology of such aquifers is often deficient and issues related to shared and sustainable production remain blurred because of poorly developed institutions and lack of capacity and awareness.

2.10.1 The ISARM Programme

The International Shared Aquifer Resource Management (ISARM) Programme operates through a co-ordination committee drawn from UNESCO, FAO and the International Association of Hydrogeologists (IAH). Each of these organisations provides a multidisciplinary initiative aiming to improve understanding of scientific hydrogeological, socio-economic, legal, institutional and environmental issues surrounding the management of transboundary aquifers. The ISARM programme is scheduled for completion in 2006 and its aim is to address the five key issues identified above. Specific project objectives are :

- To establish a network of experts from different disciplines for identification and definition of internationally shared aquifers
- To promote scientific, legal, socio-economic, institutional and environmental assessment of internationally shared aquifer resources
- To identify several case studies of internationally shared aquifers and support multidisciplinary expert teams to conduct detailed investigations
- To learn from case studies the issues relevant to good management of internationally shared aquifer resources

- To raise awareness of policy and decision makers of the significance and importance of transboundary aquifer resources, forming a critical component of the world's freshwater resources
- To disseminate the lessons learned from case studies and encourage policy and decision makers to incorporate appropriate internationally shared aquifer management
- To promote co-operation among experts from different countries that share transboundary aquifers, through making available scientific tools, water resource management options and methodologies that apply to such aquifers

2.10.2 Case Studies

One of the ISARM case studies, and relevant to this report, was carried out on the Stampriet Artesian Basin that is shared by Namibia, Botswana and South Africa. The Karoo Aquifer is predominantly utilised by Namibia where most of the recharge to the aquifer probably occurs. The aquifer is a key component of human and economic development in the arid environment of the Kalahari. The Lebung and Ecca Groups located within the Karoo Supergroup host the main significant water bearing layers of the Botswana Nossob Basin. Groundwater flow (hydraulic gradient) is to the east and southeast. The northern part of the basin is the object of an ongoing resource evaluation study, which is scheduled for completion by the end of 2005. The study will include the establishment of a numerical model with abstraction simulations to supply settlements in the region. Generally the Ecca Group sediments are represented by prograding (in the normal direction of flow) delta sediments, which were fed by rivers draining the highlands (Ghanzi Ridge) to the north. Southwards the deltas merged into a marine environment and here hypersaline conditions prevail.

In Namibia, there is a comparatively good understanding of the geology and geohydrology of the aquifer in the Stampriet Artesian Basin. Water occurs in the Auob and Nossob sandstones of the Ecca Group as well as the overlying Kalahari Group sediments. The strata dip approximately 30⁰ towards the southeast and as in Botswana, the water quality deteriorates in that direction as well. The Department of Water Affairs in Namibia was undertaking construction of a numerical model of the aquifer.

In the South African part of the basin, mainly along the Molopo and Nossob Rivers, the known productive and potable aquifers are in the Kalahari Group and the inference is that being down-gradient from the hypersaline Stampriet / Nossob Basin, the Ecca Group sediments will be similarly saline. Point source information is available in the National Groundwater DataBase. Water use, main recharge areas and general flow patterns are poorly known in that part of the aquifer. Water quality issues of elevated nitrate concentrations are generally common throughout the Stampriet / Nossob Basin. These are thought to relate to naturally occurring nitrate within the soil profile in addition to areas where large concentrations of cattle occur. The nitrates are flushed down into the aquifer following heavy rainfall events.

2.11 Aquifer Management Programmes

It is generally accepted that the thickness of the Kalahari sand, the duration and intensity of rainfall events coupled with rate of evapotranspiration have great bearing on the groundwater recharge potential in the Kalahari type environment. It has previously been assumed that areas of no or limited Kalahari sand cover play an active role in the recharging of any aquifers below the Kalahari Beds. It has thus been hypothesized that when the Kalahari strata is fractured, a fair borehole yield with relatively good water quality is more likely to be encountered in areas where there is no or very limited cover of the Kalahari Beds. However, even if the Kalahari cover is thin but no fracturing has been uncovered, the yields are still likely to be poor.

2.11.1 Recharge Research in Botswana

A research project (Groundwater Recharge Estimation Study – GRES) implemented by the University of Botswana and DGS in association with the University of The Netherlands) was setup to measure recharge rates in Botswana. This project resulted in the setting up of complex climatic measurement stations. At present these stations are based at sites close to four villages in Botswana with a variety of different climatic profiles. The settlements and conditions are as follows:

- Tsabong – southwest and very dry
- Serowe – central and representative of most of Botswana
- Bere Mathoaaphuduhudu – west central and dry
- Maun – north in the Delta

The stations have sap flow sensors and soil moisture sensors to depths of eight metres to record moisture movement through the unsaturated zone. These ground stations also incorporate measures to record the following parameters :

- Incoming and outgoing solar radiation
- Incoming and outgoing thermal radiation
- Relative humidity profiles
- Air temperature profiles
- Wind speed
- Soil heat flux
- Rainfall
- Groundwater level fluctuations

The study involved qualitative descriptions of recharge based on a combination of hydrochemical and hydraulic methods; assessment of long-term and short-term recharge using hydrochemical and hydraulic methods; quantification of recharge within the zones from groundwater flow models. The main features of the hydrochemical work were isotope studies, noble gas sampling and chloride mass balance.

Results from GRES have so far estimated recharge in the Letlhakeng – Botlhapatlou area (at the fringe of the Kalahari) at around 7mm/yr, with a decrease to less than 1mm/yr in the Central Kalahari. It appears that a critical threshold of 400mm/yr rainfall is essential for recharge. In 2000, the International Institute of Aerospace Survey and Earth Sciences set up a further eight sites in the Kalahari as a result of the Kalahari Research Programme – Establishment of Monitoring Network for Water Balance Studies. The work is ongoing

A variety of methods for estimating recharge are currently applied in Southern Africa (including Botswana). As a result recharge rates have been calculated for wellfields in the study area in several previous investigations and assessments. A number of methods have been applied to estimate recharge, with chloride mass balance been the most common. These results are often coupled with groundwater modeling to produce refined estimates. Recharge estimates using various methods from such projects, which were conducted in some parts of the study area are presented in **Table 2-9**.

Table 2-9: Recharge Estimates for Basin Area from Previous Projects Undertaken

Wellfield	Method	Recharge (mm/yr)	Ref	Recharge Area
Matsheng	Chloride mass balance	0.1 – 23	DGS, 1996b	Widespread
Tsabong	Chloride mass balance	0.16 - 77	DWA, 1993	Fractured quartzite
Werda Sekoma	Isotopes	6 - 8.6	DWA, 2003	Widespread over Kalahari area
Sikamatswe	CRD	0.1 - 2.3	DGS, 2003	Sikamatswe
Molopo River Bed	CRD	0.1 - 2.3	DGS, 2003	Molopo River Bed

Recharge estimation in the Kalahari requires much attention due to its role in sustainability of any groundwater development of whatever nature. The estimation of recharge in semi arid to arid environments, such as the Kalahari, has been proven to be rather difficult. Not much has been done in terms of employing other methods, which could give a better understanding of the replenishment of the aquifers within the study area.

2.11.2 Hydrogeological Mapping

Detailed hydrogeological maps of various types and scales are available in Botswana. They include:

- Hydrogeological reconnaissance maps (1:250,000) that summarise the hydrogeological data for areas; the information includes yield potential, water quality and where possible, flow directions (hydraulic gradient)
- Groundwater vulnerability maps in various scales
- Extensive regional and local maps are present in various reports on projects

2.11.3 Groundwater Monitoring

The Monitoring Section of DWA carries out monitoring of groundwater levels and abstraction quantities. Together with boreholes monitored by the DGS, a total of approximately 800 boreholes are monitored. The vast majority of these boreholes are hand dipped, with 57 equipped with chart recorders and 23 using transducers. Data for wellfields, operated by non-governmental organisations (such as Water Utilities Corporation, mining operations) are provided to DWA and summarised in the Water

Apportionment Board (WAB) annual reports. Since 2000, both DWA and DGS have installed standardised digital automatic water level recorders.

2.11.4 Databases

The Department of Geological Survey has historically maintained a mainframe National Borehole Archive (NBA). The NBA is a somewhat archaic and antiquated MS-DOS based stand-alone system and does not support multiple-user configurations. As such, it is maintained by DGS with a copy at DWA. DGS is responsible to provide periodic updates to. However, this occurs infrequently.

The National Borehole Archive is populated from the data recorded on Borehole Completion Certificates (BCC). However, some four years ago it was wisely decided a new system would be implemented and so data input into the old DOS based system was terminated. In 2002 a new hydrogeological database (GeoDin) was launched but it contained only the little data that was available to be transferred from the old NBA. It was intended that all the BCCs would be entered into the system. Currently data is not being entered in the GeoDin system, as the system is unserviceable. There is thus a huge backlog of data.

The Department of Water Affairs maintains separate databases as a response to the limitations of the existing database arrangements. WELLMON is a software package for groundwater monitoring data, climatic data etc. used to produce groundwater hydrographs. The data stored in WELLMON does not include all the data that had been collected during an audit into wellfields. DWA had managed their version of WELLMON for the wellfields they are responsible for. DGS, conversely, had not entered much of the data that were collected over the years. Water level recorders are installed in 55 boreholes located in some 19 wellfields. The recorders provide a continuous measurement of water level fluctuations, if and when functioning properly. The recorders are maintained by DGS, and to a lesser degree by DWA, who in theory visit them on a monthly basis to replace the charts. Due to a lack of human resources, DGS has been unable to digitise most of the charts for entry into the WELLMON system.

The quantity and quality of the data obtained from the charts were found to be very poor indeed. Some of the problems found are :

- The vertical scale was incorrectly set, which caused the water level to plot off the chart. Training should be given to all concerned

- Drum turned too slowly
- Pen got stuck or ink dried up, rendering the data incomplete and useless
- Chart was not collected within 30 days which results in the printing of two or more water level data

Abstraction data is stored in WELLMON and the data sets are from time to time somewhat problematic and generally the data within the WELLMON is poor.

2.11.5 Available Groundwater Reports of the Study Area

Numerous groundwater studies have been conducted in the study area resulting in several reports, which may be useful a reference material in any future groundwater development programmes in the area. **Table 2-10** below presents a list of available reports discussed above. The confidence level is indicative of the level of accuracy of the facts as presented in such reports.

Table 2-10: Available Groundwater Reports for the Basin Study Area

Title	Author	Date	Format	Confidence Level
Botswana Master Plan for Waste Water. Inception report.	Department of Sanitation and Waste Management	2002	Hardcopy	Low
Botswana National Water Master Plan. Final Report Volume 5, Geohydrology.	SMEC, WLPU Consultants and Swedish Geological International	1991	Hardcopy	Low
Groundwater Potential Survey Middlepits / Makopong TGLP Areas. Final Report Vol I Text, Vol II Inventory of Boreholes, Vol III A Project Boreholes, Vol V Geophysical Data,	Water Surveys (Botswana) for the Department of Geological Survey	1994	Hardcopy	High
Middlepits And Tsabong TGLP Groundwater Potential Study, Final Report.	Water Surveys (Botswana) for the Department of Geological Survey	1994	Hardcopy	High

Title	Author	Date	Format	Confidence Level
Tsabong Groundwater Investigation, Assessment and Development, Final Report,	Resources Services (Pty) Ltd For the Department of Water Affairs	2003	Hardcopy and Digital Copy	High
Groundwater Potential Survey Werda Sekoma TGLP. Final Report.	Wellfield Consulting Services for the Department of Geological Survey	2003	Hardcopy and Digital Copy	High
Groundwater Potential Survey Bokspits TGLP Areas. Final Report.	Geoflux (Pty) Ltd for the Department of Geological Survey	2002	Hardcopy and Digital Copy	High
Matsheng Area Groundwater Investigation (TB 10/2/12/92-93) Final Report...	Wellfield Consulting Services for the Department of Geological Survey	1996	Hardcopy	Medium
Water Supply Rehabilitation Programme Kokotsha, Kgalagadi District. Final Report.	Hydrogeo (PTY) Ltd For the Department of Water Affairs	2000	Hardcopy	Medium
SADC/WSCU Development of Code of Practice for Groundwater Development in the SADC Region Report No1 (Final) Situation Analysis Report	Bee Pee Groundwater Consultants	2001	Hardcopy	Low
Hydrogeological Investigation of the Molopo Farms DGS unpublished Report SKM/2/83	Mukupadhyay, S.K. Malejane, R.M and Sutcliffe, H.M	1983	Hardcopy	Low
Consolidated Emergency Programme (II) Sekoma, Maralaleng, Werda and Sekoma-Makopong Road. Final Report Volumes 1 and 2.	TTCS Groundwater Consulting Services For the Department of Water Affairs	1990	Hardcopy	Medium
Hydrochemistry of the Groundwater in the Kalahari, Southern Botswana. Unpublished MSc. Thesis	Phofuetsile, P. University College of London	1988	Hardcopy	Low

Title	Author	Date	Format	Confidence Level
Consolidated Emergency Programme (I) Makopong, McCarthy's Rust, Draaihoek Vaalhoek and Bray Final Report	TTCS Groundwater Consulting Services For the Department of Water Affairs	1989	Hardcopy	Medium

2.11.6 Water Quality DataBase

The database contains water quality analyses of surface and groundwaters. This database unfortunately does not contain and detailed positional data rendering it quite useless. The very thought of a database of this nature not containing positional data simply defies logic. A new testpumping database is in the process of being established. Attempts have been made to link the various databases but human resource limitations and lack of capacity has apparently thwarted the process. Both DWA and DGS update their separate databases independently and most of the time duplicates each other's efforts. There is definite scope for streamlining and improvement.

2.11.7 Department of Surveys and Mapping DataBases

The Department of Surveys and Mapping has a wealth of information available generally referred to as Land Information. The setup of the updating and retrieval of this information is done within a digital system known as a Land Information System. The content is of the data stored is broad and its potential uses is presented in Figure 2-7.

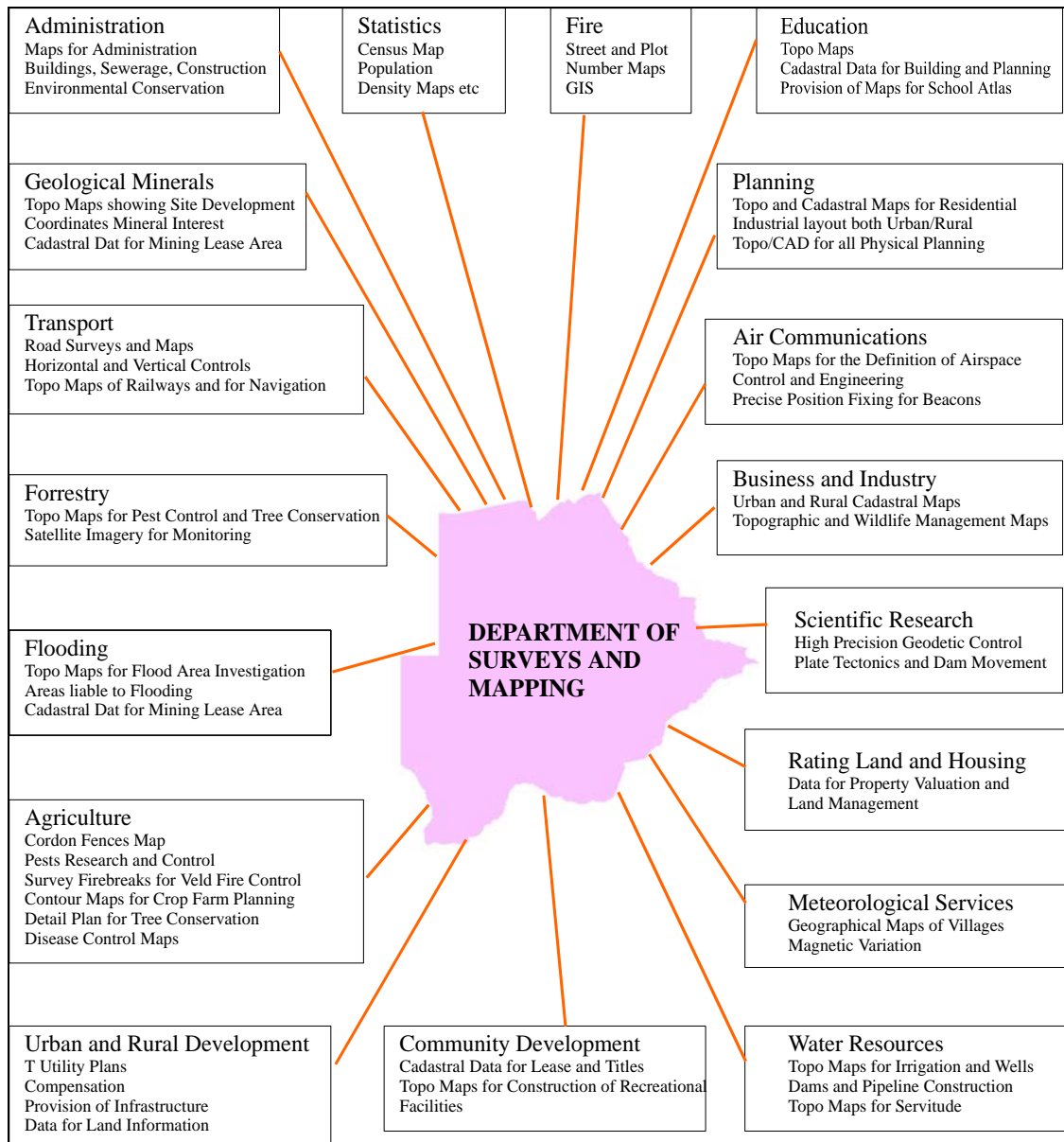


Figure 2-7: Land Information available at the Department of Surveys and Mapping

2.12 Potential and Planned Groundwater Utilisation Projects in the Basin Area

According to the Kgalagadi District Development Plan Six, the Botswana Defence Force is planning to erect a base camp in the Tsabong area. The camp is to provide both office and residential accommodation. It is currently not clear how large a development this is but it is understood to be a regional camp and may house up to 100 officers and families plus enlisted personnel. The National Master Plan for Agricultural Development (NAMPAD) of

Botswana has proposed some irrigation projects to be undertaken in the study area. The main proposed project is the establishment of vineyards in Tsabong to take advantage of the extensive sunshine and favourable conditions. The water is to be sourced from the Waterberg aquifers, which are currently exploited to supply drinking water for Tsabong and surrounding villages. Local farmers abstract minor quantities of water for stock and other watering from the aquifer. The planned maximum abstraction is estimated at 1 829 000m³/annum. NAMPAD estimates that the Molopo River in the Tsabong area has the potential of adequate groundwater and thus the envisaged vineyards irrigation project water demand would be comfortably met. Given the fact that the aquifer concerned straddles Botswana and South Africa, it is thus strongly recommended that a full water demand study be undertaken before this programme proceeds with implementation

NAMPAD has also planned further irrigation projects further east around Ngwaketse South. The groundwater source would be the Kanye wellfield (Transvaal Supergroup Dolomites aquifer). The planned water demand to meet these new developments is some 6.19x10m³/annum while the proposed wellfield has a potential groundwater production of 5x10m³/annum. The shortfall will be met with the harnessing of potential wastewater reclamation from Jwaneng and other boreholes. Clearly this shortfall should raise red flags and further planning and investigation should to be done before the project is cleared for implementation.

2.13 Reports and References

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3 NAMIBIA GROUNDWATER OVERVIEW

ORASECOM, the Orange-Senqu River Commission was established to enable Integrated Water Resources Management Planning for the Orange River Basin. The purpose of this section is to review the Namibian groundwater resources to provide relevant (existing) information for a meta-database to be developed for ORASECOM. **Figure 3-1** shows the Namibian catchments of the Orange River. As can be seen, the upper part of the Auob is cut off from the lower section; Oanob and Schaap end in a dune field northeast of Kalkrand. Likewise, below the confluence of the Auob and Nossob Rivers the river course of the Molopo is blocked and even large floods from the sub-catchments do not reach the Orange River.

