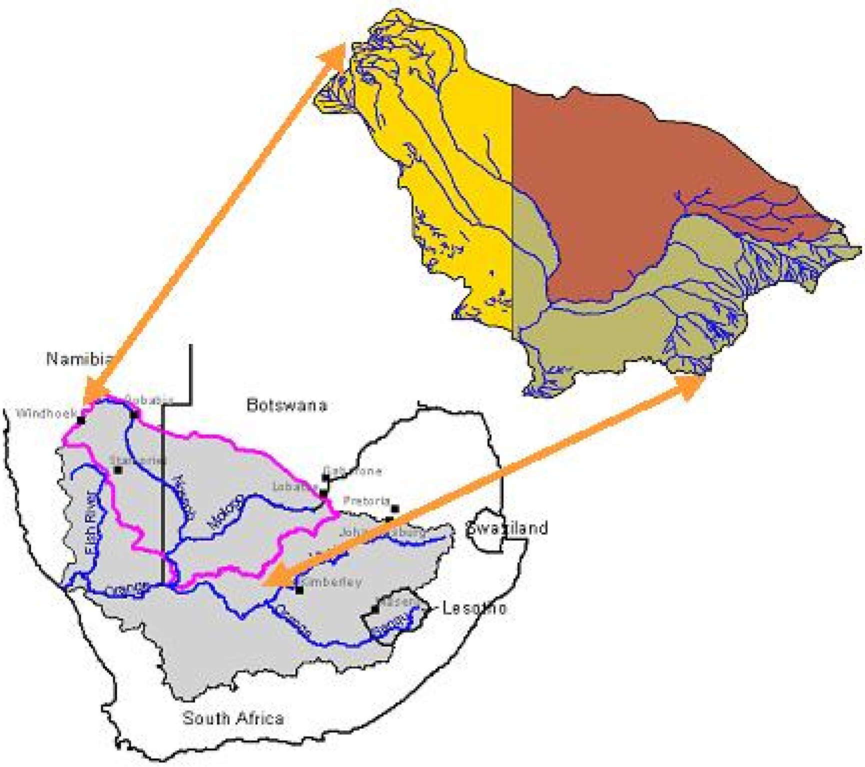
Report No. ORASECOM/005/2009

ORASECOM

GROUNDWATER REVIEW OF THE MOLOPO-NOSSOB BASIN FOR RURAL COMMUNITIES INCLUDING ASSESSMENT OF NATIONAL DATABASES AT THE SUB-BASIN LEVEL FOR POSSIBLE FUTURE INTEGRATION



FINAL REPORT

July 2009

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Groundwater Review of the Molopo-Nossob Basin for Rural Communities including Assessment of National Databases at the Sub-basin Level for Possible Future Integration

Executive Summary

The Molopo River is an ephemeral tributary of the Orange – Senqu River system, an international river basin shared by Lesotho, Namibia, Botswana and South Africa. The Orange-Senqu River Commission (ORASECOM) is established to advise the parties on water related issues. The size of the Molopo-Nossob Basin is approximately one and a half times the size of Great Britain, 12 times the size of Lesotho or almost equal to the size of Japan.

The main objective of the project was to evaluate the groundwater resources of the Molopo-Nossob Basin based on an exhaustive analysis of the available data and information. This included a thorough analysis of the data/databases in each of the basin states in order to make recommendations on how data can best be shared between the basin states and integrated in a common database.

The Molopo-Nossob Basin covers an area of 367,201 km^2 delineated from the surface water catchment. Of the basin, Botswana covers 37%, Namibia 33% and South Africa 30%. The basin contains the catchment areas of four main rivers; Molopo, Kuruman, Nossob and Auob Rivers.

The long term average annual precipitation varies from 100 mm/a in the south-western part of the basin to over 500 mm/a in the eastern part in South Africa, and 400 mm/a in the northern part in Namibia. Evaporation and potential evapotranspiration highly exceed the average rainfall. According to UNEP classification, the whole basin is arid to semi-arid.

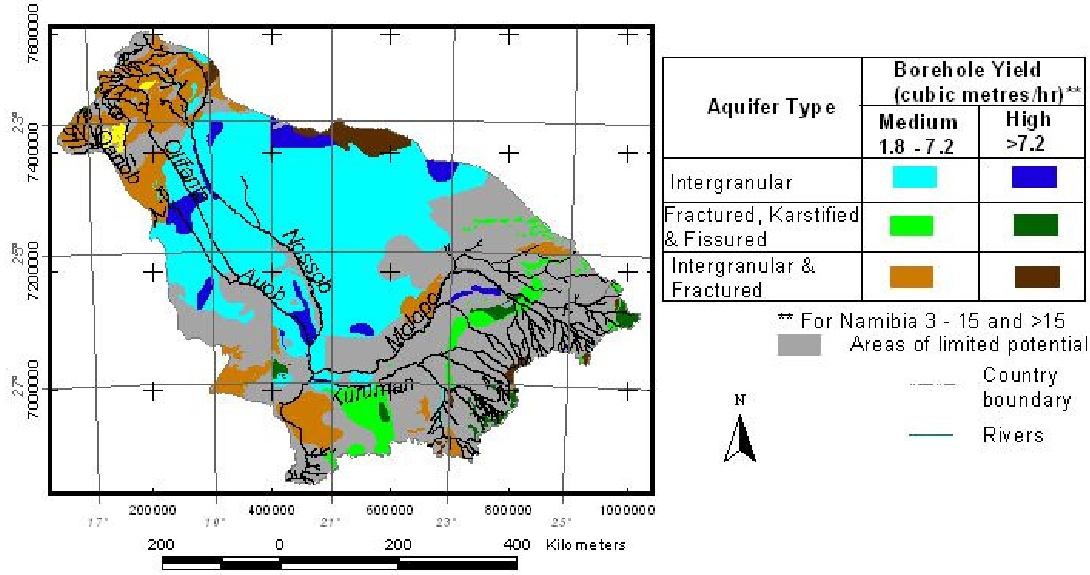
The population in the Molopo-Nossob Basin is about one million, and the livestock units (ELSU) are about 1.6 million including wildlife. The population per km^2 varies from 0.2 in Kgalagadi North District in Botswana to 62 for the Upper Molopo catchment area (Mmabatho area in South Africa) and an average for the basin the population density is 2.7 persons per km^2. The ELSU density is almost similar in the three countries (4.2 to 4.6 ELSU per km^2).

The water requirement in the Molopo-Nossob Basin is referred to domestic, livestock, irrigation and mining users. The total requirement is 128 Mm^3/a (2000). Of this 69% is required in South Africa, 18% in Namibia and 13% in Botswana. About 37% of the water requirement goes to livestock watering, 27% to domestic purposes, 27% to irrigation and 9% to industry (mining). Only 0.1% is for tourism.

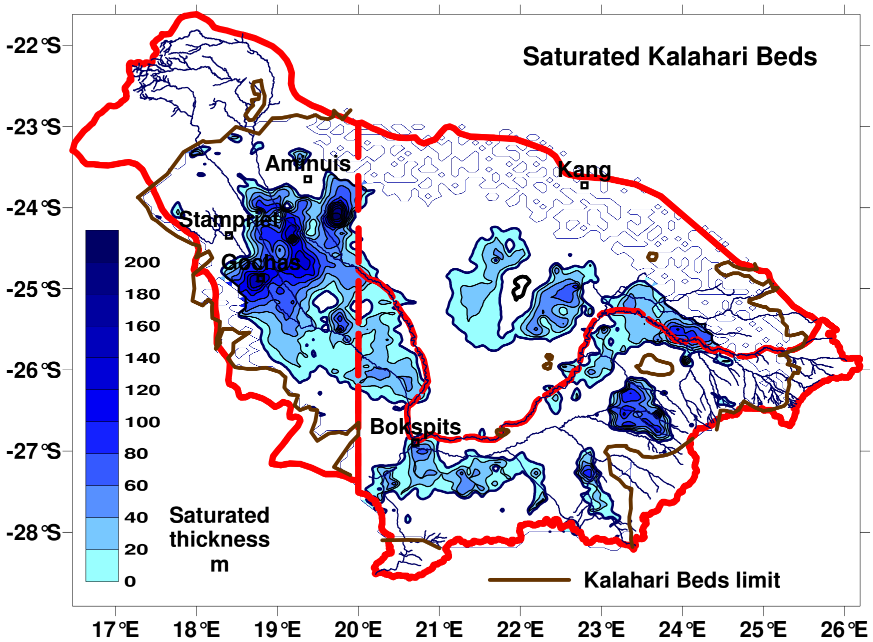
Development which requires a major quantity of water is foreseen in the Botswana part of the Basin where plans for irrigation developments will require about 6.2 Mm^3/a of water from the year 2015. Other major water consuming developments are for the mining industry in South Africa together with plans for increased irrigation. The future water requirements for the three countries will increase by the year 2015 to about 160 Mm^3/a. On the average an annual increase in the water requirement for the Molopo-Nossob Basin is about 1.5%.

The geology of the basin covers geological formations from the Archean to Recent, a time span of more than 2,500 million years. The formations host a variety of aquifers; intergranular, fractured intergranular, fractured and karstic aquifers.

The potential of the aquifer is assessed from the mean borehole yields displayed on hydrogeological maps over the Namibian and the South African part of the basin. Three classes of potential are recognized; high, medium and low potential. For Botswana the potential is based on regional groundwater maps combined with results from groundwater investigation in local areas in the basin.



The Kalahari Beds contains locally groundwater. "Saturated" Kalahari Beds are found in the Gemsbok National park and the continuation into the Namibian part of the basin following the river Nossob and Auob up to Stampriet and Aminuis. Large areas are also found along the Upper Molopo River Course, in Gordonia and in the central part of Botswana. Beside these larger areas, "perched aquifers" occur locally in the Kalahari Beds.

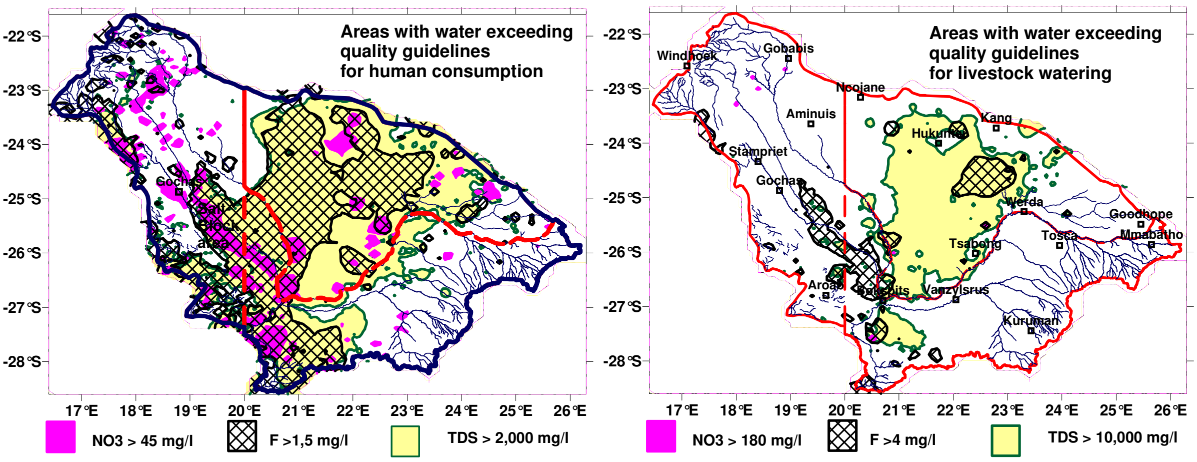


The largest aquifers in the basin are the fractured intergranular Ecca aquifer (the Auob aquifer) and the intergranular Kalahari Bed aquifer. These two aquifers interact in areas where they are in contact with each other. Multiple aquifers occur in areas in Namibia and Botswana where a deep layer of sandstone (Nossob sandstone) is found below the Ecca aquifer and interlayered low permeable formations. The extensive Ecca aquifer of Karoo Supergroup (combined with the Kalahari Bed) is classified as a medium potential aquifer, but it includes many areas assessed as high potential aquifers. In the Karoo Supergroup a high potential Ntane Sandstone aquifer is also found above the Ecca aquifer in the northern Botswana.

The aquifers with the highest potential in karst environment are found in the dolomitic formations in South Africa and Botswana. These formations are also host areas currently classified as medium potential aquifers.

The crystalline bedrock is classified as low potential aquifers. These formations are found in the northern part of Namibia and in eastern Botswana and large part of South Africa. Groundwater is available but limited to the occurrence in fractures and fissures. Where fractures form pronounced and extensive zones, good yielding local aquifers are encountered.

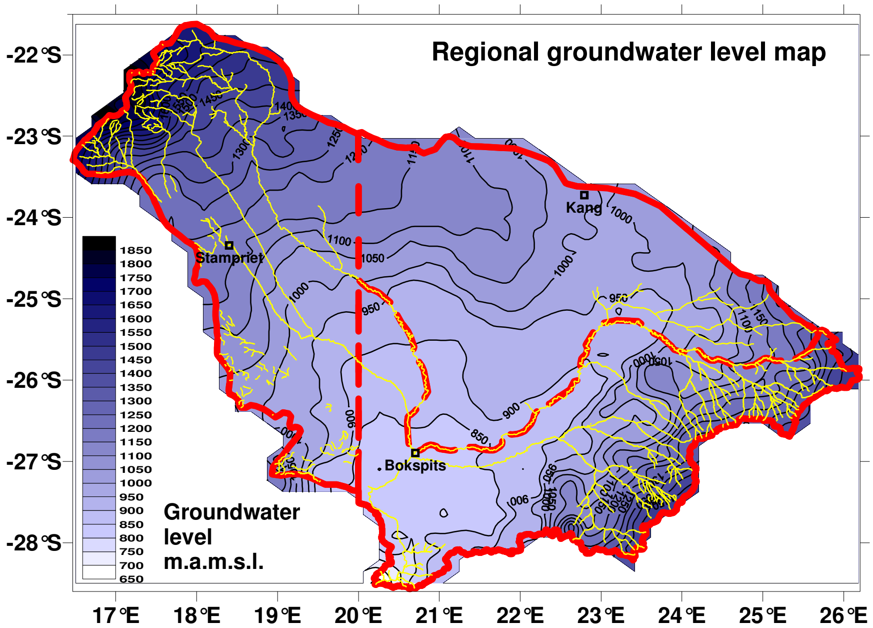
The quality of the groundwater varies within the basin. Guidelines for domestic use and for livestock watering regarding the content of Total Dissolved Solids (TDS), nitrate (NO_3) and fluoride (F) are similar in the three countries. Maps are constructed to show the areas in which the guideline values are met or exceed.



The larger part of Botswana has groundwater quality exceeding the guidelines for human consumption. In Namibia, the groundwater quality is poor along the Auob River downstream Gochas (the Salt-Block area). The area of poor water quality continues into South Africa where almost the whole Gordonia experience water quality exceeding the guideline limits for TDS and F. Areas of good water quality are found in the middle and northern part on Namibia, central and eastern part of South Africa and easternmost and north-western part of Botswana. Limited minor areas of high NO_3 are found referring to local groundwater pollution.

For livestock watering the areas of unfit groundwater are limited to central and southern parts of Botswana, the Salt-Block area in Namibia and a minor part in the Gordonia area.

Monitoring of the groundwater level is done in more than 600 boreholes in the Molopo-Nossob Basin. The majority of monitoring boreholes are close to abstraction boreholes or in wellfield areas. Monitoring is done on various time intervals and using different methods. The use of automatic monitoring devices has increased which has resulted in improved continuity of the records.

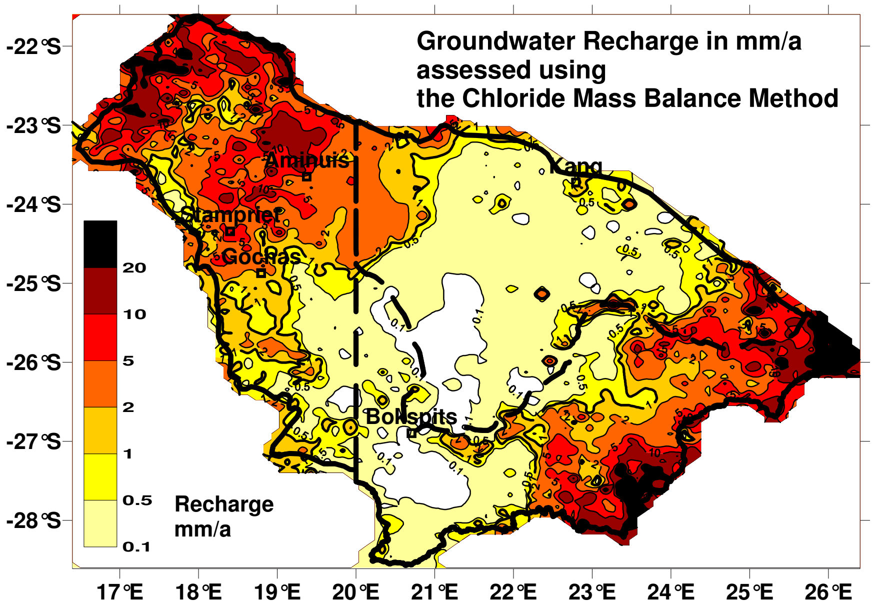


Groundwater level data stored in the borehole archives in all the three countries, together over 34,000 boreholes, forms the background information for a regional groundwater level map over the Molopo-Nossob Basin. The map shows that the highest groundwater levels (1,750 mamsl) are in the northern Namibian part of the basin. From there the groundwater flow is directed southeast into Botswana and South Africa and from there towards the south and out from the basin through the area along the southern part of the Molopo River (750 mamsl). High groundwater level is also encountered in the south-eastern South African part of the basin (1,450 mamsl).

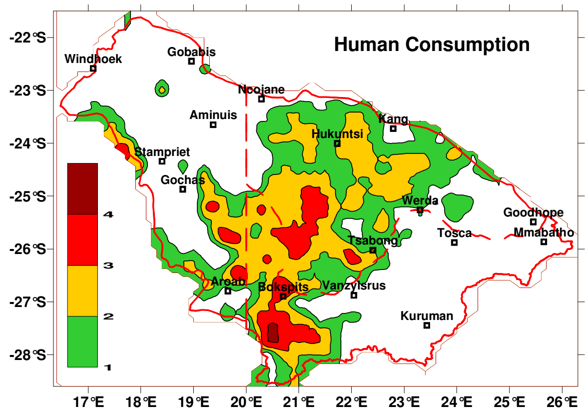
The groundwater divide in northern Botswana does not follow the surface water divide as it is illustrated on Botswana water maps. That makes in fact the Molopo-Nossob Basin smaller than derived from the surface water divide.

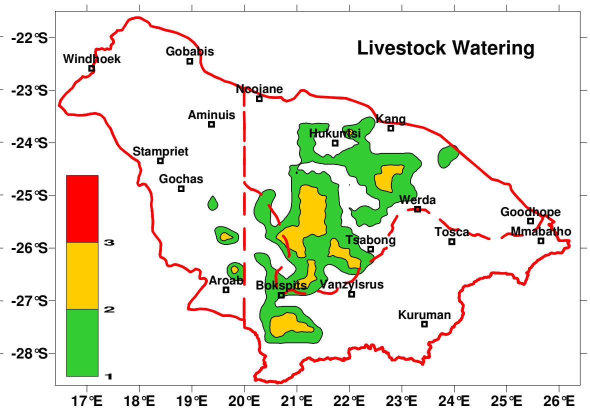
The Chloride Mass Balance method was used to assess the groundwater recharge from the rainfall. This method shows that large areas of the basin receive less than 1 mm/a recharge as a long term average. Recharge of more than 10 mm/a is assessed for the northern part and for the area northwest of Stampriet and Aminuis in Namibia and south-eastern part (Mmabatho) and the Kuruman area in South Africa.

Extreme low recharge (< 0.1 mm/a as an average annual value) is assessed for the central part of Botswana close to the Gemsbok National park, an area northeast of Bokspits and for the central part of Gordonia in South Africa. In Botswana recharge of more than 2 mm/a is found for the north-western and the south-eastern parts.



The hydrogeological regime of the Molopo-Nossob Basin is complex with many types of geological formation and hence of groundwater resources (aquifers). A qualitative indicative assessment approach was taken by combining various data sets and knowledge collected to delimit areas where the already described water quality guidelines are not satisfied together with recharge estimated at a minimum 0.2 mm/a to produce two new set of maps as part of the groundwater resource evaluation..





Integrated GIS based Basin Information System is based on the availability and level of information differs between the countries. There is a need to share data between countries in order to best understand the groundwater situation and for optimum planning, resource development and sustainable management. The integration of both databases and the exchange facilities requires that information systems within the countries are compatible.

A proposal to facilitate the exchange of data as well as possible integration will be a GIS data storage and management system. The system should have capabilities to be used as an information centre for the basin in order to provide rapid responses to groundwater evaluation and modeling of the sub-basin and facility for dissemination and exchange of data within the states.

It is recommended that the database be developed in Microsoft SQL Server technology.

It is recommended that monitoring of groundwater; both quality and level should be continued and extended to include areas which are remote and not affected by human development.

It is further recommended that more than the currently used chloride mass method for recharge assessment should be applied in the basin. The current assessment of recharge should also be assessed in comparison with the general flow of groundwater in the basin through mathematical modeling.

The use of the concept of Groundwater Harvest Potential introduced in South Africa should be extended and map produced also for Namibia and Botswana, especially for areas of low groundwater recharge.

Large parts of the basin has water unfit for human consumption and for livestock watering. Water treatment options exist and could be applied for private and communal use. The current and future use of such treatment option should be addressed.

Groundwater Review of the Molopo-Nossob Basin for Rural Communities including Assessment of National Databases at the Sub-basin Level for Possible Future Integration

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LIST OF ABBREVIATIONS AND SYMBOLS

ADG	Average Daily Gain
AEM	Analytical Element Method
AI	Aridity Index
AIDS	Acquired Immune Deficiency Syndrome
ARV	Anti Rretroviral (HIV/AIDS drug)
BH	Borehole
BDF	Botswana Defence Force
BEM	Boundary Element Method
BOBS	Botswana Bureau of Standards
CBNRM	Community based Natural Resource Management
CMA	Catchment Management Agencies
CMB	Chloride Mass Balance
CRD	Cumulative Rainfall Departures
CSO	Central Statistics Office
DEA	Department of Environmental Affairs
DGS	Department of Geological Survey
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
E	East
EC	Electrical conductivity
ELSU	Equivalent Livestock Unit
EOS	Economically Oriented Scenario
ET	Evapotranspiration
F	Fluoride
FAO	Food and Agriculture Organisation
FCR	Feed Conversion Ratio
FDM	Finite Difference Method
FEM	Finite Element Method
GDC	Ghanzi Dostrict Council
GIS	Geographic Information Systems
GOB	Government of Botswana
ha	Hectare
HIV	Human Immunodeficiency Virus
hr	Hour
JICA	Japan International Cooperating Agency
KDC	Kgalagadi District Council
Km	Kilometre

Km^2	Square Kilometre
l/s	Litre per Second
m	Meter
m^3	Cubic Meter
MAWRD	Ministry of Agriculture, Water and Rural Development
mamsl	Meters above Mean Sea Level
mg/l	Milligrams per litre
m^2/d	Square Meter per Day
m^3/a	Cubic Meter Per Annum
m^3/d	Cubic Meter per Day
m^3/h	Cubic Meter Per Hour
mm	Millimeter
Mm^3	Million Cubic Meter
Mm^3/yr	Million Cubic Meter per year
mm/a	Milligrams Per Annum
mS/m	Millisimians per meter
N	North
NAMPAAD	National Master Plan for Agricultural Development
NC	Northern Cape
NDP	National Development Plan
NO_3	Nitrate
NGIS	National Geological Information System
NWA	National Water Act
NWMPR	National Water Master Plan Review
NWRS	National Water Resource Strategy
ORASECOM	Orange-Senqu River Commission
PDE	Partial Differential Equation
PET	Potential Evapotranspiration
RAPS	Rescaled Adjusted Partial Sums
RDP	Regional Development Plan
^oC	Degree Centigrade
S	South
SAB	Stampriet Artesian Basin
SADC	South African Development Community
SDC	Southern District Council
SOS	Socially Oriented Scenario
SPI	Standardized Precipitation Index
SVF	Saturated Volume Fluctuation
SWCA	Subterranean Water Control Area
T	Transmissivity

TDS	Total Dissolved Solids
TWQR	Target Water Quality Range
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Educational Fund
UNEP	United Nations Environment Programme
USGS	United States Geological Survey
W	West
WMA	Water Management Area
WTO	World Tourism Organization
WUA	Water Users Associations
WUC	Water Utilities Corporation
%	Percentage

1 INTRODUCTION

1.1 Background

The Molopo River is an ephemeral tributary of the Orange – Senqu River system which is an international river basin shared by Lesotho, Namibia, Botswana and South Africa (**Figure 1-1**). The Orange-Senqu River Agreement signed by the governments of the four countries established the Orange-Senqu River Commission (ORASECOM) to advise the parties on water related issues.

Orange – Senqu River Commission (ORASECOM) has appointed Geotechnical Consulting Services (Pty) Ltd, to evaluate the groundwater resources in the Molopo-Nossob basin based on the analysis of available data and information basin-wide. The project commenced on November 1, 2008.

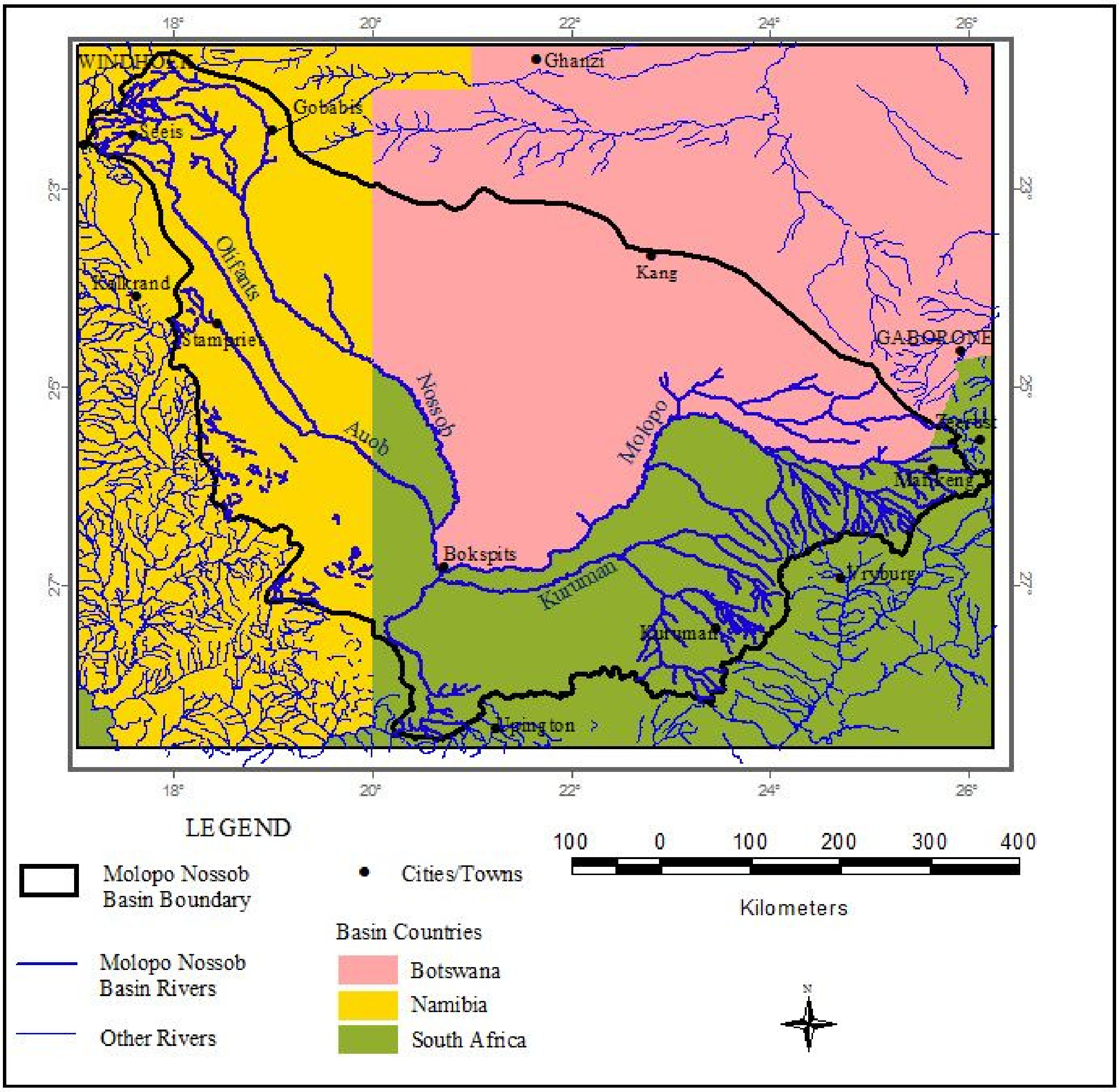


Figure 1-1 Molopo-Nossob Basin and major rivers within the basin

1.2 Purpose of the Study

The main objective of the project is to evaluate the groundwater resources of the Molopo-Nossob basin based on an exhaustive analysis of the available data and information on boreholes and wells, groundwater monitoring, existing groundwater models, water supply and demand, water uses, water rights, pollution sources, infrastructure and operating procedures, environmental and socio-economic information etc. This is necessitated accessing and analyzing the data/databases in each of the basin states for the whole project area.

A major sub-objective of the project is the quality assessment, and integration of different data sets as well as recommendations for how data can be shared between the basin states and integrated in a common database.

The study, with the mission as stated by the main objective, is divided into three phases:

1. Inception Phase
2. Data Collection, Assessment and Preliminary Integration Phase
3. Groundwater Evaluation and Reporting Phase

The three phases form a logical sequence, in addition project management and reporting will be a cross-cutting activity over the duration of the project.

1.3 Purpose of this Report

The purpose of this report is to present the results based on the exhaustive analysis of the available data and information on the groundwater resources of the Molopo-Nossob and recommendations of the study.

1.4 Structure of this Report

Chapter 2 presents the description of the Molopo-Nossob Basin which also includes the catchment areas, main rivers, dams and pans, and transfer schemes. In **Chapter 3** are deals with water requirements and use in the three basin states. **Chapter 4** describes the developmental activities in the study area. **Chapter 5** presents the geology and hydrogeological overview of the Molopo-Nossob basin. The groundwater resources evaluation is described in the **Chapter 6**. **Chapter 7** is on integration of the databases and quality assessment. **Chapter 8** presents an overview of the ENDNOTE programme and main sources of information. **Chapter 9** presents the conclusions and recommendations and **Chapter 10** presents the references.

2 DESCRIPTION OF THE MOLOPO-NOSSOB BASIN

2.1 Main Catchment areas

The Molopo-Nossob Basin is defined as the catchment area for the Molopo River and extends from the confluence with the Orange River to the end of all its tributaries, see **Figure 2-1**. The Molopo River is an ephemeral tributary of the Orange – Senqu River system which is an international river basin shared by Lesotho, Namibia, Botswana and South Africa.

The Molopo-Nossob Basin includes four major rivers summarized in **Table 2-1**. There are various figures in reports given for the area size of each river's catchment area. In the current report, the catchment areas in Namibia are designated to Molopo, Nossob and Auob Rivers respectively.

The Auob catchment area includes the sub-catchment area of Oanob River (MAWRD, 2000). This basin contains the Oanob River which rises in the Khomas Hochland and flows in a south-easterly direction to the recently constructed Oanob Dam and then through the town of Rehoboth. Thereafter the river becomes lost in the Kalahari Sands only to occur 50 km further to the south-west as a river channel, now as the Auob River (MAWRD, 2000). This river sub-basin is 15,038 km^2 (**Figure 2-2).**

In South Africa, the catchment of the Molopo River is highlighted in the quaternary Water Management Areas (WMA). These areas are designed to cover small defined catchment areas and together they make up for larger catchment areas like the Molopo River. The quaternary Water Management Areas (WMA) in South Africa together gives the catchment areas of the Molopo-Nossob Basin in that country. The total figure 110,565 km^2 differs from the figure given in other ORASECOM reports (ORASECOM, 2008a).

Figure 2-3 and **Figure 2-4** illustrate the percentage of coverage of the Molopo-Nossob Basin by the three basin countries and by the four major river courses.

Table 2-1 Main sub-catchment areas within the Molopo-Nossob River Basin

Catchment Area (km^2)				
River	**South Africa**	**Namibia**	**Botswana**	**Total**
Molopo	55,891	18,120	118,338	195,536
Kuruman	41,194	0	0	41,194
Nossob	8,339	50,050	17,426	75,815
Auob	5,141	52,702	0	57,843
Total	110,565	120,872	135,764	367,201
Percentage	30.1	32.9	37.0	

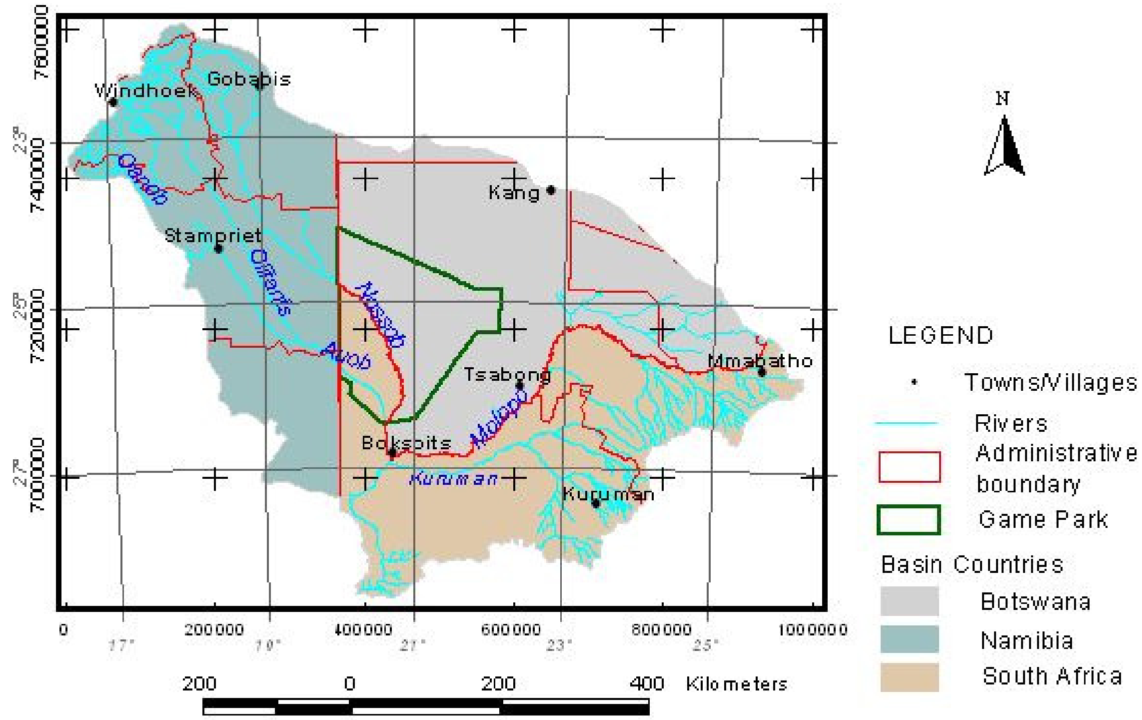


Figure 2-1 Molopo-Nossob Basin in Botswana, Namibia and South Africa

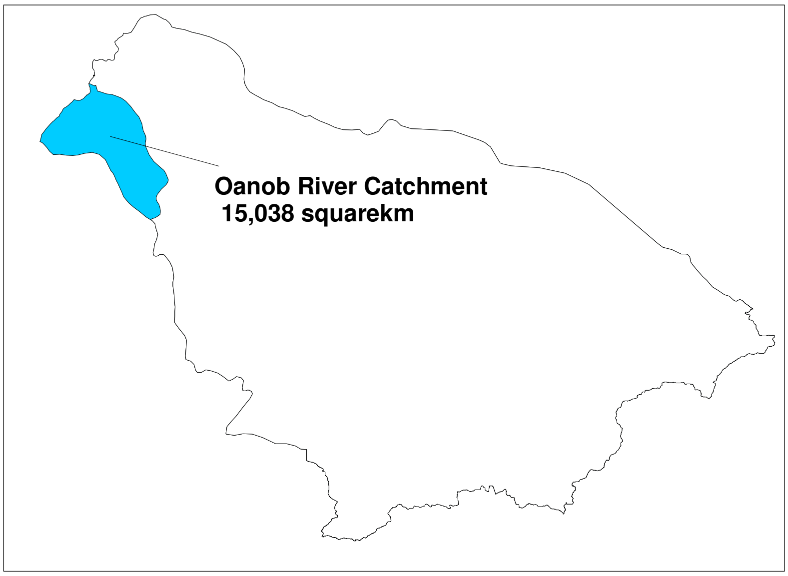


Figure 2-2 Oanob River sub-basin in the Molopo-Nossob Basin

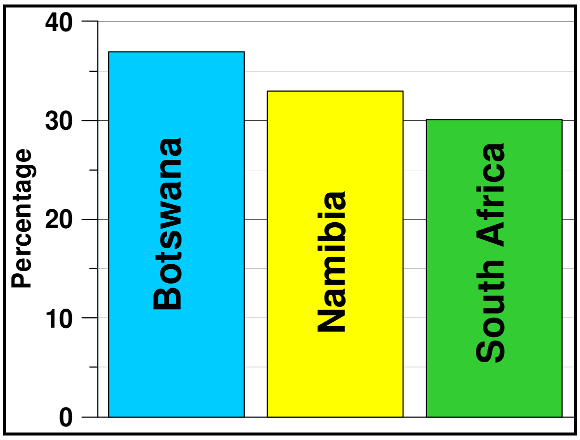


Figure 2-3 Percentage of coverage of the Molopo-Nossob Basin by Botswana, Namibia and South Africa

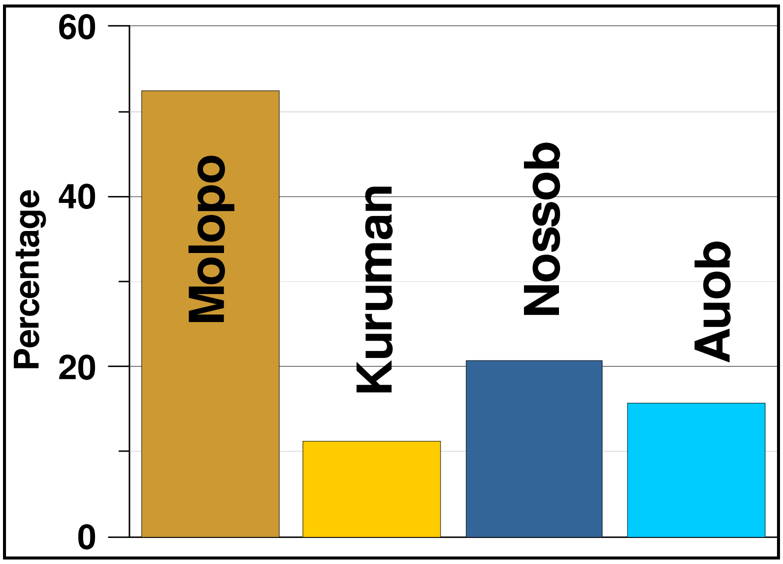


Figure 2-4 Percentage of coverage of the Molopo-Nossob Basin by the four major rivers, Molopo, Kuruman, Nossob and Auob

2.2 Relief and drainage

The highest elevations in the Molopo-Nossob are found in the northern part of Namibia and in the southern part of the Molopo and Kuruman catchment areas in South Africa. **Figure 2.5** shows the relief map of the Molopo-Nossob Basin reconstructed from 90 m spatial resolution SRTM data. It shows that around the Aoub/Oanob and Nossob water divides the elevation reach around 2400 mamsl.

2.3 Administrative Units

The three countries in the Molopo-Nossob Basin, Botswana, Namibia and South Africa all have their parts covered by different administrative units. A summary of administrative units in the three riparian states is gien in **Table 2-2**. The administrative units covering the Molopo-Nossob Basin are illustrated in **Figure 2-6**.

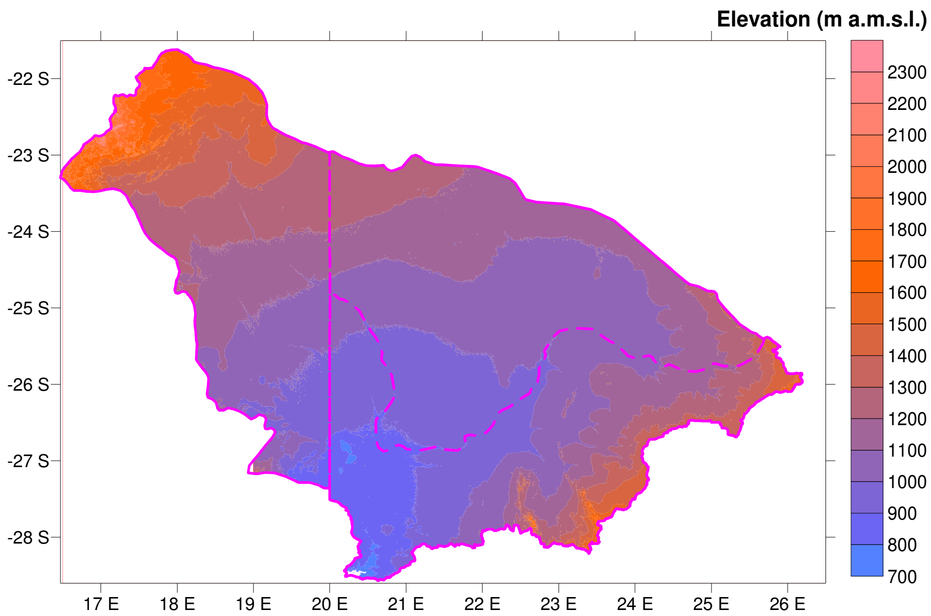


Figure 2-5 **Relief map of the Molopo-Nossob Basin**

In the Botswana part of the basin Tsabong is the largest village. Most of the villages and settlements in the Kgalagadi district are situated near pans or fossil river valleys, or on rock outcrops that serve as sources of water supply (groundwater). The administrative regions in Namibia that fall in the Molopo-Nossob basin are Omaheke, Khomas, Hardap and Karas.

In South Africa the Molopo-Nossob basin covers a northern part of the Northern Cape Province and the north-western section of the North West Province, see **Table 2-3.** The basin extends between Mafikeng and the South African – Namibian border. Mafikeng and Kuruman are major cities included in the basin area.

Table 2-2 **Administrative districts within the three riparian countries of the Molopo-Nossob basin**

Country	District, Province or Region	Total area size (km^2)	Percentage of the district in the Molopo-Nossob basin	Population in the Molopo-Nossob Basin
Botswana	Kgalagadi South	66,066	100	26,488
	Kalalagadi North	44,004	100	16,968
	Southern Ngwaketse		80	10,176
	Southern Ngwaketse West	26,876	100	10,989
	Southern Barolong		100	52,774
	Kweneng West	35,890	5	1,529
	Ghanzi	117,910	3	1,477
Namibia	Hardap	109,651		
	Karas	161,215		
	Khomas	37,007		113,849
	Omaheke	84,612		
South Africa	North West Province	116,320	11	728,107
	Northern Cape	361,830	9	11,296
Source: CSO, 2001 and ORASECOM, 2008b				

Table 2-3 Major districts and settlements in Namibia and South Africa part of Molopo-Nossob

Country	Region	Constituency	Villages in Region
Namibia	Hardap	Mariental rural	Stampriet, Hoachanas, Bernafy, Aranos, Gotchas
	Karas	Keetmanshoop rural Karasburg	Koes, Aroab, Ariamsvlei
	Khomas	Windhoek rural	Seeis
	Omaheke	Aminuis, Gobabis, Kalahari	Aminius, Leonardville, Gobabis
South Africa (North West Province)	Central/Ngaka Modiri Molema	Mafikeng ,Ratlou, Disobotla	Mafikeng
	Bophirima/Dr Ruth Segomotsi Mompatati	Molopo, Kagisano	Stella
South Africa (North West Province)	Kgalagadi	Moshaweng, Gamagara, Ga Segonyana	Hotazel, Dibeng, Dingleton/Sishen, Kathu, Kuruman
	Siyanda	Mier, District Management Area	

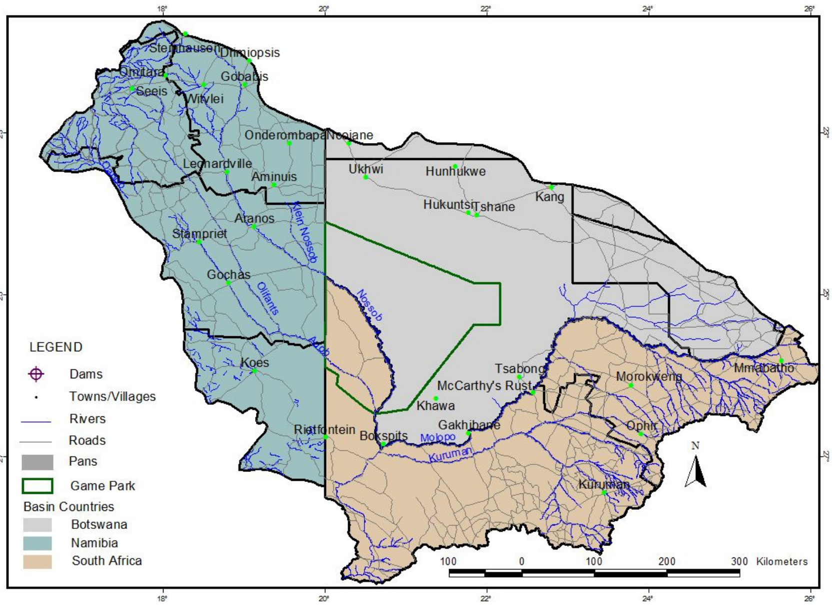


Figure 2-6 Administrative units within the Molopo-Nossob Basin belonging to Botswana, Namibia and South Africa

2.4 Climate

2.4.1 Climate data considered

Data on climate are obtained from the meteorological departments in Botswana, Namibia and South Africa. Information is also retrieved from international databases such as FAO's CLIMWAT database (FAO, 1993) and publication regarding some of the regional parameters of the Southern Africa.

Eight parameters are considered in the current climate assessment; rainfall, temperature, humidity, wind speed, solar radiation, sunshine hours, evaporation and evapotranspiration

2.4.2 Precipitation

In 2006 a comprehensive study of the climate in Botswana was presented as part of the Botswana National Water Master Plan Review (DWA, 2006). For Namibia mean annual rainfall map exists and point records at selected stations are available from the JICA (2002) study. The location of the stations is not available, which however is complemented by the FAO CLIMWAT data base. For South Africa, a total of 949 stations from the WR90 database are available in producing a precipitation map of the study area, see **Figure 2-7**.

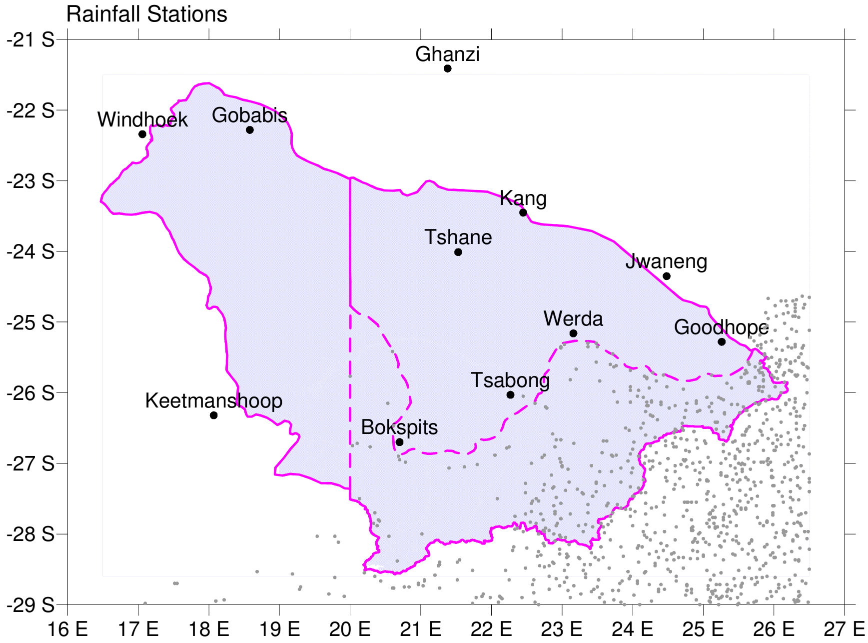


Figure 2-7 Distribution of rainfall stations in the Molopo-Nossob Basin

Table 2-4 shows the list of the stations used in the preparation of the average annual rainfall distribution in the Molopo-Nossob Basin. A number of meteorological stations in the northern part of the Molopo-Nossob Basin are added which were not included in the National Water Master Plan Review study for Botswana.

Table 2-4 Selected rainfall stations in Molopo-Nossob basin

Country	Location	MAP (mm/a)	Longitude	Latitude	Altitude (mamsl)	Observation period and Remarks
Botswana	Bokspits	219	-26.70	20.70	850	1998-06
	Ghanzi	473	-21.41	21.38	1,131	1998-08
	Goodhope	405	-25.28	25.26	1,245	1998-05
	Jwaneng	467	-24.35	24.48	935	1998-08
	Kang	388	-23.45	22.45	1,163	1998-06
	Tsabong	287	-26.03	22.27	962	1998-08, FAO
	Tshane	306	-24.01	21.53	1,118	1998-08, FAO
	Werda	304	-25.16	23.16	1,000	2002-08
Namibia	Gobabis	362	-22.28	18.58	1445	FAO
	Keetmanshoop	149	-26.32	18.07	1067	FAO
	Windhoek	361	-22.34	17.06	1728	FAO

Country	Location	MAP (mm/a)	Longitude	Latitude	Altitude (mamsl)	Observation period and Remarks
South Africa	Kimberley	415	-28.48	24.46	1204	FAO+WR90
	Kroonstad	606	-27.4	27.14	1348	FAO+WR90
	Kuruman	420	-27.28	23.26	1300	FAO+WR90
	Okiep	152	-28.36	17.52	927	FAO+WR90
	Postmasburg	325	-28.18	23.00	1324	FAO+WR90
	Potchefstroom	608	-26.44	27.04	1352	FAO+WR90
	Thabazimbi	671	-24.37	27.24	1028	FAO+WR90
	Upington	196	-28.26	21.16	809	FAO+WR90
	Zeerust	590	-25.33	26.05	1207	FAO+WR90
Note:						
FAO	from FAO's CLIMWAT database (FAO, 1993)					
WR90	Exist in FAO CLIMWAT database as well as part of the WR90 database, among which about 949 rainfall stations retrieved from WR90 database of DWAF fall within a rectangular region within 16.5 to 26.5^0 E and -29 to -21^{0}S					

A regional picture of seasonal distribution of rainfall in terms of monthly mean values at four selected stations in the basin is shown in **Figure 2-8**. Most of the rain is registered for October and April with the peak season usually in December – February. In the spatial extent, the highest average annual precipitation is found in the Eastern part of the Molopo-Nossob Basin, in the South African part. As a general picture, the rainfall decreases from North towards South and from East towards West. The area with the lowest precipitation is found in Southwest part encompassing the southernmost part of Botswana and Namibia and the Western part of South Africa (see **Figure 2-9**)

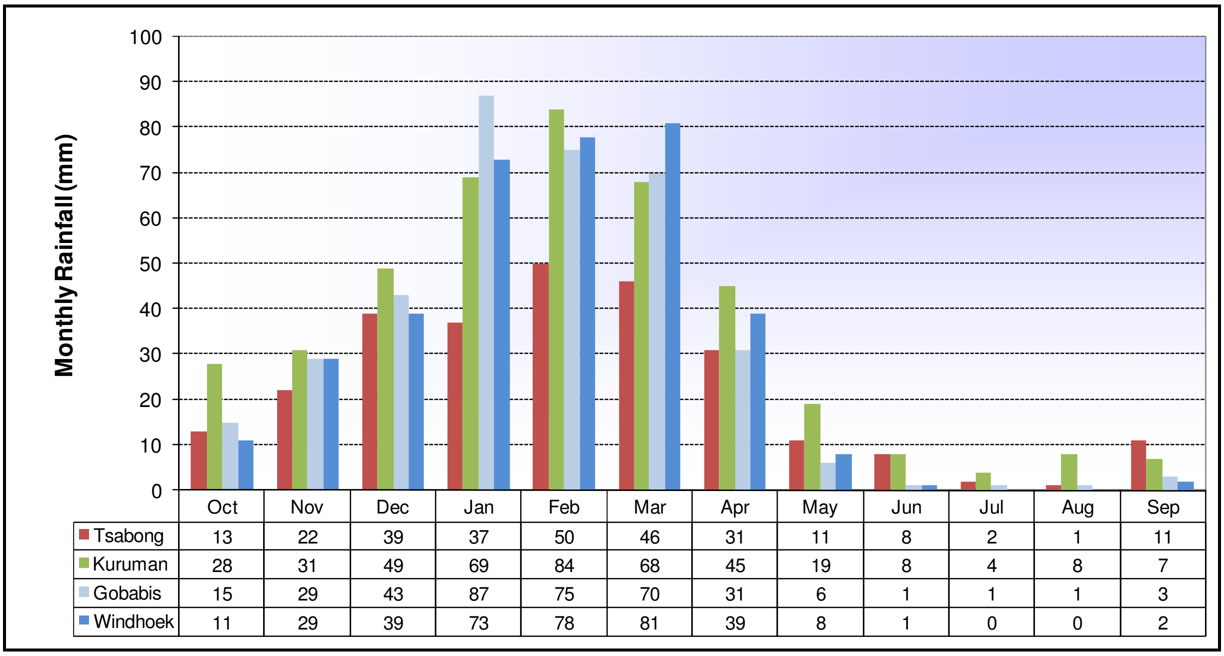


Figure 2-8 Monthly mean rainfall at selected stations in the Molopo-Nossob Basin

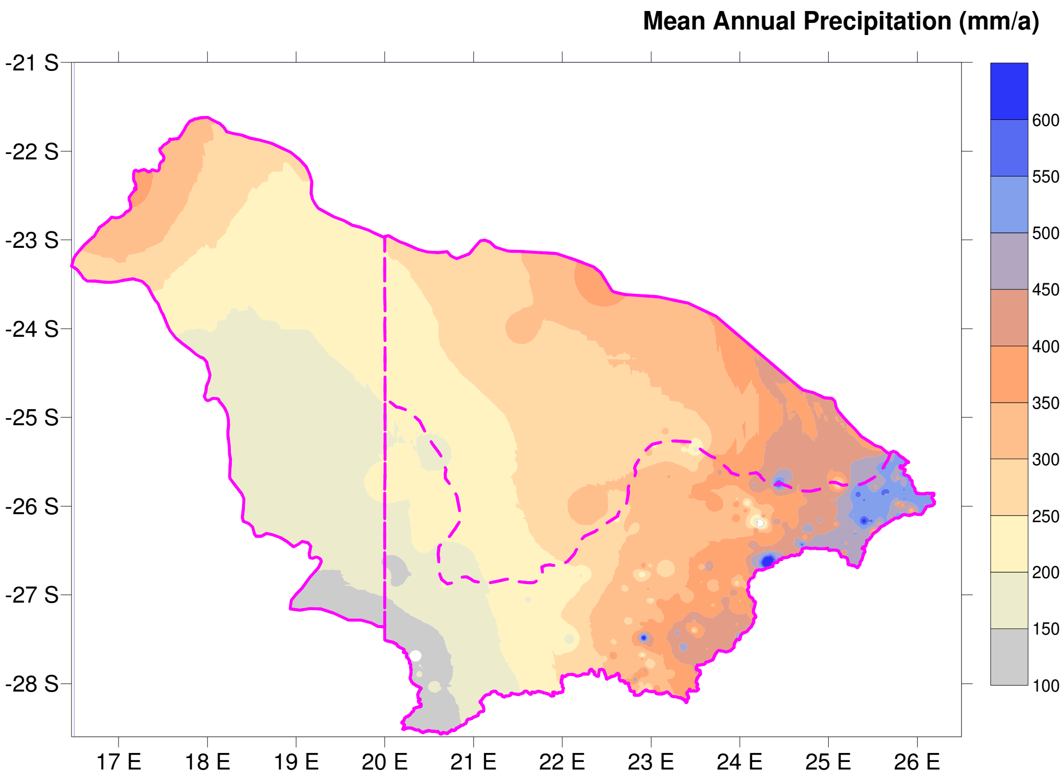


Figure 2-9 **Annual average rainfall over the Molopo-Nossob Basin**

2.4.3 Temperature

The climate in the Molopo-Nossob Basin is characterized by generally unvarying temperatures. **Figure 2-10** shows the maximum and minimum temperatures for three of the Botswana stations in Molopo-Nossob basin (synoptic stations). The monthly mean maximum and minimum temperature at four selected stations in the Molopo-Nossob Basin are shown in **Figure 2-11** and **Figure 2-12** respectively. The daytime temperatures are generally warm to hot due to high solar radiation, but because of the low humidity night-time the minimum temperatures regularly drop to freezing or below 0 °C during 'winter' time (DWA, 2006). The lowest temperatures go as low as below -10 °C (Tsabong), and the highest maximum temperatures are over 40 °C.

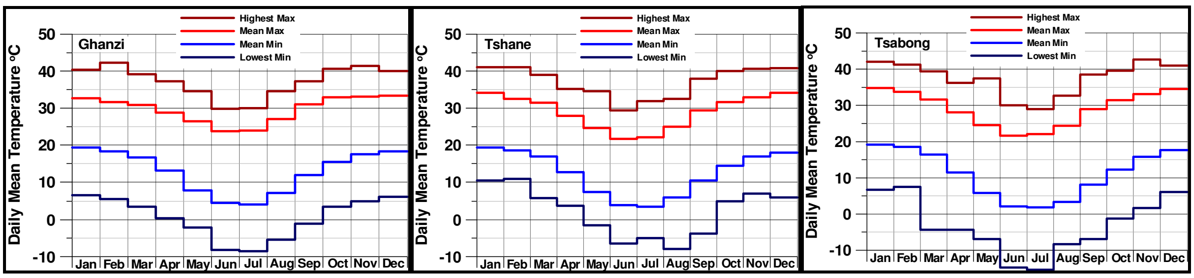
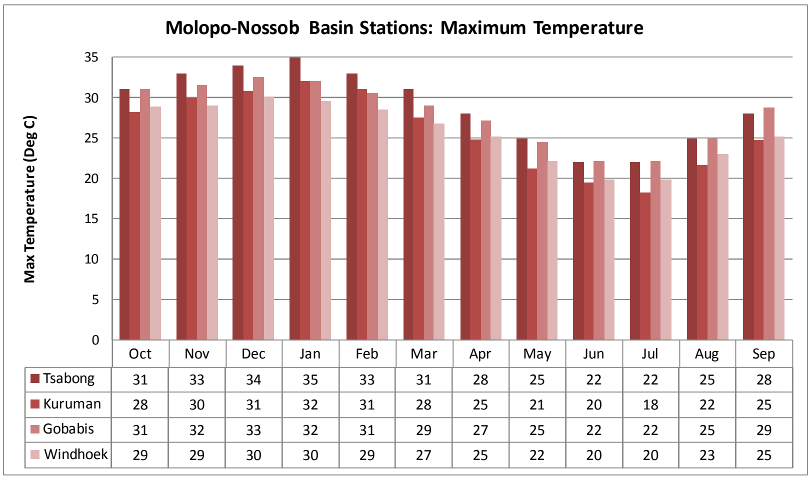
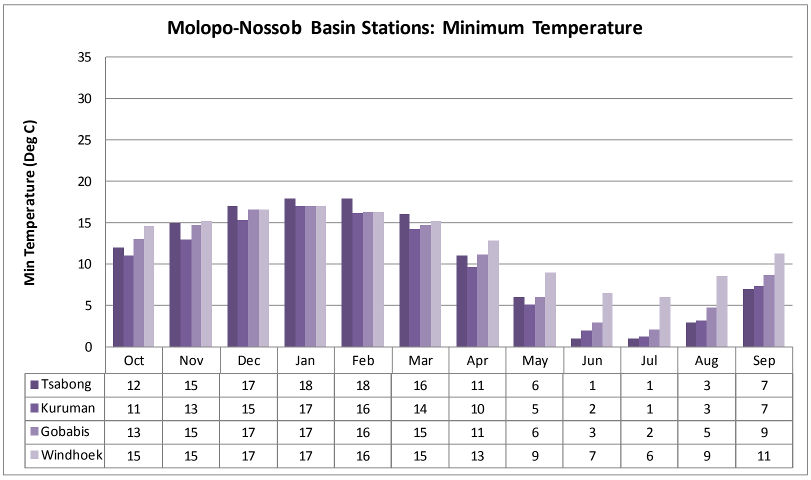


Figure 2-10 **Mean daily maximum and minimum temperatures and highest and lowest temperatures for the Meteorological stations Ghanzi, Tshane and Tsabong in Botswana (source; DWA, 2006)**



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Tsabong	31	33	34	35	33	31	28	25	22	22	25	28
Kuruman	28	30	31	32	31	28	25	21	20	18	22	25
Gobabis	31	32	33	32	31	29	27	25	22	22	25	29
Windhoek	29	29	30	30	29	27	25	22	20	20	23	25

Figure 2-11 Monthly mean maximum temperature at selected sites in the project area



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Tsabong	12	15	17	18	18	16	11	6	1	1	3	7
Kuruman	11	13	15	17	16	14	10	5	2	1	3	7
Gobabis	13	15	17	17	16	15	11	6	3	2	5	9
Windhoek	15	15	17	17	16	15	13	9	7	6	9	11

Figure 2-12 Monthly mean minimum temperature at selected sites in the project area

2.4.4 Humidity

The relative humidity is a measure of the amount of water vapour in the air. It is a value representing the ratio of the actual vapour pressure to its saturated limit at a prevailing temperature of the air. There is very high diurnal fluctuation of humidity. The humidity is higher in the mornings (0800 hrs) than in the afternoon. **Figure 2-13** illustrates this difference at three locations in the Molopo-Nossob Basin (Botswana). The relative humidity at four selected stations in the Molopo-Nossob Basin is illustrated in **Figure 2-14**. The relative humidity is in general high during the period January to March and minimum in the months of August and September.

The wind speed is another parameter responsible for aerodynamic component of evaporation process. There is also high seasonal fluctuation of wind speed. It is in general higher from around August to February and March. The wind speed at four selected stations in the Molopo-Nossob Basin is illustrated in **Figure 2-15**.

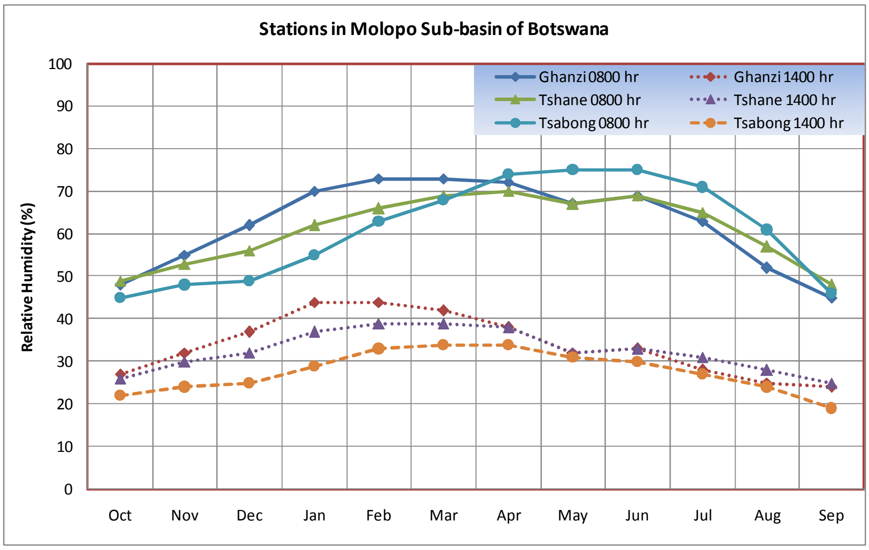
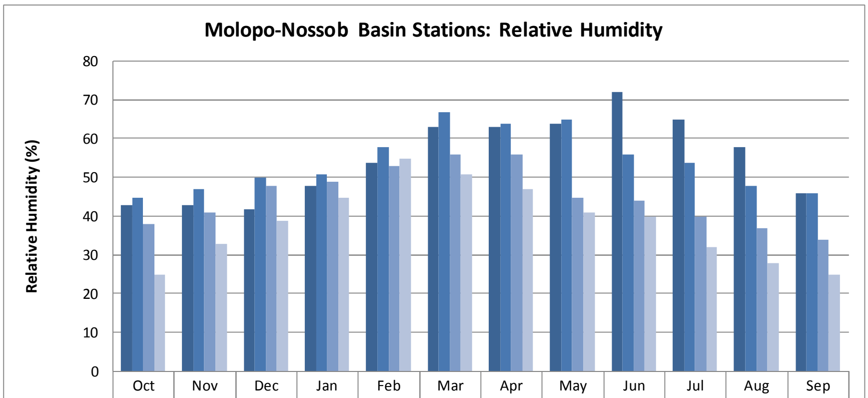
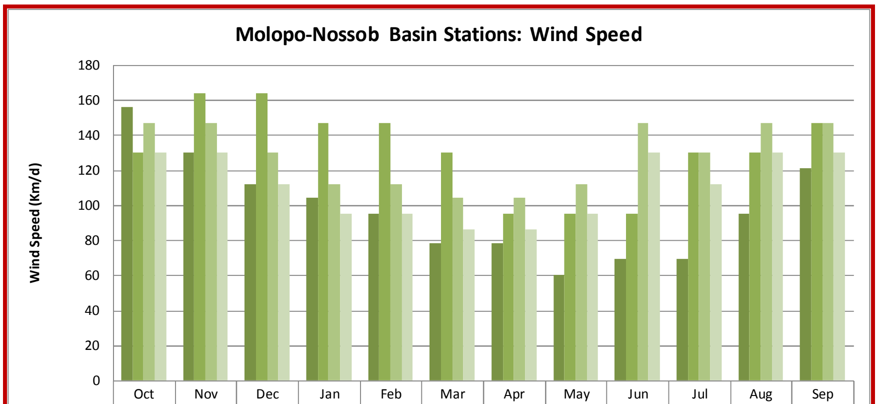


Figure 2-13 Mean monthly Relative Humidity (%) for Tsabong, Tshane and Ghanzi meteorological stations in Botswana. (Source: data DWA, 2006)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Tsabong	43	43	42	48	54	63	63	64	72	65	58	46
Kuruman	45	47	50	51	58	67	64	65	56	54	48	46
Gobabis	38	41	48	49	53	56	56	45	44	40	37	34
Windhoek	25	33	39	45	55	51	47	41	40	32	28	25

Figure 2-14 Mean monthly humidity at selected sites in the project area

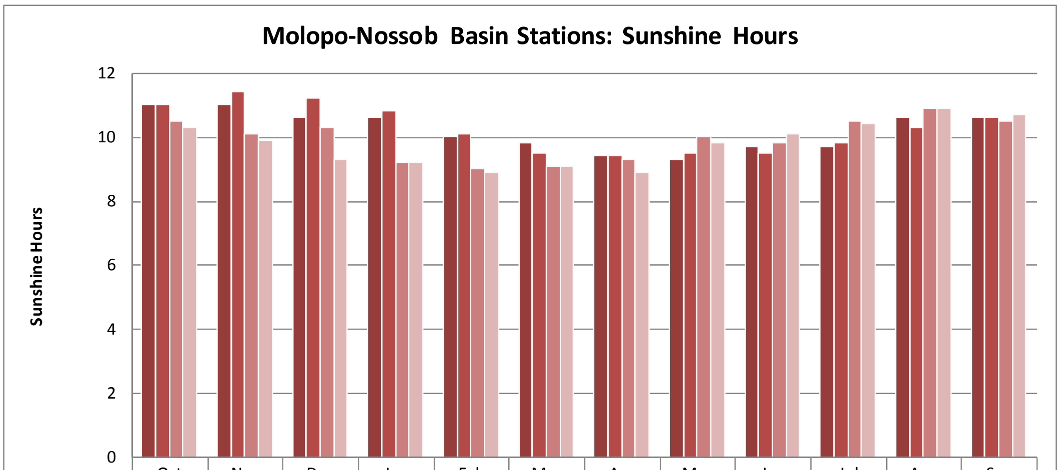


	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Tsabong	156	130	112	104	95	78	78	60	69	69	95	121
Kuruman	130	164	164	147	147	130	95	95	95	130	130	147
Gobabis	147	147	130	112	112	104	104	112	147	130	147	147
Windhoek	130	130	112	95	95	86	86	95	130	112	130	130

Figure 2-15 Monthly mean wind speed at selected sites in the project area

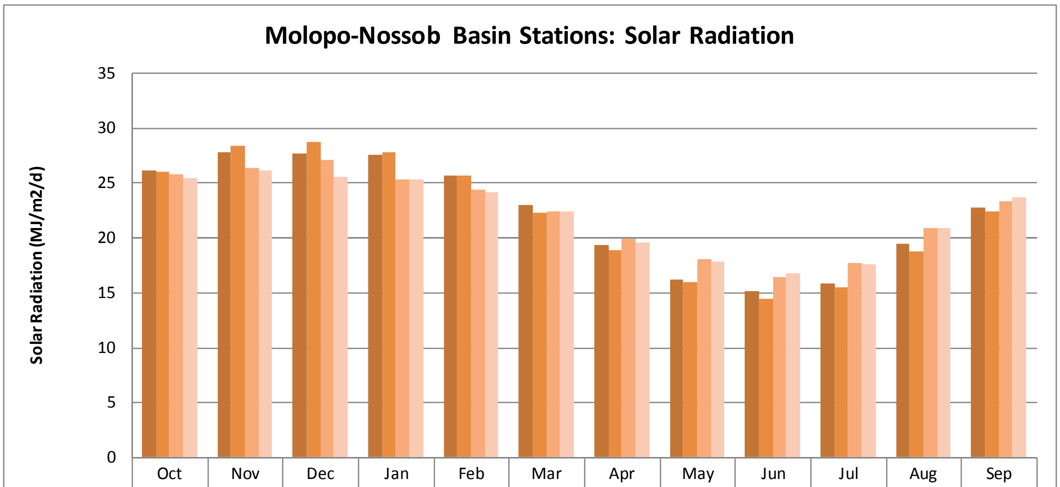
2.4.5 Solar radiation and sunshine hours

Solar radiation and sunshine hours are variables responsible for thermodynamic component of evaporation process. Solar radiation is a measure of the amount of solar radiation received from the sun while sunshine hour is the effective hours of clear sky number of sunshine hours at a given location. There is seasonal fluctuation of solar radiation and sunshine hours owing to the presence of cloud in the atmosphere. It is in general higher during rainy seasons. A comparison of the sunshine hours and solar radiation at four selected stations in the Molopo-Nossob Basin is illustrated in **Figure 2-16** and **Figure 2-17**, respectively.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Tsabong	11.0	11.0	10.6	10.6	10.0	9.8	9.4	9.3	9.7	9.7	10.6	10.6
Kuruman	11.0	11.4	11.2	10.8	10.1	9.5	9.4	9.5	9.5	9.8	10.3	10.6
Gobabis	10.5	10.1	10.3	9.2	9.0	9.1	9.3	10.0	9.8	10.5	10.9	10.5
Windhoek	10.3	9.9	9.3	9.2	8.9	9.1	8.9	9.8	10.1	10.4	10.9	10.7

Figure 2-16 Monthly mean Sunshine hours at selected sites in the project area



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Tsabong	26	28	28	28	26	23	19	16	15	16	19	23
Kuruman	26	28	29	28	26	22	19	16	14	15	19	22
Gobabis	26	26	27	25	24	22	20	18	16	18	21	23
Windhoek	25	26	26	25	24	22	20	18	17	18	21	24

Figure 2-17 Monthly mean solar radiation at selected sites in the project area

2.4.6 Evaporation and Evapotranspiration

Evapotranspiration (ET) is a term used to describe the sum of evaporation and plant transpiration from the land surface to atmosphere. Evaporation accounts for the movement of water to air from sources such as soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.

Potential evapotranspiration (PET or ETo) is a representation of the environment demand for evapotranspiration. In the irrigation water demand terms it is also referred to as reference evapotranspiration representing ET rate from a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile. It is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapor from the ground up into the lower atmosphere. Evapotranspiration is said to equal potential evapotranspiration when there is ample water.

Evapotranspiration is a significant water loss from a watershed. Types of vegetation and land use significantly affect evapotranspiration, and therefore the amount of water leaving a watershed. Because water transpired through leaves comes from the roots, plants with deep reaching roots can more constantly transpire water. Factors that affect evapotranspiration include the plant’s growth stage or level of maturity, percentage of soil cover, solar radiation, humidity, temperature and wind.

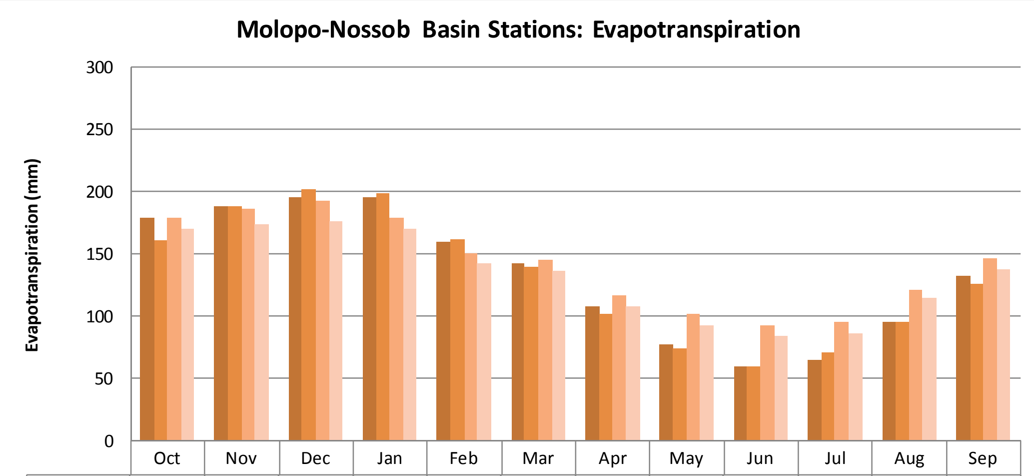
In areas that are not irrigated, in irrigation practice, actual evapotranspiration is usually no greater than precipitation, with some buffer in time depending in the soil’s ability to hold water. It will usually be less because some water will be lost due to percolation or surface runoff. An exception is areas with high water tables, where capillary action can cause water from the groundwater to rise through the soil matrix to the surface. If potential evapotranspiration is greater than the actual precipitation, soil will dry out, unless irrigation is used.

The actual evapotranspiration can never be greater than PET, but can be lower if there is not enough water to be evaporated or plants are unable to readily transpire.

Potential evapotranspiration (PET) incorporates the energy available for evaporation and the ability of the lower atmosphere to transport evaporated moisture away from land surface. PET is higher in the summer, on less cloudy days, and closer to the equator. Because of the higher levels of solar radiation that provider the energy for evaporation. PET is also higher on windy days because the evaporated moisture can be quickly moved from the ground of plants, allowing more evaporation to fill its place.

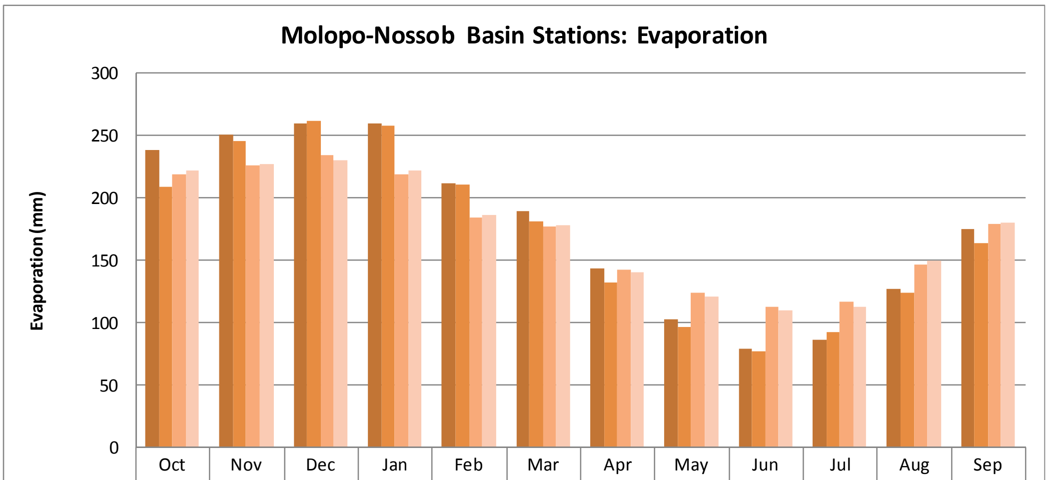
Even though, extensive open water evaporation measurements do exist in South Africa, Botswana and Namibia have very scant pan evaporation information. In Botswana, a method adopted for estimating open water evaporation was developed in 1987 (DWA, 1987) which is based on a regression model relating annual evaporation with annual rainfall. Other commonly used approach is to use models such as the Penman or Penman –Monteith Methods that rely on observed climate data. FAO has developed a widely used method based on the later approach (Allen et al, 1998). The CLIMWAT database (FAO, 1993) comprises of climate as well as derived reference crop evapotranspiration records at selected synoptic stations. An approximate map of reference evapotranspiration was prepared from network of existing climate stations available from the project area. The maps are comparable to the ones prepared based on the 1993 FAO database (FAO, 1993). The data were interpolated using the inverse distance squared method available in the Arc View spatial analyst module, results of which are reported in Alemaw and Sebusang (2008).

