No.

JAPAN INTERNATIONAL COOPERATION AGENCY

DEPARTMENT OF WATER AFFAIRS
MINISTRY OF AGRICULTURE, WATER AND RURAL DEVELOPMENT
THE REPUBLIC OF NAMIBIA

THE STUDY ON THE GROUNDWATER POTENTIAL EVALUATION AND MANAGEMENT PLAN IN THE SOUTHEAST KALAHARI (STAMPRIET) ARTESIAN BASIN IN THE REPUBLIC OF NAMIBIA

FINAL REPORT

MAIN REPORT

MARCH 2002

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO
IN ASSOCIATION WITH
SANYU CONSULTANTS INC., TOKYO

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Exchange rate on Feb.2002 is Namibian Dollar ($N) =South African Rand (Zar)= Japanese Yen ¥ 11.70= US$0.0877

PREFACE

In response to a request from the Government of the Republic of Namibia, the Government of Japan decided to conduct the Study on the Groundwater Potential Evaluation and Management Plan in the Southeast Kalahari (Stampriet) Artesian Basin and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched a study team headed by Mr. Yasumasa Yamasaki of Pacific Consultants International Co., Ltd. to the Republic of Namibia, four times between June 1999 and March 2002.

The team held discussions with the officials concerned of the Government of Republic of Namibia and conducted field surveys at the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Namibia for their close cooperation extended to the team.

March 2002

川上隆朗

Takao Kawakami
President
Japan International Cooperation Agency

THE STUDY ON THE GROUNDWATER POTENTIAL EVALUATION AND MANAGEMENT PLAN IN THE SOUTHEAST KALAHARI (STAMPRIET) ARTESIAN BASIN IN THE REPUBLIC OF NAMIBIA

March 2002

Mr. Takao Kawakami
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

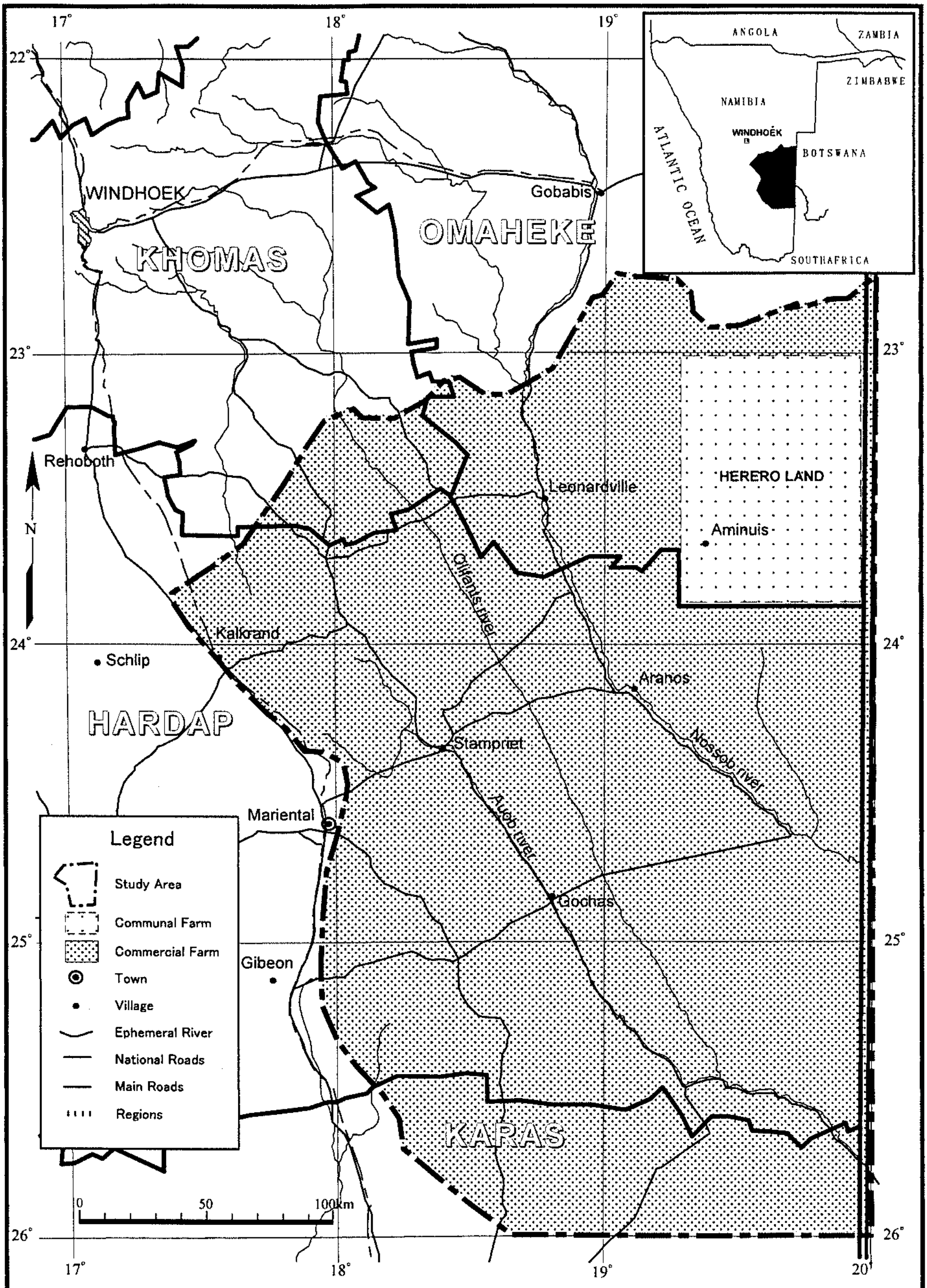
We are pleased to submit the final report entitled "THE STUDY ON THE GROUNDWATER POTENTIAL EVALUATION AND MANAGEMENT PLAN IN THE SOUTHEAST KALAHARI (STAMPRIET) ARTESIAN BASIN IN THE REPUBLIC OF NAMIBIA". The Study Team has prepared this report in accordance with the contract between Japan International Cooperation Agency and Pacific Consultants International in association with Sanyu Consultants Inc.

This report presents the results of the evaluation of the groundwater resources potential and the groundwater management plan.

All members of the Study Team wish to express grateful acknowledgments to the personnel of your Agency, Ministry of Foreign Affairs, and Embassy of Japan in South Africa, and also to officials and individuals of the Government of Namibia for their assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the sustainable groundwater use in the Stampriet Basin and other relevant projects.

Yours faithfully,

Mr. Yasumasa YAMASAKI
Team Leader



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NAMIBIA
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ATLANTIC OCEAN
SOUTHAFRICA
WINDHOEK
Gobabis
OMAHEKE
KHOMAS
Rehoboth
N
Leonardville
HERERO LAND
Aminuis
Kalkrand
Schlip
Aranos
HARDAP
Stampriet
Olifants river
Nossob river
Auob river
Mariental
Gochas
Gibeon
KARAS
Legend
Study Area
Communal Farm
Commercial Farm
Town
Village
Ephemeral River
National Roads
Main Roads
Regions
0
50
100km

Study Area

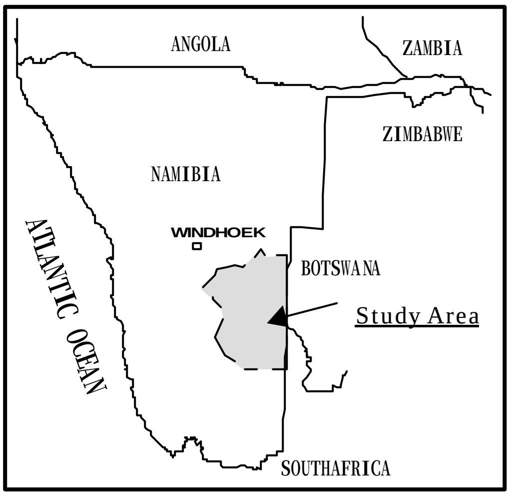
OUTLINE

Background of the Study

The Southeast Kalahari (Stampriet) Artesian Basin (hereinafter referred to as "the basin" or "the study area") is situated in the southeastern part of Namibia. This basin is the largest groundwater basin in the country, which extends eastwards into Botswana and South Africa.

Groundwater abstraction within the basin is maintained by the regulations prescribed in the Water Act. Extensive groundwater abstraction by commercial and communal 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.

Consequently, a Hydrocensus was carried out by the Department of Water Affairs (DWA) during 1986 to 1988 in order to define the impact due to abstraction of the groundwater. Since then, no further study has been done, although, groundwater use has steadily increased to nearly twofold of 1988.



<Location Map of the Study Area >

DWA (Department of Water Affaires) needs to understand the nature of entire aquifer system in order to manage the excessive abstraction. Accordingly, the Government of Namibia requested the Government of Japan to carry out an investigation of the groundwater flow and recharge mechanism of the basin, furthermore, to formulate a groundwater management plan for sustainable groundwater development. This study was carried out during from June 1999 to January 2002.