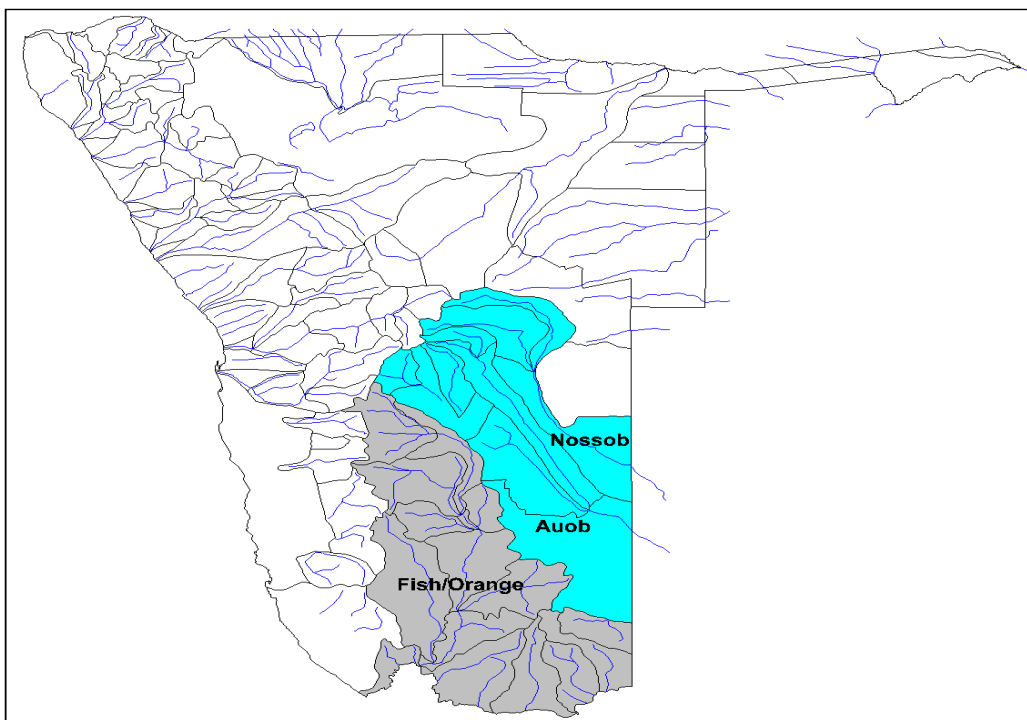


Figure 3-1: Namibian Catchment of the Orange River with Sub-Catchments

3.1 Historical Development of Water Affairs (DWA) in Namibia

Recorded drilling activities started early in the last century when the German colonial government operated a “Bohrkolonne” in the central and northern parts of Namibia and a “Bohrkolonne Sud” in the southern half of the country. Some early borehole data can be found in the National Archives as well as some early publications (Range, 1915). The

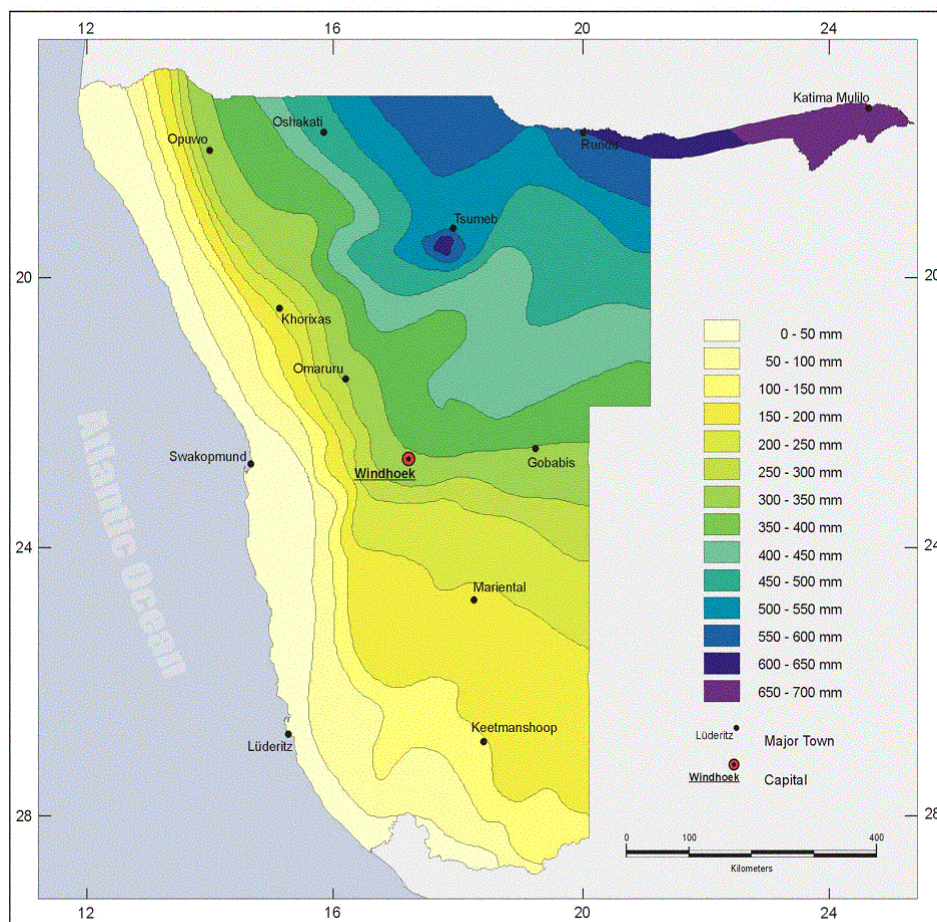
German "Schutzgruppe" had their own drilling rigs. After World War I, the South African Irrigation Department became responsible for drilling on new farming land to be issued to ex-soldiers. Sometime during the late 1930s the SWA Works Department took over the drilling activities. Later an independent Water Affairs Branch was instituted. In the 1960s the Geological Survey was established as the entity also responsible for Geohydrology.

In the late 1960s the whole SWA Administration was placed under the respective South African Departments in Pretoria and the SWA Water Affairs Branch became a subsidiary of the Department of Water Affairs in South Africa. Following South Africa, the Hydrogeological Section of the SWA/Namibian Geological Survey was transferred to the Department of Water Affairs in 1977. Under the new Namibian Government, Water Affairs has fallen under several different Ministries and is currently part of the Ministry for Agriculture, Water and Forestry.

Under this Ministry the Bulk Water Supply Section of the Department of Water Affairs has been commercialised and NamWater now operates all Bulk Water Schemes. Apart from bulk water supply, NamWater also supplies some rural communities on contract to the Directorate of Rural Water Supply (RWS), although the majority of rural water supply schemes are initiated and operated by the Directorate of RWS.

3.2 Climate

Namibia is the driest country south of the Sahara. The only perennial rivers are the border rivers of the Orange, Cunene and Okavango and Zambezi.



Source: Department of Water Affairs (1992): Updated Isohyetal Rainfall Map for Namibia

Figure 3-2: Rainfall Distribution

Figure 3-2 shows the rainfall distribution that varies from 700mm in the northeast to less than 50mm along the Atlantic Coast. The Orange River sub-catchments fall into an area that receives generally less than 250mm/yr while the potential evaporation is estimated at more than 3700mm/yr.

3.3 Population Density

The present population of Namibia is estimated at around 1.8 million people. The majority of these live in the northern half of the country. Maltahohe, Bethanien and Karasburg Districts have population densities of less than 0.25 persons/km²; Keetmanshoop and Mariental between 0.25 and 0.5 persons/km² while the communal area of Namaland and the Gobabis District have densities of around one person/km².

3.4 Economic Activities

Mining, agriculture and tourism are the main economic sectors in the study area. Agriculture is by far the largest sector with stock farming predominating. In recent years ostrich farming commenced in the Mariental and Keetmanshoop Districts and Karakul breeding has gained significant importance. Irrigation farming (lucerne, grapes and citrus and vegetables) are grown at the Hardap Scheme near Mariental and in the Stampriet Artesian area. Some irrigation also occurs below the Naute Dam (**Figure 3-3**). Large irrigation farming occurs along the banks Orange River.



Figure 3-3: Irrigation Below Naute Dam

Rosh Pinah and the recently developed Scorpion mine are two of the major mines located within the Fish River Catchment. Mining at the Haib Copper deposit near Nordoewer has not started. The diamond deposits of Oranjemund at the mouth Orange River are well known. Tourism is of lesser importance although the Fish River Canyon and the Ai-Ais Hot Springs are major attractions. Further points of interest are the Quiver Tree Forest and the Giants Playground near Keetmanshoop.

3.5 Geology

Damara schists and Nosib quartzites seem to predominate in the northernmost part of the basin. The Stampriet Artesian Basin lies in the central eastern section of the area and stretches into Botswana. Here artesian Nossob and Auob sandstone are separated and overlain by shale horizons under sediments of the Kalahari Sequence. To the west in the Fish River catchment the area consists mainly Nama-aged sandstone, shale and limestone. Karoo and Nama lithologies as well as dolerite intrusions are to be found in the southern section and Kalahari sediments occasionally overlie these lithologies.

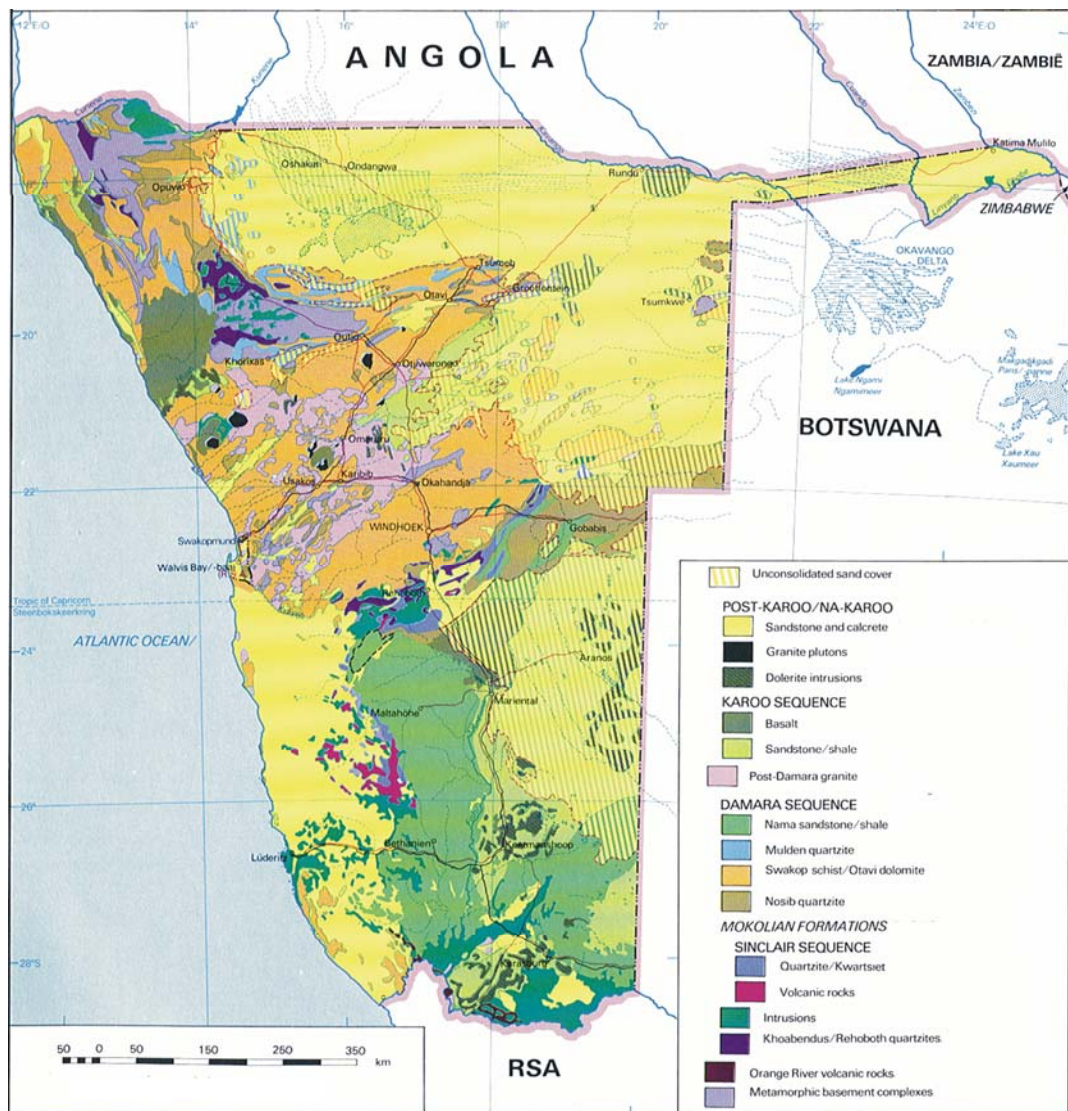


Figure 3-4: Namibian Geological Map

3.6 Geohydrology and Hydrology

The meteorological services of DWA and NamWater mainly operate the rainfall stations. In the Namibian Orange River sub-catchments there are a total of 284 stations on record (see **Figure 3-5**) that are or have been in operation for some time. The Hydrology Division of the Department of Water Affairs has compiled a Unit Runoff Map of Namibia at a scale of 1 : 1 000 000 depicting the relatively high unit runoff for the Fish River catchment. Runoff values reach up to 25mm in the southern Rehoboth District and around 10mm in the Weissrand area (between Mariental and Stampriet).

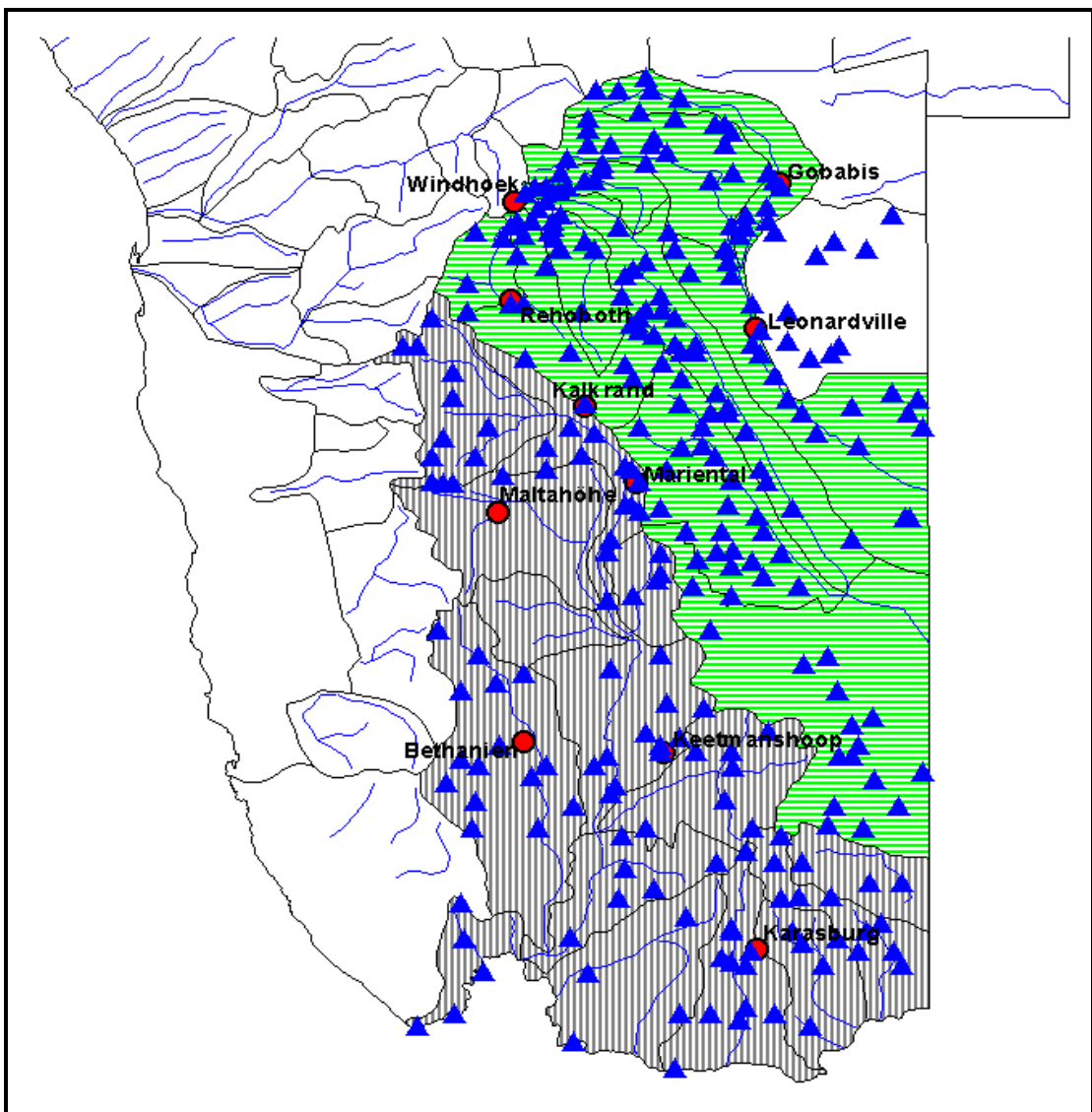


Figure 3-5: Approximate Position of Rainfall Stations

A total of 25 gauging stations are operated in the Namibian Orange River sub-catchments; three of them by NamWater and the remainder by DWA (the approximate positions are shown in **Figure 3-6**).

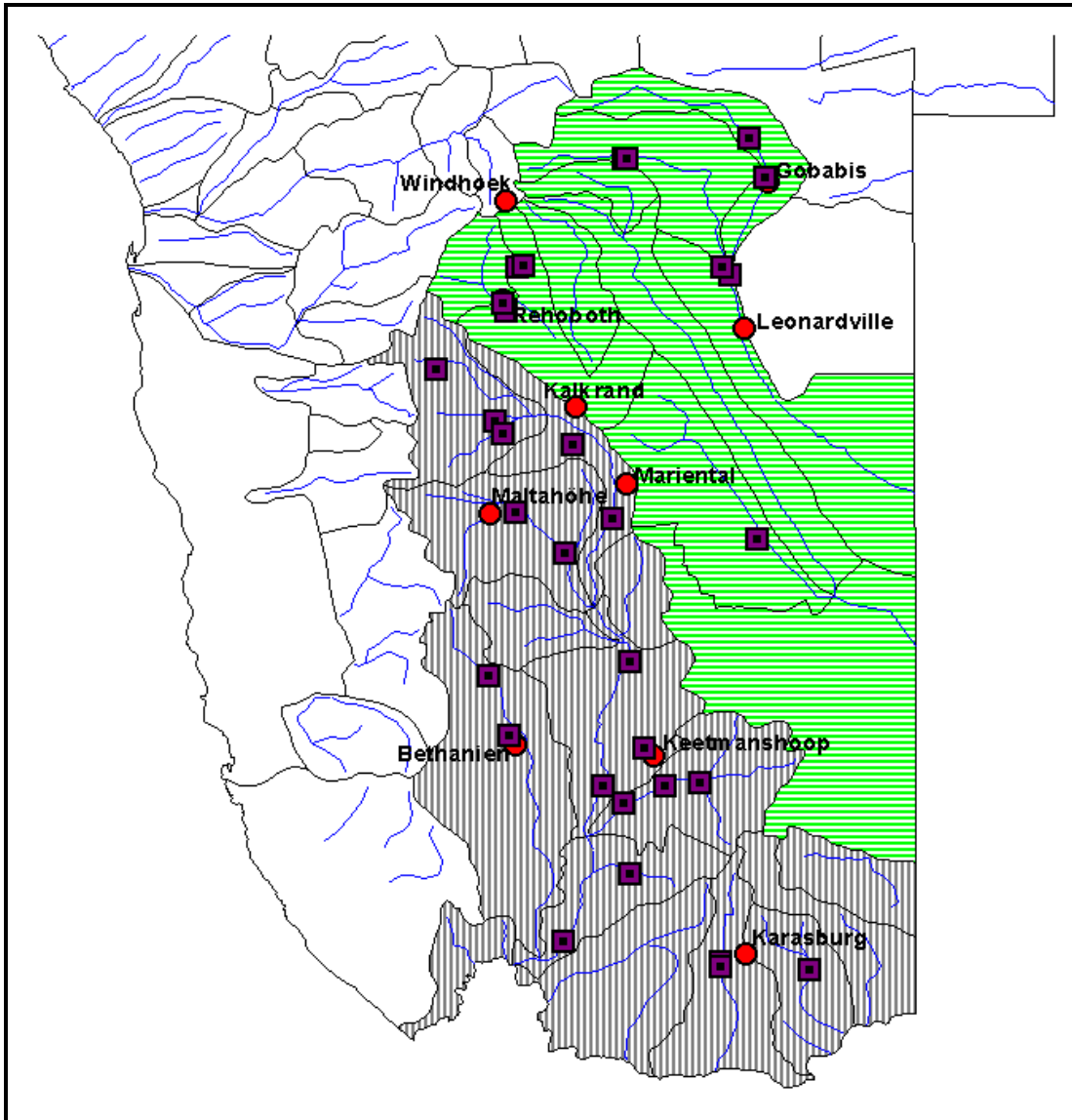


Figure 3-6: Gauging Stations in the Orange River Sub-Catchments

The groundwater potential or natural recharge of the country has not yet been fully determined. It is estimated that between one and two percent of rainfall actively recharges the Namibian groundwater. For some schemes and projects the safe yield has been determined but since recharge is rainfall dependent and as rainfall is highly variable in

Namibia, such values must be viewed with caution. In addition, groundwater potential information for certain areas does exist in certain reports (for Tsumeb and Stampriet etc.) but these have not yet been consolidated into a single report. A qualitative overview is presented in the Hydrogeological Map of Namibia (van Wyk, Straub et al. 2001).