A typical monthly distribution of potential evapotranspiration for selected stations in the Molopo-Nossob Basin is illustrated in **Figure 2-18**. The evaporation estimated by the model used in Botswana, disaggregated in monthly values assuming similar monthly distribution as the reference evapotranspiration values shown in **Figure 2-19**. A generalized spatial pattern of reference evapotraspiration map based on interpolation of the FAO CLIMWAt database (FAO, 1993) is shown in **Figure 2-20**.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Tsabong	180	189	195	195	160	143	108	78	60	65	96	132
Kuruman	161	189	202	198	162	140	102	74	60	71	96	126
Gobabis	180	186	192	180	151	146	117	102	93	96	121	147
Windhoek	171	174	177	171	143	136	108	93	84	87	115	138

Figure 2-18 Monthly mean potential evapotranspiration at selected sites



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Tsabong	239	251	260	260	212	190	144	103	80	87	128	176
Kuruman	210	246	262	258	211	181	133	97	78	93	125	164
Gobabis	219	227	234	219	184	178	143	125	113	117	147	179
Windhoek	223	227	231	223	187	178	141	122	110	113	150	180

Figure 2-19 Monthly mean evaporation at selected stations in the project area

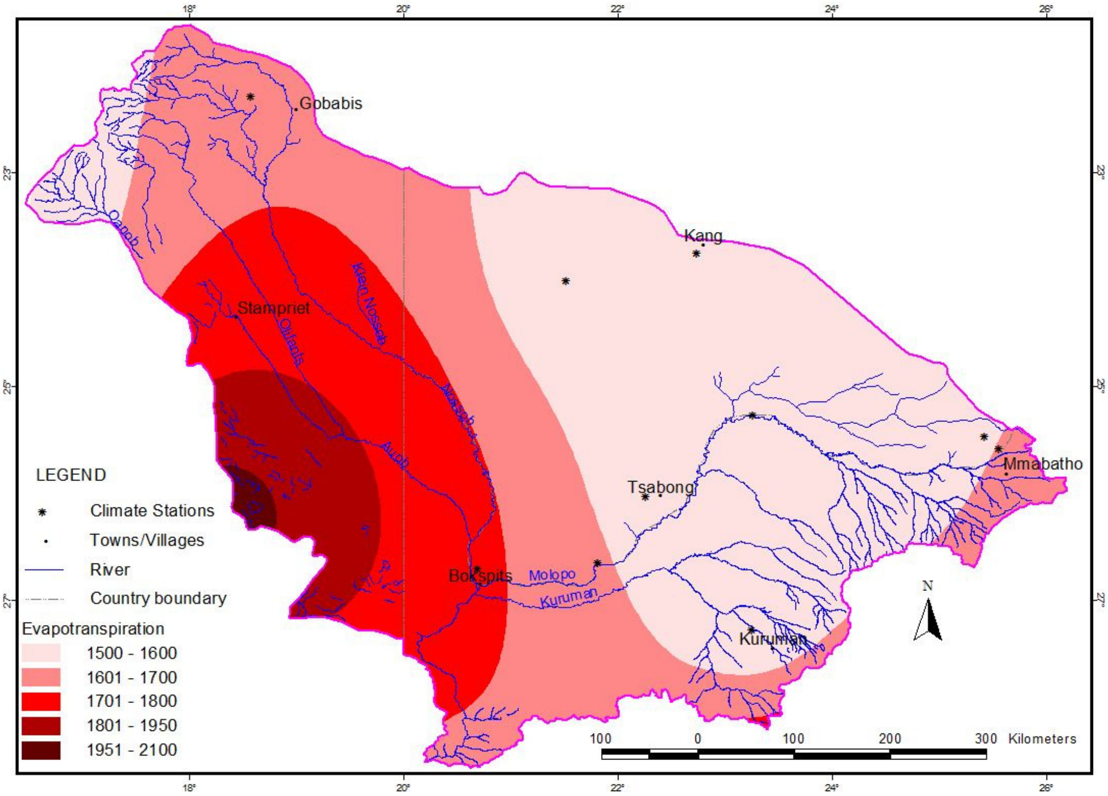


Figure 2-20 **Mean annual reference evapotranspiration in the Molopo-Nossob sub-basin**

2.4.7 Rainfall and ETo at selected stations

The Molopo-Nossob Basin and its tributary rivers have pronounced seasonal variation in flow, with negligible low season flows. Rainfall varies considerably from year to year. **Figure 2-21** shows the seasonal variation of precipitation in relation to ETo at selected stations within the Molopo-Nossob Basin.

2.4.8 Aridity Index

Average annual PET is generally compared to average annual precipitation, P. The ratio of the two, P\PET, is the aridity index (AI). Such an index is a numerical indicator of the degree of dryness of the climate at a given location, A number of aridity indices have been proposed; these indicators serve to identify, locate or delimit regions that suffer from a deficit of available water, a condition that can severely affect the effective use of the land for such activities as agriculture or stock farming.

UNEP has adopted the index of aridity, defined by the formula:

$$AI = P/PET$$

Where *PET* is the potential evapotranspiration and *P* is the average annual precipitation (UNEP, 1992). *PET* and *P* must be expressed in the same units, e.g., in mm/a. The various degrees of aridity are then defined according **Table 2-5**.

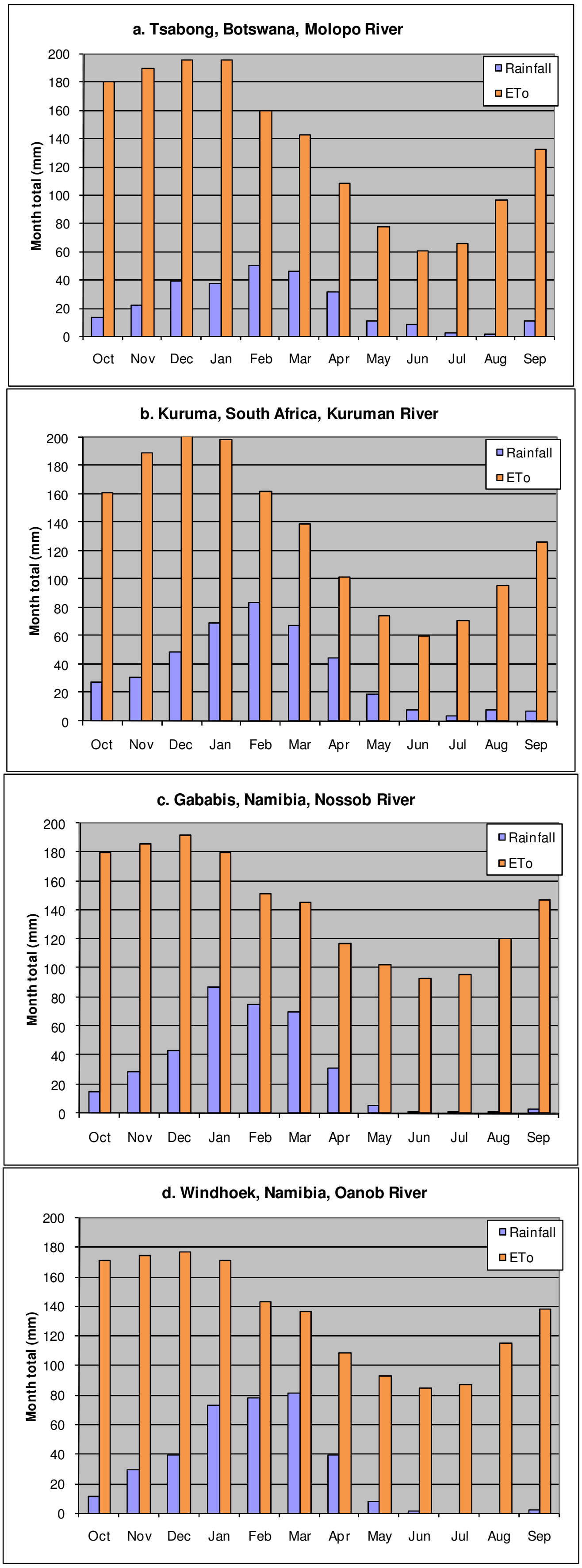


Figure 2-21 **Mean monthly rainfall and potential evapotranspiration in the Molopo-Nossob Basin**

Table 2-5 UNEP classification of various degrees of aridity based on their index of aridity (UNEP, 1992)

Classification	Aridity Index	Global land area	Molopo-Nossob Area
Hyperarid	AI < 0.05	7.5%	0%
Arid	0.05 < AI < 0.20	12.1%	40%
Semi-arid	0.20 < AI < 0.50	17.7%	60%
Dry subhumid	0.50 < AI < 0.65	9.9%	0%

The annual precipitation data and the estimated annual potential evapotranspiration of the Molopo-Nossob basin was used in developing the Aridity index map for the basin which shows that the area to be classified as Arid and Semi-Arid.

The aridity Map of the Molopo-Nossob Basin is shown in **Figure 2-22**. About 18% of the basin is classified as arid, whereas the remaining 17% is classified as semi-arid.

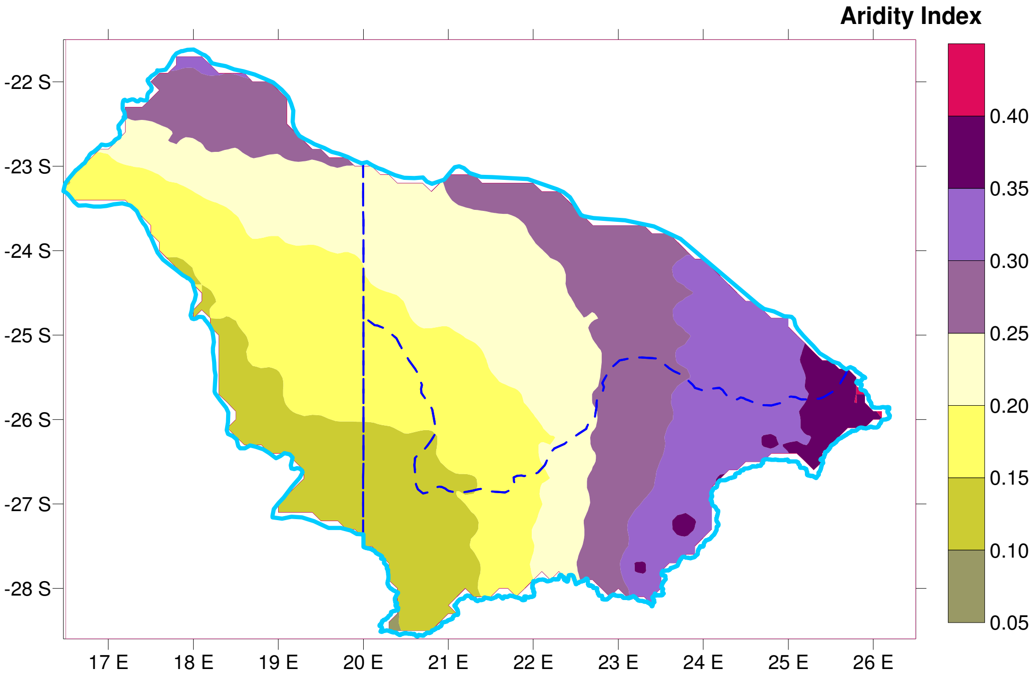


Figure 2-22 Aridity Index Map of the Study area

2.4.9 Droughts

The Molopo-Nossob Basin is at several occasions hit by what is called drought and the ramifications thereof. There are numerous conceptions of drought available in the literature. In water resources planning the concept of drought adopted is based on climatic and hydrological definitions of drought (DWA, 2006).

Meteorological drought is defined as an interval of time, generally of the order of months or years, during which the actual moisture supply at a given place cumulatively falls short of the level of supply which is appropriate under the prevailing climatic conditions of that place. Hydrological drought typically refers to periods of below-normal stream flow and/or depleted reservoir storage.

Taking these two definitions together, it is obvious that a meteorological drought may lead to a hydrologic drought but this does not necessarily be so. With careful planning, it is possible to experience a meteorological drought without it having an impact on water resources, e.g. by building storage reservoirs.

In terms of water resources planning, two aspects of drought are of interest: (i) the duration of the drought and (ii) its severity. The severity of a drought indicates the magnitude of the shortfall in the rainfall. This severity is normally expressed as an index. There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. For example, the Palmer Drought Severity Index is widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance, and this Palmer index is better when working with large areas of uniform topography.

Quantitatively, a drought is characterized with an index computed as a measure of the extent of negative departures of the rainfall from a pre-determined normal or average. The larger the departure in the negative direction, the severe the drought is taken to be. A combination of the severity and the duration gives an idea of the drought intensity.

There are many methods available for computing drought index. One consideration that influences the choice of a method is the availability of suitable data and the simplicity of the interpretation of the indices obtained.

In Botswana, the attention was focused on using the Standardized Precipitation Index (SPI) (McKee, Doesken, and Kleist, 1993). The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, stream flow, and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, the SPI can be calculated for various month time scales (3, 6, 12, 24, etc).

The SPI is based on the cumulative probability of a given rainfall event occurring at a station. The historic rainfall data of the station is fitted to a gamma distribution (as the gamma distribution has been found to fit the precipitation distribution quite well). The process allows the rainfall distribution at the station to be effectively represented by a mathematical cumulative probability function. Based on the historic rainfall data the probability of the rainfall being less than or equal to a certain amount can be assessed. Thus, the probability of rainfall being less than or equal to the average rainfall for that area will be about 0.5, while the probability of rainfall being less than or equal to an amount much smaller than the average will be also be lower (0.2, 0.1, 0.01 etc, depending on the amount). Therefore if a particular rainfall event gives a low probability on the cumulative probability function, then this is indicative of a likely drought event. Alternatively, a rainfall event which gives a high probability on the cumulative probability function is an anomalously wet event.

Rainfall is the variable in a gamma distribution function which will have a standard deviation and a mean which depends on the rainfall characteristics of that area. Different stations will most likely have a very different standard deviation and a different mean. Therefore it will be difficult to compare rainfall events for two or more different areas in terms of drought, as drought is really a “below-normal” rainfall event. And what is “normal rainfall” in one area can be surplus rainfall in another area, speaking strictly in terms of rainfall amounts.

The cumulative probability gamma function is therefore transformed into a standard normal random variable Z with mean of zero and standard deviation of one. A new variable is formed, and the transformation is done in such a way that each rainfall amount in the old (gamma) function has got a corresponding value in the new (transformed) Z function. And the probability that the rainfall is less than or equal to any rainfall amount will be the same as the probability that the new variable is less than or equal to the corresponding value of that rainfall amount. All probability functions which have resultant transformed variable are always in the same units.

The SPI is a representation of the number of standard deviations from the mean at which an event occurs, often called a “z-score”. The unit of the SPI can thus be considered to be “standard deviations”. Standard deviation is often described as the value along a distribution at which the cumulative probability of an event occurring is 0.1587. In a like manner, the cumulative probability of any SPI value can be found, and this will be equal to the cumulative probability of the corresponding rainfall event. **Table 2-6** gives the cumulative probabilities for various SPI values.

Table 2-6 SPI and corresponding cumulative probability

SPI	Cumulative Probability	SPI	Cumulative Probability
-3.0	0.0014	0.0	0.5000
-2.5	0.0062	0.5	0.6915
-2.0	0.0228	1.0	0.8413
-1.5	0.0668	1.5	0.9332
-1.0	0.1587	2.0	0.9772
-0.5	0.3085	2.5	0.9938
0.0	0.5000	3.0	0.9986

The SPI can effectively represent the amount of rainfall over a given time scale, with the advantage that it provides not only information on the amount of rainfall, but that it also gives an indication of what this amount is in relation to the normal, thus leading to the definition of whether a station is experiencing drought or not. The longer the period used to calculate the distribution parameters, the better results (e.g. 50 years better than 20 years).

McKee et al. (1993) used the classification system shown in the SPI values table (**Table 2-7**) to define drought intensities resulting from the SPI. McKee et al. (1993) also defined the criteria for a drought event for any of the time scales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought’s “magnitude”.

Table 2-7 Interpretation of SPI classes

SPI Values	Characterization
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Very dry
-2 and less	Extremely dry

The SPI was computed from the rainfall data of 55 years long-term rainfall stations for Tsabong Station. SPI was also computed for 85 years of Kuruman Station (SA Station Code 0393778W).
The calculations were done on a monthly basis and then aggregated on hydrological year basis (October to September). Both the monthly and annually aggregated values have been used to draw **Figure 2-23** to **Figure -2-26**.

The results suggest that drought is endemic to most parts of the Molopo-Nossob Basin. However, it should be noted that the annual cumulative indices plotted in the above figures actually obscure the monthly drought occurrences. This is because even for the years showing above average rainfall, there could be several months of below average rainfall.

The results show further that while drought occurs frequently, it is not persistent as shown by a large negative SPI being followed by a positive SPI. The stations used in the analysis are too few to depict any spatial pattern. However, it is interesting to note that while the rainiest part of the Molopo-Nossob Basin had no drought period, the driest part (Tsabong) only had a few years of below average rainfall: 8 years over a 55-year period analyzed.

Both the records of Tsabong and Kuruman showed beginning of 1970s and middle of 1990s as sustained period of below normal rainfall, with lowest SPI, which is a characteristic manifestation of drought occurrence during these periods. Moreover, Kuruman experienced another dry period around end of 1960s and beginning of 1970s.

2.5 Main Rivers

2.5.1 Auob River

The Auob River basin can be seen in two distinct parts, which in terms of surface water are unlikely to be connected except under exceptionally high flood conditions. The top of the basin is occupied by the Oanob River which rises in the Khomas Holchland and flows in a south-easterly direction to the recently constructed Oanob Dam and then on through the town of Rehoboth. After that the terrain becomes very flat and the river eventually becomes lost in the Kalahari Sands. Only 50 km further to the south-west does the river channel form again to meet the Auob River. The Auob River has its origin in the Karubeam Mountains Northeast of Mariental town, from where it flows in a South-easterly direction towards the South African border and eventual confluence with the Molopo River. Maximum rainfall over the catchment is close to 400 mm and this reduces to a minimum of about 200 mm in its lower part.

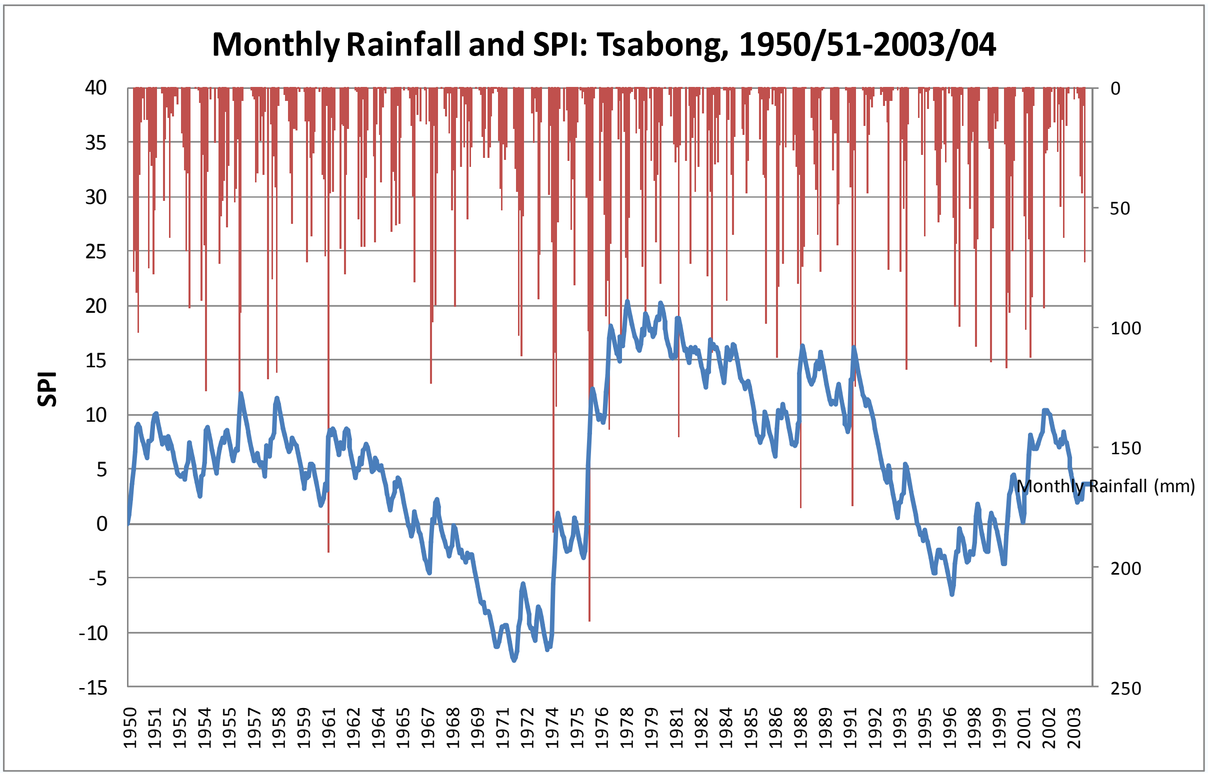


Figure 2-23 **Monthly rainfall and SPI values for Tsabong**

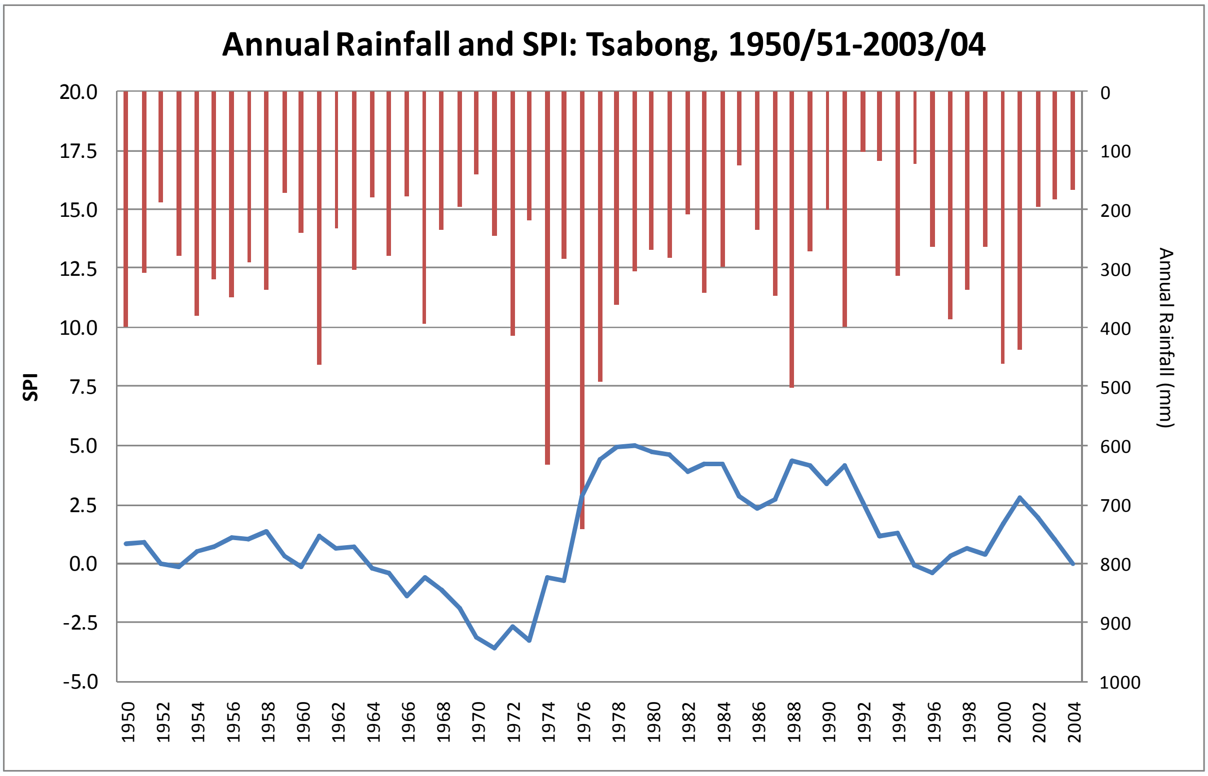


Figure 2-24 **Annual rainfall and SPI values for Tsabong**

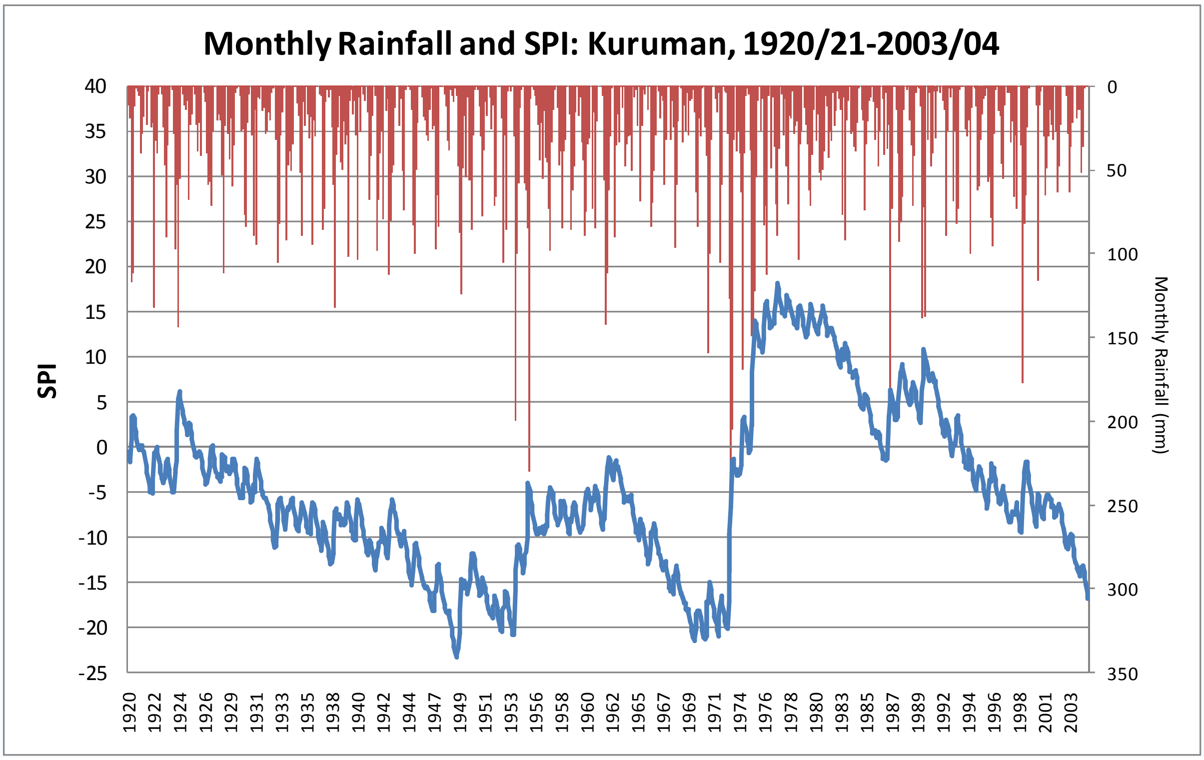


Figure 2-25 **Annual rainfall and SPI values for Tsabong**

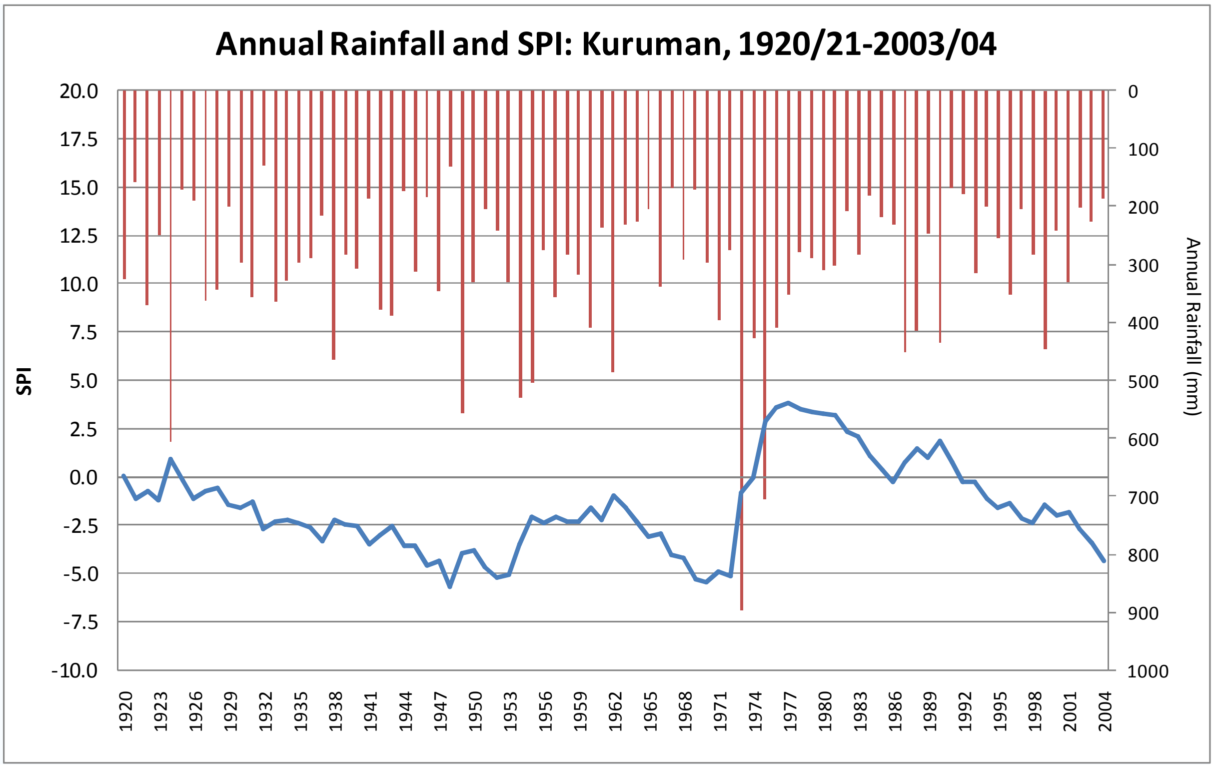


Figure 2-26 **Annual rainfall and SPI values for Kuruman**

The elevation range of the Auob Basin is 1090 -2417 mamsl (meters above mean sea level) and the catchment vegetation types are high savannah (Oanob) and mixed tree and shrub savannah (Auob).

Most of the upper part of the Oanob River catchment is commercial farmland, with many farm dams in this area. From the Oanob Dam downstream for about 30 km the land is manly communal land and most if the remaining land is commercial farmland. Around Rehoboth most of the communal area is overgrazed.

The Oanob River alluvial aquifer historically supplied bulk water to the town of Rehoboth but with construction of the Oanob Dam the wellfied has been abandoned. Although the construction of the dam has drastically reduced recharge to the downstream aquifer it still remains a resource that could be brought into production. It is however, necessary that the behaviour of this aquifer be investigated under the change recharge conditions brought about by the construction of the dam.

In the Auob River Basin the commercial farmers are provided to a great deal by artesian water to commercial farmers upstream of Stampriet and between Stampriet and Gochas. Much of the water is used for irrigation.

The Olifants River, main tributary to the Auob River originates in the mountainous area surrounding Windhoek and flows parallel to and in between the Nossob and Auob Rivers. It joins Auob River about 175 km upstream of the merging of the Auob and Nossob Rivers a short distance upstream of its confluence with the Molopo River. In its lower part the Nossob River forms the south-western boundary between Botswana and South Africa down to its confluence with the Molopo.

The mean annual runoff of the Oanob River at the Oanob Dam is 12.14 Mm^3. The dam has been placed close to the point of maximum runoff potential and the natural surface runoff reduces to zero within the next 100 km. In the Auob River the mean annual runoff is estimated at 5.23 Mm^3 at Stampriet rising to 8.60 Mm^3/yr at Gochas. After this the runoff decreases rapidly.

There are several state water schemes in the catchment, at Rehoboth, Stampriet, and Gochas. Significant quantities of groundwater are used for irrigation alongside the Auob River and some potential for irrigation in the vicinity of Rehoboth is identified (100 ha). Both the Oanob and Auob Rivers are adequately monitored.

2.5.2 Nossob River

The Nossob River rises as two main tributaries, the White Nossob in the Otjihavera Mountains to the east of Windhoek, and as the Black Nossob further to the north-east. Mean annual precipitation in these areas is approximately 370 mm.

The main commercial activity within the basin, is large stock farming, which is practiced on a commercial basis almost throughout. The economic activity centers include Gobabis, Witvlei, Leonardville and Aronos. Agriculture provides the backbone to the economy of the catchment. Development of Tourism is limited to a few lodges and game farms. In order to increase water supply security for the town of Gobabis, in the upper part of the Nossob Catchment, a wellfield is established in carbonate aquifers.

Runoff potential of the upper parts of both river is significant, especially of the White Nossob. The potential of both the White and the Black Nossob Rivers, however, is significantly affected by the presence of farm dams in the headwaters. A large dam was built on the White Nossob in 1984, which has effectively reduced the frequency of flow further downstream from flow most years (90%) to flow once in every four or five years.

Black and White Nossob Rivers join approximately 70 km south of the town of Gobabis.

Black Nossob River is dammed further downstream at Gobabis. The mean annual runoff is estimated at 1.90 Mm^3. Runoff potential of the lower parts of the basin, where the river crosses the Kalahari Sands is much lower. The Nossob River is gauged after the confluence of the two streams, and mean annual runoff here is very small, especially after the construction of the Otjivero Dam.

There is no recorded history of the Nossob River ever contributing surface water flow to the Molopo River. There are several state water schemes in the catchment, most important of which is the Gobabis Bulk Water Scheme which includes the Ontjivero, and Viljoen Dams and boreholes. Other includes Summerdown, Steinhausen, Witvlei, Leonardville and Aranos.

The elevation range of the Nossob catchment area is 1,150-2,177 mamsl. The main vegetation types in the catchment area are highland Camelthorn savannah, mixed tree and shrub savannah.
There are six gauging stations in the basin. The Black Nossob River is not gauged in its upper reaches, but otherwise the catchment is adequately gauged.

Most of the area covered by the Auob and Nossob Rivers is underlain by the Stampriet Artesian Basin which extends eastwards into Botswana. This is the largest aquifer system in Namibia, covering an area of some 65,000 km^2. This resource is used for domestic supply, livestock watering and irrigation by both commercial and communal farmers and also supplies the towns of Stampriet, Gochas, Aranos and Leonardville with bulk water. The Stampriet Artesian is a Subterranean Water Control Area as described in Chapter 3.

A decline in water levels within the Stampriet Artesian Aquifer has been recorded since 1985, when monitoring commenced. Studies of the resource were made in the late 1980's to establish the effect of irrigation farming on the resource. Irrigation activity has doubled over the past decade prompting another major investigation of the resource that is currently in progress. In the area there are over 7,000 abstraction boreholes for various purposes. Although abstraction is controlled by permits, little actual regulation and control takes place.

2.5.3 Molopo River

Molopo River emanates in South Africa from the area to the East of Mafeking, where it is fed by various springs, most notably the Molopo Eye (9.4 Mm^3/a) and the Grootfontein Eye 4.9 Mm^3/a) (ORASECOM, 2009). The river forms the border between South Africa and Botswana up to the confluence with the Nossob River. Several dry-beds, ephemeral streams join the Molopo River along its upper reaches. These include localized tributaries from the South e.g. Setklagole, Phepane and Disipi Rivers and tributaries from the North (Botswana) e.g. Ramatlabama and Melatswane.

Molopo River receives most of its flow from tributaries in the South Africa, even if its major catchment area is within Botswana (58%). In South Africa most of the river are dammed for irrigation and agriculture. As a result, inflow to the Molopo River, which forms the boundary between Botswana and South Africa, has become heavily reduced and even non-existent in some years.

Molopo River within Botswana is formed as clear channels draining from the Goodhope, Phitshane Molopo and the Karst-Dolomitic formations around the Kanye area in Southern Botswana.

After joining the Nossob River at Bokspits and the Kuruman River 4 km further downstreams, the Molopo River flows southwards to join Orange River after approximately another 250 km.

2.5.4 Kuruman River

The Kuruman River originates Southeast of Kuruman town, where it is fed by various dolomitic springs, most notably the Great Koning Eye, Little Koning Eye and the Kuruman Eye. Originally, the river flowed in a North-westerly direction over a distance of approximately 140 km. It then turns West and flows parallel to the Molopo River until its confluence with Molopo River at Andriesvale, about 4 km downstream the confluence between Molopo and Nossob Rivers. Various tributaries join the Kuruman River along its upper reaches, including Ga-Mogara, Moshaweng, Mathlawareng and Kgokgole River. The whole catchment area for the Kuruman River is located inside South Africa.

2.6 Dams

A number of dams are found within the Molopo-Nossob basin. They supply a few high water demand sites in South Africa and Namibia. The distribution of dams in the sub-basin is shown in **Figure 2-27**. The major dams are listed in **Table 2-8.**

Irrigation water use and cattle water needs in the sub-basin are also met in the different parts of the riparian states. In terms of farm dams in the Molopo-Nossob Basin, based on information obtained from evaluation of 1:50 000 topo-cadastral maps, a total of 687 farm dams (in year 2000) are identified. The total storage capacity of these dams is estimated to be 125 Mm³ (ORASECOM 2008a). These consist of in-stream dams (369) with a total storage capacity of 120 Mm³ (95.9%) and of channel dams (318) with a total storage of 5 Mm³ (4.1%) (ORASECOM 2008a, b).

Table 2-8 Dams within the Molopo-Nossob Basin

Name of Dam	Country	Nearest City	River	Latitude	Longitude	Full Supply capacity (Mm^3)	Yield (Mm^3/a)
Daan Viljoen	Namibia	Gobabis	Black Nossob	-22.2097	18.8389	0,429	0,36
Tilda Viljoen	Namibia	Gobabis	Black Nossob	-22.4442	18.9528	1,224	0,36
Otjivero Main	Namibia	Windhoek	White Nossob	-22.2886	17.9653	9,808	1,65

Name of Dam	Country	Nearest City	River	Latitude	Longitude	Full Supply capacity (Mm^3)	Yield (Mm^3/a)
Otjivero Silt	Namibia	Windhoek	White Nossob	-22.2944	17.9406	7,795	1,65
Lotlamoreng	South Africa	Mafeking	Molopo	-25.8666	25.6000	0.5	
Modimolo	South Africa	Mafeking	Molopo	-25.8500	25.5166	21,5	13,2
Disaneng	South Africa	Mafeking	Molopo	-25.7666	25.2666	17,4	1,0
Koedoesrand	South Africa	Mafeking	Koedoe	-26.2333	25.2166	0,75	Unknown
Blackheath	South Africa	Vryburg	Molopo	-25.6833	24.2500	0,124	
Leeubos	South Africa	Twe Rivieren	Swartbas	-26.7333	20.1000	1,071	
Abiekwasputs pan	South Africa	Twee Rivieren	Molopo	-27.3000	20.1000	-	Unknown
Source: ORASECOM, 2008a							

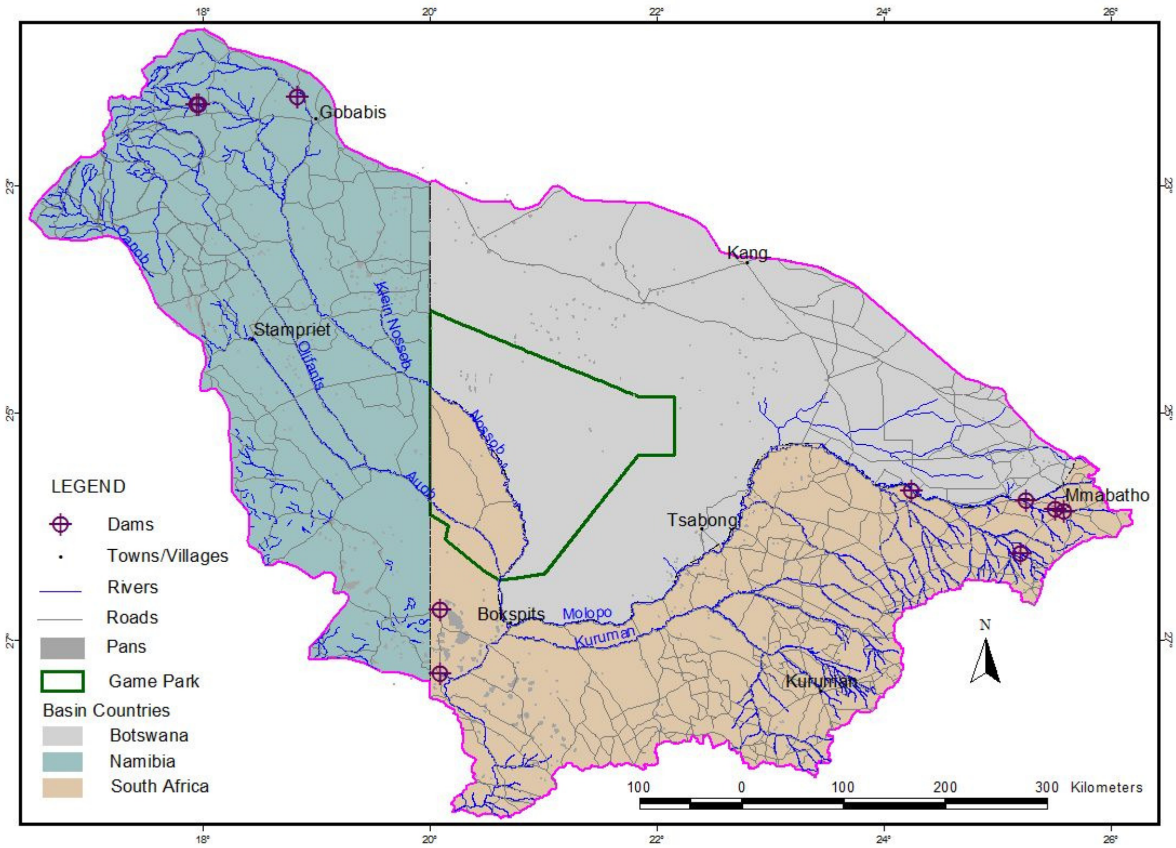


Figure 2-27 **Dams in the Molopo-Nossob Basin**

2.7 Transfer Systems

In the Molopo-Nossob basin, a number of water transfer systems exist. **Table 2-9** summarizes the water system in the basin, which is also shown on the map in **Figure 2-28**.

Table 2-9 Major water transfer schemes into and within the Molopo-Nossob Basin

Country	Scheme	Water from	Water to	Capacity Mm^3/a	Approximate transfer
South Africa	Vaal-Gamagara	Vaal River	Middle basin incl. major mines	13.3	8.4 (1995)
South Africa	Kalahari West Rural Supply	Upington's municipal system	Western basin excl. the Gemsbok area	1.99	0.42 (1995)
South Africa	Kalahari East Rural Water Supply	Vaal-Gamagara pipeline	Farming in the basin north of Upington	3.11	1.3 (1995)
Source: ORASECOM, 2008a					

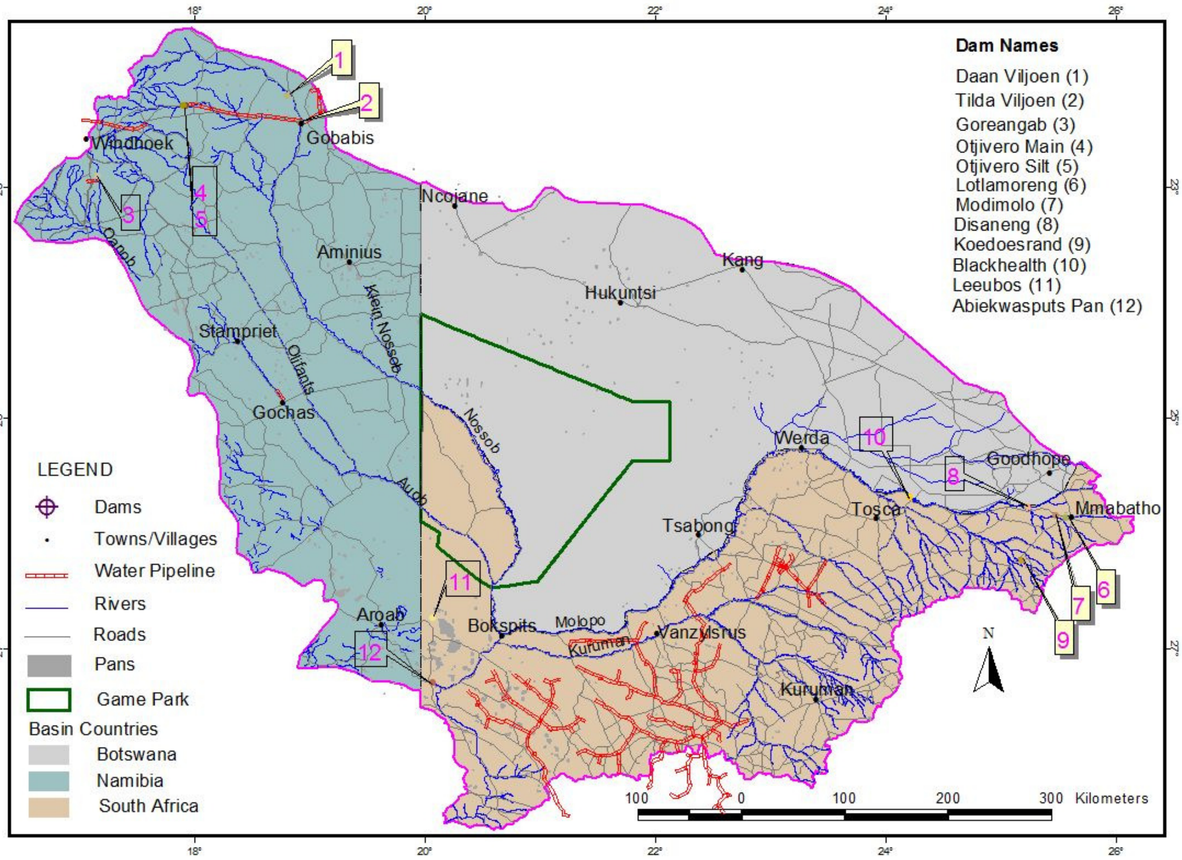


Figure 2-28 Major waterworks and transfers in the Molopo-Nossob Basin

2.8 Pans

Pans in the Molopo-Nossob Basin play a role in terms of meeting seasonal water needs. The pans are mainly found in the Botswana and Namibian parts of the Basin. Apart from being sources of water supply, in some instances they also have an impact on local drainage patterns. The distribution of the pans in the basin is shown in **Figure 2-29**.

An inventory of existing pans was undertaken through ORASECOM's recently completed project 'Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse'. According to this study the water retaining capacity of all 2607 pans that exist in the area is found to be about 1.9 Mm³ (ORASECOM 2008a,b). The distribution of these pans and their number, area and volume is summarised in **Table 2-10**.

Table 2-10 Details of Pans in the Molopo-Nossob Sub-basin

Catchment area	No. of pans	Volume (Mm3)	Area (km^2)
Molopo	1179	1406	972
Kuruman	226	71	54
Nossob	676	279	167
Auob	526	230	141
Source: ORASECOM 2008a			

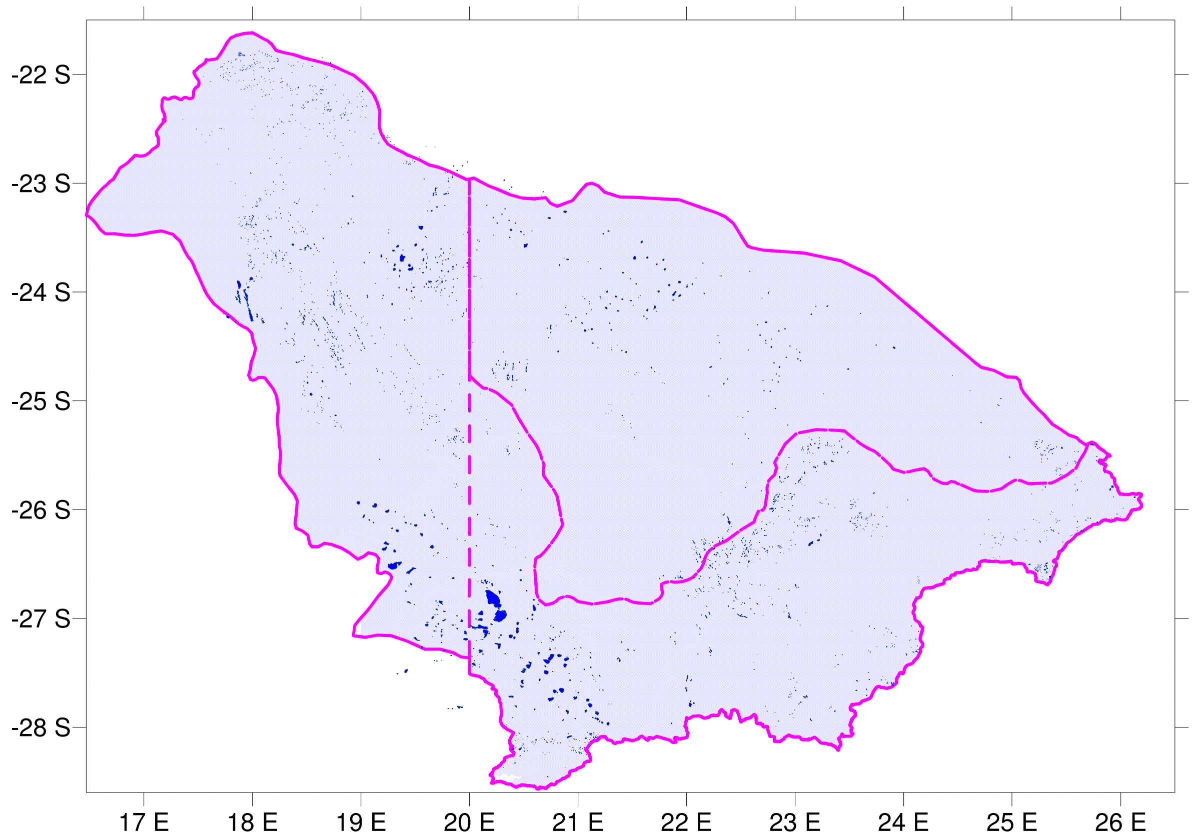


Figure 2-29 Geographic distribution of pans in the Molopo-Nossob Basin

3 WATER REQUIREMENT

3.1 Users

The main part of the Molopo-Nossob Basin is under natural vegetation and a large portion of the basin falls within the Kalahari Desert. Cultivated areas are found in the catchments areas of the Upper Nossob and Olifants Rivers, and the south-eastern parts of the Molopo River catchment near Mmabatho. In the Namibian cultivated areas, irrigation comes mainly from groundwater sources whereas in South Africa the demand is also satisfied by farm dams. According to ORASECOM (2008a), no afforestation or large-scale infestations of invasive alien vegetation occur in the Basin, although land-invasion by *Prosopis* species is on the increase in Namibia.

Large scale mining activity is found in the vicinity of Sishen and Hotazel in the upper Kuruman River catchment where manganese ore, iron ore, tiger's eye and crocidolite (blue asbestos) are mined.

The major towns and settlements in the Molopo-Nossob basin are listed in **Table 3-1**. In South Africa the mining activities are supported by scattered rural settlements.

The water users in the Basin are divided into domestic users (urban and rural domestic), irrigation, livestock watering, wildlife and mining and industry. In the domestic water requirement there is usually a portion for small industry common in urban and rural villages. Larger industry outside the domestic supply refers to activities in connection with mining, pulp, construction, and energy production etc.

3.2 Botswana

The Molopo-Nossob basin covers a large area of the southern Botswana. In the "Groundwater Pollution Vulnerability Map" (DGS, 1995) the surface water divide between the Molopo catchment area in the south and the Okavango catchment area in the north is defined. This water divide is used in the current project as the northern boundary of the Molopo-Nossob basin in Botswana. The southern boundary follows the Molopo and Nossob Rivers and the western boundary is the international border to Namibia (20^{o}E longitude). **Figure 3-1** presents the boundary and the area covered including major road and rural villages.

The basin covers approximately 130,000 km^2 in Botswana. The area is covered by part of 7 various districts and sub-districts in Botswana, summarized in **Table 3-2**. In contrast to South Africa, there are no water management areas delineated and defined in Botswana. For the assessment of water use in Botswana, the administrative areas within the Molopo-Nossob basin are used. **Table 3-3** defines these areas.

Figures on population within the Molopo-Nossob Basin in Botswana (**Table 3-2**) are collected from Central Statistics Office reports (CSO, 1997 and 2005), covering the census conducted 1991 and 2001. For villages not included in the reports, median figures from the population statistics in each sub-area are used.

Table 3-1 Major towns and villages in the Molopo-Nossob Basin

Country	Town/village	Longitude	Latitude	Population
Botswana*	Tsabong	22.4066	-26.0225	6,731
	Mmathethe	25.2746	-25.3314	4,908
	Hukuntsi	21.7292	-24.0049	4,010
	Kang	22.7919	-23.7246	3,943
	Pitsane Siding	25.6192	-25.4693	3,289
	Goodhope	25.4547	-25.4877	3,261
	Digawana	25.5626	-25.3560	2,973
	Khakhea	23.4961	-24.7076	2,136
	Werda	23.3013	-25.2635	2,003
	Lehututu	21.8355	-23.9171	1,810
	Mabule	24.5611	-25.7723	1,766
	Pitsane Molopo	25.1386	-25.7413	1,744
	Mabutshane	23.5834	-24.3782	1,713
	Ncojane	20.2879	-23.1636	1,477
	Lokgwabe	21.7765	-24.1017	1,373
	Ramatlabama	25.5364	-25.6482	1,305
	Rakhuna	25.5850	-25.5670	1,213
	Middlepits	21.8381	-26.6667	1,091
	Sekoma	23.9181	-24.5194	1,084
	Magoriapitse	25.2875	-25.4653	1,077
	Kokotsha	23.1981	-24.9189	1,043
	Gathwane	25.5334	-25.4215	1,025
Namibia	Gochas	18.7959	-24.8707	
	Windhoek (part of)	17.0932	-22.5856	
	Gobabis	18.9615	-22.4493	
	Aroab	19.6511	-26.7952	
	Stampriet	18.4022	-24.3431	
	Aminius	19.3748	-23.6507	
	Dordabis	17.6462	-22.9394	
	Uhlenhorst	17.9958	-23.7078	
	Koës	19.1233	-25.9395	
	Onderombapa	19.5536	-23.1857	
	Rehoboth	17.0784	-23.2994	
	Leonardville	18.7897	-23.5039	
	Rietfontein	20.0019	-26.7591	
	Kwakwas	16.9273	-23.1984	
South Africa	Kuruman	23.4318	-27.4459	
	Tosca	23.9545	-25.8783	
	Vanzylsrus	22.0454	-26.8783	
	Mmabatho	25.6515	-25.8648	
* =Population figures for Botswana year 2006 (CSO,2005)				

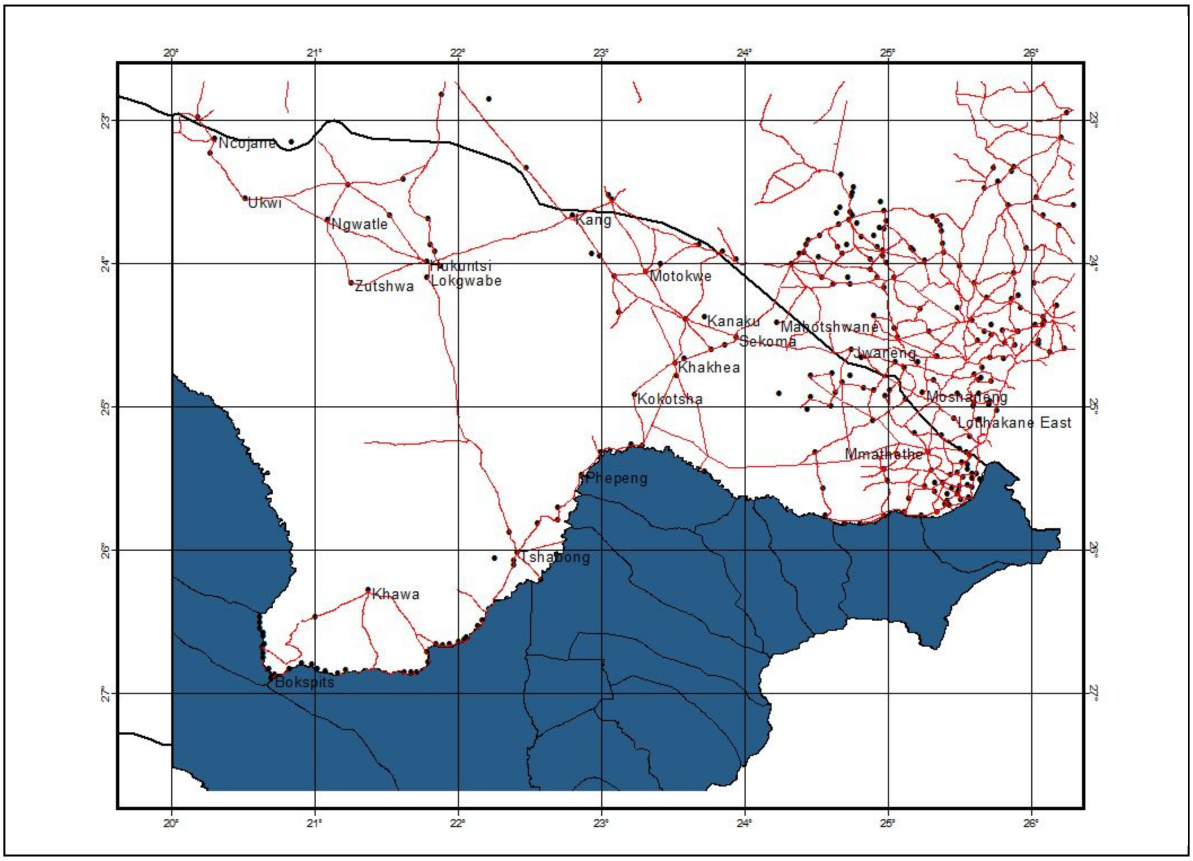


Figure 3-1 Area of Botswana included in the Molopo-Nossob basin based on surface water divide

The use of water in the area is based on groundwater or temporary surface water ponds such as pans, filled after rainy seasons. For sustainable water supply, boreholes and wells are used and all rural and major villages have their supply based on groundwater.

Table 3-2 Districts and sub-districts covered by the Molopo-Nossob basin in Botswana

District	Sub-District	Number of villages	Area in Molopo-Nossob basin km^2	Percentage in Molopo-Nossob basin	Population 2006 (CSO, 1997 and 2005)
Kgalagadi	Kgalagadi South	22	32,800	100	26,488
	Kgalagadi North	13	72,400	100	16,968
Ngwaketse	Southern Ngwaketse	14	25,783	80	10,176
	Southern Barolong	49		100	52,774
	Southern Ngwaketse West	10		100	10,989
Kweneng		1	1,244	4	1,529
Ghanzi		1	3,537	3	1,477
Total		***110***	***135,764***		***120,401***

Table 3-3 Water requirements for the village (domestic water requirement) within the district of Botswana in the Molopo-Nossob basin (DWA, 2006)

District Sub-district	Number of villages	Total water requirement (m^3/a)			
		2006	2010	2015	2020
Kgalagadi South	22	558,686	611,111	675,956	745,260
Kgalagadi North	13	432,470	476,686	530,719	595,604
Southern Ngwaketse	14	57,894	58,586	59,086	59,416
Southern Barolong	49	675,774	744,029	830,214	935,735
Southern Ngwaketse West	10	136,824	152,990	172,885	193,693
Kweneng West	1	14,865	14,939	14,986	15,010
Ghanzi	1	25,001	24,992	24,986	24,983
Total	**110**	**1,901,514**	**2,083,333**	**2,308,832**	**2,569,701**

In 2006 Botswana made a review of their National Water Master Plan (DWA, 2006). Data were compiled and assessed on water supply situation and future demands. The demand figure for domestic supply is summarized in **Table 3-3** for the districts within the Molopo-Nossob basin.

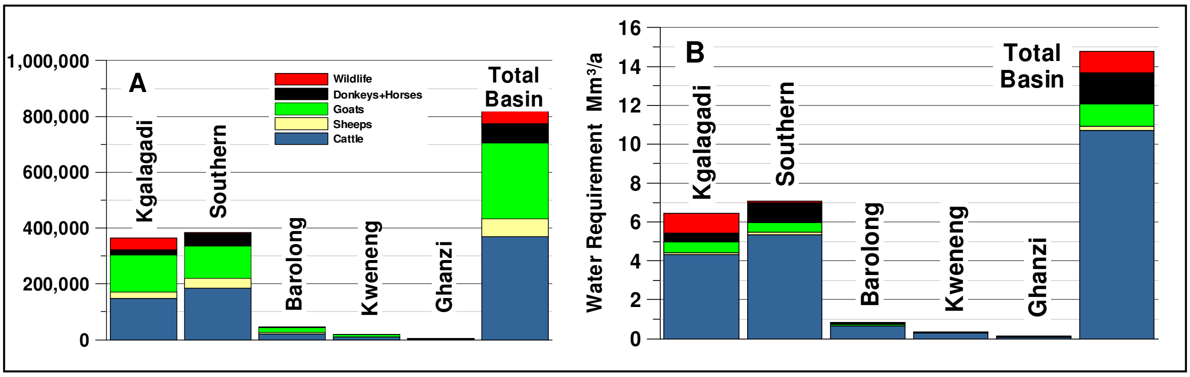


Figure 3-2 **(A) Number or various livestock and (B) Water requirement for various livestock and wildlife in the Kgalagadi, Southern, Barolong and Ghanzi District within the Nossob River basin (source: DWA, 2006)**

The livestock population within the Botswana part of the Molopo-Nossob basin is given in **Table 3-4** from data in the Annual Agricultural Survey Report 2004 (DWA, 2006). These figures are different from the livestock figures given in the Southern District Development Plan 6 (SDC, 2003).

In the calculation of the water requirement for livestock (45 l/head and day), a wastage of 50% is added to the figures assessed from number of ELSU (including Wildlife). This is similar procedure as used in calculation of the water requirement figures for livestock in Namibia. **Figure 3-2** illustrates the number of livestock in the Molopo-Nossob basin in Botswana as well as the estimated water requirement. The wildlife area is contained in the Kalahari Trans-Frontier Park and Mabuasehube Game reserve, in total comprising about 27,300 km^2.

Table 3-4 **Livestock Population by district and region in the Molopo-Nossob Basin 2002. Equivalent Large Stock Units (ELSU)**

District	Cattle	Goats	Sheep	Donkeys	Horses	Wildlife Herbivores	ELSU in Molopo-Nossob basin
Kgalagadi South	113,164	105,082	20,586	12,376	4,581	40,000	210,251
Kgalagadi North	36,200	25,929	1,871	2,200	1,465		50,812
Southern Ngwaketse	70,770	30,244	8,458	13,015	2,638	4,000	108,245
Southern Barolong	22,102	15,044	4,812	3,933	250		33,161
Southern Ngwaketse West	113,840	85,253	27,304	27,382	1,150		178,872
Kweneng West	10,222	6,957	639	871	90		14,204
Ghanzi	2,647	2,139	263	229	107		3,839
Total	***368,944***	***270,648***	***63,934***	***60,006***	***10,282***	***44,000***	***599,384***

Table 3-5 summarizes the water Requirement for the various users in the Districts within the Molopo-Nossob Basin.

Table 3-5 **Water requirement in Mm^3/a for various livestock in the Districts in Botswana within the Molopo-Nossob Basin. The requirements include wastage of water with 50%**

District	Cattle	Goats	Sheep	Donkeys	Horses	Wildlife (Herbivores)	Total
Kgalagadi	4.329	0.557	0.085	0.326	0.149	0.986	**6.432**
Southern	5.351	0.491	0.136	0.905	0.093	0.099	**7.074**
Barolong	0.641	0.064	0.018	0.088	0.006	0.000	**0.817**
Kweneng	0.296	0.030	0.002	0.020	0.002	0.000	**0.350**
Ghanzi	0.077	0.009	0.001	0.005	0.003	0.000	**0.095**
Total	***10.694***	***1.150***	***0.242***	***1.344***	***0.253***	***1.084***	***14.767***

Irrigation in the Molopo-Nossob basin in Botswana is currently non-existing. Plans for irrigation schemes have been put forward by the Botswana Government (NAMPAD, 2000). Irrigation in Botswana is mainly for high value horticultural production such as vegetables for the domestic market, wine yards and some citrus production. Nevertheless, the government of Botswana has clearly stated its desire to increase domestic agricultural production. In regards to irrigated agriculture, especially horticultural production, the objective of the government as stated in the NAMPAD report is to increase domestic production to meet 70% of the domestic horticultural demand. This is motivated by the need for some level of food security and employment generation, especially rural employment.

The National Master Plan for Agricultural Development (NAMPAD) proposed that projects should be undertaken within the Molopo-Nossob basin of Botswana for irrigation. The proposed project even includes establishment of wine yards in the area of Tsabong. A planned abstraction of 1.8 Mm^3/a for irrigation is proposed. Further in the Ngwaketse South additional irrigation projects are proposed with planned demands of 0.62 Mm^3/a. **Table 3-6** summarizes potential and planned utilization of water for irrigation

It is anticipated that irrigation schemes will be established covering the amount of about 6.2 Mm^3/a in the areas of Kgalagadi South, Borolong and Ngwaketse (Southern), see **Table 3-6**. These schemes will however not be in full capacity until 2015 and afterwards.

Projections of water requirement by visitors to lodges in and around the Kalahari Transfrontier Park were done in the NWMPR for Botswana (DWA, 2006). A total of 8,680 m^3 annually was arrived at. This figure assuming each visitor uses 100 litres per day.

Table 3-6 Potential and planned irrigation in the Molopo-Nossob Basin in Botswana (NAMPAD, 2000)

District/ Sub-District	Water Source	Potential production m^3/h	Potential Production 1000 m^3/a	Planned utilization 1000 m^3/a	
				SOS	EOS
Barolong	Existing boreholes	3-24	1,000	891	787
Ngwaketse Central	Existing boreholes Existing Mmamokhasi dam Kanye wellfield Lobatse waste water reclaims.	2-4.5 35 4-9 ?	51 280 500 1,750	30 280 0 881	0 282 0 881
Ngwaketse North	Existing boreholes Kanye waste water reclaims.	6-2.4 ?	67 2,000	61 1,007	61 1,007
Ngwaketse South	Existing boreholes Kanye wellfield	3-12.5 4-9	124 500	114 0	103 0
Ngwaketse West	Existing boreholes Kanye wellfield Jwaneng waste water reclaims.	3-6; 20; 33 4-9 ?	576 500 1,000	576 43 536	501 0 536
Tshabong (Kgalagadi South)	Existing boreholes Groundwater development along Molopo River	1.5-2 5-10	28 4,000	28 1,829	28 1,829
Total region				***6,276***	***6,015***
SOS = Socially Oriented Scenario, EOS = Economically Oriented Scenario					

The predicted total water requirement for the Molopo-Nossob basin in Botswana is summarized in **Table 3-7** and illustrated in **Figure 3-3.**

Table 3-7 Estimated water requirement for the Molopo-Nossob basin in Botswana

Consumer	Water requirement Mm^3/a			
	2006	*2010*	*2015*	*2020*
Domestic use	1.90	2.08	2.31	2.57
Livestock	13.68	13.68	13.68	13.68
Wildlife	1.08	1.08	1.08	1.08
Irrigation	0.00	0.00	6.70	6.70
Tourism	0.009	0.009	0.01	0.01
Total	***16.67***	***16.85***	***23.78***	***24.03***

There is no return flow from any of the villages and settlements. The water resources are mainly groundwater. Temporary water ponds, for instance at pans after rainy season and minor flows in parts of Molopo river can be used as water supply mainly for livestock and wildlife. The main water supply is otherwise groundwater through boreholes drilled in various types of aquifers.

The major problem with the groundwater is related to salinity. Most of the Molopo-Nossob basin in Botswana contains groundwater with total dissolved solids, TDS, above the recommended limit of 1,000 mg/l. Even when allowing the higher value of 2,000 mg/l the main part of the basin in Botswana cannot supply potable water, see further **Chapter 5.2.2**.

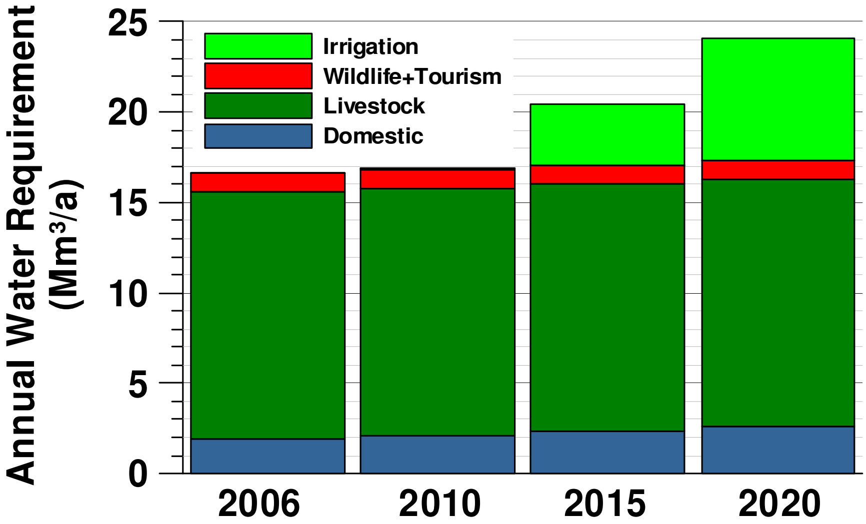


Figure 3-3 Predicted water requirements for Molopo-Nossob Basin in Botswana

3.3 Namibia

In the year 2000 an analysis was performed of the present and future water demand in Namibia. The information in that report was used to provide an overview of the present and future water requirements of Namibia within the Molopo-Nossob Basin (MAWRD, 2000).

In the 2000 report, the Molopo-Nossob basin in Namibia was assessed within two major river basins, the Auob River and the Nossob River basins. Details about these two basins and the Molopo River Basin, which constitutes the southernmost part of the Molopo-Nossob Basin in Namibia, are given in **Table 3-8.**

The latest national population census in Namibia was completed in 2001. According to the 2001 census the number of people in Namibia was about 1 826 900, and about 105 000 people resided in the Molopo-Nossob Basin (5.7 % of the Namibian population), see **Table 3-9.**

Table 3-8 Sizes of basins in the Namibian part of the Molopo-Nossob Basin (MAWRD, 2000)

Parameter	Auob River Basin	Nossob River Basin	Molopo River Basin	Total (Molopo-Nossob Basin)
Catchment area km^2	52,702	50,050	18,120	120,872
Remarks	Includes Oanob River		In the southern most part of the Basin	

Table 3-9 Estimated Population in the Molopo-Nossob Basin in Namibia (MAWRD, 2000, ORASECOM, 2007b)

River Catchment	Population			
	1999	2005	2015	2025
Auob	66,962	75,399	80,022	86,177
Nossob	37,276	38,450	40,757	43,892
Total	**104,238**	**113,849**	**120,779**	**130,069**

The Auob River basin includes Oanob River basin. There are several state water schemes in the Auob River catchment; at Rehoboth, Stampriet and Gochas. Significant quantities of groundwater are used for irrigation alongside the Auob River and some potential for irrigation in the vicinity of Rehoboth has been identified (100 ha) (MAWRD, 2000).

The Nossob River rises as two main tributaries, the White Nossob in the Otjihavere Mountains to the east of Windhoek, and as the Black Nossob further to the north-east. In these areas the mean annual precipitation is assessed as approximately 370 mm.

The main commercial activity within the Nossob basin is large stock farming, which is practiced on commercial basis. The economically active centres are Gobabis, Witvlei. Leonardville and Aranos. Agriculture products are the backbone to the economy in this catchment. Development of tourism is limited to a few lodges and game farms (MAWRD, 2000).

Parallel to and between the two rivers Auob and Nossob, the Olifants River occurs. This river joins the Auob River about 175 km upstream the merging of Auob and Nossob Rivers.

In its lower part Nossob River forms the south-western boundary between Botswana and South Africa down to its confluence with the Molopo. There is no recorded history of the Nossob River ever contributing surface water to the Molopo River (MAWRD, 2000).

There are several state water schemes in the Nossob River catchment, most important of which is the Gobabis Bulk Water Scheme which includes the Otjivero, and Viljoen Dams and boreholes. Other schemes in the area include Summerdown, Steinhausen, Witvlei, Leonardville and Aranos.

The water users in the Auob and Nossob catchment basins are considered in four groups as summarized in **Table 3-10**.

Table 3-10 Water use and requirement in Auob River and Nossob River Basin2 in Namibia 1999, 2005 and 2015 (MAWRD, 2000)

User	Auob River Basin			Nossob River Basin		
	1999	2005	2015	1999	2005	2015
Urban	2,464,454	2,161,774	2,700,596	1,141,099	1,139,651	1,228,068
Rural	133,231	128,724	117,325	100,191	94,176	91,916
Irrigation	7,059,000	7,148,000	7,237,000	949,000	961,000	973,000
Stock	3,794,452	3,288,525	3,288,525	8,636,687	7,485,129	7,485,129
Mining	2,000	2,000	2,000	0	0	0
Tourism	63,510	77,110	96,110	48,280	61,545	81,475
Total	***13,516,647***	***12,806,132***	***13,441,556***	***10,875,257***	***9,741,501***	***9,859,588***

Table 3-11 summarizes the water requirement for the two river basins which here represents the water requirement for the Molopo-Nossob Basin in Namibia.

Table 3-11 Water user and requirement (Mm^3/a) in Molopo-Nossob Basin in Namibia 1999, 2005 and 2015 (MAWRD, 2000)

User	1999	2005	2015
Urban	3,605,553	3,301,425	3,928,664
Rural	233,422	222,900	209,241
Irrigation	8,008,000	8,109,000	8,210,000
Stock	12,431,139	10,773,654	10,773,654
Mining	2,000	2,000	2,000
Tourism	111,790	138,655	177,585
Total	***24,391,904***	***22,547,633***	***23,301,144***

The water requirements in the Auob River and Nossob River basins summarized in **Table 3-10** are presented in the diagrams in **Figure 3-4A**. It can be seen from the figure that Irrigation is most pronounced in the Auob basin, whereas the highest water consumer in the Nossob basin is livestock watering.

The water requirement for the whole Molopo-Nossob Basin in Namibia as summarized in **Table 3-11** is illustrated in **Figure 3-4B**.

In Molopo-Nossob basin numerous irrigation schemes are established. In Namibia as a whole irrigation is the highest consumer taking 45.7% of the water requirement. In the whole Molopo-Nossob basin the percentage used for irrigation is 36 % (2005). The location of the major irrigation schemes in Namibia in Molopo-Nossob basin are shown in **Figure 3-5**. In the whole Namibia only 18% of the total irrigable area (42,962 ha) is currently irrigated (7,573 ha) (MAWRD, 2000). Corresponding figure for the Molopo-Nossob basin area is not established. According to records of irrigation holders in the Stampriet area (Groundwater Control area), permits for allocation of 11.18 Mm^3 per annum are allocated (DWAF, Resource Management Law Administration). It is also established that actual water consumption figures are rarely reported to the authorities (MAWRD, 2000).