Objectives of the Study

The objectives of the study are:

- To investigate the groundwater flow regime and recharge mechanism within the Southeast Kalahari Artesian Basin.
- To evaluate the groundwater potential to support sustainable development within the Southeast Kalahari Artesian Basin.
- To formulate a groundwater management plan within the Southeast Kalahari Artesian Basin.
- To achieve technology transfer to counterpart personnel during the course of the study.

Study Area

The study area covers the Southeast Kalahari Artesian Basin (approximately 71,000km^2) as shown in the figure at the beginning of the report.

Conclusions

(1) Hydrogeological Structure

The Kalahari, Auob and Nossob Aquifer do not a simple monoclinal feature but a considerably complicated structure. Redefinition of the aquifers was also done through this study. (See Fig.3.6-9)

(2) Groundwater Potential Evaluation

The Auob Aquifer has the highest potential, followed by the Kalahari Aquifer, while the Nossob Aquifer shows the lowest potential. (See Fig.5.3-9 to 11)

(3) Groundwater Flow and Recharge Mechanism

a) Groundwater Flow

Groundwater into each aquifer flows from NW to SE and it was estimated that it takes several thousand years to flow through the whole basin. (See Fig.3.7-1 to 3)

b) Recharge

The major recharge into the basin occurs via direct rainfall feeding the rivers and the fractures as well as the karstic sinkholes that are situated on the rim of the basin. Recharge via these features and structures feed the Kalahari Aquifer directly and this amounts to $105\times10^6 m^3$/year in an average rainfall year and 1,550 x $10^6 m^3$/year during an exceptional rainfall event (on average 1/50 years). Recharge into the Auob Aquifer via the Kalahari Aquifer and the Kalkrand Basalts does occur but this is mainly during the exceptional rainfall events. Recharge into the Nossob Aquifer is negligible and most of the resource in the Nossob Aquifer can be regarded as fossil water.

(4) Water Balance

a) Under average rainfall conditions, the water level of the Kalahari Aquifer decreases by 5cm/year on average. Even though a 1/50 year heavy rainfall event does reverse the drawdown to some degree for a limited period, it does not prevent the longer term water-level decline under the present conditions.

b) Groundwater recharge volume is up to 0.5% of total rainfall during a normal rainfall event and 3% during a 1/50 year heavy rainfall event. Most of the rainwater is lost by evapotranspiration. This is exacerbated by the large amount of alien vegetation and attention should be paid to solving this problem.

(5) Groundwater Demand

a) Of the total groundwater abstracted from the Basin, approximately one half of the volume of $15\times10^6 m^3$/year is used for irrigation ($6.88\times10^6 m^3$/year). Approximately 78 % of the total irrigation use is concentrated in the Stampriet area. (See P.4-12, and Table4.1-3)

b) Of the total groundwater abstraction from the Basin annually, 66% is from the Kalahari Aquifer, 33% from the Auob Aquifer and only 1% from the Nossob Aquifer respectively.

(6) Groundwater Simulation

a) Within a 60km square area around Stampriet the drawdown of the groundwater level is remarkable. (See Fig.5.3-12 to 17)

b) Some wells within the Kalahari Aquifer around the Stampriet area may dry up within the next 30 years if the present condition of water use prevails. (See Tables 5.3-2, 3 and Fig.5.3-18) In view of the present over abstraction taking place, mitigating measures as part of a water demand management plan as described in Chapter 7 of the report should be adopted.

(7) Groundwater Management Plan

a) Water Demand Management

It is proposed that the irrigation use be reduced by 30% for the short term and that the following countermeasures are suggested:

i) Start of an awareness campaign regarding the sustainable use of groundwater.

ii) Proper monitoring of water abstraction volumes.

iii) Review of permit conditions for water allocation.

iv) Reduction of over irrigated areas.

v) Switch to higher value crop cultivation.

vi) Voluntary reduction in water use by users.

vii) Application of more efficient irrigation methods.

viii) Pricing of groundwater.

b) Aquifer Management Plan

An aquifer management plan was set up as follows.

i) A regional groundwater monitoring plan was set up covering the entire basin as shown in Fig.7.3-2 and groundwater levels should be monitored on a continuous basis.

ii) A special groundwater monitoring area was also proposed in an area covering approximately 90km square around Stampriet. (See Fig.7.3-2) Here three additional observation boreholes should be drilled and installed with recorders.

c) Personal Recruitment

DWA staff should be increased to fill the approved posts in order to do the necessary follow-up work of this study and to implement the groundwater management plan.

(8) Initial Environmental Evaluation

The proposed groundwater management plan is expected to have positive environmental impacts as the groundwater potential in the Stampriet Artesian Basin will be positively affected.

(9) Counterpart Training

During this study, transfer of technical know-how to counter-part personnel was conducted between JICA study members in each field in the form of on-the-job training. The Director of Resource Management and the Deputy Director of Geohydrogy also took part in the counterpart-training course in Japan.

Recommendations

(1) This report be accepted in principle.

(2) The mean groundwater recharge into the aquifer is limited to 135 Mm^3/a, subject to future monitoring management and adjustment.

(3) An appropriate aquifer management plan, as described in Section 7 of the report, be implemented.

(4) The criteria for all allocation of water for irrigation should be adjusted as suggested in paragraph 7-1 to ensure that the benefits of using the available water resources are maximized.

(5) In view of the present over abstraction taking place, mitigating measures as part of a water demand management plan as described in Section 7 of the report should be adopted in cooperation with all water users to reduce the water demand and the local Water Committee should play a major role in this regard.

(6) Further studies must be done to improve borehole construction and reduce the leakage from the existing groundwater abstraction wells. Furthermore attention must be given to assess and rectify the suspected contamination of groundwater taking place in the Basin, to reduce the loss of artesian pressure and to enhance aquifer recharge from surface runoff in areas where this can be done. The problem of alien vegetation should be addressed.

(7) The technology used and the results obtained in this study should be utilized to manage other groundwater basins in Namibia.

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ABBREVIATIONS

ASL	: Above Sea Level
AGL	: Above Ground Level
BGL	: Below Ground Level
CMBM	; Chloride Mass Balance Method
CSAMT	: Controlled Source Audio Magnet Telluric
DO	: Dissolved Oxygen
DRWS	: Directorate of Rural Water Supply
DVS	: Directorate of Veterinary Services
DWA	: Department of Water Affairs
EC	: Electric Conductivity
GDP	: Gross Domestic Product
GPS	: Global Positioning System
GVA	: Gross Value Added
IAEA	; International Atomic Energy Agency
IEE	; Initial Environment Evaluation
IMF	: International Monetary Fund
JICA	: Japan International Cooperation Agency
MAWRD	: Ministry of Agriculture, Water and Rural development
NamWater	: Namibia Water Corporation
SABS	: South African Bureau of Standard
T	: Temperature
TDEM	; Time Domain Electric-Magnetic
TDS	: Total Dissolved Solids
TEM	: Transient Electro Magnetic
USAID	: United States Agency for International Development
USGS	: United States Geological Survey

CHAPTER 1 INTRODUCTION

1.1 Background of the Study

This Study of the Groundwater Potential Evaluation and Management Plan in the Southeast Kalahari (Stampriet) Artesian Basin (hereinafter referred to as "the Study") was carried out between June 1999 and January 2001.

The Southeast Kalahari (Stampriet) Artesian Basin (hereinafter referred to as "the Southeast Kalahari Artesian Basin" or "the study area") is situated in the southeastern part of Namibia. The Southeast Kalahari Artesian Basin is the largest groundwater basin in the country, which extends eastwards into Botswana and South Africa. Its area is approximately 71,000km^2. The basin is almost entirely overlain by the Kalahari Group.

Groundwater from the basin is abstracted by both commercial and communal farmers for their domestic, livestock and irrigation purposes. It is also supplied to the towns of Stampriet, Gochas, Aranos, Leonardville, Aminuis and Onderombapa by the bulk water supply system of NamWater.

Groundwater abstraction within the Southeast Kalahari Artesian Basin has been controlled by Regulations promulgated by the Water Act. Extensive groundwater abstraction by commercial farmers occurs in the northern and central parts of the basin. Groundwater levels have been declining continuously since 1980 according to some monitoring wells.

Subsequently, a Hydrocensus was carried out by the Department of Water Affairs (DWA) from 1986 to 1988 in order to define the impact due to abstraction of the groundwater. Since then, no further work has been done, although, groundwater use has steadily increased to nearly double that of 1988.

In order to manage the excessive abstraction, the DWA needs to understand the nature of entire aquifer system. Accordingly, the Government of Namibia requested the Government of Japan to carry out an investigation of the groundwater flow and recharge mechanism of the Southeast Kalahari Artesian Basin and to formulate a groundwater management plan for sustainable groundwater development.