3.6.1 Water Level Monitoring

Borehole loggers and recorders have been in operation at selected groundwater dependant towns and villages. Water levels are also monitored in the Stampriet Artesian Basin (south of Gobabis and east of Mariental). During a recent Japanese funded development project, ten additional observation boreholes were drilled to monitor the hydraulic characteristics of various aquifers in the area (Kalahari, Auob and Nossob aquifers). See **Figure 3-7** below for locations.

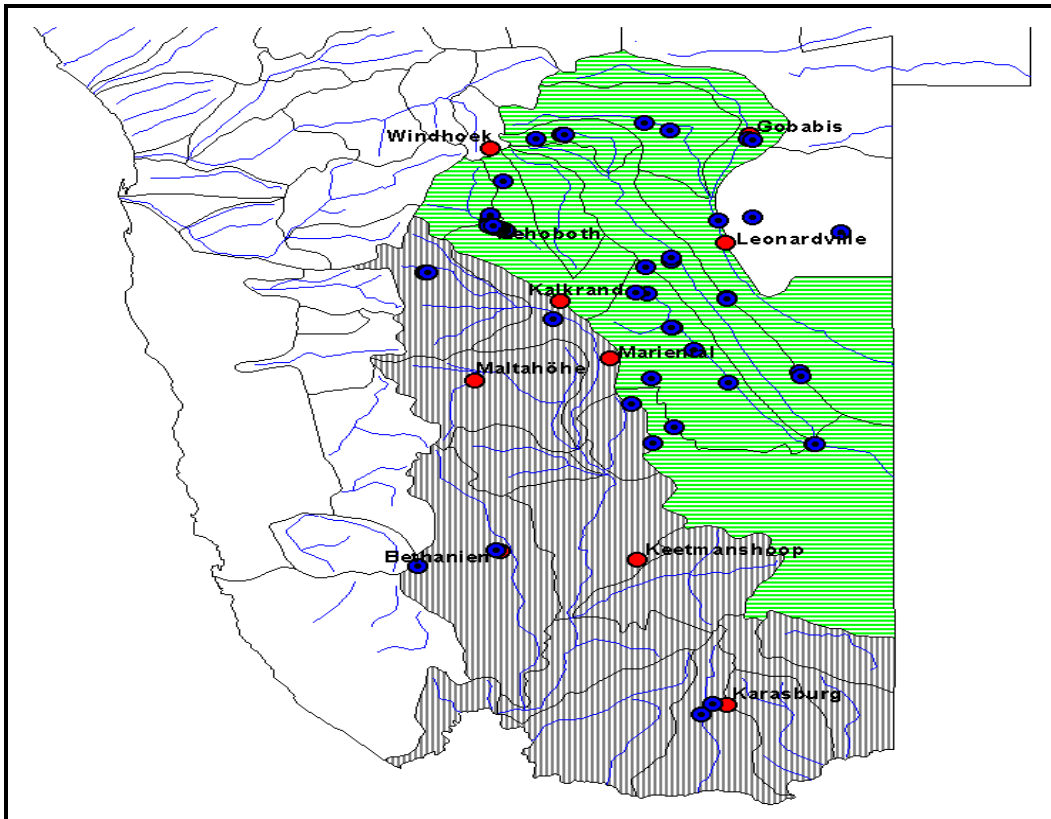


Figure 3-7: Locations of water level monitoring points

3.6.2 Data Formats - Hardcopy

There are some 40 000 records of Borehole Completion Forms of WW-numbered boreholes. The captured data records farm name and number, borehole depth, water strikes and associated yields, lithology and casing and more recently drilled boreholes include GPS data. The Department of Water Affairs owns the data sets. Some 90 000 water chemical analyses of mainly major ions plus some bacteriological data is also available. Many operational analyses from distribution networks and chemical data from numerous groundwater schemes are also available from DWA.

In addition, there are some 30 000 groundwater samples analysed by the CSIR during the CSIR Water Quality Project between 1965 and 1981. NamWater reports on production borehole utilisation rates on a monthly basis.

3.6.3 Data Formats – Electronic

There is a relatively complete set of captured data of the more important borehole parameters drilled before about 1990. Changing database platforms coupled with the new development of these databases and a lack of resources and capacity has led to a substantial backlog in the transferring of the datasets. A new database (GROWAS) became operational towards the end of 2004. Most rainfall data and surface water abstraction information (dams) is available in an electronic format.

DWA water analyses done prior to the 1980s (about 50 000 records) exist only as paper copies and some data captured in an ACCESS database since cannot be identified for various reasons. No further clarity on the issue is available. The balance of the data is available digitally but is somewhat awkward due to poor design and structure of the databases. More recent analyses are stored as (for some obscure reason) individual EXCEL spreadsheets so it seems logical that migrating these spreadsheets to ACCESS or similar should not be too complex a task. The CSIR Water Quality Map analyses data sheets have recently been captured and available in an EXCEL spreadsheet.

3.7 Groundwater and Surface Water Abstraction

In the existing Water Act of 1956, permits for large-scale groundwater abstraction are only required in Groundwater Control Areas of Namibia (see **Figure 3-8**). In the Orange River sub-catchments these are the Windhoek – Gobabis areas; the Stampriet Artesian Basin (in the map legend termed Windhoek-Gobabis-Mariental); and the Maltahohe artesian area. Good records exist for the Stampriet Artesian Basin. No permits are required for the

Hardap Irrigation Scheme and no records exist for the Maltahöhe area although it is known that grapes are grown on the Farm Neuras. In the past, irrigation also took place around Namibia's largest private dam on the Farm Voigtsgrund in the Maltahöhe District. It is not recorded whether irrigation continued after the Namibian Government acquired the property. A list of all the permits for abstraction from the Orange River indicates there are 13 permit holders with a total annual abstraction allocation of some 45MCM/a.

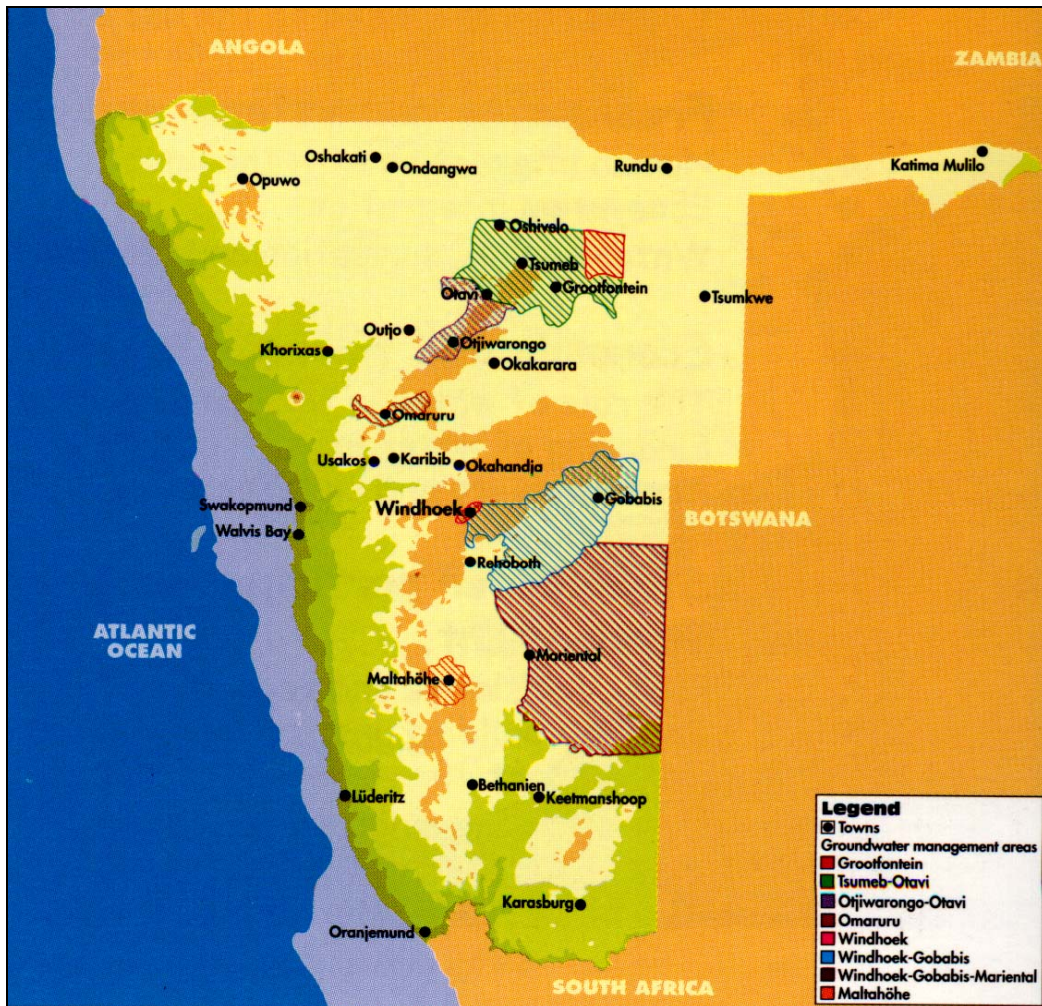


Figure 3-8: Groundwater Control Areas in Namibia

3.7.1 NamWater Schemes

The eight dams in the sub-catchments of the Orange River are shown in **Figure 3-9**. The capacity and mean annual abstraction for the major six are given in **Table 3-1**. The

capacities of the Nauaspoort and Bondels Dam are 3.32 and 1.3Mm³ respectively. The recorded mean annual abstraction from all six dams is given as 50.75Mm³.

Table 3-1: Mean Annual Abstraction from Six Major Dams

Dam Name	Capacity	Period	Mm ³ /a
Hardap	294.59	1994-2004	42.279
Naute	83.58	1994-2004	4.739
Oanob	34.51	1995-2004	2.653
Otjivero	9.74	1996-2004	0.649
Tilda Viljoen	1.22	2000-2004	0.403
Dreihuk	15.49	1999-2004	0.119

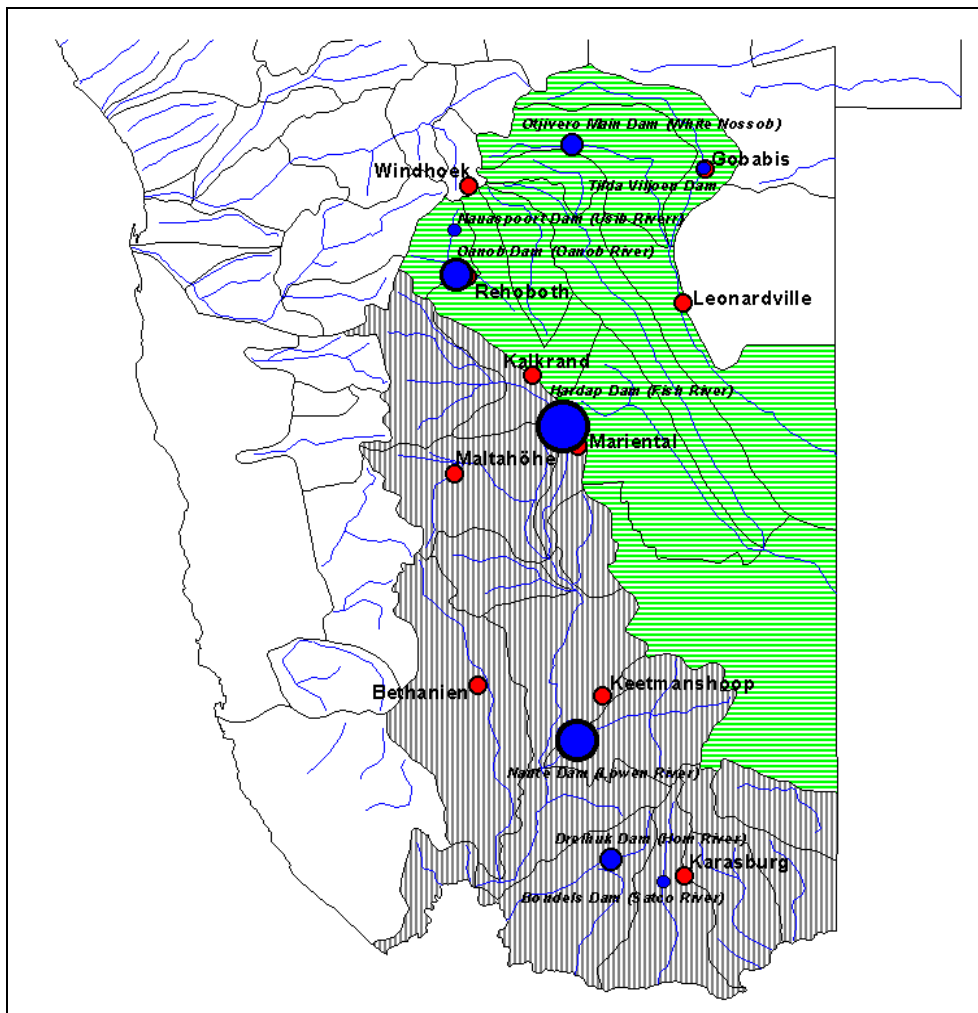


Figure 3-9: Dams in the Namibian Sub-Catchments of the Orange River

3.7.2 Groundwater Schemes

NamWater operates some 13 schemes in the Karas and Hardap Regions and two in the Omaheke and Khomas Regions supplying towns, villages and settlements as well as the Ai-Ais Resort. Mean monthly production and the number of boreholes of the respective schemes are listed in **Table 3-2**.

Table 3-2: NamWater Schemes in the Sub-Catchments of the Orange River

HARDAP REGION			KARAS REGION			KHOMAS REGION			OMAHEKE REGION		
Scheme	Boreholes	Monthly Production	Scheme	Boreholes	Monthly Production	Scheme	Boreholes	Monthly Production	Scheme	Boreholes	Monthly Production
Aminuis	2	2 000	Ai-Ais	8	5 550	Dordabis	4	1 860	Gobabis	30	144 690
Aranos	9	46 200	Arianslei	4	6 510	Windhoek Airport	12	17 170	WitMei	2	16 200
Gochas	3	9 000	Arwab	7	9 690						
Gibeon	2	48 000	Berseba	2	4 500						
Kalkrand	3	19 500	Bethanie	2	36 750						
Kries	2	2 610	Gabis	3	3 623						
Kweekwas	2		Gainachas	2	525						
Leonardville	3	10 200	Grünau	6	1 134						
Mittelhöhe	3	19 200	Karasburg	8	14 400						
Oamtes	3	23 640	Köes	2	12 240						
Onderontbapa	2	5 940	Kosis	2	3 960						
Schip	5	16 920	Tses	8	25 080						
Stampriet	2	9 300	Warrbad	2	2 400						
Total		212 510	Total		126 362	Total		19 030	Total		160 890

3.7.3 Stock Watering

The water demand for stock watering is about 50l/day for large stock units (cattle) and in the region of 5l/day for small stock units. Stock watering requirements are about 5l/ha/day in the northernmost parts of the sub-catchments and decrease somewhat in the southernmost areas. These values are rough estimates only, based on available information.

The study area size is calculated to be about 23.175 million ha. If one uses a carrying capacity of 15ha as an average, an estimated stock watering demand of some 3MCM/a would be required for stock watering.

3.7.4 Other Users

Unfortunately (and rather surprisingly) no information for the water consumption of the mines at Rosh Pinah, Scorpion and Oranjemund is available. Excluding these, a total annual water abstraction of 114MCM can be accounted for. Apart from the unaccounted mining sector abstraction rates, further allowances have been made for human consumption, gardening and water losses on farms etc.

3.8 Water Quality

A comparatively comprehensive groundwater quality database exists since the CSIR sampled and analysed most equipped boreholes and wells in the 2nd half of the 1960s and the 1970s with nearly 30,000 analyses displayed on four 1:1,000,000 maps. In addition to water quality issues, information listed includes borehole depth, yield, strike depth and water level, lithology and application. It remains unclear if the map database has been kept up to date.

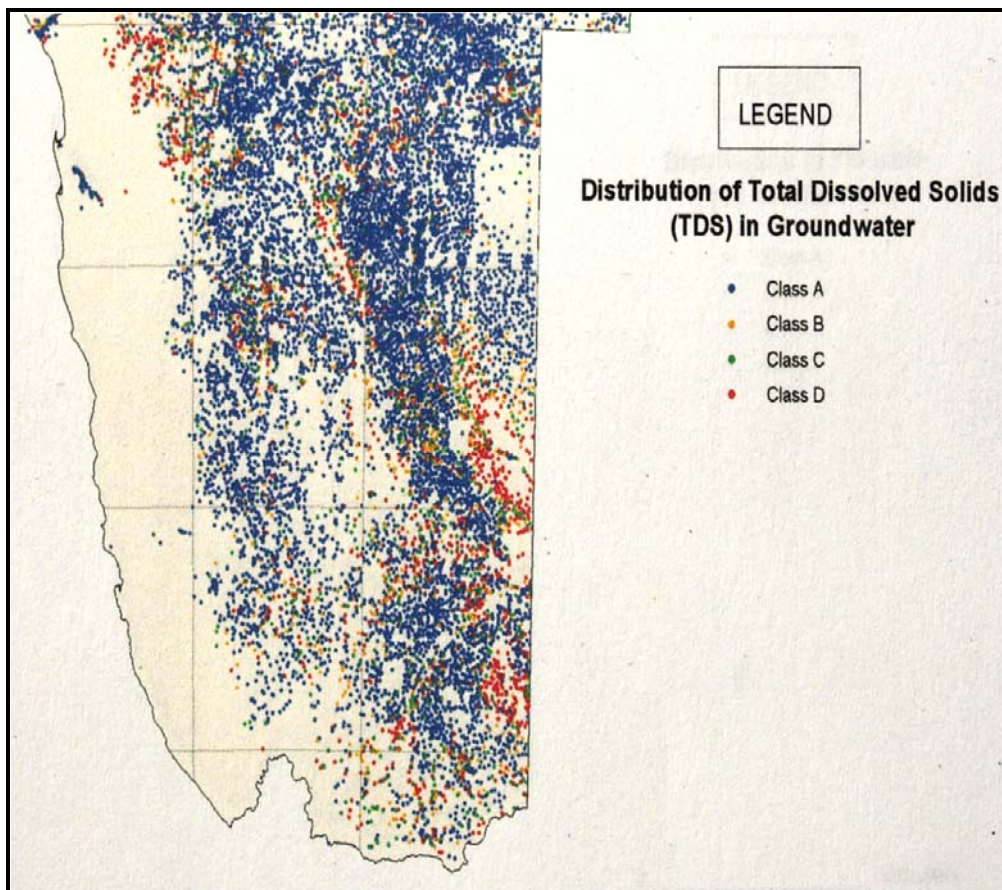


Figure 3-10: TDS Values According to Namibian Water Quality Guidelines

The groundwater chemistry is mainly of good quality and poor groundwater quality is generally confined to the southeastern corner of the Stampriet Artesian Basin. Elevated Nitrate levels are found in the same area but also appear to be slightly more widespread (see **Figure 3-11**). This is particularly true of the Kalahari and Kalkrand Basal aquifers along the western margin of the Stampriet Artesian Basin.