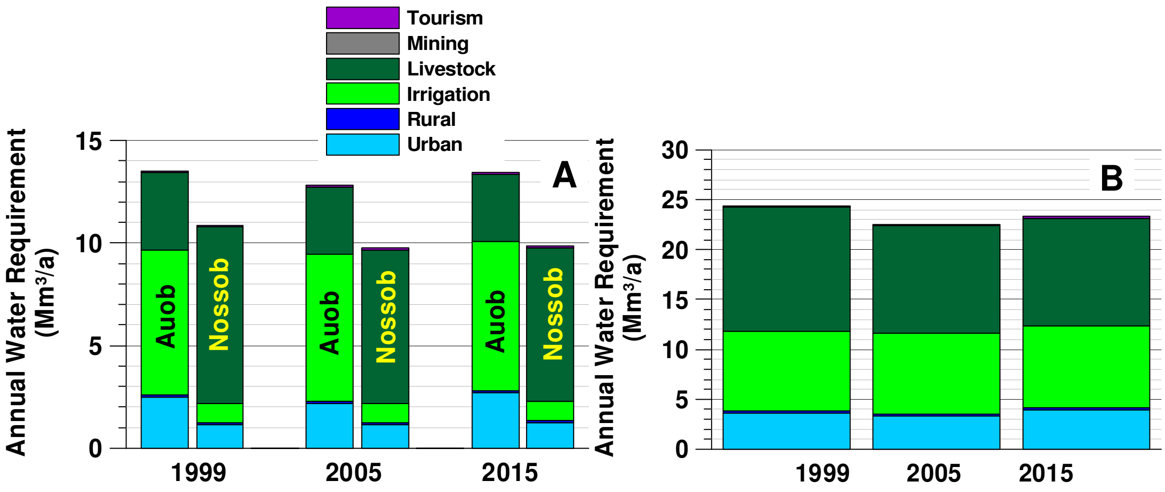


Figure 3-4 (A). Water requirement in the Auob River and Nossob River Basins in Namibia
(B). Water requirement in the Molopo-Nossob Basin in Namibia (MAWRD, 2000)

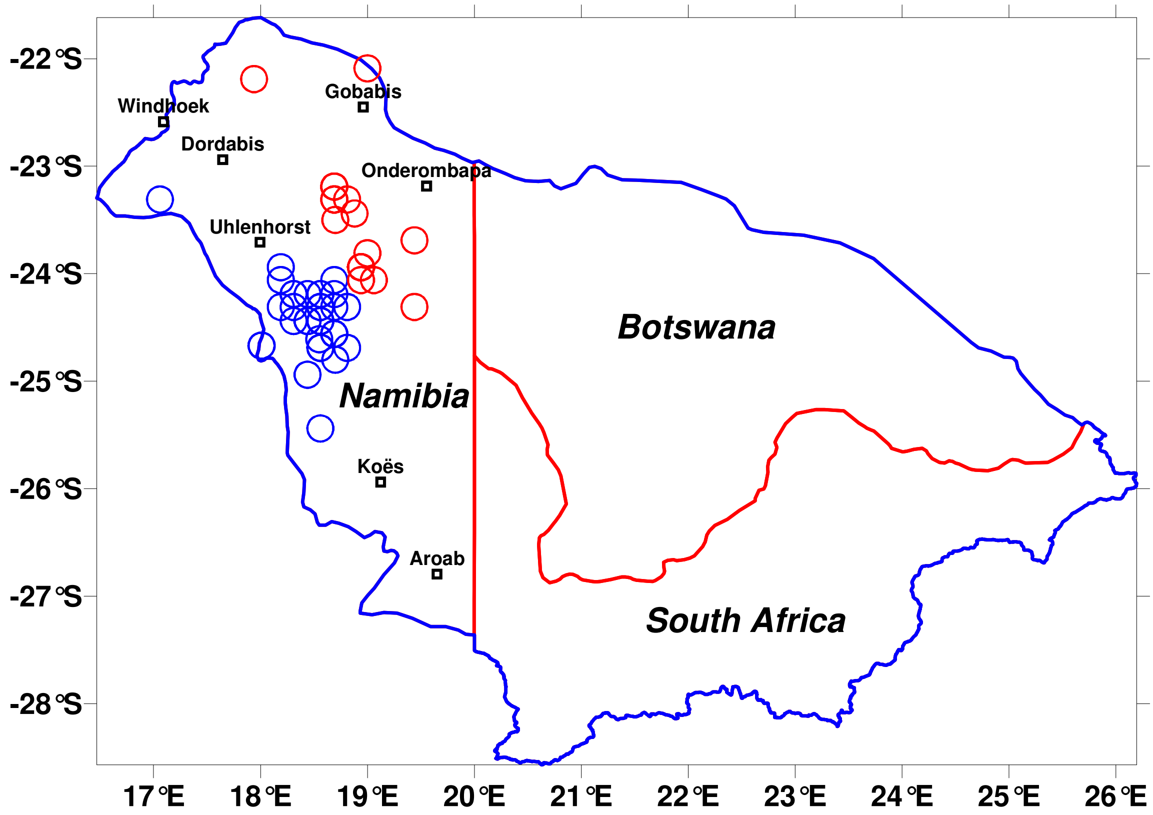


Figure 3-5 Irrigation schemes in the Auob catchment area (blue) and Nossob catchment area (red) (source: MAWRD, 2000)

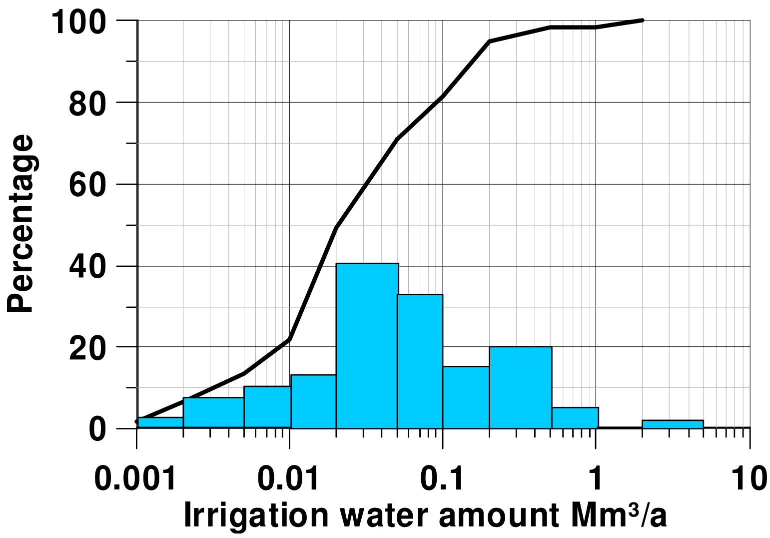


Figure 3-6 Distribution of water requirements for the Irrigation schemes in the Molopo-Nossob Basin (MAWRD, 2000)

The distribution of the water requirement for irrigation schemes (2005) is presented in **Figure 3-6**. The median value of the 59 schemes is 0.05 Mm^3/a and the average value is 0.137 Mm^3/a (MAWRD, 2000).

The water requirement for livestock is higher in the Nossob than the Auob catchment area. The number of livestock is taken from figures from veterinary areas. These areas cover more than the Molopo-Nossob basin and the amount of livestock for the Molopo-Nossob area is calculated in regard to the proportion of the veterinary area in the Molopo-Nossob basin. **Table 3-12** summarizes the size and the water requirements for livestock including wastages (MAWRD, 2000).

Table 3-12 Veterinary area codes and sizes in the Molopo-Nossob basin. Calculated water requirement for livestock, based on numbers from 1999 (MAWF, 2006)

Veterinary Area	River Basin	Veterinary Area Code	Percentage of the veterinary area in the basin	Area size km^2	Water requirement (incl. wastage) m^3/a
Gobabis	Auob		1.1	526	98,730
	Nossob	SX	57.9	27,890	5,232,676
Windhoek	Auob		50.3	18,430	1,774,393
	Nossob	SW	10.7	3,921	377,530
Okahandja	Nossob	SH	3.0	527	101,012
Keetmanshoop	Auob	SK	20.0	23,443	1,569,748
Mariental	Auob		33.0	29,498	2,542,715
	Nossob	SN	16.0	14,350	1,236,996
Total				**118,586**	**12,933,800**

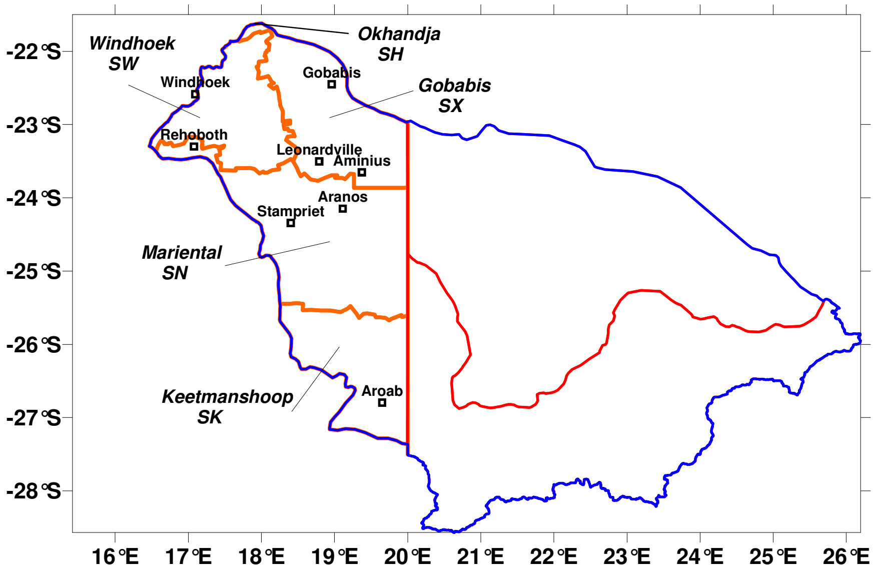


Figure 3-7 **Veterinary areas in Namibia in the Molopo-Nossob Basin**

The total demand for livestock according to **Table 3-12** is slightly higher than the figure given in **Table 3-11**. Figure for the both tables are however derived from different information sources, the "Namibia Water Resource Management Review" (MAWRD, 2000) and "Technical Summary of Water Accounts' (MAWF, 2006). The veterinary areas within the Molopo-Nossob basin are shown in **Figure 3-7**.

In the calculation of the water requirement, the water consumption for the animal heads were taken from the MAWRD report and summarized in **Table 3-13**.

Table 3-13 **Daily assumed water consumption of various animals and percentage water wastage assumed (MAWRD, 2000)**

Animal head	Daily water demand (m^3/day)	Percentage added for wastage
Cattle	0.045	50 %
Sheep	0.010	50 %
Goat	0.010	50 %
Pig	0.010	30 %
Donkey	0.015	50 %
Horse	0.025	50 %
Ostrich	0.004	50 %

The water requirement for the livestock in the Auob and Nossob basin in Namibia is illustrated in **Figure 3-8**.

The domestic water demand in the towns and the rural areas is based on water consumption data and projections of the future demand due to the population increase and the expected improvement in the standard of living.

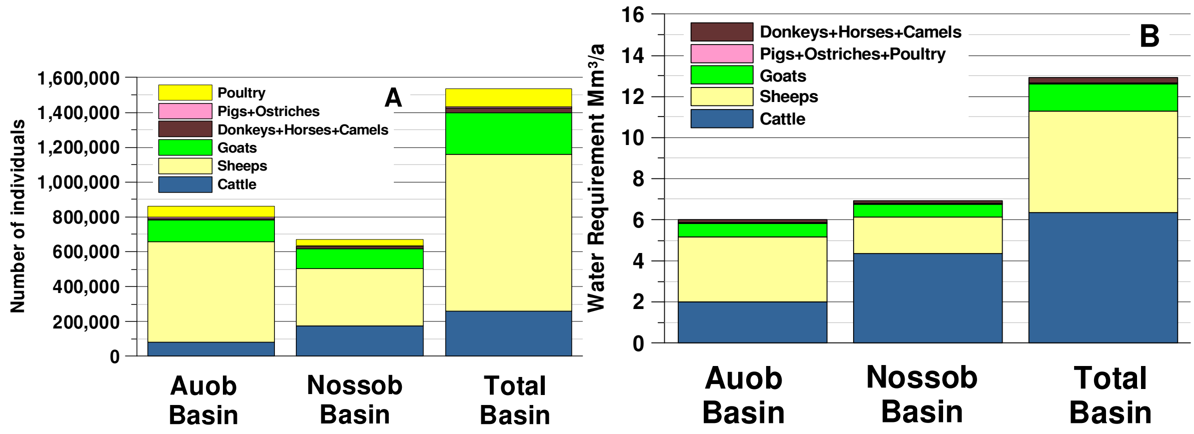


Figure 3-8 **(A) Number or various livestock and (B) Water requirement for various livestock in the Auob River and Nossob River basins (MAWF, 2006)**

A comprehensive database of livestock numbers (cattle, donkeys, horses, goats, sheep, pigs, camels, poultry and ostriches) exists and was used to determine the number of livestock in the Auob and Nossob River Basins, as well as the estimated water demand, see **Figure 3-8** and **Table 3-14**. The grazing capacity of the rangeland is limited and it is not expected that there will be a significant increase in stock numbers over time. Decrease and increase in the availability of grazing will be due to the seasonal variations in the rainfall.

Table 3-14 **Number of livestock and water requirement in Auob River and Nossob River basins (source: MAWF, 2006)**

	Number			Water demand m^3/a		
	Auob	Nossob	Total	Auob	Nossob	Total
Cattle	81,417	176,454	**257,870**	2,007,282	4,350,353	**6,357,636**
Sheep	575,974	323,856	**899,830**	3,155,618	1,774,325	**4,929,943**
Goats	124,445	117,894	**242,339**	681,801	645,913	**1,327,715**
Pigs	4,246	2,081	**6,327**	20,162	9,880	**30,042**
Donkeys	4,114	6,607	**10,721**	33,813	54,294	**88,107**
Horses	5,110	8,116	**13,226**	69,990	111,169	**181,159**
Ostriches	3,301	1,604	**4,905**	7,233	3,516	**10,749**
Poultry	63,409	36,382	**99,791**	347	199	**547**
Camels	2	33	**35**	46	718	**764**
ESLU / Total	***216,986***	***292,980***	***509,966***	***5,976,295***	***6,950,368***	***12,926,662***

The main irrigation area in the Molopo-Nossob basin within Namibia is the Stampriet artesian groundwater basin underlying the Nossob and Auob catchments.

No major mining operations are taken place within the Molopo-Nossob basin in Namibia. An older plan for coal mining in the basin is shelved due to problems envisaged on stability and water hazards.

To prevent undue depletion of water resources in certain areas, Groundwater Control Areas have been proclaimed. Based on the existing Water Act of 1956, permits for large-scale groundwater abstraction are required in these Groundwater Control Areas of Namibia, see **Figure 3-9**. In the Molopo-Nossob basin these are:

- Windhoek – Gobabis Underground Water Control Area

- "Stampriet Artesian Basin"
- Gobabis Artesian Area

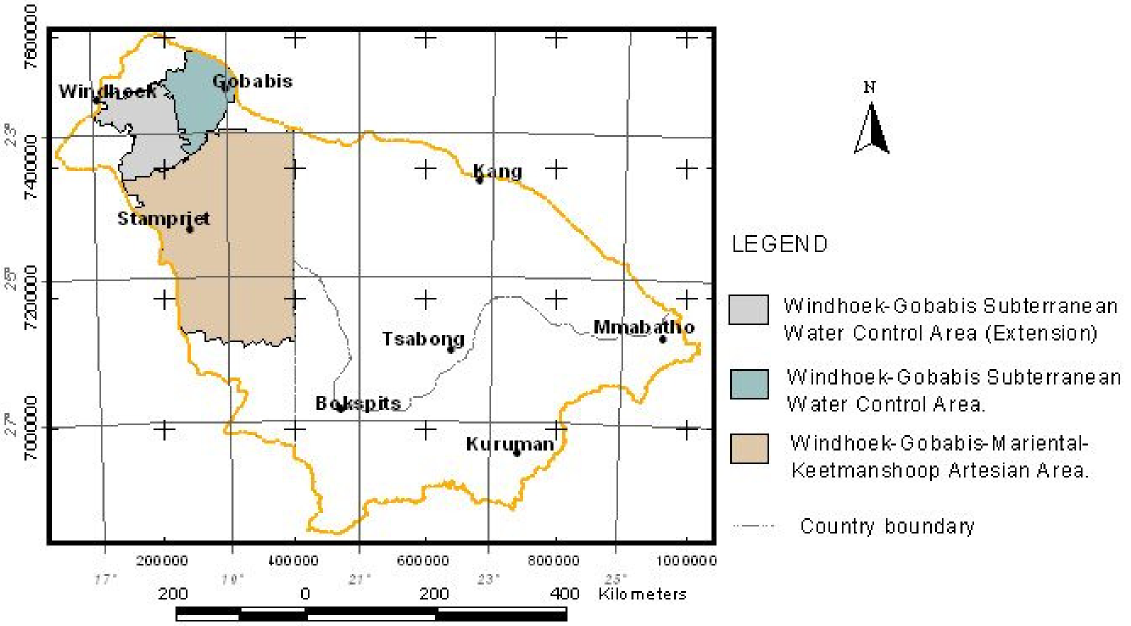


Figure 3-9 Groundwater Control Areas in the Molopo-Nossob Basin, Namibia

Village centres are supplied with water by Nam Water, and are called "Bulk Customer" and operate on a contract basis with a memorandum of agreement being exchanged. Village councils are responsible for the operation and maintenance of the feeder pipeline network as well as water supply in the villages.

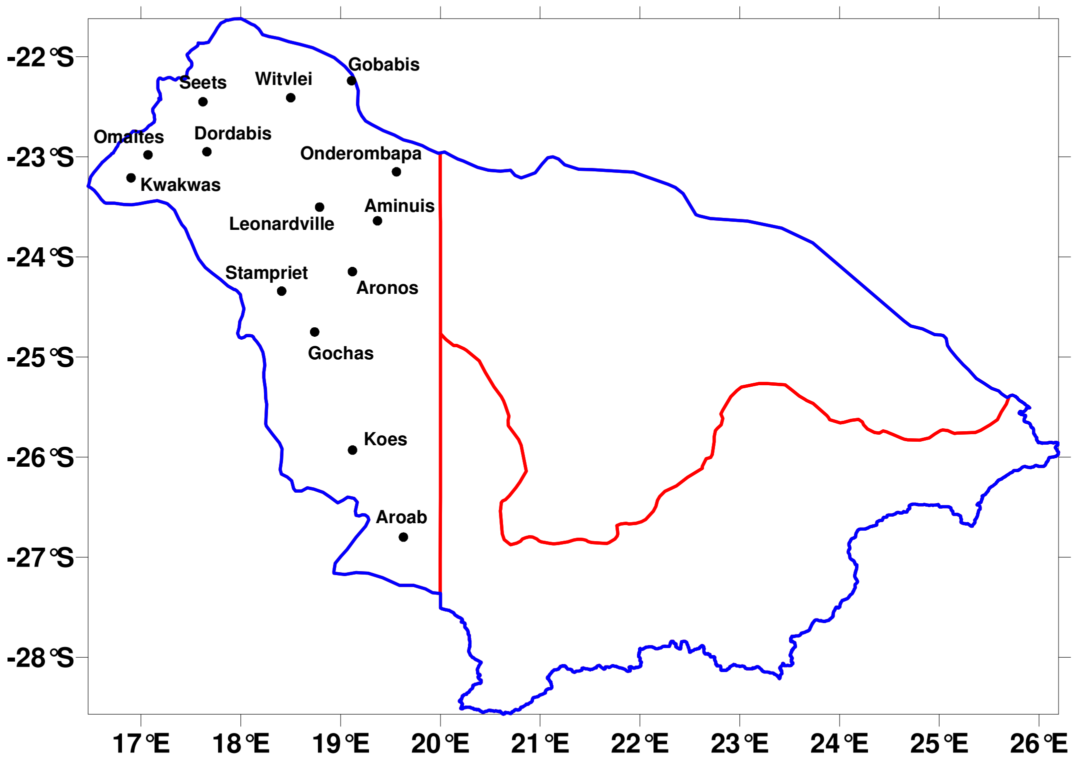


Figure 3-10 Villages supplied by Nam Water ("Bulk Consumers") in the Molopo-Nossob Basin

Nam Water operates groundwater schemes in the Hardap, Karas, Khomas and Omaheke Regions supplying towns, villages and settlements within the Molopo-Nossob Basin see **Figure 3-10**. **Table 3-15** summarizes the schemes within the Molopo-Nossob basin.

Table 3-15 Nam Water Groundwater Schemes in the Molopo-Nossob basin (Nam Water, 2008, ORASECOM, 2007a)

Region	Scheme	No of Bore-holes	Production 2007 m^3/a	Production 2010 m^3/a	Production 2015 m^3/a	Remarks
Hardap	Aminuis	2	79,126	82,984	88,958	
	Aranos	9	190,194	198,878	211,622	
	Gochas	3	49,615	51,118	53,726	
	Kriess	2	6,096	6,2816	6,602	
	Leonardville	3	61,487	63,840	67,965	
	Onderombapa	2	24,827	25,504	26,672	
	Stampriet	2	51,942	53,118	53,726	
Karas	Aroab	5	51,469	53,984	57,302	
	Koes	2	55,496	58,208	61,785	
Khomas	Windhoek airport Dorbabis Uhlenhorst	12	206,040			
	Nauaspoor	2	137,269	142,397	151,372	Recharged from dam
	Kwakwas	2	240	250	270	
Omaheke	Gobabis	25	196,068	207,281	222,202	
	Witvlei	3	97,753	102,936	109,803	
Total			***2,301,582***	***2,393,177***	***2,544,526***	

Commercial farms have their own boreholes dug using their own investment and they do not pay any water fee to the village councils.

There are a number of dams in the Molopo-Nossob basin in Namibia within the Nam Water schemes. **Table 3-16** summarizes these dams.

Table 3-16 Dams within the Molopo-Nossob basin included in the Nam Water schemes

River Catchment	Dam	Longitude	Latitude	Capacity Mm^3	95% safe yield Mm^3/a	Schemes supplied	Reference
Fish	Hardap	17.851	-24.5091	294	55.5	• Mariental • Irrigation • Small consumers	NamWater 2008
Auob	Nauaspoort					Recharge boreholes	NamWater 2008
Auob (Oanab)	Oanab			35.5	4.2	Rehoboth Fish farms	NamWater 2008
White Nossob	Otjivero Main	17.9604	-22.2886	9.74		• Gobabis • Witvlei	ORASECOM, 2008
White Nossob	Otjivero Silt	17.9406	-22.2944	7.795			ORASECOM, 2008
Black Nossob	Daan Viljoen	18.8380	-22.2097	0.429			ORASECOM, 2008
Black Nossob	Tilda Viljoen	18.9528	-22.4442	1.224			ORASECOM, 2008

3.4 South Africa

3.4.1 Water management Areas

In South Africa the Molopo-Nossob basin is covered by three major water management areas (WMA) see **Table 3-17**. These WMAs are further divided into quaternary drainage zones. These zones or smaller WMAs coincide with the catchment of each area they cover. In a closer look only parts of the three major WMA fall within the Molopo-Nossob basin. **Table 3-17** defines the quaternary WMAs falling within the Molopo-Nossob basin.

Table 3-17 Quaternary regions (WMA) in the Molopo-Nossob basin in South Africa

Water Management Area (WMA)	WMA No	Quaternary regions in Molopo-Nossob Basin
Crocodile (west) and Marico (Upper Molopo)	3	D41A
Lower Vaal	10	D41B, D41C, D41E, D41F, D41G, D41E, D41F, D41G, D41H, D41J, D41K, D41L, D41M, D42C 99%, D42D 14%
Lower Orange	14	D42A, D42B, D42C 1%, D42D 86%, D42E

In the current assessment of the water requirements, the Molopo basin in South Africa is divided into three parts or zones; Upper, Middle and Lower Molopo. These zones almost coincide with parts of the three WMA described in reports by DWAF. The differences being the quaternary WMA D42C and D42 D which are attributed to two different WMA by DWAF. They are now, in the division of Molopo basin, referred whole to one of the zones each as summarized in **Table 3-18**. The Upper and Middle Molopo are catchment areas to Molopo River whereas the Lower Molopo also includes catchment areas to Nossob and Auob Rivers.

Table 3-18 The division in three zones for assessment of the water requirement in the Molopo basin in South Africa

Zone of Molopo basin in South Africa	Catchment River	Major WMA in DWAF reports	Quaternary regions in Molopo-Nossob Basin
Upper Molopo River catchment	Molopo River	Crocodile (west) and Marico (Upper Molopo), WMA 3	D41A
Middle	Molopo River	Lower Vaal, WMA 10	D41B, D41C, D41E, D41F, D41G, D41E, D41F, D41G, D41H, D41J, D41K, D41L, D41M, D42C
Lower	Molopo River	Lower Orange, WMA 14	D42D, D42E
	Nossob River	Lower Orange, WMA 14	D42A 50%, D42B
	Auob River	Lower Orange, WMA 14	D42A 50%

The water use and demand within those quaternary regions are compiled from various WMA reports with the subtitle "Water Resources Situation Assessment" (DWAF, 2002b, 2002c and 2002d).

3.4.2 Upper Molopo

The Upper Molopo comprises one single quaternary catchment, D41A, see **Figure 3-11** and **Table 3-19**. The rainfall pattern of the Upper Molopo sub-area is highly variable and unevenly distributed within the catchment. The intermittence of the rainfall results in frequent floods and local droughts. According to the WMA report (DWAF, 2004c), the surface water resource available from the rivers in the Upper Molopo sub-area, before impact of Ecological Reserve, is estimated at approximately at 14 Mm^3/a. The Setumo Dam and Disaneng Dams are the main dams in the sub-area. The impact of the ecological Reserve is likely small and difficult to assess since the Upper Molopo River is an ephemeral river. Return flows from the sewage treatment works in Mafikeng is estimated at approximately 7 Mm^3/a.

According to the WMA report (DWAF 2004c), the natural mean annual runoff of the Upper Molopo River is approximately 37 Mm^3/a. The most significant resource in the Upper Molopo catchment is the groundwater from the dolomitic aquifers of the Grootfontein and Lichtenburg compartments.

The available surface water in the D41A area is mainly for urban use in Mafikeng (supplied from the Setumo Dam) and some irrigated agriculture downstream of Disaneng Dam.

The development in the Upper Molopo sub-area is concentrated around Mafikeng, the capital city of the North West Province. The major water user in the sub-area is the urban use of Mafikeng which has two sources of supply, namely, groundwater and surface water from Setumo Dam. Mafikeng Municipality is currently abstracting 11 Mm^3/a from the dolomitic aquifers. Their water allocation is approximately 8 Mm^3/a from the government Subterranean Water Control Area (SWCA). This means the municipality is over-abstracting by 3 Mm^3/in terms of their allocation. There is return flow from the urban and industrial areas of Mafikeng and Itsoseng.

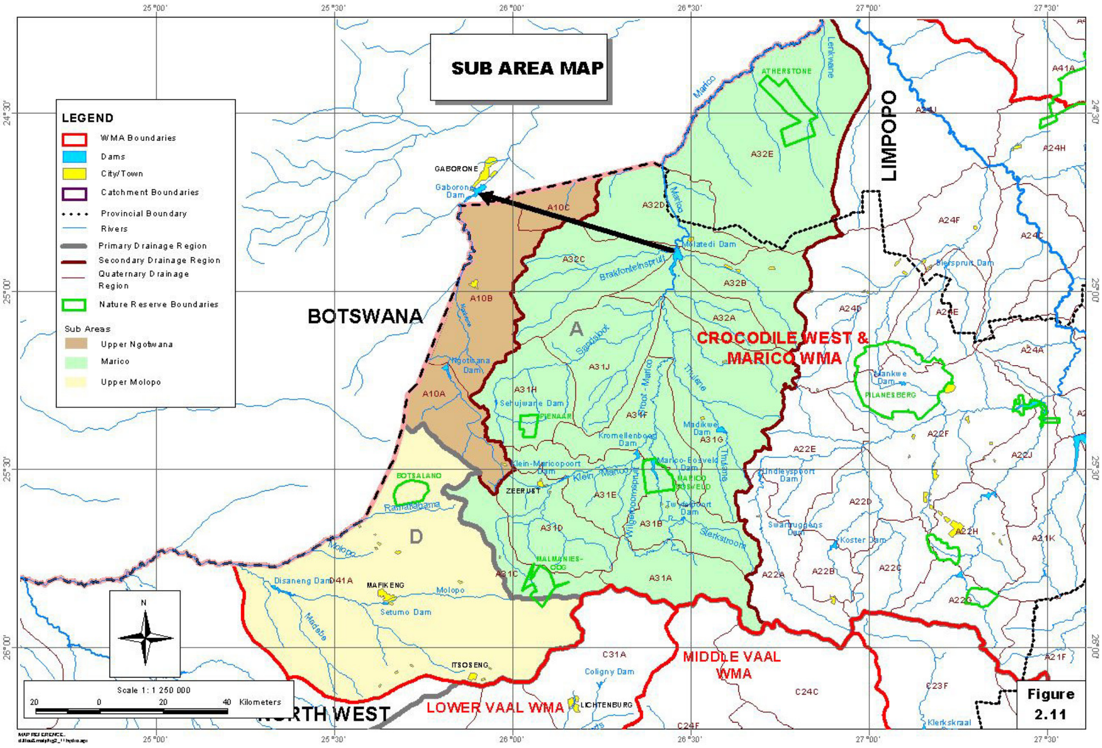


Figure 3-11 Upper Molopo WMA (the quaternary WMA D41A), marked D in the figure (DWAF, 2004c)

The second major water user for the year 1995 as shown in **Table 3-20** is irrigation. The rural domestic water requirement is increasing since most of the rural communities to the west of the sub-area had no access to potable water supplies in the past and are now at least beginning to get some basic level of service.

Most of the water requirement in the Upper Molopo sub-area is met by groundwater. However the municipality of Mafikeng is also dependant on surface water from Setumo Dam but are currently not utilising this source.

Table 3-19 Data on population, ESLU (1995) and size of the quaternary WMA in the Upper Molopo defined area (DWAF 2002d)

Area	Size km^2	Urban Population	Rural Population	Total Population	ESLU
D41A	4,322	101,000	167,500	268,500	38,620
Total (2000)*		***115,599***	***Missing data***		
****= source DWAF, 2004c***					

Table 3-20 Water requirement (1995) in Mm^3/a for the quaternary WMA in the defined Upper Molopo area (DWAF, 2002d)

Area	Urban Use	Irrigation	Mining &others	Rural use	Livestock	Total
D41A	10.7	14	5.2	3.2	2.9	36
Total (2000)*	***13***	***24***	***5****	***6***		***48***
****= source DWAF, 2004c***						
***** = industrial use***						

3.4.3 Middle Molopo

The Middle Molopo area belongs to the Lower Vaal WMA which is dependant on water releases from the Middle Vaal WMA for meeting the bulk of the water requirements by the urban, mining and industrial sectors. The local water resources are mainly used for rural demands, irrigation and smaller towns.

Before reaching the Atlantic Ocean near the town of Alexander Bay in the western corner of South Africa, the water in the Lower Vaal has joined Orange River and crossed other WMAs.

There are no distinct topographic features in the Lower Vaal WMA; most of the terrain being relatively flat. The generally semi-arid climate supports sparse vegetation over the WMA, consisting mainly of grassland and some thorn trees, notably the majestic camel thorns.

The total urban and rural population in the Lower Vaal WMA is estimated at 1,282,000, of which about 718,000 live in urban centres. **Table 3-21** summarizes the population, size and ESLU within the Middle Molopo quaternary WMA (DWAF 2002b and 2002c).

There are large rural populations in the Lower Vaal WMA, especially in the areas west of Mafikeng, around Kuruman, Pampierstad and Lichtenberg.

The National Water Resource Strategy, NWRS describes and discusses the WMA in three sub-areas, viz. the Molopo, Harts and Vaal River downstream of Bloemhof Dam (DWAF, 2003a). The geographical extents of the sub-areas are shown in **Figure 3-12**. The sub-area Molopo represents the Middle Molopo area in the current report

Table 3-21 Data on population, ESLU (1995) and size of the quaternary WMA in the Middle Molopo defined area (DWAF 2002b and 2002c)

Area	Size km^2	Urban Population	Rural Population	Total Population	ESLU
D41B	6,164	1,600	110,100	111,700	38,620
D41C	3,919	0	12,980	12,980	38,620
D41D	4,380	0	36,300	36,300	38,620
D41E	4,497	400	4,933	5,333	38,620
D41F	6,011	0	30,510	30,510	38,620
D41G	4,312	0	45,150	45,150	27,560
D41H	8,657	0	26,900	26,900	55,340
D41J	3,878	14,950	1,106	16,056	24,790
D41K	4,216	4,700	5,568	10,268	26,950
D41L	5,383	22,700	79,280	101,980	34,410
D41M	2,628	0	1,568	1,568	16,800
D42C	18,300	250	3,690	3,940	35,540
Total (1995)	***72,345***	***44,600***	***358,085***	***402,685***	***414,490***
Total (2000)*		***81,068***	***378,439***	***459,507***	
= source DWAF, 2003a					

The water requirements for the Middle Molopo area (the quaternary WMAs) are summarized in **Table 3-22**.

Table 3-22 Water requirement in Mm^3/a (1995) for the quaternary WMA in the defined Middle Molopo area (DWAF, 2002b and 2002c)

Area	Urban Use	Irrigation	Mining + others	Rural use	Livestock
D41B	0.903	1.010	0.55	2.110	2.240
D41C	0	0.120	0	0.249	1.061
D41D	0	2.160	0	0.696	1.344
D41E	0.031	0.050	0	0.095	0.965
D41F	0	0.280	0	0.585	1.275
D41G	0	0.410	0	0.865	1.195
D41H	0	4.980	0	0.515	1.625
D41J	3.980	0.010	1.93	0.021	0.599
D41K	0.364	0.050	3.3	0.107	0.703
D41L	3.242	1.030	0	1.519	1.771
D41M	0	0.010	0.33	0.039	0.401
D42C	0.019	0.010	0	0.091	3.884
Total (1995)	***8.54***	***10.12***	***6.11***	***6.89***	***17.06***
Total (2000)*	***11***	***0***	***6***		***11.8***
= source DWAF, 2003a (with exception of 1% of D42C and 86% of 42D)					

Figure 3-12 Lower Vaal WMA and its sub-areas Molopo, Harts and Vaal d/s Bloemhof Dam (DWAF 2004)

Land use within the Middle Molopo area is dominated by livestock farming. The largest water requirements, as assessed from the DWAF report is also the livestock watering. In the DWAF (2003a) report no water requirement was assessed for irrigation, whereas in the DWAF (2002c) report the same requirement was assessed at 10.2 Mm^3/a.

In the calculation of the water requirement for livestock (45 l/head and day), a wastage of 50% is added to he figures assessed from the number of ELSU. This is similar procedure as used in calculation of the water requirement figures for livestock in Namibia.

3.4.4 Lower Molopo

The Lower Orange WMA, to which the Lower Molopo, the Nossob and the Auob Rivers belong, covers the most sparsely populated part of South Africa. The WMA (D42) is the country's largest, covering 164,166 km^2, however with the population of only 382,000 persons (DWAF, 2003a). The total urban and rural population in the Lower Molopo area is approximately 11,500 persons, of which about 6,400 live in urban centres. **Table 3-23** summarizes the population, size and ESLU within the Middle Molopo quaternary WMA (DWAF 2002b and 2002c).

From a land use perspective, the area still remains almost totally under natural vegetation. Sheep and goat farming is practised over most of the area. In the Lower Orange WMA large mining operations occur in various parts. However in the Lower Molopo area no major mining is established. There are no large urban developments or power stations in the Lower Orange WMA. Due to the arid climate, no afforestation occurs. Invading alien vegetation is found along some tributary water courses and on the banks of the Orange River and is a problem in some localised areas (DWAF, 2003b).

Table 3-23 Data on population, ESLU (1995) and size of the quaternary WMA in the Lower Molopo defined area (DWAF 2002b and 2002c)

Area	Size km^2	Urban Population	Rural Population	Total Population	ESLU
D42A	10,282	0	773	773	23,482
D42B	3,198	4,700	424	5,124	7,304
D42D	16,210	0	2,324	2,324	9,610
D42E	4,208	1,653	1,626	3,279	9,610
Total (1995)	***33,898***	***6,353***	***5,147***	***11,500***	***50,006***
Total (2000)*		***6,353***	***4,943***	***11,296***	
****= source DWAF, 2003b*** (with exception of 99% of D42C and 14% of 42D)					
*****= source DWAF, 2003b can be questioned since D42A is fully covered by the Gemsbok National Park***					

The main water related activity in the Lower Molopo area is for livestock watering. Groundwater plays a major role in meeting the water requirements of rural settlements although the volumes are not large.

The Lower Orange WMA is divided in a number of sub-areas. This division was based on practical considerations such as size and location of sub-catchments, homogeneity of natural characteristics, location of pertinent water infrastructure (e.g. dams), and economic development (DWAF, 2003b). One of these sub-areas is the Lower Molopo area (in this report upgraded with the full quaternary areas include). The sub-areas are shown on **Figure 3-13.**

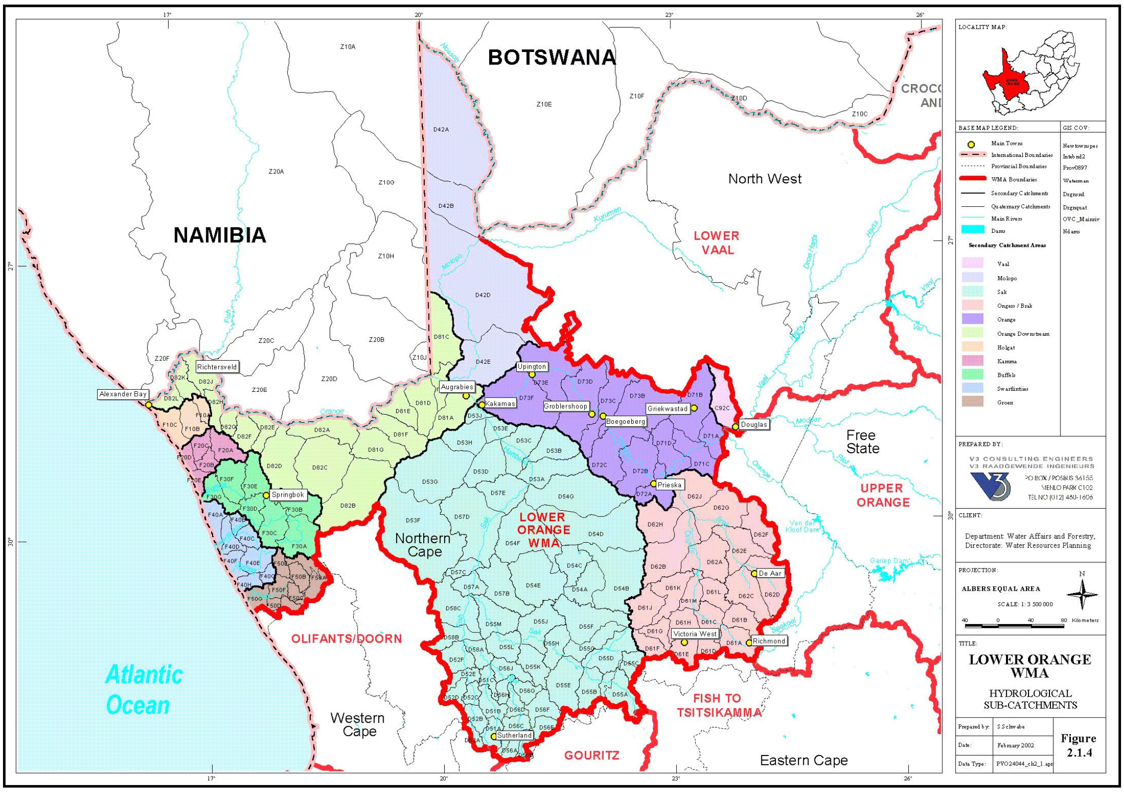


Figure 3-13 Lower Orange WMA and hydrological sub-catchments (DWAF, 2004b)

The water requirement for the defined Lower Molopo area is summarised in **Table 3-24**.

Table 3-24 Water requirement in Mm^3/a (1995) for the defined Lower Molopo area (DWAF, 2002b and 2002c)

Area	Urban Use	Irrigation	Mining&others	Rural use	Livestock
D42A	0	0	0	0.019	0.528
D42B	0.111	0	0	0.010	0.173
D42D	0	0	0	0.057	0.793
D42E	0.039	0	0	0.040	0.221
Total	***0.15***	***0.00***	***0.00***	***0.13***	***1.72***
Total (2000)*	***0.15***	***0***	***0***	***1.81****	
****= source DWAF, 2003b*** ***** = includes water for livestock***					

In an effort to refer the water requirement to the major river catchments, a division as shown in **Table 3-18** is applied to the figures given in **Table 3-24.** The results are summarized in **Table 3-25.**

Table 3-25 Water requirement in Mm^3/a (1995) for the defined Lower Molopo area referred to the major river catchment areas (DWAF, 2002b and 2002c)

River catchment	Urban Use	Irrigation	Mining+ others	Rural use	Livestock
Molopo	0.039	0	0	0.097	1.014
Nossob	0.111	0	0	0.019	0.437
Auob	0	0	0	0.010	0.264

3.4.5 Summary for Molopo-Nossob Basin in South Africa

Sizes of the sub-areas of the Molopo basin in South Africa are summarized in **Table 3-26**.

Table 3-26 Summary of sizes, population and ESLU in the Molopo-Nossob basin in South Africa

Sub-Area	River Catchment	Size km^2	Population (1995)			ESLU
			Urban	Rural	Total	
Upper Molopo	Molopo	4,322	101,000	167,500	268,500	38,620
Middle Molopo	Molopo, Kuruman	72,345	44,600	358,085	402,685	414,490
Lower Molopo	Molopo, Kuruman	20,418	6,353	5,147	11,500	50,006
	Nossob	8,339				
	Auob	5,141				
Total		**110.565**	**151,953**	**530,732**	**682,685**	**503,116**

The sizes of the quaternary WMA and of the three sub-areas defined are shown in **Figure 3-14**.

The number of livestock units (ELSU) and population in the quaternary WMA are illustrated in **Figure 3-15**. Summarized figures for the three considered sub-areas, Upper, Middle and Lower Molopo, are given in **Figure 3-16**.

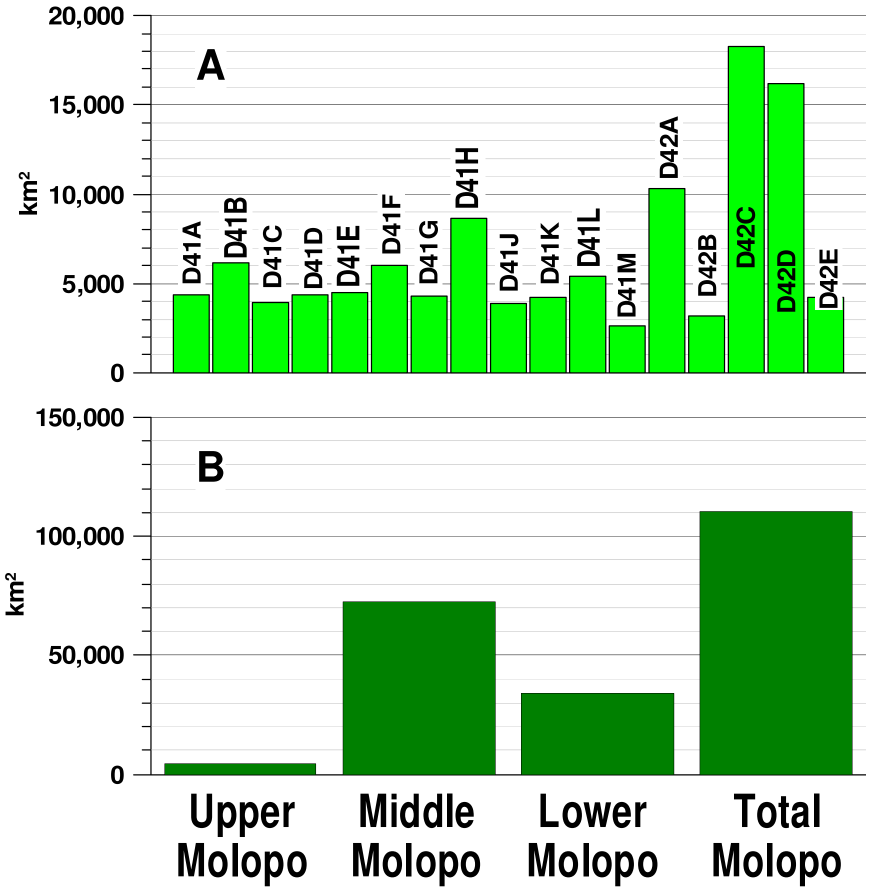


Figure 3-14 A. Sizes of the quaternary WMA in the Molopo basin in South Africa
B. Sizes of the sub-areas defined in the Molopo basin in South Africa

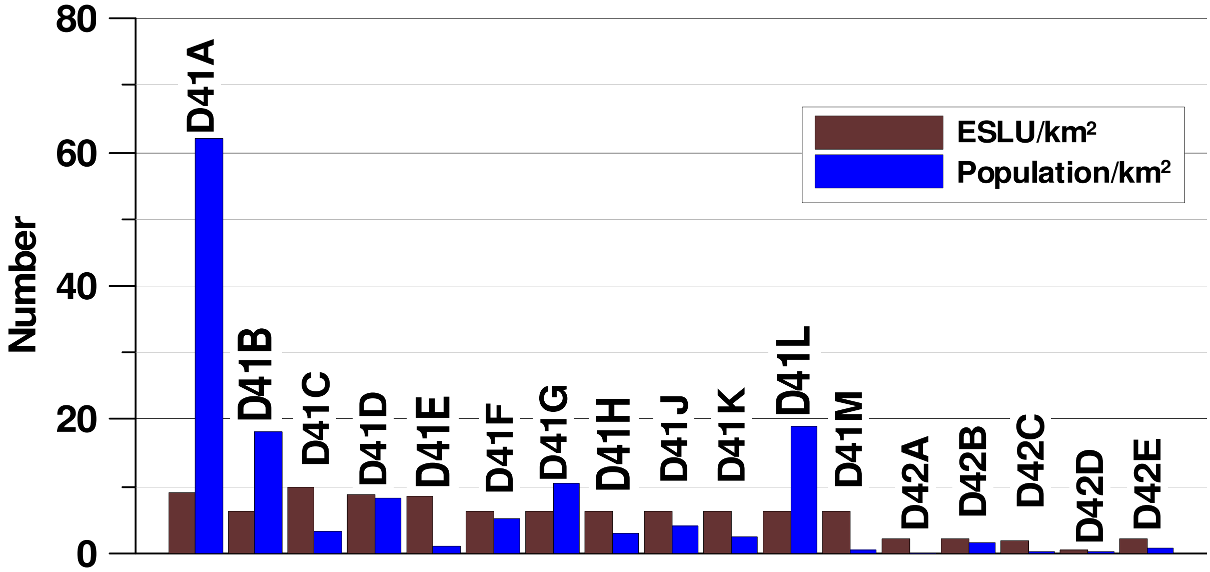


Figure 3-15 Number of livestock units (ESLU) and population in the quaternary WMA in the Molopo River basin of South Africa

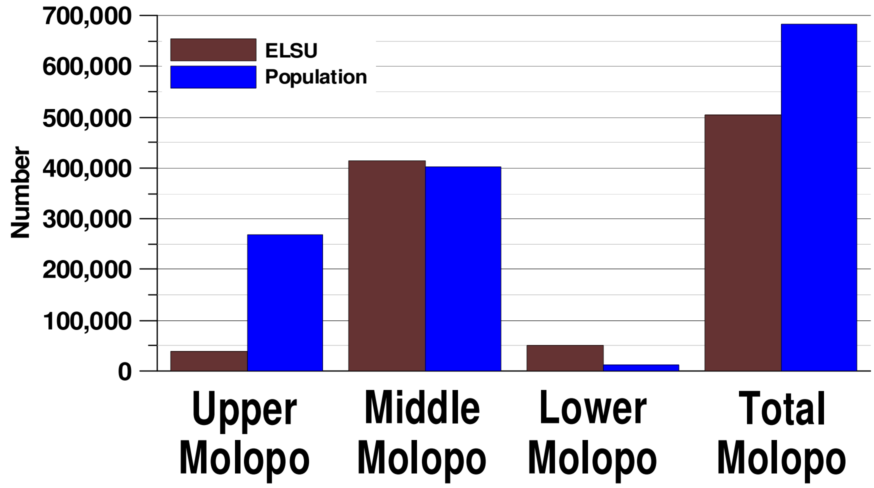


Figure 3-16 Number of livestock units (ESLU) and population in the Molopo River sub-areas of South Africa

The water requirements for the three Molopo areas defined and discussed in previous chapter are summarized in **Table 3-27**.

Table 3-27 Summary of water requirements (1995) for the Molopo-Nossob basin in South Africa

Sub-Area	Water Requirement (Mm³/a)						Transfer	Total Requirement
	Urban water	Rural	Irrigation	Livestock	Mining and bulk Industrial	Total local requirements	Water taken out from the area	
Upper Molopo	10.70	3.21	15.53	2.94	5.20	37.58	0	37.58
Middle Molopo	8.54	6.89	10.12	17.06	6.11	48.72	0	48.72
Lower Molopo	0.15	0.13	0.04	1.72	0	2.03	0	2.03
Total	**19.39**	**10.23**	**25.69**	**21.72**	**11.31**	**88.34**	**0**	**88.34**

The water demands for the various main users are illustrated in **Figure 3-17** and **Figure 3-18** for the quaternary WMA and the three sub-areas respectively.

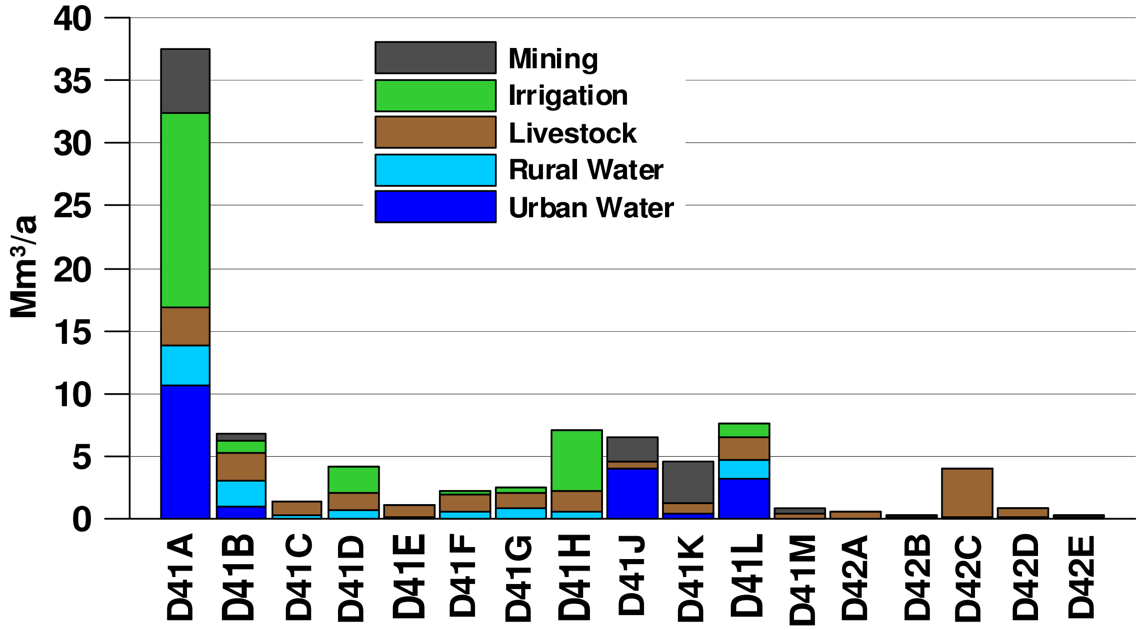


Figure 3-17 Water requirements (1995) in the quaternary WMA in the Molopo River basin of South Africa

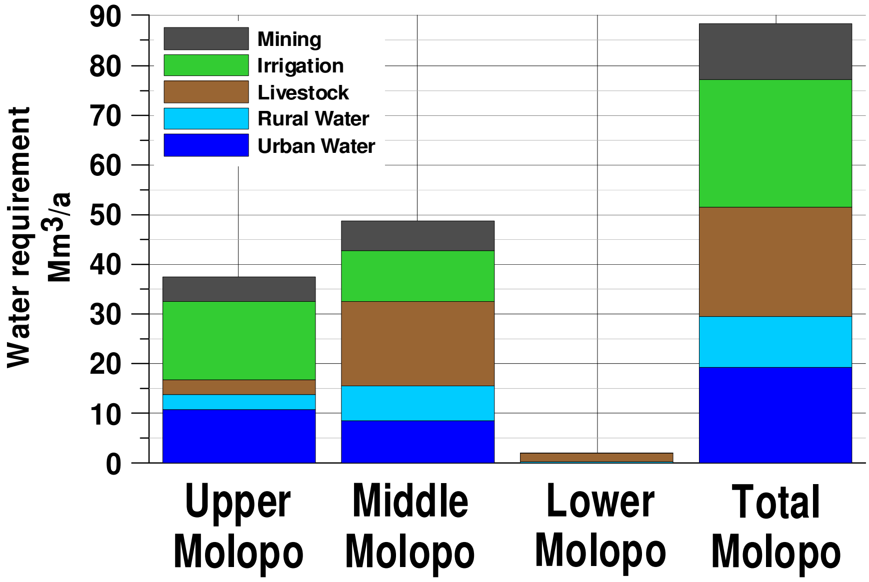


Figure 3-18 Water requirement (1995) in the Molopo River sub-areas of South Africa

The water requirements as assessed for 1995 by DWAF calculated as an annual area requirement (m^3/km^2) are summarized in **Figure 3-19** and **Figure 3-20**.

In addition to the requirements for local users, a requirement concerning transfer of water out from the resources within each area is considered. In the case of Molopo-Nossob basin, no transfer out from the sub-areas considered is taken place in South Africa.

There is however a transfer of water into the sub-areas from other WMA. These contributing WMA are outside the Molopo-Nossob basin "WMA". In **Table 3-28**, a summary is presented of the amount of water transferred in to each sub-area.

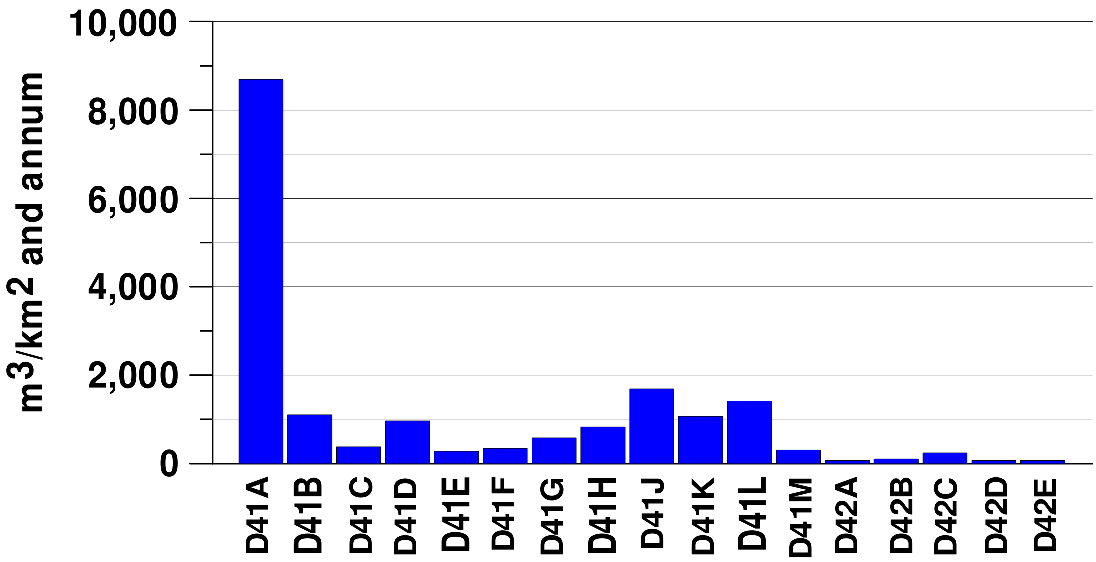


Figure 3-19 Water requirement assessed as m^3/km^2 annually (1995 data) in the quaternary WMA in the Molopo River basin of South Africa

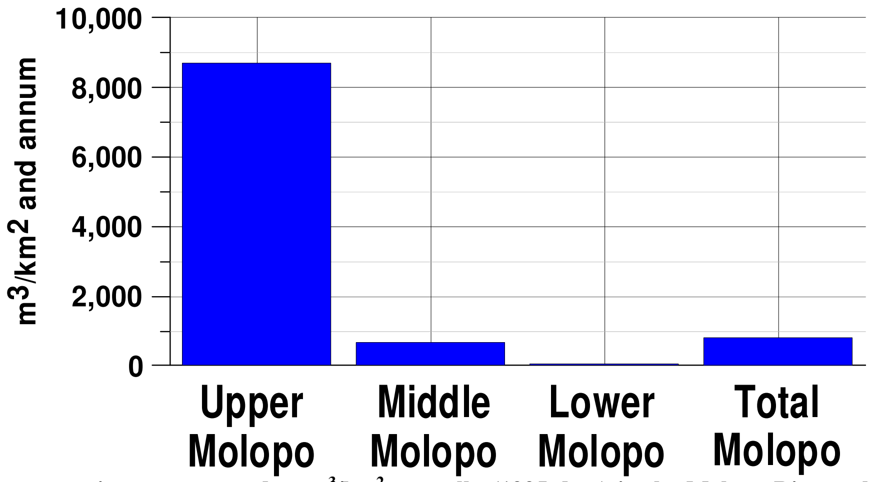


Figure 3-20 Water requirement assessed as m^3/km^2 annually (1995 data) in the Molopo River sub-areas of South Africa

Table 3-28 Transfer of water into the Molopo-Nossob basin in South Africa

Sub-Area	Transfer of water into the sub-area (Mm^3/a)	Transfer Scheme
Upper Molopo	0	
Middle Molopo	4	Transfer through Kalahari East Water Supply Scheme as an extension of the Vaal Gamara Water Supply Scheme
Lower Molopo	0.46	Transfer through Kalahari-West Water Supply Scheme and Karos-Geelkoppen Rural Water Supply Scheme
Total	4.46	

Based on the resources available and the water requirement, a water balance is made for each of the sub-areas of the Molopo-Nossob basin in South Africa. **Table 3-29** summarizes the water balance. The data used in the calculation are taken from the WMA reports (DWAF, 2002b, 2003a, 2003b, 2004a, etc)

Table 3-29 Water balance for the Molopo-Nossob basin in South Africa in the year 2000 (Mm^3/a)

Sub-Area	Local water requirements	Ecological reserve + Alien vegetation	Grand total water requirement	Transfer of water into the sub-area	Usable return flows	Surface water	Ground water	Total water resources	Balance
Upper Molopo	21.44	5	41.05	0	7	14	9	30	-11.05
Middle Molopo	48.72		48.72	4	2	31	2	33	-9.72
Lower Molopo	2.04		2.04	0.46		0	2.51	2.51	0.93
Total	**72.20**		**91.81**	**4.46**	**9**	**45**	**13.51**	**58.51**	**-19.84**

Table 3-29 shows that for the 1995 figures, only the Upper and Lower Molopo sub-areas have positive balances. An increase in water requirements comes mainly from the increasing demand associated with population growth and higher level of services in communities. In the western part of the Upper Molopo catchment area the rural communities are growing. The WMA report (DWAF 2004b) recommends that the local groundwater resources of the Upper Molopo catchment should first be fully developed to meet the future water requirements of the rural communities before transfer of water is considered.

3.5 Summary for Molopo-Nossob Basin

The figures about the sizes of areas, population and ESLU are summarized in **Table 3-30**. The highest population figure is in South Africa, whereas the ESLU units are highest in Botswana. Distributed on the area, the figures regarding ESLU are uniformly, about 4.2-4.6 ESLU/km^2. The population per km^2 varies on the other hand considerably, as seen in **Figure 3-21**.

Table 3-30 Figures on area sizes, population and ESLU in the Molopo-Nossob Basin

Country	Size	Population	ESLU	Pop/km^2	ESLU/km^2	ESLU/Pop
Botswana	135,764	120,401	599,384	0.89	4.41	4.98
Namibia	120,872	113,849	509,966	0.94	4.22	4.48
South Africa	110,565	739,303	503,116	6.69	4.55	0.68
Total Basin	***367,201***	***973,553***	***1,612,466***	***2.65***	***4.39***	***1.66***

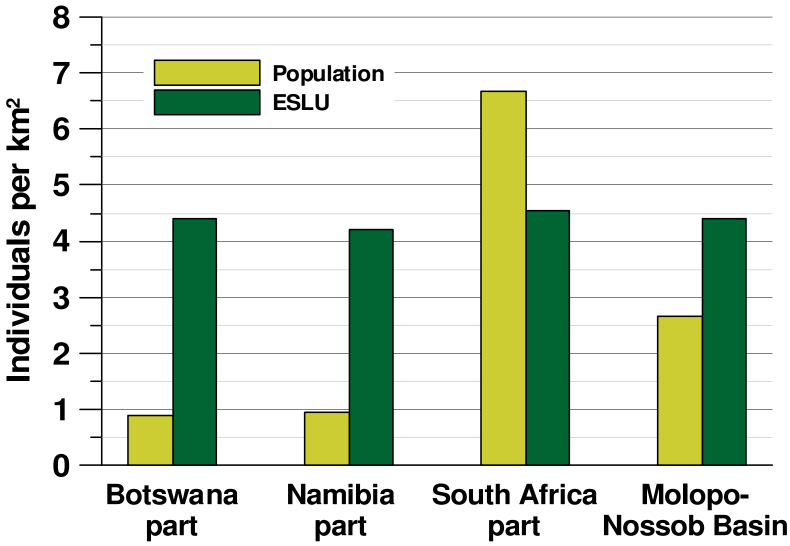


Figure 3-21 Population and ESLU per km^2 in Botswana, Namibia and South Africa in the Molopo-Nossob Basin

Looking at the figures of population and ESLU per km^2 for various regions in the Molopo-Basin, the variations are much greater, see **Table 3-31**. The highest figure on population per km^2, the highest density, is in the Upper Molopo, South Africa, where the town of Mmabatho is the reason for the high figure. The ESLU density is highest in the Barolong and Southern District area in Botswana. High ELSU density is also found in the Upper Molopo, South Africa, see **Figure 3-21**.

Table 3-31 Figures on area sizes, population and ESLU in different regions in the Molopo-Nossob Basin

Country	Region	km^2	Population	ESLU	Pop/km^2	ESLU/km^2
Botswana	Kgalagadi South	32,800	26,488	210,251	0.81	6.41
	Kgalagadi North	72,400	16,968	50,812	0.23	0.70
	Barolong+Southern	25,783	73,939	320,278	2.87	12.42
	Kweneng	1,244	1,529	14,204	1.23	11.42
	Ghanzi	3,537	1,477	3,839	0.42	1.09

Country	Region	km²	Population	ESLU	Pop/km²	ESLU/km²
Namibia	Auob + Molopo	70,822	75,399	216,986	1.06	3.06
	Nossob	50,050	38,450	292,980	0.77	5.85
South Africa	Upper Molopo	4,322	268,500	38,620	62.12	8.94
	Middle Molopo	72,345	459,507	414,490	6.35	5.73
	Lower Molopo	33,898	11,296	50,006	0.33	1.48
Total		***367,201***	***973,553***	***1,612,466***	***2.65***	***4.39***

The water requirements in the Molopo-Nossob Basin for the three countries are summarized in **Table 3-32**. The highest requirement is in the South Africa part of the basin with in total 88.34 Mm^3/a. Namibia and Botswana only reach up to 39.23 Mm^3/a together, less than half (44%) of South Africa's requirement in the Molopo-Nossob Basin. **Figure 3-22** illustrates the water requirement for the countries in the Molopo-Nossob Basin.

Table 3-32 Water requirement for Botswana, Namibia and South Africa in the Molopo-Nossob Basin

Country	Urban	Rural	Domestic	Livestock	Irrigation	Mining	Tourism	Total
Botswana	0	1.9	1.90	14.77	0.00	0.00	0.01	16.68
Namibia	3.3	0.22	3.52	10.77	8.11	0.002	0.14	22.55
South Africa	19.39	10.23	29.62	21.72	25.69	11.31		88.34
Total	***22.69***	***12.35***	***35.04***	***47.26***	***33.80***	***11.31***	***0.15***	***127.56***

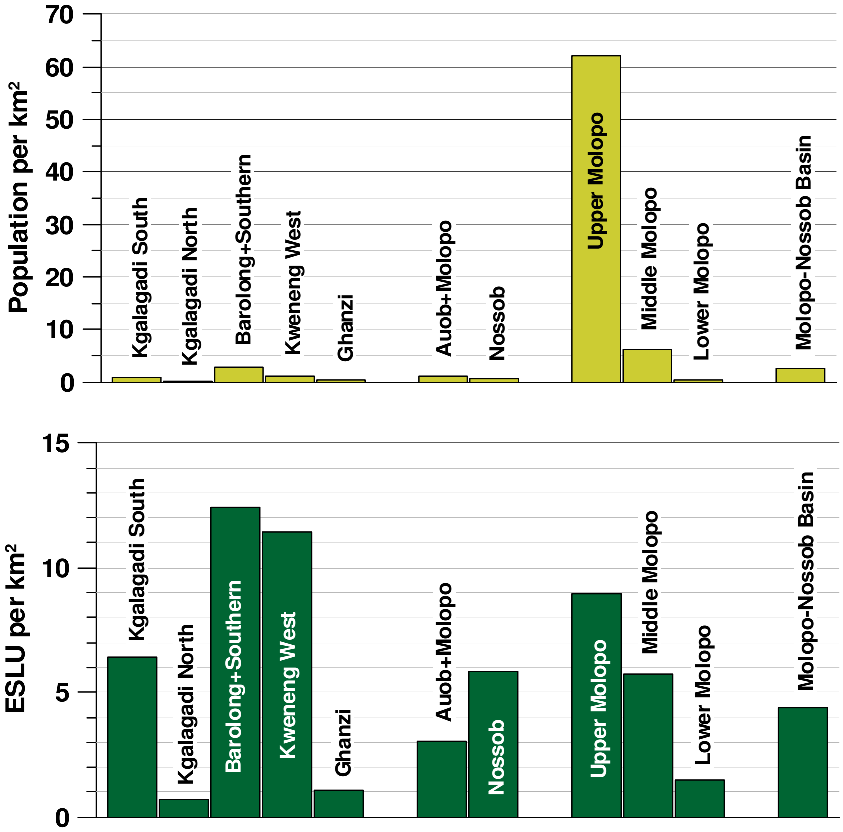


Figure 3-22 Population and ESLU per km² in Botswana, Namibia and South Africa within the Molopo-Nossob Basin

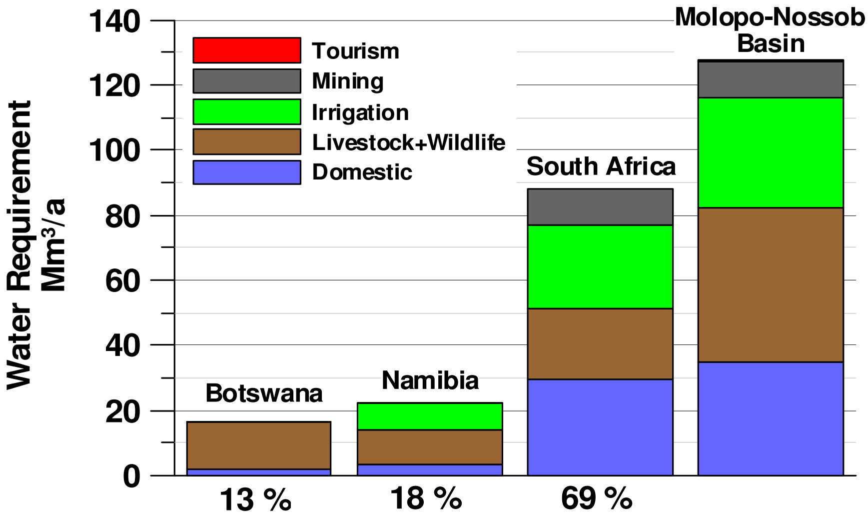


Figure 3-23 Water requirements for Botswana, Namibia and South Africa in the Molopo-Nossob Basin

Table 3-33 Water requirement for various uses in different regions in the Molopo-Nossob Basin

Country	Region	Water Requirement in Mm^3/a					
		Total	Domestic	Livestock	Irrigation	Mining	Tourism
Botswana	Kgalagadi South	5.75	0.56	5.18			0.01
	Kgalagadi North	1.68	0.43	1.25			
	Barolong+ Southern	8.76	0.87	7.89			
	Kweneng	0.37	0.02	0.35			
	Ghanzi	0.12	0.03	0.10			
Namibia	Auob + Molopo	12.81	2.29	3.29	7.15	0.002	0.077
	Nossob	9.74	1.23	7.49	0.96		0.062
South Africa	Upper Molopo	37.58	13.91	2.94	15.53	5.20	
	Middle Molopo	48.72	15.43	17.06	10.12	6.11	
	Lower Molopo	2.04	0.28	1.72	0.04		
Total		***127.57***	***35.05***	***47.26***	***33.80***	***11.31***	***0.15***

The water requirements for the different regions in the Basin are presented in **Table 3-33** and illustrated in **Figure 3-24.** The same figures calculated as water requirement per km^2 and year is summarized in **Table 3-34** and **Figure 3-25**.

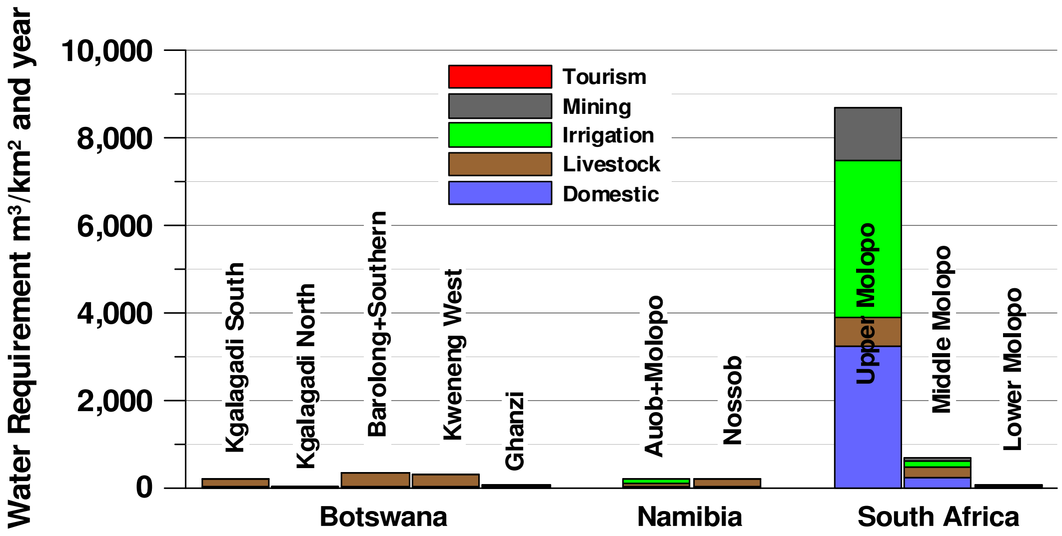


Figure 3-24 Water requirements for various regions in the Molopo-Nossob Basin

Table 3-34 Water requirement for various uses in different regions in the Molopo-Nossob Basin

Country	Region	Water Requirement in m^3/km^2 and year					
		Total	Domestic	Livestock	Irrigation	Mining	Tourism
Botswana	Kgalagadi South	175.3	17.0	157.9	0.0	0.0	0.3
	Kgalagadi North	23.3	6.0	17.3	0.0	0.0	0.0
	Barolong and Southern	339.8	33.7	306.1	0.0	0.0	0.0
	Kweneng	293.4	12.1	281.4	0.0	0.0	0.0
	Ghanzi	33.9	7.1	26.9	0.0	0.0	0.0
Namibia	Auob and Molopo	180.8	32.3	46.4	100.9	0.0	1.1
	Nossob	194.6	24.7	149.6	19.2	0.0	1.2
South Africa	Upper Molopo	8,695.0	3,218.4	680.2	3,593.2	1,203.1	0.0
	Middle Molopo	673.4	213.3	235.8	139.9	84.5	0.0
	Lower Molopo	60.2	8.3	50.7	1.2	0.0	0.0
Total		***347.4***	***95.4***	***128.7***	***62.3***	***30.8***	***0.4***

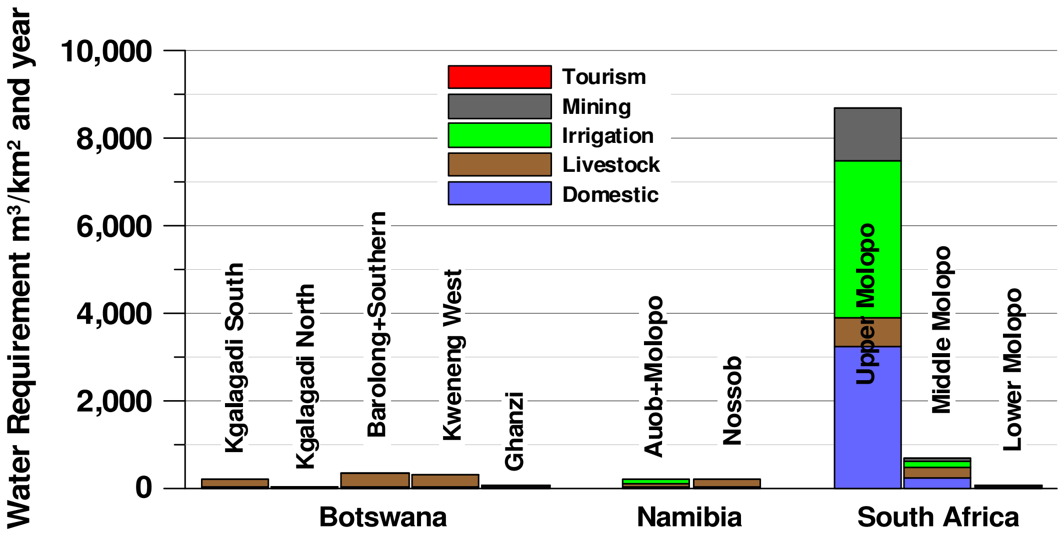


Figure 3-25 Water requirements in m^3/km^2 per year for various regions in the Molopo-Nossob Basin

4 DEVELOPMENT ACTIVITIES

4.1 Introduction

The major activities in the Molopo- Nossob Basin are agriculture, mining and tourism. Planned developments will refer to these major activities.

4.2 Current Development Activities

4.2.1 Botswana

About 7 % of the population of Botswana lives within the Molopo-Nossob Basin area. **Table 4-1** summarizes the population statistics. The rural population density is low, especially in the sparsely populated Kgalagadi District (0.4 persons per km^2).

Table 4-1 Population Botswana districts in the Molopo- Nossob Basin

Country	District/Sub-District	Area size (km^2)	Percentage in the Molopo-Nossob basin	Population
Botswana	Kgalagadi South	66,066	100	26,488
	Kalalagadi North	44,004	100	16,968
	Southern Ngwaketse	26,876	80	10,176
	Southern Ngwaketse West		100	10,989
	Southern Barolong		100	52,774
	Kweneng West		5	1,529
	Ghanzi		3	1,477
Source: CSO, 2001 and ORASECOM, 2008a				

Over the last 10 years the demographics of the country have changed significantly with increasing numbers concentrated around the urban centres. Botswana's population is becoming increasingly urbanized. The traditional way of life of people moving between the village home *(ko gae),* the fields or lands area *(ko masimong)* and the cattle post *(ko morakeng)* is in the decline with people having additional town *(ko toropong)* domiciles.

Education and health care continue to be priority areas for the nation as pledged in the Vision 2016 document. Botswana 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 15 km of a health facility. Public health expenditure averaged 5-8% of the national budget between 1980 and 1999.

The HIV/AIDS epidemic continues to deepen in Botswana. The overall, adjusted HIV prevalence rate for pregnant women aged 15-49 in Botswana 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 of 1993. Population growth and 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 an estimated high of about 66.2 years to the projected low of 47.4 (1999 & 2000 GOB Human Development Reports). It is estimated that by 2010 life expectancy could as low as 29 years. Additionally, if nothing is done to halt the deepening of the epidemic, one third of Botswana's adult population could be lost over the next 8-12 years.

The structure of the population will shift to increasing numbers of both 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 poverty datum line by around 5%. Ever decreasing household resources may be increasing channelled to medical and care expenses, with less going to education and social amenities.

The epidemic has a catastrophic impact on the economy with an HIV prevalence of 36 % among the workforce. The number and quality of people available to work will decline over the next 5-10 years. The loss of skills, institutional memory and experience will create vacuum in the labour market. Labour costs will rise along with recruitment and retraining costs in order to meet the needs of business and industry. Added to that, the costs of meeting expected medical and support costs may seriously reduce corporate earnings, savings and investment levels, depressing the economy. It is estimated that the HIV/AIDS epidemic will cause a contraction of the GDP growth by 1.5% over the next 20-25 years resulting in an economy at least 31 % smaller than would otherwise be projected without impact of the epidemic.

A decrease in growth rate of population means that the increase in water requirement as predicted in any water planning will also be affected.

4.2.2 Namibia

Despite rapid urbanisation, Namibia is still a mainly rural society. This is anticipated to change considerably and by 2010 it is expected that 50% of the population will be urbanised.

Namibia's population was 1.8 million in 2001 and the growth rate is estimated at 2.6 % (Namibia Household Income and Expenditure Survey, 2003-2004). However, according to UNICEF, the HIV prevalence rate in Namibia amongst the population aged 14-64 was estimated at approximately 19.6 % at the end of 2005. To temper growth-related expectations, these figures as well as decreasing fertility (UNDP, 2008) has to be factored into the population growth rate figures, which are projected at 2.61 million by 2011.

The Molopo-Nossob Basin in Namibia is sparsely populated. In Namibia the majority of the population (60 %) lives in the northern regions that do not fall in the basin. Khomas Region is home to 14 % of the Namibian population, and is the most populated area in Namibia. The growth rates for the various regions in the Molopo-Nossob Basin are given in **Table 4-2**.