1.2 Objectives of the Study

The objectives of the Study are:

- To investigate the groundwater flow regime and recharge mechanism within the Southeast Kalahari Artesian Basin;
- To evaluate the groundwater potential to support sustainable development within the Southeast Kalahari Artesian Basin;
- To formulate a groundwater management plan within the Southeast Kalahari Artesian Basin;
- To achieve technology transfer to counterpart personnel during the course of the study.

1.3 Study Area

The study area covers the Southeast Kalahari Artesian Basin (approximately 71,000km^2) as shown in the figure at the beginning of the report.

1.4 Implementation of Study

The Department of Water Affairs (DWA) of the Ministry of Agriculture, Water and Rural Development (MAWRD) was assigned as the counterpart organization by the Government of Namibia, while the Japan International Cooperation Agency (JICA) was assigned as the official agency responsible for the implementation of the technical cooperation program of the Government of Japan.

The study was conducted by the Japanese study team, comprising members of the Pacific Consultants International (PCI) and Sanyu Consultants Inc., officially retained by JICA for the study, and the counterpart staff provided by the DWA. The study was commenced in June 1999 and will be completed in March 2002. The total schedule of the study is shown in Table 1.4-1.

The study consists of a hydrological study, hydrogeological study, evaluation of groundwater potential, water use, socio-economic aspects, environmental aspects and the formulation of groundwater management plan.

The members involved in the study are listed below.

Name	Assignment
< Study Team of JICA >	
Mr. Yasumasa YAMASAKI	Team Leader/Groundwater Management Planner
Mr. Norifumi YAMAMOTO	Hydrogeologist (A)
Mr. Tadashi YAMAKAWA	Geologist/Remote Sensing Expert
Dr. Mahbub A. K. REZA	Hydrologist/Water Balance Expert
Dr. Gideon TREDOUX	Water Quality/Environmental Specialist
Mr. Kohei SUGAWARA	Geophisycist
Mr. Yuichi HATA	Hydrogeologist (B)/Drilling Expert
Mr. Katsuhiro FUJISAKI	Groundwater Simulation Expert
Mr. Kensuke IRIYA	Socio-Economist
Mr. Akira OGIHARA	Socio-Economist
Mr. Hiroyoshi YAMADA	Coordinator (Hydrogeologist)
<DWA Staff>	<Title>
Mr. Piet HEYNS	Director: Resource Management
Mr. Greg CHRISTELIS	Deputy Director: Geohydrology
Mr. Guido Van LANGENHOVE	Deputy Director: Hydrology
Mr. Dudley BIGGS	Deputy Director: Planning
Mr. Don LOUW	Principal Hydrogeologist
Mr. Hartmut STRUB	Senior Hydrologist
Mr. Piet LIEBENBERG	(Irrigation Division, Department of Agriculture)
Mr. Rick Williams	Socio-Economist (Department of Planning)
Mr. Alex KATJUONGUA	Chief Technical Assistant
Ms. Theopauline NGULA	Technical Assistant

Table 1.4-1 Total Schedule of the Study

Year	1999	2000	2001	2002
Month	Jun, Jul, Aug, Sep, Oct, Nov, Dec	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	Jan, Feb, Mar
Work in Namibia	***1st Field Survey*** [4] Submission and discussion of IC/R [5] Existing data collection, review and analysis [6] Landsat imagery interpretation [7] Aerial photo Interpretaion [8] Topographical, geological and hydrogeological investigation [9] Existing borehole survey [10] Water usage [11] Preliminary environmental survey [12] Geophysical survey [13] Formulation of study plan for 2nd and 3rd field survey [14] Preparation and discussion of P/R (1)	***2nd Field Survey*** [15] Test borehole drilling, borehole logging and pumping test [16] Observation of groundwater levels [17] Water quality analyses [18] Renewal of database of boreholes [19] Present water usage and water consumption forecast ***3rd Field Survey*** [20] Test Borehole drilling, borehole logging and pumping test [21] Observation of groundwater levels [22] Water quality analysis [23] Elevation survey for existing boreholes (DGPS) [24] Survey on meteorology and hydrology [25] Preliminary hydrogeological analyses [26] Groundwater modeling(1) [27] Preparation and discussion of P/R(2)	***4th Field Survey*** [34] Discussion of IT/R [35] Groundwater simulation [36] Evaluation of the groundwater potential for sustainable usage [37] Formulation of groundwater management plan	***5th Field Survey*** [39] Discussion of DF/R
Work in Japan	***Preparation of the Study*** [1] Collection, review and analysis of related data and data [2] Examination of study approach and methodology [3] Preparation of IC/R		***1st Work In Japan*** [28] Hydrogeological analysis [29] Water balance analysis [30] Groundwater modeling (2) ***2nd Work In Japan*** [31] Preliminary groundwater simulation [32] Preliminary evaluation of the groundwater potential for sustainable usage [33] Preparation of IT/R ***3rd Work In Japan*** [38] Preparation of DF/R	***4th Work In Japan*** [40] Preparation of F/R
Study Stage	**Phase I : Data Collecting and Analysis**	**Phase II : Groundwater Field Survey**	**Phase III : Analysis and Evaluation**	
Report	▲ Inception Report ▲ Progress Report (1)	▲ Progress Report (2)	▲ Interim Report	▲ Draft Final Report ▲ Final Report

<Notes> ☐ : Completed. IC/R: Inception Report P/R: Progress Report IT/R: Interim Report DF/R: Draft Final Report F/R: Final Report

1.5 Composition of Report

This report consists of four (4) volumes: Summary Report, Main Report, Supporting Report and Data Book.

The Main Report presents the summarized results of all the studies. In Chapter 2, basic information for the study is described. Hydrogeology and groundwater potential evaluation are presented in Chapter 3 and Chapter 5. Water demand and groundwater management plans are described in Chapter 4 and Chapter 7. Chapter 8 deals with the conclusion and recommendations.

Detailed study results are described in the Supporting Reports and Data Book. The contents of the Supporting Report are as follows;

In Chapter 2 through 8, basic information for the study is described. Water supply, demand and groundwater development potential are described in Chapter 9 to 11. Groundwater modelling is described in Chapter 12. Environmental and Socio-Economic aspects are described in Chapter 14 and 13, respectively. Chapter 15 deals with the groundwater value

CHAPTER 2 GENERAL DESCRIPTION OF STUDY AREA

2.1 Geomorphology

Geomorphology of the study area was interpreted by using LANDSAT/TM images and monochromic aerial photographs. The results are shown in Table 2.1-1 and Fig. 2.1-1.

Table 2.1-1 Geomorphologic Interpretation Chart

Unit Name	General Altitude	Geomorphology	Other Ground Surface Characteristics
Hh	High	Hill	Even and inclined with smooth surface
Hm	Moderate	Hill	Even and very smooth surface
Hl	Low	Hill	Rough texture
Sd	-	Sand Dune	Yellow coloured linear texture with N-S direction
Bd	Low	Bed Rock	Colours and geomorphology depending upon their geology
Vg	-	(Vegetation)	Generally sparse

In general, topography of the study area is flat, of which gradient is 2/1000 in average. Elevation of the study area decreases toward southeast from 1,500m to 950m.

The characteristics of geomorphology are closely related to the geology of the study area. Most of the areas where Kalahari calcretes crop out show significantly flat. However, the western and southern parts of the study area form cliffs or steep slopes, where the sandstones of the Nossob and the Auob Members, basalts of the Kalkrand Basalt and dolerite sills are distributed widely. These features provide three categories of hilly topography that are called high, moderate and low hills in relation to their altitudes, textures and so on.

The sand dunes developed in the northern and central part of the study area indicate typically linear shapes in all sizes, affected by seasonal winds in NW-SE direction. These dunes and other sand covers seal bedrocks under beneath. Vegetations are mainly composed of natural colonies, but cultivated areas represented by the Hardap irrigation scheme are apparently extracted from the images.

Drainage is divided into two groups. One is an external drainage such as surface streams and the other is an internal drainage, which is called as “Pans” in this district developed from sinkholes in the distribution area of the Kalahari Member. They show almost circular or ellipse shapes with numerous sizes in their diameters.