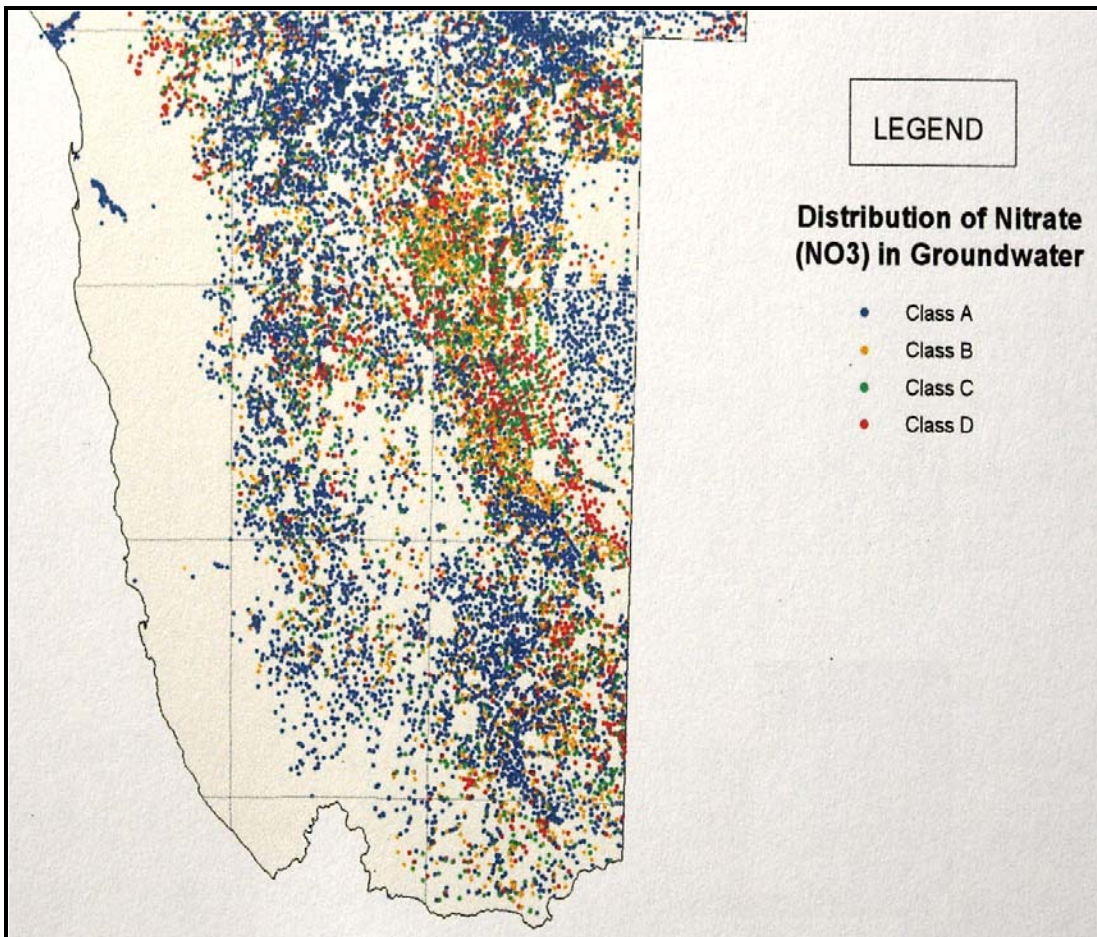


Figure 3-11: Nitrate Levels According to Namibian Water Quality Guidelines

3.9 Report and Information Listing

All the reports are held at the Department of Water Affairs and the format is mainly paper copies and only some reports after the early 90s are available digitally. Generally an acceptable confidence level can be expressed in these reports. The following is a list of available reports (all information is also available in a metadata file on the CD accompanying this report).

-
- (1964). Diamond core drilling, site and surface investigation for Naute Dam SWS.- Report
- (1969). Rosh Pinah Mine, S.W.A.: HISTORICAL.- Report
- (1975). Hidrologiese ondersoek Asab omgewing.- DWA/Windhoek: Report
- (1977). Olifantswater: Completion reports; Pump test and Letters.- Geohydrology/DWA/Windhoek: Report
- (1978). Addendum tot die verkenningsverslag: Watervoorsiening aan Aroab.- DWA/Windhoek: Report
- (1978). Beplanningsverslag : Addendum tot die verslag NR 3120/R7/1 watervoorsiening aan Rehoboth.- DWA/Windhoek: Report 3120/R7/1, 18 pp.
- (1978). Geologiese opname - Artesiese gebied Stampriet (Lidfontein omgewing).- Geological Survey/Windhoek: Report
- (1978). Groundwater potensiaal van Namaland.- Geohydrology/DWA/Windhoek: Report GH 490/2, 19 pp.
- (1978). Namaland groundwater potential report GH 490/2.- Geohydrology/DWA/Windhoek: Report
- (1978). Navorsingsverslag :Probleme as gevolg van en oplossing vir die hoë water tafel.- Geohydrology/DWA/Windhoek: Report
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- (1978). Planning report Kosis State Water Scheme.- DWA/Windhoek: Report 10 pp.
- (1978). SWA Coal Project (Aranos Basin).
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- (1985). The development of the Fish River catchment basin with special reference to water supply.- DWA/Windhoek: Report
- (1987). Euro Namibian investment Co. Ltd.: Aranos Coal Deposit Locality Plan.
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- (1987). Vergadering onder die voorsitterskap van die Minister van Landbou, Waterwese, en Seevisserye met grondeienaars wat binne die geproklameerde Stampriet, Gochas, Leonardville, Aranos ondergrondse waterbeheergebiet val.
- (1987). Vergadering onder voorsitterskap van die Ministerie van Landbou, Waterwese en seevisserye met grondeienaars wat binne die geproklameerde Stampriet Gochas, Leonordville, Aranos ondergrondse waterbeheergebiet val.- Report
- (1988). Databank Area 3: Reports and letters on Stampriet Artesian Area.- Geohydrology/DWA/Windhoek: Report
- (1988). The development of the Fish River catchment basin with special reference to water supply.- DWA/Windhoek: Report
- (1990). Ariamsvlei staatwaterskema: 'n Ondersoek na die grondwaterpotential en ontsluiting van addisionele grondwaterbronne in die Ariamsvlei-omgewing.- Geohydrology/DWA/Windhoek: Report 28 pp.
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4 LESOTHO GROUNDWATER OVERVIEW

4.1 Introduction

Groundwater resources have played a crucial role in water supply for both rural villages and urban centres in Lesotho. Use of developed and undeveloped springs as well as handpumps, high capacity production boreholes and river abstraction (Senqu / Orange) systems are all somewhat contingent upon groundwater supplies. Beyond the Geohydrology and subsurface environment the quantity and quality of Lesotho's groundwater resources are of critical interest in the planning and management within the water sector in general, but particularly for the ORASECOM Integrated Water Resources Management Plan.

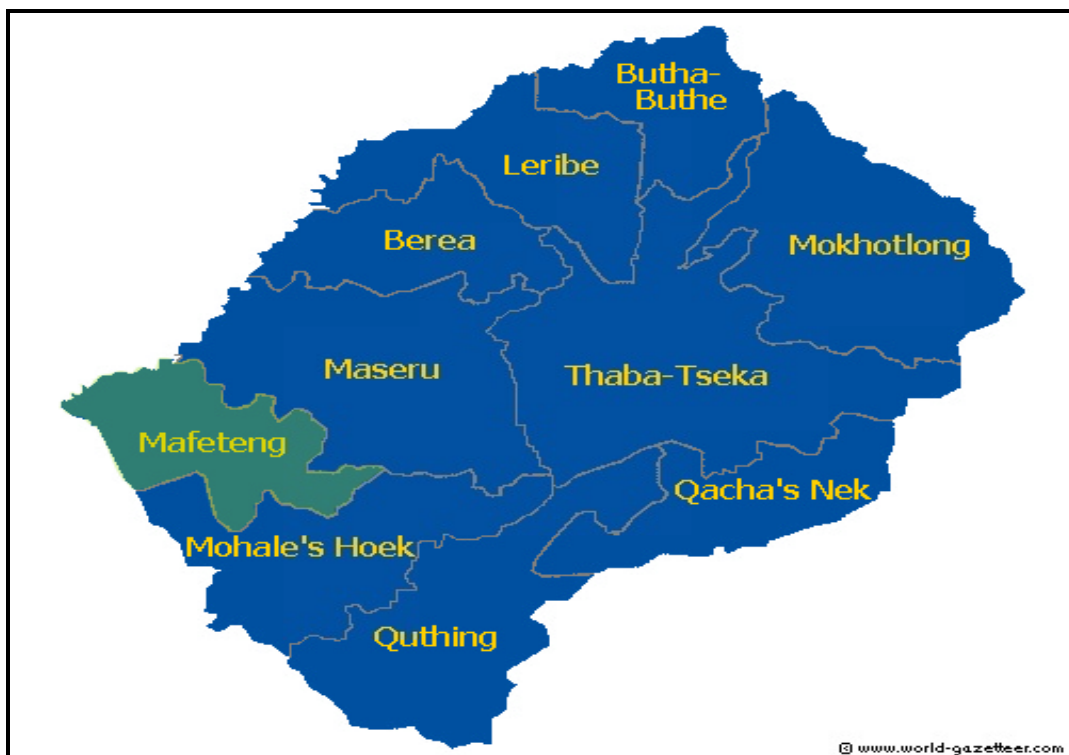


Figure 4-1: Locality map of Lesotho

The groundwater resources of Lesotho have been examined in various studies, primarily beginning in the early 1970s. Historically, the dominant use of surface water for town supplies and naturally occurring springs for rural village supply did not necessitate detailed examination of groundwater occurrence and availability. However, with the rapid growth

within the Senqu (Orange) River Basin, dependence on groundwater resources has expanded greatly. Furthermore, as the need for reliable year-round sources for towns becomes an increasing priority, several towns have augmented river abstraction systems with the conjunctive use of groundwater from boreholes and wellfields.

The water requirements of the once growing number of textile manufacturing companies in Lesotho was partially met from groundwater sources, and given the current (January 2005) unclear future of these entities and the projected future water demands for such industries, groundwater would be able to provide a significant proportion of water supply to meet said demand. The importance of groundwater to the national economy must not be ignored, and requires effective resource evaluation, planning and management. At present, the Ministry of Natural Resources (MoNR) through the DWA, DRWS and WASA controls groundwater development in Lesotho.

4.1.1 The Department of Water Affairs (DWA)

The Groundwater and Water Pollution Control Divisions of DWA are responsible for groundwater exploration, management and resource assessment at national and district level. This includes the monitoring of groundwater abstraction and water quality assessment of groundwater vulnerability to pollution, as defined by the Water Resources Act of 1978. Groundwater development is regulated by DWA; facilitated by DRWS and WASA; designed and supervised by consultants; implemented by contractors; and funded by international donors. The principle hydrogeologist and his small team of hydrogeologists forming the Groundwater Division (GWD) are the only qualified hydrogeologists in Government service. DWA has a good library of project reports.

4.1.2 The Department of Rural Water Supplies (DRWS)

DRWS formerly implemented rural groundwater supply projects using contractors to install spring fed gravity systems and handpump or motorised pump equipped boreholes for domestic supply. Since an evaluation of the function of DRWS in 1996, the Department has, with the assistance of Helvetas, a Swiss NGO, changed role from that of implementer to facilitator. During 1998-2002 DRWS adopted the demand response approach to rural community water supply provision assisting communities to make informed choices about water supply systems, facilitating their active involvement in planning, installation and operation and maintenance (O&M) activities thus enabling community ownership of the systems. Whether this has happened in practice, needs to be determined.

In addition to the Head Office in Maseru, DRWS has three regional and ten district offices. DRWS rely upon DWA and consultants for professional hydrogeological expertise. DRWS water engineers supervise the installation of boreholes, spring supplies gravity fed systems and other distribution systems. Rural groundwater development projects are funded and supported technically by various donor agencies. DRWS currently supplies water to 60% of the rural population of which two thirds comes from spring-supplied gravity fed schemes, and the remaining third from boreholes equipped with handpumps or submersibles. Summary borehole data sets are held in a digital database at headquarters, with detailed borehole and supply system data held at district level in hard copy files.

4.1.3 Water and Sewage Authority (WASA)

WASA is responsible for water supply and sanitation in the 13 urban areas of Lesotho. Maseru does not have a WASA water reticulation system. In Butha-Butha, Hlotse, Mapoteng, Maputsoe, Maseru, Maseru's Hoek, Morija, Peka, Quthing, Roma and Teyateyaneng surface water sources are supplemented by groundwater from high yielding boreholes or river intakes. The Maseru and Maseru water reticulation schemes are supplied from surface water. WASA has a good library of project reports.

4.1.4 The Department of Mines

The Department of Mines includes the Geological Survey of Lesotho that formerly included a groundwater development division. Their library holds copies of most of the records of early groundwater development undertaken during 1960-1980 in Lesotho. The Department of Mines has a library on the geology of Lesotho that is the source of all geological maps for Lesotho.

4.1.5 Consultants

Groundwater Consultants BeePee (Pty) Ltd (GWC) is the main hydrogeological consultant in Lesotho. It, in association with several international consultants, has been responsible for site surveys, borehole design and construction and testpumping of wellfields installed for most of Lesotho's townships. GWC has a library of groundwater related reports, a database and in-house hydrogeological experience in Lesotho. They prepared the Geology and Groundwater resources chapter of the TAMS (1996) report. Sechaba Consultants of Maseru undertook various sociological baseline surveys as part of the TAMS 1996 study including a survey of the location and status of rural community water sources.

4.2 Geohydrology of Lesotho

Within the Senqu / Orange River Basin in Lesotho, groundwater occurs within the fractured Karoo Supergroup sedimentary and basalt rock aquifers, alluvial sediments and within fracture and dolerite intrusion zones. The variable occurrence of groundwater is illustrated by borehole yields that vary from dry (seepage) to up to 8.0 litres/sec within a few metres of a dolerite intrusion. What little is understood of the hydrogeological and hydraulic characteristics of these aquifers has been derived from analysis of the National Groundwater Database of borehole records compiled by TAMS (1996). No attempt has been made to assess the composition, porosity and permeability variations within the aquifers using plugged core samples of the rock formations. The quality of groundwater is thought to be good but hydrochemical analyses are few and far in number and limited to major ions and some trace elements. Fluoride has been determined as occurring at levels potentially harmful to health at a small number of sites.

4.2.1 Burgersdorp Formation Geohydrology

This mainly argillaceous formation has low productivity with borehole yields of less than 0.5 litres/sec. Boreholes drilled adjacent to dolerite intrusions, especially ring dykes, tend to display higher yields of 1-2 litres/sec obtained from baked sediments. An average borehole yield for the Burgersdorp Formation is 1.6 litres/sec, reflecting the large number of boreholes drilled adjacent to dolerite intrusions. The average borehole depth is 59m and average depth to water table is 22m. Average transmissivity of $20\text{m}^2/\text{m}/\text{d}$ and storativity of 0.00117 indicate semi-confined to confined conditions within a low permeability aquifer.

4.2.2 Molteno Formation Geohydrology

The Molteno Formation sandstone aquifer has good groundwater development potential. The quality of this aquifer varies according to the sand / shale ratio and degree of cementation of the component sandstone layers. This aquifer has been developed at Roma and Teyateyaneng where wellfields with individual yields of greater than 3 litres/sec have been installed. The total recommended yield for the Roma wellfield is 21 litres/sec ($75.6\text{m}^3/\text{hr}$) and that of Teyateyaneng wellfield is 22 litres/sec ($79.2\text{m}^3/\text{hr}$).

The Molteno aquifer can have both limited primary intergranular permeability as well as secondary fracture permeability. The most productive boreholes are located adjacent to dolerite dykes where secondary permeability has been developed by the baking and jointing of the formation during periods of contact metamorphism. Other productive

boreholes have been located in well-developed fracture zones unrelated to intrusions (Groundwater Consultants 1992, 1995). The Molteno outcrops also form an important spring line with individual spring discharges as high as 0.5 litres/sec. Statistical analysis of available borehole data suggest an average borehole yield in the Molteno aquifer of 1.6 litres/sec, average borehole depth of 61m and average depth to water table of 24m. Average transmissivity of $20\text{m}^2/\text{m}/\text{d}$ and storativity of 0.001 are indicative of a low permeability aquifer under semi-confined groundwater conditions.

4.2.3 Elliot Formation Geohydrology

Within the Elliot Formation groundwater mainly occurs within the interbedded sandstone layers that show significant lateral variability in thickness. Drilling and testpumping data analyses indicate that the Elliot Formation is often in hydraulic continuity / connectivity with the underlying Molteno Formation. Water strikes are often recorded during the drilling at the contact between these formations. Analysis of available Elliot Formation borehole data indicate an average borehole yield of 1.3 litres/sec, an average borehole depth of 60m and an average depth to water table of 27m. Average transmissivity of $24\text{m}^2/\text{m}/\text{d}$ and storativity of 0.0005 indicate the Elliot Formation has low permeability under confined conditions and with less development potential than the Molteno or Burgersdorp Formations.

4.2.4 Clarens Formation Geohydrology

The Clarens Formation is composed of compact sandstones with poor aquifer qualities. Important spring zones occur and the Lesotho basalt – Clarens sandstone contact and at the upper sandstone – siltstone junction with the main Clarens Formation. Analysis of borehole data from this formation gave an average borehole yield of 0.9 litres/sec, an average borehole depth of 62m and an average depth to water table of 28m. The average transmissivity of $5\text{m}^2/\text{m}/\text{d}$ indicates a low permeability aquifer.

4.2.5 Lesotho Formation Basalts Geohydrology

In the highland areas (headlands of the Senqu / Orange River) numerous springs occur at all levels mainly from weathered basalt horizons at the inter-basalt flow zones and adjacent to dolerite dykes. Some of the few boreholes drilled into this formation have high yields, with water strikes occurring in the weathered mantle, at inter-flow zones and in dykes and fracture zones. In the Likalaneng area water strikes have been recorded at depths greater than 150m with blow yields exceeding 10 litres/sec. The limited borehole

data gave an average borehole yield of 2.6 litres/sec, an average borehole depth of 66m (due to deeper water strikes in precipitous and mountainous topography).

4.2.6 Dolerite Dykes and Fracture Zones Geohydrology

Analysis of testpumping data from boreholes drilled into and adjacent to dykes suggest that, although permeable, the storage capacities of dyke zones are generally low. Therefore, although the presence of a dyke may greatly improve hydraulic conductivity, the storage potential of the country rock should define the yield and drawdown characteristics of the production borehole. A borehole sited in a dyke zone in the Molteno aquifer will be more productive than one located in a dyke zone in the Elliot aquifer.

4.2.7 Alluvial Sediments Geohydrology

The Quaternary and Recent alluvial aquifers have good hydraulic characteristics although their size is limited. The hydraulic characteristics are variable and often site specific, making borehole siting difficult. Some of the largest deposits of exploitable alluvial aquifers are in the Maputsoe wellfield area, in the area around Butha Buthe, north of Teyateyaneng and near Mazenod. Water is abstracted from these alluvial sediments using well point or gallery systems. Analysis of testpumping data results from the Maputsoe wellfield indicated a potential yield of 40 litres/sec when first developed. Similarly, the testpumping of boreholes installed to supply Butha Buthe Township have been installed in Quaternary and Recent age alluvial sedimentary aquifers with potential borehole yields of 1.5 to 4.0 litres/sec. An open well sunk in Mohale's Hoek produces 3 litres/sec for the town's water supply system.

Analysis of borehole testpumping data from alluvial deposits gave an average depth to water table of 15m and an average borehole depth of 41m. Both of these parameters reflect the generally shallower nature of these aquifers compared to bedrock aquifers. The average transmissivity is $106\text{m}^2/\text{m}/\text{d}$, indicative of the significant primary porosity. An average storativity of 0.04 suggests unconfined and semi-confined aquifer conditions.

4.3 Hydrogeological Data Availability and Procedures

A range of hydrogeological data is required for the estimation of groundwater resources and associated aspects of resource development and management. These data have been and should be acquired during each stage of the resource development. The data types available, their sources and format and their collection procedures in Lesotho (but

certain aspects apply to the Basin Member Countries – SADC Groundwater Protocol) are outlined below.

4.3.1 Borehole Siting

Fine grained and compact sedimentary rocks with low intrinsic permeability underlie the western Lowlands region of Lesotho. The optimum sites for water well drilling are located accurately on zones of fracturing and contact metamorphism adjacent to dolerite dykes where groundwater occurrence is enhanced by patterns of intense jointing and weathering. Information obtained from surveys of such sites include:

- Location of geophysical surveys and proposed drilling sites located using GPS or grid reference from a 1:50 000 scale topographic map
- Analysis of data from geophysical surveys to indicate dyke attitude, as well as the thickness of the dyke, the baked zone of contact metamorphism and weathered zone
- Descriptions of the local surface geology, topography and patterns of drainage
- Location and use of existing points of water abstraction such as boreholes, rivers and springs

DWA teams are able to locate borehole drill sites using geophysical survey equipment (not defined) donated by a Japanese funded project undertaken in 1996-7. Geophysical equipment (not defined) left by the Italian Groundwater Project cannot be used due to lack of trained staff.

DRWS technicians formerly located borehole-drilling sites using aerial photography and geological maps. During 1994 they also used magnetic geophysical surveys for drill site location. Currently, consultants locate new borehole sites on fracture and dyke zones using data from interpretation of aerial photographs, geological maps and field geophysical surveys. Geophysical methods used to locate drilling targets include magnetic traversing, electromagnetic survey traversing and resistivity vertical electrical soundings (VES).

Geophysical survey and drilling sites should be accurately located using a geographical positioning system (GPS) and 1:50 000 scale topographic maps. The geophysical survey data and interpretations should be reported. Where professional borehole siting expertise is absent, drilling contractors use dowsing with geological and visual inspection to locate drilling sites (dowsing should not be encouraged).

Although a good density of boreholes and detailed geological maps (may) exist, data crucial for hydrogeological assessments such as thickness of weathered zones, lithology, colour changes and water strike/loss zones are rarely recorded. Thick surficial weathered zones often mask the solid geology. Lithological data collected during borehole drilling are needed for assessment of hydrogeological characteristics and lack of these data sets clearly needs to be addressed. Institutions responsible for drilling boreholes should ensure the collection of representative geological and hydrogeological samples to be examined under laboratory conditions, especially where boreholes are drilled in marginal areas.