The population density in the basin is 0.01 to 1.1 people per km^2. Whilst 33 % of the population lived in urban centres in 2001, the urban population is currently growing at a much higher rate (over 5 % per annum), than the rural population. The vision is for Namibia to be a "highly urbanised country with 75 % of the population residing in the designated urban areas (ORASECOM, 2008a).

Table 4-2 Namibian Population Growth

Region	Population (2001)	Population (2007)	Population Growth
Karas	**69 321**	**71 701**	**3.4%**
Keetmashoop Rural	6 349		
Karasburg	14 693		
Omaheke	**68 041**	**75 620**	**11.1%**
Aminuis	12 343		
Gobabis			
Kalahari			
Hardap	**68 246**	**70 584**	**3.4%**
Mariental	13 596		
Khomas	**250 260**	**304 341**	**21.6%**
Windhoek Rural	19 908		
Source: Central Bureau of Statistics			

The National Statistics on HIV/AIDS in Namibia according to the Human Development Report of UNDP (2002) are summarized in **Table 4-3**.

Table 4-3 Summary of the Projected Effect of Aids on the Namibian Population

Indicator	1991	1995	2001	2006
Total Population (million)	1.4	1.6	1.9	2.1
Population growth rate (%)	3.6	3.1	2.1	1.5
Annual Number of deaths from AIDS	390	1 440	13 880	23 220
Life expectancy at birth	60.0	58.3	43.8	40.2
Orphans due to AIDS (<15 yrs)	50	1 630	31 290	118 050
Source: Human Development Report, UNDP 2002.				

From the national statistics it is clear that HIV/AIDS will have a devastating impact on the Namibian population. Firstly, the population growth rates will decline as indicated in **Table 4-3** from 3.6 % per annum to a mere 1.5 %. Secondly, HIV/AIDS will play havoc with quality of life indicators in Namibia as depicted in the table. Life expectancy decreased from 60 years in 1991 to 40 years in 2006. The number of people dying as a result of HIV/AIDS increased significantly from 390 in 1991 to 23 220 in 2006. HIV/AIDS orphans have increased from 50 in 1991 to 118 000 in 2006.

In the Hardap Regional Development Plan (2001/2002 – 2005/2006) it is contemplated that the total population of 68,249 (2001) will decrease to approximately 52, 300 by 2010. The expected population decrease is mainly attributed to the increased mortality as a result of HIV/AIDS and increased, migration from Hardap Region to larger urban centres in Namibia. If this scenario is realized, it implies relatively low or possible declining growth in water demand.

4.2.3 South Africa

The population of South Africa part in the Nossob- Molopo is shown in **Table 4-4**.

Table 4-4 Population of South Africa districts in the Molopo- Nossob Basin (CSO, 2001 and ORASECOM, 2008b)

Country	Province/ Region	Area size (km^2)	Percentage in the Molopo-Nossob Basin	Population in the Molopo-Nossob Basin
South Africa	North West Province	116,320	11%	728,107
	Northern Cape	361,830	9%	11,296

It is generally agreed that the impact of HIV/AIDS on South Africa is likely to be considerable including:

- an increased general mortality rate;
- an increased infant mortality rate;
- a decrease in life expectancy;
- a decrease in the fertility rate;
- a decrease in the population growth rate and;
- an increase in deaths among the economically active age groups.

The above issues will result in a range of negative social and economic consequences for the country and thus it is imperative that interventions be made to reduce the impact of the disease.

The impacts of HIV/AIDS on the demographics of the Molopo River Basin are different depending on a range of related factors. For example, a high HIV/AIDS death rate could lead to a reduction in the economically active population in an area and an increase in opportunities for those living outside the area to be drawn to the jobs of those who are ill or who have died. Thus whilst there is an impact from HIV/AIDS on the sparsely populated areas of the Northern Cape, the overall population change in the area is more likely to be as a result of economic opportunities , which will give rise to migratory shifts. In the case of a lack of economic opportunities and the out-migration of the economically active, the HIV/AIDS rate is likely to increase the rate of population decrease in the area.

The availability and use of Antiretroviral (ARV) drugs in Botswana, Namibia and South Africa will have a major impact in population growth rates in the three countries.

For more details on HIV/AIDS in South Africa refer to ORASECOM Task 10: Demographics & Economic Activity (2007).

4.3 Development Activities in the Districts

Three main activities currently taking place in the area are identified as the main drivers of economic development in the study area. These are agriculture, mining and tourism, with agriculture further divided into irrigation and livestock farming.

4.3.1 Agriculture

Irrigation

Agriculture is one of the major economic activities in the Molopo-Nossob Basin and irrigation activities covers around 207 km^2. It is estimated that of this area, around 167 km^2 or 80.5% utilizes groundwater and 40 km^2 or 19.5 % surface water. Although there are a diverse number of crops under irrigation, the most commons are groundnuts, Lucerne, maize, potatoes, wheat and vegetables.

Livestock farming

Livestock is an important farming activity and economic activity provides both income and a livelihood to a large number of households. Livestock farming is divided into two categories; commercial and communal/subsistence livestock framing, with the former mainly undertaken as a business venture. Stock farming is limited by availability of water. Boreholes are extensively used to open up areas for grazing, but in many cases the quality of the groundwater is such that it affects the health of the animals. As a consequence some innovative ideas are implemented in the past to overcome this problem, such as the holes that were dug in the middle of some pans in South Africa (so-called gatdamme) to conserve rain water. This had limited success, and this method of rain water harvesting is largely replaced by the Kalahari West Rural Water Supply Scheme that brings water from the Orange River to the area.

Livestock farming: Botswana

The total value of livestock activity in the Botswana part of the catchment area is estimated at about P266.9 million (R320.3 million) (ORASECOM, 2008a). It is divided between commercial (75%) and communal (25%) farmers. The average number of cattle per communal farmer converts to 30 Livestock Unit (LSU), with an average annual take-off of 6 animals. With the assumption that 50% is for own consumption and that three animals are sold, the estimated cash revenue per farmer is around P7, 400. The estimated number of employees in Livestock Farming is estimated at 3,385 (ORASECOM, 2008a).

Livestock Farming: Namibia

The value of livestock farming in the Molopo-Nossob part in Namibia is estimated to be around N$258 million annually (ORASECOM, 2008). Very little if any communal farming takes place in the Namibian section of the catchment area. The estimated number of employees in Livestock Farming is 2,789 (ORASECOM, 2008a).

Molopo-Nossob Basin in Namibia is about 120,872 km^2. The area hosts about 510,000 LSU requiring almost 13 Mm^3/a, see **Chapter 3**.

Livestock Farming: South Africa

In the South African part of the catchment the value of livestock farming is estimated at R326, 4 million per annum. This might however be an under estimation because it appears that large tracts of land is being converted to game farming and according to a number of sources, this type of farming is much more profitable (ORASECOM,2008a). Also important to note, in South Africa a large area of land is occupied by communal farmers, approximately 27 % of the land.

About 64% of rural families own cattle and a slightly higher number own goats. This percentage is in line with other estimates, specifically in the Transkei region. According to the survey, the average number of cattle kept by the communal farmer is 20 which converts to 17 LSU units, less than the 30 LSU in Botswana. It therefore appears that the average cattle owner has as an annual cash income of around R7, 000 per annum. It must however be borne in mind that only 64 % of the rural households are actually cattle owners and that the number of cattle vary from 1 to 67 (ORASECOM, 2008a).

The estimated number of employees in livestock framing is estimated at 3,303 (ORASECOM, 2008a).

Summary on livestock farming in the Molopo –Nossob Basin
There is a potential that the livestock numbers in the three countries basin countries may increase. The livestock increase will be dependent on available land and good rainfall years. There is also a possibility of livestock numbers decreasing due to the effect of drought (condition of the veld) and an outbreak of livestock diseases. As for the stocking rates, these are different from country to country. For example the stocking rates in Botswana are as high as 30 LSU whereas in South Africa it is 17 LSU. The stability of stocking rates in the three countries will be dependent on government policy and also climatic conditions.

4.3.2 Mining

There are several mining operations in the study area especially on the South African side. The major minerals being mined are diamonds, iron ore and manganese. On the South African side mining has grown at a hectic pace in the last three years and the current number of mine workers involved is estimated to be around 7,500 permanent and 3,100 contract workers. Information from the area also indicates that further growth is due to take place in the immediate future (ORASECOM, 2008a).

Botswana
In Botswana, presently one diamond mine is in operation employing approximately 120 people with an annual turnover of P7.6 million.

Namibia
Mining is not a significant land use in the Namibian part of the Molopo-Nossob Basin. Planned mining developments in the basin could are not identified. An older plan for coal mining in the basin is shelved due to problems envisaged on stability and water hazards. In Namibia at present one copper mine could be identified in the area employing around 375 people with an annual turnover of N$267 million (ORASECOM, 2008a).

South Africa
In South Africa a number of mines operate and the most important activity takes place at the Kathu–Hotazel hub with an expansion, due to the worldwide demand for these commodities, at the iron ore and manganese pits. At present the total number of people employed in the mining industry appears to be around 10,600 of which around 7,500 are fulltime and the rest part time or on contract. All indications are that this will further increase in the next 2 to 3 years. The present annual monetary turnover is estimated at R11.5 billion.

From the above analysis it appears that, especially in SA, mining activity is growing dramatically and is an important employment and income generator which appears to have further potential to expand.

4.3.3 Tourism

Tourism is an important activity in the basin, especially on the South African side. Two specific categories of tourists are identified, eco-tourists and business tourists. Tourism can contribute to development and the reduction of poverty in a number of ways. Economic benefits are generally the most important element, but there can be social, environmental and cultural benefits and costs. Tourism contributes to poverty eradication by providing employment and diversified livelihood opportunities. Within the Molopo-Nossob Basin the major type of tourism related activities are natural resources based or ecotourism; with the rich wildlife biodiversity and vast undisturbed wilderness areas being the major attractions

Botswana

The objectives of Botswana Tourism Policy are:

- To increase foreign exchange earnings and government revenues;
- To generate employment , mainly in rural areas;
- To raise incomes in rural areas in order to reduce urban drift;
- Generally to promote rural development and stimulate the provision of other services in remote areas of the country;
- To improve the quality of national life by providing educational and recreational opportunities and;
- To project a favorable image to the outside world.

Over and above the mentioned objectives, the Tourism Policy is designed to ensure that tourist activities are carried out on an ecologically sustainable basis. The Policy provides local communities with direct and indirect benefits from tourism activities. By doing so the Policy will encourage concerned communities to appreciate the value of wildlife and its conservation and giving them growing opportunities to participate in wildlife –based industries including tourism.

Tourism opportunities are virtually untapped largely due to poor state of the districts' infrastructure and other supporting facilities. Wildlife is an important renewable resource in Kgalagadi District for example, with wildlife areas accounting for about 4.8% of the district area. The district's potential for tourism has improved since the merging of the Gemsbok National Park and the Kalahari Gemsbok National Park. The introduction of community based natural resource management (CBNRM) policy has also contributed to improved tourism and incomes in the district. There are five areas earmarked for CBNRM activities. Community mobilization to engage in CBNRM projects commenced in 1998 in the Kgalagadi District. The aim of CBNRM is to give the communities an opportunity to manage natural resources especially wildlife in their respective areas.

Namibia

The Molopo-Nossob Basin in Namibia has no protected or conservation areas. Between Windhoek and Gobabis conservancies on freehold land occur in the sub basin. There is a need to coordinate the establishment of these conservancies since the area has a number of private game farms.

Also in Namibia tourism in (remote) rural areas is perceived as a particularly lucrative and sustainable income–generating and poverty reducing activity.

According to Vision 2030 of Namibia, tourism already plays an important role in economic development but it is not yet been exploited to its full potential. In the Molopo-Nossob Basin, the number of tourism facilities decreases towards the south and the tourism potential decreases proportionally. The southern part of the basin is identified with low tourism potential and between Windhoek/ Gobabis and Mariental, medium–high to high (Namibia Vision 2030).

South Africa

In South Africa, strategic interventions to stimulate the development of tourism in the Northern Cape are identified, as it is considered to have the potential to become a preferred adventure and ecotourism destination with its recognized cultural heritage. The preservation of the natural and cultural heritage of the province is crucial to ensure this, and transformation in the sector needs to be accelerated to ensure equitable growth (Northern Cape Provincial Government, 2007). North West and Northern Cape's share of foreign tourists arrivals decreased, with North West's decreasing from 7.1% in Quarter 3 2006 to 6.2% in Quarter 3 in 2007. Whereas Northern Cape is decreasing from 4.1 % in Quarter 3 2006 to 2.7% in Quarter 3 2007 (SA Tourism Index, Quarterly report Q3, July to September 2007).

In Kgalagadi DM the Moffat Mission, the Raptor Rehabilitation Centre, the Wonder Caves and the Kuruman Eye are tourist attractions. The Kuruman Eye is a natural underground fountain delivering 20-30 million litres of water daily, and apparently it is the biggest natural fountain in the southern hemisphere. It was declared a national monument in 1992. The Wonderwerk Caves were formed by gas and water, close to Kuruman. According to the Kgalagadi Nodal Economic Profiling Project, 2007, most of the bed and breakfast (B&B) in Kuruman accommodate contractors and long term renters.

The whole part of Molopo-Nossob Basin in South Africa serves as a stopover on the way to Namibia, the Kgalagadi Transfrontier Park and Botswana. Some Germans, Belgians and British second comers specifically come to visit this area. The niche market is eco-tourism, adventure routes, historical/archaeological sites, and business people (Kgalagadi Nodal Economic Profiling Project, 2007).

The Khomani San received farms adjacent the Kgalagadi Transfrontier Park with game that can be used commercially for hunting (Department of Land Affairs, 2002). The department recommended that serious effort should be made to capacitate the community members responsible for the management of these game camps in the tourism industry, financial management and marketing (ORASECOM, 2008a).

Summary on Tourusm Activity in the Molopo –Nossob Basin

Table 4-5 shows a summary of tourism activities (number of bed nights and total income generated per annum) for the three Molopo – Nossob basin countries.

Table 4-5 Tourism Activity in Molopo- Nossob catchment (2007estimates)

Country	Total annual bed nights sold	Total available beds	Total income per year: R million
Botswana	8 432	66	9.33
Namibia	62 981	493	36.71
South Africa	362 226	2 544	179.93
Source: ORASECOM, 2008			

Three growth scenarios were developed for the three countries over a period of 10 years. (It must be stressed that these are not expectations of growth but merely predictive tools to pose the question “what……..if?).

Various figures and trends of visitor numbers (annual bed nights sold) were used to generate the tourism growth scenarios. These include but are not limited to the following;

- The visitor statistics for tourist arrivals in Botswana, Namibia and South Africa from the Tourism Boards of the respective counties.
- The visitor statistics for people staying in lodges/hotels/ campsites in the three countries.
- World Tourism organization (WTO) figures and predictions for increases in world-wide tourism broken down to the Southern African region by country.
- Emerging issues such as the impact of Credit Crush on financial expenditure and visitors (local, regional and international).

The three scenarios considered are summarized in **Table 4-6**.

Table 4-6 Scenarios for Tourism Growth over a Period of 10 years

Country	Current situation	Scenario		
	Total amount of bed nights sold	Low growth 7.2% annually	Medium growth 11.6% annually	High growth 14.9% annually
		2 time the beds sold	3 times the beds sold	4 times the beds sold
Botswana	8,432	16,864	25,296	33,728
Namibia	62,981	125,962	188,943	251,924
South Africa	362,226	724,452	1,086,678	1,448,904

The growth in tourism in the Molopo –Nossob basin will be contributed to some extent new attractions such as the Kgalagadi Transfrontier National Park and the construction of new ecotourism lodges in the three countries. The rich wildlife biodiversity and the stable political environment in the region play an important role in tourism growth.

4.4 Planned Development Activities

Botswana: Potential and Planned Groundwater Water Utilization Projects

According to the Kgalagadi District Development Plan 6, the following potential projects are planned in the area:

- The Botswana Defence Force (BDF) is planning to build a base camp in Tsabong area. This camp is going to provide both office accommodation and residence. It is not clear how big this facility is going to be, but it was said to be a regional camp which may have the potential to house about 100 officers and their families.
- The National Master Plan for Agricultural Development (NAMPAD) of Botswana has proposed some irrigation projects to be undertaken in the study area The major proposed project is the establishment of wine yards in Tsabong to take advantage of sunlight hours of the area and the conditions suitable to stress the crop to the required standard. The project is further described in Chapter 3.2
- There are also plans to harvest water from the water borne sewage system proposed for the Tsabong area. Tsabong and Goodhope have waterborne sewage systems planned for NDP 9; this development is anticipated to increase the water demand of

these villages quite extensively. There are plans to harness waste water from these systems for reuse in agriculture. However, there are cultural barriers which the implementing officers have to overcome before the communities could wholly accept such schemes.

- In Ngwaketse South, NAMPAD has proposed some irrigation projects. The source of the groundwater to be used in these projects would be from the development of Kanye wellfield in Transvaal Supergroup Dolomites aquifer that is just in the fringe of the Molopo River Basin northern boundary. The planned water demand for these proposed projects is 6.2 Mm^3/a; the shortfall would be met with the harnessing of potential wastewater from Jwaneng and existing boreholes, refer to Chapter 3.2.

Namibia: Potential and Planned Groundwater Water Utilization Projects

The potential and planned groundwater utilization projects in Namibia include the following;

- The Hardap Regional Development Plan (RDP) identified Aranos as a primary growth point. Infrastructural development would need to be undertaken and the accepted target date for the development will be towards the end of 2010. The estimated 2007 population of the village was approximately 2 920. Approximately 50 % of the high income group consumers have access to their own boreholes for gardening water. The rest of the population would require water to be provided to them.
- Mariental Town Council plans to upgrade services to the informal settlement area. Through the Build Together Scheme approximately 20 houses will be built a year.
- According Hardap RDP further fish farms may be established near Hardap. Unless fish or fish products are produced for a larger market in Namibia, it is not anticipated that new fish farms will be established at Hardap. Currently that proposal is to upgrade the hatchery to supply fingerlings to the industry. It is not clear if it will influence the potable water demand of 8 000 to 10 000 m^3/ month as supplied during 2007. During the 2007 financial year the raw water requirement was 32 000 m^3/month for the growing ponds.

South Africa: Potential and Planned Groundwater Water Utilization Projects

In South Africa, some future plans for tourism development are as follows:

- Tourism will be developed more in the Northern Cape area.
- Water provision for tourism must take into account the arid conditions in the area.

4.5 Future Water Requirement

In the South African part of the Molopo-Nossob Basin, Mafeking town has the highest water requirement regarding urban water supply. According to Department of Water Affairs and Forestry (DWAF, 2004) more than 11 Mm^3/a is drawn from the groundwater resources in Grootfontein which is more than the allocation of water.

The rural villages west of Mafeking do not have access to treated water. It is proposed to bring water from the Middle Vaal Water Management Area (WMA) to supply these villages. Plan for an extended irrigation of 2 km^2 ha in the NW province using water from the Disaneng dam will increase the water requirement in the area. Between 1995 and 2004 an average annual water increase of 5.9 % is recorded. For the future water requirement, a lower increase rate might be expected in accordance with increase for the Middle and Lower Molopo River catchment areas.

Due to negligible or even negative population growth and economic growth in the Middle Molopo River catchment area, a small decrease in the domestic (urban and rural) and industrial requirements for water are expected. No change is foreseen with respect to the water requirements for irrigation. Water requirements for mining purposes, which are of more localized importance, are also expected to remain relatively unchanged. Two scenarios were developed by DWAF (2003a) a base scenario indicating a water requirement decline of 0.2% per year and a high scenario with a yearly increase of 0.5%.

Little changes are foreseen with respect to the future urban and rural requirements in the Lower Molopo River catchment area. A small reduction may be experienced in these sectors as a result of an expected decline in population. Should there be strong economic development in the water management area; a moderate increase in the urban, industrial and mining requirement for water may result.

In a quantification of the projected future requirements for water in the Lower Orange Water Management Area, development of an additional 40 km^2 of irrigation is included, as was approved in principle by the Minister for purposes of poverty relief and the settlement of emerging farmers. The location of these irrigation areas is not specified but they will probably be outside the Molopo-Nossob Basin boundary. The additional water requirement for those 40 km^2 is around 47 Mm^3/a. Two scenarios were developed by DWAF (2003b), a base scenario indicating a water requirement decline of 0.1% per year and a high scenario with a yearly increase of 1.5%. These scenarios were without the additional irrigation areas included.

As a summary for the South African part of Molopo-Nossob Basin, the future water requirement is foreseen to increase slowly (or even to decrease) since the population growth in the Middle and the Lower Molopo catchment areas is not strong. In the Upper Molopo catchment area an increase is foreseen of maybe up to 2% annually. **Figure 4-1** summarizes the future water requirement for the three South African parts of the Molopo-Nossob Basin. Together with the water requirements for Botswana and Namibia, given in Chapter 3, a summary is presented in **Figure 4-2** of the total future water requirement for the Molopo-Nossob Basin.

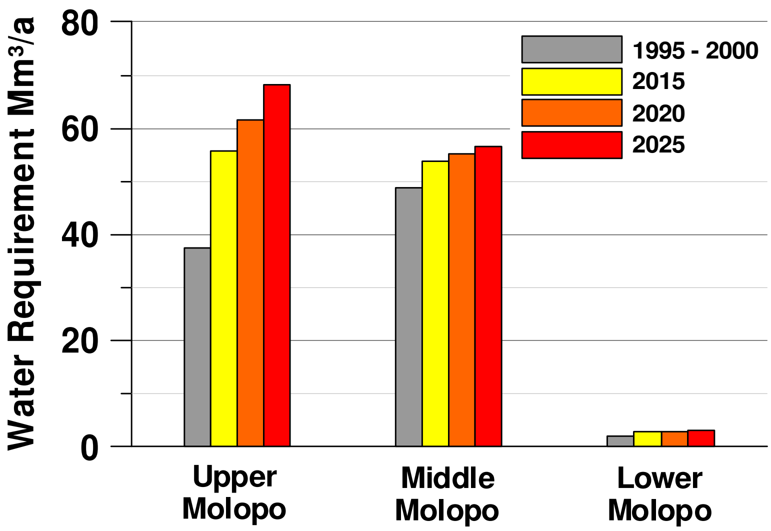


Figure 4-1 **Future predicted water requirement for the three sub-areas of the Molopo-Nossob basin in South Africa**

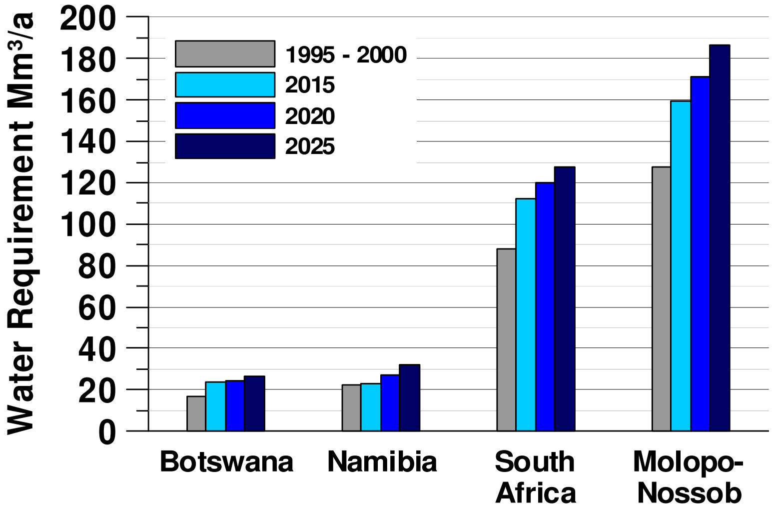


Figure 4-2 **Future predicted water requirements for the Molopo-Nossob River Basin**

5 GEOLOGY AND HYDROGEOLOGY

5.1 Geology

5.1.1 Background Information

Molopo-Nossob basin is covered by national geological and hydrogeological maps from each riparian country. **Table 5-1** lists the maps available and used to compile the general covering geology map of the Molopo-Nossob Basin. The geological formations are given various names in the different country. In the geological map compiled and presented in **Figure 5-1**, the nomenclature of the formations used is shown in **Table 5-2** and **Table 5-3**. In selecting the formations to illustrate in the map, primary emphasis is given to the formations' importance for groundwater occurrence.

Table 5-1 Geological and Hydrogeological maps used in collation of the simplified geological map in Figure 5-1.

Country/ Organisation	Map	Scale	Reference
Botswana	Groundwater Resources Map of the Republic of Botswana	1:1,000,000	DGS, 1987
	Groundwater Pollution and Vulnerability Map of the Republic of Botswana	1:1,000,000	DGS, 1995
	The Pre-Kalahari Geological Map of the Republic of Botswana	1:1,000,000	DGS, 1997
Namibia	Namibia Geological Map	1:1,000,000	GSN, 1980
	Hydrogeological Map of Namibia	1:1,000,000	DWAF, 2001a
South Africa	Hydrogeological Map of the Republic of South Africa	1:2,000,000	DWAF, 2004d
	Groundwater Resources of the Republic of South Africa	1:2,500,000	DWAF,1995
	Hydrogeoloical Map Nossob 2419	1:500,000	DWAF, 2002a
	Hydrogeological Map Vryburg 2522	1:500,000	DWAF, 2000
	Hydrogeological Map Kimberly 2722	1:500,000	DWAF, 2003d
	Hydrogeological Map Upington/Alexander Bay 2718	1:500,000	DWAF, 2001b
SADC	Isopach Map of the Kalahari Group	1:2,500,000	SADC, 1999

5.1.2 Geological Map

5.1.2.1 Simplified Geological Map

Information from the geological maps listed in **Table 5-1** is used to compile a simplified geological map over the Molopo-Nossob Basin. In the map bedrocks have been grouped together have the same type of composition and of the same or close to the same geological age and history. The nomenclature used for the geology differs between the three countries. In the simplified map, **Figure 5-1**, four main formations are considered, Kalahari, Karoo, Proterozoic and Archaean rock. These formations are then divided in subgroups, in total 12 groups. The division and characteristics of each group is described in **Chapter 5.2.2.2**.

The main lithostratigraphic units presented in **Figure 5-1** over the Molopo-Nossob Basin area comprise the Kalahari Group, Karoo Supergroup, Nama Group, Proterozoic and Archaean Basement rocks. The generalized stratigraphic sequence in the Molopo-Nossob Basin is presented in **Table 5-2**.

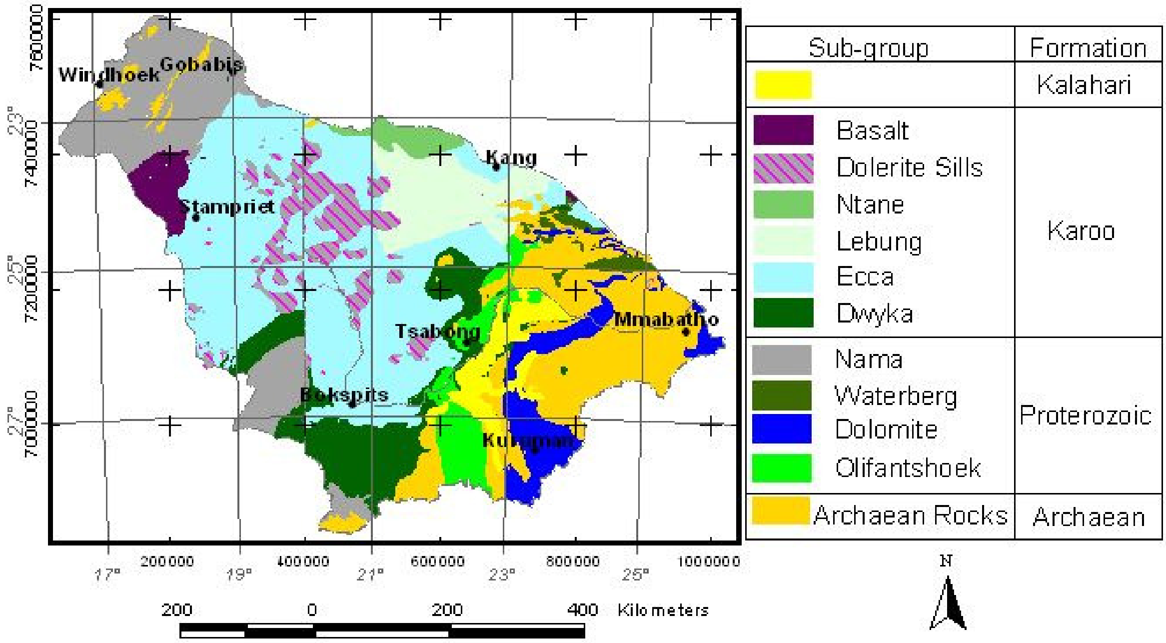


Figure 5-1 **Simplified geology map over the Molopo-Nossob Basin. References given in Table 5-1**

5.1.2.2 Archaean Basement Rocks

The Archaean era (also spelled Archaean) is more than 2,500 million years old. Instead of being based on stratigraphy, this era is defined chronometrically. All the rocks of the Archaean age are put together in one group in the Map (**Figure 5-1**). The Archaean Basement rock occupies the eastern part of the Molopo-Nossob Basin where some of the rocks are concealed by a veneer of Tertiary to Quaternary continental sediments known as the Kalahari Group.

One of the oldest units in the Archaean units is the Kraaipan, consisting of metabasalts, basic schists, ultrabasic and amphibolites.

Other units in the Archaean Group in the Molopo-Nossob Basin are all included under the Archaean Group Basement in **Figure 5-1**.

Generally, aquifers in the Basement Archean rocks are poor prospects of securing groundwater in the Molopo-Nossob Basin. Groundwater occurrence in these rocks can be wholly attributed to fissures, fractures and joints and controlled by the size of these fractures and their interconnectivity.

The Swazian Granite and Gneiss which extend from west of Mmabatho in the east to Morokweng in the west to Cassel in the South Africa, is an example of basement rock groups where the ability to host groundwater is enhanced by the presence of fractures and dykes.

Table 5-2 Regional stratigraphy in the Molopo-Nossob Basin

Age (M. years ago)	Era	Supergroup	Group/Formation	Description
<85	Cretaceous to Recent	Kalahari Beds		Unconsolidated sand, clay and duricrusts
65 – 145	Cretaceous	Dolerite intrusions and dykes		Dolerite dykes and sills
145 – 360	Carboniferous to Cretaceous	Karoo	Stormberg Lava Lebung Ecca Dwyka	Basalt Sandstone, siltstones, mudstone Interlayered sandstones, siltstones, mudstones with carbonaceous mudstones and thin coal seams Tillite, mudstone and siltstone
490 – 552	Cambrian	Nama		Conglomerate, sandstones and siltstones
552 – 2,500	Proterozoic to Cambrian	Waterberg Dolomites Olifantshoek		Assemblage of sandstones, conglomerates and siltstones (continental red-beds) Dolomitic rocks, quartzites and chert brezzia Undifferential grey-red quartzite and phyllite units
>2,500	Achaean	Mokolium Vaalium Various granites and volcanic complex Swazian Kraaipan		Metamorphic and igneous rocks

The grade and depth of weathering of the Archean rocks, a function of climate and mineralogy, is of importance in finding groundwater resources, however limited. This is illustrated by a considerably variation in borehole yields.

The Basement aquifers are restricted mainly to the east of the Molopo-Nossab Basin and in Botswana classified as having a poor groundwater potential by the National hydrogeological reconnaissance maps of Botswana. Achaean basement rocks are also identified in the northern part of the Molopo-Nossob Basin in Namibia.

5.1.2.2 Proterozoic rocks

Olifantshoek Supergroup

In the Proterozoic Rock Group, the Olifantshoek Supergroup is identified and outlined in the map **Figure 5-1**. The Supergroup comprises mainly of coarse arenites including red beds likely to be of fluvial or shallow marine origin (Beukes, 1990). The Olifantshoek Supergroup outcrops in and around Tsabong in Botswana. The Supergroup continues in South Africa (named the Volop and Postmasterburg groups).

The Olfantshoek Supergroup constitutes a group from which promising groundwater resources can be found. Several boreholes were drilled in the Olifantshoek Supergroup in Botswana for village water supply. The quartzite generally outcrop in the area but can be overlain by Kalahari Beds and river alluvial. Tsabong village in Botswana has the only major supply wellfield within the Molopo River Basin catchment area exploiting the Olifantshek Supergroup

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

Dolomites

Aquifers in Dolomites, karstified fractured aquifers, are represented by Transvaal dolomite units, in Botswana and Ghaap Group in South Africa. In Botswana, groundwater occurs in the dolomite sequence of Taupone Group of Transvaal Supergroup well developed as Chert Breccia aquifer in Kgwakgwe area and as Dolomite aquifer in Ramonnedi area both supplying the Kanye village (the village however outside the Molopo-Nossob Basin).

The dolomites of Ghaap Group in South Africa has generally good groundwater potential and yields in excess of 7.20 m^3/hr (2.0 l/s) are common. Groundwater occurs along the fractures, joints, and solution cavities commonly associated with faults and dolerite dykes. Among the major supply areas from the dolomites are both Mmabatho and Kuruman.

Nama Group

The Nama Group rocks of Proterozoic or Cambrian age occur widely in the Namibian part of the Molopo-Nossob Basin. The group rocks are exposed at the Namibia border, northwest of Rietfontein, Gordonia. The Nama Basin extends from Gobabis area in Namibia in the north to Vanrhynsdorp in South Africa in the south, a distance of 1000 km. The Nama Group rocks consist of red, brown, and purple cross bedded sandstone, limestone and grey shales. The Nama Group is divided into a lower Kuibis sub-group, middle Schwarzrand sub-group and an upper Fish River sub-Group. In Botswana the Nama Group is not reported in any boreholes in the Molopo-Nossob Basin.

5.1.2.3 Karoo Supergroup

The Karoo Supergroup represents a volcano-sedimentary sequence of rock across much of southern Africa, deposited in a time span of about 120 million years (Carboniferous through Cretaceous era) starting from about 300 million years ago. The lithostratigraphic column of the Karoo Supergroup in the Molopo-Nossob Basin with some typical lithologies is given in **Table 5-3**.

Dwyka Group

The Dwyka Group is the lowermost unit of the Karoo Supergroup. The group hosts glacial sediments such as diamictites, pebbly mudstone, sandstone and tillites. The Dwyka Group has variable thickness and lithology, its distribution and facies being controlled by the Pre Karoo landscape. The Dwyka Group covers the southern part of the Molopo-Nossob Basin in South Africa and southern parts in Botswana along the Molopo River.

The Dwyka Formation does not constitute an important aquifer in the Botswana part of Molopo-Nossob Basin. In South Africa the Dwyka Formation is classified as a fractured aquifer and consists predominantly of diamictite (tillites). Dwyka Formation extending north of Upington into the Molopo-Nossob Basin is considered an aquifer promising for local water supply.

Table 5-3 Karoo Supergroup Stratigraphy and nomenclature in Botswana, Namibia and South Africa relevant to the Molopo-Nossob Basin

Age	Botswana		Namibia		South Africa		This Report	Lithology
Creta-ceous	Dolerite intrusions and dykes		Dolerite intru-sions and dykes		Dolerite intru-sions and dykes		Dolerite Sills	Dolerites and sills
Jurassic	Stormberg lava		Kalkrand		Drakens-berg		Stormberg	Basalt
Triassic	Lebung	Ntane Fm			Clarens FM		Ntane	Reddish to pink fine to medium grained sandstone
		Mosolot-sane Fm		Neu Loore			Mosolot-sane	Basal conglomeratic sandstone, greenish-yellow sandstone interbedded with red-brown siltstones, red-brown mudstones
	Beaufort	Kule Fm			Beau-fort			Fine grained sandstone, grey mudstone/siltstone/shale. Purple-brown mudstone
Permian	Ecca	Otshe Fm	Ecca	Auob	Ecca	Auob	Ecca	In Namibia three sandstone layers interbedding two layers of bituminous shale and coal horizons. Similar in Botswana
		Kobe		Muko-rob		Muko-rob		In Namibia a shale section overlain by an upward-coarsening sandstone
		Ncojane		Nossob		Nossob		In Namibia a one to two cycles of white sandstone that coarsens upwards into fine to coarse-grained white sandstone
Carboni--ferous	Dwyka		Dwyka		Dwyka		Dwyka	Tillite, mudstone and siltstone
	= not represented in Molopo-Nossob Basin							

Ecca Group

The Ecca Group sediments cover a large part of the Molopo-Nossob Basin. The group hosts the most widely distributed aquifer in the basin.

Ecca group contains two major aquifers, the Auob aquifer in the upper sequence and the Nossob aquifer at almost the bottom of the Ecca sequence. Further the Auob aquifer contains in general three different sandy layers interbedded by coal seams and bituminous mudstones. The two main aquifers, Auob and Nossob, are separated by a thick layer of low permeable sequence of mudstones and siltstones (the Mukorob Formation). These two aquifers are thoroughly investigated in Namibia (JICA, 2002) where the groundwater head and quality show different status. **Figure 5-2** shows a profile through the Namibia Ecca sequence in the Stampriet Artesian Basin.

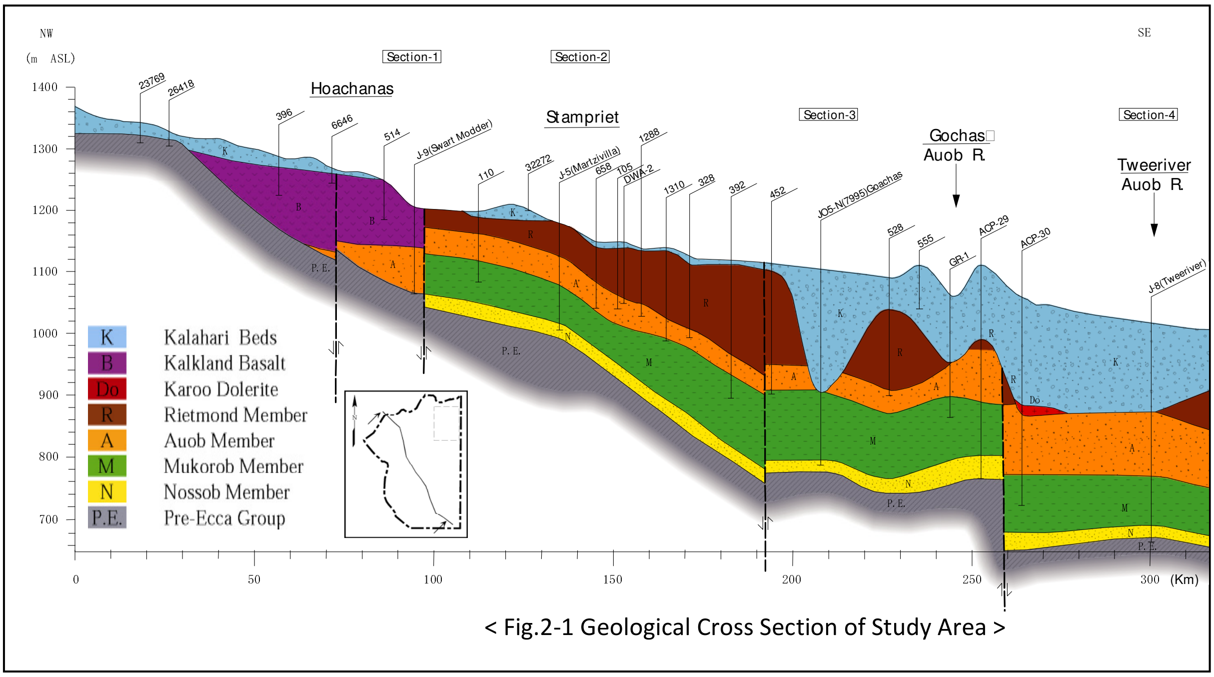


Figure 5-2 Geological cross-section through the Ecca sediments in the Stampriet Artesian Basin from North-West to the border with South Africa in South-East (Gemsbok Park). The Auob aquifer in orange, Nossob Aquifer in light yellow and the Kalahari beds in light blue. (Copied from JICA, 2002)

In the Botswana part of the Molopo-Nossob Basin similar two aquifer layer conditions are recognized. Here, however the two Ecca aquifers investigated in the northern part of the Molopo-Nossob Basin are interpreted as being two different part of the Auob aquifer, in Botswana called the Otshe aquifer.

The Auob (Otshe) aquifer is of a complex succession of canalized fluvial and deltaic sediments consisting consist of multiple interbedded layers of fine to coarse-grained sandstone, shale, mudstone, carbonaceous shale and poor coal (DGS, 1994). Argillaceous units within the formation confine the individual water bearing sandstone units.

The Otshe (Auob) sandstone generally provides sufficient yields (2-3m^3/h) for livestock watering in both confined and unconfined conditions. The confined Nossob sandstone generally yields very saline water. The semi-confined Auob sandstone yields usable brackish water, in some the water is too saline for any agricultural use.

The Kobe Formation in Botswana overlies the Dwyka Group and this unit can be correlated with the Nossop and Mukorob Members in Namibia. The Kobe Formation comprises interbedded sandstones and siltstones with minor shales and mudstones. The Kobe Formation is divided into lower Kobe Formation (Ncojane sandstone) and Upper Kobe Formation. The lower Kobe Formation and the Nossob Formation consists of dark grey siltstone followed by grey sandstone to dark grey siltstone and carbonaceous mudstone. The Nossob Formation in Namibia and the Nojane sandstone formation in Botswana form the Nossob aquifer with artesian conditions.

In Botswana the Otshe aquifer in the Ncojane Block occurs beneath relatively thin Kalahari Beds and Lebung/Beaufort Group rocks.

The Nossop sandstone formation in Botswana forms a thin confined aquifer near the north-eastern boundary of the Kgalagadi Transfrontier Park yielding saline water under very high pressure head conditions. This formation is, however, very deep and has very saline water and thus does not constitute an important aquifer.

Lebung

The Lebung group is divided into the Mosolotsane formation and the Ntane sandstone formation

The Mosolotsane Formation consists of red and brown mudstones, sandstones and siltstones. The sandstone intercalations are poorly cemented and vary in colour. The formation, which is found in an area in the north of Botswana and in limited areas in the Stampriet Artesian basin in Namibia under the name New Loore, is not considered a major groundwater resource.

The Ntane sandstone is one of the most important and widespread aquifer in Botswana. In the Molopo-Nossob Basin, the sandstone is encountered only in a limited part in the northern Botswana part where it continues further outside the Molopo-Nossob Basin.

Lithologically the Ntane sandstone consists primarily of red or pink, fine to medium grained friable sandstone. In large parts of Botswana the sandstone is overlain by the Stormberg Basalt and the aquifer in the sandstone is under confined conditions. In the Molopo-Nossob Basin, the occurring Ntane sandstone is not covered by the basalt but by Kalahari Beds. The hydraulic condition in the aquifer is therefore to be considered as unconfined.

A general rule for the Ntane sandstone in Botswana is that it has a good average yield. Where intersected by fracture zone, the transmissitivity of the aquifer become high and large amount of water may be abstracted from the sandstone. In the Molopo-Nossob Basin the Ntane sandstone is to be regarded as an important aquifer, especially in the area where no or limited surface water resources can be found. Further the aquifer overlays the Auob (Otshe) aquifer beneath in the Ecca group sequence.

Stormberg Basalt

The Stromberg Lava Group is the uppermost member of the Karoo Supergroup. This unit can be correlated with the Kalkrand Basalt in Namibia. It consists of variably weathered, green or reddish purple, amygdaloidal lava flows. Locally good yielding boreholes can be drilled but in general the formation is regarded as an unproductive groundwater resource.

5.1.2.4 Kalahari Beds

Kalahari Beds is an informal lithostratigraphical term given to an association of loosely-consolidated deposits that is between a few meters and almost 400 m thick (Carney et al, 1994).

The Kalahari Beds forms a unit of continental sediments of Quaternary to Recent age. The Kalahari Group of sediments covers most of the Molopo-Nossob Basin, obscuring the bedrock geology and structures except some exposures occur along the Molopo River. Pre-Kalahari valleys are of importance for the groundwater occurrence in the Kalahari Beds. This is well illustrated in the Molopo Valley around Middlepits area. Recent alluvial gravels are found in the present and sometimes earlier courses of these rivers but are now buried by wind blown sands. Gravels are possibly deposited on old terraces of the Molopo River (DGS, 1994).

Broadly the Kalahari Group consists of a layer of aeolian sand up to 20 m thick which may display relict dune structures. The sand is generally underlain by a duricrust layer of silcrete and calcrete which must represent an unconformity within the succession. The duricrust is underlain by poorly consolidated sandstones which are in many places calcareous. Where a full succession is present, the sandstones are underlain by red marls and a basal clayey gravel of undoubted fluvial origin.

The thickness of the Kalahari succession is largely a function of pre-Kalahari Group topography, with the gravels being largely confined to palaeo-valleys. The maximum known thickness of this unit within the Molopo-Nossob Basin is in the excess of 250 m according to the SADC map of the Isopach of the Kalahari Beds (SADC, 1999). The surface aeolian sands, named the Gordonia Sand Formation (SACS 1980), are up to 20 m thick and are underlain by a duricrust horizon of silcrete and calcrete.

On the Map in **Figure 5-1**, the area covered by the Kalahari Beds is not highlighted. A map of the Kalahari Beds extension and thicknesses is instead found in **Figure 5-3**. This map is composed of data from the borehole archives of Botswana, Namibia and South Africa. To the map is added information from the SADC Isopach map of the Kalahari Beds and the 15 m contour line on the South African Hydrogeological map sheets. In total, 1,435 information points are behind the map in **Figure 5-3**.

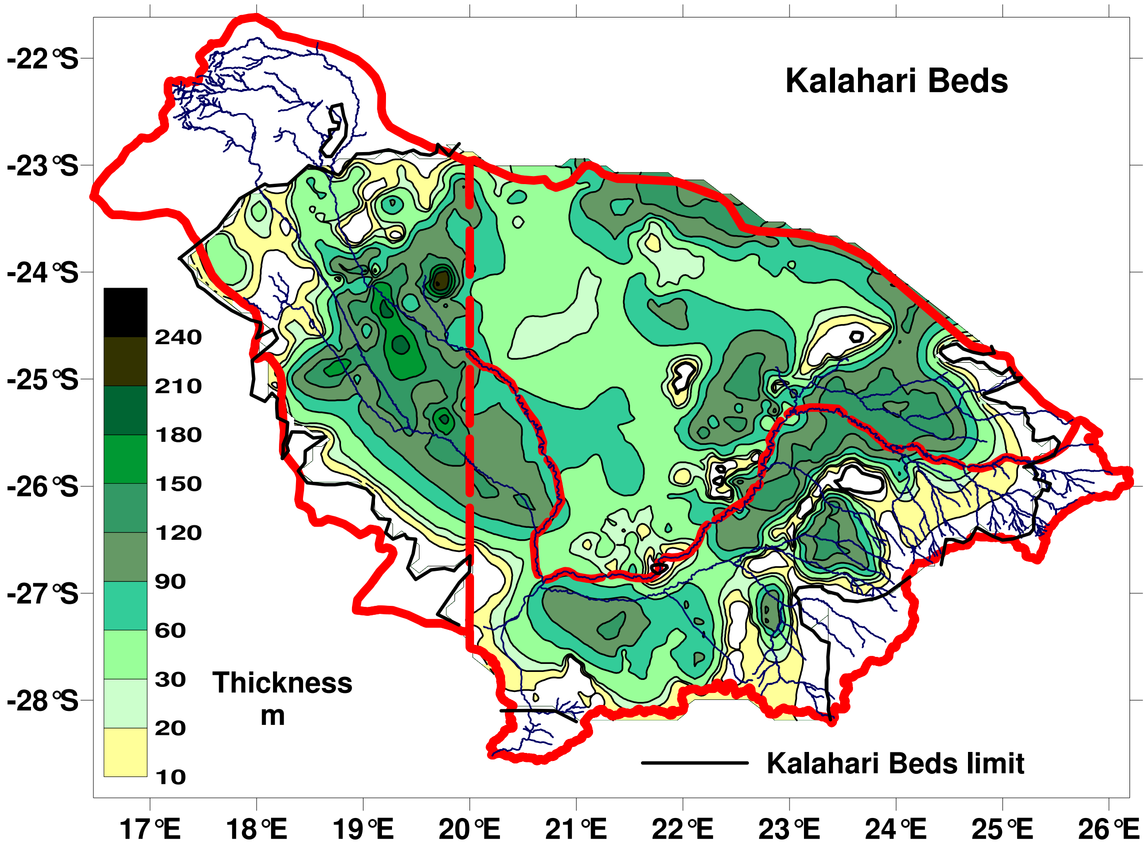


Figure 5-3 **Kalahari Bed thickness**

The map in **Figure 5-**3 shows that only the southeastern most part of the basin together with the northernmost part is not covered by the Kalahari Beds. The thickest deposits are found in the pre-Kalahari valleys in Namibia, along the middle and upper part of Molopo River course, in southeastern Gordonia and the northern part of the basin in Botswana. In those areas the thickness exceeds 90 m.

The pre-Kalahari surface is shown in **Figure 5-**4 constructed as the ground surface substracted by the Kalahari thickness. The lowest parts of this surface is north and east of the confluence of the Molopo and Nossob Rivers and also in the area of the present large pans in South Africa, west of Molopo River (Hakskeenpan and Koppieskraalpan area). Clearly identified valley follows the Molopo River and the Nossob Auob area (the Salt-Block area).

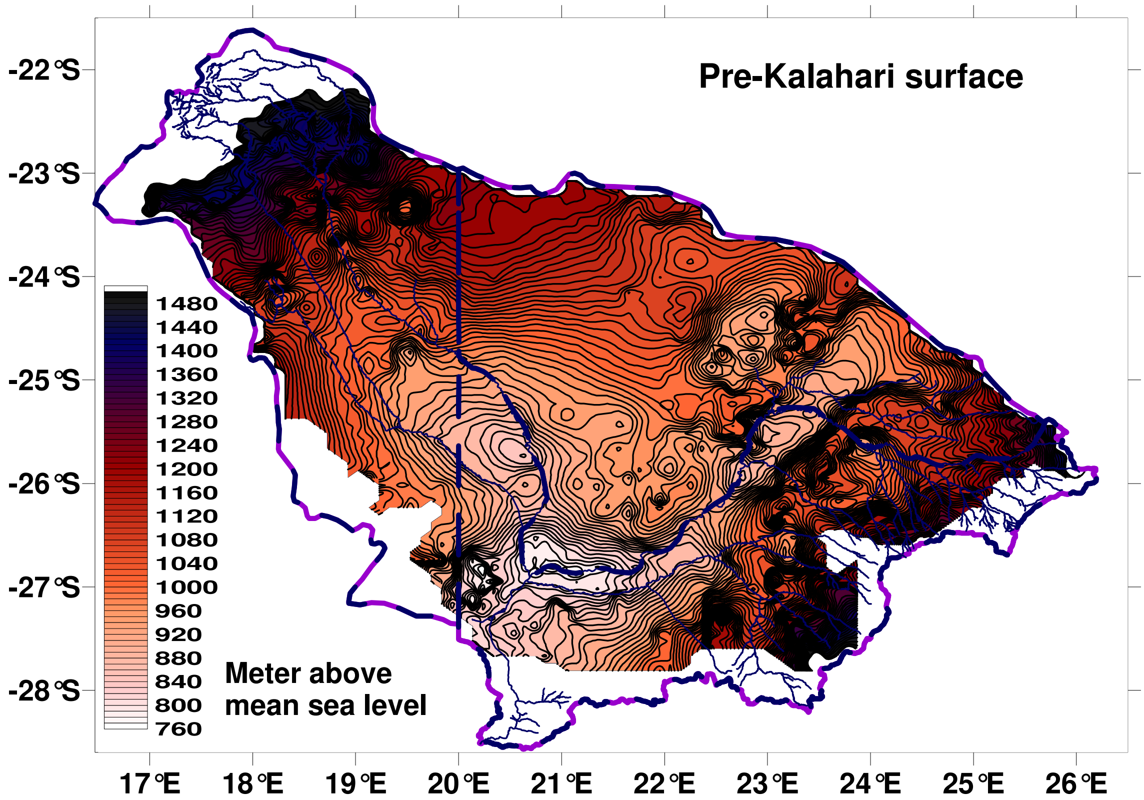


Figure 5-4 **Pre-Kalahari surface**

The Kalahari Beds contains locally groundwater. The groundwater level established from numerous boreholes and displayed in **Figure 5-4** can be used as an indicator of groundwater occurrence in the Kalahari Beds. **Figure 5-5** illustrates the areas in which the groundwater level in the Molopo-Nossob Basin is found to be within the Kalahari Beds. The map is constructed from information of ground surface level, thickness of Kalahari Beds and the groundwater level. The largest area of “saturated” Kalahari Beds are found in the Gemsbok National part and the continuation into the Namibian part of the basin following the Nossob and Auob rivers up to Stampriet and Amimuis. Large areas are also found along the Upper Molopo River Course, in Gordonia and in the central part of Botswana. The map does not show any of the possible perched aquifer which may exist in the Kalahari Beds in the basin.

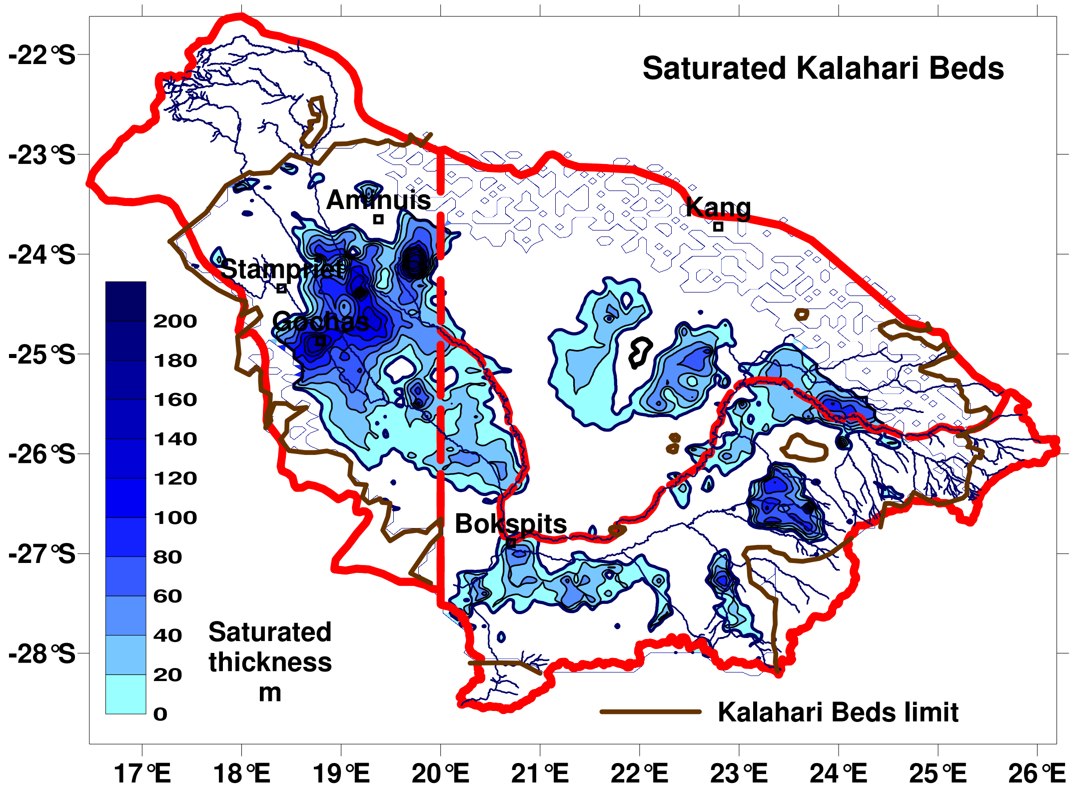


Figure 5-5 **Thickness of Kalahari Beds below the groundwater surface**

5.2 Hydrogeology

5.2.1 Aquifers

Definition

An aquifer is defined as a geological formation which contains and transmits groundwater under gravity conditions in appreciable quantities. Aquifers are commonly divided into four main types:

- porous (intergranular)
- fractured,
- fractured porous (intergranular and fractured)
- karstic aquifers.

The division is based on how the groundwater occurs within the aquifer.

"Intergranular" describes aquifers in which groundwater occurs in openings between granules and grains of unconsolidated material such as sand and gravel. Such openings can either be of primary or secondary nature. Primary openings refer to the voids left during the deposition of the material. The capacity of intergranular aquifers to store water is influenced by factors such as grain size, roundness of grains, ratio of different grains sizes, clay content and the density of compaction. The greatest restricting factors on the yield or the development potential of porous (intergranular) aquifers are occurring content of finer material as for instance clay and silt.

"Fractured" describes aquifers where groundwater is associated with fractures, fissures and joints. Such structures are usually called secondary because they are commonly formed at a later stage and not related to the original rock-forming process. Interstices of this nature are normally the result of tectonic action. Tectonic stress causing compaction, de-composition, faulting, folding and shearing can result in fractures and fissures in especially more resistant, lithologies and on contact of different lithologies. Decompression by the removal of material through erosion can cause openings on contacts and/or bedding planes, especially in sedimentary successions. Intrusions can likewise cause fracturing. Baking of the host lithology in the contact zone by molten intrusive can render this zone brittle and thus susceptible to fracturing. All of the above generally lead to favourable groundwater targets (van Dyk and Ksiten, 2006).

Fractured porous (intergranular and fractured) aquifers, describe aquifers, in which groundwater occurs in both fractures and intergranular interstices. In these aquifers, the fractures act as the main conduits of water and the pores itself in the rock, the intergranular spaces, for instance in a sand, sandstone, arkose or even siltstone, are contributing water to these main conduits when water are taken out from a fractured porous aquifer. Weathering is a process where the less resistant material in a formation, for instance a medium to coarse-grained hard rock lithology, such as granite and gneiss, is removed. These results in preferred pass-ways for the water where the remaining more resistant parts still have an intergranular pore space.

The terms primary and secondary features used for intergranular and fractures are misleading since the structures called secondary does not imply for instance that fractures, fissures, etc are of secondary importance for the occurrence and movement of water in the aquifer. Usually in such media, the fractures are more important for the location and abstraction of groundwater than the intergranular interstices themselves.

Fractured porous aquifers are also referred to as having a dual porosity system. Such aquifers show a specific behaviour once water is being release from them. In fact dual porosity system exist in most type of aquifers, fractured, porous as well as fractured porous, where water is transmitted in fractured and pores of various transporting and storing capacities.

Karstic aquifers are carbonate rocks where solution weathering along joints, fractures, and bedding has enhanced the water-bearing capabilities of the rock. Those aquifers are limited in aerial extent and located eastern and southern part of the Molopo-Nossob Basin and represented by dolomites.

5.2.1.1 Hydraulic Parameters

Definitions

With hydraulic parameters in groundwater hydrology (hydrogeology) is understood the following parameters:

- Transmissivity
- Storativity
- Effective porosity

Transmissivity is a measure of the rate of flow of water across the unit width of the entire saturated thickness of the aquifer under a unit hydraulic gradient. It is expressed in terms of m^2/day or equivalent (SADC, 2001).

$$T = K_h H$$

Transmissivity (T) is directly proportional to average horizontal permeability (K_h) and aquifer thickness (H). For a confined aquifer, this remains constant, as the saturated thickness remains constant. The aquifer thickness of an unconfined aquifer is from the base of the aquifer to the groundwater table. The water table can fluctuate, which changes the transmissivity of the unconfined aquifer.

Hydraulic conductivity, symbolically represented as K, is a property of soil or rock that describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation. Hydraulic conductivity is the parameter in the Darcy equation expressing the relation between the groundwater flow and the hydraulic gradient. The hydraulic conducitivity varies between geologic media from less than 10^{-8} m/s to more than 10m/s.

Porosity (n) is a directly measurable aquifer property; it is a fraction between 0 and 1 indicating the amount of pore space between unconsolidated particles or within a fractured rock. Typically, the majority of groundwater (and anything dissolved in it) moves through the porosity available to flow (sometimes called effective porosity).

Effective porosity refers to the fraction of the total volume in which fluid flow is effectively taking place (this excludes dead-end pores or non-connected cavaties). This is important for groundwater flow, as well as for solute transport in groundwater.

Hydraulic parameters on Aquifers in the Molopo-Nossob Basin

From investigation, mainly for groundwater supply but also for regional groundwater studies, in the Molopo-Nossob Basin, the hydraulic parameters are assessed. Basically three different approaches are used:

- Direct measurements through various aquifer tests in the filed
- Laboratory measurements on samples
- Modeling exercises where the parameters are assessed from model calibration and/or water balance calculations.

Methods of direct measurements include test pumping where a borehole is tested usually with a constant rate and at the same time the drawdown in the borehole and in neighbouring boreholes are measured as function of time. From such test, the hydraulic parameters Transmissivity and storativity can be calculated. In groundwater investigation there is also a first estimate of the yield of a borehole by blowing or pumping out the water to an assessment of the borehole yield in approximate figure. The yield of a borehole is proportional to many parameters, but the main parameter is the aquifer transmissivity.

Drawdown in a pumping well (pumped with a constant rate) is a function of discharge (Q), time (t), transmissivity (T), storativity (S), linear and non-linear well losses and aquifer geometry (including the barrier and/or recharge boundaries).

$$s_w = \frac{Q}{4\pi T}\{W(u) + 2\xi\} + DQ^2$$

Where, s_w is the drawdown, Q = discharge, T = transmissivity W (u) = Well function (depending on borehole diameter, time and aquifer storativity), ξ the skin-factor and C a constant expressing non-linear losses in a discharging borehole. So even if there are a number of various parameters on which the borehole yield depend, the main and most important one is the aquifer transmissivity T.

It is assumed that variations of yields and transmissivity in an aquifer in general can be expressed as a log-normal distribution. In such a distribution the median value represents a characteristic value for the formation. The spreading of the parameter, can be expressed using the standard deviation of the log-normal distribution, in the current approach, these value refer to the borehole yields.

Information on borehole yields from various aquifers is available in reports from areas of investigation. **Table 5-4** indicates a number of investigations from which information on borehole yield is obtained.

The yield information is illustrated as log-normal distributions in **Figure 5-6** and **Figure 5-7**. The number of information used in the fitting with normal distribution and the coefficient of determination, r^2 are expressed in **Table 5-5**.

The results of the statistical treatment of the borehole yields expressed as the Yields to be expected within the standard deviation limits of log-normal distribution are given in **Figure 5-8**.

Table 5-4 Reports from groundwater investigations used in collecting information on borehole yields and aquifer parameters

Country	Area	Report	No of information		
			Yield	T-value	Aquifer
Botswana	Kanye	DWA, 2006	16		Dolomite
	Kang	DWA, 2007	21	17	Ecca
	Ncojane	DWA, 2008	12	9	Ntane
			42	27	Ecca
	Bokspits	DGS, 2004	31	3+2	Kalahari
			38	11	Ecca
			7		Dwyka
			26		Olifantshoek
	Middlepits	DWA, 1999	2	2	Ecca
			2	2	Olifantshoek
	Middlepits-Makopong	DGS, 1994	8	8	Ecca
	Tsabong	DWA, 2002	5	2	Kalahari
			66	23	Olifantshoek
	Werda-Mabutsane	DGS, 2003	21	8	Kalahari
			21	17	Ecca
	Hunhukwe-Lokalane	DGS, 2000	9	9	Ntane
			7	7	Ecca
Namibia	SAB	JICA, 2002	47	5	Kalahari
			13		Basalt
			55	6	Ecca
			16	6	Nossob

Table 5-5 Number of information used in the fitting the yields from various aquifers with normal distribution and the coefficient of determination, r^2

Figure No	Rock Type	Area	r^2	Points used	Total data points
5.2-1	Kalahari	Botswana	0.9310	38	57
5.2-1	Kalahari	SAB	0.9774	37	47
5.2-1	Basalt	SAB	0.9507	13	14
5.2-1	Ntane	Ncojane	0.9063	12	14
5.2-2	Ecca	Dutlwe	0.9151	19	21
5.2-2	Ecca	Kang	0.9772	21	26
5.2-2	Ecca	Bokspits	0.9696	38	60
5.2-2	Ecca	Ncojane	0.9696	42	47
5.2-2	Ecca	SAB	0.9025	48	55
5.2-2	Nossob	SAB	0.8196	7	16
5.2-2	Dwyka	Bokspits	0.8985	7	17
5.2-1	Olifantshoek	Botswana	0.9685	69	92
5.2-1	Dolomite	Kanye	0.9074	16	27

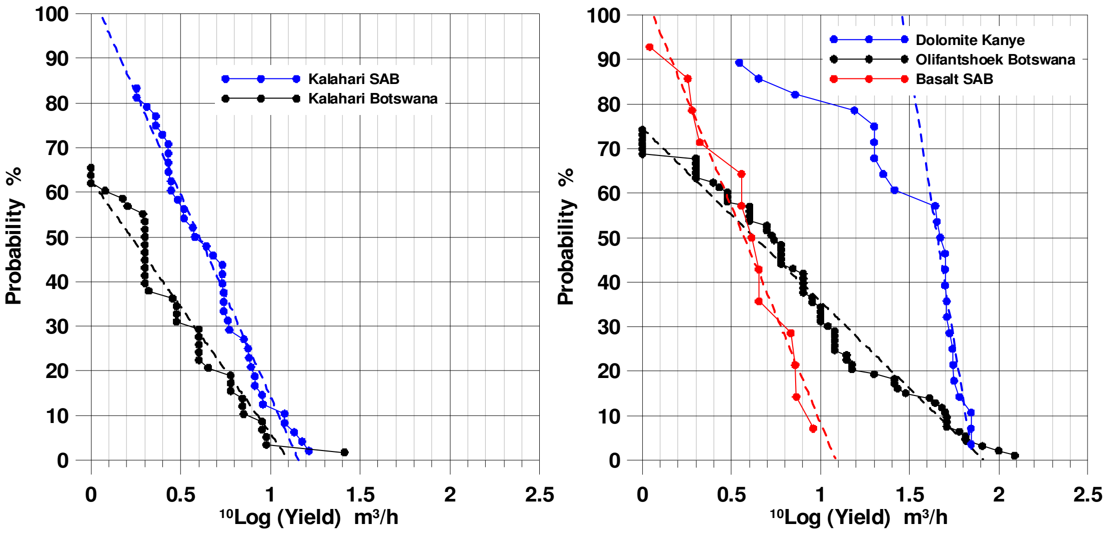


Figure 5-6 Borehole yield data from various aquifers and locations in Botswana and Namibia. SAB (Stampriet Artesian Basin)

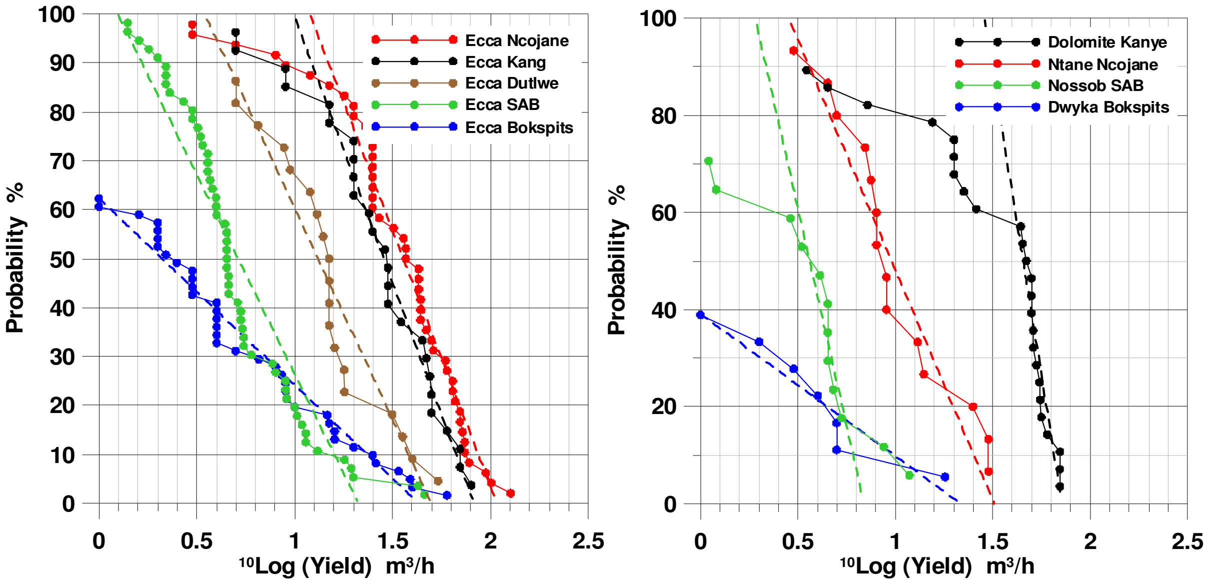


Figure 5-7 **Borehole yield data from various aquifers and locations in Botswana and Namibia. SAB (Stampriet Artesian Basin)**

<u>Transmissivity</u>

In order to obtain reliable value on transmissivity two main approaches are done (i) flied tests and (ii) modeling exercises. In the field test usually a limited number of boreholes are subjected to testing. These selected boreholes are also the ones showing the highest yields established during the drilling process. **Figure 5-8** shows that the yields from the Ecca aquifers (Otshe and Auob) have different median values but they are distinguished from the other formations. The transmissivity values reported from theses aquifers are presented in log-normal diagram in **Figure 5-9.**

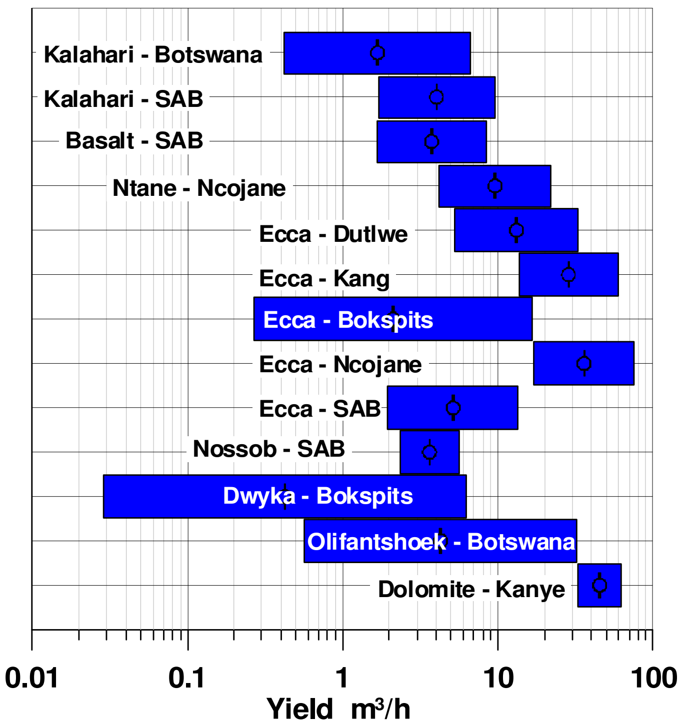


Figure 5-8 **Borehole yields to be expected within the standard deviation limits of the log-normal distribution of borehole yields from various aquifers in Botswana and Namibia. ⚲ =median value**

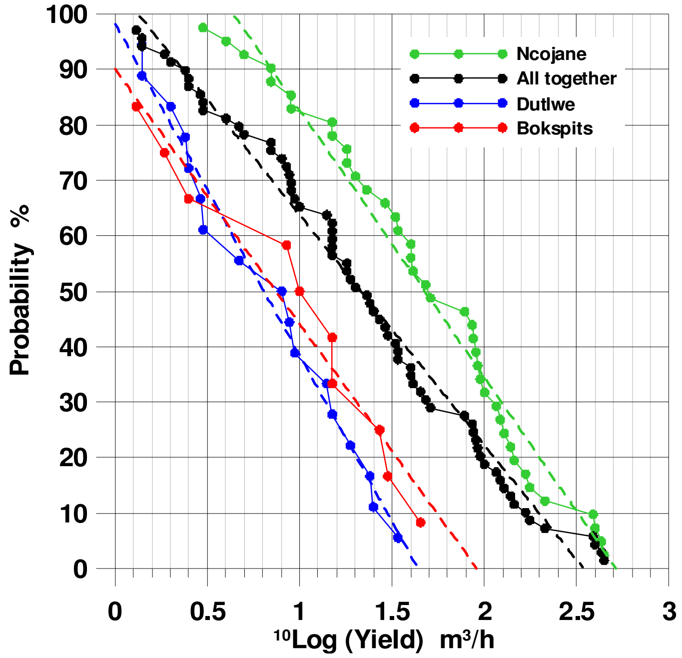


Figure 5-9 **Transmissivity data from Ecca aquifer at various locations in Botswana**

The results of the statistical treatment of the transmissivity data expressed as the transmissivity to be expected within the standard deviation limits of log-normal distribution are given in **Figure 5-10**.

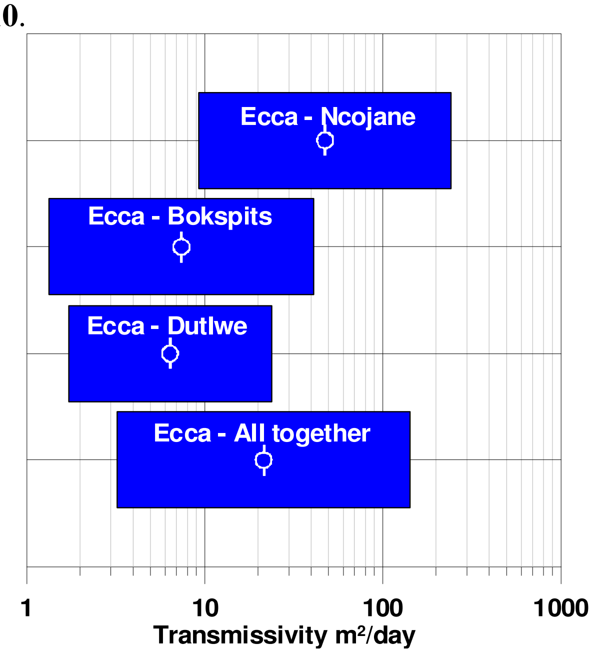


Figure 5-10 **Transmissivity data to be expected within the standard deviation limits of the log-normal distribution of transmissivity from Ecca aquifer in Botswana. ⚲ =median value**

Storativity.

Storativity is defined as the volume of water released from storage per unit surface area of the aquifer per unit decline in the hydraulic head. It is dimensionless coefficient (SADC, 2001). The size of the storativity depends on whether the aquifer is confined or unconfined:

- Unconfined Aquifer. An aquifer in which the water is in direct contact with the atmosphere through open spaces. It has a free water table and the true thickness of the aquifer is more than or equal to the saturated thickness.
- Confined Aquifer. An aquifer that is confined from top and bottom by impervious layers and the piezometric surface is above the top confining layer.

In unconfined aquifers the storativity varies in general between 10^{-4} to 10^{-2}, whereas in confined aquifers the values usually are between 10^{-6} to 10^{-4}. Storativity values are obyained from test pumping procedures where drawdown observation are done in boreholes outside the pumped boreholes and/or from modeling exercises and from analyses of water level fluctuations and recharge assessment.

5.2.1.2 Potential Aquifers

In hydrogeological maps over Botswana, Namibia and South Africa, the groundwater resources are given with reference to the yield of the boreholes in a delineated area. Usually the average or median yield is used to characterize the area. In the three riparian countries, different scales are used in order to define the yield class or principal groundwater occurrence. **Table 5-6** summarizes the scales used in Botswana, Namibia and South Africa.

Table 5-6 Borehole yield classes used in Botswana, Namibia and South Africa. (Taken from DWA, 1987, Christelis and Struckmeier, 2001, DWAF, 1995

Country	Yield Classes (median borehole yield)				
Botswana		<1.8 m^3/h	1.8-7.2 m^3/h	7.2-18 m^3/h	>18 m^3/h
Namibia	<0.5 m^3/h	0.5-3 m^3/h	3-15 m^3/h		>15m^3/h
South Africa	0.0-0.1 l/s	0.1-0.5 l/s	0.5-2.0 l/s	2.0-5.0 l/s	>5.0 l/s
Used in Figure 3-3			Medium	High	

In the aquifer productivity map shown in **Figure 5-11**, two classes are given. These are based on the Botswana and South African division, however using m^3/h for the median borehole yield. For the Namibian part of the map, the selected intervals are slightly higher, see legend to map in **Figure 5-11**.

Of the three type of aquifer identified the intergranular (porous) covers the largest area. Areas of high potential within this group are identified in Namibia and Botswana (Ecca formation) and in smaller spots in South Africa (Kalahari Beds). Of the intergranular and fractured aquifer, the Ntane sandstone in the northern Botswana is highlighted as an aquifer of high potential. Other high potential areas of this aquifer type are found in southern South Africa. The Olifantshoek formation, which stretches from South Africa into Botswana is assign a medium potential on the Botswana side.

Dolomite aquifers are prevailing as the aquifers of the highest potential in South Africa. The formations holding these aquifers are stretching up into Botswana and in some part showing high potential.