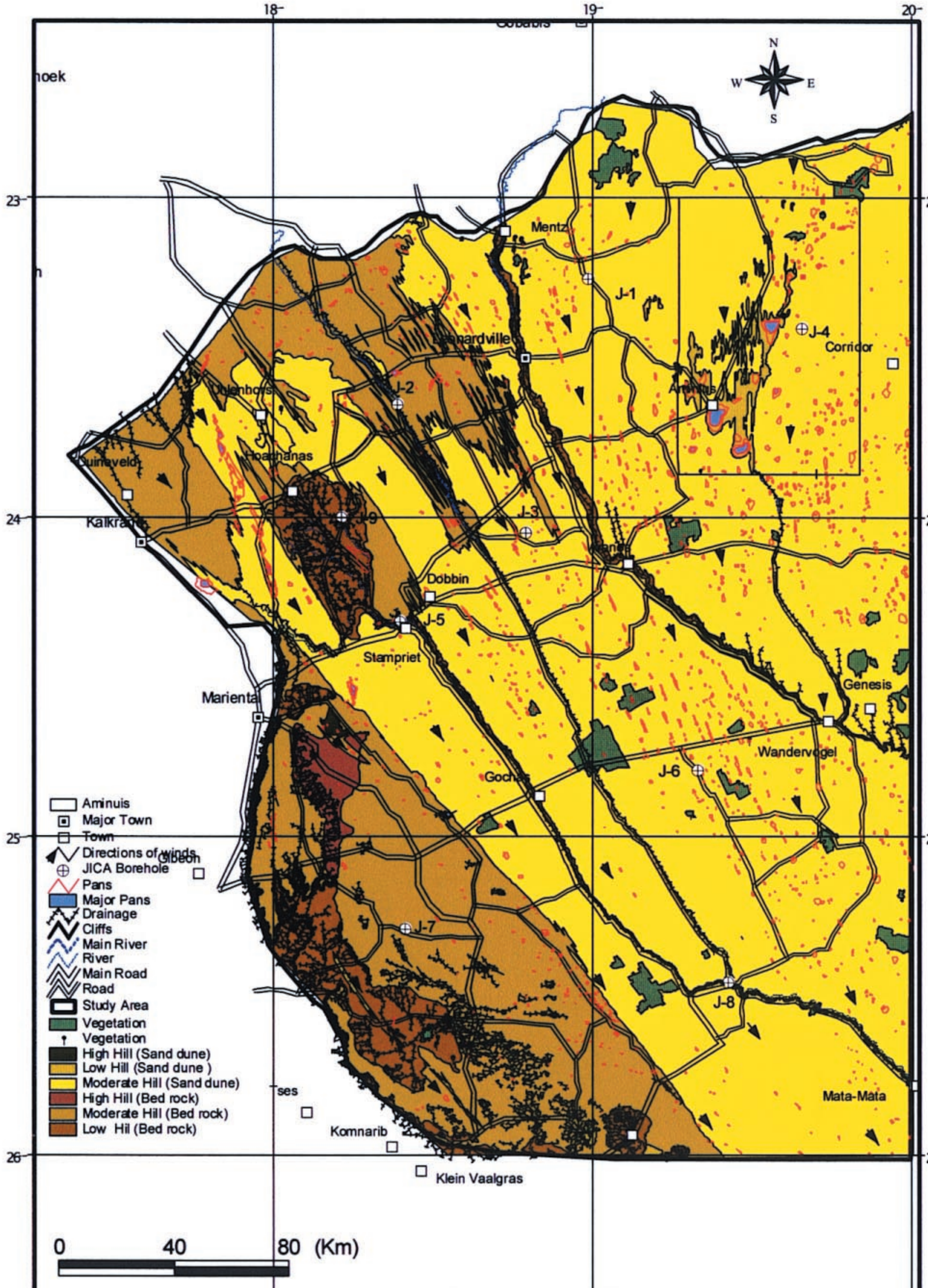


Fig. 2.1-1 Geomorphology of the Study Area

2.2 Geology

2.2.1 General Geology

Geology of the study area owes to previous contributions by Heath (1960), Martin (1963), Kingsley (1985), CDM Mineral Surveys (CDM, 1982, 1983; McDaid, 1982, 1983), Gold Fields Prospecting (Castelyn, 1983), Agip Carbone (1982, 1983) and Geology of Botswana (J.N.Carney et al.,1994).

Although different classifications were presented in the previous studies, geology of the study area is summarized in Table 4.1-1 following "Mineral Resources of Namibia"(MSN, 1992).

The Damara Sequence, the Nama Group and the Dwyka Group are regarded as the basement rocks of the study area because they serve as an impermeable layer from a hydrogeological point of view. The Damara Sequence and the Nama Group were formed through the Pan–African Orogeny or Movement. The Dwyka Group consists of glacial sediments that were deposited in the late Carboniferous to the early Permian Period.

The Nossob and the Auob members as the major aquifers in the study area are included in the Prince Albert Formation that consists mainly of sediments that were deposited in the early Permian Period in a basin in which water depth fluctuated through time.

Faults and dolerite dykes or sills occur in the Prince Albert Formation. The Kalkrand Basalts were formed widely in the northwestern part of the study area, namely the north of Mariental. The Kalahari Beds, of which age is from the late Cretaceous to the Recent, were deposited on an erosional landscape known as the "African Surface" into which a deep "Pre-Kalahari Valley" was eroded.

A geological map, geological cross sections of the study area and location map of the sections are shown in Fig. 2.2-1, Fig. 2.2-2 to Fig. 2.2-5 and Fig.2.2-6 respectively.

Table 2.2-1 Stratigraphy in the Study Area

Era	Period	Formation	Lithology	Thickness	Note
Cenozoic	Quaternary 2Ma Tertiary 65Ma	Kalahari Beds	Sand, gravel, calcrete,calcrete-cemented conglomerate	0 (W)-290 (E)	"Kalahari Beds" is an informal lithostratigraphical term. They rest on an erosional landscape known as the "African surface" (Pre-Kalahari Valley).
Mesozoic	Cretaceous 143Ma		-	-	-
Mesozoic	Jurassic	Karoo Sequence / Ecca Group / Karoo Dolerite (180 Ma)	Dolerite	100?	Many of the faults in the Karoo Sequence have been intruded by dolerite dykes.
Mesozoic	Jurassic	Karoo Sequence / Ecca Group / Kalkrand Basalt (180Ma)	Basalt; thin interbeded pan sandstone and sandy limestone with abundant gypsum casts. Equivalent age intrusive dolerite dykes and sills	0-370	Rifting of the Gondwana supercontinent (180 Ma in eastern South Africa; 128 Ma in Namibia)
Mesozoic / Paleozoic	212Ma Triassic 247Ma Permian	Karoo Sequence / Ecca Group Unconformity	-	-	-
Paleozoic	Permian	Karoo Sequence / Ecca Group / Prince Albert Formation: Rietmond member	Multicolored sandstone (mainly brown), shale, yellow shale, coal, black shale	50-100	Lower Ecca subgroup was deposited in lakes and deltas in the post-glacial environment following the retreat of the Dwyka glaciers. The middle and upper subgroups were mostly formed in rivers and deltas under subarctic to cool temperature climatic conditions and include the coal-bearing formations. Regional unconformity exists between Dwyka Group and Nossob member.
Paleozoic	Permian	Prince Albert Formation: Auob member	Upper sandstone, upper coal, middle sandstone, lower or Impala coal, lower sandstone	27-153	
Paleozoic	Permian	Prince Albert Formation: Mukorob member	Upper interbedded white siltstone and grey shale. Lower dark grey to black shale	57-102	
Paleozoic	Permian	Prince Albert Formation: Nossob member	Two coarsening upward sandstone units	6-36	
Paleozoic	289Ma Carboniferous	Karoo Sequence / Dwyka Group	Complex succession of lithofacies, commencing with a basal tillite followed by glaciomarine mudstones with dropstones and minor, local glaciofluvial sandstone		The western margin of the glacial "Kalahari Basin" was inundated by the arm of a shallow sea.
Paleozoic	367Ma Devonian 415Ma Silurian 446Ma Ordovician 500Ma	Unconformity	-	-	-
Paleozoic	Cambrian	Nama Group: Upper Nama Group	Thick alternating units of red, distal molasse sandstone and shale. 545 - 530 Ma.	-	The sediments were folded during later Pan-African movement until 420Ma. Nama G. have been affected by northeast-trending faults that define a half-graven structure. ACP21 reached to fine-grained Nama quartzite in Aranos.
Paleozoic	Cambrian 575Ma	Nama Group: Lower Nama Group Unconformity	Basal sandstone, black shelf limestone, upper grey shales with sheet sandstones. 650 - 545 Ma		
Proterozoic	Pre-Cambrian	Damara Sequence	Complex orogenic succession of sedimentary and volcanic rocks; deformed, metamorphosed and intruded by granite during Pan-African Orogeny. 900 - 505 Ma	-	"Damara Sequence" The various units were accumulated between about 900Ma and 530Ma and were folded and faulted during the Pan-African deformation.