These data are needed for groundwater resource assessment at district or sub-district level. Production borehole design is dependant upon the following :

- Type and dimensions of borehole pump
- Yield/drawdown characteristics of the borehole
- Available drilling method
- Depths of water strike zones
- Static water level variations
- Geology of the aquifer formation
- Access for water level monitoring equipment

With decentralisation of rural water supply and greater involvement of NGOs, there has been a tendency to use minimum standards of construction to reduce the borehole installation costs. Community borehole ownership can only be ensured if they can afford to contribute a realistic proportion of the cost of borehole installation, operation and maintenance. The use of minimum diameter borehole components results in access of water level measuring equipment being sacrificed.

Information required to be collected during borehole drilling that will inform borehole construction includes:

- Description of the drilling method, drilling system equipment and capacities
- Accurate location of the borehole drilling site, including village name and GPS location
- Dates of start and completion of drilling and construction
- Drill penetration rate with bit types and sizes as well as borehole flushing medium per metre including the addition of foam

- Collection of formation chip samples and their lithological description (including colour) at 1m intervals. The samples should be placed in sequence along a sectioned half tube and photographed with a digital camera to record colour change with depth. In unconsolidated alluvial materials disturbed samples of at least 1 kg/m should be obtained for grain size analysis especially from water producing zones
- Depths of water strike and water loss with determination of water flow by airlift at 3m intervals
- Details of all components used in borehole construction including types and lengths of casing and screen with coupling types, materials and dimensions, slot sizes, zones of grouting and gravel packing (grain size and source of pack material)
- The above information is needed for borehole design and for recognition of causes of problems resulting from borehole operation

Most boreholes installed for DWA, DRWS and WASA are now drilled using rotary air flush down-the-hole-hammer equipment and generally only private boreholes are drilled using cable tool percussion equipment. Except for DWA exploration boreholes, all production boreholes are drilled, constructed and test pumped by drilling contractors who are required to complete DWA standard borehole completion forms.

During 1982-1992 the DRWS installed nearly 6000 low capacity boreholes, most equipped with handpumps and a few with submersible pumps. These boreholes were mainly drilled to depths of 40 to 100m with a few as deep as 120m and the occasional borehole drilled to more than 150m. While the older boreholes of the pre 1980 period were drilled using DRWS cable tool percussion rigs, those installed during the last 20 years were drilled using the down-the-hole-hammer drilling system.

4.3.2 Aquifer Sustainability and Hydraulic Parameters

Although aquifer testpumping seems to be undertaken at each borehole site, little understanding of the true meaning of the transmissivity and storage parameters is achieved from analysis of testpumping data.

Where boreholes have been drilled into fractured low permeability aquifers (preferably into fractures, weathered dykes and associated baked zones of contact metamorphism) the methods of testpumping data analysis employed is not strictly applicable. Most of the groundwater abstracted at such sites is derived from the linear zone of relatively high permeability. With prolonged abstraction, even at the low discharge rates experienced using handpumps, such aquifers can be dewatered over a period of several years if there is no active recharge from a source such as the bed of a perennial river. Otherwise, during the dewatering, some water slowly seeps from the surrounding low permeability rocks into the linear feature at a rate much less than that of abstraction. In the absence of water level monitoring, the reduction in resources will be noticed belatedly by a reduction in discharge rate, making handpump operation more difficult. This often leads to the failure of the borehole that is commonly recognised as being due to pump failure rather than the dewatering of the aquifer.

Therefore, some information on the distribution of relative permeability and porosity in the country rocks and within the fracture zone needs to be obtained. In such low permeability fractured aquifer systems, flow contributions from fractures determined using packer tests and flow logging with intrinsic permeabilities and porosities of the rock unit determined using formation core sample tests help determine the sustainability of a boreholes yield. However, significant understanding of the nature of groundwater flow patterns within a fractured aquifer can only be obtained from observations made during borehole drilling at the wellhead.

4.4 Groundwater Data Collection

Data collection procedures in Lesotho remain clearly poor. In 1996 only four to five percent of borehole records contained yield data and only 1 to 3% had transmissivity and storativity data (TAMS 1996). This situation does not appear to have changed.

Improved data collection during new DWA projects is being practiced by consultants during borehole siting, drilling, and construction and testing. Data collected during non-DWA groundwater projects are not being submitted to the Groundwater Section. A standard form for collection of drilling, construction and testpumping data has been produced by DWA based upon data input requirements of the WISH groundwater software, but its use is limited to the DWA. DRWS used borehole completion forms produced by the Department of Water Affairs and Forestry of South Africa. Although comprehensive, they are usually completed by drillers recording little meaningful data.

DRWS is now planning to use the DWA forms for future borehole drilling programmes. Although data collection by consultants during WASA and DRWS programmes meets acceptable standards, only worked data are presented in project reports, raw data are not passed to DWA. Hence there are usually insufficient data for hydrogeologists to assess groundwater occurrence, aquifer resources or aquifer sustainability.

4.5 Data Storage and Retrieval

The comments made in this section applies equally well to all the other countries addressed in this report (Namibia, Botswana and South Africa). The pattern of groundwater resource development in Lesotho is typical of that observed with the Orange River Basin Member countries (they all fall within the SADC Region and thus should adhere to the SADC Groundwater Protocols). The style of resource development is dependant on :

- The experience of the government department
- The controls of the international donors
- The type of natural disaster that, maybe, is impacting upon groundwater (e.g. drought)

Aid donors tend to import high cost, high technology solutions such as groundwater information systems that cannot be locally maintained after project support has ceased. Unfortunately, data sets collected during such projects can end up locked into software systems that cannot be accessed without new software and/or dongles designed to limit access in the first instance. Therefore, it is important that raw data are stored in readily retrievable spreadsheets that can be imported into any newly introduced GIS systems and in paper files as hard copy. The data units used in the spreadsheets and GIS systems must be clearly recorded. There is also a need to record point source geo-referenced data that can be imported for spatial analysis into a groundwater information system.

4.5.1 Digital and Hardcopy Data

Groundwater data were found to be available on hard copy paper datasheets at DWA (Maseru) and DRWS (Maseru and Mafeteng), hardcopy reports and maps in the libraries of DMG (Maseru), DWA (Maseru) and WASA (Maseru) and electronic databases at DWA (Maseru), at DRWS (Maseru and Mafeteng), at Sechaba Consultants (Maseru) and at GWC in Maseru. There are four main groundwater database sets. These are discussed in below.

4.5.2 DWA / Italian Programme

The groundwater division of DWA maintains a national groundwater database, initiated in 1982 at the start of an Italian funded national groundwater exploration development project (The Groundwater Programme). This database probably contains geological and borehole construction logs, testpumping data, hydrochemical data but it is difficult if not downright impossible to access.

4.5.3 DRWS

The DRWS provides data from boreholes drilled for rural water supply in the National Database (NDB). The NDB is an administrative database listing information such as village name, borehole depth, handpump type and installation information. Although it is the largest database of borehole and spring data, the NDB lacks technical data such as geo-referenced co-ordinates, geological logs, borehole yield, testpumping data and hydrochemistry. Some of these data are held in paper files at district level. Some geo-referencing of boreholes was done as part of the TAMS / GWC study, Data held in hardcopy paper files at the Maseru DRWS divisional office were destroyed in a recent fire.

4.5.4 TAMS

The DWA / Italian project database was modified and expanded in 1996 by TAMS to contain 8070 (?) records of which about 70% have been geo-referenced. The database is in dBase IV format and is fully compatible with the Arcinfo based GIS system created during the project. Although this database can be imported into Access and thereby transformed into a series of component Excel spreadsheets, it has sadly not yet been set up for continued use and easy updating of records.

4.5.5 DWA / WISH

Data obtained from projects implemented by DWA after 1996 are, for some reason, maintained separately by the Groundwater Division within a WISH based GIS using software from the University of Bloemfontein. Unfortunately, the raw data cannot be extracted from this database system without the necessary proprietary software.

4.5.6 Relevant Literature

Listings of groundwater related reports held by DWA and GWC were compiled for the TAMS study. These listings form the basis of the bibliography compiled by Ambrose (2001) and also form part of the Appendix. These listings need to be updated and listings

held by WASA and Sechaba compiled. These bibliographies could then be used to produce a comprehensive listing of all local consultant and departmental groundwater related reports produced in Lesotho for not only the Senqu River, but for the whole country in general. The consultant's reports that form the main source of raw and interpreted groundwater data from wellfields with the Senqu River Basin include :

- Binnie Shand (1977) – The Twelve Towns Project
- Groundwater Consultants (1995) – Leribe
- Groundwater Consultants (1995) – Maseru
- Groundwater Consultants (2000) – The Six Towns Project
- Johnstone (1991) – Alluvial aquifers at Mashoehoe International Airport
- Lahmeyer (1992) – Maseru
- Riemeyer (1988) – The Two Towns Project
- WEMMIN (1988) - Maputsoe

Earlier reference lists have been compiled during studies undertaken by Binnie Shand (1971) and TAMS (1996). Further data sets are recorded within the 130 technical reports produced during the Groundwater Programme. Hardcopy topographic, hydrogeological and geological maps of Lesotho are available. The first hydrogeological map of Lesotho produced by Mott MacDonald (1990) at a scale of 1:250,000 is difficult to access.

The second national hydrogeological map produced by the Italian led Groundwater Project by Arduino, Bono and Del Sette (1994) at a scale of 1:300,000 can be obtained from the Department of Water Affairs library. Geological maps of Lowland Lesotho at scales of 1:50,000 and 1:100,000 can be obtained from the Department of Mines and Geology. Maps depicting the locations of village boreholes are held at DRWS district offices.

4.6 Groundwater Resource Evaluation

TAMS (1996) estimated the renewable groundwater resources of Lesotho to be 10.84m³/s (cumecs), of which 7.37m³/s is available in the Lowland areas of the basin. Water balance studies indicate 2.5% of annual rainfall recharges to groundwater systems. There is unfortunately no water-level data to support these estimates. It is recommended that a series of digital hydrogeological parameter data layers, created with GIS, should be used to show:

- The distribution of the aquifers
- The distribution of aquifer parameters
- The interaction of surface and groundwater with vulnerability to change
- Aquifer recharge potential (and groundwater harvest potential)
- The vulnerability of aquifers to pollution
- The effects of prolonged drought

4.6.1 Hydrogeological Map

Data sets obtained from water supply boreholes and other relevant sources have been collated in the national geological map to produce hydrogeological maps of Lesotho. These maps are not yet available in digital format but Lesotho, in common with the other Basin Member Countries (and SADC), has been asked to produce a digitised national hydrogeological map as a component of the proposed hydrogeological map of the SADC region.

4.6.2 Potential Aquifer Recharge and Harvest Potential Map

Although recharge to groundwater forms an integral part of the complex hydrological cycle, rates and patterns of aquifer recharge and harvest potential are difficult to determine. None of the methods of recharge evaluation used in Southern Africa is readily applicable or reliable. Determination of recharge data remains a research topic rather than a groundwater management and development tool in Lesotho in particular, and it is suggested potential solutions are workshopped and resolved at some not too distant stage. Methods of estimating groundwater recharge include water balance, chemical isotope and long-term level change studies. In South Africa, the results of regional recharge studies were used to produce a tentative recharge potential map. Such map of potential recharge should be produced for Lesotho using base-line data sets collected during the 1980-1992 drilling programme and survey of current aquifer conditions.

Detailed hydrogeological maps of various types and scales are available. They include :

- Hydrogeological reconnaissance maps (1:250,000) that summarise the hydrogeological data for areas; the information includes yield potential, water quality and where possible, flow directions (hydraulic gradient)
- Groundwater vulnerability and harvest potential maps in various scales

- Extensive regional and local maps are present in various reports on projects

4.6.3 Groundwater Vulnerability to Pollution

The susceptibility or vulnerability of groundwater to anthropogenic pollution is defined as “the tendency and likelihood for general contaminants to reach the water table after introduction at the ground surface”. The vulnerability of an aquifer to pollution depends on the characteristics of the strata separating the saturated aquifer from the ground surface. Once the contaminants have arrived at the water table, the aquifer is deemed as polluted. To assess the impact of contamination, groundwater vulnerability is related to the groundwater resource.

The pollution of aquifers by human waste, urban run-off and other pollutants are described by Coughanowr (1994). Coughanowr considers that in the developing world case studies of severe groundwater pollution by hazardous and industrial wastes are rare. However, in rural areas, there is increasing contamination of aquifers by fertilisers, pesticides and human and animal waste. DRWS boreholes are only tested for bacterial contaminants if health problems such as gastroenteritis, cholera or typhoid are reported.

Representative water samples are obtained after drilling or during testpumping procedures for hydrochemical analysis of major ions and bacteria at WASA sites. Borehole sanitary seals are grouted in around boreholes as part of standard operating procedures. Protection zones are not demarcated around wellfields supplying the urban centres therefore some of WASA’s urban supply boreholes are already heavily polluted. There is no routine in-country testing for heavy metals or organic contaminants that potentially pose long-term pollution and health risks.

4.6.4 Drought Vulnerability Mapping

A drought vulnerability map aims to show regions where groundwater resources are vulnerable to drought conditions to indicate the availability of the resource to provide a supply during drought events. Key determinants of vulnerability include aquifer type, depth of the weathered zone, well and borehole yields and rainfall (amount and variability). Such a physical dataset identifying availability of resource and ease of access can be superimposed on a sociological dataset, analysing the distribution of demand, to form a composite drought vulnerability map. This map is then used to identify vulnerable communities where efforts can be targeted to provide drought proofing in pre-drought

periods, and to ensure that appropriate drilling methods and borehole designs are used effectively.

Such a map of Lesotho would have been useful to The World Bank drought relief study of 1995. Lesotho would have been affected by the regional drought of 1984, 1992 and 1994 among others. Without long-term water level records to correlate with climatic records the impact of drought events upon groundwater resources cannot be determined.

In areas underlain by low permeability aquifers where there are limited groundwater resources, and borehole yields are low, the effect of prolonged periods of drought may be disproportionately large especially if abstraction leads to the mining of the groundwater resource.

4.7 Groundwater Resource Assessment and Exploration

The Groundwater Division of DWA is responsible for groundwater exploration and resource assessment. Groundwater exploration procedures should generally be the preserve of DWA and not consultants but due to lack of resources and expertise the Division is limited in what it can achieve. DWA aims to assess the availability of sustainable groundwater resources and borehole yields as well as economics of groundwater development on a district / aquifer basis. Boreholes drilled for production purposes can be regarded as exploration boreholes to maximise collection of data. Some data sets are available in a number of reports on geophysical siting, drilling and testpumping carried out during the Groundwater Project. These data sets and those from subsequent exploration and development programmes need to be collected and collated to present an overview of groundwater resources and development in Lesotho to complement the hydrogeological map. Such a report would produce clear guidelines for groundwater development and resource assessment / management.

TAMS (1996) estimated groundwater resources in terms of both dynamic (renewable) and static resources for major surface water basins and administrative districts. Estimates of groundwater usage were also produced using a rural water supply inventory and administrative records. A potential and indeed very welcome outcome of this would be the production of hydrogeological maps of Lesotho at a scale of 1:50,000 as tools for planning and development.

The supervision of rural groundwater development by professional hydrogeologists or suitably qualified technicians is rare due to the misconception that they are expensive to

employ. In contrast, consultant hydrogeologists supervise the geophysical siting and other aspects of urban water supply boreholes for WASA. The Groundwater Division lacks experienced professional staff. The DRWS have no in-house hydrogeologists to supervise and control borehole drilling and testing programmes they facilitate. This has led to poor data collection and reporting. Few borehole records contain pertinent and relevant information such as water strikes or lithological logs. Of the 5,000+ boreholes drilled by DRWS to date, few comprehensive boreholes completion reports are available. Hydrogeological supervision is provided on WASA drilling and testing programmes by specialist consultants. The reporting standard is fairly high and analysis is provided. Similar supervision and reporting were provided during recent groundwater exploration programmes.

All borehole records for the Maseru region of DRWS pre 1988 were lost in 1998 when the DRWS district office in Maseru was burnt to the ground. This clearly demonstrates the requirement for a backup data system. The groundwater sector is poorly funded although it plays an important role in the urban and rural water supply of Lesotho, as reflected in public and private sector groundwater capacities. Neither DWA nor DRWS have sufficient in-house groundwater expertise, therefore has to outsource these activities. The GWD of DWA has some professional capacity with two drilling rigs and a testpumping unit.

4.7.1 Groundwater Reserves

The groundwater resources available for development can broadly be categorised as dynamic reserves and static reserves. The dynamic groundwater reserve represents the long-term average annual recharge under conditions of maximum groundwater use. Under these conditions, the entire basin area forms the recharge area and groundwater discharge occurs only through the pumping wells. Static reserve is the groundwater contained within the permanently saturated zone of groundwater reservoir and represents the total groundwater reserve minus the dynamic reserve.

Groundwater resources of Lesotho are summarised in **Table 4-1**. The resources are calculated assuming specific yield values comparable with respective aquifers and the water level fluctuation comparable with observed fluctuations in the monitored boreholes. In order to calculate the static groundwater reserves, total reserves available from each aquifer are worked out taking into account the thickness of the aquifer and its specific yield. Subtracting the dynamic reserve from the total reserve gives the static reserve. This groundwater reserve is available for future groundwater development in Lesotho specially

to meet the water demand under emergency like severe drought. To make it more comprehensive, the groundwater resources have been worked out on per square kilometre basis. The complexity of hydrogeological conditions i.e. strong structural control of groundwater by geological structures warrants that these resources should be explored for occurrence and demarcation of exploitable aquifer zones.

Table 4-1: Groundwater Reserves of Lesotho

Aquifer	Area km ²	Specific Yield	Water level fluctuation	GW Resource MCM/year	GW Resource per km ²
Molteno	3777.99	0.015	2	113.33	0.03
Elliot	4331.30	0.01	1.5	64.96	0.015
Burgersdorp	3519.27	0.005	1	17.59	0.005

It is suggested that the vast available resources in Molteno aquifer and that it can accommodate about 11 boreholes per square kilometre, each yielding 2 litres/sec on a 24 hour basis. It is considered that 2 litres/sec is the yield of a successful productive borehole in Lesotho. Similarly Elliot aquifer can accommodate four boreholes per square kilometre and Burgersdorp can accommodate two boreholes per square kilometre.

As far as the dynamic resource is concerned, there is still scope to sink more boreholes within the safe yield limits of the annually renewable resource. However, in future, if there is need to exceed the limits of dynamic reserve, no detrimental effect on the aquifer is anticipated as it will provide scope for induced recharge from the runoff.

4.8 General Recommendations for Lesotho Groundwater Issues

Groundwater is used extensively within rural Lesotho, both as a source of domestic water supply and for irrigation. Information derived from boreholes drilled by the Department of Rural Water Supply should be used to provide indication of groundwater availability in areas designated as potential sites for peri-urban and urban development by 2035. Although these areas of the lowlands region of Lesotho are underlain by dolerite dyke intruded Karoo age sedimentary rocks and basalts of low permeability and porosity, the limited groundwater resources could provide temporary water supplies to newly formed peri-urban areas.

The vulnerability of these aquifers to pollution from effluent deposited in the large number of pit latrines that proliferate within peri-urban settlements and associated waste disposal sites needs to be assessed to define the limited period of useful exploitation. The results of wellfield development undertaken for WASA by GWC and other consultants need to be fully assessed and produced as a series of aquifer case studies to be used as conceptual models for the development of further wellfields in areas of sufficient groundwater development potential, as identified from the results of baseline surveys and GIS digitised data.

It is essential that groundwater database and long-term monitoring systems be upgraded to provide the necessary information if these developments are to take place. Groundwater will continue to play a secondary but important role to surface water in supplying the needs of Lesotho's peri-urban and urban populations.