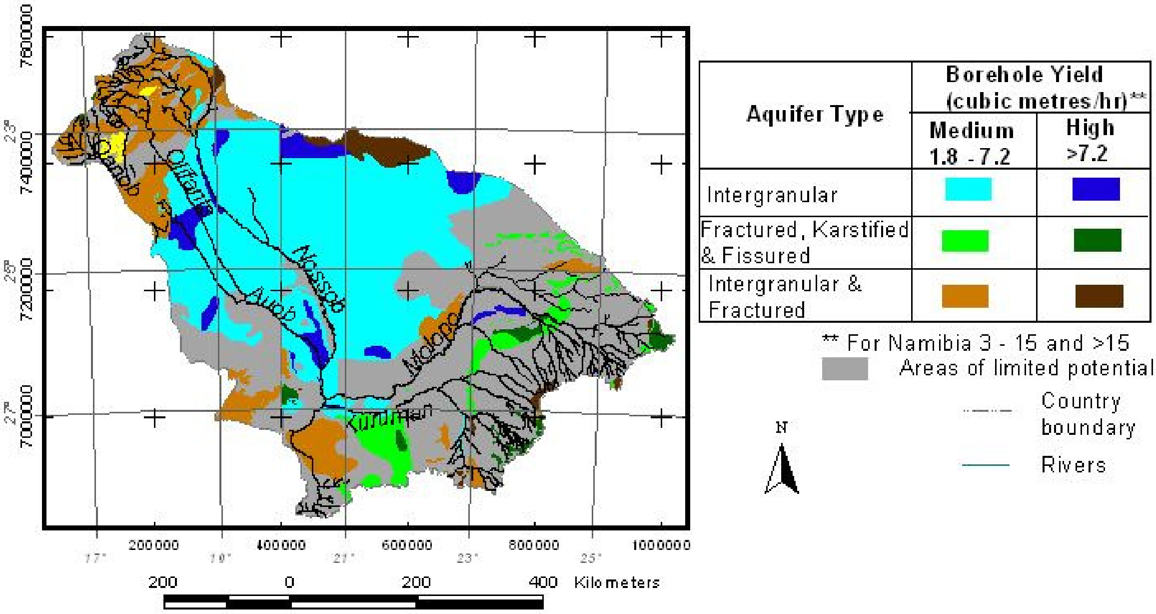


Figure 5-11 **Groundwater Potential Map. Compiled from hydrogeological Maps over Botswana, Namibia and South Africa**

5.2.2 Groundwater Quality

5.2.2.1 Quality Components and Guidelines

Three (3) groundwater quality components are considered for the Molopo-Nossob Basin, TDS, NO_3 and F. The groundwater quality components are assessed from compilation of chemical analyses performed on water samples taken. In the currents maps are constructed showing the variation of the components within the basin.

The databases from which information of water quality is obtained are summarized in **Table 5-7**. For Botswana, data are also compiled from investigations reported within areas included in the Molopo-Nossob basin.

Table 5-7 **Databases from which information of groundwater chemistry are extracted to form the base for construction of map over Molopo-Nossob basin**

Country	Data bases containing information of TDS, NO_3, F in groundwater
Botswana	National Borehole Archive Water Quality database Investigation reports over selected areas
Namibia	Groundwater database GROWAS
South Africa	Water Management System

Water quality guidelines for water use for domestic supply exist in all three countries. **Table 5-8** summarizes the guideline for the water quality components considered.

Table 5-8 Guidelines and recommendations for domestic water supply regarding the components TDS, NO_3 and F

	WHO 1993	Botswana, 2000			Namibia, 1991				South Africa, 2006	
		Class 1	Class 2	Class 3	Group A	Group B	Group C	Group D	Class I	Class II
	Guide-line Value	Ideal mg/l	Acceptable mg/l	Max. Allowable mg/l	Excellent Quality mg/l	Good Quality mg/l	Low Health Risk mg/l	Unsuitable mg/l	Recommended for operational limit mg/l	Max allowable for limited duration mg/l
TDS	1,000	450	1,500	2,000	975*	1,950*	2,600*	>2,600*	<1,000	1,000-2,400
NO_3	45	45	45	45	45	90	180	>180	45**	45-90**
F	1.5	0.7	1.0	1.5	1.5	2.0	3.0	>3.0	<1.0	1.0-1.5
*= recalculated values from Electronic conductivity using TDS (mg/l) = EC (mS/m) x 6.5										
** = recalculated from nitrogen in Nitrate										

Guidelines for water use for livestock published by FAO (FAO, 1976) are shown in **Table 5-9** regarding TDS. The tolerance of livestock to salinity varies with the animals. South Australia Department of Agriculture gave in their fact sheet no 82/77 the maximum TDS for healthy growth to 6,000 mg/l for sheep, 3,000-4,000 for cattle and 4,000 mg/l for horses, see **Table 5-10**. The maximum values of TDS suggested for Southern Kgalagadi in Botswana (DGS, 1994) are cattle 10,000, sheep/goats 13,000 and horses 6,500 mg/l (DGS, 1994).

Table 5-9 Guidelines on Total Dissolved Solids, TDS for water use for livestock from FAO (1976) and proposal from DGS (1994)

Livestock (FAO), 1976					
Excellent	**Very Satisfactory**	**Satisfactory**	**Reasonable safety for dairy and beef cattle, sheep, swine and horses; to be avoided for pregnant and lactating animals**	**Considerable risk for pregnant or lactating cows**	**Unfit**
<1,000	1,000 – 3,000	3,000 – 5,000	5,000 – 7,000	7,000 – 10,000	> 10,000

Table 5-10 Livestock salinity tolerance (South Australia department of Agriculture, Livestock Water Supplies facts sheet no 82/77, September 1982) (Source: DGS, 1994)

Animal	Max TDS for healthy growth (mg/l)	Max TDS to maintain condition (mg/l)	Max TDS tolerated (mg/l)
Sheep	6,000	13,000	*
Beef cattle	4,000	5,000	10,000
Dairy cattle	3,000	4,000	6,000
Horses	4,000	6,000	7,000
Pigs	2,000	3,000	4,000
Poultry	2,000	3,000	3,000
*Depends on type of feed available, e.g. greenfeed, dry feed or saltbush			

The amount of data of tree parameters compiled, TDS, F and NO_3 from the different databases and countries as summarized in **Table 5-11**.

Table 5-11 Number of data used in the compilation of water chemistry maps over Molopo-Nossob basin

Parameter	Botswana	Namibia	South Africa	Total
TDS	2,147 *	6,905	7,367	14,933
NO_3	1,560	6,898	5,464	13,922
Fluoride	1,648	5,870	5,391	12,909
= data included from neighbouring areas outside the Molopo-Nossob Basin				

5.2.2.2 Total Dissolved Solids (TDS)

General TDS

The total dissolved solids (TDS), measured in mg/l (or ppm), and is a measure of the amount of various inorganic salts dissolved in water. The TDS concentration is usually measured by:

- an estimate of the EC value
- the dry weight of the salts after evaporation of a known volume of filtered water;
- the sum of the concentrations of the constituent cations and anions.

The TDS concentration is directly proportional to the electrical conductivity (EC) of water. Since EC is much easier to measure than TDS, it is routinely used as an estimate of the TDS concentration.

Electrical conductivity (EC) is a measure of the ability of water to conduct an electrical current. This ability is a result of the presence of ions in water all of which carry an electrical charge. Most organic compounds dissolved in water do not dissociate into ions, consequently they do not affect the EC.

The TDS concentration is given in mg/l, as well as the equivalent EC, expressed in milli-Siemens per meter (mS/m), measured at, or corrected to a temperature of 25 ^{o}C.

For most natural waters electrical conductivity is related to the dissolved salt concentration by a conversion factor ranging from 5.5 - 7.5. The average conversion factor for most waters is 6.5. The conversion equation is as follows:

$$EC\ (mS/m\ at\ 25\ ^{o}C) \times 6.5 = TDS\ (mg/R)$$

The exact value of the conversion factor depends on the ionic composition of the water, especially the pH and bicarbonate concentration. When accurate measures of TDS are required, the conversion factor should be determined for specific sites and runoff events.

Virtually all natural waters contain varying concentrations of TDS as a consequence of the dissolution of minerals in rocks, soils and decomposing plant material and the TDS of natural waters is therefore usually dependent on the characteristics of the geological formations the water is in contact with.

The concentration of the TDS varies but is typically (DWAF, 1996a):

- in rainwater is low, generally less than 1 mg/l

- in water in contact with hard crystalline rocks, siliceous sand and well-leached soils are generally low, less than 30 mg/l.
- in water in contact with sedimentary rock formations is generally in the range of 195 – 1,100 mg/l.

TDS are likely to accumulate in water moving downstream because salts are continuously being added through natural and manmade processes while very little of it is removed by precipitation or natural processes. Domestic and industrial effluent discharges and surface runoff from urban, industrial and cultivated areas are examples of the types of return flows that may contribute to increased TDS concentrations. The main factor responsible for increasing TDS in the Molopo-Nossob Basin is the natural processes of interaction between water and geological media.

High TDS concentrations in surface water are also caused by evaporation in water bodies which are isolated from natural drainage systems. The saline pans in the central parts of Southern Africa are such water bodies.

Treatment TDS

Although some salts, such as those of calcium, magnesium and certain heavy metals can be removed by chemical precipitation, most of the inorganic salts dissolved in water can only be removed by distillation or by highly sophisticated physical-chemical separation technologies. All these technologies are characterised by their high cost and/or their high energy requirements.

The common technologies available for reducing the concentration of TDS in water are:

- **Demineralization** in a mixed-bed **ion exchange** column, usually where the feed TDS concentration is approximately 2 000 mg/l. Disposable ion exchange canisters can be used to produce potable water for domestic consumption whereas large banks of ion exchange filter beds, which are capable of being regenerated, are used on an industrial scale. Ion exchange processes are also used for the production of ultra pure water.

- Treatment by membrane processes such as **reverse osmosis** or **electro dialysis** where the TDS concentration is in the range of 2 000 - 3 500 mg/l. Small low-pressure reverse osmosis modules fed from a domestic supply line reliably produce potable water for household consumption and are easily replaced after one to three years if the membrane becomes fouled through scaling. Large-scale treatment is achieved with banks of reverse osmosis modules in parallel.

- **Distillation**, in cases where the TDS concentration is approximately 10,000 mg/l.

All the process alternatives are usually fouled by suspended matter and may also be impeded by severe scaling from hard waters. All large-scale processes require high levels of design, operator and maintenance skills. Furthermore, all processes produce a concentrated waste stream of the salts removed from the water and may cause disposal difficulties.

Effects on humans from TDS

The norms used in the guideline for TDS consider aesthetic and human health effects and economic impacts.

Low concentrations of particularly calcium and magnesium salts have nutritional value, although water with an extremely low TDS concentration may be objectionable because of its flat, insipid taste. Health effects related to TDS are minimal at concentrations below 2 000 - 3 000 mg/l. In contrast, high concentrations of salts impart an unpleasant taste to water and may also adversely affect the kidneys.

Some of the physiological effects which may be directly related to high concentrations of dissolved salts include:

- laxative effects, mainly from sodium sulphate and magnesium sulphate,
- adverse effects of sodium on certain cardiac patients and hypertension sufferers;
- effects of sodium on women with toxaemia associated with pregnancy; and
- effects on kidney function.

Bathing and washing in water with excessively high concentrations of TDS may give rise to excessive skin dryness and hence discomfort.

Chemical corrosion may occur when the alkalinity, i.e. the concentrations of carbonate, bicarbonate and hydroxide are low, the TDS concentration is high, particularly the concentrations of chloride and sulphate, and the pH is low. Excessively high concentrations of TDS may adversely affect plumbing and appliances and hence the maintenance and replacement requirements. The effects of TDS and EC on human health, aesthetics, household distribution systems and water heating appliances are summarized in **Table 5-12**.

Effects on Livestock from TDS

The norms used in the guidelines for livestock watering are based on (DWAF, 1996b):

- the palatability (tastiness) and toxicological effects of the TDS on livestock consumption; and
- the effects of the TDS on clogging and encrustation of livestock watering systems.

Common salt, sodium chloride (Na Cl), is frequently added to livestock rations to regulate feed intake, enhance palatability, and as a carrier for other required elements.

Table 5-12 Effects of TDS and EC on Human Health, Aesthetics, Household Distribution Systems and Water Heating Appliances (DWAF, 1996a)

TDS Range mg/l	EC Range mS/m	Aesthetic/Economic Effects	Health Effects
Target Water Quality Range 0 – 450	*Target Water Quality Range*	Extremely low TDS may give flat, insipid taste. No effects on plumbing or appliances.	No health effects are expected with TDS <300 mg/l. The upper limit (450 mg/l) takes into account the higher water consumption which may be expected in hot climates.

TDS Range mg/l	EC Range mS/m	Aesthetic/Economic Effects	Health Effects
	0 -70		
450 – 1,000	10 – 150	Noticeable salty taste. Well tolerated. No effects on plumbing or appliances.	No health effects are likely
1,000 – 2,000	150 – 300	Marked salty taste. Probably not used on aesthetic grounds (if alternative supplies are available). Some effects on plumbing and appliances (increased corrosion or scaling).	Consumption of water does not appear to produce adverse health effects in the short term.
2,000 – 3,000	300 – 450	Taste extremely salty. Corrosion and/or scaling of pipes and appliances increases.	Short-term consumption may be tolerated, but with probable disturbance of the body's salt balance
>3,000	>450	Taste extremely salty and bitter. Corrosion and/or scaling of pipes and appliances increases.	Short-term consumption leads to disturbance of the body's salt balance. At high concentrations, noticeable short-term health effects can be expected.

Saline water may detrimentally affect animal health and thus performance by rendering the water unpalatable. Palatability is also influenced by the types of salts present and not just the level of salinity. Magnesium sulphate (Epsom salts) is more harmful than sodium chloride or sodium sulphate (Glauber's salt). The main water quality constituents implicated in palatability effects are chloride, sulphate, magnesium, bicarbonates and calcium. However, other factors such as dust, temperature and algae can also contribute to whether or not water is deemed palatable or unpalatable by livestock.

Direct effects of unpalatable water are (DWAF, 1996b):

- Refusal to consume water.
- Depending on the degree of unpalatability stock may consume the water, but at a level below the physiological requirement (a concurrent increase in water intake with increasing salinity is required for adequate renal plasma clearance to take place).
- In extreme cases, the stock will refuse the water but will eventually be driven to it by thirst. This may result in a consumption of excessive amounts of water and therefore salts, which may manifest as "salt poisoning" when a sodium salt is involved.

Indirect effects of unpalatable water are:

- Initial refusal to consume water and hence a decline in productivity. Typically, this may last a few days for stock which have not previously encountered saline waters. The implications are:
    - economic loss for intensive systems where time is a crucial factor; and
    - health implications for systems where new, young stock are brought in and are stress-sensitive (electrolyte imbalance), such as in feedlots.
- In more severe cases the stock may regularly consume sufficient water for adequate plasma clearance, but production declines. This is primarily due to the high positive correlation between water intake and feed intake. A decline in water intake results in a decrease in feed intake (dehydration-induced hypophagia) with a resultant drop in

performance parameters such as milk production, average daily gain (ADG), feed conversion ratio (FCR) and body weight.

The types of effects of exposure to TDS concentrations in excess of the TWQR (Target Water Quality Range) depend on the ability of the stock to adapt to saline or unpalatable water, and whether or not the stock have been previously exposed to saline water.

Livestock can adapt to highly saline water and continue production without adverse effects after an initial decline in production. Adaptation may require several days or weeks, depending on the TDS level and salts involved.

The main effects of TDS on toxicological aspects are attributed to the following:

- Symptoms of diarrhea and dehydration due to initial exposure to saline waters. The primary constituents involved are sulphate, magnesium and bicarbonate.

- Ingestion of large volumes of highly saline water following a period of refusal to unpalatable water. Adverse effects are usually osmotic which may lead to "salt poisoning", but may be related to a specific ion, depending on the amount of water ingested and the concentration of the specific ion in the water and feed.

- Salt poisoning is invariably acute. Toxic effects related to specific ions are often indirectly due to the increased water intake and can result in constituents eliciting a toxic response at levels normally safe. Salts that have little effect on the palatability of water but are toxic include nitrates, fluorides and the salts of heavy metals.

The recovery from volume-loaded hypertension depends on the TDS concentration, the length of exposure time and the primary salts involved. Recovery may be complete or incomplete. Recovery from high ingestion rates of potentially hazardous constituents depends on the specific salts and constituents involved). *It should be noted that there are vast differences in salt tolerance between and also within species.* More information is given by DWAF “Water Quality Guidelines” (DWAF, 1996b).

TDS in Molopo-Nossob Basin

Using the available data on TDS obtained from analyses of groundwater from boreholes, a map showing the areal distribution of TDS is constructed, see **Figure 5-12**. In the map, contour lines for TDS in accordance with the major guidelines for TDS in water are applied, see **Table 5-13**. The calculation is done through the interpolation technique “inverse instance to a power” using the computer programme “Surfer”.

Figure 5-12 shows that the highest values and also largest area of saline groundwater is found in Botswana. Using the upper limits of 2,000 and 10,000 mg/l as the limits for human and livestock consumption, the areas unsuitable for water consumption is assessed as summarized in **Table 5-14**. The areas are illustrated in **Figure 5-13**.

Table 5-13 TDS concentration limits chosen for the construction of the TDS map (Figure 5-12)

TDS equiv.-concentration level	Remarks
450	Upper limit set by Botswana for "ideal" water quality
1,000	Guideline value limit WHO Standard and South African Class I
2,000	Upper limit Botswana Class 3
5,000	Upper limit for satisfactory water quality for livestock according to FAO
10,000	Unfit water quality for livestock watering according to FAO
20,000	Extreme saline water

Table 5-14 Area sizes in the Molopo-Nossob Basin of unsuitable groundwater for human and livestock consumption based on TDS limits of 2,000 and 5,000 mg/l respectively

Country	km^2 unfit for human consumption (>2,000 mg/l)	km^2 unfit for livestock consumption (>10,000 mg/l)	% of country basin size TDS>2,000 mg/l	% of country basin size TDS>10,000 mg/l
Botswana	106,400	70,400	78	52
Namibia	28,800	1,000	24	<1
South Africa	45,500	5,600	41	5
Total	***180,700***	***77,000***	***49***	***21***

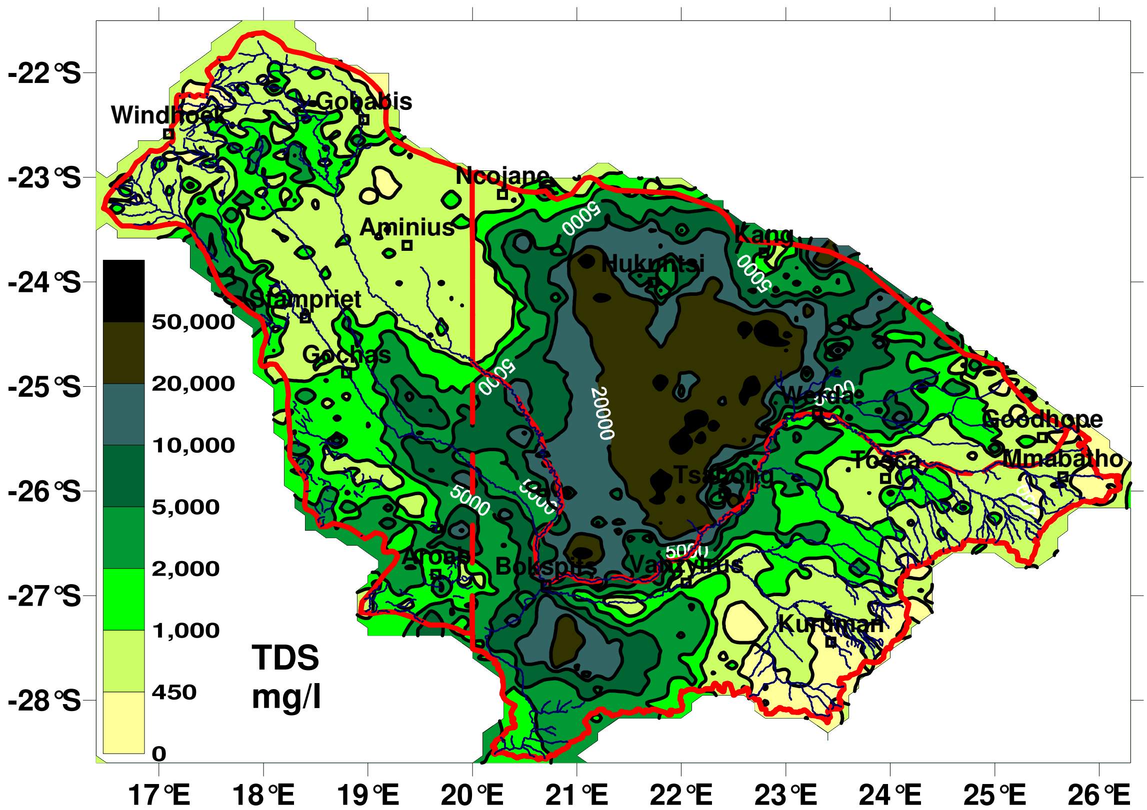


Figure 5-12 TDS concentration in the groundwater within the Molopo-Nossob Basin

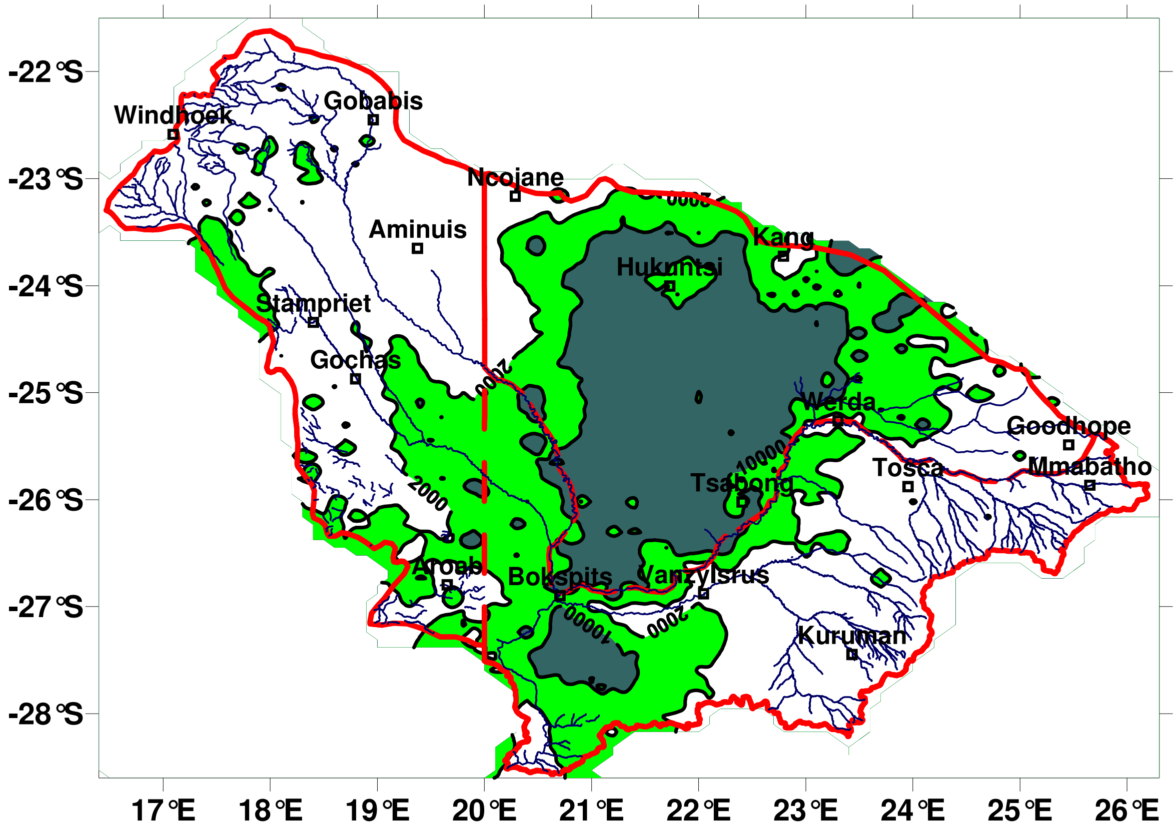


Figure 5-13 **Areas of unsuitable groundwater quality of human consumption (TDS>2,000 mg/l) and livestock watering (TDS>10,000 mg/l)**

In the Namibian part of the Molopo-Nossob basin, multiple aquifer system was identified n the Stampriet Artesian Basin (JICA, 2002), see further **Chapter 5.2.2.2**. The groundwater quality in the lowermost aquifer, the Nossob aquifer, shows quality conditions different from the upper aquifer, the one represented by the regional condition in **Figure 5-12**. The TDS values in the Nossob aquifer are higher than in the upper two aquifers. **Figure 5-14** illustrates the TDS values in the Nossob aquifer within the Stampriet Artesian Aquifer.

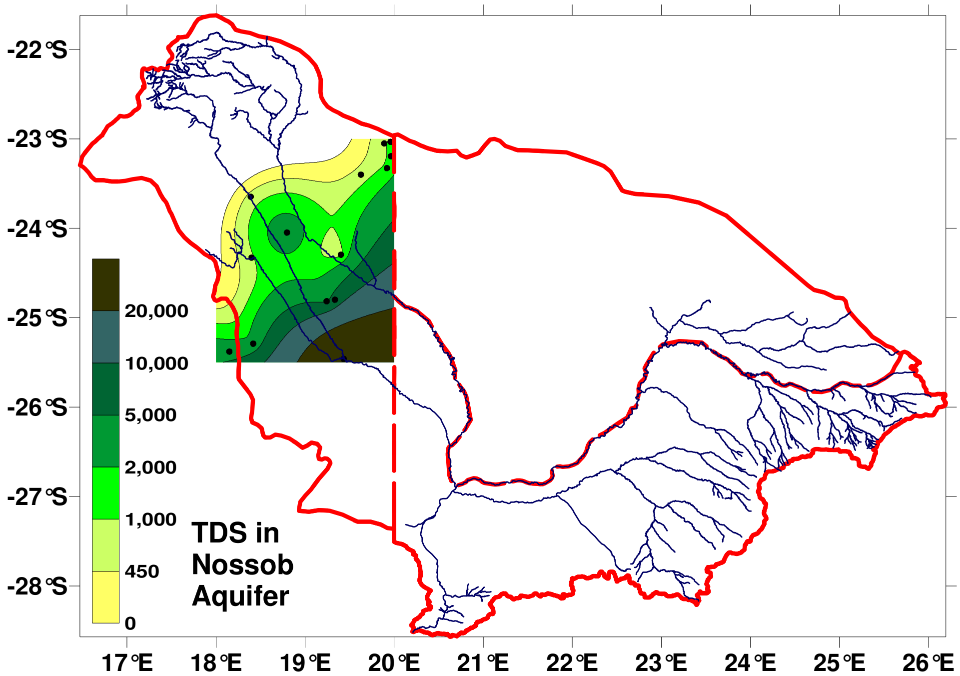


Figure 5-14 **TDS in the Nossob Aquifer in the Stampriet Artesian Aquifer in Molopo-Nossob Basin in Namibia. Data source: JICA, 2002**

5.2.2.3 Nitrate, NO_3

General NO_3

Nitrate is the end product of the oxidation of ammonia or nitrite. Nitrate (NO_3) and nitrite (NO_2) are the oxy-anions of nitrogen. Nitrates and nitrites occur together in the environment and inter conversion readily occurs. Under oxidizing conditions nitrite is converted to nitrate, which is the most stable positive oxidation state of nitrogen and far more common in the aquatic environment than nitrite.

Nitrate in drinking water is primarily a health concern since it can be readily being converted in the gastrointestinal tract to nitrite as a result of bacterial reduction.

Mineral deposits of nitrates are rare due to the high water solubility of nitrates. Nitrates are ubiquitous in soils and in the aquatic environment, particularly in association with the breakdown of organic matter and eutrophic conditions.

Concentrations of nitrate in water are typically less than 5 mg/l of nitrate-nitrogen (or, alternatively, 22 mg/l nitrate). A significant source of nitrates in natural water results from the oxidation of vegetable and animal debris and of animal and human excrement. Treated sewage wastes also contain elevated concentrations of nitrate.

Nitrate tends to increase in shallow ground water sources in association with agricultural and urban runoff, especially in densely populated areas. Nitrate together with phosphates stimulate plant growth. In aquatic systems elevated concentrations generally give rise to the accelerated growth of algae and the occurrence of algal blooms.

Where water is well-oxygenated, it can be assumed that the nitrate plus nitrite nitrogen concentrations are largely due to the presence of nitrate. Nitrite concentrations only become significant in deoxygenated systems.

Nitrate in water is commonly expressed in mg NO_3/l, but also the concentration focused on the nitrogen as mg N/l (nitrate-nitrogen) is used. The conversion factors between the two expressions are given as:

$$1 \text{ mg/l } NO_3 = 0.23 \text{ mg/l N}$$
$$1 \text{ mg/l N} = 4.43 \text{ mg/l } NO_3$$

Treatment NO_3

Nitrate is not readily removed from domestic water supplies. Some reduction of nitrate may be achieved using slow sand filtration, but the method is not reliable. Biological reduction of nitrate to nitrogen gas (de-nitrification) is feasible in the presence of a suitable carbon source, but the increase in carbonaceous matter is not compatible with a high quality water supply. Non-specific methods of removing nitrate include:

- Passing the water stream through an **ion exchange** column with a selective affinity for nitrates. The method is expensive because other anions will be removed at the same time, depending on the nature of the resin used. However, it may be attractive on a household scale where only water used for drinking purposes is treated.
- **Reverse osmosis**, which will remove nitrate effectively from water, along with high percentages of virtually all other ions and many organic compounds. A low-pressure home unit will conveniently treat small quantities of drinking water satisfactorily. The module is replaced when it begins to block through fouling or scaling.

On a commercial scale the processes described require competent operation, control and maintenance.

Effects on Humans from Nitrate and Nitrite

The norm used in the guideline for nitrate and nitrite concerns human health. There are no direct aesthetic impacts.

Upon absorption, nitrite combines with the oxygen-carrying red blood pigment, haemoglobin, to form methaemoglobin, which is incapable of carrying oxygen. This condition is termed *methaemoglobinaemia*. The reaction of nitrite with haemoglobin can be particularly hazardous in infants under three months of age and is compounded when the intake of Vitamin C is inadequate.

Metabolically, nitrates may react with secondary and tertiary amines and amides, commonly derived from food, to form nitrosamines which are known carcinogens. The effects of nitrate on human health are summarized in **Table 5-15**.

Effects on Livestock from Nitrate and Nitrite

The norms used in the guideline for nitrate and nitrite are based on the toxicological and palatability (tastiness) effects associated with nitrate in water used by livestock.

Nitrate does not cause direct toxic effects, but in its reduced form, nitrite (NO_2), it is 10 - 15 times more toxic than nitrate. Nitrite is formed through the biological reduction of nitrate in the rumen, and ruminants (mammals that digests plant-based food by initially softening it within the animal's first stomach, known as the rumen, then regurgitating the semi-digested mass and chewing it again. Examples of ruminating mammals are cattle, goats, sheep, giraffes, camels, wildebeest and antelope) are therefore susceptible to nitrite poisoning. The same process occurs in the caesium of horses. They are therefore also susceptibility to nitrite toxicity due to the ingestion of nitrate, although less so than ruminants, but more so than monogastrics (humans, pigs, dogs and cats).

Table 5-15 Effects of Nitrate on Human Health (DWAF, 1996a)

Nitrate/nitrite Range (as mg/l NO_3)	Nitrate/nitrite Range (as mg/l N)	Effects
Target Water Quality Range 0 – 27	Target Water Quality Range 0 – 6	No adverse effects
27 – 45	6 – 10	Rare instances of methaemoglobinaemia in infants; no effects in adults. Concentrations in this range generally well tolerated.
45 – 90	10 – 20	Methaemoglobinaemia may occur in infants. No effects in adults.
>90	>20	Methaemoglobinaemia occurs in infants. Occurrence of mucous membrane irritation in adults.

It is essential to adapt livestock to water with elevated nitrate concentrations, in order to avoid poisoning by nitrite. If unadapted animals are suddenly exposed to too high nitrate/nitrite levels, the rumen is unable to "detoxify" (reduce NO_2 to ammonia), whereas adapted animals cope without any signs of adverse effects. Non-ruminants are less susceptible, as conversion to nitrite is limited (saliva and intestinal flora) to approximately five percent of that of ruminants.

Nitrite oxidizes haemoglobin to methaemoglobin which, unlike haemoglobin, cannot transport oxygen in body tissues. Poisoning results in suffocation due to lack of oxygen in the tissues and the mucous membranes are often visibly "brownish" in colour due to the presence of methaemoglobin. Nitrites also cause vasodilation of the capillary bed and thus a profound drop in blood pressure, which can cause death, even without excessive amounts of methaemoglobin being formed. Nitrite can cross the placental barrier; the haemoglobin of foetuses is more susceptible to toxic effects, and abortions may result. Nitrite is not usually found in milk.

Symptoms of acute nitrate toxicity in non-ruminants include clinical signs of restlessness, frequent urination, dyspnoea and cyanosis. Advanced stages may include vomiting, ataxia, convulsions, inability to rise and death. Symptoms of methemoglobinemia include weakness, ataxia, hypersensitivity, dyspnoea, rapid pulse rate, increase in respiration and urination and cyanosis. Acute nitrate poisoning in ruminants may manifest itself within two to three hours after ingestion. Chronic poisoning is associated with a decrease in methemoglobinemia within one week due to rumen micro-organism adaptation.

The target water quality range is 0 – 100 mg/l NO_3, and for higher concentrations, monogastrics are more affected than ruminants. More information is given in DWAF "Water Quality Guidelines" (DWAF, 1996b).

Nitrate in the groundwater in the Molopo-Nossob Basin

Data on NO_3 obtained from analyses of groundwater from boreholes and stored in the water departments in the three basin countries are used to construct a map showing the areal distribution of NO_3, see **Figure 5-15**. In the map, contour lines for NO_3 in accordance with the major guidelines for NO_3 in water are applied, see **Table 5-16**. The calculation is done through the interpolation technique "inverse instance to a power" using the computer programme "Surfer".

Table 5-16 NO_3 concentration limits chosen for the construction of the NO_3 map (Figure 5-12)

NO_3 equiv.-concentration level	Remarks
45	Upper limit set by Botswana for "ideal" water quality. Rare Instances of methaemoglobinaemia in infants
90	Upper limit Namibia Group B. Methaemoglobinaemia may occur in infants. No effects in adults.
180	Upper limit Namibia Group C
>180	Unsuitable

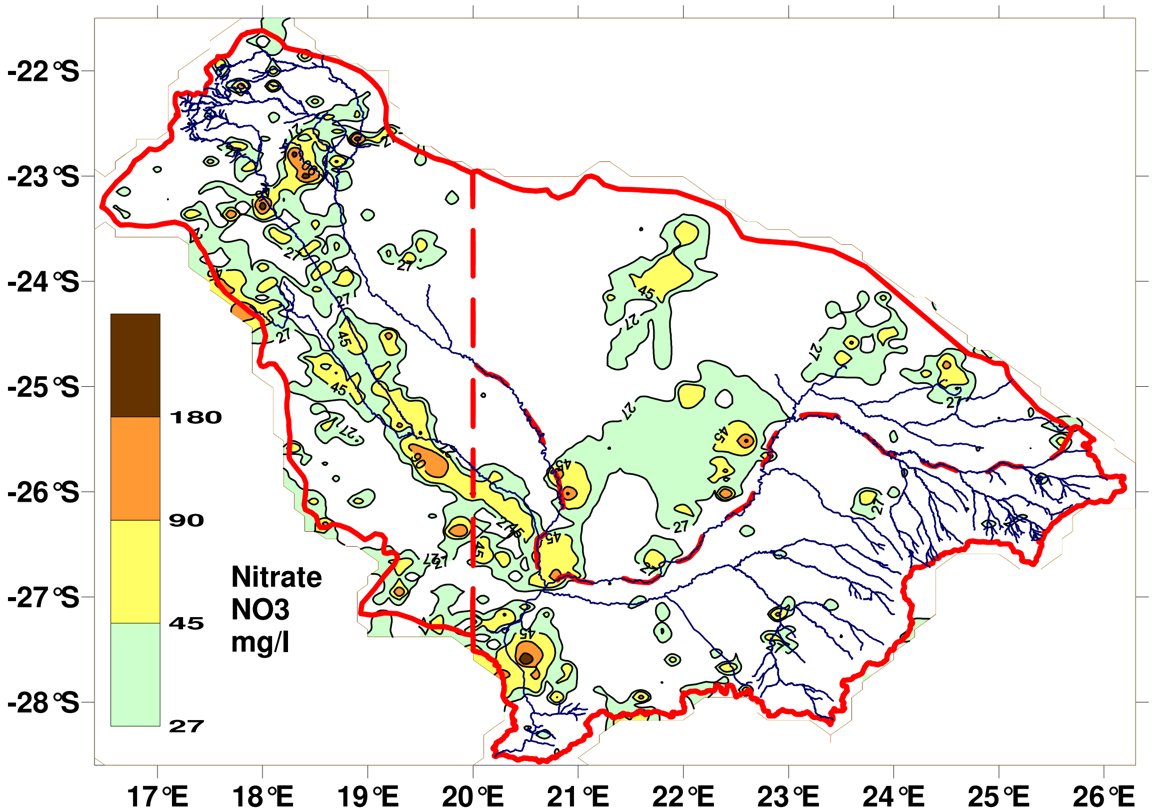


Figure 5-15 NO_3 concentration in the groundwater within the Molopo-Nossob Basin

The areas of highest Nitrate in groundwater are found in the area following the Auob River and in the south-western part of South Africa. Some few other areas have nitrate level of 45 mg/l, for instance around Hukuntsi, East of Nossob River and north of Tsabong in Botswana and West of Stampriet in Namibia.

In the Nossob aquifer in the Stampriet Artesian Basin in Namibia, NO_3 in the groundwater is below the limit for human consumption. An old (1954) data gives a value higher than the limit, but can represent a local pollution at the time of sampling.

5.2.2.4 Fluoride, F

General F

Fluoride is the most electronegative member of the halogen group of elements in the periodic system. It has a strong affinity for positive ions and readily forms complexes with many metals. In its elemental form, fluorine is a greenish-yellow gas which readily dissolves in water to form hydrofluoric acid. Fluorine is highly reactive and will attack most materials, including glass. Most fluorides are insoluble in water. However many soluble complexes are formed with silicates and the transition metals.

The presence of fluoride in drinking water reduces the occurrence of dental caries in adults and children. A small amount of fluoride is necessary for proper hardening of dental enamel and to increase resistance to attack on tooth enamel by bacterial acids. In humans and animals, fluoride accumulates in the skeleton.

Common fluoride minerals are flour-spar (CaF_2) and flour-apatite, a calcium flour-phosphate. Others of importance include various flour-silicates and mixed fluoride salts.

Typical concentration of fluoride in waters is (DWAF, 1996a):

- unpolluted surface water, approximately 0.1 mg/l;
- ground water, commonly up to 3 mg/l, but as a consequence of leaching from fluoride containing minerals to ground water supplies, a range of 3 - 12 mg/l may be found;
- sea water, approximately 1.4 mg/l.

Fluoride is present in much food stuff and in water. Drinking water is estimated to contribute between 50 % - 75 % of the total dietary fluoride intake in adults. In domestic water supplies as well as industrial supplies used in the food and beverage industries, the fluoride concentration in the water should not exceed approximately 0.7 mg/l.

Due to the very pronounced electron affinity of the fluoride atom, fluoride is capable of interacting with almost every element in the periodic table. Fluoride reacts readily with **calcium** to form calcium fluoride, which is reasonably insoluble and can be found in sediments. In the presence of phosphate the more insoluble apatite or hydroxy apatite may form. Fluoride also reacts very readily with **aluminium**, a property which is made use of in the removal of fluoride from water.

Treatment Fluoride, F

Fluoride is difficult to remove from water to a required concentration range. Although calcium fluoride is relatively insoluble, its solubility is an order of magnitude higher than the levels which need to be achieved by treatment. The common methods for the removal of fluoride include:

- Adsorption in a bed of activated alumina;
- Removal in ion exchange columns along with other anions; and
- Removal in membrane processes such as reverse osmosis and electro dialysis together with virtually all other ions.

Regeneration of the activated alumina or ion exchange bed produces a high fluoride stream which may pose disposal difficulties. A concentrated reject stream is also produced from reverse osmosis and electro dialysis, hence possible disposal problems.

Effects on Humans from Fluoride (F)

The norms used in the guideline for fluoride primarily concern human health effects. Fluoride does not affect the aesthetic quality of domestic water.

When fluoride is ingested, it is almost completely absorbed, where after it is distributed throughout the body. Most of the fluoride is retained in the skeleton and a small proportion in the teeth. Fluoride accumulates most rapidly in the bones of young people, but continues to accumulate up to the age of about 55.

The difference between concentrations of fluoride that protect tooth enamel and those that cause discolouration is marginal. Discolouration of dental enamel and mottling occurs at concentrations in the range of 1.5 - 2.0 mg/l in persons whose teeth are undergoing mineralization. Generally, children up to seven years of age are susceptible.

High doses of fluoride interfere with carbohydrate, lipid, protein, vitamin, enzyme and mineral metabolism. Skeletal fluorosis may occur when concentrations of fluoride in water exceed 3 - 6 mg/l and becomes crippling at intakes of 20 - 40 mg/day. This is equivalent to a fluoride concentration of 10 - 20 mg/l, for a mean daily water intake of two litres. Systemic toxicity and interference with bone formation and metabolism occur at high concentrations.

Chronic effects on the kidneys are observed in persons with renal disorders and rarer problems, including effects on the thyroid gland, which may occur with long-term exposure to high fluoride concentrations. Acute toxic effects at high fluoride doses include haemorrhagic gastroenteritis, acute toxic nephritis and injury to the liver and heart- muscle tissues. Many symptoms of acute fluoride toxicity are associated with the ability of fluoride to bind to calcium. Initial symptoms of fluoride toxicity include vomiting, abdominal pain, nausea, diarrhoea and convulsions.

Where concentrations of fluoride in the drinking water are low dietary fluoride supplements are recommended. Fluorosis is less severe when drinking water is hard, rather than soft, since the occurrence of calcium together with fluoride limits fluoride toxicity. However, there is no way of mitigating against the effects of long-term ingestion of higher than recommended concentrations of fluoride.

The effects of fluoride on aesthetics and human health are summarized in **Table 5-17**.

Table 5-17 Effects of Fluoride on Aesthetics and Human Health (DWAF, 1996a)

Fluoride Range (mg/l)	Effects
Target Quality Range 0 - 1.0	***Necessary to meet requirements for healthy tooth structure is a function of daily water intake and hence varies with annual maximum daily air temperature. A concentration of approximately 0.75 mg/l corresponds to a maximum daily temperature of approximately 26 °C – 28 °C. No adverse health effects or tooth damage occurs.***
1.0 – 1.5	Slight mottling of dental enamel may occur in sensitive individuals. No other health effects are expected.
1.5 – 3.5	***The threshold for marked dental mottling with associated tooth damage due to softening of enamel is 1.5 mg/l.*** Above this, mottling and tooth damage will probably be noticeable in most continuous users of the water. No other health effects occur.
3.5 – 4.0	Severe tooth damage especially to infants' temporary and permanent teeth; softening of the enamel and dentine will occur on continuous use of water. ***Threshold for chronic effects of fluoride exposure***, manifested as skeletal effects (detected mainly by radiological examination, rather than overt).
4.0 – 6.0	Severe tooth damage especially to the temporary and permanent teeth of infants; softening of the enamel and dentine will occur on continuous use of water. Skeletal fluorosis occurs on long-term exposure.
6.0 – 8.0	Severe tooth damage as above. Pronounced skeletal fluorosis occurs on long-term exposure.
>8.0	Severe tooth damage as above. Crippling skeletal fluorosis is likely to appear on long-term exposure.
>100	Threshold for onset of acute fluoride poisoning, marked by vomiting and diarrhoea.
>2,000	The lethal concentration of fluoride is approximately 2,000 mg/l.

Ambient air temperature strongly influences the total water intake of humans and animals, and hence indirectly, susceptibility to the detrimental effects of fluoride. Generally, the hotter it is, the greater is the water consumption. Calcium and particularly aluminium concentrations influence the absorption of fluoride. The criteria have taken into account the effects of these variables at the values likely to be encountered in a "typical" water sample.

The European Union recognizes two maximum admissible concentrations for fluoride, namely, 1.5 mg/l at 8 - 12°C and 0.7 mg/l at 25 - 30°C. Under conditions in Southern Africa this is probably in the region of 0.75 mg/l, equivalent to approximately 26 - 28°C maximum temperature. The relationship between air temperature and recommended fluoride concentrations is shown in **Figure 5-16**.

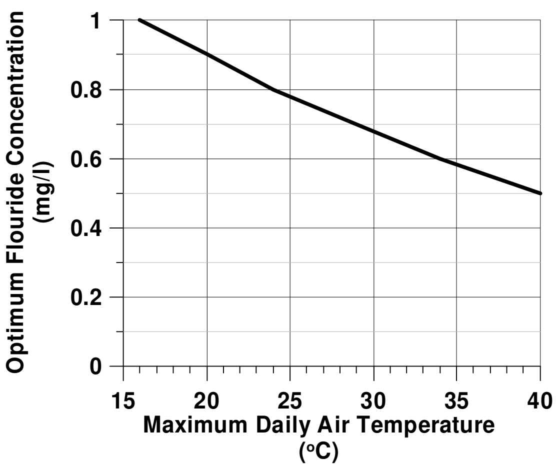


Figure 5-16 Relationship between Maximum Daily Air Temperature and Optimum Fluoride Concentration (after DWAF, 1996a)

Effects on Livestock from Fluoride (F)

The norm used in the guideline for livestock watering is primarily based on the toxicological effects associated with ingestion of fluoride.

Excessive amounts of fluoride result in tooth damage in young growing animals and bone lesions that cause crippling in older animals, especially in cattle. However, fluoride is also beneficial to animals and reduces osteoclast activity and increases osteoblast activity.

Signs of fluorosis are generally observed in the second and third year of exposure. Adverse effects due to fluorosis are indirect and include lameness and decreased feed and water intake (foraging, mastication and drinking become painful), which result in a decline in growth and health. Fluorosis first manifests itself in the permanent incisors (front teeth); dairy cattle are the most sensitive livestock and the most crucial stages are between six months to three years of age.

Toxicity by fluoride does not directly affect the health of calves since they (i) store the fluoride in bones and teeth to substantial levels before any adverse effects occur and (ii) high urinary excretion of fluoride occurs.

It is generally accepted that milk and meat are free from significant accumulations of fluoride and hence are safe to consumers.

Fluorosis is less severe when drinking water is hard, rather than soft (the presence of calcium and chloride reduces fluoride toxicity) since the occurrence of calcium together with fluoride limits fluoride toxicity.

Table 5-18 summarizes the effects of Fluoride on livestock health.

Table 5-18 Effects of Fluoride on Livestock Health (DWAF, 1996b)

Fluoride Range (mg/l)	Effects	
	Ruminants	Monogastrics
Target Water Quality Range 0 – 2	No adverse effects	No adverse affects
2 – 4	No adverse effects	**Adverse chronic effects associated with dental fluorosis in young livestock and skeletal fluorosis in mature livestock, such as mottling of teeth and enamel hypoplasia, a decrease in feed and water intake and a decline in productivity** may occur, with continuous long-term exposure. But are unlikely if: - feed concentrations are normal - exposure is short term Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement
4 – 6	Adverse effects may occur	**Adverse chronic effects (as above) and effects such as crippling , lameness and weight loss may occur, although** short-term

Fluoride Range (mg/l)	Effects	
	Ruminants	Monogastrics
		exposure could be tolerated depending on site-specific factors such as nutritional interactions and water requirement
6 – 12	**Adverse chronic effects associated with dental fluorosis in young livestock and skeletal fluorosis in mature livestock, such as mottling of decrease in feed and water intake and a decline in productivity,** may occur, with continuous long-term exposure. But are unlikely if: - feed concentrations are normal - exposure is short term Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement	As above
>12	**Adverse chronic effects (as above) and effects such as crippling , lameness and weight loss will occur, although** short-term exposure could be tolerated depending on site-specific factors such as nutritional interactions and water requirement	As above

Fluoride F in Molopo-Nossob Basin

Using the available data on F obtained from analyses of groundwater from boreholes, a map howing the areal distribution of F is constructed, see **Figure 5-17**. In the map, contour lines for F in accordance with the major guidelines for F in water are applied, see **Table 5-19**. The calculation is done through the interpolation technique "inverse instance to a power" using the computer programme "Surfer".

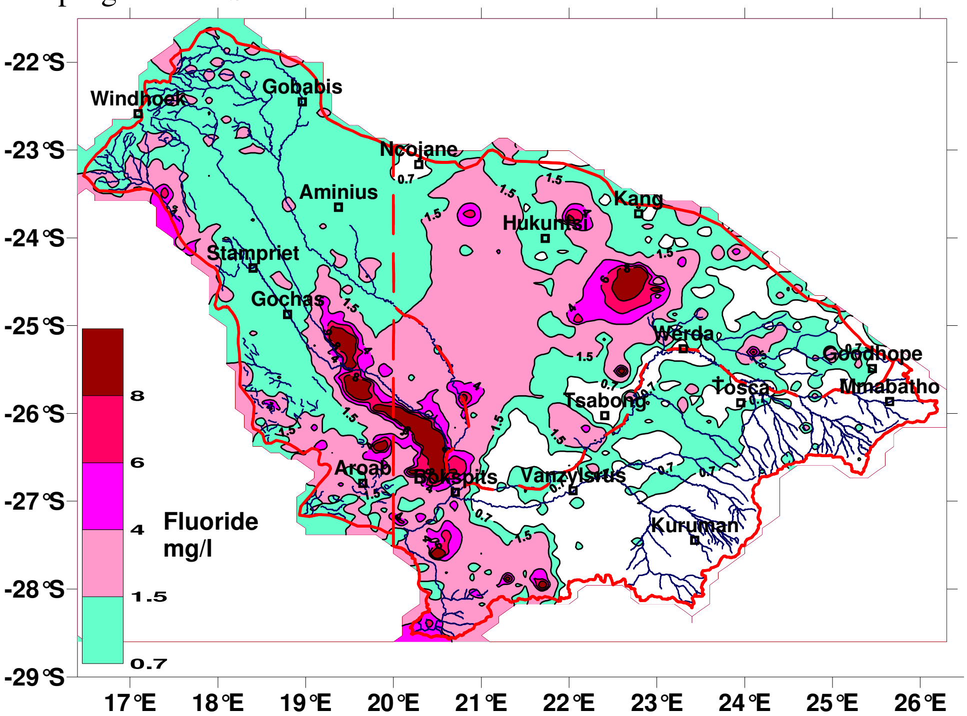


Figure 5-17 Fluoride (F) concentration in the groundwater within the Molopo-Nossob Basin

Table 5-19 F concentration limits chosen for the construction of the Fluoride map (Figure 5-14)

TDS equiv.-concentration level	Remarks
0.7	Upper limit set by Botswana for "ideal" water quality
1.5	Guideline value limit, WHO Standard, Namibia Group A and Botswana max allowable limit, Class 3. Threshold for softening of enamel.
4	Threshold for chronic effects of fluoride exposure
6	Severe damage on teeth and skeleton
8	Crippling skeletal fluorosis on long-term exposure.

In a major part of Botswana from the South-West up through Kgalagadi and further into the area mentioned South oh Kang, the groundwater contains F above the limit of 1.5 mg/l, see **Figure 5-17**. A major part of the Southern part of Molopo-Nossob Basin along the Auob River in Namibia has F values above the limit of 1.5 mg/l. Low fluoride values are found in South Africa with the exception of the western part.

In the Nossob aquifer in the Stampriet Artesian Basin, the groundwater show elevated level of fluoride, see **Figure 5-18**.

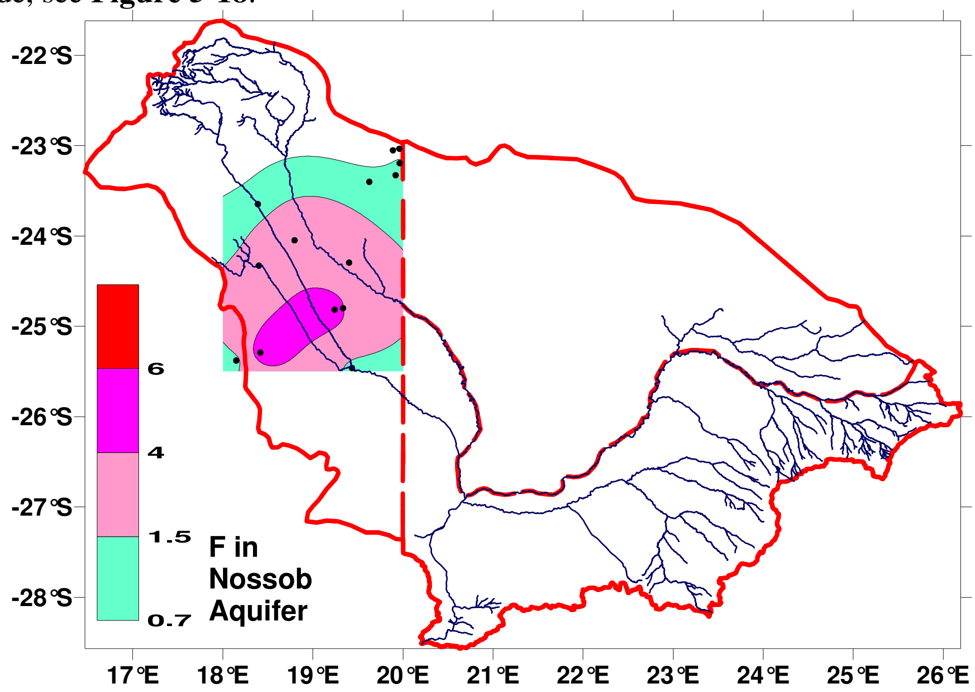


Figure 5-18 Groundwater Fluoride (F) content in the Nossob aquifer in the Stampriet Artesian Basin in Namibia. Data source: JICA, 2002

5.2.2.5 Areas of Poor Groundwater Quality in the Molopo-Nossob Basin

The three groundwater quality parameters TDS, NO_3 and F, have each delineated areas which exceed the limits set up in the guideline for water use (domestic consumption and livestock watering).

Figure 5-19 shows for each of the parameter an area delineated in which the guideline limits are exceeded for human consumption (TDS >2,000 mg/l, NO_3 >45 mg/l and F >1.5 mg/l).

Figure 5-20 shows similar areas delineated by the guidelines for livestock watering (TDS >10,000 mg/l, NO_3 >180 mg/l and F >4 mg/l).

The areas exceeding the guideline, overlain in **Figure 5-19 and 5-20;** show as a result regions within Molopo-Nossob basin having one, two or all parameters exceeding the guideline values used in the current study.

The regions where having all three guidelines for human consumption exceeded are found in the South-western part of Botswana, the Western part of South Africa and the South-eastern part along the Auob River in Namibia. For livestock watering only some limited areas, probably associated with local pollution of the water sources, show NO_3 exceeding 180 mg/l. Regions exceeding two of the guideline limits for livestock watering are found in the same areas as for exceeding the guidelines for human consumption in the south-western Botswana, Western South Africa and along the Auob River in the South-eastern part of Namibia, however in reduced area extension. An area between Hukuntsi and Werda in Botswana also has TDS and F exceeding the guideline limits for livestock watering.

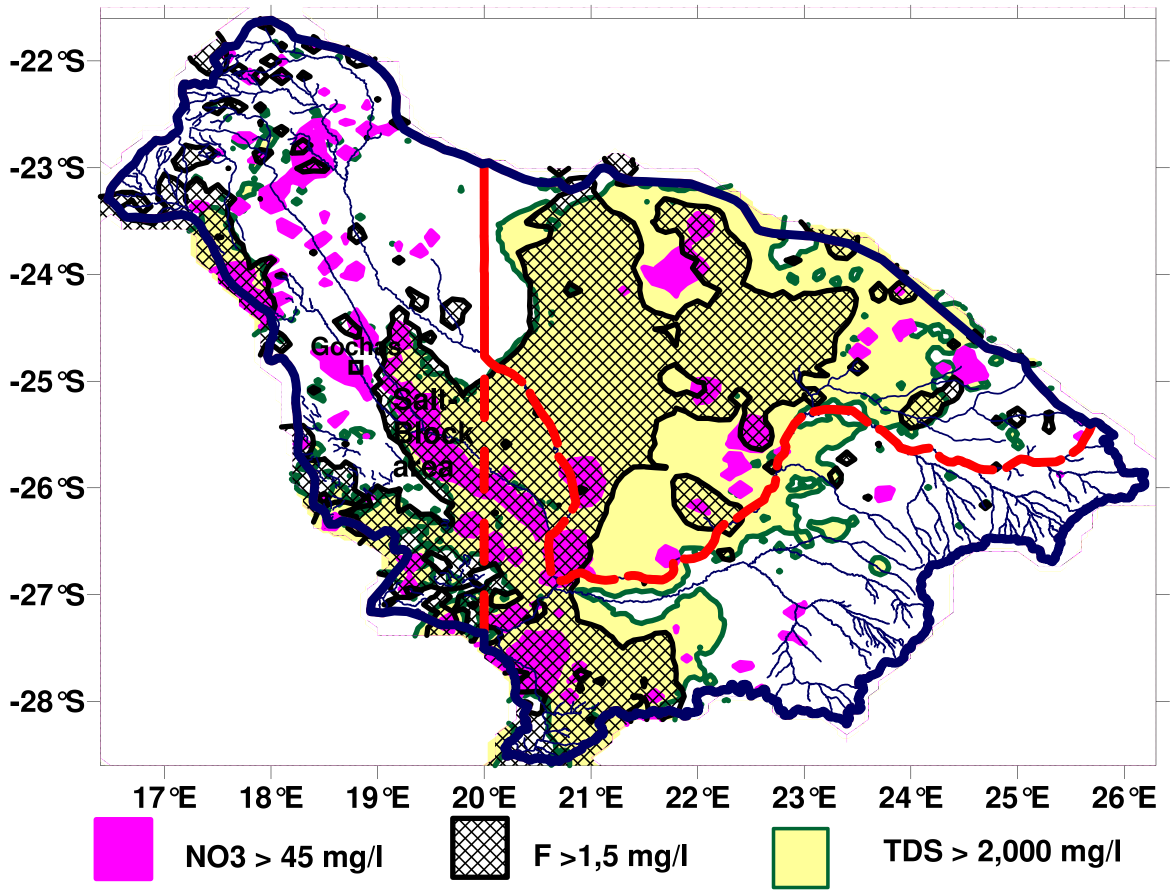


Figure 5-19 Areas exceeding guideline limits for human consumption

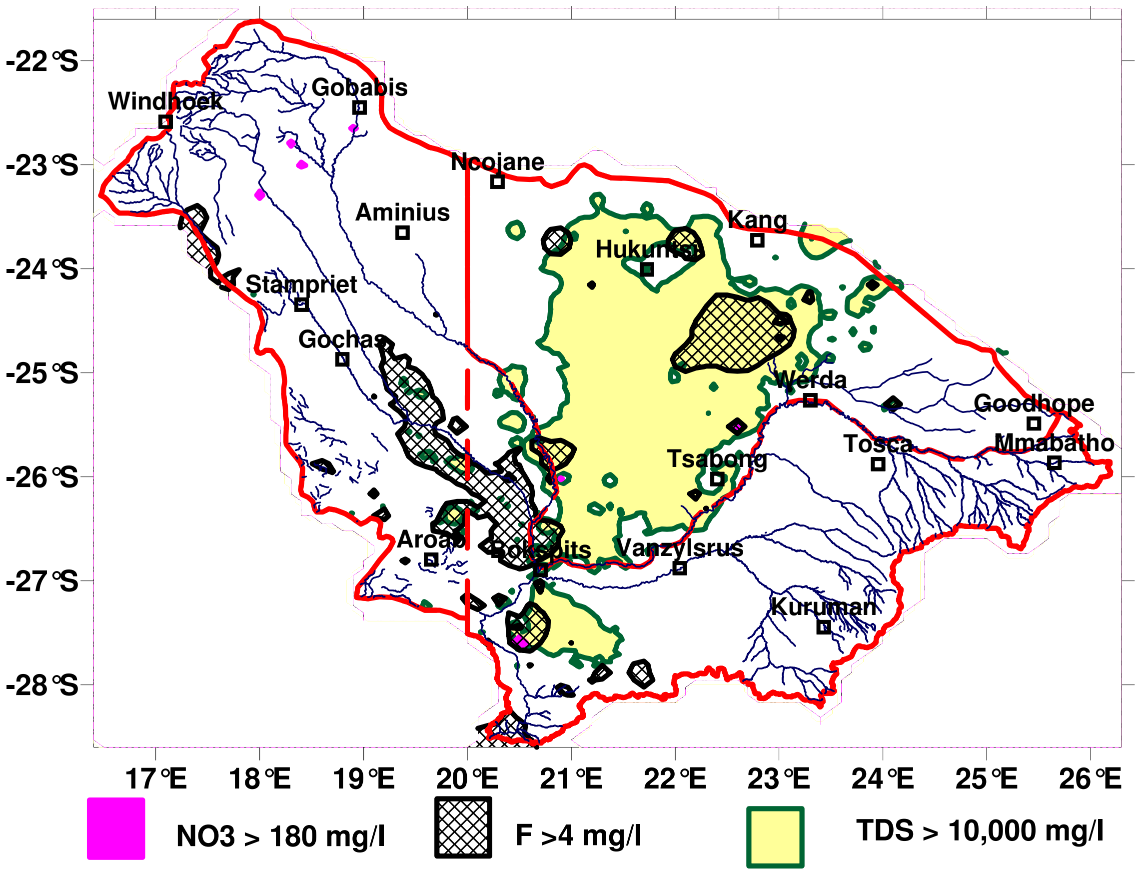


Figure 5-20 **Areas exceeding guidelines for livestock watering**

It should be noted that the number of groundwater quality information (borehole data) varies over the Molopo-Nossob Basin. Whereas South Africa and Namibia are well covered, Botswana on the other side has only limited number of information on groundwater quality. **Figure 5-21** illustrates this difference where each borehole used in the assessment of the groundwater quality is shown.

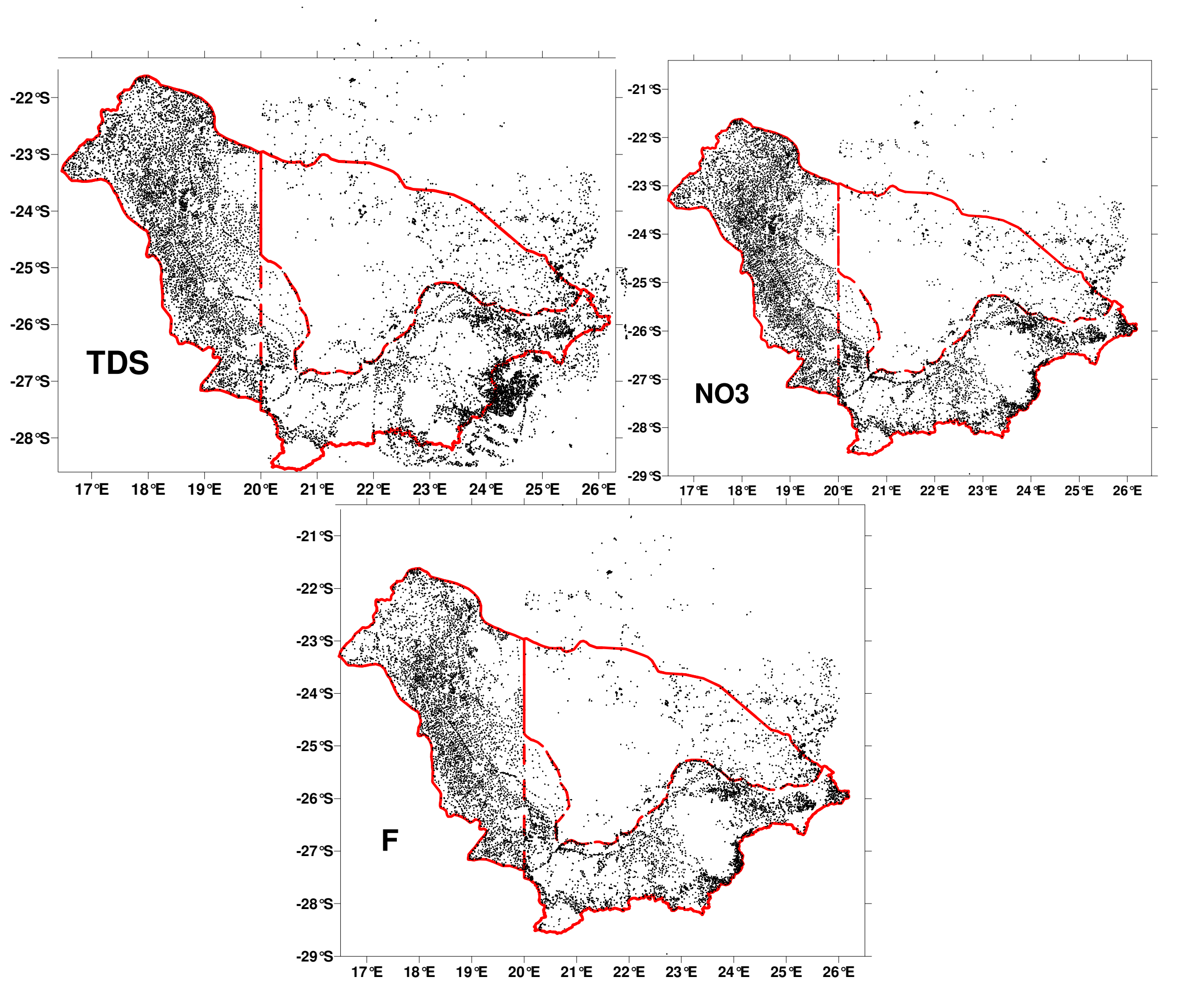


Figure 5-21 **Location of data (boreholes) from which information of TDS (upper left), NO_3 (upper right) and F (lower) are obtained**

5.2.3 Groundwater Monitoring and Flow

5.2.3.1 General

Groundwater monitoring is one of the most important topic in the supply, development and planning of water for all sectors of a country's society. Domestic, industrial as well as agricultural water supply for the future of a nation depends on available water resources where groundwater resources play the most important role. Currently it is estimated that around 80-90% of the water supply in the Molopo-Nossob Basin comes from groundwater. The climate situation in the basin does not favour any large replenishment of groundwater. Therefore groundwater abstraction on very large scales must always consider the available replenishment to allow groundwater to be abstracted and used in a sustainable manner.

It is of the greatest importance that the available groundwater resources are monitored in order to avoid situations in which the resources are exploited and no or limited groundwater resources are left for the future prosperity and development.

With groundwater monitoring is understood the measurement of:

- Groundwater level

- Groundwater abstraction
- Groundwater quality

In order to be considered as a monitoring exercise measurements have to be done continuous at regular interval, decided by the local groundwater situation such as abstraction of groundwater, mining, irrigation etc within the region subjected to monitoring.

Abstraction of groundwater always has an impact on the groundwater level. The size of the impact, measured as changes in the groundwater level depends on the stress imposed, the abstraction (or human implied replenishment), and of the hydraulic parameters of the groundwater resource and the natural replenishment to the groundwater.

A balance between the outtake of water and the groundwater level is reached in general terms when the replenishment balances the abstraction. In the climatic environment of the Molopo-Nossob Basin, extreme large groundwater abstraction will imply that large area will be influenced with a groundwater lowering in order to reach such a balance.

Beside groundwater abstraction, impact on the groundwater levels can be caused by:

- Land use change
- Irrigation and drainage
- Climate change
- Mining and underground construction

Groundwater quality will also be affected by the changes mentioned. However, whereas the changes in groundwater level are a more or less instance response to any stress or impact, the changes in quality will take longer time. Groundwater level is changing in time and groundwater quality is changing with location is a common expression in hydrogeology.

Groundwater monitoring is usually the responsibility of government organizations. There is however also monitoring has done by communities and private institutions as requirement within permits given for water abstraction or release of used or unused water.

Most of the groundwater monitoring in the Molopo-Nossob basin are done and collected by the water departments in the three countries. However the monitoring of groundwater (abstraction, level, quality, outflow and recharge) is performed by several departments, and there is the risk of limited flow of information between the stakeholders.

Currently monitored data of the groundwater resources are used in planning purposes for expansion of the supply, investigation for new resources and for international agreement of the use of transboundary water resources. In recent time the effect of climate change is an additional impact source on the groundwater resources. Monitoring is therefore also focused on providing data on how and where this impact affects the groundwater resources.

In the Molopo-Nossob Basin all sectors of the society are heavily dependent on groundwater. Good and reliable data about this most important resource is of the greatest importance for the prosperity and future development of this area and also to approach many of the challenges now appearing as impacts of the environment, pollution of water, supply of water, global climate changes, to mention a few.

A vital aid to good groundwater management is a well-conceived and properly supported monitoring and surveillance system. 'Out of sight, out of mind' is a poor philosophy for sustainable development.

The general neglect of groundwater resources in terms of national planning, monitoring and surveillance will only be overcome once effective monitoring is regarded as an investment rather than merely a drain on resources.

For this reason monitoring systems should periodically be reassessed to make sure that they remain capable of informing management decisions so as to afford early warning of degradation and provide valuable time to devise an effective strategy for sustainable management.

Groundwater monitoring in the Molopo-Nossob Basin is at many places done in connection with abstraction of groundwater. The monitoring serves as a control that the water level is not lowered to such level that the water abstraction is jeopardized or that water in surrounding area is getting so low that boreholes and wells will get dry and compensations will be claimed. **Table 5-20** summarizes the number of sites where the groundwater is monitored in the Molopo-Nossob Basin. At each site one or more boreholes are monitored and in some places, various groundwater levels in various aquifers are monitored in the same borehole (e.g. Stampriet area in Namibia).

Table 5-20 Number of sites and boreholes for groundwater monitoring in Molopo-Nossob Basin

Country	Number of sites	Boreholes	
		Total	Presented in this report
Botswana	11*	164	35
Namibia	63		29**
South Africa	456		35
*=Including the Kanye and Makunda monitoring boreholes **=number of measuring intervals in borehole (different aquifers)			

5.2.3.2 Botswana

The location of monitoring boreholes in the Botswana part of the Molopo-Nossob Basin is shown in **Figure 5-22.**

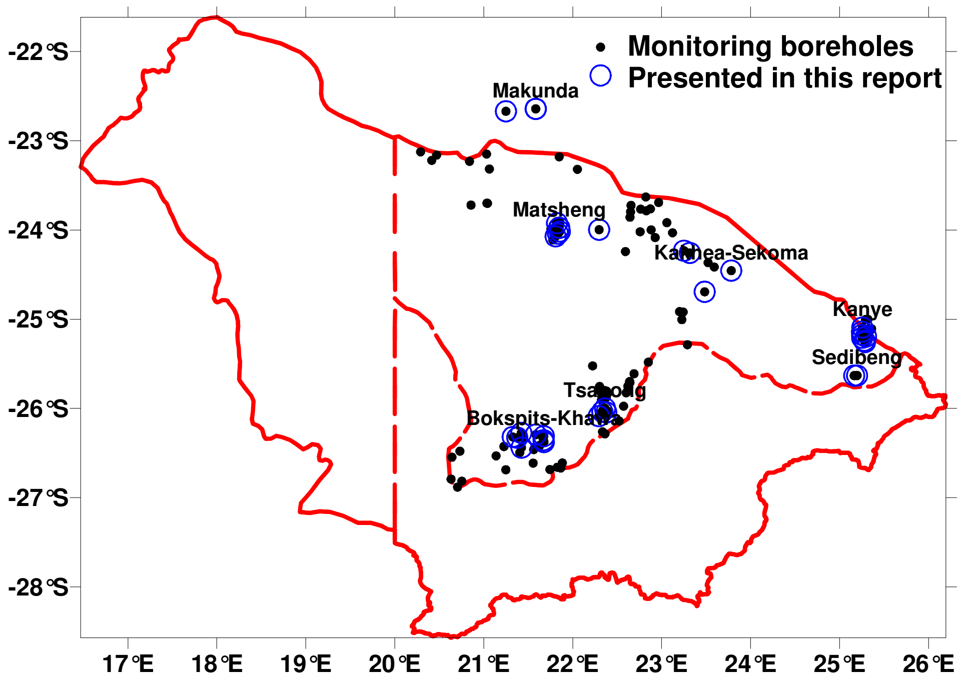


Figure 5-22 **Monitoring boreholes in Botswana and boreholes presented in the current report**

The longest time-series of monitoring exists in the Kanye wellfield area. This wellfield area, comprising three separate wellfields, is on the north-eastern boundary of the basin and the surface water divide is running through the wellfield, see **Figure 5-23**. A number of the monitoring boreholes within the basin show an impact of the abstraction from the wellfields. Other boreholes within the Molopo-Nossob boundary show no or minor impact of the abstraction from the Kanye wellfields, see **Figure 5-24**.

The abstraction from the wellfield is predicted to be the order of 4 Mm^3/a in the year 2010, see **Figure 5-25**.

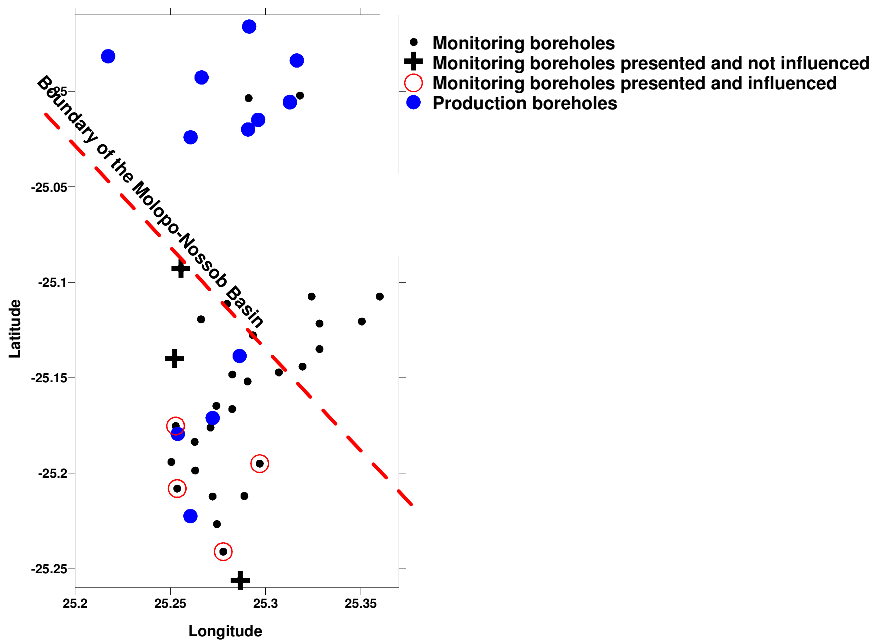


Figure 5-23 **Monitoring and abstraction boreholes in the Kanye wellfield area in Botswana**

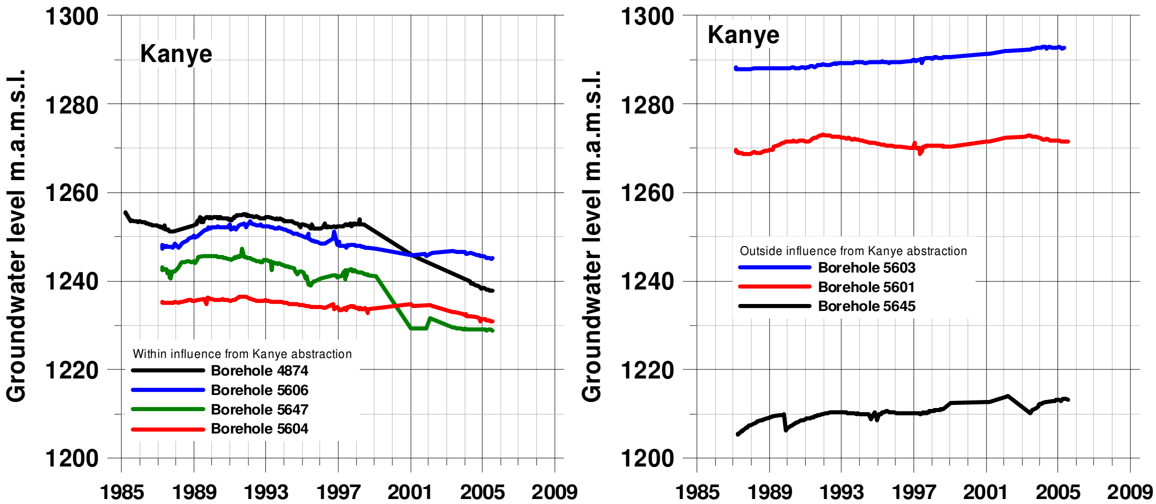


Figure 5-24 Groundwater level in monitoring boreholes in the Kanye wellfield area, influenced and not influenced by the abstraction from the wellfields

Table 5-21 summarizes the basic information about the presented graphs on the groundwater level in the Kanye area.