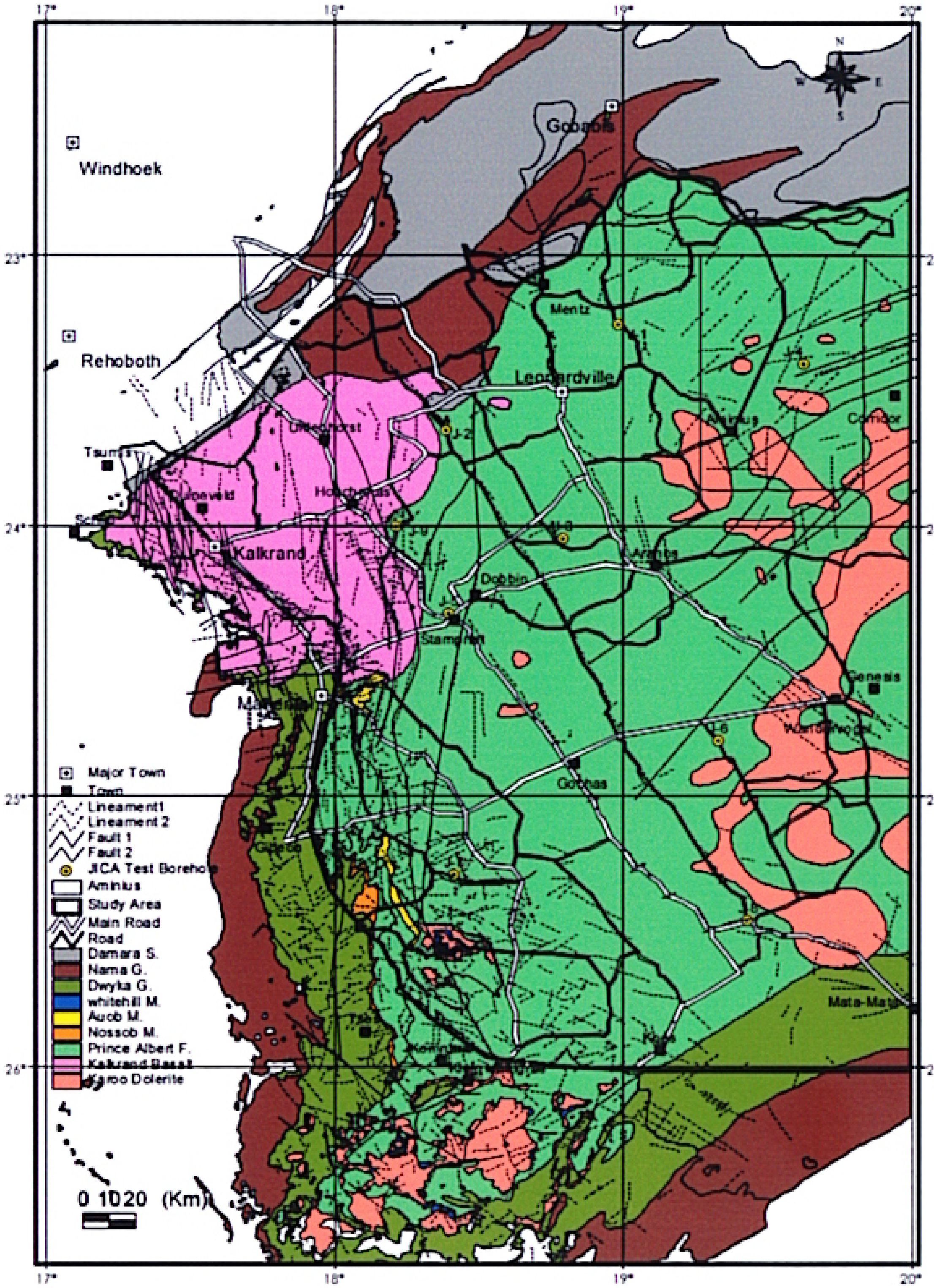
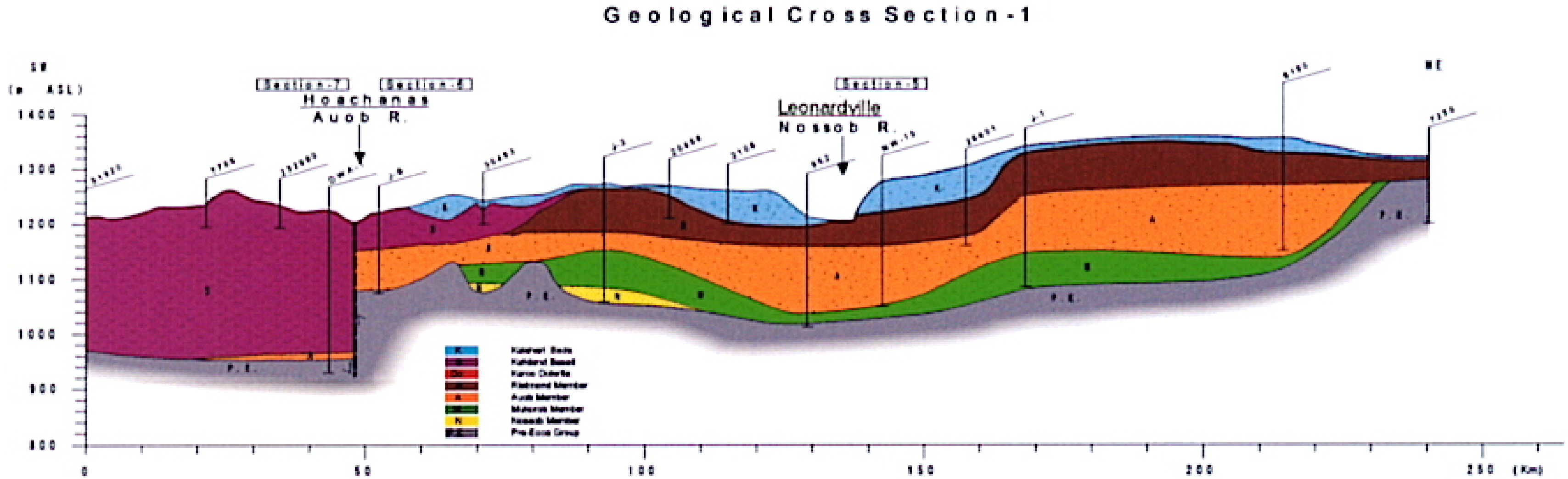


Fig. 2.2-1 Geological Map of the Study Area



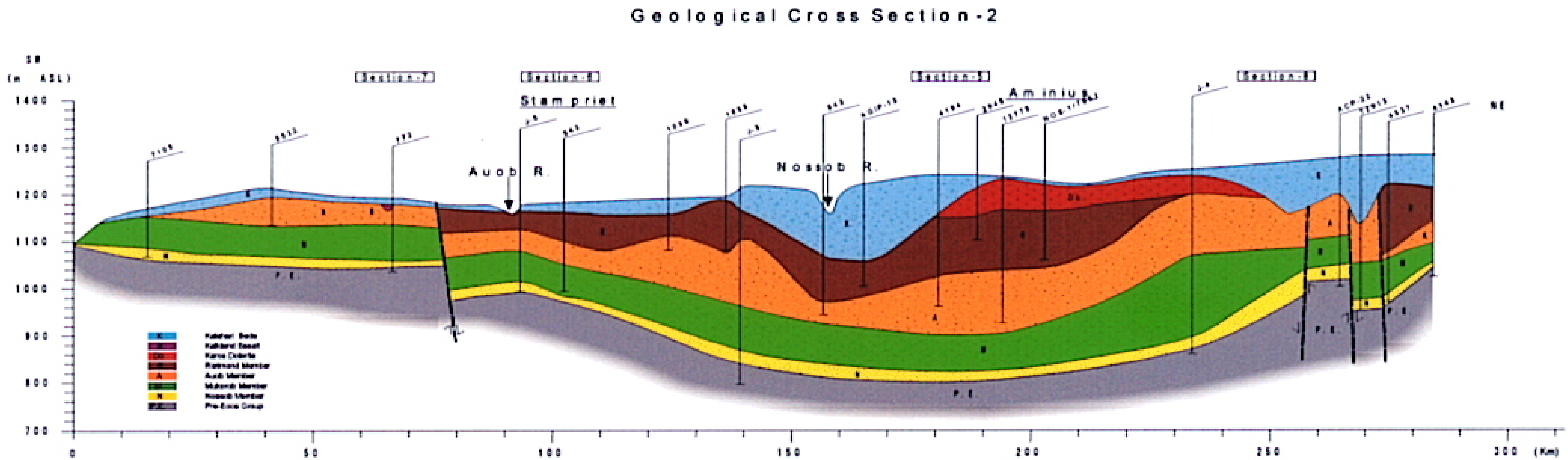


Fig. 2.2-2 Geological Cross Section of the Study Area (1)