4.9 Available Groundwater Reports

DWA Ref	GWC ref	Ambrose ref	GWP ref	Date	Title
	44	315	3	Oct 86	Water Branch : Moroeroe Catchment Area – Pumping Tests Prelim Report
14		319	4	Dec 86	Preliminary report on the boreholes construction for the Butha Buthe Hospital
15		321	5	Feb 87	Mafeteng LNDC Site: Groundwater Forecasting
26		326	10	May 87	Project Lesili: Forecast of groundwater resources
17		329	11	Jun 87	Final report on the boreholes construction for the Butha-Buthe Hospital
18		328	12	Jun 87	Teyateyaneng: Borehole field - St Agnes Catchment Area
19		330	13	Jun 87	Butha-Buthe Woodlot nursery - borehole pumping test
2		332	14	Aug 87	Village water supply: Thaba Bosiu Pumping Test (Bh 8)
3		337	16	Sep 87	Village water supply: Masitise Pumping Test (Bh10A)
46			17	Sep 87	Butha-Buthe: Base flow measurements in 1983, 1984 and 1985

DWA Ref	GWC ref	Ambrose ref	GWP ref	Date	Title
48			18	Oct 87	Hydrogeological outlines of Maoamafubelu drainage basin
45		338	20	Nov 87	Village Water Supply Hydrogeological survey at Ha Ralejoe -Ha Phaloane
49		316	21	Nov 87	Khamane Village Pumping Test (Bh1, Bh2)
50		336	22	Nov 87	Village Water Supply: Mese-Pela pumping test (Bh1)
51		340	23	Jan 88	Leribe Woodlot pumping test (Bh1)
52		342	25	Feb 88	Lesotho Youth Service Train Work Village Hydrogeological Survey
27		343	26	Feb 88	Geological Survey for Borehole siting: Leribe District and Mafeteng District
28		345	27	Feb 88	Forestry division: Maseru Woodlot Nursery Hydrogeological survey for borehole siting
29		348	28	Mar 88	Thabana Li Mele:'Craft centre': Drilling and pumping tests on two boreholes
30		349	29	Mar 88	Hydrogeological Investigation in Mount Tabor
31		350	30	Mar 88	Sekameng Mine: Boreholes drilling and pumping test
32		351	31	Mar 88	Masite Mission Pumping Test: Bh 11
33		353	33	Mar 88	Masianokeng Roads Camp Hydrogeological Survey
34		355	34	Apr 88	Ha Ralejoe: Drilling and pumping test on 3 boreholes
35	71	360	35	Jun 88	Water Branch: Boreholes survey for Roma water supply
36		361	36	Jun 88	St Monica: Holy Family High School water supply
37		365	41	Jul 88	Borehole Siting for Dilli Clinic, Quthing
38		372	51	Oct 88	Letsie High School (Thaba-Bosiu)
39		373	52	Oct 88	VWS hydrogeological survey for borehole siting Thiokol, Nqechane Village, Leribe District

DWA Ref	GWC ref	Ambrose ref	GWP ref	Date	Title
40		362	53	Oct 88	St Monica: Holy Family High School Water Supply pumping test on bh No 2
41		377	54	Dec 88	Village Water Supply Geological Survey for Bh siting, Ha Molokai: Maseru District
42		375	55	Nov 88	Ts'a Kholo Area: Hydrogeological Survey for bh siting
43		380	56	Jan 89	Linotsing Clinic Water Supply
44		383	57	Mar 89	Caledonspoort pumping test: Archiplan studies
23		386	69	May 89	Linotsing pumping tests
	76	393	71	Sep 89	Thabeng High School: pumping test - Morija
11		400	76	Jan 90	Maputsoe Water Supply for Water Branch
	63	406	88	May 90	TY St Agnes water supply drilling and pumping test
	37	400	89	Jun 90	Teyateyaneng Water Supply; Borehole Wellfield at Phuthiatsana treatment plant
	73	455	119	Oct 92	WASA borehole pumping tests Katlehong and Lower Thetsane
47		335		Oct 87	Upper Koete Dairy Farm: Matsieng (Bh 1)
	47	279		Feb 83	Hydrogeological Survey in Morija Wellfield
	75			Feb 83	Hydrogeological Survey in Morija Wellfield (possible duplication – see above??)
	30	290		Jun 84	National University of Lesotho Study for Water Supply
310		310		Feb 85	Construction of 50 Boreholes in the Rural Area of Tsa-Kholo - Mafeteng District
9		314		Sep 86	Marsieng Water Supply - Preliminary Report
	8	364		Jul 88	Hydrogeological Investigation for Butha-Buthe Water Supply: Drilling and pumping test

DWA Ref	GWC ref	Ambrose ref	GWP ref	Date	Title
24		452		Jul 92	Site visit to Maputsoe and TY Wellfields
8		394		Sep 89	Progress Evaluation of the Groundwater Project Activities and Equipment Inventory
				Mar 04	Six Towns Water Supply – Desk Study and Siting Report. Groundwater Consulting Services. March 2004.

Key

DWA – Department of Water Affairs Library Number

GWC – Groundwater Consultants BeePee Library Number

Ambrose – Dr David Ambrose's Bibliography

GWP – Groundwater Project Technical Report Number

4.10 References and Additional Reports For Lesotho

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5 SOUTH AFRICA GROUNDWATER OVERVIEW

The Orange River rises in the eastern highlands of Lesotho where it is known as the Senqu River and is the largest and longest river in South Africa and straddles five Water Management Areas; Upper Vaal, Middle Vaal, Lower Vaal as well as the Upper and Lower Orange Water Management Areas (WMA).

It is the main source of water for the Lower Orange WMA (including some users by Namibia), and for the Fish to Tsitsikamma water management area. The Lesotho Highlands Water Project, which is an integral and crucial component of the Vaal River System, also relies on water, which under natural conditions would flow into the Upper Orange WMA.

From the Upper Orange Water Management Area, the river flows through the Lower Orange WMA where it discharges into the Atlantic Ocean some 2,300km from its origin in Lesotho.

Substantial variation in climatic conditions occur over these catchments, with the Mean Annual Precipitation (MAP) reducing from 1,500mm in Lesotho and 1,000mm in the RSA in the Upper Orange to a mere 20mm along the western coast in the Lower Orange WMA. This tendency is reversed when considering annual evaporation, which increases from 1,200mm in the Upper Orange to 3,000mm in the Lower Orange WMA. Agriculture, mining, trade and Government are the main economic sectors contributing to the GDP in the WMAs.

Extensive inter-catchment transfer schemes have been developed for the transfer of water within the Water Management Area as well as to other WMAs. The most significant transfers being from Katse Dam via the Lesotho Highlands Water Project to the Upper Vaal WMA and from Gariep Dam via the Orange-Fish tunnel.

The main storage dams in the Orange River WMAs are :

- Gariep and Vanderkloof Dams on the Orange River, which command the two largest reservoirs in South Africa. Hydropower for peaking purposes is generated at both sites
- Armenia and Egmont Dams on tributaries in the Caledon sub-areas. Welbedacht Dam is located on the main section of the Caledon River, with Knellpoort Dam an off-channel storage dam that supplements Bloemfontein's water supply

- Rustfontein, Mockes and Krugersdrift Dams are situated on the Modder river, and the Tierpoort and Kalkfontein Dams on the Riet River

Katse and Mohale Dams in Lesotho do have significant impact on the available water in the Orange River as the bulk of the Orange River flow is generated in Lesotho. Katse Dam is located in the Senqu sub-areas of Lesotho and is used for the transfer of water to the Upper Vaal WMA. Mohale Dam, which has recently been completed, is located in the same sub-area. The dam is also used to support the transfer of water to the Upper Vaal WMA.

5.1 Geology, Climate and Vegetation of the Orange River in South Africa

The river originates as the Senqu in the Maluti Mountains (rainfall >1,800mm per year) in the highlands of Lesotho. The Lesotho Highlands consist mainly of basalt, and are covered by alpine grassland with isolated high altitude marshy areas, giving rise to high quality runoff. Some wooded areas occur in the valleys below the highlands. On the edges of the overlying basalt, shales, sandstone and mudstone come to the surface, with resultant highly erodible soils and high sediment loads in some areas.

To the west of Lesotho, the climate progressively becomes more arid. The vegetation group consist of several Karoo and False Karoo veld types as well as significant Karoo like invasions of other veld types. Rainfall here varies from 600mm per annum in the east to less than 100mm per annum in the Richtersveld area. The geology is underlain by sedimentary rocks (shales, mudstones and sandstones) of the Ecca and Beaufort Groups, and the Karoo Supergroup, which have been intruded in places by dolerite sheets. The Cape Supergroup is developed in the southern portion of the basin and consists of the Table Mountain, Bokkeveld and Witteberg Groups. Sandstones and shales of the Table Mountain Group are developed in the south and southwestern areas of the basin.

The Richtersveld area in the west of the basin is underlain by a variety of sedimentary, metamorphic and volcanic rocks, with some unique and very striking features exposed by the river. Precious little rainfall occurs from here to the Atlantic coast (0-100mm/a). The area has a potential evaporation of over 3,000mm per annum, which is typical of a temperate desert climate. Vegetation is sparse and is characterised by desert succulents, including the famous Koker trees.

5.2 Groundwater Development Potential and Related Issues

South Africa is divided up into 65 Groundwater Regions (see map overleaf) and groundwater has always been an important source of rural water supply within the study area. It provides water for domestic needs, small vegetable gardens and stock. The generally low borehole yields and low storage of Karoo aquifers require large capital expenditure to develop a large-scale supply. This in turn does not encourage farmers to develop commercial scale irrigation. No quantitative estimation of a total rural water use has been made. An exception to this is the high level of groundwater utilisation within the Lower Vaal Water Management Area.

Numerous towns and villages in the basin have developed their own water supplies utilising local groundwater. Larger towns, established at rivers, had sufficient financial resources to build their own dams and water purification works. Groundwater is generally used during droughts to supplement the shrinking dam reserves. With the increase of urban population (the rural population has remained practically unchanged) during the last few decades, DWAF developed an affordable subsidy system and grants for municipalities and consequently more local dams were constructed. On a larger scale, the construction of the Sterkfontein dam, together with water releases to the Vaal River drainage system and water from the Katse dam in Lesotho, increased the availability of the surface water in the central part of the basin. This resulted in a gradual decrease of groundwater utilisation. Many towns switched to a conjunctive water use where municipal boreholes were used only during peak seasonal demand and periodical droughts.

Recent municipal groundwater use has substantially decreased despite the overall increase in the urban population due to surface water resources becoming available. Unfortunately no accurate figures for current groundwater use are available. The generally low degree of groundwater utilisation by the local authorities is the result of generally low aquifer permeability and storativity, coupled with inherently low borehole yield.

Under these circumstances, any large groundwater development programme will be expensive, and given the generally low development potential, not really recommended. The subsequent high costs of a groundwater wellfield further question the viability of such undertakings and ventures. Another important element to be factored in is the inherent negative attitude and approach by potential groundwater users and this generally requires interventions by institutional and social development facilitators. The lack of enthusiasm by

beneficiary communities is in part based on the lack of confidence of the sustainability of the resource as a result of no or little understanding of the groundwater regime.

Medium scale groundwater developments say for a single farm, industrial plant or small community, if based on sound scientific approach can be economical. Engagement of groundwater professionals in this process is now obligatory and hence will reduce the usually large number of dry and unsuccessful boreholes drilled, eliminate improper spacing of production boreholes and aquifer over-pumping, in addition to ensuring proper and effective aquifer management procedures. This will improve overall wellfield performance and resource sustainability. The proper application of the National Water Act of 1998 can and will improve the confidence of the end-user in the developed resource and encourage its sustainable utilisation.

The groundwater resources are somewhat limited in some areas and largely undefined within the basin. The generally low yields of production boreholes are in the range of 1.5 to 2.0 litres/sec and groundwater extracted is at times saline (Vegter & Seymour, 1996). On a local scale, groundwater is strategically important for some towns in the study areas as it generally provides them with their primary water source. (Jolly, pers comm., 1995). From available information, it appears no one full and detailed regional groundwater overview of the complete basin area has been completed to date. The following section therefore focuses on possible sources of groundwater within the general study area and their relative association with geological units. DWAF has compiled a set of regional scale maps outlining the groundwater potential of most of the Orange River Basin.

5.3 Groundwater Sources within the Orange River Basin

5.3.1 General

Aquifers can be divided into two broad classes and both occur within the study area. Within **Primary aquifers** intergranular porosities and permeabilities occur which produce the water-bearing characteristics. Some sandstones of the Beaufort Group are considered to be weak primary aquifers (Loxton Venn, 1982). **Secondary aquifers** are aquifers where the water-bearing characteristics are dependant on openings occurring within the rock itself, which have occurred subsequent to deposition. Porosity is formed in weathered rock, fractures or faults such as the in Karoo Supergroup. More specific aquifer types occurring within the Orange River Basin are discussed in the following section.

5.3.2 Dolerite Intrusions

Numerous dolerite dykes and sills have intruded the sediments of the Karoo Supergroup throughout the basin. The dolerite themselves, or the baked contact zones between the dolerite and the surrounding country rock are fractured and thus act as secondary aquifers. Dolerite intrusions in competent host rocks such as the thick sandstones have generally higher groundwater potential than intrusions in less competent rocks such as shales. The highest groundwater yields would occur where a fractured dolerite / contact zone is overlain by saturated alluvium or crossed by a perennial watercourse as this would facilitate and promote aquifer recharge.

5.3.3 Fractured Sedimentary Rocks

Tectonic stress, for example, and the resultant folding and faulting have caused the fracturing of sedimentary rocks and these fractures result in the formation of secondary aquifers. The fracturing is most pronounced in competent (hard) sandstone units such as those found in the Beaufort Group.

5.3.4 Weathered Zone

Weathered zones in which secondary porosity is created may also act as aquifers. Shales and mudstones are more easily eroded than sandstone and this form of aquifer is therefore often developed within the shales of the Ecca Group.

5.3.5 Alluvial Deposits

These have primary porosity and are developed to a limited extent along certain section of the river

5.3.6 Upper Orange WMA Groundwater Overview

Underlain by hard formations, no large porous aquifers are found in the water management area of the Upper Orange. Although relatively large quantities of groundwater are abstractable from fracture zones at dolerite intrusions, recharge rates and therefore the sustainable yields are low over most of the area. Higher recharge rates occur in localised areas, such as where lime bogs are found. In the drier parts of the area, groundwater constitutes the main, and in many cases the only source of water for rural domestic supplies and stock watering, as well as for towns such as Colesberg. Severe over-exploitation of groundwater occurs in some peri-urban areas, notably at the Bainesvlei smallholdings near Bloemfontein. Groundwater over-exploitation also occurs at

Petrusburg in the Riet / Modder sub-area due to increasing irrigation from groundwater. The groundwater quality is naturally good in the eastern high rainfall parts of the basin, becoming more mineralised and brackish in the drier areas and in the vicinity of salt pans.

A dolomite area (Karst Development) provides the source to numerous smaller rivers including the Molopo, Marico and Harts Rivers and these aquifers extend north and eastwards to the Crocodile (West) and Marico, Upper Vaal and Middle Vaal Water Management Areas. The actual source of these rivers is referred to as "dolomite eyes" or dissolution chambers, which are water bodies fed by groundwater originating from fractures in the underlying dolomite. The water is typically alkaline having picked up magnesium and calcium carbonates through solution from the parent dolomite. The Lower, Middle and Upper Vaal Water Management Areas fall within the Orange River Basin.

5.3.7 Upper Vaal WMA Groundwater Overview

An important feature with regard to the groundwater resources of the Orange River Basin is the large dolomitic aquifers of the Upper Vaal WMA. Much of the water in the Mooi River, which is well known for its strong base flow, originates as springflow from these aquifers. Large quantities of water are also abstracted through pumping for urban use (such as Rand Water) and for irrigation. As a result of the direct hydraulic connectivity between the dolomitic aquifers and surface streams, increases in groundwater abstraction will result in corresponding decreases in surface flow. Dewatering of the dolomitic compartment can also result in the formation of sinkholes. Extensive dewatering of the dolomitic compartments for mining purposes has occurred in the northwest of Upper Vaal WMA where gold deposits underlie dolomitic formations. This resulted in temporary increases in surface flow while water tables were being lowered. Reductions in surface flow will be experienced when mine pumping ceases and the compartments are allowed to fill again. The remainder of the water management area is mainly underlain by fractured rock aquifers, which appear to be well utilised for rural domestic supplies and stock watering, with little undeveloped potential remaining. Although of specific importance in some areas, only 3% of the total water requirements in the water management area are supplied from groundwater.

Groundwater quality in the WMA is generally of an acceptably high standard. Due to chemical reactions when groundwater infiltrates into mine caverns, poor water quality often results which can cause serious groundwater pollutions.

5.3.8 Middle Vaal WMA Groundwater Overview

Large dolomitic aquifers occur in the northern part of the water management area. These extend from Stilfontein in a northerly direction across the WMA to the vicinity of Ventersdorp. The aquifers, which occur in different compartments, also underlay large sections of the WMA. Water from these aquifers is abstracted for urban domestic use at Ventersdorp as well as being bottled. Water is also abstracted for irrigation and rural water supply. The remainder of the water management area is mostly underlain by fractured rock aquifers, which are well utilised for rural water supplies and with little undeveloped potential remaining.

Dewatering of dolomitic compartments for mining purposes occurs in the vicinity of Stilfontein, and pollution of groundwater due to chemical reaction may result when mining operations are discontinued. Problems have been experienced with the seepage of groundwater containing elevated manganese levels from mining areas into the Vaal River. These problems have subsequently been addressed and remedial action taken. The groundwater quality over the remainder of the water management area is generally of an acceptably high standard. About 11MCM/a of water pumped from mine dewatering operations evaporates from pans.

5.3.9 Lower Vaal WMA Groundwater Overview

The Lower Vaal groundwater utilisation is of major importance and constitutes the only source of water over much of this WMA. Groundwater is mainly used for rural domestic supplies, stock watering, potable water supplies to several towns in the area and in some instances for irrigation, such as Tosca (see Chapter 5.3.10). Significant quantities of groundwater are abstracted with the total yield from groundwater in the Lower Vaal WMA more than double than that obtainable from the local surface water resources (WRP 2003).

Much of the groundwater abstraction in the Molopo sub-area is in the vicinity of dry sandy riverbeds. With a substantial part of the recharge of groundwater assumed to be from these watercourses, great concern exists about the impacts of upstream farm dams as well as from invasive alien vegetation along the watercourses, on the sustainable yield from groundwater.

Major de-watering of groundwater aquifers for mining purposes occurs at Sishen, where up to 28MCM/a is planned to be abstract from groundwater. Expectations are that this will stabilise at about 18MCM/a by the year 2027. The quality of groundwater in the Lower

Vaal WMA is generally good, although brackish water does occur in some areas. Pollution of dolomitic groundwater is occurs at the Pering Mine near Reivilo, as the direct result of mining activities

5.3.10 Lower Orange River WMA Groundwater Overview

Groundwater is of major importance in the Lower Orange Basin and constitutes the only source of water over large areas. It is mainly used for rural domestic supplies, stock watering and water supplies to some inland towns. As a result of low rainfall over this section, groundwater recharge is somewhat limited and generally only small quantities can be abstracted on a sustainable basis. In the Orange River tributaries sub-area, about 60% of the available water is supplied from various groundwater sources. Most, if not all, of the groundwater abstracted near the river is directly from induced recharge from the river to the local groundwater regime. Groundwater availability in the coastal region is extremely limited as a direct result of the lack of rainfall and risk of seawater (saline) intrusion into the coastal aquifers. Current utilisation of groundwater in the water management area is thought to be approximately in balance with the sustainable yield from the source. No significant potential for further development exists and some over-exploitation has been experienced in certain areas within the coastal zone.

The groundwater quality varies from good to unacceptable in terms of potable standards. The groundwater quality is one of the main factors affecting the development of available groundwater resources. Although there are numerous problems associated with water quality, some of which are easily corrected, Total Dissolved Solids (TDS), nitrates and fluorides represent the majority of serious water quality problems that occur. Much of the groundwater in the coastal zone is of poor quality (see map overleaf), containing elevated levels of sodium chloride and in some cases traces of radioactivity.

For the optimum development of groundwater resources within the basin and elsewhere for that matter, sound groundwater management practices are essential in order to prevent over-exploitation and / or pollution of these valuable resources and in order to achieve some measure of sustainable resource yield. The Karoo aquifers that cover virtually most of the area have generally only a moderate development potential. Low permeability, storativity and available aquifers storage are the limiting factors. Significant water quantities can only be obtained by spreading a great number of boreholes over a large area. This seriously influences the development costs and the final water cost.

The most common groundwater management approach applied (where possible and indeed feasible) should be the conjunctive use of groundwater and surface water. Groundwater is accordingly used during dry periods when little surface water is generally available (except for areas close to the river).

Proper management and monitoring of groundwater sources by municipalities and other users are of vital importance. There is a need to provide groundwater information and to create an improved understanding of groundwater at a local level (WRP, 2004). Municipalities should investigate groundwater potential outside town boundaries as a possible source. The reader is referred to Appendix A for more detailed information on the groundwater issues of the WMA.

5.3.11 Groundwater Resources and Use : Mining and Industrial

Mining plays an important role in Lower Orange WMA's economic development. Several diamond mines are located in the WMA including the Kleinzee, Alexcor and Hondeklipbaai mines. Diamonds are recovered at these mines from alluvial deposits. A number of small-scale diamond diggings are also found in the area. Some impacts do exist with regard to localised dewatering of aquifers. These impacts appear to be localised and very little information is available in the public domain. Black Mountain base metal mine utilised surface water from the nearby Orange River for processes. No data is available on the water resources utilised by the Okiep Copper Mines.