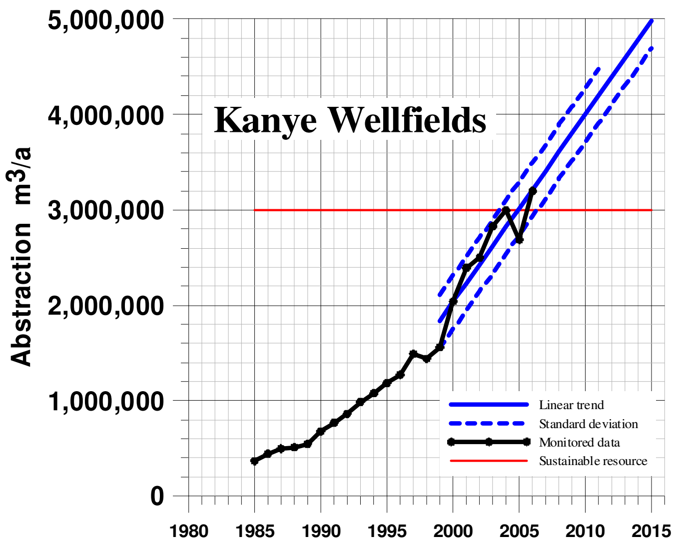


Figure 5-25 Abstraction from the Kanye wellfields predicted from linear extrapolation of monitored annual abstraction

Table 5-21 Basic information on the groundwater level monitoring in the Kanye area, Southern District, presented in Figure 5-24

Site Id	Name	No of data	Long	Lat	Altitude	Colour
Influenced boreholes						
4874	Ramonnedi	263	25.252778	25.175278	1264.00	Black
5606	Kanye	172	25.296944	25.195000	1268.88	Blue
5604	Kanye	166	25.277778	25.241111	1260.35	Red
5647	Kanye	174	25.253611	25.208056	1250.59	Green
Not influenced boreholes						
5645	Mmathethe	168	25.286667	25.256111	1229.26	Black
5603	Kanye	171	25.255556	25.092778	1325.00	Blue
5601	Kanye	176	25.252222	25.140000	1296.92	Red

Of the monitoring boreholes shown in **Figure 5-22**, monitoring from 35 boreholes is presented in the current report.

Groundwater monitoring the Botswana Molopo-Nossob Basin area is mainly performed by the Department of Geological Survey (DGS), with the exception of the recently started monitoring in the Kang and Ncojane areas. Since 1992, Department of Water Affairs has carried out the groundwater monitoring in the Tsabong area, see **Figure 5-26**. The water level in the boreholes shows in general a decreasing trend, however with periods of recoveries. The abstraction from the wellfield in Tsabong, as shown in **Figure 5-27**, increased up to the year 2004 after which a lower amount was abstracted during the following years up to year 2007 when an increase was recorded. This fluctuation in abstraction is reflected in the monitoring of the groundwater level in some of the boreholes shown in **Figure 5-26**.

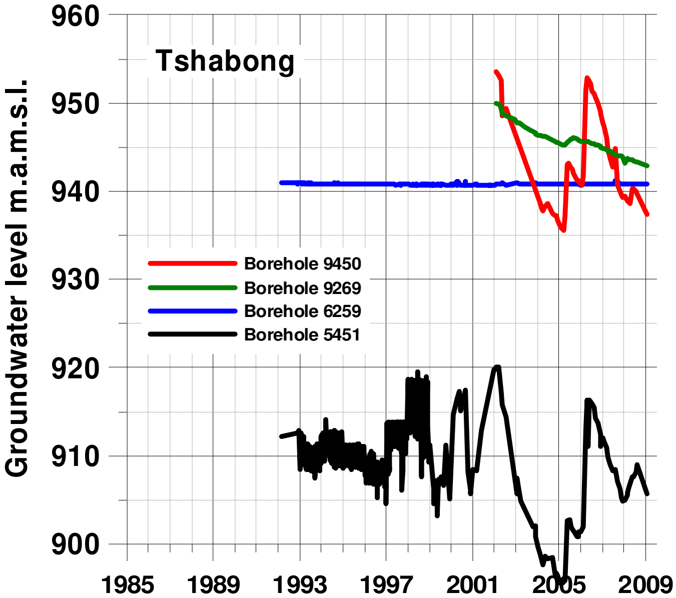


Figure 5-26 **Groundwater level monitored in observation boreholes surrounding the Tsabong wellfield in Botswana**

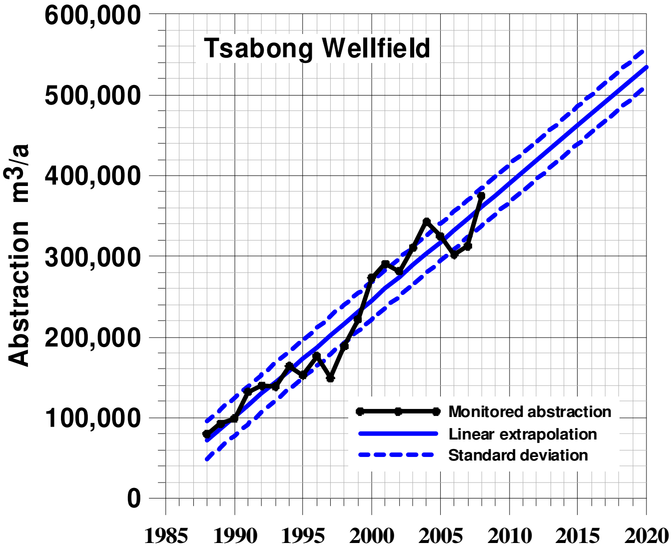


Figure 5-27 **Monitored and predicted abstraction from the Tsabong wellfield, Botswana**

Monitored groundwater level in boreholes at Matsheng, is shown in **Figure 5-28**. The boreholes are all in a perched aquifer the Kalahari beds from which water is abstracted from an existing wellfield in the area. The dotted graphs in the figure illustrate a groundwater level which slightly decreases with time but not influenced by any variations in abstraction from the wellfield, whereas the full lines are from boreholes where influences of recharge are noticed.

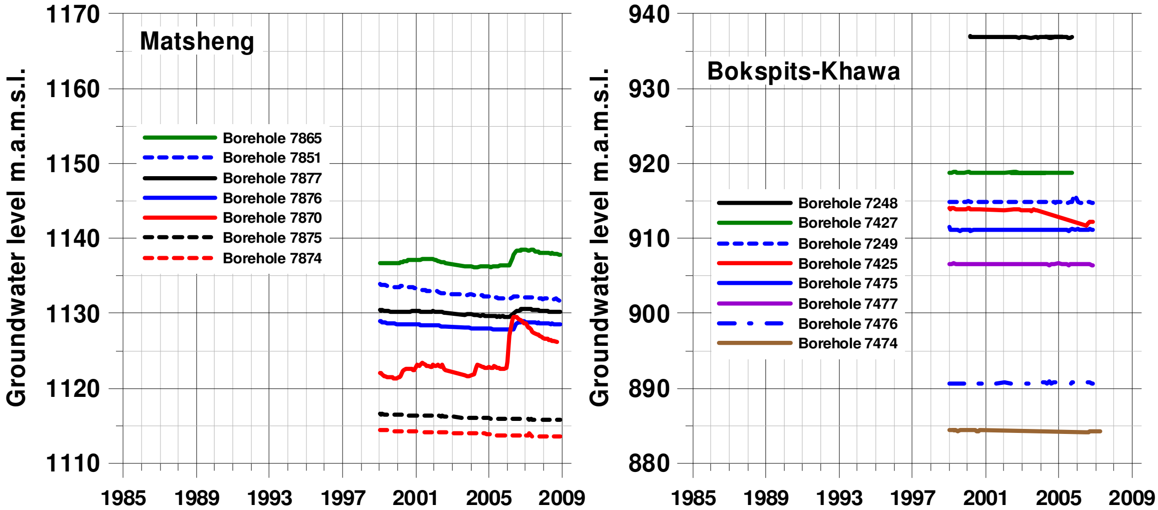


Figure 5-28 Groundwater level in monitoring boreholes in Matsheng and Bokspits-Khawa

Figure 5-28 also shows the groundwater level monitored in the Ecca (Auob) aquifer in the southernmost part of Botswana (Bokspits-Khawa). No major wellfield is associated with these monitoring boreholes and a more or less stable groundwater level, with a very slight decline with time, see **Table 5-22**.

Table 5-22 Changes in groundwater level monitored in Bokspits-Khawa area

Monitoring area	Borehole No	Monitored period	Average water level change, mm/a
Bokspits - Khawa	7248	2000-2005	-18
	7424	1999-2005	-10
	7249	1999-2006	-5
	7475	1999-2006	3
	7477	1999-2006	-3
	7476	1999-2006	10
	7474	1999-2006	-27
	7248	1999-2006	-18
Makunda	7763	1999-2008	-17
	7764	1999-2008	-1
	7768	1999-2008	18
Minus sign indicates groundwater level decline			

Since the area in the southern most Botswana is not influenced by any major water abstractions, the only abstractions are for local settlements and for watering of livestock (mainly sheep and goats), a major impact on the water level is not expected. The monitored decline might therefore be a sign of an impact caused by changes in the climate. A change in temperature over the period from 1960 is recorded at the nearby meteorological station in Tsabong. An increase in the daily mean monthly minimum temperature for the hottest month of the year, January, is recorded and a decrease in the same temperature is observed for the coldest month, July. This means that the difference in mean month minimum temperature has increase with approximately 0.08 °C/a, see **Figure 5-29**.

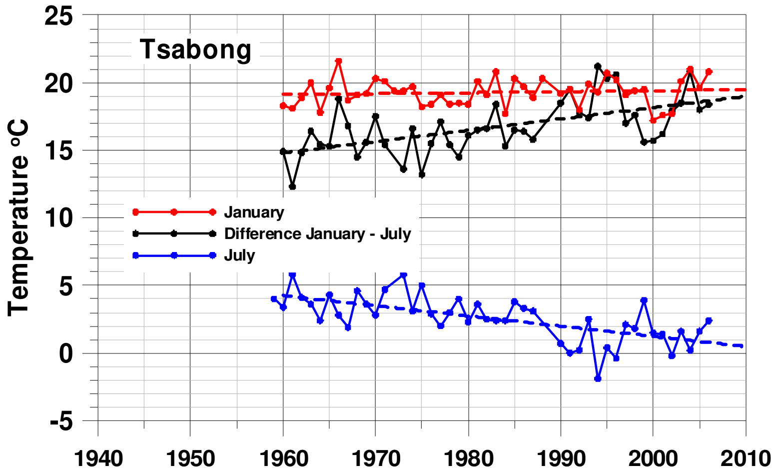


Figure 5-29 **Mean annual minimum temperature for January and July from the meteorological station in Tsabong. Calculated difference between the January and July annual mean minimum temperature. (Data source: Department of Meteorological Services, Botswana)**

Groundwater level monitoring from Makunda, north of the Molopo-Nossob Basin shows stable groundwater level as from 1999, see **Figure 5-30**. The slight decline recorded is calculated as an average value in the same size as for the decline in Bokspits-Khawa, see **Table 5-22**.

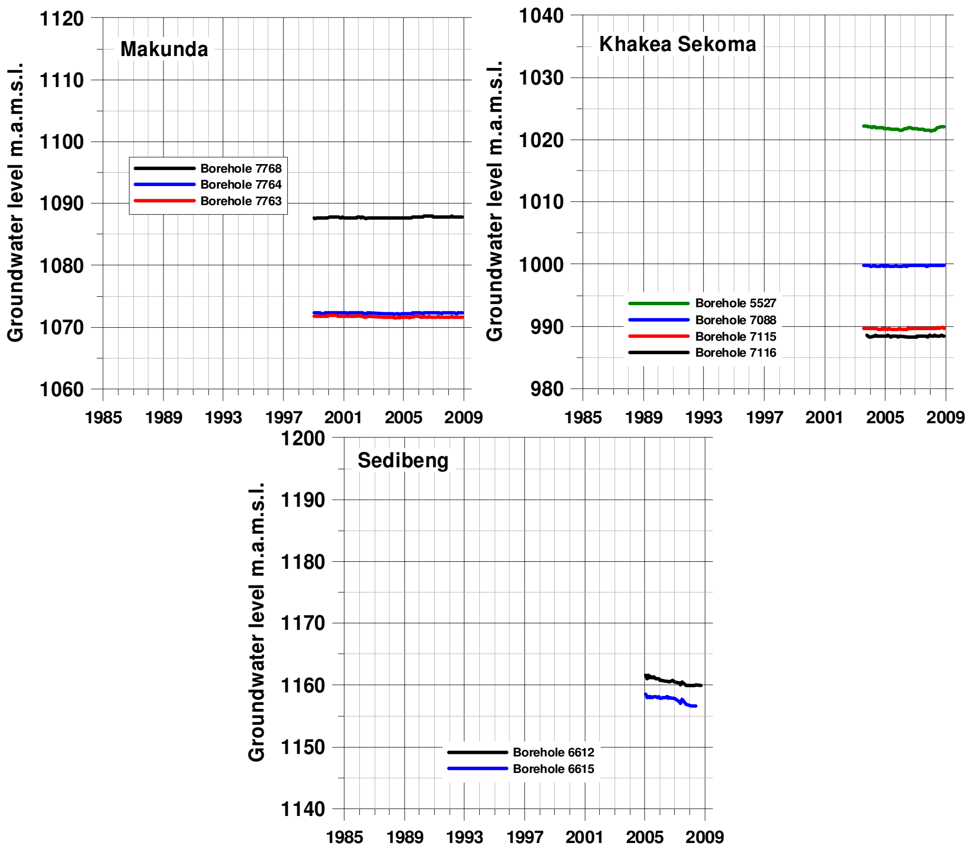


Figure 5-30 **Groundwater level in monitoring boreholes in Makunda, Khakea-Sekoma and Sedibeng**

Groundwater level is also monitored in areas of the Kakhea-Sekoma and the Sedibeng villages as illustrated in **Figure 5-30**. Locations of the monitoring areas are shown in **Figure 5-22**.

5.2.3.3 Namibia

Stampriet Artesian Basin

The groundwater monitoring in Namibia is focused on the Stampriet Artesian Basin, SAB. In the JICA report (JICA, 2002) results of monitoring of groundwater level in the three identified aquifers, (i) Kalahari, (ii) Auob and (iii) Nossob are presented. In general the groundwater level in the three aquifers differs; in some area, the Nossob aquifer has the highest water level, in other areas it has the lowest level. In order to understand the hydrogeological conditions in the SAB a short description of the basin given by Prof J. Kirschner is given below, taken from the report "Groundwater in Namibia" (Christelis and Struckmeier, 2001).

The Stampriet Artesian Basin, SAB, covers the main part of the Molopo-Nossob Basin in Namibia. It lies roughly between 23^o and 26^o S; 17.5^o and 20^o E (the border to Botswana). It is the largest groundwater basin in Namibia.

Groundwater extraction within the basin is maintained by the regulations prescribed in the Water Act. Extensive groundwater extraction by commercial farmers occurs in the central area of the western side of the basin. According to some monitoring wells installed during 1978, groundwater levels have been declining continuously since 1980.

The groundwater condition (artesian) was recognized in 1906 during siting of boreholes. Various processes of borehole drilling continued after the first and the second World Wars. Major investigations covering the whole area of the SAB were undertaken. The problem of saline groundwater was addressed over a 12-years period (1969-1981) with results presented in maps and reports.

A hydro census was carried out by the Department of Water Affairs (DWA) during 1986 to 1988 in order to define the impact due to extraction of the groundwater. A major development project, in cooperation with the Japanese Government with the aim to establish a groundwater management plan to optimally utilize the groundwater resources of the basin was completed in 2002 (JICA, 2002).

The Stampriet Artesian Basin is bounded in the west by an escarpment that rises about 80 meters. West of the Auob River a dune field commences which stretches eastwards to and beyond the Nossob River. The stationary longitudinal dunes are nearly parallel to the river system and about 10 to 15 m high. The valleys between are several hundred meters wide.

The Auob River below Stampriet and the Nossob River from Leonardville to Aranos are evidence of a much wetter climate in the past. Here the valleys are several hundred meters wide and at places incised more than 50 m into the Kalahari sediments. The present river courses are generally little more than 10 m wide and only 1.5 m deep in occasional gullies. The Auob River is cut off from its upper tributaries by a dune field east of Kalkrand that blocks the Oanob and Skaap rivers.

The geology and hydrogeology of the Stampriet Artesian Basin within Namibia is comparatively well understood. It is not well known how far the SAB aquifers stretch into Botswana and South Africa, partly because the area is sparsely populated and partly because the quality of the water becomes less suitable towards the southeast. During the past few years the Artesian Aquifer is identified and explored in Botswana (DWA, 2008).

The aquifer system in SAB is sub-divided into three major aquifers, see **Figure 5-31**:

- The upper phreatic to semi-confined Kalahari aquifer, G3. The Kalahari Sequence consists of unconsolidated to semi-consolidated sand and silt. This upper aquifer is in most cases separated from the lower Auob sandstone aquifer by an aquiclude of Karoo shales and mudstones.
- A shale layer also separates the upper Karoo sandstone aquifer (Auob aquifer, G2 in Namibia) from the lower Karoo sandstone aquifer.
- The lower Karoo sandstone aquifer (Nossob aquifer, G1 in Namibia) is underlain by shales that act as an aquitard, and glacial tillites of the Dwyka Formation.

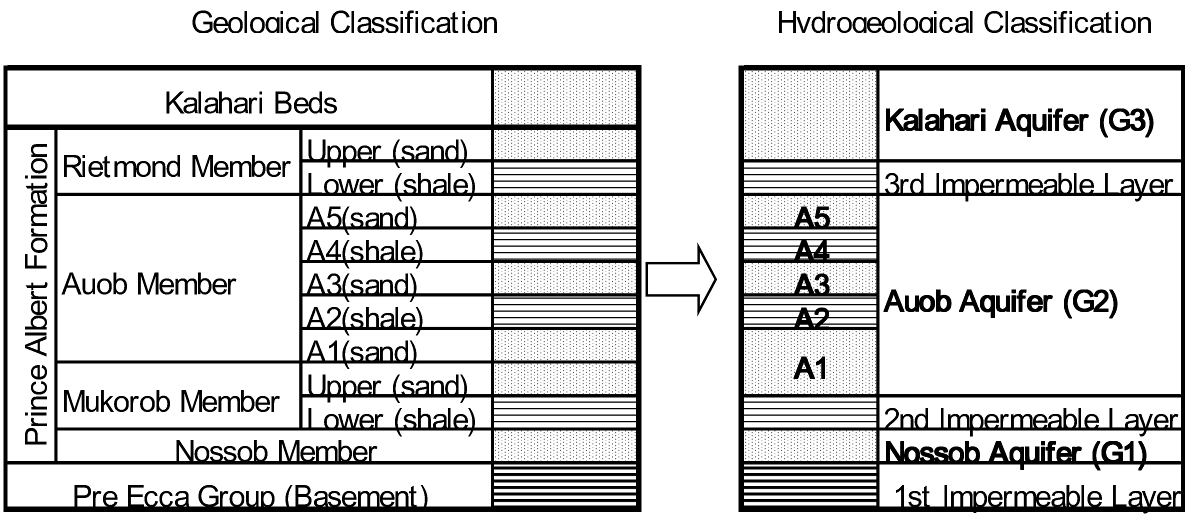


Figure 5-31 Brief overview of the geological and hydrogeological classification of the Stampriet Artesian Basin (JICA, 2002)

Not all of the aquifers occur everywhere and the use of them is determined by water quality, depth to the aquifer and their yields. The southern part of the Stampriet Artesian Basin borders to South African Kalahari National Game Park and the Gordonia District. In Gordonia, the water quality of the Karoo aquifers appears to be as poor as in the Salt block area, described below.

The Auob and the Nossob aquifers are confined and free-flowing (artesian) in the Auob valley at and downstream of Stampriet and in the Nossob valley around Leonardville. Elsewhere sub-artesian conditions prevail, that is, the water in the aquifer is confined, but the pressure is not sufficient for the water (water level) to rise above the ground surface.

Prior to the deposition of the Kalahari sediments, a major river system entered Namibia at about 24° S and 20° E. This river flowed in a south-westerly direction, turning east of Gochas towards the Mata Mata area at the South African border. A major tributary from the north joined the main river at about 24.75° S and just East of 19° E. This river system cut deeply into the underlying Karoo sequence, in places right down to the base of the Auob formation.

The Kalahari sediments covering the Karoo sequence are thin with calcrete or dune-sand at the surface along the northern and western boundaries of the basin. South-eastwards the sediments reach a thickness of 150 m, but in the pre-Kalahari river mentioned the sediments can reach 250 m in thickness.

With the low rainfall, high potential evapotranspiration and no runoff outside the Auob and Nossob valley, salts accumulate in the Kalahari and the groundwater quality deteriorates in a south-easterly direction. Because the confining layers and the Auob aquifer are largely removed in the pre-Kalahari valley, the quality of the groundwater in the Auob aquifer is also affected south-east of that valley and that part of the Stampriet Artesian Basin is called the "Salt bock" (see **Figure 5-32**).

The recharge mechanisms of the aquifers are understood to be dependent on the occurrence of identified small, shallow depression caused by dissolution of calcrete where local runoff is concentrated and fed into permeable layers or structures below. From there the water continues percolation down into the artesian aquifers below. The artesian aquifers are recharged during years with abnormally high rainfall.

Most of the water supply schemes in the Stampriet Artesian Basin extract groundwater from the Auob aquifer, only Koës uses the Nossob aquifer.

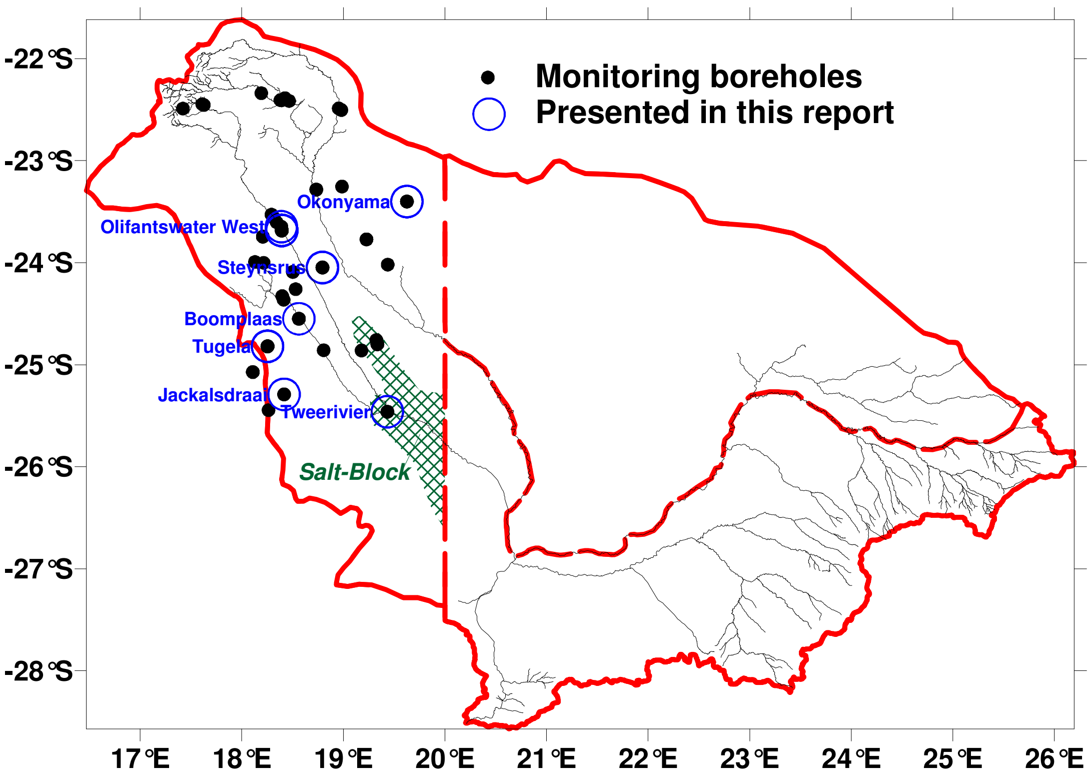


Figure 5-32 **Monitoring boreholes and boreholes presented in the current report**

Groundwater level monitoring

The location of the groundwater monitoring boreholes (or sites) in the Namibian part of the Molopo-Nossob basin is illustrated in **Figure 5-32**. In the current report only a selected number of these sites are presented, summarized in **Table 5-23**.

Monitoring of the groundwater level in the Nossob aquifer (red lines in diagrams) shows in general a stable level with time. A slight decline is observed in the monitoring boreholes at Olifantswater, sees **Figure 5-33 and 5-34**, and however interrupted by a 6 years higher level in borehole 22545 and at the same time a slight raise at Tugela. This can be attributed to the heavy rains during the years 1999 and 2000 which affected the water level in the Kalahari aquifer (JICA, 2002).

Table 5-23 Data on monitoring sites presented in the current report

Map No	Site Id	Name	No of data	Long	Lat	Altitude	Aquifer	Colour in diagrams
2319BC	39845	Okonyama	1778	19.62489	-23.40098	1258.05	Kalahari	Black
	39846	Okonyama	613	19.62577	-23.40049	1256.39	Auob	Blue
	39847	Okonyama	1198	19.62621	-23.40105	1256.38	Nossob	Red
2519AD	39854	Tweerivier	2520	19.43266	-25.46122	1021.25	Kalahari	Black
	39856	Tweerivier	2492	19.43324	-25.46148	1021.26	Nossob	Red
2518AD	39852	Jackalsdraai	1785	18.41678	-25.29163	1148.19	Kalahari	Black
	39853	Jackalsdraai	1785	18.41650	-25.09117	1148.14	Nossob	Red
2318CB	22546	Olifantswater West	273	18.39241	-23.68523	1268.08	Kalahari	Black
	22546	Olifantswater West	273	18.39241	-23.68523	1268.08	Auob	Blue
	22546	Olifantswater West	273	18.39241	-23.68523	1268.08	Nossob	Red
2418CD	22838	Tugela	269	18.25379	-24.82056	1206.46	Kalahari	Black
	22838	Tugela	268	18.25379	-24.82056	1206.46	Auob	Blue
	22838	Tugela	269	18.25379	-24.82056	1206.46	Nossob	Red
	22839	Tugela	272	18.25271	-24.81949	1203.00	Kalahari	Black dots
	22839	Tugela	272	18.25271	-24.81949	1203.00	Auob	Blue dots
	22839	Tugela	272	18.25271	-24.81949	1203.00	Nossob	Red dots
2318CB	21815	Olifantswater West	273	18.39452	-23.68436	1269.63	Kalahari	Black
	21784	Olifantswater West	273	18.39452	-23.68436	1269.63	Auob	Blue dots
	21814	Olifantswater West	273	18.39452	-23.68436	1269.63	Kalahari	Black
	39840	Olifantswater West	2795	18.38976	-23.64725	1275.26	Auob	Blue dots
	39841	Olifantswater West	2795	18.38970	-23.64783	1275.60	Nossob	Red
2318CB	22544	Olifantswater West	359	18.39462	-23.68476	1269.70	Auob	Blue
	22545	Olifantswater West	273	18.39398	-23.68266	1268.08	Kalahari	Black
	22545	Olifantswater West	273	18.39398	-23.68266	1268.08	Auob	Light Blue
	22545	Olifantswater West	273	18.39398	-23.68266	1268.08	Nossob	Red
2418BB	39842	Steynsrus	2377	18.79340	-24.04592	1208.05	Kalahari	Black
	39843	Steynsrus	2377	18.79312	-24.04792	1208.05	Auob	Blue
	39844	Steynsrus	276	18.79614	-25.04858	1208.05	Nossob	Red
2418DA	10120	Boomplaas	13.2	18.56223	-24.54999	1000.00		Black

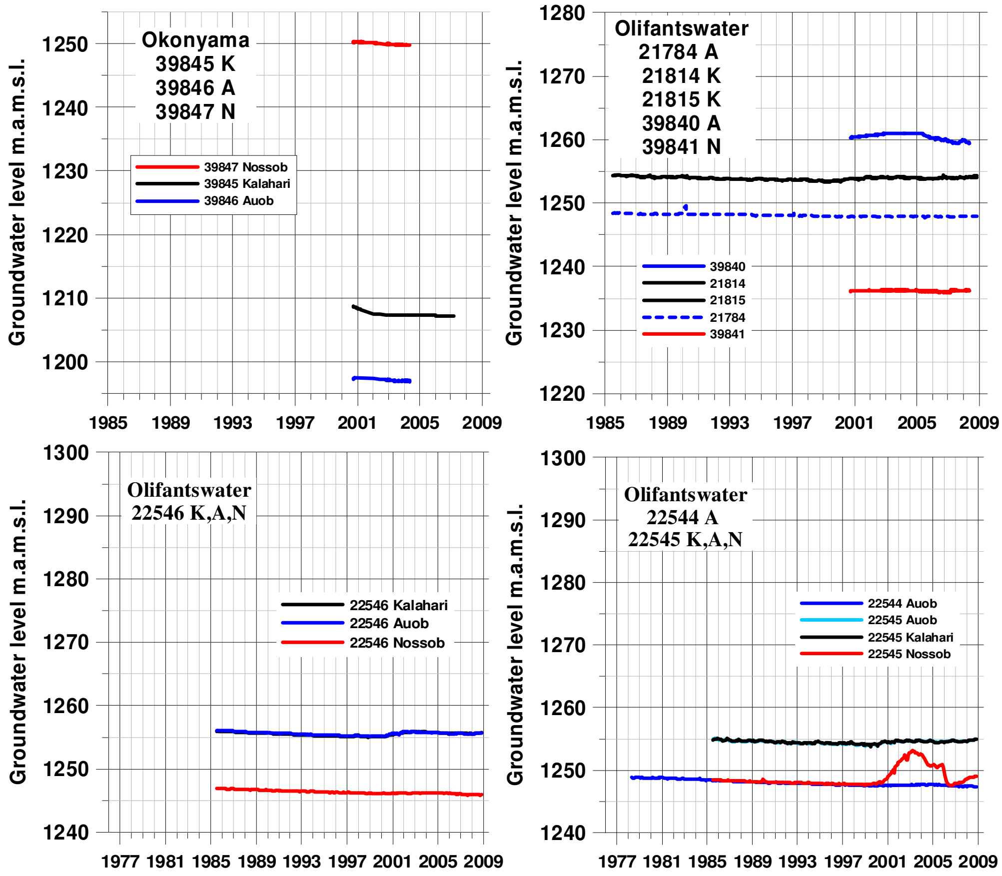


Figure 5-33 Groundwater level monitoring at Okonyama and Olifantswater in Namibia

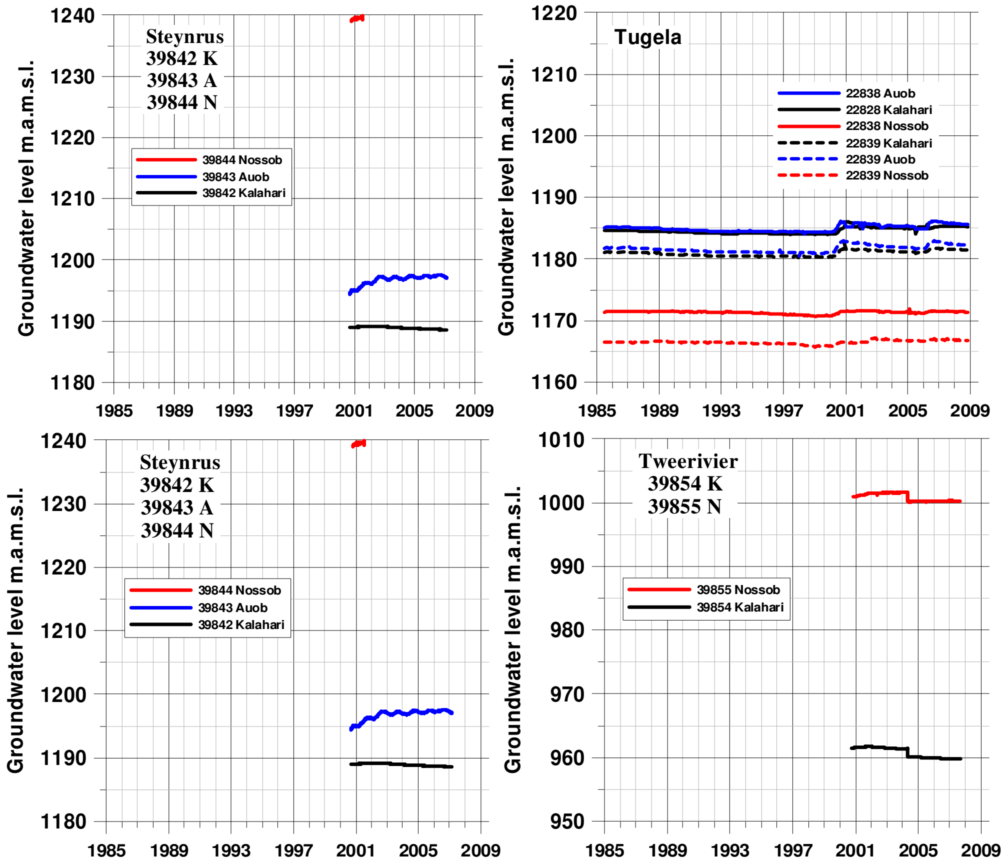


Figure 5-34 Groundwater level monitoring at Steinrus, Tugela, Jackalsdraai and Tweerivier in Namibia

The Nossob aquifer, under confined condition was identified in a number of boreholes in the study of the Stampriet Artesian basin (JICA, 2002). Groundwater level monitored in those boreholes gives a general flow picture of the water in the Nossob aquifer as illustrated in **Figure 5-35**. South of Aranos the groundwater level is lowered to create a local depression in the otherwise gentle slope towards southeast.

The monitored groundwater level in the Nossob aquifer is higher than in the other aquifers in a large part of the Stampriet Artesian Basin, see **Figure 5-36**, also presented by the monitoring sites (Okonyama, Steynrus and Tweerivier). In some places, as shown in **Figure 5-37**, the groundwater level (head) of the Nossob aquifer is above the ground surface (artesian conditions). The general direction of groundwater flow in the Nossob Aquifer is from the NW to the SE with an average of piezometric gradient of around 1/1000 (JICA, 2002).

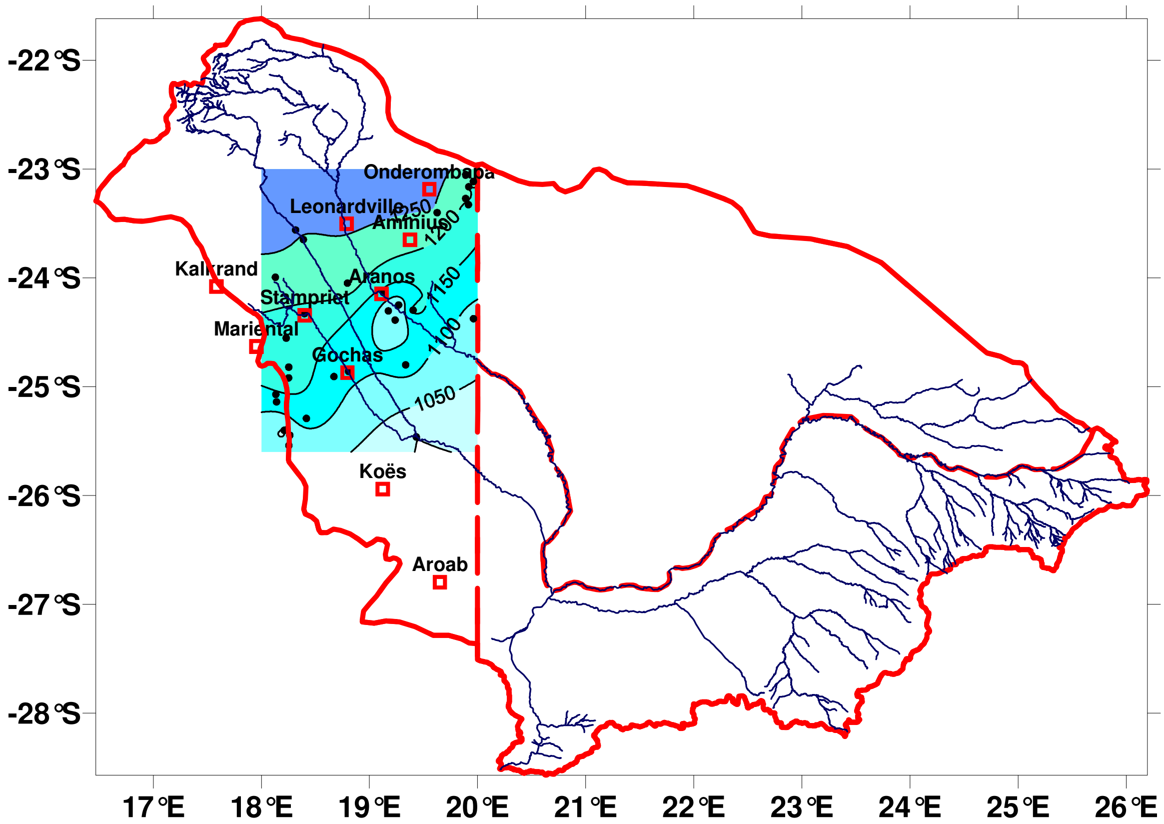


Figure 5-35 **General groundwater contours in the Nossob aquifer from monitoring of water level in boreholes penetrating the aquifer. (Data source: JICA, 2002)**

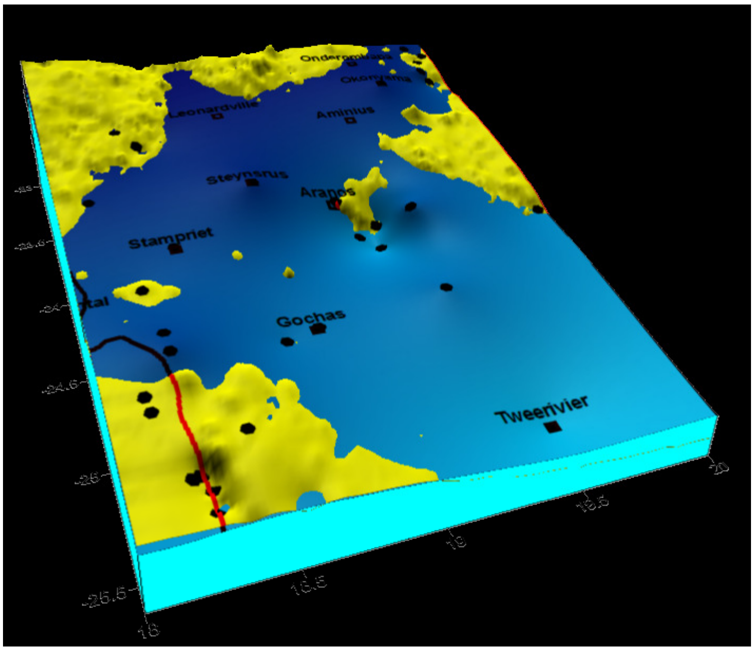


Figure 5-36 **Blue areas show the groundwater level in the Nossob aquifer being higher than the general groundwater level (Auob and Kalahari aquifers). (Data source: JICA, 2002)**

In the Kalahari Aquifer the groundwater flow is from the northwest to the southeast harmonizing with hydrogeological conditions. The gradient of the groundwater table becomes steeper in Aranos -Gochas area but then flattens toward the Salt-block (JICA, 2002).

Groundwater flow of the Auob Aquifer as a whole is similar to the Kalahari Aquifer, and is seen in the map showing the general groundwater contours over the Nossob-Molopo Basin, **Figure 5-46.**

The variation of the groundwater level in the Kalahari Aquifer at Olifants water and Tugela is shown in **Figure 5-33 and 5-34**. A slight decreasing water level was recovered in 2000-01. According to the Japanese study periodic fluctuation of approximately 5 cm/year on average since 1986 were recognized (JICA, 2002).

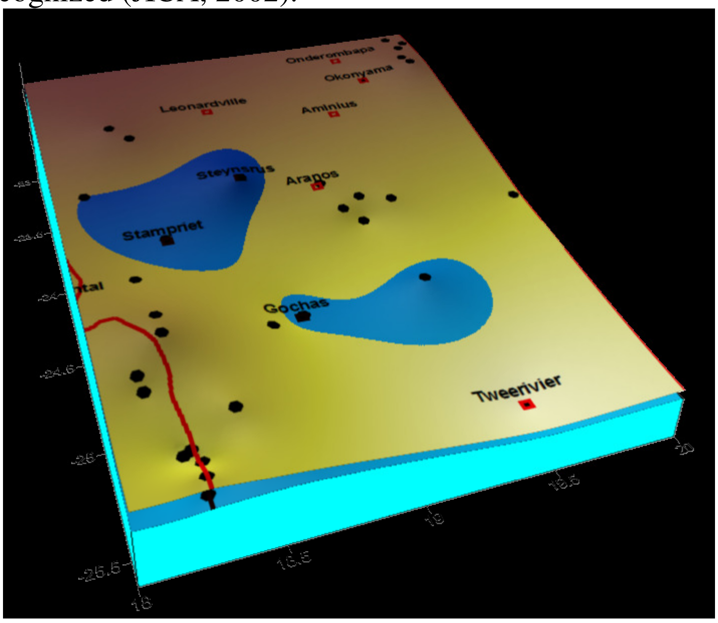


Figure 5-37 **Blue areas show the groundwater level (head) in the Nossob aquifer above the ground surface level (artesian conditions). (Data source: JICA, 2002)**

5.2.3.4 South Africa

Groundwater level monitoring

In South Africa, the regional water and forestry offices (DWAF) are responsible for the regional groundwater observation networks. The aim of these networks is to observe natural groundwater trends and water resource reactions to large-scale abstraction. The Catchment Management Agencies (CMA) also operates large-scale abstraction and compliance observation networks. Water Users Associations (WUA) representing a group of water users also manage observation networks in their areas or they will feed into the CMA networks. Individual water users like mines, municipalities, irrigators, industrial users are also expected to make groundwater observations to define the impact of their activities on water resources. Compliance of these users is reported to the CMA. It is also expected that these users keep records of their observations, capture observations onto database and evaluate the trends. On request these users may be expected to report on their observations. Observation equipment can vary from common dip meter readings to complicated electronic measuring and logging devices (van Dyk et al, 2008).

The location of the groundwater monitoring boreholes (sites) in the South African part of the Molopo-Nossob basin is illustrated in **Figure 5-38**. In the current report only a selected number of these sites are presented, summarized in **Table 5-24**.

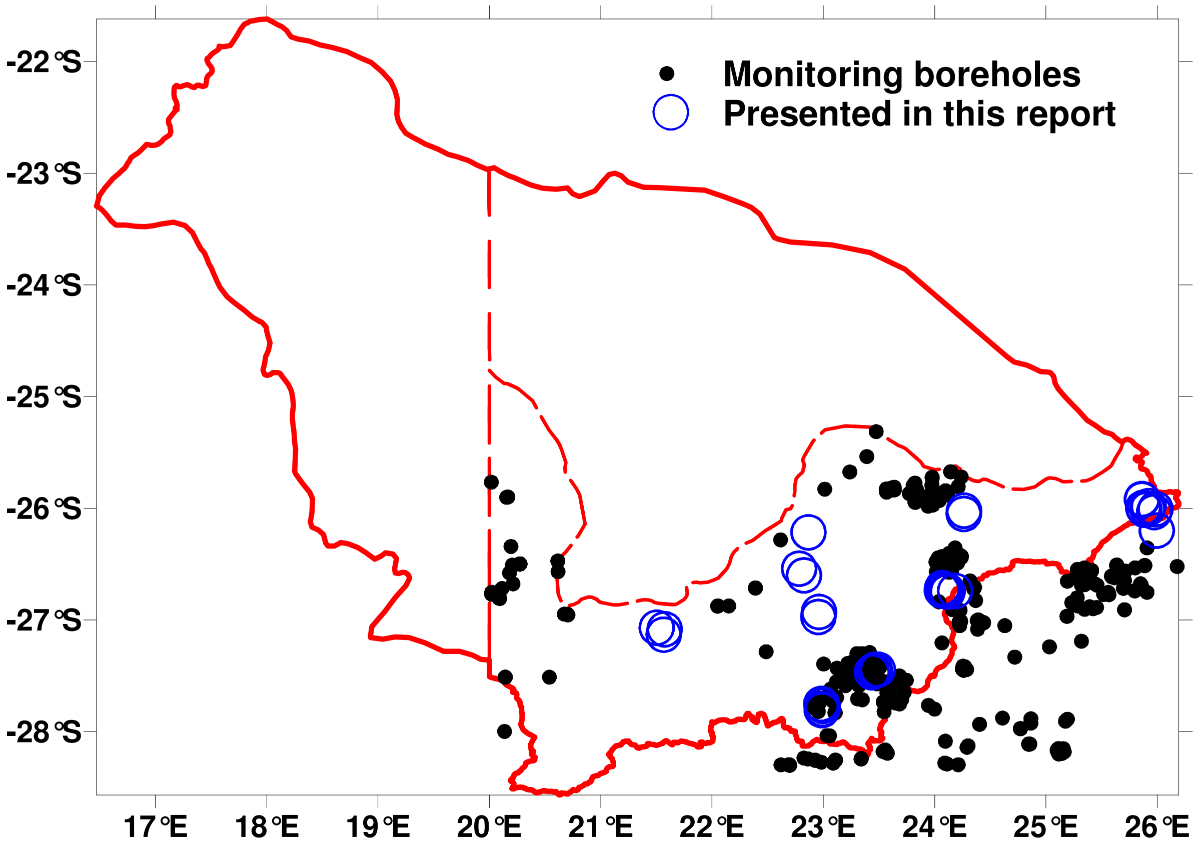


Figure 5-38 Monitoring boreholes in South Africa and monitoring results presented in the current report

Table 5-24 Data on monitoring sites presented in the current report

Map No	Site Id	Name	No of data	Long	Lat	Altitude (mamsl)	WMA	Colour diagrams
2525DD	003	Grootfontein	12798	25.86246	-25.9185	1450	D41A	Black
	031	Grootfontein	11499	25.86321	-25.9229	1450	D41A	Blue
	035	Grootfontein	2948	25.9105	-25.9524	1470	D41A	Red
	036	Grootfontein	306	25.9087	-25.9741	1470	D41A	Green
	037	Grootfontein	2198	25.90961	-25.9369	1470	D41A	Black
	025	Valleifontein	1866	25.84424	-25.9233	1450	D41A	blue
	028	Blaauw Bank	6126	25.87396	-25.9977	1470	D41A	Red
	029	Kuplaagte	4424	25.92252	-25.982	1480	D41A	Green
2723AD	393	Kuruman Town	4214	23.43603	-27.4695	1330	D41L	Black
	381	Kuruman Town	89	23.49044	-27.4469	1340	D41L	Blue
	382	Kuruman Town	92	23.46373	-27.4477	1320	D41L	Red
	075	Kuruman	58	23.45864	-27.4559	1320	D41L	Green
2722DD	195	Sishen	283	22.98701	-27.8093	1200	D41J	Black
	210	Gamagara	224	22.98211	-27.7536	1200	D41J	Blue
	190	Sishen	184	22.99443	-27.7698	1200	D41J	Red
	641	Sishen-Myn	115	22.99218	-27.8	1200	D41J	Green
	642	Sishen-Myn	113	22.99224	-27.8	1200	D41J	Brown
2625BB	031	Dudfield	8741	25.99584	-26.2007	1470	D41A	Black
	016	Blaau Bank	1430	25.91207	-26.0088	1480	D41A	Blue
	144	La Reys Stryd	330	25.97237	-26.0352	1500	D41A	Red
	019	Blaau Bank	305	25.88474	-26.0143	1480	D41A	Green
	004	La Reys Stryd	184	25.98368	-26.0069	1490	D41A	Brown
2624AB	003	Swellendam	11	24.26222	-26.0519	1350	D41C	Black
	004	Swellendam	24	24.26389	-26.0225	1350	D41C	Blue
2624CA	010	Mooihoek	23	24.0972	-26.7417	1323	D41H	Black
	082	Mooihoek Groenhoek	24	24.11665	-26.7444	1330	D41H	Blue
	084	Mooihoek Groenhoek	26	24.11609	-26.7469	1330	D41H	Red
	094	Gannalaagte	26	24.18472	-26.7417	1360	D41H	Black
	060	Long Valley	25	24.06526	-26.7375	1327	D41H	Blue
	185	Long Valley	26	24.06804	-26.7153	1340	D41H	Red
	043	Mooihoek	27	24.08276	-26.7344	1320	D41H	Green
2622BB	020	Bath	39	22.86667	-26.2167	1020	D41H	Black
2622DD	034	Pioneer (Kuruman)	95	22.96167	-26.9297	1060	D41M	Blue
	115	Karlsruhe (Kuruman)	12	22.95556	-26.9745	1040	D41M	Red
2622DB	047	Tweed	51	22.78333	-26.5422	1000	D41G	Green
	045	Severn(Kuruman)	105	22.82667	-26.6019	1020	D41G	Brown

At Grootfontein, in the easternmost part of the Molopo-Nossob Basin, groundwater is abstracted for the supply of town of Mmabatho. Groundwater level boreholes in that area, however during different time periods since the start in the late 1960-es. **Figure 5-39** shows the monitored level in some selected boreholes displaying long time series.

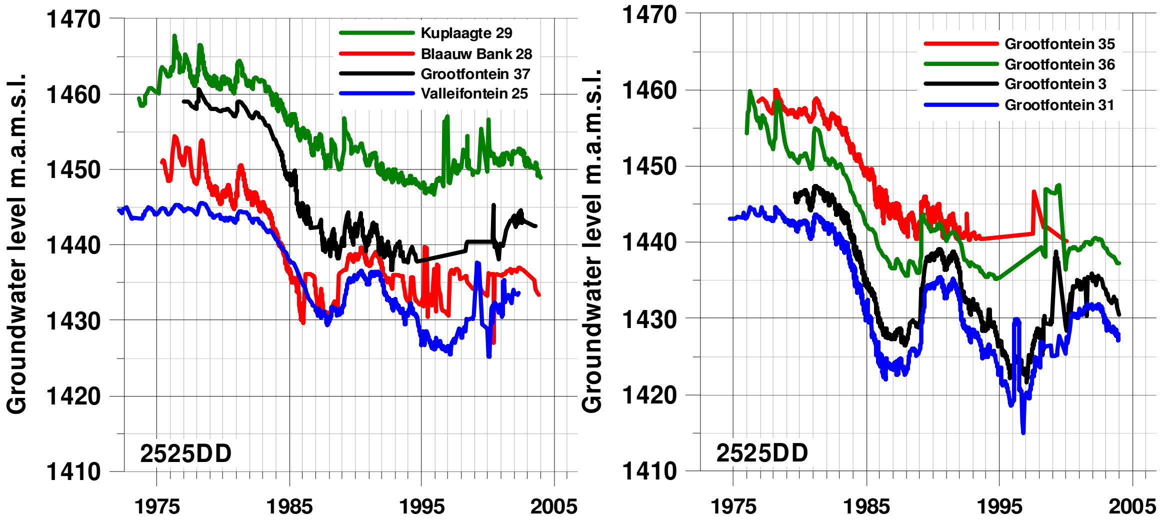


Figure 5-39 **Monitored groundwater level in boreholes in the Grootfontein area, South Africa, Water Management Area, WMA, D41A**

The groundwater level in the Grootfontein area in the early-mid 1980-es and in the recent time (2000-2004) is illustrated in the two maps in **Figure 5-40**. A 3-D view of the groundwater level is shown in **Figure 5-41**.

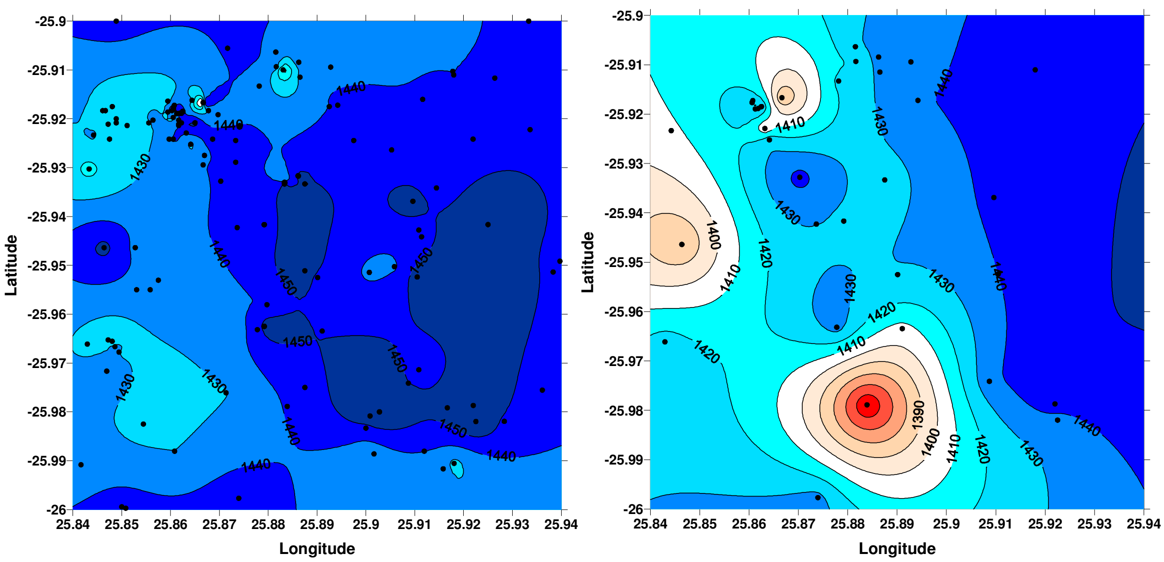


Figure 5-40 **Grootfontein, WMA D41A, South Africa, groundwater level counters early-mid 1980-es (Left) and groundwater counters form recent time, 2000-2004, (Right). The counters interpolated using Kriging application in the Surfer programme**

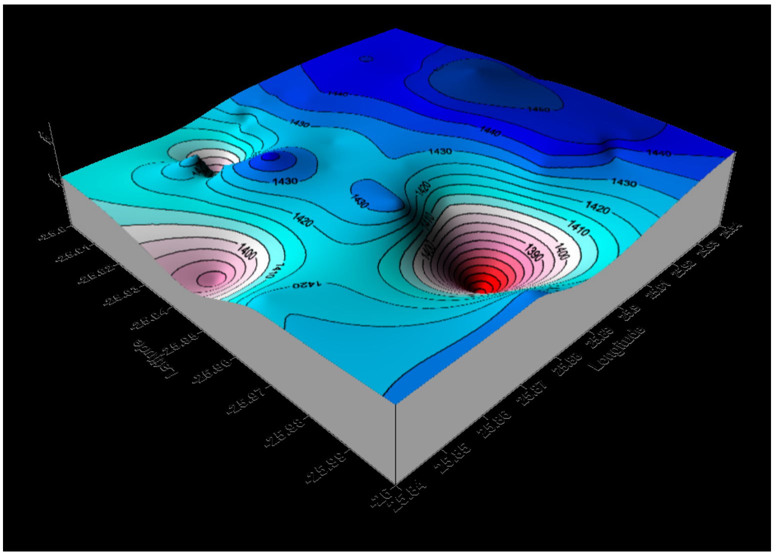


Figure 5-41 **3-D graph for the groundwater level from monitoring boreholes at Grootfontein, South Africa, WMA D41A**

In the western South Africa part of the Molopo-Nossob Basin, groundwater monitoring in the map square 2622 is only conducted up to the year 1978. A raise is groundwater level is monitored, see Figure **5-42**. This raise can be compared to the more than usual rainy years in the end of the 60-ties beginning of 70-ties monitored at the Tsabong meteorological station about 50 to 150 km Northwest of the monitoring boreholes. In other monitoring boreholes, the groundwater level is declining; see **Figure 5-43 and 5-44**.

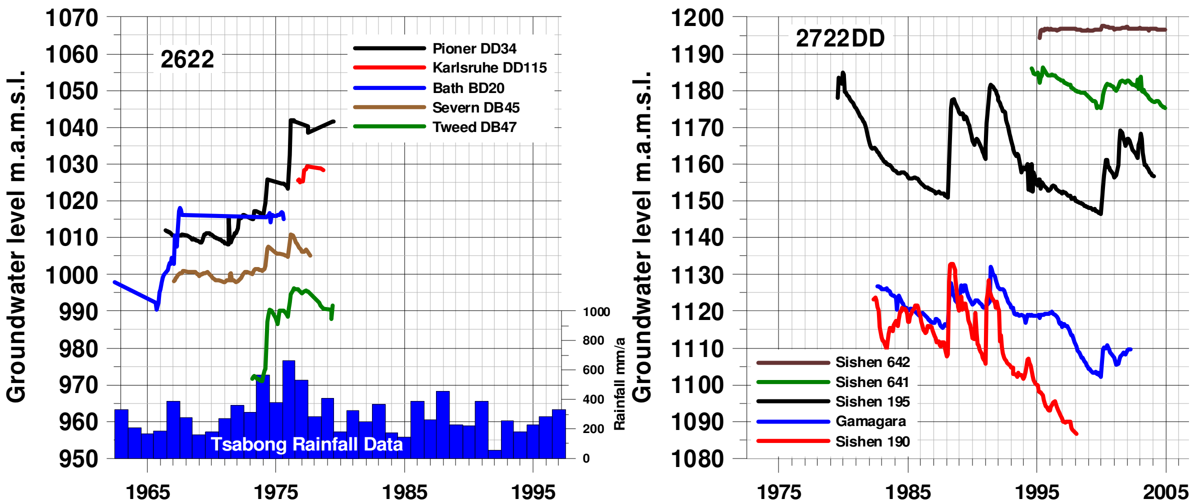


Figure 5-42 **Monitored groundwater level in boreholes in the South Africa, Water Management Area D41G, H, J and M, see Table 5-24**

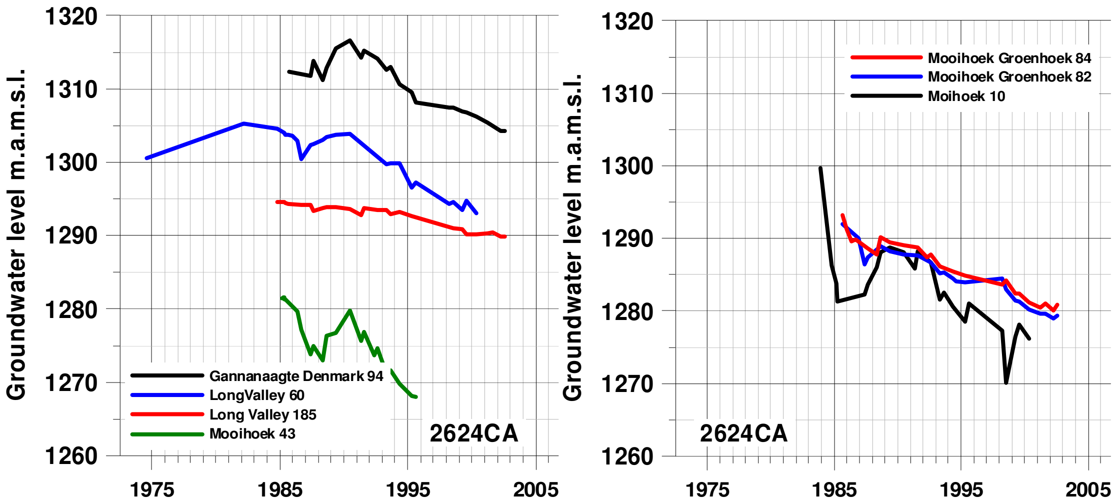


Figure 5-43 Monitored groundwater level in boreholes in South Africa, Water Management area D41H, see Table 5-24

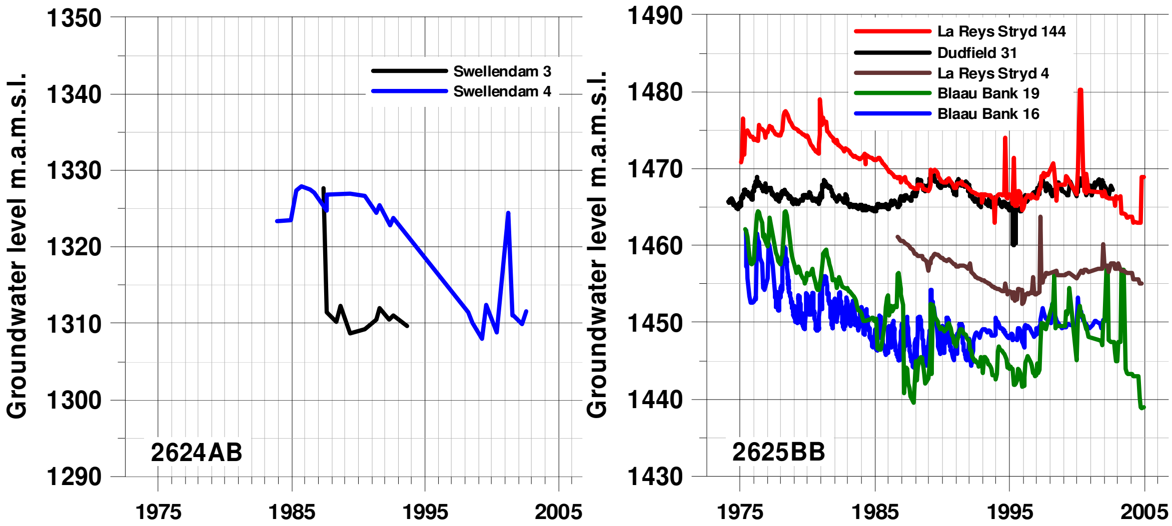


Figure 5-44 Monitored groundwater level in boreholes in South Africa, Water Management Area D41a and C, see Table 5-24

Groundwater Monitoring in the Northern Cape Province; Trends and Status of Groundwater Resources 2008

Department of Water Affairs and Forestry, the regional office for Northern Cape Province in Kimberley presented in a brochure the trends and status of the groundwater resources in their area (van Dyk et al, 2008). From the brochure the following information is extracted.

The regional groundwater observation network is aimed at observing regionally representative water quantity, water levels and water quality trends. It is almost impossible or too costly to observe trends at all boreholes in the areas. Therefore it is essential that observation points are chosen carefully. The natural factors that could influence changes in groundwater in the area include the host rock, the precipitation, the evapotranspiration, drainage, vegetation to name but a few.

The host rock geology contributes to the water level and quality of water in the aquifer. In the Northern Cape (NC) region groundwater is hosted by sediments of the Kalahari, fractures in the sedimentary Karoo rock, weathering and fractures in the crystalline rocks and in karst in the dolomites.

The precipitation, intensity and timing thereof influence the selection of borehole positions and timing of groundwater observations. The precipitation in the Northern Cape region is summer precipitation that varies from 600 to 200 mm in the east to a winter precipitation that varies from almost 0 to 400 mm in the west. The evaporation is a major contributor with evaporation rates of more than 2000 mm from the west receding to between 1000 and 2000 mm. This evaporation determines the evapotranspiration of plants and in riverbeds. Where plants do occur, water levels and quality is influenced. A groundwater monitoring network needs to account for the east west variation in precipitation and evapotranspiration.

The long-term groundwater trend in the semi-arid western South Africa is overwhelmed by the two flood events of 1973 to 1976 and again in 1988. Both were followed by dry events in 1985 to 1987 and 1992.

After the recharge event in 1988 numerous groundwater schemes of abstraction boreholes with associated observation boreholes were developed. Due to the volume and regional extent of the 1988 precipitation event and recharge to the aquifers, it is assumed that most aquifers were recharged to their full capacity in 1988 and the following years. For purposes of evaluation of groundwater status 1988 to 1990 water levels are taken as the basis of elevated water levels and full capacity in aquifers.

From observed water level trends a groundwater status map was compiled to indicate the spatial status of groundwater in 2008, see **Figure 5-45**. The legend, based on observed trends, was developed to describe water level situation, aquifer status and associated risk.

Aquifers in the west, south and north (blue areas in the map) are under natural conditions with only seasonal trends responsible for small water level fluctuation.

Groundwater in the central and eastern portion of the area (green area) is under natural conditions however with the absence of major precipitation and recharge. Therefore slightly depleted aquifers with associated problems to abstract water are prevalent. Within these green areas localized impacted areas (yellow) exist where abstraction is the reason for depleted aquifers with associated water abstraction problems.

The red and purple areas indicate areas where severe and critical depletion is responsible for the poor groundwater conditions with associated problems. Boreholes will dry up and aquifers will dewater. Ground instability and subsidence with do line and sinkhole formation could result as a consequence of the compaction and destruction of major aquifers.

After the 1988 recharge event numerous groundwater schemes of abstraction boreholes with associated observation boreholes were developed. The abstraction for water provision, irrigation, and mine de-watering purposes is responsible for an accelerated water level decline in aquifers. A classic example is the water level declines of more than 60 m in the Tosca Molopo aquifer. After 2004 water restrictions were imposed and stabilization and recovery of the water level are observed since then.

The episodic major recharge and recession events is the dominant observed trend in the groundwater levels, The reoccurrence of these major recharge events from existing information is between 15 and 18 years. Depending on the aquifer type the magnitude in water level fluctuation can be 2 to 5 m. The seasonal trends with wavelength 1 to 2 years are super imposed on major trend with fluctuation up to 2 m due to seasonal recharge and recession. Impacts like abstraction is super imposed on above fluctuations with another observed fluctuations larger than 5 m that can manifest gradually over few years. Water levels mostly decline and major recharge can recover the water levels.

The status of water use in each catchment can further be evaluated by comparing the assessment of the reserve of each catchment with the registered water use for each catchment. For 92 quaternary catchments of the area, 31 reserves have been determined and when compared with the water use in each, it is evident that 6 catchments are over allocated.

It is essential that extensive observation networks are operated in catchments where the allocation of water is close to the potential of the catchment. Groundwater trends in red and orange catchments (see **Figure 5-45**) must therefore be carefully observed for impacts. In these catchments extensive irrigation, mine/industrial and municipal use takes place. These economic activities are dependent on sustainable water resources based on long-term groundwater resource observations.

The map in **Figure 5-45** indicates the areas where groundwater observations are made and the type of observation. In the area rainwater samples, groundwater samples are taken for recharge and quality purposes, and water level monitored with the use of dippers and/or electronic/mechanic logging devices.

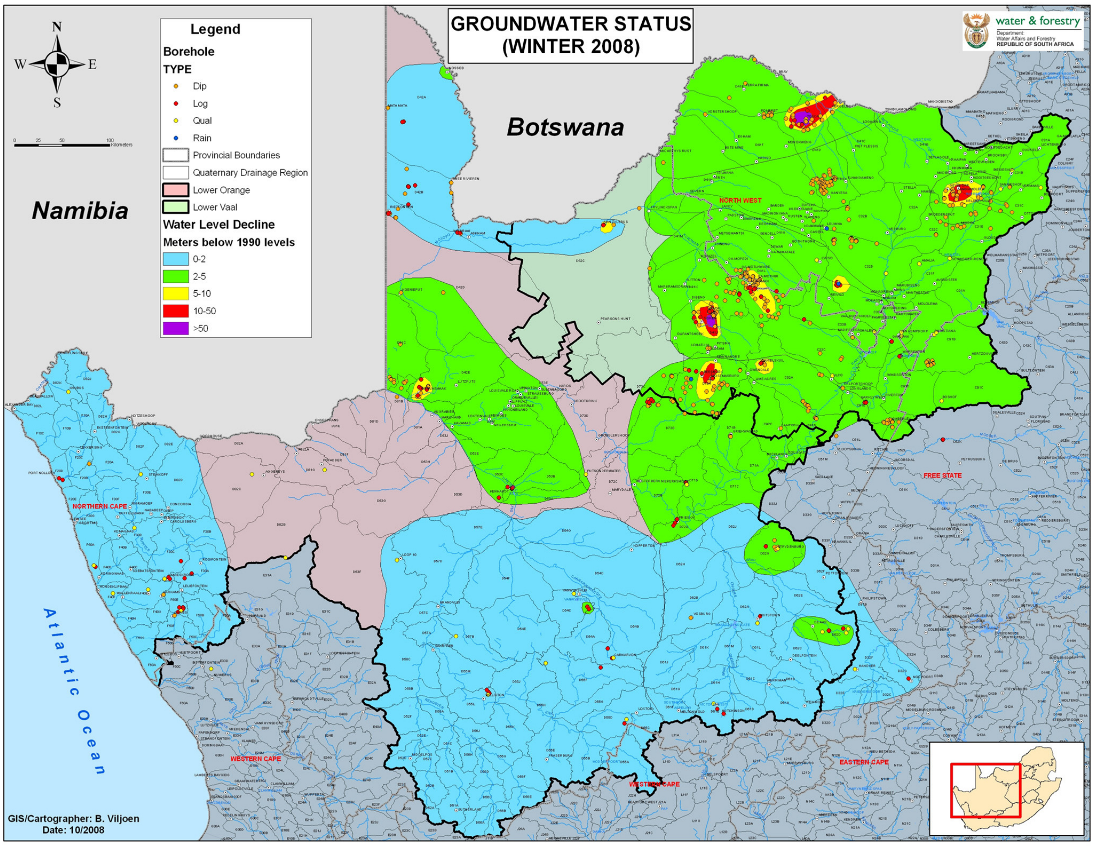


Figure 5-45 **Groundwater Status in the Northern Cape, winter 2008, based on Groundwater level Decline since 1990 (van Dyk et al, 2008)**

5.2.3.5 Regional Groundwater Flow in the Molopo-Nossob Basin

When boreholes are completed after construction, a certificate showing the essential of the site, the drilling and the construction and equipping of the boreholes is issued. As one part of the certificate, information about the groundwater level, usually measured as meter below to top of the boreholes is given. Coordinates together with the altitude of the ground surface (or the top of the borehole) at the borehole site make it possible to calculate the level of the groundwater in meters above mean sea level. This procedure is done for all boreholes drilled and registered.

From records of the registered boreholes in Botswana, Namibia and South Africa groundwater level measurements are put together to form a regional groundwater level map over the Molopo-Nossob Basin. The number of boreholes used is summarized in **Table 5-25**.

In the registers there is information which is incorrect and the information is gathered over a long period of time. Groundwater level varies due to natural course and due to human interferences and in the construction of the regional groundwater level map incorrect data and data which represent time when different conditions were prevailing have been subtracted. The groundwater level map is illustrated in **Figure 5-46**.

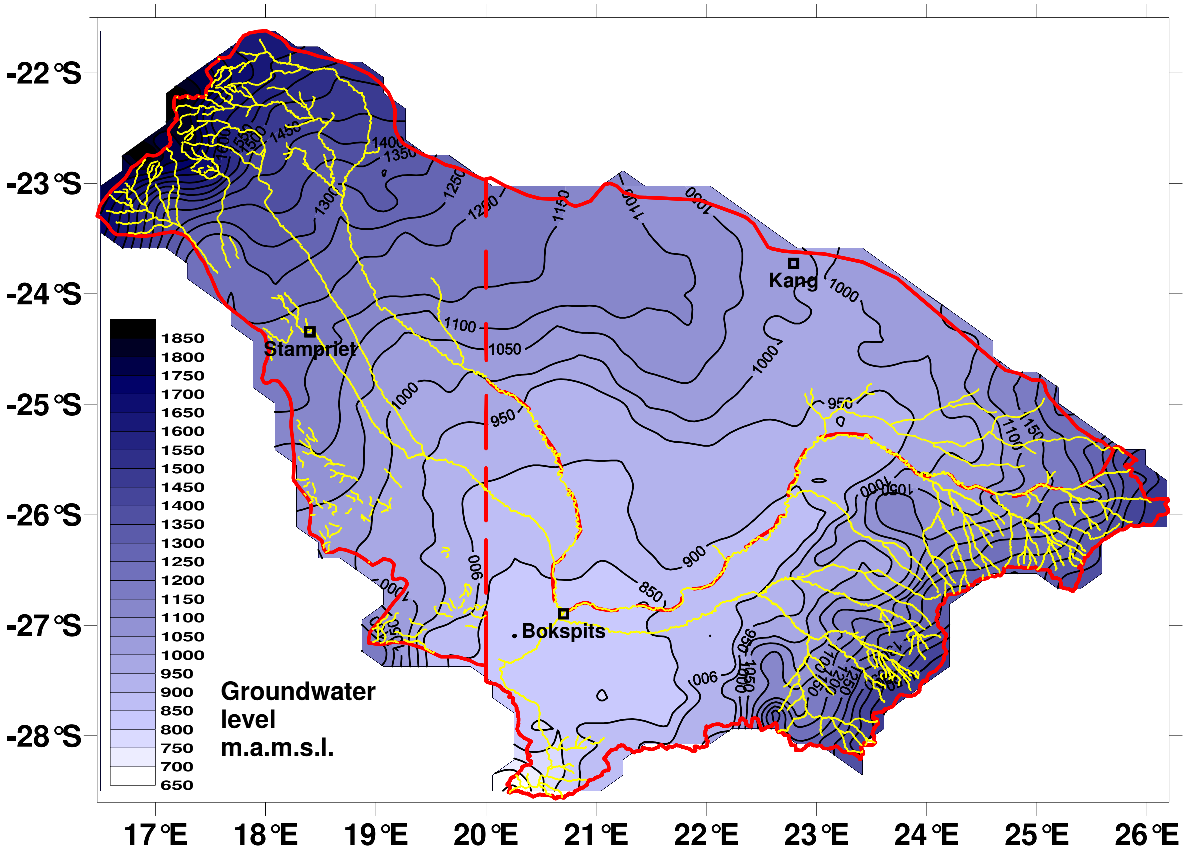


Figure 5-46 **Regional groundwater level map over Molopo-Nossob Basin**

Table 5-25 Groundwater level information sources in the Molopo-Nossob Basin

Country	Database	Host	No of boreholes	No of boreholes used in the construction of the groundwater level map on the Molopo-Nossob Basin
Botswana	National Borehole Archive	DWA and DGS	3,391	1,214
Namibia	GROWAS	MAWRD	9,843	4,262
South Africa	Borehole Information Database	DWAF	21,185	13,299
Total			***34,399***	***18,775***

The groundwater flow gradient within the Molopo-Nossob Basin follows, in the regional scale, the topography. Exception is in the north of Botswana, where the basins boundaries, taken as the surface water divide (the topography) does not coincide with the groundwater divide. There is however limited number of groundwater observations in that area which can be seen in the Map showing the location of borehole used in the construction of the groundwater level map (**Figure 5-47**).

The lowest groundwater level is found in the south-western part of South Africa, along the Molopo River course out of the basin to the Orange River. In this part of the basin and also up in the southern part of Botswana the groundwater gradient is less than 0.05%. In the middle part of the basin in Namibia the groundwater gradient is around 0.10 to 0.15%. The highest groundwater gradients are found in the north-eastern (Namibia) and eastern part (South Africa) with gradients according to the map of 0.15 to 0.25%. In the basin's westernmost area in Namibia the gradient is as high as 0.5%.

5.2.4 Springs

A spring is any natural occurrence where water flows onto the surface of the earth from below the surface, and is thus where the aquifer surface meets the ground surface. In the Molopo-Nossob Basin springs are registered in South Africa and Namibia. No spring is found in the Botswana area of the basin.

In South Africa the springs occur in the dolomite areas and are given names of "eye" in connection to their locality. The largest ones identified in the basin are shown in Figure 5-48. The springs in South Africa all have outflows of 1,000 m^3/day or more (Vegter, 1995).