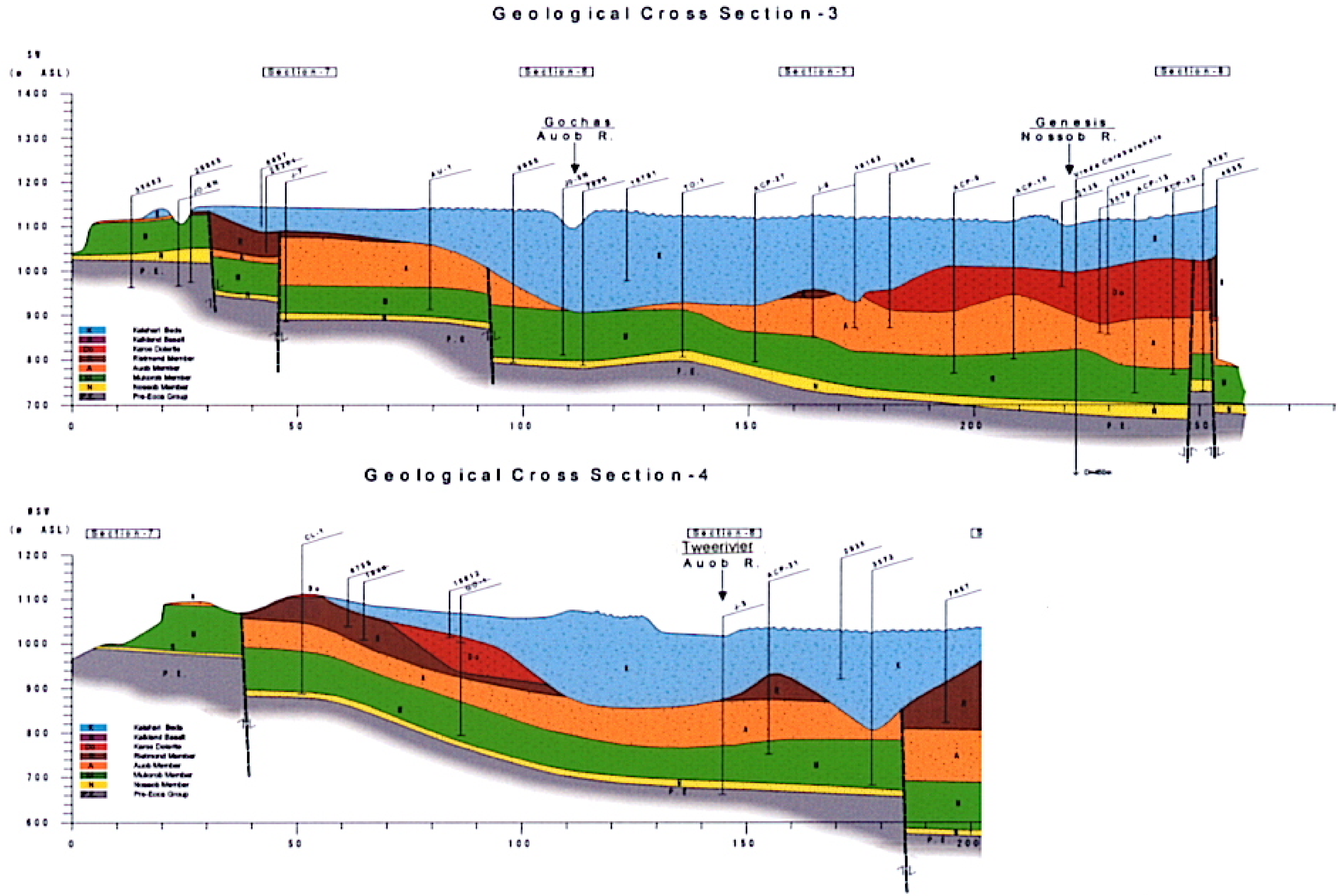
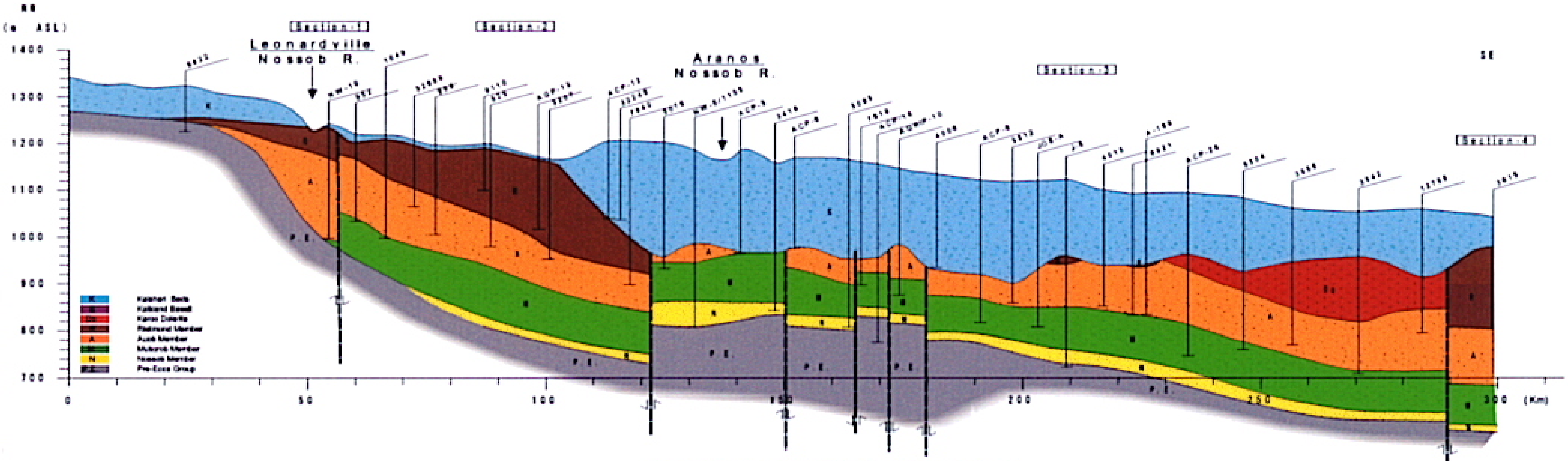


Fig. 2.2-3 Geological Cross Section of the Study Area (2)

Geological Cross Section-5



Geological Cross Section-6

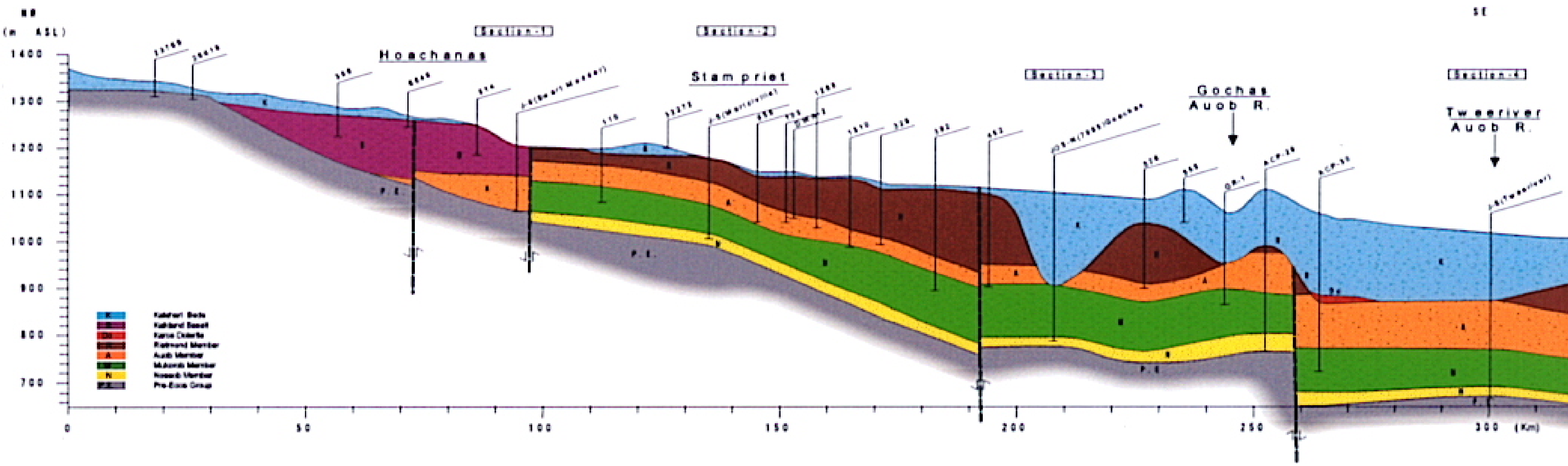


Fig. 2.2-4 Geological Cross Section of the Study Area (3)