5.3.12 Groundwater Resources and Use : Agriculture

Most farming settlements are dependant on groundwater for domestic and stock watering use. The groundwater resource is of such a nature that it cannot be utilised for large-scale irrigation throughout the WMA, except in the areas underlain by dolomitic aquifers.

5.3.13 Groundwater Resources and Use : Domestic

As discussed above, groundwater is utilised for individual domestic use in most rural and farming areas. Groundwater is the most important resource for bulk supply in areas located far from the surface water bulk supply network. The naturally poor quality and poor yields of some aquifers are a constraining factor in the utilisation of this resource. This is overcome in some areas by good water management practices and treatment of the groundwater.

Data received from DWAF suggests the total abstraction of groundwater at some 10MCM/a for domestic supply for approximately 100,000 inhabitants dependant on the source (DWAF,2003). The majority of the water (43%) is abstracted from granite and gneiss aquifers, 25% is from the Dwyka and Ecca Karoo sediments, 17% from the Beaufort Karoo sediments and the remainder from the dolomites (6%) and other primary aquifers (2%).

5.3.14 Groundwater Abstraction: Additional Comments

Large abstractions (see Chapter 5.5) are generally the domain of the mining and irrigation fraternity and the average water user is not in a position to exhaust the resource to the extent that conflicting situations between different users are created. This is due to the generally low aquifer permeability and small zone of influence of individual boreholes.

Some of the largest groundwater abstraction takes place in the Kroonstad / Welkom areas, where mines of the Free State Goldfields are pumping approximately 33×10^6 cubic metres annually of groundwater to the surface. Generally the elevated salinity level of this water prohibits its utilisation and is thus mostly discharged to numerous evaporation pans and dams. The effect of the dewatering on the shallow Karoo aquifer is considered to be negligible as the mines are operating in a deep, confined aquifer. The pollution threat to local, shallower groundwater by all surface mining related activities like tailing, dumps and effluents etc. was acceptably addressed by the relevant mining companies.

Groundwater abstraction in excess of 1.2×10^6 cubic metres per annum occurs in the Petrusburg surrounds and in an area northwest of Bloemfontein. Moderate groundwater use for irrigation occurs in the Luckhoff, Hopetown and De Aar districts and in a few other localities. Some towns and villages rely on groundwater and by way of example, the four municipalities of De Aar, Jagersfonten, Fauresmith and Reddersburg are currently using groundwater in excess of 100,000 cubic metres per annum. Most farms are dependant on groundwater for domestic use and stock watering but no total abstraction volumes are available.

The following is a partial list of various municipal groundwater use to illustrate the importance of groundwater use (E Baran 2001) and should not be viewed as a current comprehensive account of municipal groundwater utilisation.

Table 5-1: Municipal groundwater use

Town	Use x10 ³ m/a	Report number	Author	Date	Remarks
Vredefort	202	GH3340	J Coetzer	Oct 82	-
Leeudoringstad	249	GH1421	C Opperman	May 69	40% from private boreholes
Newcastle	775	11/2/2/3	Town Eng.	1993	-
Newcastle Iscor	1,040	GH3282	J Kruger	Jul 83	-
Kroonstad	1,643	GH1798	W Boehmer	Jul 72	-
Cornelia	66	GH2995	O Gombar	Dec 77	83,000m ³ /a could be safely abstracted
Cornelia	26	GH3468	E Nealer	Jul 86	26,000m ³ /a safely abstracted??
Steynsrus	100-133	GH2961	O Gombar	Sep 77	76 private boreholes
Petrus Steyn	135	GH2953	J Kruger	Aug 77	-
Clarens	60	GH3405	C Erasmus	Nov 85	Spring augmented
Edenville	150	GH3902	T Kok	Jan 82	Pvt BHs augment
Kastel	40	GH1796	W Boehmer	1972	-
Ficksburg	292	GH2818	P Smit and O Gombar	Feb 75	Infiltration gallery in Caledon River supply 50% of town's water
Soutpan	96	GH3496	G Bekker	Nov 86	-
Witsieshoek	1,700	GH2903	T Kok	Oct 76	-

5.4 Implementation of Groundwater Resource Directed Measures

The objective of resource directed measures (RDM) is to facilitate the proactive protection of our water resources, in line with fundamental sustainability principles. The National Water Act (NWA) recognises the need to develop and use our collective water resources to grow. However, the Act also clearly recognises that our water resources are not be used

to the detriment of future users. RDM hence strives to ensure that water resources are afforded a level of protection that will assure a sustainable level of development for the future. To this end, RDM comprises three main interrelated components, namely :

- Classification
- Reserve
- Resource Quality Objectives

It is important to remember that RDM is part of an overall iterative process to manage water resources within South Africa, and should be implemented under ORASECOM, within the basin member countries. RDM focuses on the basic principle of resource sustainability, while equity and other related issues are effectively addressed elsewhere in the water management process.

5.4.1 Tosca Dolomite Aquifer Over Abstraction Case Study

The following is a summary from the WRC's Groundwater Resource Directed Measures Manual (GRDM 2005) concerning lessons learnt from over abstraction and the subsequent reduction in regional groundwater levels clearly demonstrates why ORASECOM should implement resource directed measures.

The Tosca Dolomite Aquifer in the North West Province is recognised as a major aquifer within the basin (as is the area northwest of Vryburg). As a result of the over-abstraction of groundwater for irrigation from the Tosca Dolomite Aquifer, the aquifer is now regarded as a stressed aquifer. Agriculture is the main activity in the area. Small-scale subsistence farming predominated for a number of decades but a rapid escalation in the area of land under irrigation has occurred in the last ten years. A concomitant increase in the volume of groundwater abstracted and a resulting lowering of groundwater levels have accompanied this.

Because of over abstraction of groundwater and subsequent associated conflicts, an intermediate reserve determination was commissioned by DWAF and completed in April 2002.

Background Information

The study area is located in the North West Province and falls in the Lower Vaal Water Management Area. Nearby settlements include Pomfret, Tosca and Morokweng with a

combined total population of 14,500. Since 1990, rapid development of irrigation transformed the socio-economic and environmental prospects of the area. By 2002, it was estimated from registration of irrigation, satellite images, surveys and reports from farmers that approximately 2,000ha were under irrigation. This amounts to some 18.9MCM/a being abstracted for this purpose.

No surface water resources are used in the area due to the unreliability of the resource and because of a lack of infrastructure. Groundwater is the sole source of water for both agriculture and domestic requirements. The water use of stock, domestic and other activities is considered negligible (0.5%) when compared to the volume used for irrigation (99.5%). As such irrigation farming has placed an enormous strain on the dolomite aquifer.

A combination of factors led to the development of groundwater for irrigation purposes. During 1990, the CSIR undertook a geohydrological investigation of the area and characterised the groundwater resources as high yielding. Quality and isotope samples were taken from the water at that time indicated that some of the groundwater was fossil water (long residence times). This suggested that the sustainability of the resource was not as high as the borehole yields indicated. Nonetheless, the farming community pressed on with the development of groundwater and established irrigation-based crops.

Physiography and Climate

The area of interest is characterised by a flat topography. From the watershed in the east at 1210m the elevation gradually declines to 1070m in the west over a distance of 60km. The only topographic features being the Waterberge rising to 50m above the plain to the north and a number of non-perennial riverbeds. The area experiences a mean annual rainfall (MAR) of about 400mm/a with a potential evaporation loss of more than 2000mm/a. Most rainfall occurs during the summer months.

Sediments of the Kalahari Group underlain by Karoo cover much of the area. The sub-outcrop geology is shown in **Figure 5-1** and a SW-NE cross section of the study area is presented in **Figure 5-2**. The study area occupies some of the quaternary catchments within the Lower Vaal Water Management Area but the main focus was over the stressed Tosca – Vergelegen Aquifer.

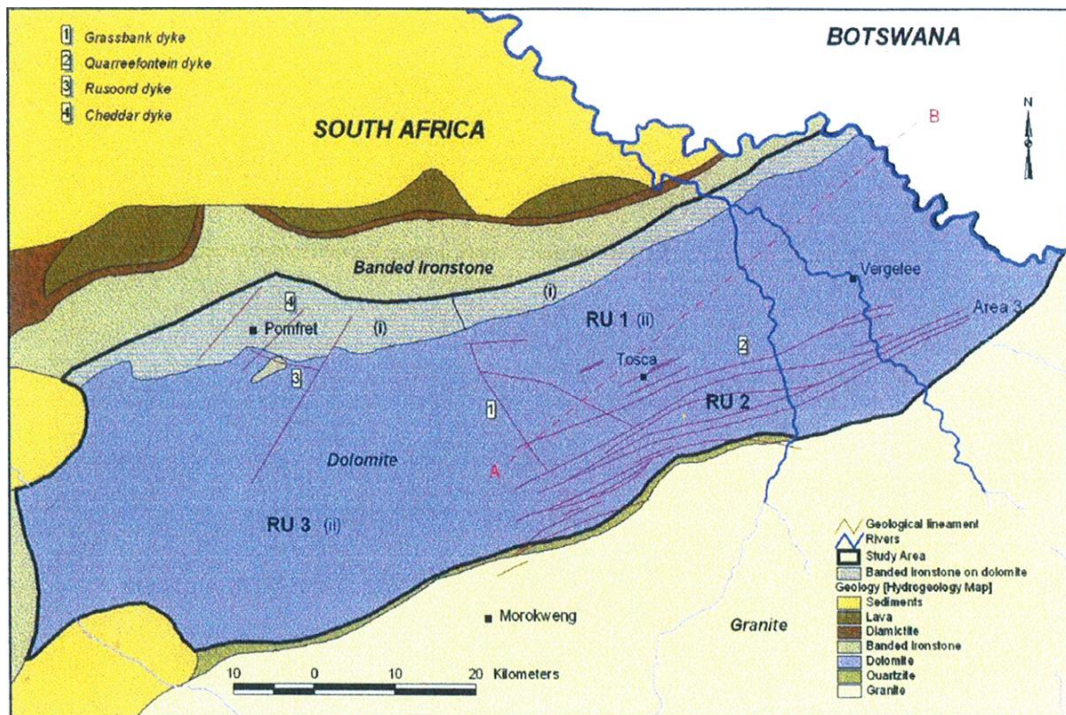


Figure 5-1: Pomfret – Vergelegen Dolomitic Aquifer showing sub-outcrop Geology

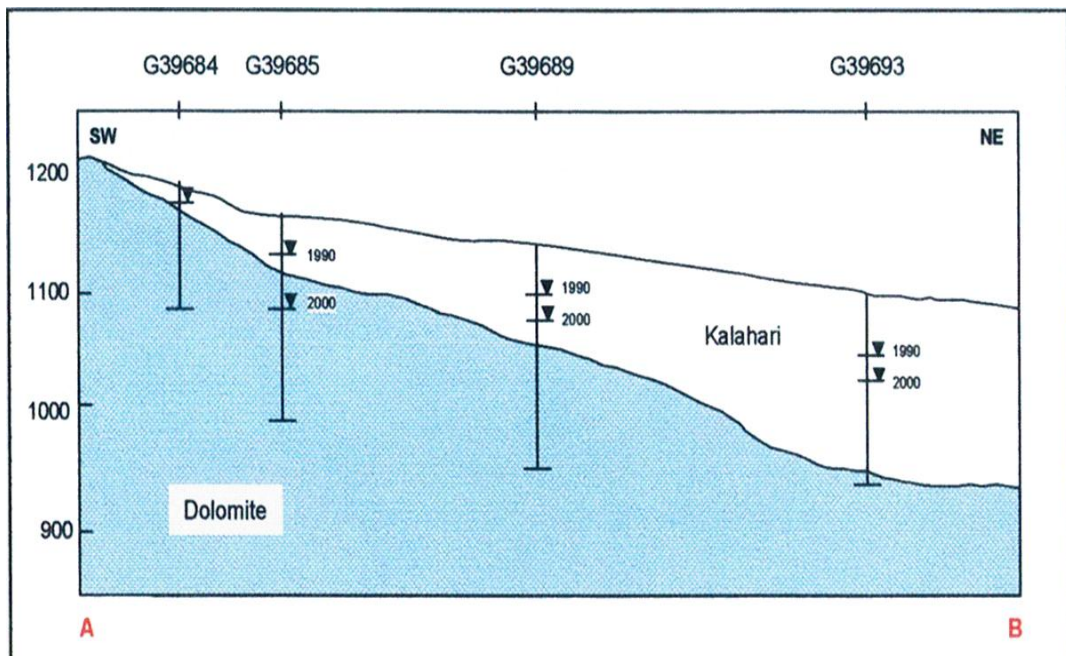


Figure 5-2: Cross-section through the Tosca Dolomitic Aquifer

The area is drained by the Thlagameng, Vals, Doring and Wildebeesthorng Rivers, which all drain into the Molopo River. The rivers are ephemeral and no flow occurs for between 60 and 70% of the year. The Molopo River is an influent river that recharges underlying aquifers during runoff events.

Geohydrology

Dolomitic aquifers are the major aquifer types in the study area. Localised areas of significant groundwater potential are associated with fault zones where fracturing, weathering and leaching of the rock has occurred. The fault zones vary from a few metres to tens of metres in width and can extend laterally for several kilometres. Brecciated fault zones consist of fractured dolomite, small solution cavities and Mg-rich wad material. Borehole yields range between 0.1 litres per sec and 126 litres per sec with average yields around 6.3 litres per sec.

In the northern parts of the study area, the dolomite is underlain by banded ironstone formations. Due to the low dip angle of these formations, the majority of the boreholes drilled into the banded ironstone penetrate the underlying dolomite formations. Natural groundwater levels vary between 5 and 10m below ground level (mbgl) in the west and to between 50 and 60mbgl northeast at the Molopo River.

Regional groundwater levels measured during a hydrocensus of the area in 1977 and again in 1990 (Duvenhage & Meyer, 1991) were available to assess reference conditions (see **Figure 5-3**).

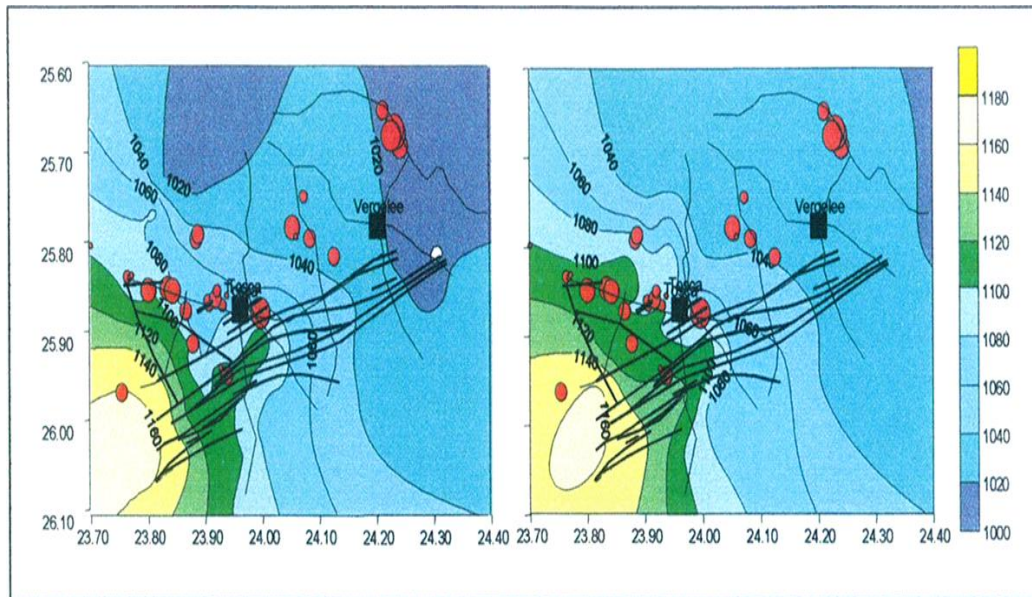


Figure 5-3: Groundwater level contours (mamsl) for 1977 (left) and 1990 (right)

Only minor changes in groundwater levels were evident between 1977 and 1990. The most significant differences in groundwater levels were elevated groundwater levels along the Molopo River and elevated groundwater levels along the dyke swarms parallel to the Quarreefontein dyke. Nonetheless, the groundwater levels in 1990 are still considered unimpacted and representative of reference conditions.

According to Vegter (WRC, 1995), recharge within the catchment ranges between 3 and 12mm/a. Recharge software developed by van Tonder (2000) was used to assess recharge. Areas of highest recharge are shown in **Figure 5-4**.

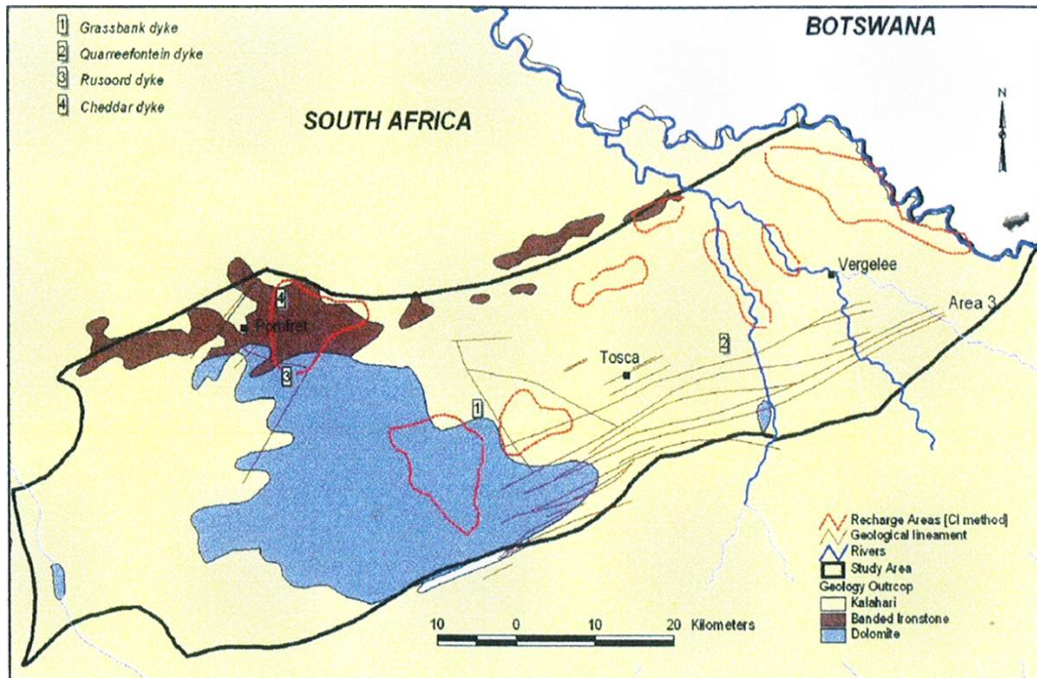


Figure 5-4: Areas of highest recharge

Recharge to the Tosca Dolomitic Aquifer was calculated to be 6.9MCM/a. Based on results from applying the Chloride Recharge Method, the following mechanisms of recharge to the dolomitic aquifer were considered important :

- Recharge through geological lineaments (faults, not dykes)
- Recharge through shallow outcrop and sub-outcrop of dolomite (southwestern area)
- Recharge through banded ironstone formation (northern border areas)
- Recharge through alluvial channels

Groundwater usage in the area has periodically been assessed by DWAF between 1990 and 2002. Abstraction from the Tosca Dolomite Aquifer increased dramatically from 2MCM/a to over 12MCM/a during this period. This abstraction has led to an alarming decline in groundwater levels in the area (see **Figure 5-5** and **Figure 5-6**). Between 1990 and January 2002, groundwater levels declined by as much as 60m in the southwestern part of the Tosca Dolomitic Aquifer and the southeastern part of the Pomfret Dolomitic

Aquifer. These areas coincide with areas of intense pivot irrigation, as indicated by the blue circles in **Figure 5-6**.