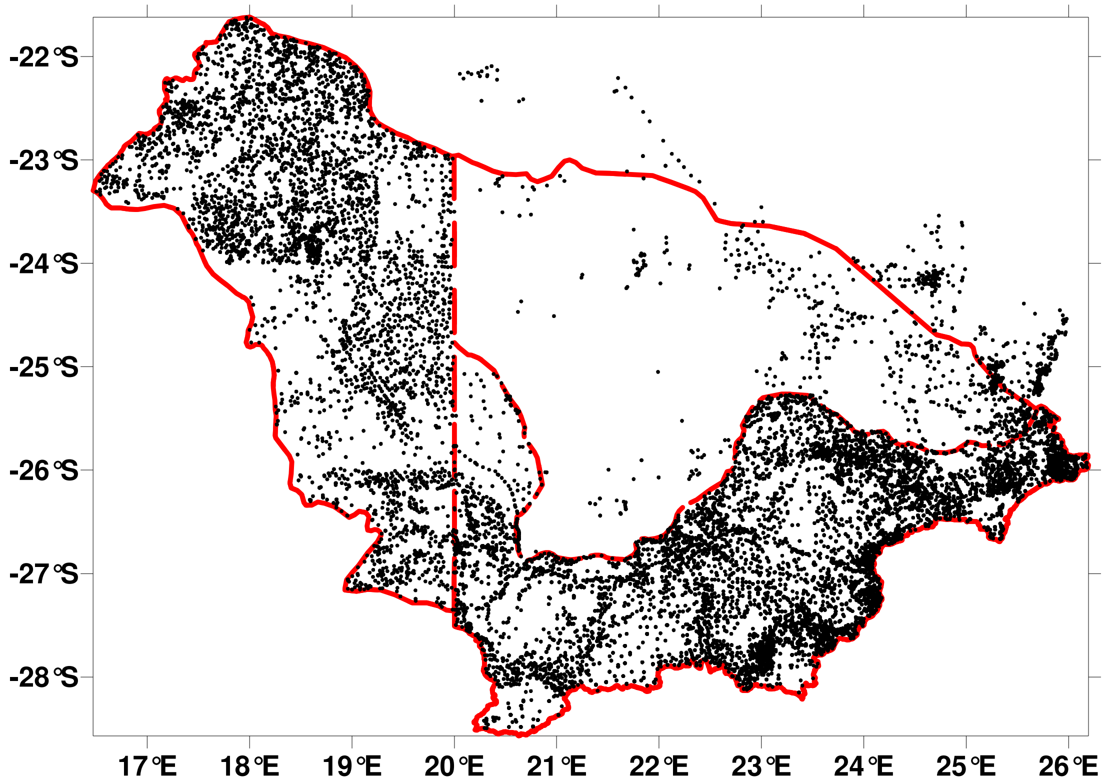


Figure 5-47 Location of boreholes used in the construction of the groundwater level map over Molopo-Nossob Basin (Figure 5-46)

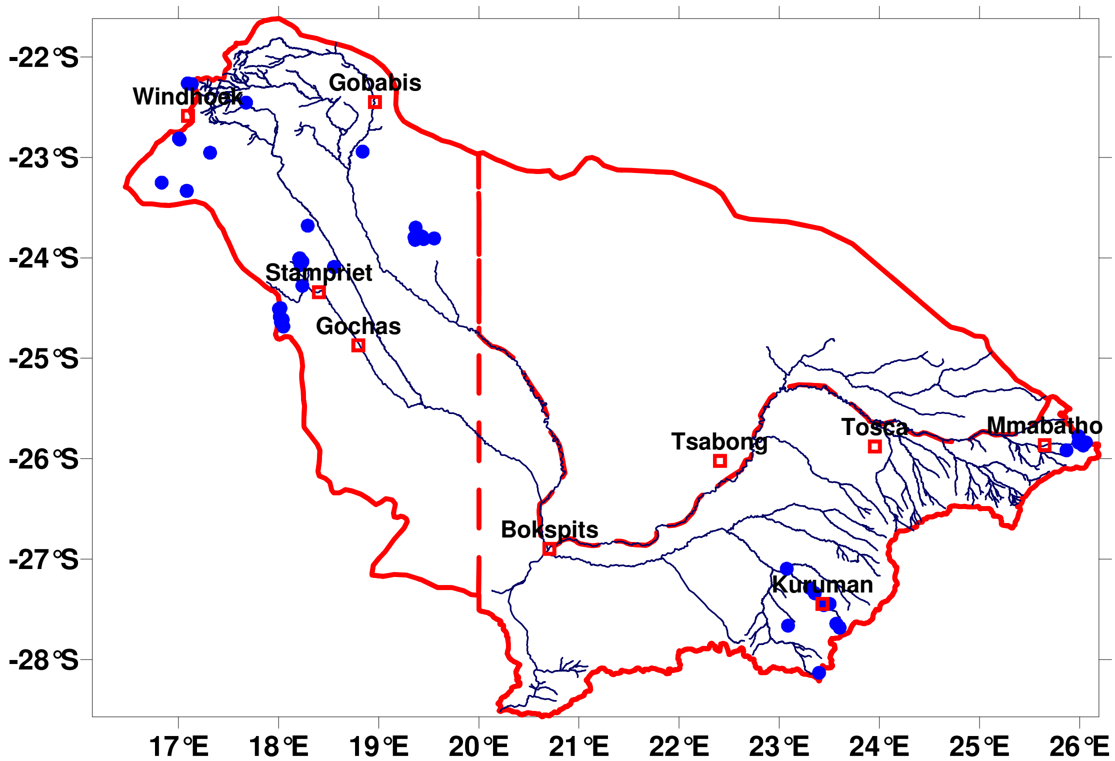


Figure 5-48 Location of springs in Molopo-Nossob Basin (data source: Vegter, 1995 and DWA Namibia)

5.2.5 Groundwater Replenishment

5.2.5.1 Recharge

Replenishment of water to an aquifer includes a variety of processes. The major ones are the vertical replenishment, usually called recharge or percolation of water from the rain or through leakage of water from an aquifer above or below. In the latter case there is usually a semi permeable layer (aquitard) separating the aquifer from where the water emanates and the receiving aquifer.

An aquifer is also replenished by groundwater flowing in horizontally due to the natural groundwater head gradient. There is also the component of losing water from the aquifer by outflow and/or leakage of water to another aquifer.

Recharge is one of the important parameters in describing a groundwater resource. Together with lateral inflow (and outflow) of water to an aquifer it is the renewal part of the groundwater. In order to get estimates on the amount of water being renewed, the value of an average annual recharge is required. Usually this parameter is given in mm/a or as a percentage of the mean annual precipitation. However recharge varies with climate geology and topography and the average values, have to be determined over long time observation of mainly meteorological factors and groundwater level variations.

Usually recharge from precipitation and surface water is divided into (Allison, 1988):

- Diffuse recharge from rainfall which infiltrates directly, reaching the water table by percolation in excess of soil moisture deficits and short-term vegetation requirements.
- Localized recharge resulting from infiltration through the beds of perennial or (more typical) ephemeral surface water courses and from run-off to closed depressions, lakes, swamps, and alluvial pans on flood plains.

In both categories the recharge occurs in two ways: through preferred pathways or as a front going through the whole soil profile.

5.2.5.2 Methods to Determine Recharge

Recharge can be assessed using a variety of methods. Bredenkamp et al (1995) describes the methods into different types as summarized in **Table 5-26**.

Table 5-26 Various practical methods to determine recharge (Bredenkamp et al, 1995, ORASECOM, 2009)

Class	Method	Parameters needed
Chemistry methods	Chloride Mass Balance	Chloride deposition, Rainfall data, Groundwater Chloride content
Meteorological methods	Cumulative rain fall departures, CRD	Long-term rainfall data (monthly) and groundwater level data
	Saturated volume fluctuation method (SVF)	Long-term groundwater level data over a defined area.
	Rainfall-Recharge relation	Simulation of recharge variability from rainfall

Class	Method	Parameters needed
		records
	One dimensional lumped parameter model	Rainfall, Potential evapotranspiration, soil moisture parameters, groundwater level
Isotopic Methods	Carbon Isotopes and groundwater age	^{12}C, ^{13}C, ^{14}C
	Stable Isotope Composition	D (^{2}H), ^{18}O
	Tritium method	T (^{3}H)
Aquifer Modeling	Mathematical modeling	Hydraulic parameters, aquifer boundaries and thickness, geology

Principles of CMB Method (Selaolo, 1998)

The chloride mass balance (CMB) approach capitalizes on the inert behaviour of the chloride ion once taken into groundwater solution. The ion does not readily enter into rock water reactions. In areas with no other chlorides sources than rainfall and dry deposition and with insignificant surface run-off, a rather uncomplicated relationship exists between the chloride concentration in groundwater Cl_{gw}, in precipitation Cl_p and the dry deposition D and the annual recharge R.

$$R = \frac{PCl_p + D}{Cl_{gw}}$$

Since deposited chloride does not evaporate, the recharging water will carry the deposited chloride to the groundwater. In general the concentration in the rainwater can be taken as constant. The fact is however that it varies during the year and probably between wet and dry periods. A very detailed use of this technique can therefore involve numerous of assumptions not fully valid in time and space. It could however be a useful assessment method on regional scale assessment

Principles of CRD Method (DGS, 2002)

The cumulative rainfall departures are defined as follows:

$$\hat{R}_i = R_i - k\overline{R} + \hat{R}_{i-1} \qquad (1)$$

Where $\hat{R}_i$ is cumulative rainfall departure (CRD) for month I [mm]; R_i is rainfall in month i [mm]; $\overline{R}$ is average monthly rainfall for the entire rainfall record [mm]; k is constant representing pumping or injection (equals 1 for no pumping) [dimensionless].

Most often the acceptable correlation exists between the CRD and the groundwater level h_i, expressed as proportionality constant a:

$$h_i = a\hat{R}_i + H_w \qquad (2)$$

Where H_w = average depth of the groundwater level below surface; or as change in groundwater level Δh_i:

$$\Delta h_i = a\left(R_i - k\overline{R}\right) \qquad (3)$$

Constant a represents a lumped coefficient of recharge and storativity, R_p/S. The objective is to find a fixed proportion of rainfall for every month. The correlation between the CRD and the groundwater levels can be improved by introducing the concept of lag effects:

$$\hat{R}_i = \frac{1}{m}\sum_{j=1-(m-1)}^{i} R_j - k\frac{1}{n}\sum_{j=1-(n-1)}^{i} R_j + \hat{R}_{i-1} \qquad (4)$$

where *m* denotes a time lag required to observe the effect of a recharge event on the water table (short memory) [month]; and *n* is a redistributed effect of recharge over long term, usually reflecting subtle climatic or hydrological cyclicity (long-term memory) [month]; *i*, *j* subscripts denote *i*-th and j-th month representing long and short term memory (typically i=1, 2,…120 and j=1, 2…12). Considering the change in saturated volume approximated to CRD we obtain:

$$V_i \propto a\left(\frac{1}{m}\sum_{j=i-(m-1)}^{i} R_j - k\frac{1}{n}\sum_{j=1-(n-1)}^{i} R_j + \hat{R}_{i-1}\right) \qquad (5)$$

The relationship between CRD and water levels is sought using iteration/optimization techniques. By changing parameters such as *m* and *n* and/or *k* (if abstraction is important) iteratively, the best fit can be found. The optimization routine can be carried out for individual boreholes (to assess a point value of recharge) or for a domain (global recharge estimate).

Principles of SVF Method (DGS, 2002)

The SVF method transforms groundwater level fluctuations above a given datum plane to equivalent amounts of water. A simplified (saturated) water balance can be expressed as follows:

$$S\frac{\Delta V}{\Delta t} = Q_i - Q_o + R - Q_a \qquad (1)$$

Where Q_I *and* Q_o = lateral inflows and outflows [mm], respectively during time increment Δt; Q_a = net abstraction or discharge from the aquifer [mm]; R = recharge [mm], S = storativity and ΔV is a change in saturated volume of the aquifer.

When the lateral flow can be neglected, the net volume change is dependent only on recharge and the abstraction. The recharge is equal to abstraction when there is no change in groundwater level status and the storativity has not changed - this is the basis of equal volume method. By correlating the equal volume rainfall and abstraction the recharge as a portion of rainfall can be calculated.

The SVF technique is a lumped parameter method – the hydrological status of the aquifer is integrated into a composite integrated hydrograph derived from water level records in the studied area. The integration of water levels is achieved over a Thiessen polygon network. The usual assumptions include (1) the base of aquifer to be impermeable and (2) the evapotranspiration losses are included in the recharge term.

When the changes over a time period are zero the storativity term is eliminated. The zero change conditions usually apply to different periods, implying recharge/abstraction conditions for various monthly rainfall values. The average recharge can thus be calculated using recharge (from equal volume periods) and rainfall relationship as follows:

$$R = kR_a + (Q_i - Q_o) \qquad (2)$$

Where R_a = mean rainfall for the evaluated period.

Empirical rainfall-recharge relationship

Empirical rainfall-recharge relationships are used to obtain approximate values of possible recharge once the log term annual precipitation is known. Primarily the relationship needs to be calibrated by other techniques to estimate the recharge. Any relationship obtained is valid for long term average and is site-specific. However some relations developed for specific geological conditions could be applied in similar conditions (ORASECOM, 2009).

Bredenkamp (1988) obtained a linear relationship between rainfall and recharge for a dolomite area in Transvaal, South Africa:

$$R = A(P - B)$$

Where B represents the threshold rainfall that is required to affect recharge, P is the annual precipitation, and A is lumped catchment parameter. In the ORESECOM report (2009) the relationships are further developed to be both in exponential and linear relations as summarized in **Table 5-27**.

The recharge in the Kalahari Beds in Botswana was approached by van Straten (1955), Boocock and van Traten (1962) and Foster et al (1982) stating the unlikelihood of recharge in area where the thickness of the Kalahari Beds exceeds six meters. De Vries (1985) used calculation based on existing hydraulic gradients and came to the conclusion that the recharge rate will be less than 5 mm/a. Recent studies by Selaolo (1998) and Obakeng (2007) show that recharge is possible in their study areas in Central Kalahari in Botswana.

Table 5-27 Recharge rainfall relationship in the Molopo-Nossob Basin in South Arfica developed and presented in ORASECOM report (2009)

Aquifer	Location	Eqv No	Relationship	Estimated recharge (mm/a)
Basic relations	Sishen	OR1	$R=0.898e^{0.032x1}$	
	Rietondale	OR2	$R=0.2837e^{0.0348x}$	
	Manyeding	OR3	$R=0.2733e^{0.0473x}$	
	Kuruman	OR4	$R=0.7425e^{0.0538x}$	
	Louwa-Coetzerdam	OR5	R=0.086(Rf-286)	
Kalahari aquifers		OR1 OR2 OR3		4.6 2.6 -1.4
Tosca dolomite aquifer		OR1 OR3 OR4		5.3 12.0 42.2
Coetzersdam granite		OR1 OR2 OR3 OR5		6.6 13.7 18.6 16.8

5.2.5.3 Recharge values from studies in the Molopo-Nossob Basin

From investigation carried out in various parts of the Molopo-Nossob Basin, assessments of the recharge values are obtained. The methods used and the recharge values arrived at are summarized in **Table 5-28**.

In the National Water Master Plan for Botswana (DWA, 1991) estimates of the recharge using the CMB method and data on chloride deposition rate presented by GRESS (1989) were done based on the groundwater chloride content and the average precipitation. Results applicable to the Molopo-Nossob Basin are included in **Table 5-28.**

The chloride mass balance, CMB, is used to assess estimates of the regional recharge in the Molopo-Nossob Basin. Beekman et al (1996) presented a map of the total chloride deposition in mg/a per m^2. The map is also published by Selaolo (1998). In the JICA report (JICA, 2002) a relationship between the chloride deposition and the average annual rainfall is brought forward (without any reference).

$$Cl_p = 0.000002 * P^2 + 0.0003 * P + 0.2207$$

$$D = 0.1 * Cl_p$$

A comparison between the chloride deposition assessed by Beekman et al (1996) and the deposition calculated by the formula given in the JICA report (2002) shows a general relation of about 0.75. Such discrepancy with have and impact on the recharge calculated by the CMB method. In the assessment of the recharge for the Molopo-Nossob Basin the chloride deposition calculated by the JICA formula is reduced by a factor 0.75. The map, presented in **Figure 5-49** shows the chloride deposition over the Molopo-Nossob Basin.

Table 5-28 Recharge methods and values obtained from investigation in the Molopo-Nossob Basin

Country	Area	Method	Recharge value (mm/a)	Reference	Remarks
Botswana	Ncojane	CMB Modeling 14C	5 – 38 0.15 – 0.63 0.7 – 1.4	DWA, 2008	Ecca (Auob) aquifer
		CMB 14C	6 1 - 6	DWA, 2008	Ntane aquifer
	Kang-Phuduhudu	CMB Stable Isotopes Modeling	3.2 – 15 8 0	DWA, 2007	Modeling done with conservative approach
	Bokspits	CMB CMB	0.8 0.5	DGS, 2002 DWA, 1991	Three zones with recharge 0.1, 0.3 and 1.5
	Tsabong	CMB Stable Isotopes	5 11.5	DWA, 2002	
	Kakhea	CMB	2.9	DWA, 1991	50% value
	Sekoma	CMB	2.3	DWA, 1991	50% value
	Tshane	CMB	1.3	DWA, 1991	50% value
	Middlepits	CMB	1.0	DWA, 1991	50% value
	Matsheng	Modeling	3.5	DWA, 1996	
	Sikamatswe	CMB	0.37	DGS, 1994	
Namibia	Stampriet Artesian Basin		1.5	JICA,2002	Ordinary Year
South Africa	Kalahari aquifers		2.2	ORASECOM, 2009	Average value
	Dolomite aquifers		19.8	ORASECOM, 2009	Average value
	Granite aquifer		13	ORASECOM, 2009	Average value

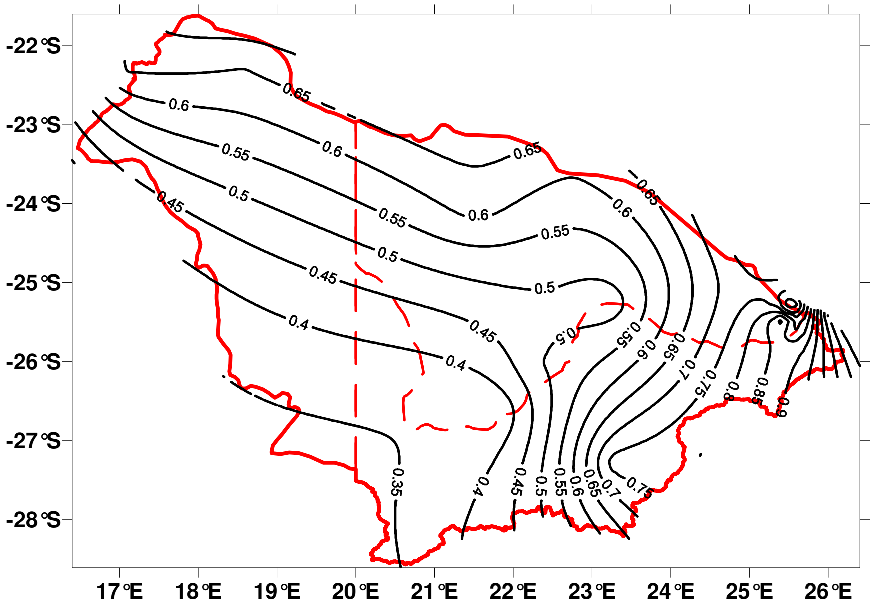


Figure 5-49 **Total chloride deposition (mg/a and m²) calculated for the Molopo-Nossob Basin according to formula given by JICA (2002) and adjusted with a factor 0.75**

Data on groundwater chloride from boreholes within the Molopo-Nossob Basin are used to construct a map showing the areal distribution of the Cl in groundwater, see **Figure 5-50**. The chloride distribution follows in general the same pattern as the TDS distribution. The highest concentration of Cl (> 20,000 mg/l) is found in Gordonia. Large area of Botswana has chloride concentration in exceeding 2,000 mg/l. The WHO Guideline value for human consumption is Cl <250 mg/l.

The maps on chloride deposition and chloride content are the base in the construction of the groundwater recharge map in **Figure 5-51**. The map is based on the chloride mass balance method and serves as a general picture of the recharge in the Molopo-Nossob Basin.

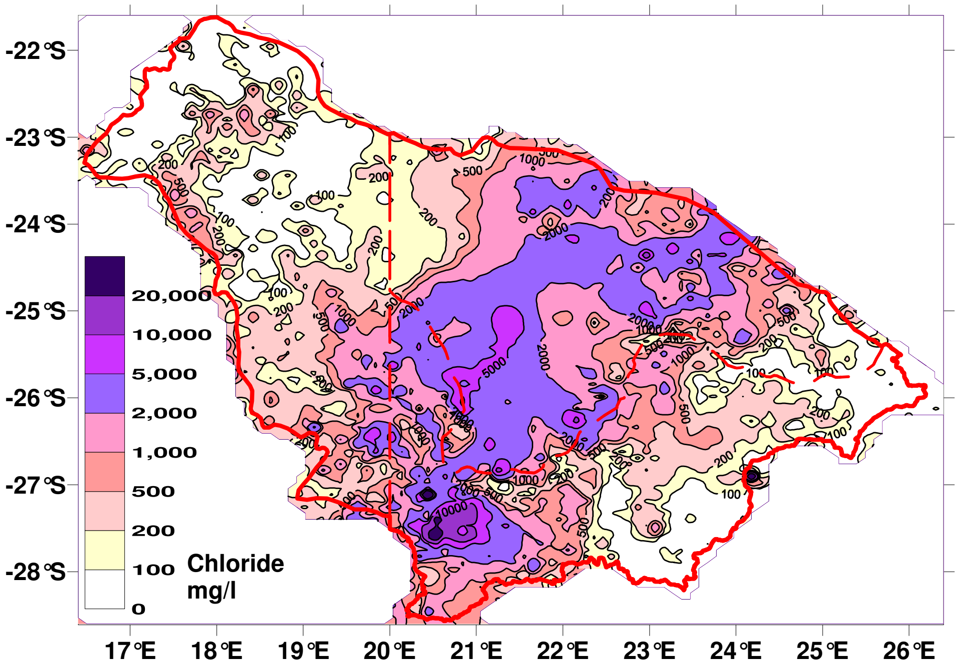


Figure 5-50 **Chloride concentration in the groundwater within Molopo-Nossob Basin**

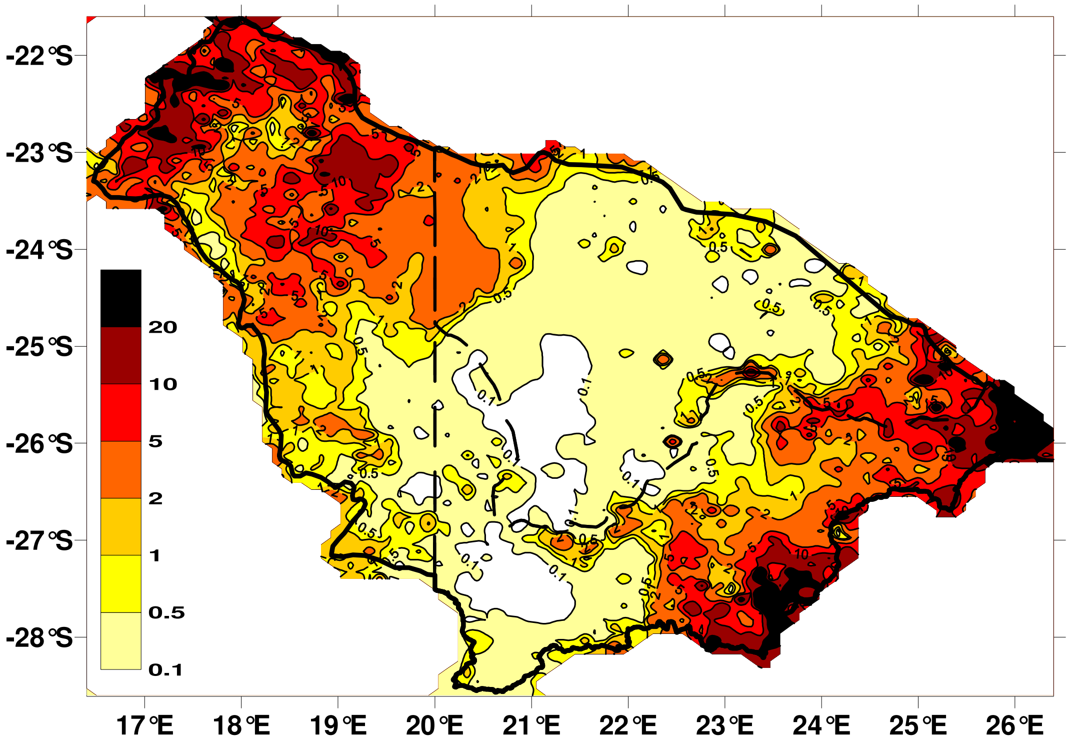


Figure 5-51 Groundwater recharge in mm/a assessed using the Chloride Mass Balance method (CMB)

5.2.6 Groundwater Modeling

5.2.6.1 Mathematical Methods

To use the groundwater flow equation to estimate the distribution of hydraulic heads, or the direction and rate of groundwater flow, a partial differential equation (PDE) must be solved. Both initial conditions (heads at time (t) =0) and boundary conditions (representing either the physical boundaries of the domain, or an approximation of the domain beyond that point) are needed in the process of solving the equation. Often the initial conditions are supplied to a transient simulation, by a corresponding steady state simulation (where the time derivative in the groundwater flow equation is set equal to 0.

There are two broad categories of how the (PDE) would be solved; either by analytical or methods, or something possibly in between. Typically, analytic methods solve the groundwater flow equation under a simplified set of conditions *exactly*, while numerical methods solve it under more general conditions to an *approximation*.

Analytical methods

Analytic methods typically use structure of mathematics to arrive at a simple, elegant solution, but the required derivation for all the simplest domain geometries can be quite complex. Analytic solutions typically are also simply an equation that can give a quick answer based on a few basic parameters. The Theis equation is a simple (yet still very useful) analytic solution, typically used to analyze the results of an aquifer pumping test.

Numerical methods

The topic of numerical methods is quite large, obviously being of use to most scientific and engineering fields in general. Numerical methods have been around much longer than computers have, but they have become very important through the availability of fast and cheap personal computers.

There are two broad categories of numerical methods, gridded or discretized methods and non-gridded or mesh-free methods. In the common finite difference method (FDM) and finite element method (FEM) the domain is completely gridded. The analytical element method (AEM) and the boundary intregral equation method (also called (BEM, or Boundary Element Method) are only discretized at boundaries or along flow elements (line sinks, area sources, etc.), the majority of the domain is mesh-free.

Gridded Method

Gridded methods like FDM and FEM solve the groundwater flow equation by breaking the problem area (domain) into many small elements (squares, rectangles, triangles, blocks, etc.)and solving the flow equation for each element (all material properties are assumed constant or possibly linearly variable within an element), then linking together all the elements using conservation of mass across the boundaries between the elements, see Figure 5-49. This results in a system which overall approximates the groundwater flow equation, exactly matches the boundary conditions (the head or flux is specified in the elements which intersect the boundaries).

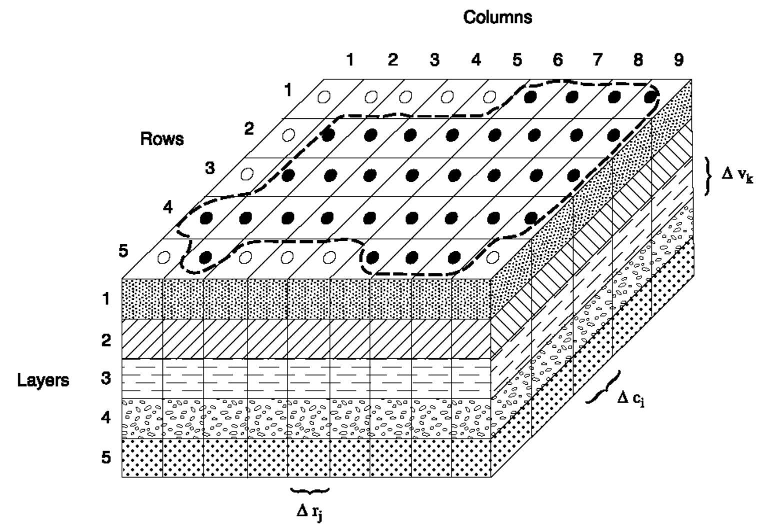


Figure 5-52 Example of a 3-dimensional grid for numerical modeling

FEM are a way of representing continuous differential operators using discrete intervals (Δx and Δt), and the finite difference methods are based on these. For example the first order time derivative is often approximated using the following finite difference, where the subscripts indicate a discrete time location.

$$\frac{\partial h}{\partial t} = h'(t_i) \approx \frac{h_i - h_{i-1}}{\Delta t}.$$

The forward finite difference approximation is unconditional stable, but leads to and implicit set of equations (that must be solved using matrix methods). The similar backwards difference is only conditional stable, but it is explicit and can be used to “march” forward in the time directions, solving one grid node at a time.

MODFLOW is a well-known example of a general finite difference groundwater flow model. It is developed by the US Geological Survey as a modular and extensible simulation tool for modeling groundwater flow. It is free software developed, documented and distributed by the USGS. Many commercial products have grown up around it, providing graphical user interfaces to its input file based interface, and typically incorporating pre-and post-processing of user data. Many other models have been developed to work with MODFLOW input and output, making linked models which simulate several hydrologic processes possible (flow and transport models, surface water and groundwater models and chemical reaction models), because of the simple, well documented nature of MODFLOW.

FEM programs are more flexible in design (triangular elements vs. the block elements most finite difference models use) and there are some programs available (SUTRA, a 2D or 3D density-dependent flow model by USGS; Hydrous, a commercial unsaturated flow model; FEFLOW, a commercial modeling environment for subsurface flow, solute and heat transport processes; to mention a few), but unless they are gaining in importance they are still not as popular in with practicing hydrogeologists as MODFLOW is. Finite element models are more popular in university environments, where specialized models solve non-standard forms of the flow equation (saturated flow, density dependent flow, coupled heat and groundwater flow, etc.)

Mesh – Free Methods

These include mesh-free methods like the Analytical Element Method (AEM) and the Boundary Element Method (BEM) which are closer to analytic solutions, but they do approximate the groundwater flow equation in some way. The BEM and AEM exactly solve the groundwater flow equation (perfect mass balance), while approximating the boundary conditions. These methods are more exact and can be much more elegant solutions (like analytic methods are), but have not seen as widespread use outside academic and research groups yet.

5.2.6.2 Modeling Performed

A number of modeling exercises are performed in the Molopo-Nossob Basin. These exercises are done in connection to groundwater investigation with the aim of supplying water to local and/or regional consumers. Modeling is also conducted in regional groundwater studies and in connection with academic projects.

A list of groundwater modeling performed is given in **Table 5-29** and shown in **Figure 5-53**. The latest modeling attempt known is within the Transboundary Groundwater Resource Program where the Stampriet Artesian Basin, SAB, was modelled by BGR. Other attempts were previously conducted in the JICA project 2002 and by DWA Namibia over the same area (SAB). In Botswana, numerical modelling of the area north of Bokspits was performed. Also the existing wellfield area around Tshabong and future groundwater abstraction from planned wellfields and Kang and Ncojane were modeled by DWA.

Table 5-29 Modeling exercises conducted in the Molopo-Nossob Basin

Country	No	Area	Size km^2	Model used	Reference	Remarks
Botswana	B1	Kang	8,480	Modflow	DWA, 2007	
	B2	Ncojane	55,300	Modflow	DWA, 2008	
	B3	Bokspits	4,000	Modflow	DGS, 2002	
	B4	Tsabong	35	Modflow	DWA, 2002	
	B5	Hunhukwe/Lokalane		Modflow	DGS, 2000	
	B6	Kanye		Modflow	DWA, 2006	
Namibia	N1	SAB	71,000	Modflow	JICA, 2002	
	N1	SAB	71,000	Feflow	Bäumle, 2008	DWA work 2004/2005
South Africa	SA1	Tosca Molopo	4,000	Modflow	Van Dyk, 2005	
		Pering Mine			Moseki, 2001	
	SA2	Louwna-Coetzerdam	1,330?		Botha and van Wyk 1995	
	SA3	Sishen Mine			Steenekanp, 1998	

The models used in the exercises were mainly Modflow and Feflow. The models all have the possibility to undertake a two or three dimensional, finite difference groundwater flow modeling.

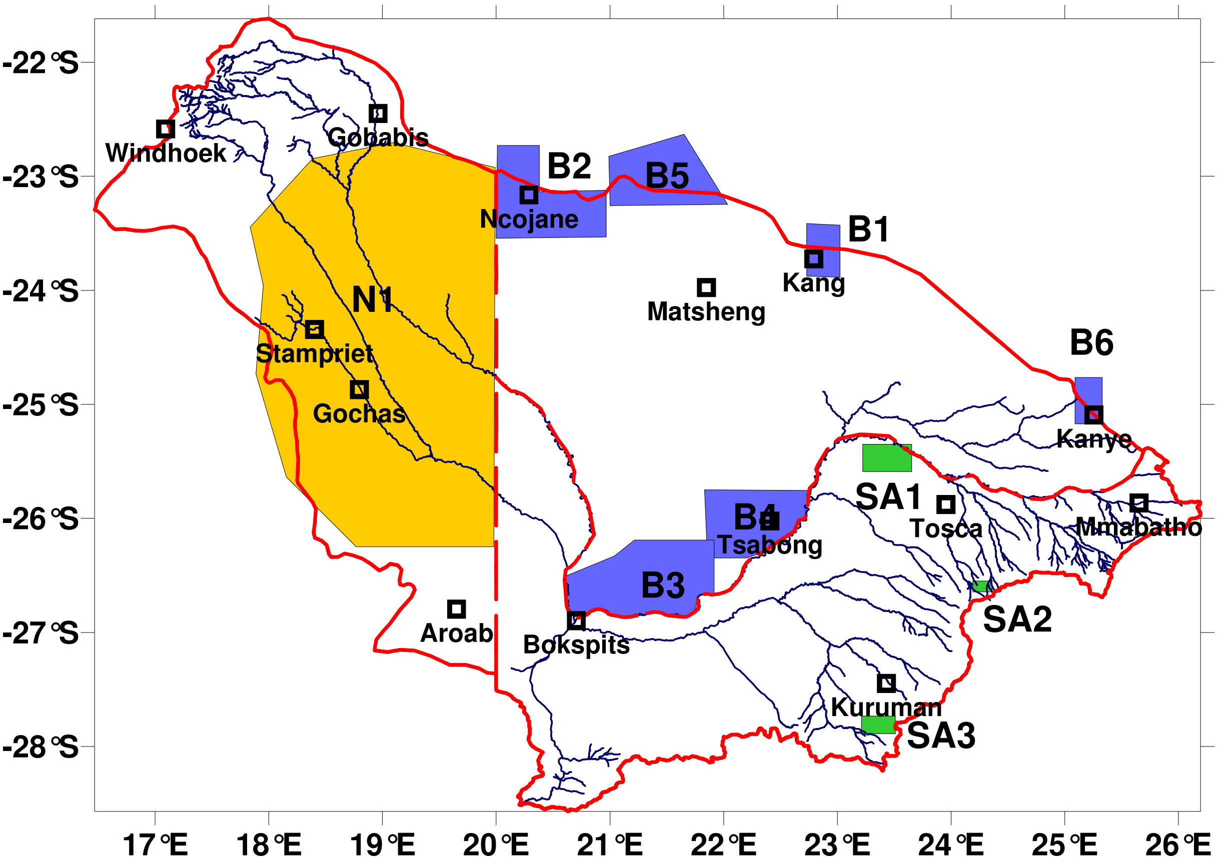


Figure 5-53 Location of areas where groundwater modeling is conducted. Numbers refer to Table 5-29

The basic data sets required for development of numerical models will come from the results of the data assessment:

- Topography
- Aquifer base and thickness (geology and structures)
- Hydraulic conductivity, transmissivity, and storativity
- Recharge
- Piezometric surface for steady state calibration
- Boundary conditions
- Precipitation
- Salinity distribution
- Evapotranspiration data
- Piezometric head (hydrographs) and time series of abstraction for transient calibration

All the above data sets except for hydrographs are discretizised according to the model grid units. Some of the data such as hydraulics parameters, piezometric surface, aquifer thickness, recharge, and TDS are compiled into scattered data files and then gridded before inputting into the model grid.

A first standard calibration is usually carried out under steady state condition to simulate observed initial piezometric heads with appropriate boundary conditions. Its aim to refine the transmissivities/hydraulic conductivity values, natural recharge and evapotranspiration.

The second standard calibration is under transient conditions using hydrographs and piezometric evolution patterns. The aim is to refine the storativity of the aquifer.

Each model parameter is also subjected to a sensitivity analysis to establish its effect to uncertainty on the calibrated model.

Once the model is calibrated, the response of the aquifer system to both future natural and human induced stresses is established in terms of both quantitative and qualitative. The various scenarios to be applied are usually discussed with the main stakeholders and planners. The modeling results can also be used for delineation of protection zones based on travel time in the groundwater by various potential pollutants, see example **Figure 5-54**.

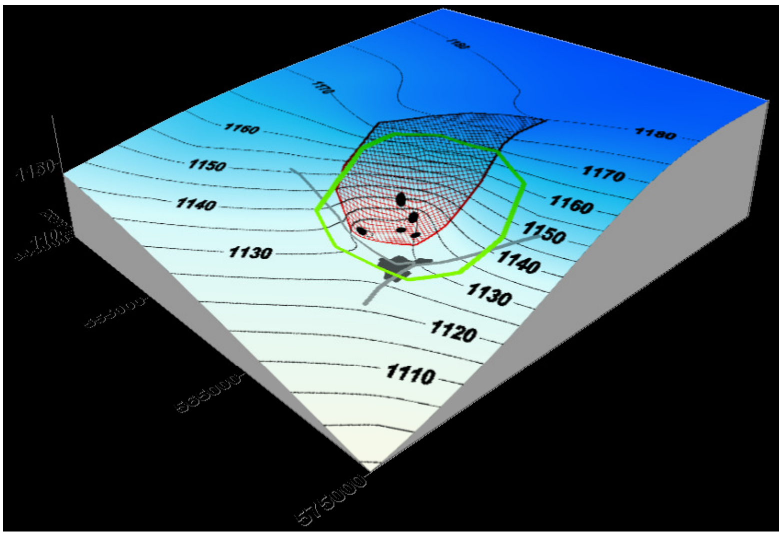


Figure 5-54 **Example of protection zone delineation (Ghanzi, Botswana) using results from numerical modeling (Red zone for 100 years travelling time, green zone restricting for drilling and abstraction of groundwater)**

Kang-Phuduhudu

Groundwater investigations for the supply of Kang village and surrounding rural villages and farms were carried out in 2007 (DWA, 2007). The study included a modeling exercise with the objective:

- To comprehensively evaluate and quantify the groundwater resources of the aquifers present
- To optimize utilization of the identified groundwater resources while mitigating any detrimental environmental effects of such development
- To determine and assist in delineating protection zones for new and existing wellfields
- To use groundwater modeling as a tool for future groundwater resources management and as a reliable tool for decision making
- To predict future aquifer response to various abstraction stress conditions

The targeted aquifer was the Ecca Group aquifers consisting of the Boritse and the underlying Kweneng Formation where substantial yields were encountered. The Ecca aquifer is separated from the Kalahari and Lebung by a thick Kwetla and Mosolotsane mudstone sequence.

Major structures significantly influenced the depth of occurrence of the main aquifer, as well as the thickness and distribution of the overlying Karoo units, by virtue of the horst and graben movements with subsequent erosion. The regional groundwater flow within the modeled area is northwest to south-east.

It was considered highly unlikely of any direct recharge to the Ecca aquifers since thick Kalahari (20-150 m) and thick Kwetla (>200 m) overlay the aquifer. For modeling purposes no direct recharge to the aquifer was considered in the modeled area.

With the assumption of assuming zero recharge into the model, the model was calibrated with a fixed/head dependant boundary to the west during steady state modeling. For the most conservative approach to resource modeling, the western boundary could also be closed and zero inflow assumed so as to evaluate wellfield response to closure of the boundary.

Three main types of groundwater fluxes were considered, inward flux from the northwest and west, outward fluxes to the south, north and southeast and abstraction fluxes. The inward flux from the northwest was taken from values given by work undertaken in the Stampriet basin in Namibia, (JICA, 2002).

The numerical model used had the following characteristics;

- A Finite Difference MODFLOW model, rectangular grid of 1 km^2 consistent with the UTM coordinates, see **Figure 5-55**. The size of the total model 8,480 km^2
- A 2-LAYER model with the two layers separated by a very low permeability unit

- Fluxes 3-D mainly horizontal flow within each layer and vertical flow across the intervening aquitard.
- Transmissivity and storage coefficient (only in the transient phase) automatically convertible between confined and unconfined conditions.

After proper calibration the model was used to:

- Simulate groundwater abstraction to the year 2025
- Assess the potential of each individual borehole in meeting the demand
- Verify the recommended abstraction rates interpreted from test pumping data by numerical groundwater modeling
- Assess the potential of the groundwater resources in meeting the projected water demand
- Evaluate drawdown spatial distribution from abstraction to 2025.
- Assess the overall regional groundwater flow regime as a result of abstraction to 2025.
- Delineate aquifer protection zones.

The maximum drawdown achieved during predictive modeling was between 30-40m for the entire model area.

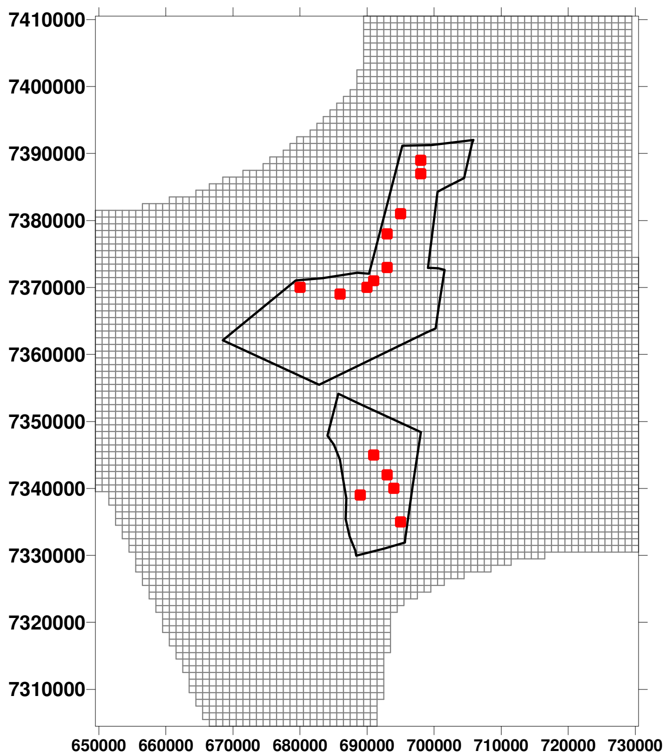


Figure 5-55 **Grid lay-out for the Kang-Phuduhudu numerical model wit delineated wellfield areas and simulated production wells (DWA, 2007)**

Some of the conclusions and recommendations from the modeling exercise were:

- The horizontal flow from the northwest was estimated to be 1,300 m^3/d which value is 5 times less than the out flux of 6,800 m^3/d calculated for the Stampriet basin in Namibia.
- It is a need to evaluate the nature and volume of the groundwater influx into the modelled area to the northwest.
- Drawdown contour maps showed insignificant spread of the cone of depression outside the major structural features, with drawdown of one metre observed beyond the northwest boundary.
- The predictive model results show that the projected water demand until 2025 will easily be met with the available production boreholes.
- Aquifer groundwater storage will account for 68% of the total groundwater abstraction by 2025. This aquifer storage use will have delayed effects on the aquifer recovery with recovery rates of 74-78% estimated after a 20 year period of non-pumping.
- Low groundwater vulnerability within the modelled area due to a deep aquifer, thick overlying strata which are also generally impermeable. Wellhead protection zones were delineated based on travel time and travel distance calculation from particle tracking methods. The 100 day travel time shows travel distances of <100m, while, the 100 year travel time shows distance of at most 400m.The protection zones were delineated based on aquifer drawdown response to abstraction at the end of 2025.

Ncojane and Matlho-a-Phuduhudu Blocks

Groundwater investigations to locate and develop sufficient potable groundwater resources for the supply to the demand centres of northern Kgalagadi District in Botswana were carried out in 2008 (DWA, 2008). The study included a modeling exercise with the objective:

- To comprehensively evaluate and quantify the groundwater resources of the aquifers present
- To simulate potential wellfield abstraction
- To determine and assist in delineating protection zones for new and existing wellfields
- To use groundwater modeling as a tool for future groundwater resources management and as a reliable tool for decision making
- To predict future aquifer response to various abstraction stress conditions

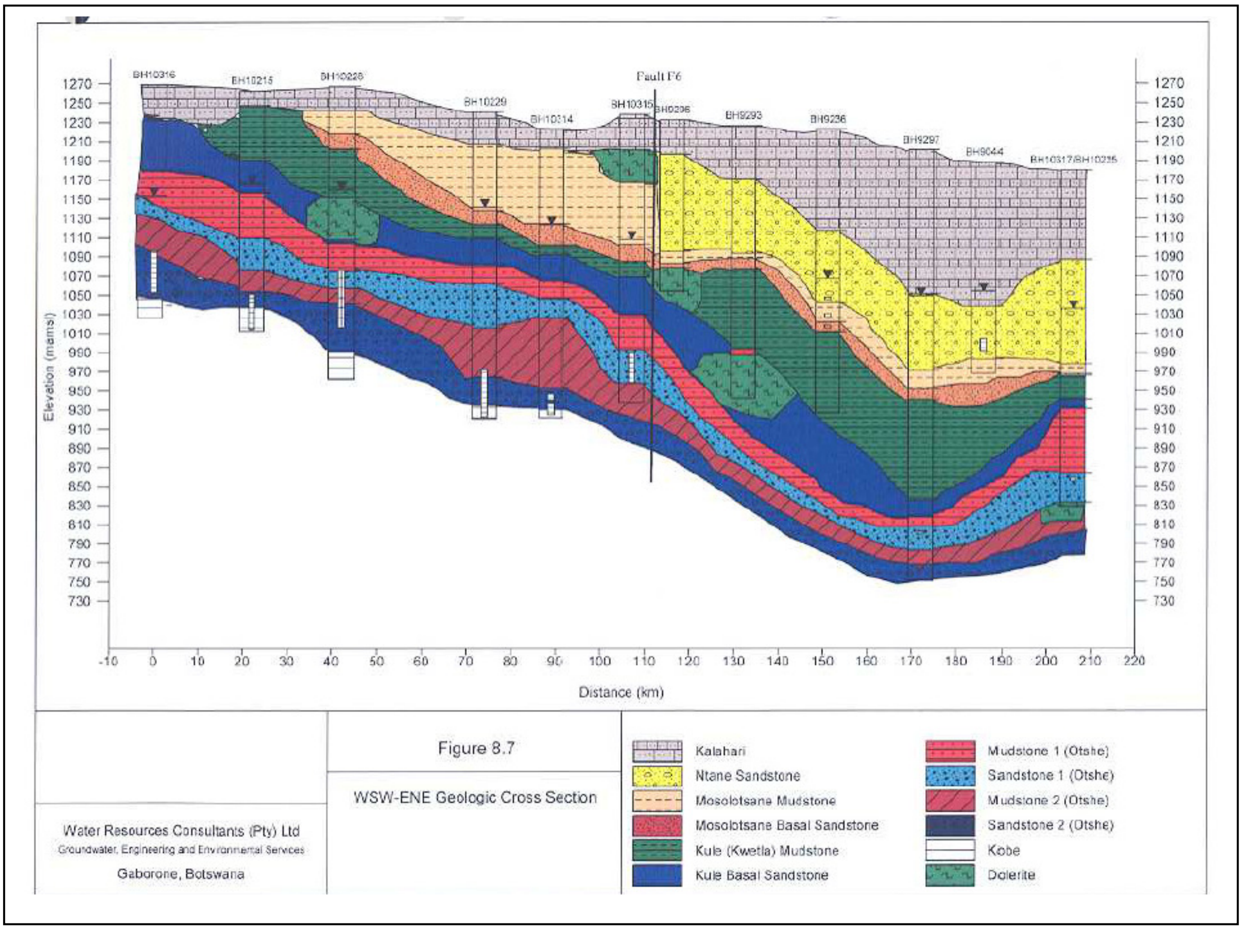


Figure 5-56 Geologic cross section WSW-ENE through the Ncojane area in Botswana (DWA, 2008). The three aquifers considered are Ntane, Otshe sandstone1 and Otshe sandstone 2.

The targeted aquifers were the Ecca and the Ntane sandstone aquifers. The modeled aquifer system was conceptualized in terms of a four layer model where the top layer represented the saturated formations overlying the Ecca aquifer (Ntane, Kalahari Beds or a combination). The underlying layers 2 through 4 represented interpreted aquifer units in the Ecca, with layer 4 representing the deepest saline portion of the system (Kobe aquifer). **Figure 5-56** shows a cross-section over the investigated area with the identified aquifers.

Recharge was applied only to the western part with the value 0.15 to 0.63 mm/a.

The model was given Transmissivity vales of 50 m^2/d in the upper layer (layer 1) In the lower layers a Transmissivity of 25 m^2/d was assigned, however with high values (100 m^2/d) in zones identified

The numerical model used had the following characteristics;

- A Finite Difference MODFLOW model, rectangular grid of 10x10 km to 1x1 km. The size of the total model 55,300 km^2
- A 4-LAYER model separated by a very low permeability unit with vertical leakage

- Fluxes 3-D mainly horizontal flow within each layer and vertical flow across the intervening aquitard.

After proper calibration the model was used to:

- Simulate a production of 9,600 m^3/d from the Ecca aquifer
- Simulate a scenario with two wellfields, western and eastern, in Ecca and Ntane with abstraction for 20 years of 16,800 and 13,200 m^3/d respectively.
- Delineating of protection zones for the wellfields.

Some of the conclusions and recommendations from the modelling exercise were:

- The total recommended abstraction rate of 9,600 m^3/d, representing about half the recharge value will on long term be a sustainable yield.
- The wellfield will probably reach steady-state after a period of more than 80 years..
- In the two wellfield scenario, the abstraction from the Ecca aquifer will be just barely possible. However the abstraction from the Ntane aquifer will result in drying up of the boreholes.
- The predictive model results show a sustainable abstraction from the Ntane sandstone aquifer should be lower than 2,500 m^3/d.
- A groundwater protection zone with a radius of 4 km around each production borehole will contain a capture zone for 100 years of travel time in the aquifer of any pollution.

Bokspits

To summarize and recommend groundwater abstraction in the Bokspits TGLP area, a 3D finite difference (MODFLOW) model of the regional groundwater flow was constructed using information from borehole, water level and pumping test data. The model had approximately 4 km grid spacing and covered more than 4000 km^2. In conceptual model building information from hydro chemical and isotope evaluation was also used.

Great attention was given to the estimation of recharge and several techniques such as SVF and CRD were evaluated. Water level contour map was developed with the aid of a digital terrain model based on grid with 30 arc second resolution.

The model was represented by one layer with interpolated bottom and top based on drilling results, see **Figure 5-57**. The model was calibrated as steady state against the regional piezometry in September 2001. Four hydraulic conductivity and four recharge zones were considered in the model. Due to poor spatial coverage of the transient data, the unsteady state calibration was not attempted.

Modeled domain, which extends beyond the project area boundaries, was set up to receive recharge in the order of over 6000 m^3/d (0.5 mm/y). Discharge was taking place mainly in the south to southwest at a rate of about 0.5 l/s per km. This value was however charged with large uncertainty due to unavailability of abstraction data on the South African side.

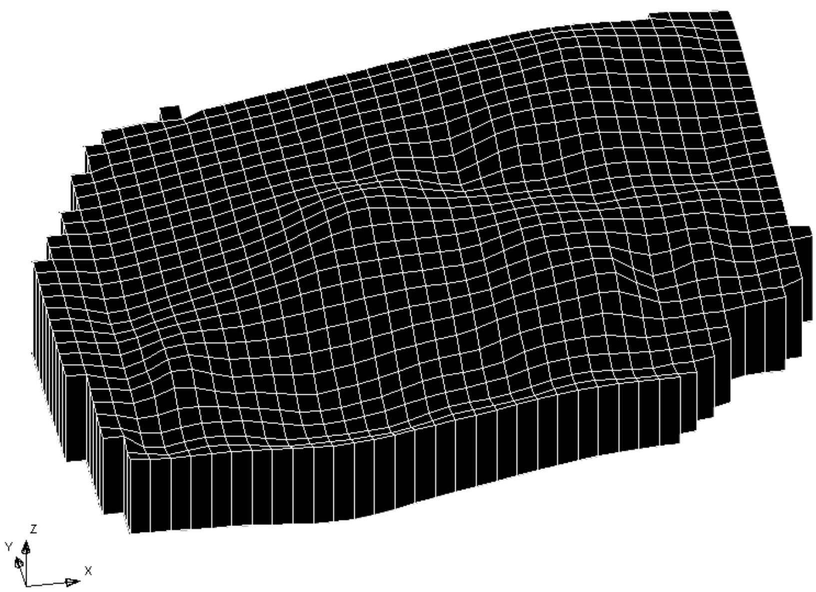


Figure 5-57 **Three-dimensional image of the modeled aquifer system. (Note that the upper surface is not the topographic surface, but extrapolated depth to first water strike. The system thus represents confined/unconfined structure) (DGS, 2003)**

Proposed pumping rate of 1,515 m^3/d from 13 production boreholes was found to be not feasible. This was not due to overall deficit, in fact the available recharge exceeded pumping requirements about three times, but due to demands on specific boreholes. Simulations for 20 and 50 years (using reasonable storativity estimates 0.0015-0.0028) were used to adjust proposed pumping rates of about 37%.

To improve the modelling exercise it was proposed that:

1. Data from should be requested from the South African to improve the model reliability in the south and west. The data should include measurements of water levels and abstraction.
2. The northern boundary of the model should be moved further north and data required between the current project boundary (northern) and moved model boundary (about 20-30 km further north).
3. Instead of large pumping from one borehole, the pumping load should be spread to several boreholes.
4. Hydro chemical monitoring is crucial and influx of saline waters may destroy pumping schemes if the hydro chemical changes were not monitored. This was considered especially important in case of Sikamatswe-Khawa wellfield development area.
5. Periodic reassessment of recharge (and potential model recalibration) was required together with monitoring of water levels and sampling for isotope data.

Tsabong

Groundwater investigations for the supply of Tsabong village and surrounding rural villages and farms were carried in 2002 (DWA, 2002). The study included a modeling exercise with the objective:

- To evaluate and quantify the groundwater resources of the aquifers present
- To determine and assist in delineating protection zones for new and existing wellfields
- To use groundwater modeling as a tool for future groundwater resources management and as a reliable tool for decision making
- To predict future aquifer response to various abstraction stress conditions

The targeted aquifer was the Olifantshoek aquifer consisting of quartzite sandstone outcropping and covered by Kalahari Beds. The model used was limited to a grid measured 50 by 70 grids and cantered on a water yielding lineament. Each cell in the grid measured 100x100 m and the size of the model was 35 km^2, see **Figure 5-58**.

The aquifer comprised the fracture zone forming a tabular body, generally dipping to the southeast. In the model this fracture was assigned 300 m width, 2-5 m thickness and 6,500 lengths. The aquifer was considered both confined and unconfined.

Constant head boundaries were assigned to the two outflow area opposite each other whereas the other two boundaries were considered no flow boundaries. The transmissivity along the structural feature was set at 15 and 30 m^2/d respectively. Outside the lineament a low Transmissivity of 0.1 m^2/d was assigned.

Recharge of 15 mm/a was assigned to the unconfined part of the aquifer, the rest of the model was given 3.7 10^{-5} mm/a.

During calibration process against water level during steady and transient state (test pumping) the Transmissivity and recharge assignment were adjusted.

Some of the conclusions and recommendations from the modelling exercise were:

- The model applied was simple and not recommended to be used for future groundwater planning purposes.
- The recharge at the rock outcropping area was found to be around 40 mm/a.

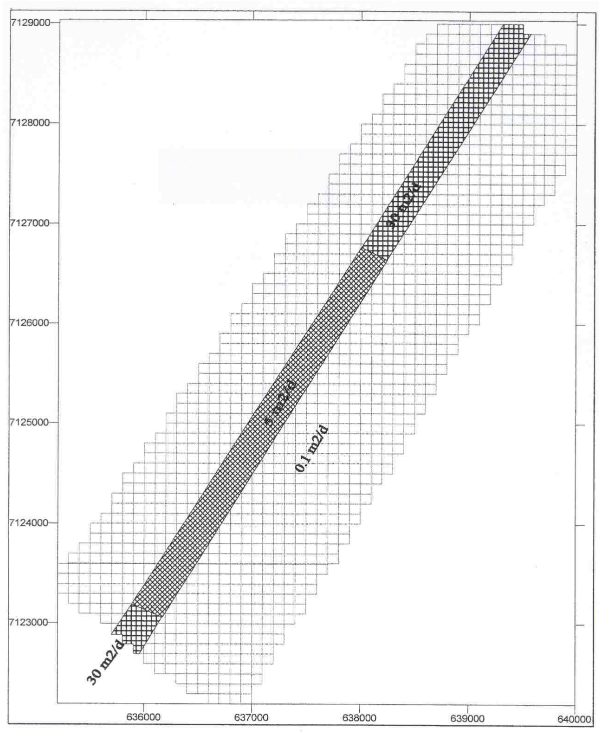


Figure 5-58 Grid net used and assigned Transmissivity values in modeling in Tsabong (DWA, 2002)

Stampriet Artesian Basin, SAB

The Stampriet Artesian Basin was investigated regarding the groundwater flow regime, the recharge mechanism, sustainable groundwater abstraction and to lay out a groundwater management plan. As part of the groundwater potential evaluation, a numerical modelling was performed over the area covering about 71,000 km^2 (JICA, 2002).

The model used was a finite difference three-dimensional model (Visual Modflow). The model covered the three aquifers (Kalahari, Auob and Nossob). The Kalahari aquifer was modelled in unconfined, and the Auob and Nossob aquifer as confined aquifers.

The northern and south-eastern boundaries were regarded as a constant head boundary to approximate groundwater inflow and outflow.

The model used the data on recharge, aquifer hydraulic properties and abstraction assessed from the study of the SAB. Irrigation 6.9 Mm^3/a, stock watering 5.7 Mm^3/a and domestic groundwater abstraction of 2.4 Mm^3/a were applied as stress in the model. Model calibration was done against monitored groundwater levels.

In the prediction modeling, six (6) different scenarios were applied and simulated for a 100 years period. Case 1 and 2 were assumed to maintain the groundwater use found in the study. Case 3, introduced an increase of 120% on the irrigation in comparison with use found in the study. In Cases 4 to 6, the irrigation use was decreased to 70%, 50% and 0% respectively. **Table 5-30** summarizes the scenario cases.

The simulation results showed that the Stampriet area in the SAB was over-pumped at the groundwater usage at the time of the study. A 50% reduction in irrigation use was recommended necessary for the Stampriet area; otherwise, the Kalahari Aquifer in the area will dry up in near future. **Table 5-31** summarizes the results. The groundwater level drawdown in the Kalahari and Auob aquifers simulated after 100 years of pumping (Case 2) are illustrated in **Figure 5-59.**

Table 5-30 Scenario cases in the JICA groundwater modeling of the SAB (JICA, 2002)

Case	Pumping Rate (Mm^3/year)			
	Domestic	Stock Watering	Irrigation (%)	Total (%)
1	2.36	5.69	6.89 (100)	14.94 (100)
2	2.36	5.69	6.89 (100)	14.94 (100)
3	2.36	5.69	8.27 (120)	16.32 (109)
4	2.36	5.69	4.82 (70)	12.87 (86)
5	2.36	5.69	3.44 (50)	11.49 (77)
6	2.36	5.69	0 (0)	8.05 (54)

Table 5-31 Results of the Groundwater Simulation of the SAB (JICA, 2002)

Area	Stampriet Area				Other Area			
Constraint	Water Balance		Economic		Water Balance		Economic	
Case / Aquifer	Kalahari	Auob	Kalahari	Auob	Kalahari	Auob	Kalahari	Auob
1	NA	NA	UD	A	A	A/UD	G	G
2	NA	NA	UD	A	A	A	G	G
3	NA	NA	UD	UD	A	A	G	G
4	NA	UD	UD	G	A	A	G	G
5	A/UD	A	G	G	A	A	G	G
6	A	A	G	G	A	A	G	G

Remarks: Water Balance, G=Good (0-0.03m/y), A=Allowable (0.03-0.10m/y), UD=Undesirable (>0.11m/y), NA=Not Allowable (Dry up)
(Drawdown) Economic: G=Good (0-10m), A=Allowable (10-20m), UD=Undesirable (>20m), NA=Not Allowable (Dry up)

On the other hand, in other areas in the SAB, no problem arose in any of the simulation cases. In those areas the groundwater use was mainly for stock watering or domestic purpose, and no remarkable increase was noticed. In Stampriet area, Case 5 (reducing irrigation use to 50%) and Case 6 (reducing irrigation use to 0%) were considered acceptable. Case 4 (reducing irrigation use to 70%) could not be recommended since the Kalahari Aquifer then would dry up within 80 years. To prevent the dry-up of the aquifer, groundwater pumping for irrigation use it was proposed that it should at least be reduced to 50% of that in 1999, almost the same as the irrigation use in 1992.

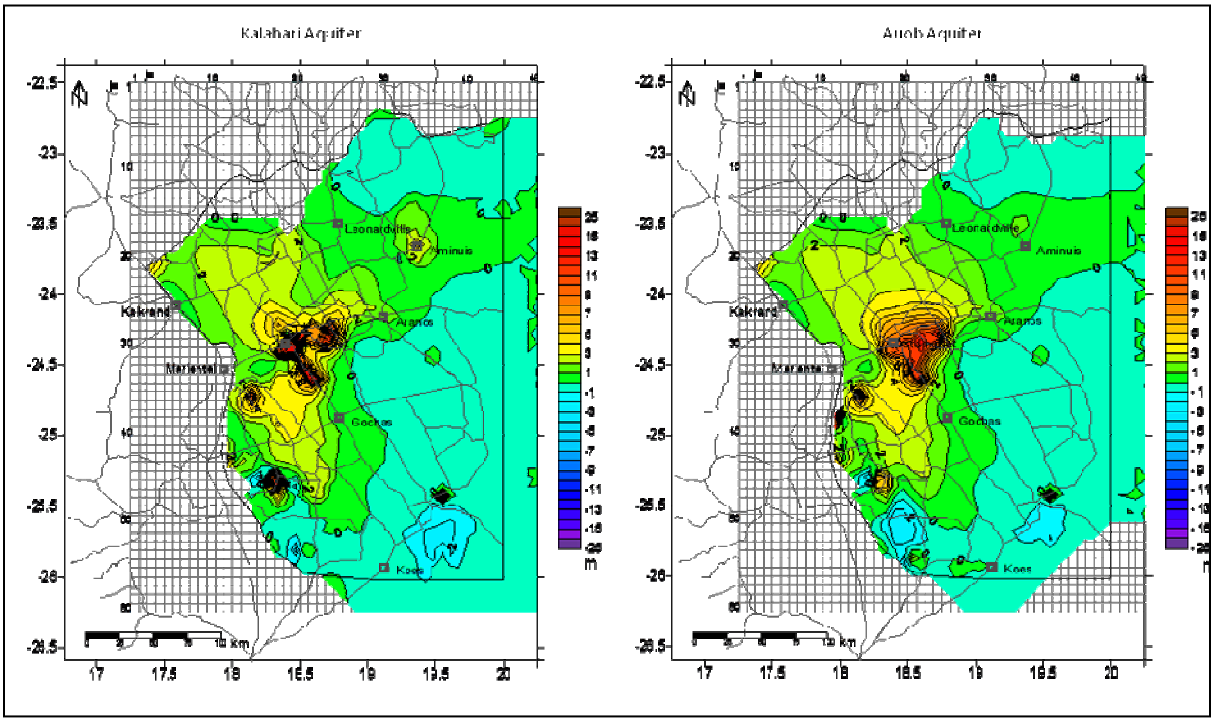


Figure 5-59 **Simulated drawdown in the Kalahari and Auob aquifers (Case 2) in the Stampriet Artesian Basin, SAB (JICA, 2002).**

Tosca Molopo

A study to investigate the impact of irrigation on the resource and initiate actions to manage the resource was conducted in 2005 (van Dyk, 2005). The background for the study was a monitoring of groundwater decline of up to 60 m due to a rapid development of irrigation from groundwater resources in dolomite aquifers.

In the evaluation a modeling exercise was performed using the MODFLOW PMWIN 5.1.7 (Chiang 2000) software to construct a 2-layer finite difference flow model. The model covered an area of 4000 km^2 was divided into cells of 0.5 x 0.5 km generating 100 rows and 160 columns. Based on the understanding of the hydrogeology (a conceptual model), provision was made for 2 layers comprising an unconsolidated primary aquifer by fine-grained sediments of the Kalahari Group and an underlying fractured dolomite with its aquifer characteristics.

The general flow is from the SW to the NE with the Molopo River the base of drainage. From the observed water level reaction the sediments contribute largely towards the storage of the aquifer system with the fractures of the dolomite contributing to high yielding flow.

Dolerite dykes were taken into consideration in the model and the two most influential (Grassbank and Quarreefontein dykes, about 15 m thick each) acted as no-flow boundaries of the Neumann (impervious) type impeding flow from the south and west of the area.

The first layer ranges from an elevation of 1160 mamsl (meters above mean sea level) at a depth of 10 m in the southwest. To the northeast it range from an elevation of 1080 mamsl to a depth 960 mamsl or a thickness exceeding 120 m. The base of the sediments is the top of the fractured dolomite aquifer with its base at 900 mamsl.

The surface and groundwater shed formed by the Banded Iron Formation of the Waterberg formed the boundary to the west. The combination of both a geological contact and watershed was a leaking boundary. The Molopo River formed the eastern boundary.

Recharge to the aquifer was determined with using the chloride mass balance method. Various recharge zones as determined from this chloride analysis were used in the model and the recharge was based on seasonal recharge for the winter (ranging from 0.5% or 0.4 mm to 3% or 1.5 mm) and summer (ranging from 0.5% or 1.6 mm to 3% or 8.3 mm) depending on the precipitation.

In the modeled area, the sole source of water for both agricultural and domestic requirements was groundwater. As irrigation use was responsible for 99.5 % of the total use, the domestic and stock watering abstraction was not considered in the modeling exercise. The irrigation volume was averaged over a six-month period (182.5 days) according to crop cultivated to obtain the daily abstraction from the aquifer.

Table 5-32 Scenario modeled and results obtained in the Tosca Molopo investigation (van Dyk, 2005)

Scenario No	Precipitation and Recharge	Abstraction	Results	
1	Average and normal	Current high 16.1 Mm3/a	level declines of 20 to 30m and 60 to 110 m	Not acceptable
2	Average and normal	Irrigation abstraction restricted to 11.1 Mm3/a	water level declines of 10 to 20m and 30 to 60m	With strong abstraction control this scenario with controllable water level declines was acceptable
3	20% les average and normal	Irrigation abstraction restricted to 11.1 Mm3/a	Water level decline similar to Scenario 1	Not acceptable and below normal precipitation would be an exception.
4	Average and normal	No irrigation	Water level recovered after 10 years	Not realistic

The calibrated model was used to test the following 10-year future scenarios of abstraction and recharge in order to assist in decisions regarding management of abstraction from the aquifer system. Four scenarios were simulated in the modeling exercises, see **Table 5-32**.

Based on the evaluation and modeling of the resource the regulating and management of abstraction was addressed within the legal framework provided by the National Water Act (NWA) to obtain sustainable, equitable and fare dispensation of water use.

6 GROUNDWATER RESOURCES

6.1 Evaluation process

The hydrogeological regime of the Molopo-Nossob Basin is complex with many types of geological formation and hence of groundwater resources (aquifers). In order to assess the "groundwater potential" of the basin a groundwater model would be the obvious way in such an assessment. The paucity of data and the lack of a clear quantitative understanding of the aquifer parameters over such a large area make it not possible or reliable to assemble such a model without additional field investigations.

Instead a qualitative assessment is approached by combining various data sets and knowledge collected during the current project and applying semi-quantitative weighting factors to such data.

Groundwater potential describes the possibility and ability of an aquifer at a specific area to supply groundwater in desired quantity and quality to the end user. It must be kept in mind that an area can have different potential dependent upon the ultimate intended use of the resource. Groundwater potential in the Molopo-Nossob Basin is therefore approach on potential for human consumption and secondly also for livestock watering.

In the groundwater potential assessment the hydrogeological characteristics or attributes that directly or indirectly affect the availability of what is defined as 'suitable' groundwater include the following parameters:

1. Groundwater quality
    a. Total dissolved solids, TDS
    b. Nitrate, NO3
    c. Fluoride, F
2. Groundwater recharge potential

The groundwater quality is described over the whole Basin is described in maps showing the distribution of the parameters TDS, NO_3 and F, see **Chapter 5**. These groundwater maps are reclassified with emphasis given to the limits in respect of human consumption and of livestock watering. **Table 6-1** summarized the limits used for the two categories of users.

Figure 5-51 shows the groundwater recharge assessed from chloride mass balance, CMB. This map is reworked, see **Table 6-1** and **Table 6-2** for human consumption and livestock watering respectively, in order to assess areas of different classes and to be combined with the classes reassessed for the groundwater chemistry.

Areal distribution of the borehole yield is not assessed mainly due to the lack of reliable data and division of the boreholes on various aquifers they represent. In **Chapter 5.2**, a number of aquifer with borehole yields and aquifer Transmissivity values are compiled. These data shows some characteristics related to the aquifers they represents, summarized in **Table 6-3**. Instead of borehole yields assessed in the current project, yields given on the hydrogeological maps from the three countries are put together in the map under **Chapter 5.2** and delineated as groundwater potential aquifers within limits set on high and medium borehole yields.

Table 6-1 **Classes and values used in the assessing of groundwater potential in the Molopo-Nossob Basin (human consumption)**

Parameter	Class	Value	Remarks
TDS	1. 450 mg/l and lower 2. linear 3. interpretation between 4. upper and lower value 5. 2,000 mg/l and higher	1 2 3 4 5	Limit Class 1 Botswana Upper limit Class 3 Botswana
F	1. 0.7 mg/l and lower 2. linear 3. interpretation between 4. upper and lower value 5. 1.5 mg/l and higher	1 2 3 4 5	Upper limit for 'ideal' water WHO guideline upper limit
NO_3	1. 27 mg/l and lower 2. linear 3. interpretation between 4. upper and lower value 5. 45 mg/l and higher	1 2 3 4 5	Target quality upper limit (South Africa) WHO guideline limit
Recharge	1. 5 mm/a and higher 2. linear 3. interpretation between 4. upper and lower value 5. 0.2 mm/a and lower	1 2 3 4 5	Limit set in the current report

In the process of reclassify and reassess the data, the distribution of the three groundwater quality parameters, TDS, F and NO_3 were used as presented in **Figure 5-12, 5-15, and 5-17**. Over the special distribution a grid-net of 0.2 geographical degrees spacing, see **Figure 6-1**, were overlaid and the values at the interconnection points were used in the reassessment process.

Table 6-2 **Classes and values used in the assessing of groundwater potential in the Molopo-Nossob Basin (livestock watering)**

Parameter	Class	Value	Remarks
TDS	1. 2,000 mg/l and lower 2. linear 3. interpretation between 4. upper and lower value 5. 10,000 mg/l and higher	1 2 3 4 5	Limit Class 1 Botswana Upper limit Class 3 Botswana
F	1. 2 mg/l and lower 2. linear 3. interpretation between 4. upper and lower value 5. 6 mg/l and higher	1 2 3 4 5	
NO_3	1. 100 mg/l and lower 2. linear 3. interpretation between 4. upper and lower value 5. 180 mg/l and higher	1 2 3 4 5	 Limit for Botswana
Recharge	1. 5 mm/a and higher 2. linear 3. interpretation between 4. upper and lower value 5. 0.2 mm/a and lower	1 2 3 4 5	3 3 3 3 3

Table 6-3 Characteristics from the borehole yield and Transmissivity distribution diagrams in Chapter 5.2

Aquifer	Area	Success rate %	Median yield m^3/h	±Standard dev/ median yield
Kalahari	Botswana	60	1.7	3.7
Kalahari	SAB	100	4.0	2.0
Basalt	SAB	100	3.7	1.8
Ntane	Ncojane	100	9.6	1.9
Ecca	Dutlwe	100	13.2	2.1
Ecca	Kang	100	28.6	1.6
Ecca	Bokspits	60	2.1	7.7
Ecca	Ncojane	100	36.0	1.6
Ecca	SAB	100	5.1	2.2
Nossob	SAB	70	3.6	0.9
Dwyka	Bokspits	40	0.4	14.6
Olifantshoek	Botswana	75	4.3	7.4
Dolomite	Kanye	100	45.3	0.6
Gneisses	Botswana, Southern District *	95	3.2	
*=Source: DWA, 1991				

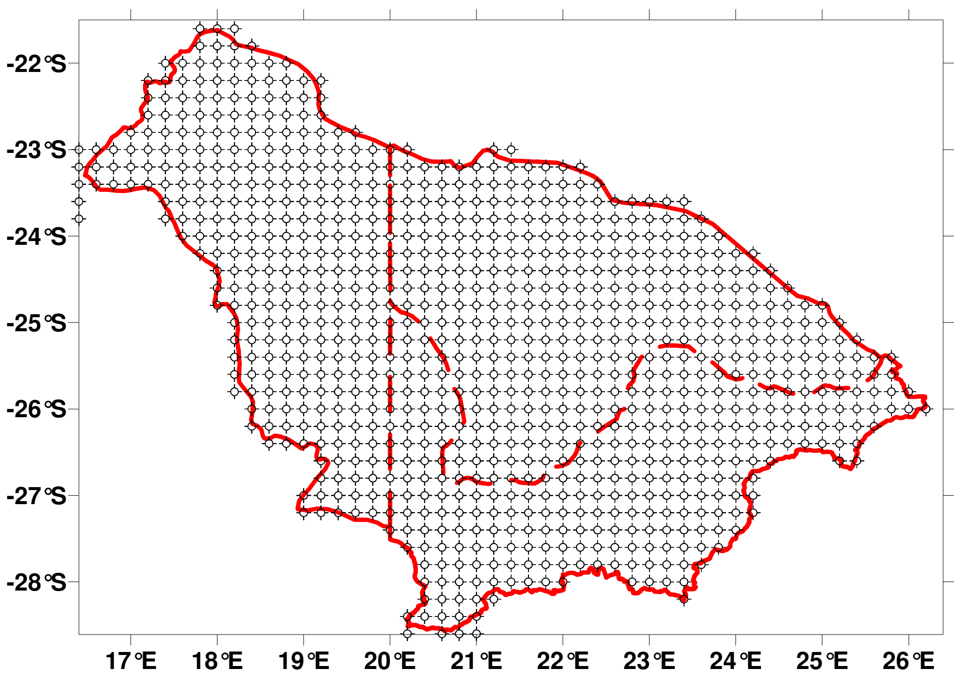


Figure 6-1 Grid-net of 0.2° distance over the Molopo-Nossob Basin to achieve values inn points of chemical and recharge data

6.2 Resources

In **Chapter 5.2**, areas are delineated in which the values for TDS, NO_3 and F are higher than the guideline values. These areas are also showed together as overlays in **Figure 5-6** and **Figure 5-7** for human consumption and livestock watering respectively. These areas are given an indicator each and in **Figure 6-2** these indicators are overlaid to show areas in which one or more of the guideline values are exceeded for human consumption and livestock watering respectively.

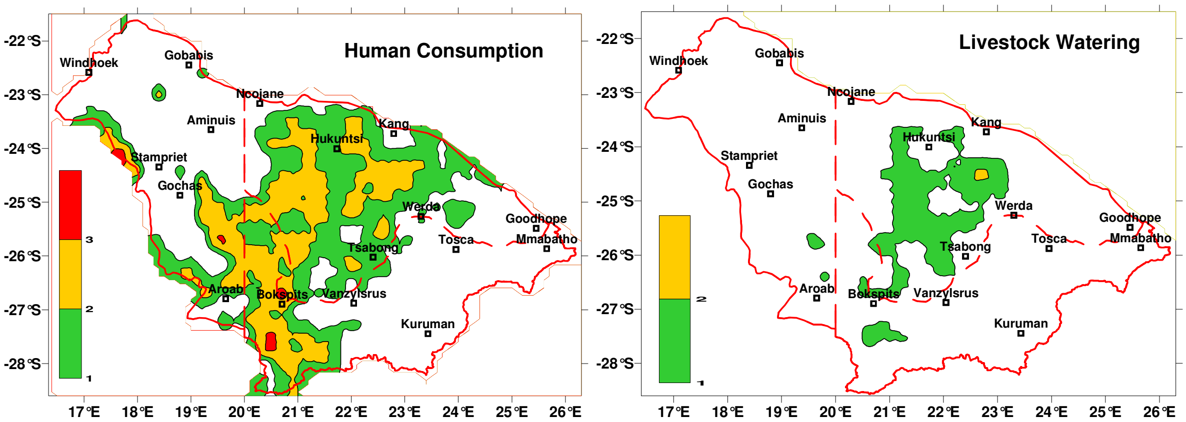


Figure 6-2 **Number of chemical guideline for human consumption and for livestock watering exceeded in the Molopo-Nossob Basin (indicator maps)**

The limits for groundwater recharge set at 0.2 mm/a can serve as an additional indicator and together with the three chemical indicators, two new set of maps are produced, **Figure 6-3**.

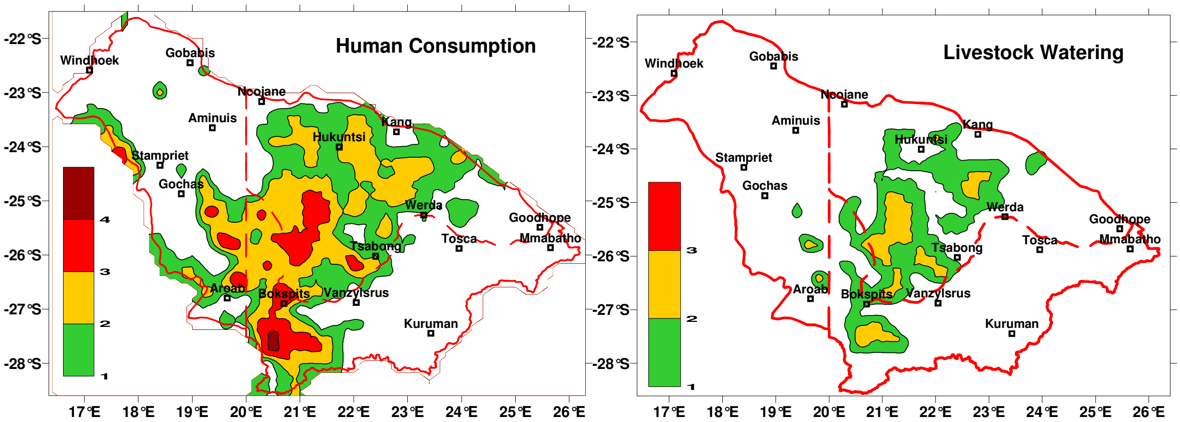


Figure 6-3 **Number of chemical guideline for human consumption and for livestock watering exceeded and recharge of 0.2 mm/a not achieved in the Molopo-Nossob Basin (indicator maps)**

The maps presented in **Figure 6-2** and **Figure 6-3** are indicator maps, that means they indicate areas where water quality (and/or recharge) are above (or below) one or several of the guidelines put forward. Another way to assess the potential is to give different value to the parameters considered (chemical parameters and recharge) as proposed in **Table 6-1**. This means that even if a parameter at one grid point is better than the lowest value given (one) it is given the value one. The same if it is over the maximum value of five, it will be given five. In between these two values however the parameter will be given the calculated value in accordance with **Table 6-1**.