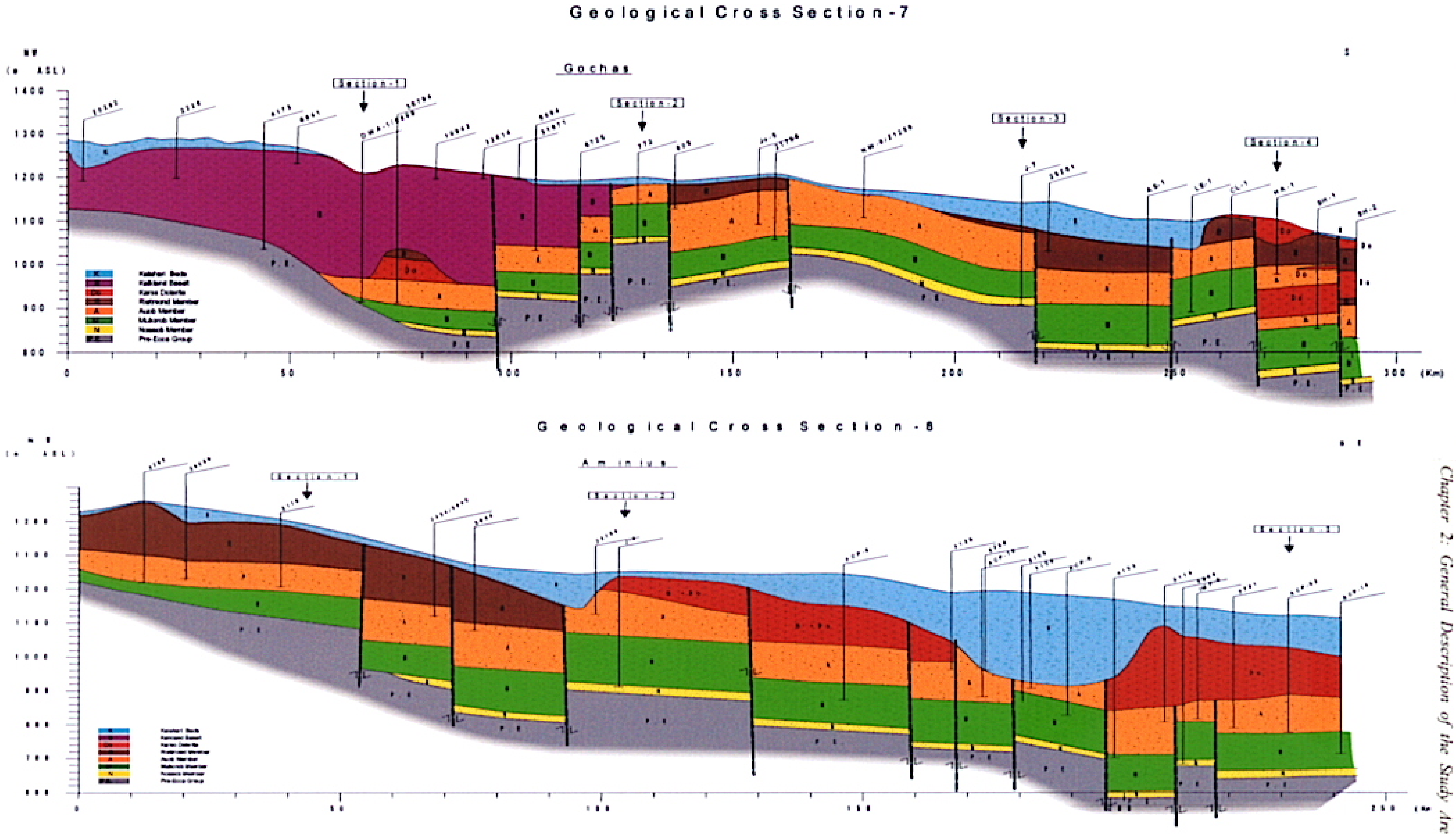


Fig. 2.2-5 Geological Cross Section of the Study Area (4)

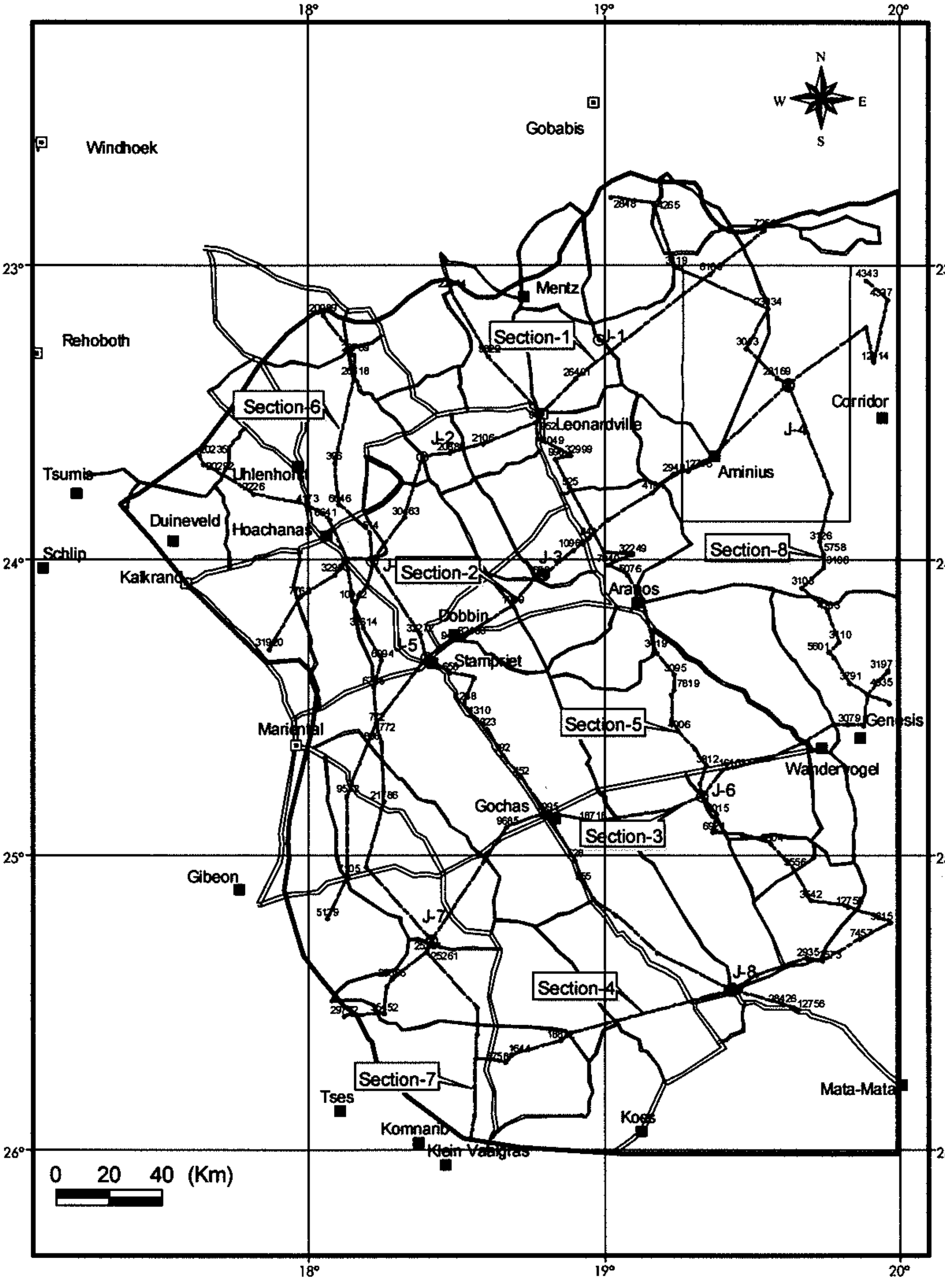


Fig. 2.2-6 Location Map of Geological Cross Sections

2.2.2 Geological Description

In this Chapter, general features of each geological unit are presented (for more detailed description, see Chapter 4 of the Supporting Report).

1) Pre-Karoo Basement

Red sandstones and shales of the Fish River Subgroup of the upper Nama Group underlie the Karoo succession throughout most of the basin. They outcrop to the west and south. They have been intersected below the Karoo in boreholes in the study area such as the deep Vreda core borehole (Wilson, 1965) and JICA test borehole No. J-9A: Klein Swartmodder (in detail, see Chapter 3 of this report and Chapter 6 of the Supporting Report). Very few of the water boreholes have been drilled through the Karoo into this in the northern basement area.

2) Karoo Sequence

The Karoo Sequence in the Stampriet Artesian Basin, in terms of the SACS (1980) nomenclature, consists of a basal Dwyka Group, overlain successively by the Prince Albert Formation, the Rietmond Member and the Whitehill Member. The Rietmond Member is included as a formation at the top of the Prince Albert Formation. The Whitehill Member remains a formation on its own at the top of the succession in accordance with the 1:1 million geological map of Namibia since it overlies the Rietmond Member conformably (Heath, 1972).

(1) Dwyka Group

The Dwyka Group is uppermost Carboniferous to earliest Permian in age. The Dwyka Group thickens significantly to the south, being 100 m thick in the Mariental area and 210 m thick in the Asab area.