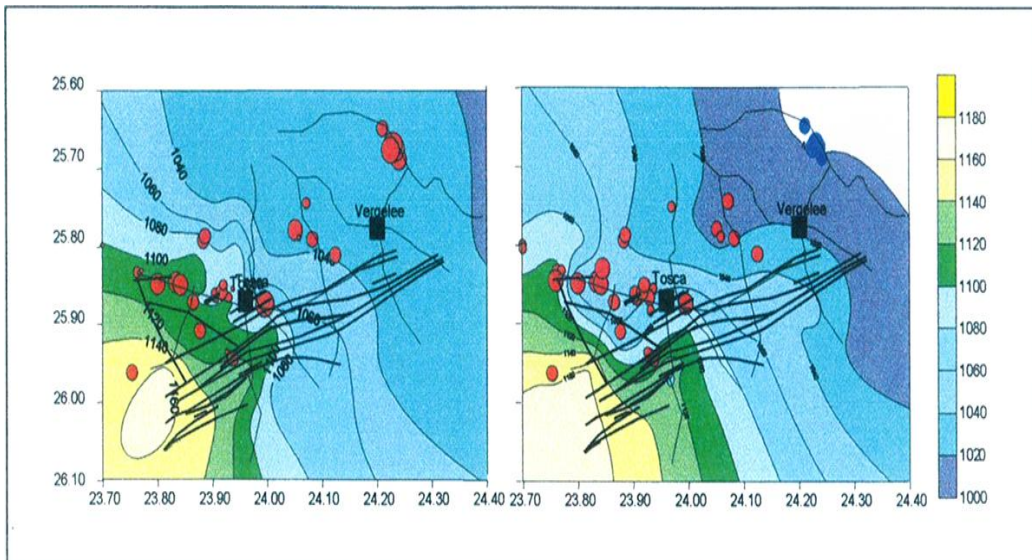


Figure 5-5: Groundwater level contours mamsl 1990 (left) and 2002 (right)

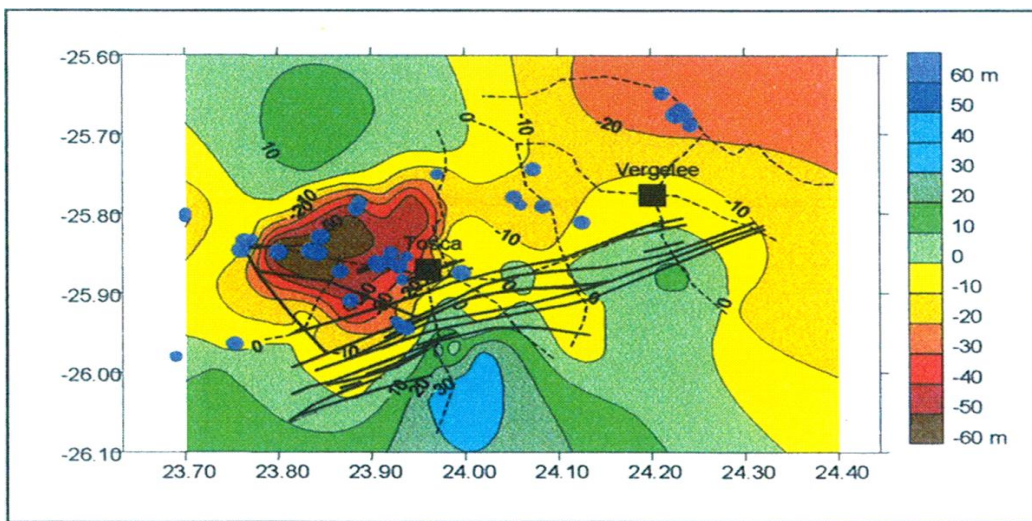


Figure 5-6: Difference in groundwater levels between 1990 and 2002. Blue circles represent areas of intense pivot irrigation

Recharge to the Tosca Dolomitic Aquifer was estimated to be 6.90MCM/a with an associated abstraction of 12.1MCM/a has clearly indicated an over-pumping of the aquifer of some 5.3MCM/a. Hence the subsequent classification of the aquifer as critically stressed.

It is evident from the assessment of groundwater levels and usage that at some point between 1990 and 2002, the sustainable yield of the aquifer was exceeded, causing a rapid decline in groundwater levels and as a result of this resource mismanagement, the aquifer is considered stressed.

Resource Quality Objectives (RQO) – Remedial Action

As a result from the GRDM assessment, the following Resource Quality Objectives to address the current unsustainable groundwater abstraction from the aquifer were proposed :

Groundwater levels in the Pomfret – Vergelegen Dolomitic Aquifer should not be allowed to decline any further over the long-term

This objective can only be achieved by reducing abstraction from the aquifer and allowing groundwater levels to recover. No new production boreholes should be drilled in recharge areas or in currently over-utilised dolomitic compartments. Existing production boreholes should not be pumped at more than 60% of their tested sustainable yield, and should not be pumped continuously for more than 12 hours per day. Spacing between production boreholes should be optimised to reduce further interference.

Summary and Conclusions

While groundwater plays no part in sustaining river flow in the area and the volume of groundwater required to meet basic human needs too small, over abstraction of groundwater for irrigation purposes has resulted in a critical decline in groundwater levels in the Tosca Dolomitic Aquifer. The aquifer is classified as critically stressed and over-exploited. Groundwater levels should not be allowed to decline any further and management actions are required to allow the aquifer to recover. A groundwater allocation plan has been developed in consultation with groundwater users to reduce groundwater abstraction by about 50% over a five-year period.

Thus the effective implementation of the GRDM programme within the Orange River Basin will determine the classification of significant water resources, set the Reserve and help define resource quality objectives.

5.5 Geohydrological Data and Mapping (National and within the Basin)

A programme of geohydrological mapping was embarked on in 1993 as a means of providing a quick overview of groundwater information (Vegter 1994). The Water Research Commission (WRC) and DWAF published a set of national maps (which included most of the basin on the SA side) together with an explanatory document in 1995 depicting in two A2 sized sheets (Vegter 1995) :

- Borehole prospects
- Saturated interstices
- Mean annual recharge
- Groundwater component of river flow
- Depth to groundwater level
- Groundwater quality
- Hydrochemical types

5.5.1 1:500 000 Map series

DWAF has embarked on the production of a general geohydrological series on a scale of 1:500 000 and the programme is currently on going.

5.5.2 Vulnerability Map

Understanding and recording the susceptibility of groundwater to pollution is important. Lynch et al. (1997) applied the DRASTIC concept (Aller et al. 1987) and GIS technology to produce a groundwater vulnerability map of South Africa. The map should be seen as a first attempt at depicting vulnerability using methodology initially developed for U.S.A. conditions. It has some limitations inherent to DRASTIC methodology and shortcomings in that certain data sets were not available and assumptions had to be made (Vegter 2001).

5.5.3 Groundwater Harvest Map

The Groundwater Harvest Potential Map of South Africa 1996 (Baran et al. 1998) is a derivative of the set of maps "Groundwater Resources of South Africa" published in 1995. Paraphrasing from the accompanying explanatory report: "The map quantifies groundwater resources. It permits direct comparison of different groundwater areas and

facilitates comparison with surface resources. Harvest potential is the sustainable volume of groundwater that may be abstracted per Km² per annum.”

5.5.4 Groundwater Recharge Maps

Two national scale maps of recharge are currently available. While preparing his geohydrological maps of South Africa, Vegter (1995) attempted to quantify recharge (see map overleaf). Schulze (1997) prepared a similar map, but of the annual recharge of soil water into the vadose zone (unsaturated). Both maps are deemed useful of obtaining a quick indication of recharge in a particular area. However, they must be used with caution. They provide only an indication of average recharge over an area, and cannot be used to determine recharge on a local scale. Whenever possible, more detailed and site-specific information should be used.

5.5.5 Available Groundwater Data

The following data sources with regard to groundwater related issues are available:

- NGDB database
- WARMS database
- Catchment Management Studies / Reports
- DWAF GH (Geohydrology) Reports
- WRC projects and related reports
- Geohydrological maps
- Consultant reports

Although there are many available sources of groundwater data it is often not easy, and at times frustrating, to access the data. The NGDB and WARMS databases are populated with a number of points. However, the NGDB often only contains water level measurements. Very little is available on abstraction volumes and groundwater quality. The WARMS database contains information regarding abstraction of groundwater for all registered and licensed users but this data still needs to be verified.

Other data sources in the public domain include Catchment Management Studies, geohydrological maps (e.g. Vegter and Barnard) and GH and WRC reports and studies. Some Environmental Impact Reports (EIRs) dealing with impacts on the groundwater domain are also available. This data is valuable since the studies are mainly focussed on a

regional scale and deals with specific groundwater related problems. It should be noted that this data should be centralised in a database such as WMS or NGA / NGDB in order to make the data more accessible for management purposes.

Another source of valuable information that is not readily available is consultant reports. Often industries and mines request consultants to investigate specific groundwater issues. The reports are generally discussed with DWAF but the data does not land up in the public domain. In spite of repeated requests for report listings, most consultants failed to respond. The reluctance to divulge information (especially information paid for by State funds) is unfortunately an inherent problem and systems should be put in place to ensure compliancy.

The reader is referred to Appendix B for references and detailed information on the availability of groundwater related data, its status, and format and confidence levels expressed in the data sets. The information is also available on the attached CD in an ACCESS database file and some notes are attached in Appendix B describing the operation of the database.

5.6 Additional Relevant Groundwater Comments and Observations

Besides the various major mining activities, major industries in the basin include Sasol Chemical Industries, DOW Chemicals, and Omnia fertiliser, Iscor, Sappi, AECI, Sasol Synthetic Fuels and Samancor Base Metal Refinery. None of these industries utilise groundwater as a resource but they do have localised impacts on the groundwater quality.

The Upper Vaal WMA falls within the most highly industrialised zone in the country and the industries are very diversified. Little site-specific data is available in the public domain regarding industrial pollution but from the nature of the activities, the principle potential problems can be highlighted. The major impacts from power stations, in terms of groundwater quality, are associated with the ash disposal and coal stockpiling areas. Hodgson and Krantz (1998) have indicated the major groundwater quality concerns at power stations are elevated sulphates, elevated TDS values and in certain cases very high pH waters. Where these high pH conditions exist, metals such as Al and Mn can go into solution and are cause for great concern.

Gold mining with the WMA on the West and East Rand and coal in the Vaal basin has contributed to the regional degradation of groundwater quality and a broad encompassing

study should be implemented to delineate the degree of point and diffuse groundwater pollution.

Management of the groundwater resource in this strategically important WMA takes place on an adhoc basis (Fayaz, 2003) due to the lack of capacity in the Geohydrology Division of DWAF's Gauteng Regional Office. Only groundwater problems that require immediate attention are addressed. This management style impacts negatively on the valuable water resources. Provision should be made for adequate professional staffing levels to effectively manage the resource.

5.7 Groundwater Monitoring

Groundwater in South Africa was regarded as private under the 1956 Water Act, and as a result its status was not monitored or assessed to the same extent as surface water. However, groundwater has the potential to contribute significantly to meeting the needs for water in rural areas, particularly for domestic supply. Existing monitoring networks will need to be expanded and refined, and surveys undertaken to improve understanding of the quantities and quality of water available if this potential is to be realised and the use of groundwater integrated with surface water use (conjunctive use).

Groundwater levels and water quality are currently recorded on a continuous basis at some 150 points and at regular intervals at about another 1,000 points. Continuous monitoring at an estimated 460 points is required for an effective national network. The current understanding is for DWAF to refine and develop the present system (which will have direct benefit for the ORASECOM programme) to create an integrated monitoring network at three levels, namely

- National monitoring by the Department in relatively unimpacted areas to provide background and baseline information on water levels and water quality. The establishment of this part of the network has the highest priority and its expansion is planned for completion by 2006
- Monitoring of major aquifers by catchment management agencies to determine trends in water levels and water quality resulting from human activity. This will initially only cover physico-chemical monitoring, although scope will eventually need to be expanded to microbial, toxicity and radioactivity monitoring. The Department will continue with this monitoring until the catchment management

agencies can take over the responsibility. Pilot networks have been established in the water management areas that have been prioritised

- Local impact monitoring. Information provided by users in terms of the conditions attached to general authorisations and licensing will have an important source of information on groundwater use. Additional information will be derived from reports on conditions encountered during borehole drilling

5.8 South African References

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6 GROUNDWATER INFORMATION SYSTEMS FOR ORASECOM IWRMP

It is clear that groundwater information for the Orange River Basin is currently held by various institutions in many various forms and formats, and such dissemination of information is a waste of a valued resource. Availability of timely, adequate and **valid** geohydrological data and information will be crucial to the success of the ORASECOM IWRMP. It is imperative, therefore, that collection of new geohydrological data be accompanied by the continuous enhancement of powerful and standardised (within the SADC Region) information tools such as databases, information systems, maps and reports. These should be used to convey the relevant information to ORASECOM, Government departments within the basin member countries, geohydrological specialists, water resource managers, decision makers and other interested parties.

Information can be made available in various formats. The classic formats such as printed maps and reports are important, but increasingly these are supplemented by electronic (digital) systems, which are capable of supplying data customised for specific purposes. The printed maps are key and important tools in water management and the ORASECOM Commissioners should hold a relevant selection.

A number of computer-based systems are available for storing and sharing of the geohydrological data and information, in addition to libraries and technical reports in the four basin member countries. In South Africa, a new portfolio titled the National Groundwater Information Systems (NGIS) is in the final stages of design to meet increasing demands for groundwater information in a rapidly changing water business sector. The NGIS portfolio includes several projects. Amongst the most important are REGIS Africa and National Groundwater Archive (NGA). The latter is a relational database management system. The system will be distributed among regional offices, and will integrate both spatial and non-spatial data and information. It also accommodates increased visualisation and analytical functionality.

The mainframe-based National Groundwater Database (NGDB) has been replaced with a server-based system as a bridging solution until the web-based National Groundwater Archive (NGA) becomes operational. The development of the system and the transfer of data is expected to be completed soon. The Institute for Groundwater Studies (IGS) maintain the HYDROCOM database but proprietary software is required to access the data sets. The National Water Quality Database (NWQDB) containing over 55,000

analyses of groundwater samples, mostly of macro elements, has recently been replaced with the Water Management System (WMS). Data from the National Groundwater Quality Monitoring Network has been included. To make the database useful over a long period of time, it is important that the collected data sets are comparable. The features of the some of the geohydrological / hydrological information systems with DWAF SA relevant to ORASECOM IWRMP are listed in the table below :

Table 6-1: Features of some geohydrological / hydrological information systems

	REGIS	HydSys	WMS	WSAM	WARMS
Primary Function	Geohydrology	Surface hydrology	Water quality	Water situation assessment	Authorised water use
Mapping Component	ArcView	Proprietary formats	ArcView	ArcView	None present
Database	Oracle	Proprietary	Informix	Access	Informix
Data exchange	ASCII tables	ASCII	ASCII	ASCII	ASCII
Spatial Data Exchange	Shape files	Shape files	Shape files	Shape files	Shape files

A problem of many databases and information systems is incorrect data. This is damaging to the trust and hence usefulness of the database and systems and structures should be in place to ensure the risks are minimised.

Given the dispersed nature of the huge volume of information and the fact that most of the data is in a non-digital format, information verification is not feasible under the current available project funding. The annual allocation of only 100,000 Euros is drawing out and delaying the tasks and ways must be found to either bridge finance the project or to convince the funding agent to provide the full budget in one year.

7 CONCLUSIONS AND RECOMMENDATIONS

If groundwater is to be included in not only the ORASECOM IWRMP but also any other Integrated Water Resource Management Plan, management of groundwater has to comply with the policy, strategy and practice of **common** standardised water resource management within the Orange River Basin and all of its member states. Where management practises must differ from, or be modified to accommodate unique geohydrological characteristics, a clear statement from the Geohydrological Department of the relevant ORASECOM basin member country should be required as to why the policy, strategy applied in the IWRMP cannot be applied to the management of groundwater.

The following conclusions recommendations are aimed at setting up mechanisms to fill the data gaps and identify additional systems and structures needed:

- Management of the water resources in the Upper and Lower Orange WMAs, as well as the Upper, Middle and Lower Vaal WMAs must be within the framework of ORASECOM as should the relevant areas in the bordering countries
- The already full development utilisation of groundwater and surface water resources across most of the remaining WMAs with the Orange River Basin (on the SA side especially) should become key ORASECOM management considerations
- Explore and promote the conjunctive use of groundwater (augment surface water where feasible)
- Botswana's groundwater potential within the Olifants Sequence north of Middelpits needs to be quantified as reports suggest the area had good groundwater development potential
- Any groundwater development concerning spatial flow in transboundary/shared aquifers needs to be managed in a sustainable and responsible manner
- The Kalahari Sequence basal aquifer potentially constitutes a useful resource and additional studies are needed to further delineate the zone
- Planned development resulting in over-exploitation and stressing of the Kanye wellfield in Botswana needs careful planning and investigation before project implementation

- Orange River Basin groundwater development and associated recharge potential needs to be better understood and additional studies are needed before accurate localised maps can be produced
- All mining institutions should be encouraged to place all groundwater related information in the public domain
- The four basin member countries should all work towards using common borehole design, construction methods and data management procedures
- More comprehensive bibliographical data needs to be supplied by consultants. Consultants inherently are reluctant to part with report listing information and it is suggested that relevant systems and structures are put in place to address this
- Improved management style by the provision of adequate professional staffing levels to more effectively manage and monitor groundwater resources
- Collect, geo-reference, collate and digitise all available data from all available raw data files. Store data in common readily accessible and updateable databases
- Maintain existing and establish new effective groundwater monitoring systems and undertake hydrochemical and hydrocensus baseline surveys
- Produce geological and hydrogeological maps from digitised regional data
- Produce soil distribution maps from digitised regional data
- Produce fracture analysis map (satellite imagery) from digitised regional data
- Produce dyke distribution map (use areomagnetics) from digitised regional data
- Produce digital terrain map
- Produce groundwater use map (from hydrocensus and other relevant data)
- Digital data for the above entered into a GIS would enable various data layers to be combined to produce a map of groundwater resource development potential for designated peri-urban and urban areas
- Exploration (investigation) boreholes should be drilled within those areas identified for peri-urban development to determine their groundwater development potential for interim (conjunctive use/augmented) water supply
- Aquifer vulnerability mapping in selected and relevant (urban / peri-urban and adjacent rural areas) to identify susceptible zones
- Hydrocensus survey to assess the distribution of dry, failing and successful boreholes that could be used to indicate areas of good groundwater development potential. This survey would indicate which of the designated urban areas could

be supplied from groundwater sources. The survey should include all aspects such as GPS location, yields, water quality etc.

- Study of the pollution threats from mining, agriculture and from pit latrines (VIPs) especially in areas identified for peri-urban development
- Groundwater use / utilisation survey with the four basin member countries to determine the overall distribution of groundwater abstraction, which will help identify areas where groundwater can successfully be used for rural and peri-urban development etc.
- Implementation and use of Groundwater Resource Directed Measures based on the WRC SA Model and guidelines by the domestic groundwater institutions should be encouraged in all basin member countries
- Survey of groundwater wellfields to assess their long-term sustainability and reassess their groundwater resources (development potential). Information derived from the development of these wellfields could be compiled as a series of case studies to be used in the planning and design of wellfields in similar hydrogeological environments
- Improved collection of all geological information (such as lithological logs) etc.
- Detailed hydraulic parameters such as permeabilities and porosities from core plug samples and data derived from other relevant testing procedures
- Logging of boreholes will inform patterns of groundwater flow and other aquifer hydraulic characteristics
- Available hydrochemical data to be processed, statistically analysed and published in the form of maps
- Reconnaissance or broad encompassing surveys to locate significant dispersed and point pollution or contamination of groundwater and other risks
- Investigation of groundwater-environmental interactions (especially in the developed and industrialised zones of the basin)
- More attention should be given to groundwater balance determinations for estimating recharge in the basin
- Groundwater modelling should be developed increasingly into a more useful and strategic tool
- Data acquisition storage and processing facilities needs to be greatly improved and expanded

- Groundwater data and information of certain geohydrological units (important aquifer areas) within the basin should be processed and compiled in the form of basin specific geohydrological maps and groundwater assessment inventories
- Verification of data contained in the WARMS database

Many issues have been raised relating to practical problems experienced in managing Southern Africa's groundwater resources. Many of the problems relate largely to the **separate manner** in which groundwater is managed. In essence, five generic strategies are proposed to change the traditional approach and ensure successful implementation:

- Integrate groundwater into the management of water resources for the benefit of all
- Actively promote groundwater and the conjunctive use of groundwater so that water resource managers, water-users and the general public are more aware of the role, occurrence and value of groundwater
- Encourage and enable Geohydrologists to work outside their line function, and be integrated into the broader water resource planning and management functions
- Develop a larger, skilled and experienced specialist geohydrological workforce
- Develop a **common** groundwater monitoring network and a **common** geohydrological information system to assist in the provision of data to those who need it

The simple fact that groundwater is used as a source of water for more than 15 million people in South Africa alone, clearly demonstrates the importance of the resource. It is no longer acceptable to manage groundwater in a separate manner and by the conjunctive use of the resource, the effective use of groundwater will gain wider acceptance.

From available information, it appears no one full and detailed regional groundwater overview of the complete basin area has been completed to date and it is therefore recommended that a full and detailed regional study encompassing the co-basin member states be conducted. A strategy to accomplish these needs to be developed.

On an international and national level, co-operative governance needs to be factored into the overall integrated water resources management undertakings, to ensure a benefit to all

users. Existing local and international communication systems should be fully utilised to keep track of proposed water resource developments and planning.

Bold initiatives are required to ensure the ORASECOM Integrated Water Resources Management Plan can be implemented at an international, national, catchment and local level.