Results from the value assessments are given in **Figure 6-4** for the chemical parameters taken together with the same weight (weight one for each of them). Including the recharge, also with the weight one, the results are presented in **Figure 6-5**.

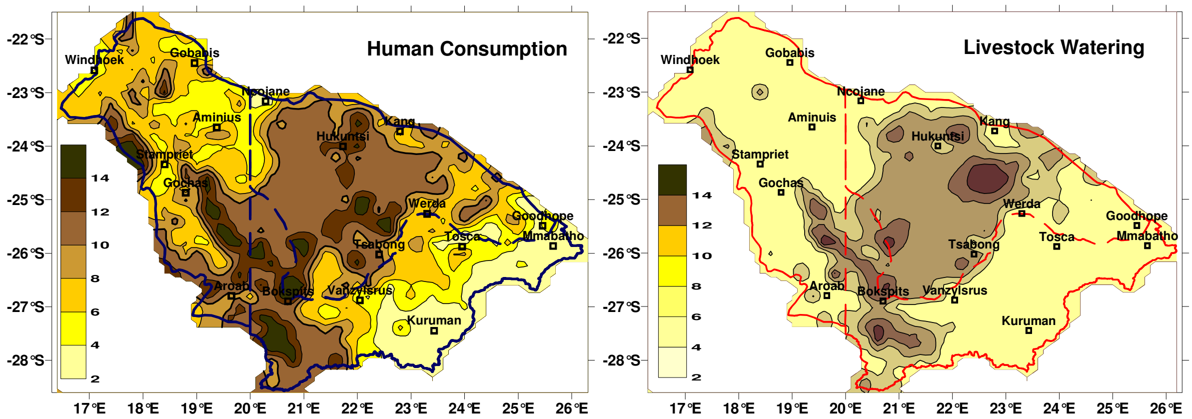


Figure 6-4 Values for the groundwater chemistry in accordance with Table 6-1

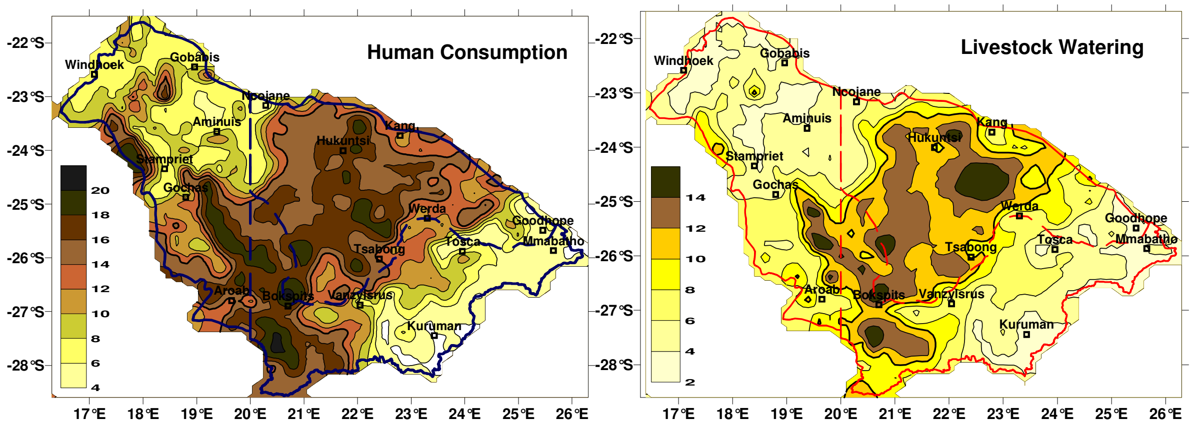


Figure 6-5 Values for the groundwater chemistry and recharge in accordance with Table 6-1

Combining the value maps, the indicator maps and the map showing the potential aquifers (**Figure 5-11**) the most promising aquifers can be distinguished. In these aquifers, no limit on water quality should be exceeded, which leaves out a large area of Botswana for livestock watering, see **Figure 5-20**. Also part of the Gordonia area in South Africa and the area along the Auob River up to east of Gochas have values exceeding the guidelines.

The area useful for livestock watering without exceeding the guidelines for any of the three studied components is shown in **Figure 6-4** as the area having an assigned value of less than 6. The westernmost and the major part of the eastern part of Botswana and the major part of Namibia and more or less the whole South Africa, with exception of the Gordonia part have suitable water for livestock watering When the set guidelines, in this report, of recharge exceeding 0.2 mm/a, is included as an additional indicator, the area 'unsuitable' for livestock watering becomes larger, see **Figure 6-5.**

For human consumption, the areas in which one or more of the chemical guidelines were exceeded is shown in **Figure 6-2 and 6-3** (indicator maps) and **Figure 5-19.** The limit for TDS is here set at 2,000 mg/l and large part of Botswana is excluded. Also excluded is the area along the Auob River, what is also called the 'salt block' and the Gordonia area in South Africa? Also an area northwest of Stampriet (Kirkland) has water exceeding one or two of the guidelines considered. When the limit of recharge exceeding 0.2 mm/a, Gardenia and part of southern Namibia Molopo-Nossob Basin are excluded together with the main part of Botswana In Botswana only the eastern part and the north-western most part have favourable condition for the groundwater.

The indicator maps should be used when the restrictions on water are hard. Using the value assigned to the groundwater chemistry, means that in an area, the limit value according to the guideline could be exceeded for one parameter but the other parameters are so good that the sum value will become reasonable. In such cases, treatment of the water on the parameter exceeding the guidelines is one option for consider the water as potential for consumption.

Regarding the quantity of the groundwater, the map based on the borehole yields serves as a way to assess this parameter. In combination the following points are shown:

- The best yielding dolomite aquifers have no limits due to groundwater quality and recharge (as defined in the current report)
- The aquifers assigned as median borehole yields in fractured, fissured and certified formations have water quality parameters exceeding the guidelines in the Gardenia area and along the Molopo River course and also in Botswana.
- The intergranular and fractured aquifer assigned high borehole yield has good chemical parameter in the Ncojane area.
- The intergranular and fractured aquifer assigned median borehole yield have all one or more chemical parameter exceeding the guideline limits with the exception of in the northern part of Namibia.
- The intergranular aquifers with assigned high borehole yields have the best quality in the Stampriet, the Ncojane and the Kang area.
- The intergranular aquifers with assigned median borehole yields have the best quality in Namibian part of the Molopo-Nossob Basin and in the western part of Botswana.

In order to develop a groundwater resource, drilling of boreholes is required. The depth to the groundwater level will not always tell the drilling depth required since in many places in the Molopo-Nossob Basin artesian aquifer is encountered, especially in the Stampriet Artesian Basin in Namibia. **Figure 6-6** shows the depth to the groundwater level established from the groundwater level map, **Figure 5-46** and the ground surface level map **Figure 2-5**.

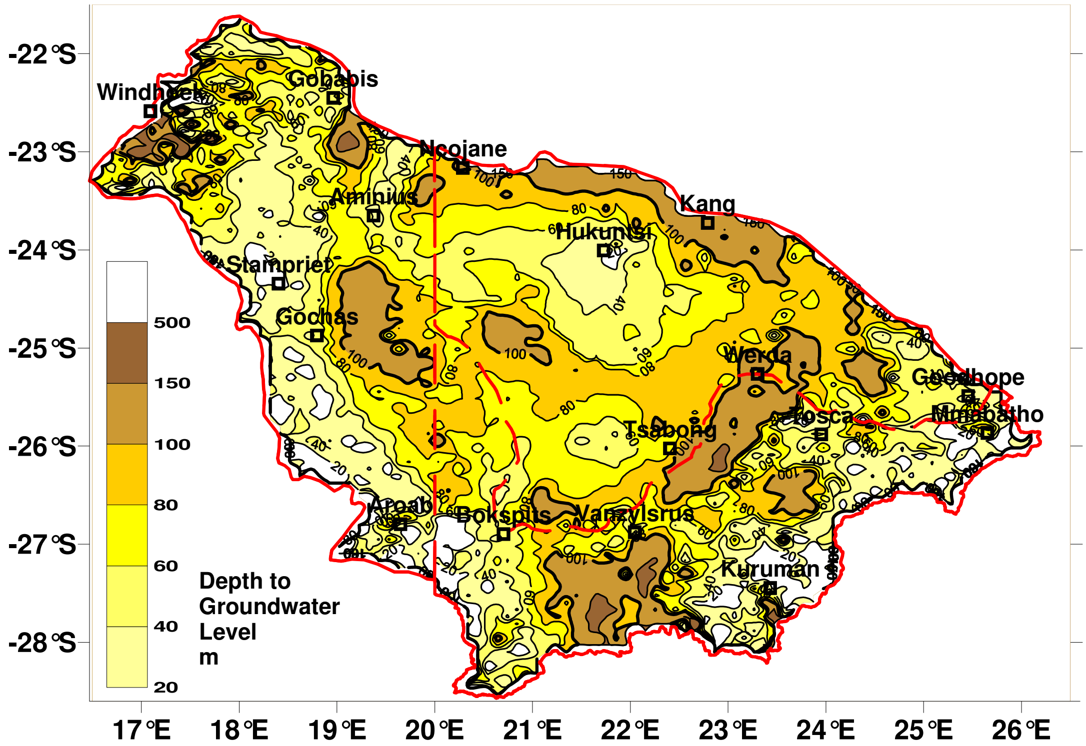


Figure 6-6 **Depth to the groundwater level. Map constructed from the ground surface map and the groundwater level map given in this report**

7 INTEGRATED GIS BASED SUB-BASIN INFORMATION SYSTEM

7.1 Background

The Molopo-Nossob Basin is a sub-basin in the Orange-Senqu whole river catchment area. The basin covers three countries, each of them with approximately equal shares of the area cover. In population there is however a large difference as highlighted in **Chapter 2 and 3**. The development on information and the amount of information differ between the countries. For the understanding of the groundwater situation and for planning and implementation of future water and environment related activities, there is a need to share the data between the three countries. The integration of both databases and the exchange facilities requires that information systems within the countries are compatible.

A proposal to facilitate the exchange of data as well as possible integration will be a GIS data storage and management system. The system should have capabilities to be used as an information centre for the basin in order to provide rapid responses to groundwater evaluation and modeling of the sub-basin and facility for dissemination and exchange of data within the states.

7.2 Elements in an integrated database system

The most important element in integrating data from country database is similar field naming of data tables. There are currently no naming standards set or used in the basin countries as such each country data table for similar feature has different field names. Initial data that is required for regional groundwater monitoring are:

- Monitoring – water levels and abstraction
- Chemistry – TDS, nitrates and fluoride
- Hydrogeology map

All these information are tied to a borehole number, and for each country database consisting of general borehole information is using different field names, used different formats (i.e. text, numbers) for this field, thus making integration of the data tables difficult. Therefore editing of the data tables is required prior to integration. Furthermore fields used in water level monitoring tables are different except for the water level field, for Botswana for instance the date and time are captured in one field while in South Africa they are separate fields.

Currently none of the country database is internet based which means to get data from one database, there will have to be an individual in the respective country contacted to send the required data.

7.3 Existing databases

7.3.1 Botswana

Groundwater monitoring in Botswana is done by numerous governmental organisations and the various databases are currently not properly linked. The main databases used for groundwater monitoring are handled by the Department of Water Affairs and are stored in the following stand-alone databases:

- National Borehole Archive (NBA) database - General borehole information
- WELLMON database – stores water level monitoring from production and observation boreholes, rainfall and reservoir readings
- AQUABASE database - Water quality

An example of data tables from the above mentioned databases are shown in **Table 7-1, 7-2 and 7-3**.

Table 7-1 Summary of Borehole data table

Field	Value
Borehole Number	5276
Completion date	02/02/55
Depth (mbgl)	76
Drilled diameter (mm)	0 – 76m : 152
Casing interval (m)	0 – 5m
Casing diameter (mm)	152
Casing type	Plain steel
Water strike (mbgl)	61
Estimated yield (m^3/h)	1
SWL (mbgl)	57.91
Geology	0 – 5m: Soil 5 – 8m: Sandstone 8 – 76m: Shale
Geological formation	Recent Deposits Recent Deposits Upper Tlapana
Comments	

Table 7-2 Groundwater monitoring data table

Bh_No	OnDate	Dry	Water_level (m)	Technician	Comment
5276	3/4/1993 8:00	FALSE	9.67	Fred	

Table 7-3 Water quality data table

Field	Value	Field	Value
BH_NUM	5299	CL	532.3
DISTRICT	CENTRAL	SO4	119.7
VILLAGE	DUKWI	NO3	4.5
LOCATION	NJUUTSHA	F	0.79
DATETEST	1/18/1994	NA	425.0
PH	7.45	K	7.0

Field	Value	Field	Value
EC	2818	CA	76.9
TDS	1758	MG	23.1
CO3		FE	0.03
HCO3	483	MN	

All these databases are not linked to each other and at the moment they are not internet based but the Department is in the process of migrating the databases to National Geological Information System (NGIS) which will be internet based.

Other groundwater databases are summarized in **Table 7-4**. Data are also found at the Central Statistics Office. These data are mainly from the databases mentioned in **Table 7-4**; however these are manipulated and evaluated by the Botswana Government Statistician. Other databases are found at the major non-governmental organisations which have been given permit for water abstraction and requirements to monitor their abstraction and water levels.

Table 7-4 Databases carrying groundwater information in Botswana

Department or organization	Database	Information
DWA and DGS	National Borehole Archive	Boreholes. Location, construction, yield and formation
DWA and DGS	Wellmon	Groundwater level data from abstraction and observation boreholes
DWA (O&M division)	Water abstraction major villages	Abstraction from individual boreholes on monthly basis
District offices	Water abstraction rural villages	Abstraction from individual boreholes on monthly basis
DWA, DGS, DEA, WUC and BOBS.	Aqua base, Water quality	Results of water chemical and biological analyses
DWA (Groundwater division)	Test pumping data	Tested yield, drawdown and aquifer hydraulic parameters
DGS	NGIS	All kind of information regarding geology and location
DEA	Environmental database	Environmental data

7.3.2 Namibia

In Namibia the groundwater database is GROWAS hosted in the Ministry of Agriculture, Water and Rural Development in Namibia, see **Figure 7-1**. The database deals with information from boreholes consisting:

- General Borehole Information
- Water Analysis
- Groundwater Monitoring
- Hydraulic Testing
- Geophysical Siting

- Permits
- Borehole Equipment

The database is not internet based, but is available within intranet at the Department of Water affairs. These information tables are linked by borehole number. The database also contains documents archive. Spatial aspect of boreholes and the lithology is based on the GEODIN database system.

The GROWAS front end is implemented in MICROSOFT Visual Basic 6.0, the database itself is running on MICROSOFT SQL Server 2000 (**Figure 7-1**). The data model was designed by the Division Hydrogeology who is also the custodian of the database.

Figure 7-1 **The GROWAS database front-end page**

An example of data forms from GROWAS databases are shown in **Figures 7-1, 7-2 and 7-3.**

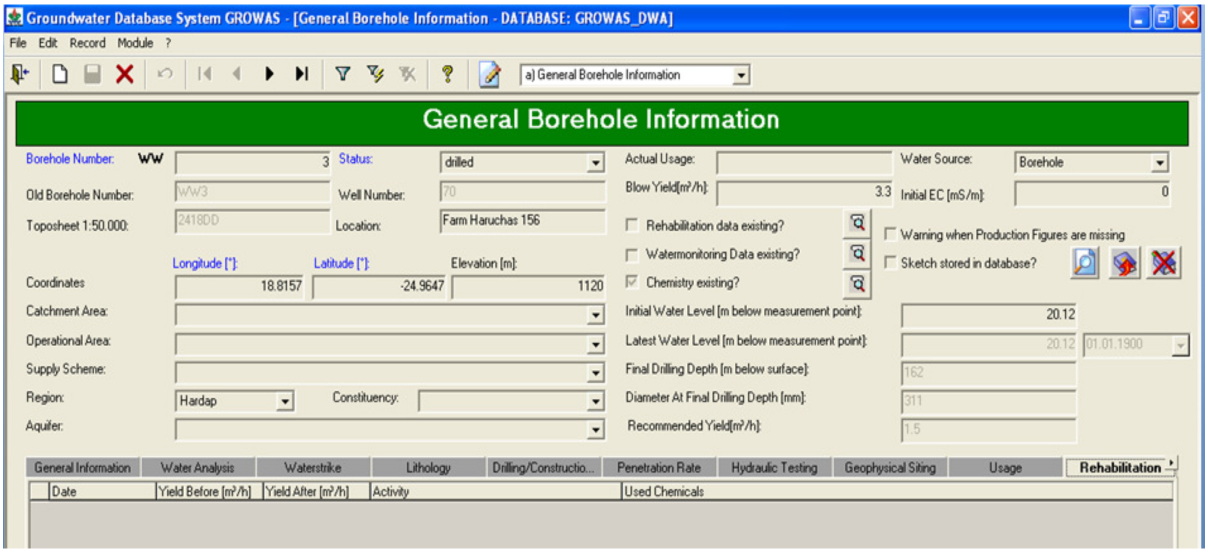


Figure 7-2 The GROWAS database - General Borehole Information form

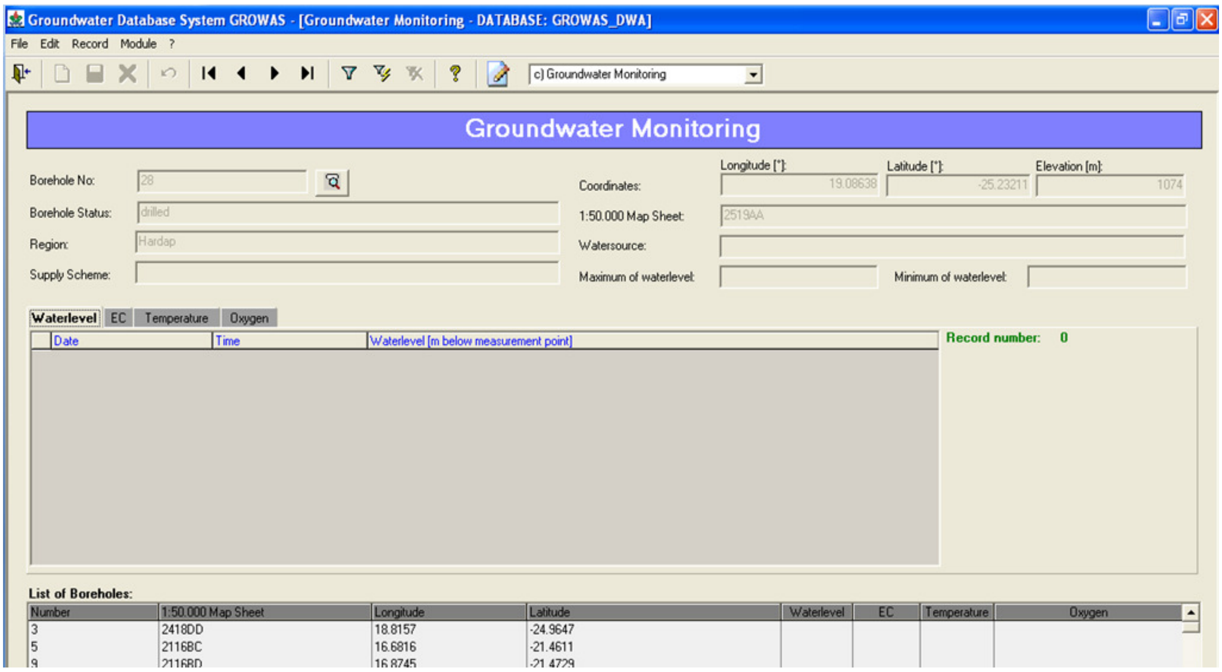


Figure 7-3 The GROWAS database - Groundwater Monitoring form

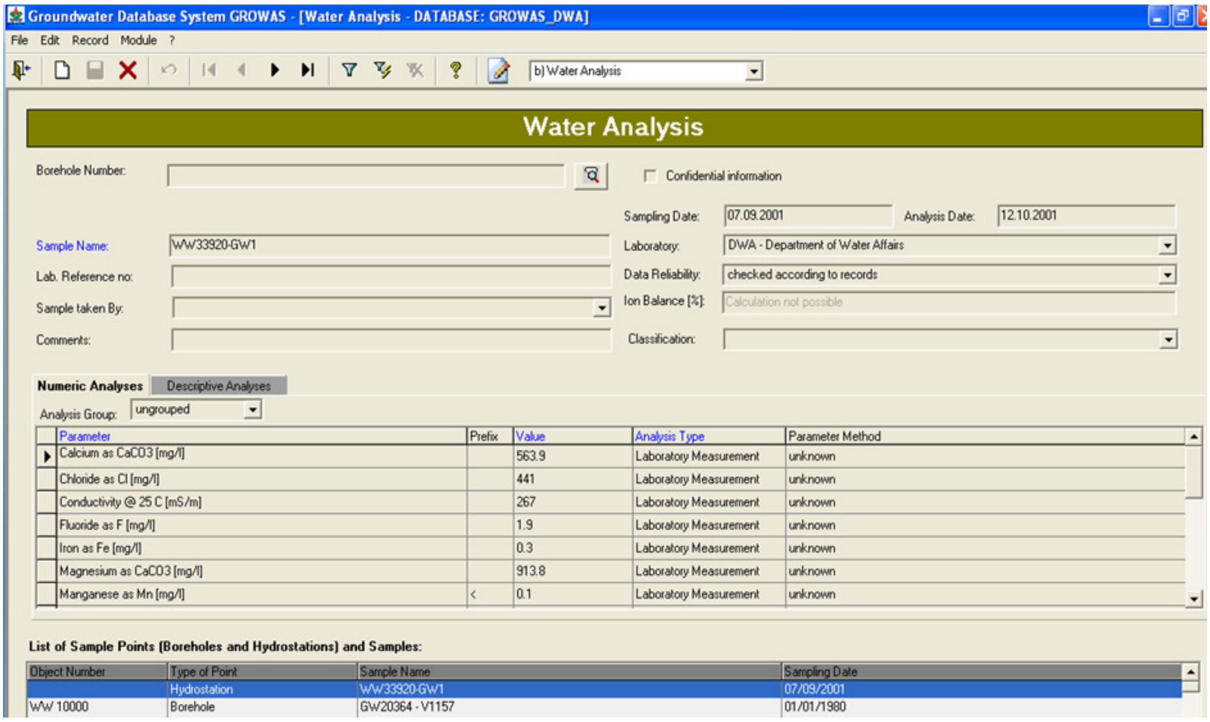


Figure 7-4 The GROWAS database – Water Analysis form

7.3.3 South Africa

Hydrogeology Databases and Information Systems for Department of Water Affairs (DWAF) in South Africa consists of several databases that all contain relevant groundwater and groundwater-related data (Ernst, 2007). The databases contained include the following:

- National Groundwater Archive - NGA [other groundwater sources that are not boreholes]
- Borehole information database - Open-NGDB [General borehole information]
- Water Management System - WMS [Water quality data]
- Water monitoring database - Hydstra [borehole time-series data]
- Reports database – GH Reports database [Hydrogeology reports archived by Department of Water Affairs national and regional offices]
- Geo Info base – Groundwater data Spatial database
- General spatial database – SLIM [Spatial and Land Information Management]
- CHART – Analysis tool using data from WMS
- WARMS – a database containing all information on licensing/registration of water use (not linked to DWAF databases)

The database is not internet based, but is available within intranet at the Department of Water affairs. These information tables are linked by site identifier.

The database is running on INFORMIX, with front-end implemented on DELPHI. The data model for the database is shown in **Figure 7-5** (Draft this model still under development).

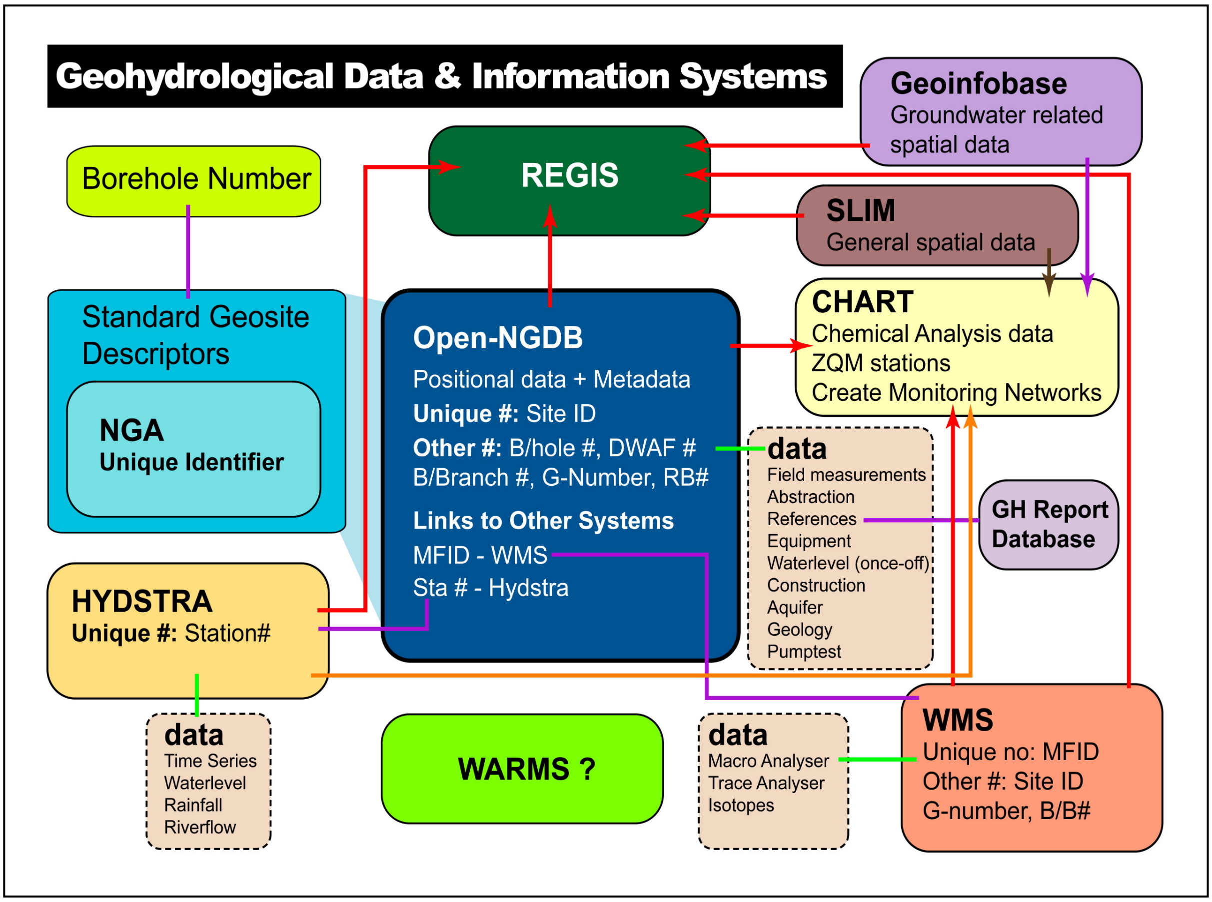


Figure 7-5 **Model for the Databases in South Africa (E. Bertman, DWAF, 2007)**

An example of data tables from the databases are shown in **Tables 7-5, 7-6, 7-7 and 7-8.**

Table 7-5 **Basic site information/borehole data table**

Field	Value	Field	Value
Site id	2321CC00035	Longitude	21.13333
No on map	35	Co-or Acc	2
Orig. site name	AVONDS SCHIJN	Altitude	870
Drainage reg.	D410	Site status	G
Map no	2621CC	Site purpose	P
Site type	B	Rep inst	DBMI
Latitude	-26.8722	Equip	Q
		Portability	G

Table 7-6 **Other borehole identifier used**

Site id	Other id	Other id type	Assignor
2520AA00001	KGP36	DWAF	VAN WYK; E
2520AA00001	PJS65	DWAF	SMIT; PJ

Table 7-7 Water level data table

Site id	Date measured	Time measured (hh mm)	Water level	Method	Status
2520AA00001	19861120	1200	62.72	E	S
2520AA00002	19640205	1200	58.5	E	S

Table 7-8 Water quality table

Field	Value	Field	Value
Monitoring Point ID	84961	Na-Diss-Water Result	3.91
Monitoring Point Name	2525DB00395 TWEEFONTEIN UPPER (A1G003) - WR70	PO4-P-Diss-Water Result	0.014
Latitude	-25.5454	SO4-Diss-Water Result	5.243
Longitude	25.9408	Si-Diss-Water Result	5.399
Located on Feature Name	2525DB00395 TWEEFONTEIN UPPER (A1H003) - WR70	TAL-Diss-Water Result	204.958
Located on Type	Spring/Eye	TEMP-Phys-Water Result	
Drainage Region Name	A10A	pH-Diss-Water Result	8.348
Feature Reference Code		Al-Diss-Water Result	
Monitoring Active	No	As-Diss-Water Result	
Sample Start Date	########	B-Diss-Water Result	
Sample Start Time	10:00:00	Ba-Diss-Water Result	
Sample End Date		Be-Diss-Water Result	
Sample End Time		Cd-Diss-Water Result	
Time Interval		Co-Diss-Water Result	
Sample Start Depth		Cr-Diss-Water Result	
Sample End Depth		Cu-Diss-Water Result	
Depth Interval		Fe-Diss-Water Result	
Preservative	HGCL2	Hg-Diss-Water Result	
Action Type	Sample	Mn-Diss-Water Result	
Ca-Diss-Water Result	43.243	Mo-Diss-Water Result	
Cl-Diss-Water Result	6.59	Ni-Diss-Water Result	
DMS-Tot-Water Result	337.031	Pb-Diss-Water Result	
EC-Phys-Water Result	39.9	Sr-Diss-Water Result	
F-Diss-Water Result	0.132	Ti-Diss-Water Result	
K-Diss-Water Result	0.15	V-Diss-Water Result	
Mg-Diss-Water Result	23.714	Zn-Diss-Water Result	
NH4-N-Diss-Water Result	0.091	Zr-Diss-Water Result	
NO3+NO2-N-Diss-Water Result	0.902		

7.4 Meta database

Metadata is defined as "Data about Data". Metadata is descriptive information about an object or resource whether it is physical or electronic. While the term “metadata” is relatively new, the underlying concepts behind metadata have been in use for as long as collections of information have been organized. For example, library card cata logs represent a well-established type of metadata that has served as collection management and resource discovery tools for decades. Metadata is information that describes data (the content, quality, condition, and other characteristics of data). Metadata contains information about the data such as; fitness for use of a particular dataset, that a user knows where the data came from, how it was captured, how up-to-date it is, at what scale it was captured and what is its accuracy, etc. However Metadata do not, in any way, represent the actual content of the data they only describe the data.

Generating metadata if not initiated by the data custodian is a task on its own. The task is more daunting when attempting to generate a huge volume of metadata without knowing the data, its usage, its background knowledge, and its accuracy. Challenges in generating this metadata included the fact that data sets are scattered, they are not documented, most of data custodians were not involved in generating the data (either due to originator having left the departments, or data generated by consultants). Other challenges associated with generation of metadata are:

The Molopo-Nossob basin metadata consisting of spatial and non-spatial data has been developed in MS Access. The metadata is based on ISO1915 standard. The metadata elements and their definitions are listed in **Table 7-9**:

Table 7-9 Metadata elements

Name	Definition
Title	The name by which the cited resource is known
Alternate Title	An alternative name used for the sited resource
Originator	The organisation that created the original resource
Abstract	Brief narrative summary of the content of the resource
Date Stamp	The date that the metadata was created
Dataset Reference Date	Date when resource was created
Presentation Type	How is the resource presented (document, image, etc)
Access Constraint	Restrictions related to accessing the resource
Use Constraint	Restrictions related to using the resource
Topic Category	Main theme(s) of the dataset
West Bounding Coordinate	Western-most coordinate of the limit of the dataset extent, expressed in longitude in decimal degrees (positive east)
East Bounding Coordinate	eastern-most coordinate of the limit of the dataset extent, expressed in longitude in decimal degrees (positive east)
North Bounding Coordinate	Northern-most coordinate of the limit of the dataset extent, expressed in latitude in decimal degrees (negative north)
South Bounding Coordinate	southern-most coordinate of the limit of the dataset extent, expressed in longitude in decimal degrees (negative north)
Spatial Reference System	Name or description of the system of spatial referencing, whether by coordinate or geographic identifiers, used in the dataset
Spatial Resolution	Factor which provides a general understanding of the density of

Name	Definition
	spatial data in the dataset
Extent	Extent covered by resource
Additional Information Source	Identification of, and means of communication with, person(s) and organisations associated with the dataset
Sample of Dataset	An image of the resource
Metadata language	Language used for documenting metadata
Spatial Reference Type	Method used to spatially represent geographic information
Lineage	Information about the events or source data used in constructing the data specified by the scope or lack of knowledge about lineage
Online Resource	Address for accessing resource via internet

Populating all these elements for existing data was not exhaustive because where data had exchanged numerous hands it was impossible to get detailed information. Of the three countries only Namibia and South Africa had metadata for some of the datasets. However the elements used do not cover all of the elements proposed for this project. The list of metadata records is attached in **Appendix - II**. This list only shows the Title, Abstract and Topic category defined in **Table 7.9**. The full details of the meta database is contained in the MS Access database and also in the Metadata application.

The actual data is linked to allow users to have access to data. Where the size of the linked datasets are big, these have been compressed and are attached as zip files (*.zip) which will need to be decompressed before opening the files. For map files, that is Arc view files, these have a number of file extensions all belonging to one layer (*.dbf, *.sbn, *.sbx, *.shp, *.shx, *.xml and *.prj).

7.5 Proposal for storage and exchange of information

7.5.1 Separate databases

To ensure that data is handled by the professionals, the information system should consist of separate databases as currently done by the basin states. This will allow the relevant professionals in the basin states to post data to a relevant database within the basin information system. As none of the country databases are internet based, there is never going to be a situation where data will be harvested remotely by ORASECOM, it will have to be through contact with country database managers. It will be best if such data when received at ORASECOM is saved under relevant database for ease of use with similar data from the basin countries.

7.5.2 Data integration

Database integration is possible which will allow the data from Namibia, Botswana and South Africa to be brought together in one table. A system will have to be developed which will import data tables from the various databases through export files that can either be in Comma Separated Value (CSV) Files or through Microsoft Excel or SQL Server Database Transfer or any other common data transfer and integration medium.

It is proposed that the Integrated Database will import an initial CSV file from each country database to populate all records and the be able to perform a reconciliation of new records, record updates and record deletions in order to perform periodic updates

It is proposed that the database be developed in Microsoft SQL Server technology which facilitates for easier integration and data imports with Microsoft Excel in addition to which the Namibian Database is based on SQL Server technology as well allowing for seamless integration with that data. Also through Microsoft SQL Server database tools such as Data Transformation Services (DTS) most data formats are easily importable into a SQL Server database and can be scheduled to perform the data integration periodically as specified by the Database Administrator who will be responsible for integrating the databases.

Figure 7-6 shows the proposed integration Table for Water Levels

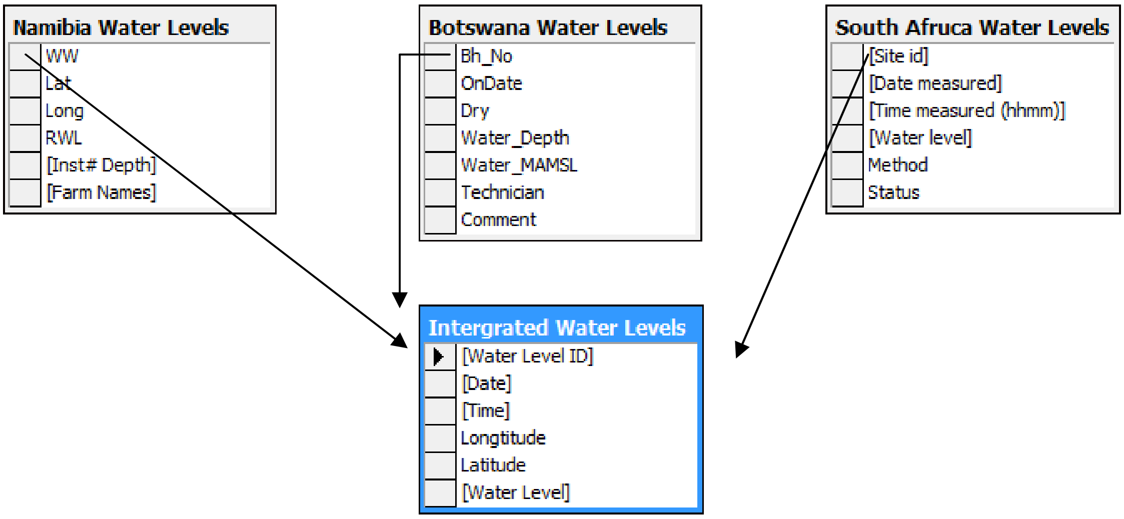


Figure 7-6 Integration of water level monitoring data

Table 7-10 Integrated Water Levels Table Record Example

Water Level ID	Text	W39854
Date	dd/mm/yyyy	31/12/2009
Time	hh:mm	13:00
Longitude	decimal	19.43266
Latitude	decimal	-25.46122
Water Level	meters	37.07

Below is an example of a CSV export file record for the Integrated Water Levels Data:
W39854,31/12/2009,13:00,19.43266,-25.46122,37.07

7.5.3 Requirements for developing basin information system

To develop and integrated database for the following requirements will have to be met:

- User Needs Analysis: There is need to understand the **users needs** in terms of their business, what do they want to use the information system for, what information/data do they have and how to they want to present the information (tables, graphs, maps, etc).

- Data Management Requirements: Secondly, is the need to have **developed database and populated them with data** (selected relevant data, tested them for robustness / ambiguity, checked that data are available at the right spatial and time scale). Before any information system solution is designed a complete and robust set of database need to have been developed, tested and populated with data.

- System Requirements, Design, Testing and Implementation: The areas that need to be considered in the design process are: Outputs, Inputs, File Design, Hardware, and Software. Outputs and Inputs will be determined during user needs analysis and data requirements.

  Only once these elements have been completed then, and only then, can a system be designed to house the data. The designed will have to be appropriate to ORASECOM requirements. The system solution needs to follow, support or be based upon the user's needs and the database managers' abilities. That is, **the system solution should not determine the users' needs**! The salient point being that the information system solution is decided at the **end of the process** (once the needs and abilities are fully understood), not at the beginning of the process. Once the system has been tested it can then be implemented.

- System Documentation: To ensure smooth running of the system by any user, following system and user documentations will have to be produced. User guides are written in plain English rather than technical language which are used in the System documentation.

  The user guide should cover how to run the system, how to enter data, how to modify data and how to save and print reports. The guide should include a list of error messages and advice on what to do if something goes wrong.

8 LITERATURE REFERENCES

8.1 ENDNOTE Software

In any project, research or compilation of information, access to a thorough and up to date literature reference database is of uttermost importance. Such reference database can be set up on personal basis or as a product to which companies, organizations or associations have access.

ENDNOTE is software to set up, maintain and use database information based on literature references. Once a bibliographic database is established ENDNOTE software include on line search tools, a simple way to search and retrieve references. The software also provides the possibility to import information from a variety of online services and databases (**Figure 8-1**). ENDNOTE is specializes in storing, managing, and searching for bibliographic references in private reference library. It can organize images including charts, tables, and figures and assign each figure its own caption and keywords.

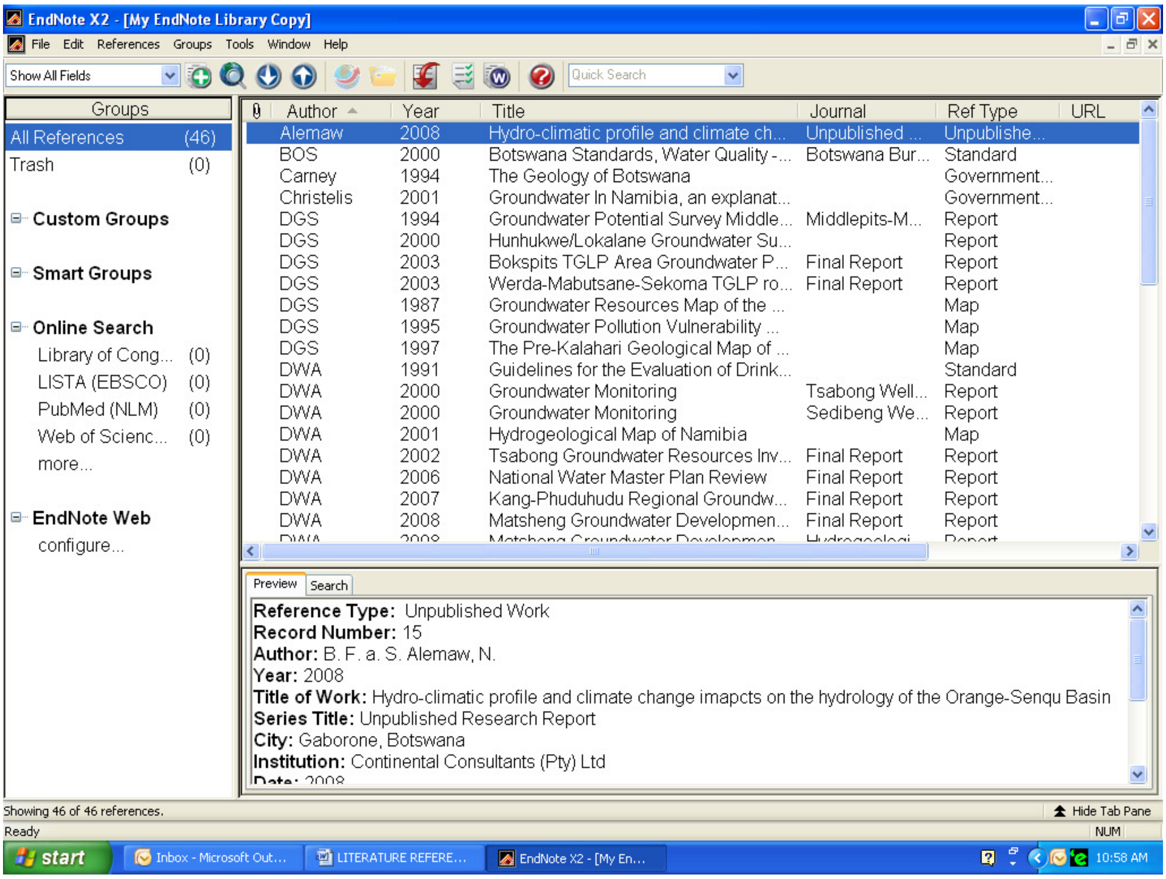


Figure 8-1 **Overview of ENDNOTE software**

The ENDNOTE software also provides different predefined 48 reference types (**Figure 8-2**). The reference type table shows which fields are used in each of the different reference types. Particular reference type can be assigned to each reference entered into a specific library.

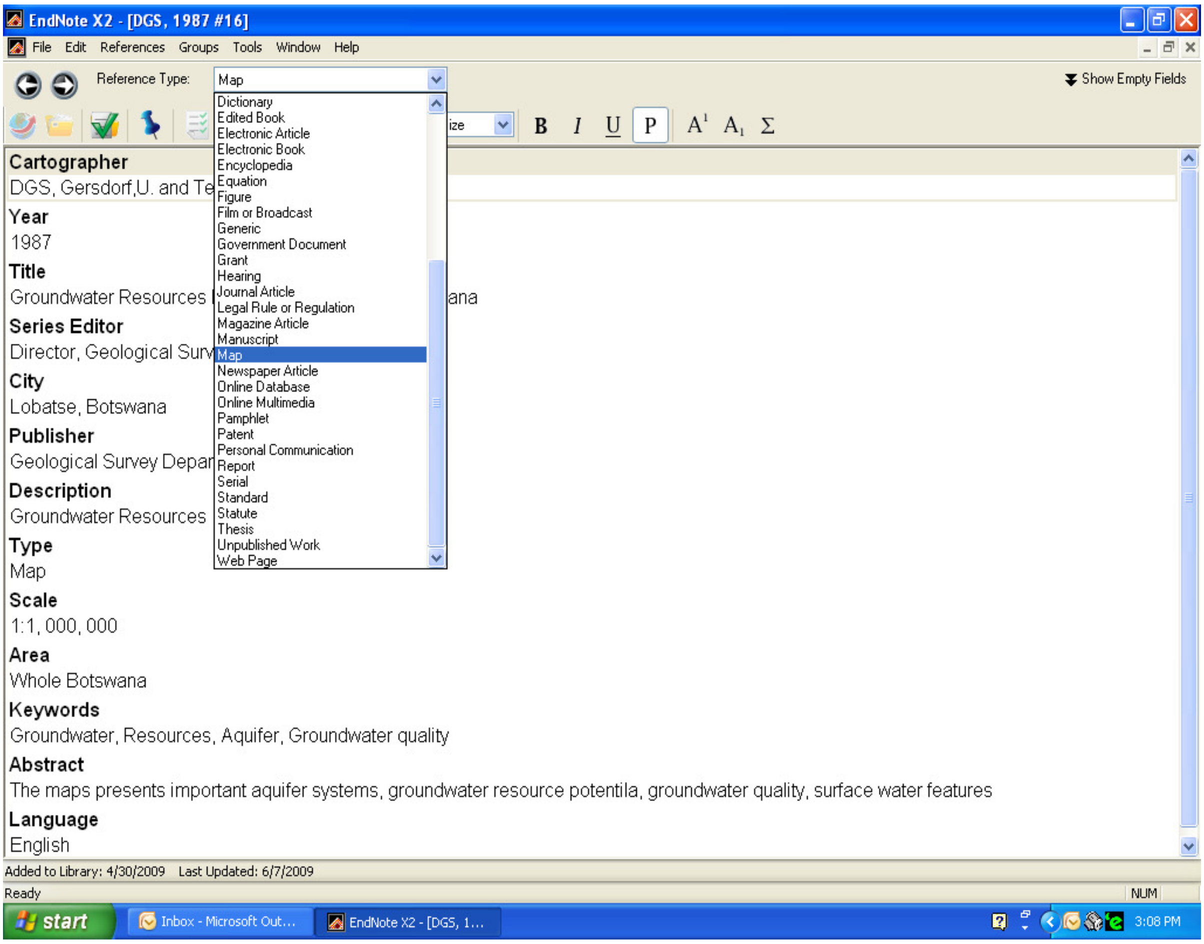


Figure 8-2 **Reference types in the ENDNOTE Software**

Collection of information is a never ending process in every project. In the current project, information from the three member states in the Molopo-Nossob Basin, Botswana, Namibia and South Africa, was continuously obtained from the water organizations and through studies of various relevant literature covering the project area and the related matters.

The ENDNOTE software in the current project hosts information of about 50 relevant documents in the form of reports, maps, guidelines and some numerical data. The main sources of information are grouped as geographic and administrative description, Climatic information, water requirements, hydrology, geology and hydrogeology, future development plans. All the references used in the project area given in the reference list in Chapter 10, are available in digital format. The bibliography prepared using library ENDNOTE software are given as separate volume.

8.2 Geographic and Administrative Description

The Molopo River is an ephemeral tributary of the Orange – Senqu River system which is an international river basin shared by Lesotho, Namibia, Botswana and South Africa. The Molopo-Nossob sub river basin covers a wide area, from Windhoek in Namibia to Lobatse in Botswana and Mmabatho in South Africa. The three countries in the Molopo-Nossob Basin, Botswana, Namibia and South Africa all have their parts covered by different administrative units. A summary of administrative units in the three riparian states and their population has been obtained from various government departments and consultant reports. Some of the references are given below:

- Central Statistics Office (CSO), 2001. Population of Towns, Villages and Associated localities, Government Printer, Gaborone.
- DWA, 2006. National Water Master Plan Review. Report prepared by Ministry of Minerals, Energy and Water Resources, Gaborone.
- ORASECOM, 2008a. Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob. Watercourse. Final Inception Report – February 2008.
- MAWRD, Ministry of Agriculture, Water and Rural Development, 2000. Namibia Water Resources Management Review. – Reports Vol1 to 5, Windhoek. March 2000.

8.3 Climatic Information

The climatic data is collected from the Meteorological departments within the three member states and also from the various government and consultant reports. Some of the references are provided below:

- Alemaw, B.F. and N. Sebusang. 2008. Hydro-climatic profile and climate change impacts on the hydrology of the Orange-Senqu Basin. Unpublished Research Report No. RR/CCL/03/08 for Continental Consultants (Pty) Ltd, Gaborone, Botswana. 44 pp + appendices
- DWA, 2006. National Water Master Plan Review. Report prepared by Ministry of Minerals, Energy and Water Resources, Gaborone.
- FAO. 1993. FAO CLIMWAT for CROPWAT, CD-ROM. Agro climatic database. Rainfall and evaporation figures. FAO. Rome.

8.4 Hydrological Information

The Molopo-Nossob River Basin hosts four major river courses, namely, Molopo, Nossob, Auob and Kuruman Rivers. Information about the rivers is collected from various reports and maps. Some of the references are listed below:

- ✓ ORASECOM, 2008. Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob. Watercourse. Catchment Status Inventory Report – Draft report August 2008.
- ✓ ORASECOM. 2008. Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse. Draft Hydrology Report

8.5 Groundwater Information

The regional geology and hydrogeological information is obtained from national geological and hydrogeological maps from each riparian countries and reports. Some of the literature is given below:

- Carney, J.N., Aldiss, D.T., Lock, N.P. 1994. The Geology of Botswana. – Bulletin 37 Department of Geological Survey, Botswana.
- Christelis, G., Struckmeier, W. 2001. Groundwater in Namibia, an explanation to the Hydrogeological Map. – Department of Water Affairs, Division Geohydrology, December 2001.
- DWAF, 1995. Groundwater resources of the Republic of South Africa. – Map produced by Department of Water Affairs and Forestry, South Africa. 1995.
- GSN, 1980. Namibia Geological Map. – Map produced by Geological Survey Namibia. 1980.
- DGS, 1987. Groundwater Resources Map of the Republic of Botswana. – Map produced by Department of Geological Survey, Botswana. 1987.
- DGS, 1997. The Pre-Kalahari Geological Map of the Republic of Botswana. – Map produced by Department of Geological Survey. Botswana. 1997.
- ORASECOM 2007a. Review of Groundwater Resources in Orange River Catchment. – August 2007.
- SADC, 1999. Isopach Map of the Kalahari Group. – Map produced by the Council for Geoscience, South Africa on behalf of SADC. 1999.
- DGS, 1995. Groundwater Pollution and Vulnerability Map of the Republic of Botswana. – Map produced by Department of Geological Survey, Botswana. 1995.

8.6 Water Requirements

The main part of the Molopo-Nossob Basin is under natural vegetation and a large portion of the basin falls within the Kalahari Desert.

- DWA, 2006. National Water Master Plan Review. Report prepared by Ministry of Minerals, Energy and Water Resources, Gaborone.
- MAWRD, Ministry of Agriculture, Water and Rural Development, 2000. Namibia Water Resources Management Review. – Reports Vol1 to 5, Windhoek. March 2000.
- ORASECOM 2007b. Summary of Water Requirements from the Orange River. – August 2007.
- DWAF 2002b. Lower Orange Water Management Area. Water Resources Situation Assessment. –Main Report No P 14/000/00/0101. March 2002.
- DWAF 2002c. Lower Vaal Water Management Area. Water Resources Situation Assessment. –Main Report No P 03/000/00/0101. November 2002.
- DWAF 2002d. Crocodile West and Marico Water Management Area. Water Resources Situation Assessment. Volume 1, Report No P03/000/00/0301. April 2002.
- DWAF, 2004a. Internal Strategic Perspective. Lower Orange Water Management Area. – Version 1 Report No P WMA 14/000/00/0304. July 2004.
- DWAF, 2004b. Internal Strategic Perspective. Lower Vaal Water Management Area. – Version 1 Report No P WMA 14/000/00/0304. October 2004.
- DWAF 2004c. Crocodile (West) Marico Water Management Area. Internal Strategic Perspective for Marico, Upper Molopo and Upper Ngotwane Catchments. – Version 1, February 2004.

8.7 Future Plans and Developments

The information on future development plans are obtained from various reports and some of them are:

- ✓ MOA, 2000. National Master Plan for Agricultural Development, Final Report.
- ✓ Botswana National Water Master Plan (2006). Final Report Volume 4 – Hydrogeology, by SMEC in association with EHES.
- ✓ ORASECOM (2007) Orange River Integrated Water Resources Management Plan, Review of Groundwater Resources in the Orange River Catchment, by WRP (Pty) Ltd., Jeffares Green Parkman Consultants (Pty) Ltd., Sechaba Consultants, Water Surveys (Botswana) and Windhoek Consulting Engineers in association.
- ✓ ORASECOM (2007) Orange River Integrated Water Resources Management Plan, Water Quality in the Orange River, by WRP (Pty) Ltd., Jeffares Green Parkman Consultants (Pty) Ltd., Sechaba Consultants, Water Surveys (Botswana) and Windhoek Consulting Engineers in association.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The total Molopo-Nossob Basin covers an area of 367,201 km^{2}delineated from the surface water catchment. Of the basin, Botswana covers 37%, Namibia 33% and South Africa 30%. According to UNEP classification, the whole basin is arid to semi-arid.

The long term average annual precipitation is from 100 mm/a in the southwestern part of the basin to over 500 mm/a in the eastern part, in South Africa, and 400 mm/a in the northern part, in Namibia. Evaporation and potential evapotranspiration highly exceed the average rainfall.

The Molopo-Nossob basin is composed of the catchment areas of four main rivers; Molopo, Kuruman, Nossob and Auob Rivers. Parts of these rivers are ephemeral and at the basin's outflow to Orange River there are no records of any surface outflow.

The basin covers geological formations from the Archean time period to Recent, a time span of more than 2,500 million years. The formations host a variety of aquifers; intergranular, fractured intergranular, fractured and karstic aquifers. The aquifers are given names after the formations they occur in. Some of the formations further have different names in the different countries.

The largest aquifers in the basin are the intergranular Kalahari Bed aquifer and the fractured intergranular Ecca aquifer (the Auob aquifer). These two aquifers interact or are combined in areas where they are in contact with each other.

Multiple aquifers occur in areas in Namibia and Botswana where a deep layer of sandstone (Nossob sandstone) is found below the Ecca aquifer and interlayered low permeable formations.

The potential of the aquifer is assessed from the mean borehole yields displayed on hydrogeological maps over the Namibian and the South African part of the basin. Three classes of potential are recognized; high, median and low potential. For Botswana the potential is based on regional groundwater maps combined with results from groundwater investigation in local areas in the basin.

The aquifers with the highest potential in karst environment are found in the dolomitic formations in South Africa and Botswana. These formations also host areas currently classified as medium potential aquifers. Karst environments are the result of mildly acidic water acting on soluble bedrock such as limestone and dolomits. This mildly acidic water dissolves the bedrock along fractures or bedding planes. Over tome, these fractures enlarge as the bedrock continues to dissolve. Opening in the rock increase in size, and un underground drainage system begins to develop, allowing more water to pass through the area, and accelerating the formation of underground karst feature.

The extensive Ecca aquifer (also combined with the Kalahari Bed) is classified as a median potential aquifer, however with many areas within assessed as high potential aquifers. The Ecca formation is one of many formations in a larger formation group called the Karoo. In this group (Supergroup) a high potential sandstone aquifer is found above the Ecca aquifer, the Ntane aquifers, displayed in the northern Botswana.

The Kalahari Beds locally contains groundwater. Areas in which the groundwater level in the Molopo-Nossob Basin are found to be within the Kalahari Beds "saturated" Kalahari Beds are found in the Gemsbok National part and the continuation into the Namibian part of the basin following the river Nossob and Auob up to Stampriet and Amimuis. Large areas are also found along the Upper Molopo River Course, in Gordonia and in the central part of Botswana. Beside these larger Kalahari saturated basin, "perched aquifers occur locally in the Kalahari Beds.

The crystalline bedrock of older age than the Karoo and Kalahari Beds is classified as low potential aquifers. These formations are found in the northern part of Namibia and in eastern Botswana and large part of South Africa. Groundwater is available but limited to the occurrence in fractures and fissures. Where fractures form pronounced and extensive zone, good yielding local aquifers are encountered.

The quality of the groundwater varies within the basin. Guidelines for domestic water use and for livestock watering regarding the content of TDS, NO_3 and F are similar in the three countries. Maps are constructed to show the areas in which the guideline values are exceed. The larger part of Botswana has groundwater with quality exceeding the guidelines for human consumption of one or more of the chemical components addressed. In Namibia, the groundwater quality is poor along the Auob River downstreams Gochas (the salt-block area). The area of poor water quality continues into South Africa where almost the whole Gordonia experience water quality exceeding the guidance limits for TDS and F. Areas of good water quality are found in the middle and northern part on Namibia, in the central and eastern part of South Africa and in the easternmost and northwestern part of Botswana. Limited minor areas of high NO_3 are found referring to local groundwater pollution.

49% of the basin area has groundwater with TDS exceeding 2,000 mg/l (limit or human consumption). TDS of 10,000 mg/l is exceeded in 21% of the basin area (unfit for livestock consumption).

For livestock watering the areas of unfit groundwater are limited to central and southern parts of Botswana, the Salt-Block area in Namibia and a minor part in the Gordonia area. Since higher NO_3 is accepted for cattle watering than for human consumption, only a minor area in Gordonia is found to have groundwater of too high NO_3 content.

Monitoring of the groundwater level is done in more than 600 boreholes in the Molopo-Nossob Basin. Most of the boreholes are in South Africa. The majority of monitoring boreholes are in connection to abstraction boreholes or in wellfield areas. Monitoring is done on various time intervals and using different methods. The use of automatic monitoring devices has increased which has resulted in improved continuity of the records and in an addition of new boreholes. There is however a large number of monitoring boreholes which are abandoned and therefore only display limited time series of groundwater level observation.

Monitoring groundwater levels are stored at the water departments in Botswana, Namibia and South Africa, head and regional offices. In the largest portion of the monitoring borehole a declining trend is observed also in borehole located outside the influence of groundwater abstraction.

Groundwater level data stored in the borehole archives at the water departments in Botswana, Namibia and South Africa, together over 34,000 thousand boreholes, forms the background information to a regional groundwater level map over the Molopo-Nossob Basin. The map shows that the highest groundwater levels (1,750 mamsl) are in the northern Namibian part of the basin. From there the groundwater flow is directed southeast into Botswana and South Africa and from there towards the south out from the basin through the area along the southern part of the Molopo River (750 mamsl).

High groundwater level is also encountered in the southeastern South African part of the basin (1,450 mamsl). From there the groundwater flow direction is towards northwest until the Molopo River where the flow is directed southwest to the regions around the lower Molopo River in Gordonia.

The groundwater divide in northern Botswana does not follow the surface water divide as it is illustrated on Botswana water maps. That makes in fact the Molopo-Nossob Basin smaller than derived from the surface water divide.

Assessment of groundwater replenishment through recharge is an issue which can be approached by different methods. The Chloride Mass Balance method is based on the relation between chloride deposited through rainfall and wind to the chloride content in the groundwater. This method shows that large areas of the basin receive less than 1 mm/a recharge as a long term average. Recharge of more than 10 mm/a is assessed for the northern part and for the area northwest of Stampriet and Aminuis in Namibia. Also in South Africa areas of recharge above 10 mm/a are found for the southeastern part (Mmabatho) and the Kuruman area.

Extreme low recharge (< 0.1 mm/a as an average annual value) is assessed for the central part of Botswana close to the Gemsbok National park, an area northeast of Bokspits and for the central part of Gordonia in South Africa. In Botswana recharge of more than 2 mm/a is found for the north western and the south eastern parts.

The areas of low recharge in the basin are also the areas of poor groundwater quality.

The depth to the groundwater level is more than 100 m in the northern part of Botswana, east of Gochas in Namibia, along the Molopo River between Tsabong and Werda and in the southeastern part of Gordonia. It should be mentioned that the groundwater level in the Nossob aquifer in Namibia, located below the Ecca aquifer, is artesian in large area of the Namibian part of the basin with a groundwater head in places above the ground surface.

The population in the Molopo-Nossob Basin is about 1 million, and the livestock units (ELSU) is about 1.6 million including wildlife. Whereas the ELSU per km^2 is similar for the three countries (4.2-4.6) the population per km^2 varies from 0.2 in Kgalagadi North District (Botswana) to 62 for the Upper Molopo catchment area (Mmabatho area in South Africa). As an average for the basin the population density is 2.7 persons per km^2.

The water requirement in the Molopo-Nossob Basin is referred to domestic, livestock, irrigation and mining users. The total requirement is 128 Mm^3/a (2000). Of this 69% is required in South Africa, 18% in Namibia and 13% in Botswana. About 37% of the water requirement goes to livestock watering, 27% to domestic purposes, 27% to irrigation and 9% to industry (mining). Only 0.1% is for tourism.

The highest water requirement is found in the Upper Molopo catchment area (Mmabatho area in South Africa). The requirement represents about 8,700 m^3/km^2 and annum whereas the average value for the whole Molopo-Nossob basin is about 350 m^3/km^2 and annum.

Development which requires a major quantity of water is foreseen in the Botswana part of the Molopo-Nossob Basin. Plans for irrigation developments will require about 6.2 Mm^3/a of water from the year 2015. Other major water consuming developments are for the mining industry in South Africa together with plans for increased irrigation. The future requirements for the three countries will increase the water requirement for the Molopo-Nossob Basin by the year 2015 to about 160 Mm^3/a, the year 2020 to 170 Mm^3/a, and in 2025 to 187 Mm^3/a. On the average an annual increase in the water requirement for the Molopo-Nossob Basin is about 1.5%.

The assessed recharge to the basin (within the groundwater catchment area) is 1,105 Mm^3/a. The current water requirement represents 11.5 % of this recharge.

A variety of databases exist to capture and store information on water and geology in the Molopo-Nossob Basin. In Botswana the main custodian, holding and using the databases is Department of Water Affairs and Department of Geological Survey, Four main databases are working dealing with borehole archive, groundwater monitoring and groundwater chemistry. In Namibia a groundwater database (GROWAS) is hosted in the Ministry of Agriculture, Water and Rural Development handles information from boreholes regarding location, quality, monitoring, testing, permits and borehole equipment.

In South Africa several databases exist containing relevant groundwater information and groundwater related data such as borehole location, water quality, monitoring, information of licensing and registration, water management and groundwater reports. The databases are included in the Geohydrological Data and Information Systems at Department of Water Affairs and Forestry. The data bases are used also in the regional offices of DWAF in South Africa.

Information over the Molopo-Nossob Basin, other than stored in digital databases, are found in numerous reports, maps and information sheets. References used in compilation of the water requirements, the future development plans, climate, geology and hydrogeology of the basin are summarized in short abstracts with keywords using the MicroSoft computer program ‘EndNote’. This program is specialized in storing, managing and searching in bibliographic references.

9.2 Recommendations

- Monitoring of groundwater, both quality and level should be continued and extended to include area which are remote and not affected by human development to capture the natural changes cause by global climate change and regional human development.

- The distribution of the information from boreholes is hardly skewed. In Botswana, one borehole covers as an average about 38 km^2 whereas the average in the Molopo-Nossob Basin is one borehole per 10 km^2. Especially the western and central part of the Molopo-Nossob Basin in Botswana is extremely limited on borehole information. Since those areas are of major importance for both a more detailed understanding of water chemistry, recharge and flow and for an improved understanding of the regional groundwater system in the Molopo-Nossob Basin, it is recommended that additional boreholes be drilled and continuous monitored in these areas.

- The continuation of the groundwater resources in the Nossob sandstone, identified in Namibia should be established. The aquifer probably continues into Botswana but limited information is available to confirm this. In the on-going project "Integrated Shared Aquifer Resource Management", the continuation of the Nossob aquifer and its chemistry, flow, recharge and possible future use should be approached.

- Changes in the groundwater resources are currently on-going. The most obvious evidence of this is an on-going lowering of the groundwater table. A regional and continuous assessment of such lowering, as is done for the Northern Cape in South Africa, is recommended to be performed for both for regions in the basin and for the whole Molopo-Nossob Basin.

- Recharge is one of the major elements in a groundwater balance study. Various methods exist to determine the recharge and it is recommended that more than the one used in the current project be applied in the basin. The current assessment of recharge should be assessed in comparison with the general flow of groundwater in the basin. Such studies will preferably be done through mathematical modelling.

- The use of the concept of Groundwater Harvest Potential introduced in South Africa should be extended and map produced also for Namibia and Botswana, especially for areas of low groundwater recharge.

- The current use of 11.5% of the total recharge in the basin must be detailed down to smaller regions where the use of groundwater exceeds the recharge in order to get both a comprehensive and detailed understanding of the groundwater situation within the large Molopo-Nossob basin.

- Large parts of the basin has water unfit for human consumption and for livestock watering. Water treatment options exist and could be applied in for private and communal use. The current and future use of such treatment option should be addressed.

- EndNote software program to capture, store and retrieve literature references was used in the current project. It is recommended that the software be used in similar projects and the databases established using the software be exchanged between the users.

- Database integration is recommended which will allow the three countries to share information through a database transfer and integration medium. It is recommended that the database be developed in Microsoft SQL.

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APPENDIX – I
Molopo-Nossob Basin metadata records

Summary of records within Molopo-Nossob Basin metadata

File_name	Abstract	Topic_Category
Basin_country_boundary.shp	International boundaries of countries covered by Molopo-Nossob river basin	Boundaries
Basin_country_boundary_line	International boundaries of countries covered by Molopo-Nossob river basin	Boundaries
Bot_na_sa.shp	International boundaries for Botswana, Namibia and South Africa (Including Lesotho and Swaziland	Boundaries
Bots_admin_bnd	Administrative boundaries within Molopo-Nossob basin boundary in Botswana	Boundaries
Bots_vet_districts	Veterinary zones in Botswana within Molopo-Nossob Basin boundary	Boundaries
Bots_vet_line	Veterinary zones in Botswana within Molopo-Nossob Basin boundary	Boundaries
Molopo_catchment	Molopo-Nossob river catchment boundary from the Illiso Project	Boundaries
Molopo_Nossob_catchment	Molopo-Nossob rivers catchment boundary	Boundaries
Molopo_nossob_catchment_line	Molopo-Nossob rivers catchment boundary	Boundaries
Municipality boundary_1996_census	1996 Municipality boundaries in South Africa within Molopo-Nossob basin	Boundaries
Nam_admin_bnd	Administrative boundaries within Molopo-Nossob basin boundary in Namibia	Boundaries
Nam_vet_district	Veterinary zones in Namibia within Molopo-Nossob Basin boundary	Boundaries
Nam_watercontrol_areas	Water Control areas in Namibia within Molopo-Nossob Basin boundary	Boundaries
Orange_basin	Map showing Orange River Basin Boundary	Boundaries
Parks	Wildlife area within the Molopo-Nossob Basin area	Boundaries
Proposed_basin_wma	Proposed Water Management Area boundaries in the Molopo-Nossob basin	Boundaries
Province_New2007	2007 Province boundaries in South Africa within Molopo-Nossob basin	Boundaries
SA_admin_bnd	Administrative boundaries within Molopo-Nossob basin	Boundaries

File_name	Abstract	Topic_Category
	boundary in South Africa	
SA_WMA	Water Management Area boundaries in South Africa that are within Molopo-Nossob basin	Boundaries
Botswana_detailed_rainfall(monthly)98-08	Detailed monthly rainfall data for some of the villages in Botswana	Climatology
Botswana_rainfall_annual(98-08)	Annual rainfall in Botswana	Climatology
Gantsi mean monthly maxmin for 1997-2007(2)	Gantsi mean monthly maxmin for 1997-2007(2)	Climatology
Jwaneng mean monthly max, min for 1997-2007	Jwaneng mean monthly max, min for 1997-2007	Climatology
Molopo_nossob_climate_stn	Climate stations within Molopo-Nossob basin boundary	Climatology
Molopo_nossob_evapotranp	Map showing evapotranspiration within Molopo-Nossob basin	Climatology
Molopo_nossob_rainfall	Map showing rainfall distribution within Molopo-Nossob basin	Climatology
Molopo_nossob_temp	Map showing temperature distribution within Molopo-Nossob basin	Climatology
Molopo_nossob_temp_line	Map showing temperature distribution within Molopo-Nossob basin	Climatology
Rainfall et and temp	Rainfall, evapotranspiration and temperature data from a few climatic stations covering Molopo_nossob basin	Climatology
rsa_rain station	Rain stations in South Africa within Molopo-Nossob basin	Climatology
Tsabong & Tshane climatic data for 1990-2007	Tsabong & Tshane climatic data for 1990-2007	Climatology
Werda climatic data 2002-2007	Werda climatic data 2002-2007	Climatology
Basin_altitude_200m_interval.shp	Contours covering Molopo Nossob Basin at 200m interval	Elevation
Basin_contours_100m_interval.shp	Contours covering Molopo Nossob Basin at 100m interval	Elevation
Molopo_Catchment_20m_contours	Contours covering Molopo Nossob Basin at 20m interval	Elevation
Aquifer_map	Map showing aquifers within Molopo-Nossob basin	Hydrogeology
Basin_geology.shp	Hydrogeology map covering Molopo Nossob Basin	Hydrogeology
Basin_kalahari_outline	Kalahari formation in Molopo-Nossob basin	Hydrogeology
Borehole map.jpg	Boreholes within Molopo-Nossob basin	Hydrogeology

File_name	Abstract	Topic_Category
Boreholes for flouride	List of boreholes with flouride data	Hydrogeology
Boreholes for NO3	List of boreholes with nitrate data	Hydrogeology
Boreholes for TDS	List of boreholes with TDS data	Hydrogeology
Boreholes for water level	List of boreholes with water level data	Hydrogeology
Bots_kalahari_formation	Kalahari line in Botswana within Molopo-Nossob Basin	Hydrogeology
Bots_monitoring_bholes	Monitoring boreholes in Botswana within Molopo-Nossob basin	Hydrogeology
F_bholes	Boreholes used for plotting fluoride distribution map	Hydrogeology
geology	Geology in South Africa within Molopo-Nossob basin	Hydrogeology
geology structure	Geological structures in South Africa within Molopo-Nossob basin	Hydrogeology
Groundwater Harvest Potential of The Republic of South Africa	Groundwater Harvest Potential of The Republic of South Africa	Hydrogeology
Groundwater Pollution and Vulnerability Map, Republic of Botswana	Groundwater Pollution and Vulnerability Map, Republic of Botswana	Hydrogeology
Groundwater Resources Map of The Republic of Botswana	Groundwater Resources Map of The Republic of Botswana	Hydrogeology
gw_quality_1_in_1500000	Groundwater quality map at 1 : 1 500 000 in South Africa within Molopo-Nossob basin	Hydrogeology
Harvest_potential	Harvest potential map in South Africa within Molopo-Nossob basin	Hydrogeology
Hydrogeological Map of Namibia	Hydrogeological Map of Namibia	Hydrogeology
Hydrogeological Map of The Republic of South Africa	Hydrogeological Map of The Republic of South Africa	Hydrogeology
in_stream_dams_final	In-stream dams within Molopo-Nossob Basin	Hydrogeology
Isopach Map of the Kalahari Group	Isopach Map of the Kalahari Group	Hydrogeology
Kalahari thickness compiled Botswana	Kalahari thickness compiled Botswana as points	Hydrogeology
Kalahari thickness compiled Namibia JICA	Kalahari thickness compiled Namibia JICA as points	Hydrogeology
Kalahari_formation	Kalahari formation in Molopo-Nossob basin	Hydrogeology
Lithology	Lithology map in South Africa within Molopo-Nossob basin	Hydrogeology
Molopo_Nossob_basin_boreholes	Boreholes within Molopo Nossob Basin	Hydrogeology

File_name	Abstract	Topic_Category
Molopo_nossob_basin_flouride_poly	Map showing fluoride distribution in Molopo-Nossob basin	Hydrogeology
Molopo_nossob_basin_gw_yield	Groundwater yield map within Molopo-Nossob basin	Hydrogeology
Molopo_nossob_basin_monitoring_boreholes	Monitoring boreholes within Molopo-Nossob basin	Hydrogeology
Molopo_nossob_basin_nitrate_poly	Map showing nitrate distribution in Molopo-Nossob basin	Hydrogeology
Molopo_nossob_basin_tds_line	TDS map as line in Molopo-Nossob basin	Hydrogeology
Molopo_nossob_basin_tds1_poly	TDS map in Molopo-Nossob basin	Hydrogeology
Molopo_nossob_geology	Geology map of Molopo-Nossob basin	Hydrogeology
Molopo_nossob_waterlevel	Groundwater level map within Molopo-Nossob basin	Hydrogeology
Monitoring boreholes in Stampriet area	List of monitoring boreholes in Stampriet area	Hydrogeology
Monitoring_boreholes_analysed	Monitoring boreholes selected for analysis during the project	Hydrogeology
Nam_auob_aquifer	Auob aquifer in Namibia within Molopo-Nossob basin	Hydrogeology
Nam_kalahari_formation	Kalahari line in Namibia within Molopo-Nossob Basin	Hydrogeology
Nam_monitoring_bholes	Monitoring boreholes in Namibia within Molopo-Nossob basin	Hydrogeology
No3_bholes	Boreholes used for plotting Nitrate distribution map	Hydrogeology
SA_ecca_aquifer	Ecca aquifer in South Africa within Molopo-Nossob basin	Hydrogeology
SA_kalahari_formation	Kalahari line in South Africa within Molopo-Nossob Basin	Hydrogeology
SA_monitoring_bholes	Monitoring boreholes in South Africa within Molopo-Nossob basin	Hydrogeology
TDS Botswana, Namibia and South Africa	TDS data for Botswana, Namibia and South Africa	Hydrogeology
Tds_point	TDS map as points in Molopo-Nossob basin	Hydrogeology
vegter_gw_regions	Groundwater regions in South Africa within Molopo-Nossob basin	Hydrogeology
waterpoints hardap_GCS_Schwarzeck	Distribution of water supply schemes in Hardap	Hydrogeology
waterpoints_omaheke_GCS_Schwarzeck	Distribution of water supply schemes in Omaheke	Hydrogeology
yield_gw_occurence	Groundwater occurrence in South Africa within Molopo-Nossob basin	Hydrogeology

File_name	Abstract	Topic_Category
Nam_pipeline	Water Transfer pipelines in Namibia within Molopo-Nossob basin	Infrastructure
Water_transfer_pipeline	Water Transfer pipelines within Molopo-Nossob basin	Infrastructure
african_dams060908-Bots-Nami-SA	List of Dams	Inlandwaters
dams	List of dams	Inlandwaters
dams500g_wgs84	Dams in South Africa within Molopo-Nossob basin	Inlandwaters
Molofo_catchment	Molopo catchment boundary in South Africa within Molopo-Nossob basin	Inlandwaters
Molopo_Nossob_basin_dams	Dams within Molopo-Nossob basin	Inlandwaters
Molopo_Nossob_basin_pans	Pans within Molopo-Nossob basin	Inlandwaters
Molopo_Nossob_basin_rivers	Rivers forming Molopo-Nossob Basin	Inlandwaters
Off-channel_dams_final	Off-channel dams within Molopo-Nossob basin	Inlandwaters
Orange_basin_rivers	Rivers forming Orange basin	Inlandwaters
Primary rivers	Primary rivers in South Africa within Molopo-Nossob basin	Inlandwaters
Rivers_molopo_nossob	Rivers forming Molopo-Nossob Basin	Inlandwaters
Secondary Rivers	Secondary rivers in South Africa within Molopo-Nossob basin	Inlandwaters
Basin_localities.shp	Villages, towns and cities within Molopo-Nossob basin	Society
Basin_location.shp	Villages, towns and cities within Molopo-Nossob basin	Society
Basin_settlements.shp	Cities, Towns and Villages within Molopo Nossob Basin	Society
Cities	Cities and Towns in and around Molopo Nossob Basin in Botswana, Namibia and South Africa	Society
Cities_Towns	Cities and Towns in South Africa within Molopo-Nossob basin	Society
Places	Villages, towns and cities within Molopo-Nossob basin	Society
Towns and settlements	Location of 600 towns and other settlements in Namibia	Society
Basin_roads.shp	Roads within Molopo Nossob Basin	Transportation
Railway_sa	Railway line in South Africa within Molopo-Nossob basin	Transportation