Although most of the shale units above the basal tillite are greenish to yellowish in outcrop, drilling has shown all to be dark grey to black in depth. However, the dark Dwyka shales can be distinguished from similar looking Mukorob shales by the presence in places in the former of paper-thin pyrite lamellae on bedding-plane. Dropstones are also a distinguishing feature of the Dwyka shales.

(2) Nossob Member

The base of the Nossob sandstone marks a regional unconformity and the lowest stratigraphic unit of the Prince Albert Formation (see table 2.2-1).

The change from Dwyka to Nossob depositional conditions was abrupt and the base of the Nossob Member is marked in places by a distinct scour surface on which a thin, pebbly sandstone up to 54cm thick with pebbles derived from the underlying Dwyka sediments was deposited in places.

The Nossob Member consists of two coasing shale-siltstone units. Locally, a third, thin unit occurs either at top or at the base.

In the Weissrand Escarpment several natural springs seep out in the escarpment face at the base of the Nossob Member or a few metres down in the shales below the sandstone.

(3) Mukorob Member

For the purposes of this study, the Mukorob Member is taken as the shale-siltstone-sandstone succession between the top sandstone of the Nossob Member and the scoured base of the medium- to coarse-grained Auob Member.

The base of the Mukorob Member is marked in several places by a gradual transition over about 20 m through an interbedded siltstone and shale succession above the Nossob sandstone from dark grey to black, plane bedded shales. An important marker at or near the top of the shale-dominated lower part of the Mukorob Member is a very thin but widespread, grey limestone or calcareous siltstone or shale layer between 2 and 36 cm thick.

The upper part of the Mukorob Member is marked by a gradual progradation and coarsening upward over as much as 40 m of section through thin, highly micaceous fining-upward siltstone-shale cycles into fine-grained sandstone-siltstone cycles with or without shaley tops.

For the purposes of this study, the medium- to coarse-grained upper part of the Mukorob Member is considered to be part of the Auob aquifer and possibly even the underlying fine-grained sandstones where they are essentially shale free and porous.

(4) Auob Member

The Auob Member is divided into five units as shown in Table 2.2-2, a lower sandstone (A1), a lower bituminous shale and coal (A2), a middle sandstone (A3), an upper bituminous shale and coal (A4), and an upper sandstone (A5). Neither the shale nor the coal horizons crop out and it is therefore uncertain which of the sandstone horizons the outcropping sandstone represents. Evaluation of the shale horizons is considered important as they may form significant barriers to flow between the three sandstone horizons.

Table 2.2-2 Description of Subdivided Auob Member

Formation			Lithology
Auob Member	Upper Sandstone	(A5)	White, massive sandstone weathering light yellow. Coarse-grained to locally gritty; high porosity and permeability; accessory biotite; cross beds and clay pellets up to 13 mm. . Common brownish black, calcareous concretions up to 3.6 m. , in places coalescing to form a continuous layer;
	Upper Auob Bituminous Shale and Coal	(A4)	
	Middle Sandstone	(A3)	Light grey to light brown, well bedded, fine to medium-grained sandstone; sand grains well rounded and well sorted; accessory biotite; isolated clay pellets. Petrified wood, often inside elongate, calcareous concretions in a layer of red, Fe-rich or yellowish white clayey sandstone; logs up to 50 cm. , 23 m long. Wood – *Dadoxylon porosum* and *Phyllocladopitys capensis* mainly, also *Abietopitys perforata,* Dadoxylon *rangei, Medullopitys sclerotica*; leaf impressions – *Glossopteris, Cordaites hislopi.*
	Lower Bituminous Shale and Coal	(A2)	
	Lower Sandstone	(A1)	Medium-to coarse-grained, white to cream-coloured, thick bedded, faintly cross bedded channel sandstones. Mainly multistory channel sands up to 30 m thick. Thickness 5 to 30 m.

(i) Lower Sandstone (A1)

The Lower sandstone rests on the Mukorob Member with a scoured contact. The change from the medium- to fine-grained, light brown, thinly cross bedded deltaic sands of the upper Mukorob Member to the medium- to coarse-grained, immature, feldspathic, more massive to thickly cross bedded, cream-coloured channel sands of the lower Auob sandstone is marked. The unit is largely built up of multistory channel sands up to 30 m thick. Thickness of the unit varies from 5 to 30 m but there are places where the unit appears to be missing having pinched out or been removed by pre-Kalahari erosion.

(ii) Lower Bituminous Shale and Coal (A2)

Swamp and marsh deposits of bituminous shale and coaly material are interbedded in places with thin, distal crevasse splay deposits consisting of thin fining-upward cycles of fine-grained sandstone, siltstones and dark, often carbonaceous shales.

(iii) Middle Sandstone (A3)

This Sandstone gradually coarsens upwards. Carbonaceous shales and silts at the base gradually pass upwards into increasingly coarser and thicker upward-fining cycles of intertidal deposits and crevasse splays with wavy and ripple lamination of micaceous sandstone, siltstone and shale. Beach sands are common in places and channel sands are scattered through the sequence but become more abundant towards the top. Widespread bioturbation is indicative of shallow water conditions. Numerous thin coaly and micaceous laminae occur in these sediments indicating the proximity of swampy conditions.

Facies changes over relatively short distances appear to be a characteristic of this Middle Sandstone. Distal crevasse splays passed laterally in to swampy depressions in which coal and carbonaceous shale deposits accumulated. These are commonly overlain by both distal and proximal crevasse splays. Channel switching and erosion of lower lying units appears to have been common as many of the sandstones contain shale and coal fragments.

(iv) Upper Bituminous Shale and Coal (A4)

This marks a second event of widespread swamp, marsh and possibly lagoon deposition with associated coals. Thin, bioturbated, fine-grained, coarsening-upward crevasse splay sandstones and possible beach sandstones are interbedded with the black, bituminous swamp shales and coals. Wavy and ripple laminated sandstone-shale tidal deposits may also be present. The coal in this unit is approximately 50 m above the lower coals. As with the lower shale and coal unit, thickness varies significantly from just a metre or two to 36 m. The unit is not as laterally continuous as the lower shale and coal unit and correlation from well to well is not always straightforward. In places, scour and erosion by the overlying channel sandstones has removed the upper shale and coal unit completely and the Middle and Upper Sandstone merge into one thick unit.

(v) Upper Sandstone (A5)

This horizon consists of stacked, coarse-grained channels sandstones, often with lag deposits, and associated proximal splay deposits of fining-upward cycles of medium- and fine-grained sandstone. A thin black, bituminous shale layer up to 4 m thick occurs in this unit. Preserved thickness has been severely affected by thick Karoo dolerite sills that intrude the Upper Sandstone and by pre-Kalahari erosion which cuts deep into this and lower units in places.

Preserved thickness varies from 0 to 61 m.

(5) Rietmond Member

The Rietmond Member consists of two units, a Lower Rietmond Member consisting of shale and an Upper Rietmond Member consisting mainly of sandstone with some shale layers. The Upper Rietmond rests unconformably on the Lower Rietmond.

(i) Lower Rietmond Member

The Lower Rietmond Member shale appears to rest conformably on the Auob Member sandstones. It crops out east of Mariental on the farm Rietmond 118 and east of Asab on the farms Goamus 70 and Salami 239. It weathers to light and dark grey tones but below the Kalahari unconformity it has weathered to a yellow colour. In borehole cuttings where it is fresh, the colour varies from grey to blue grey, dark grey and almost black. In borehole logs it has often been described as "blue shale". In several places below the Upper Rietmond unconformity, the Lower Rietmond shale is deeply weathered to a yellow colour. However, the erosion that preceded deposition of the Upper Rietmond Member also removed this yellow weathered capping in places so that one also finds the Upper Rietmond sandstones resting directly on grey Lower Rietmond shales.

The Lower Rietmond shale was deposited over the whole basin but was partly or completely removed in many areas by two periods of erosion, one preceding deposition of the Upper Rietmond Member and the other preceding deposition of the Kalahari succession. Where best developed, it is over 100 m thick but because of the above erosion, thickness varies erratically in the areas where it is present.

The Lower Rietmond Member is the impervious cap and the main aquitard to the Auob artesian sandstone. However, it can happen, although very rarely, that a borehole drilled to near the base of the Lower Rietmond shale, but not right through it, becomes artesian due to fractures in the basal part if the shale providing connectivity to the underlying sandstone (e.g. borehole WW 39874).

(ii) Post-Lower Rietmond – Pre-Upper Rietmond Erosion

Prior to deposition of the Upper Rietmond Member, the Lower Rietmond sediments were uplifted, exposed and eroded. In the northern and southwestern parts of the basin, this erosion removed very little of the Lower Rietmond shales and thicknesses are generally in excess of 50 m (Fig. 3.6-3). In places in these areas, this period of weathering and erosion caused strong alteration of the top part of the shale to a yellow colour. Elsewhere in the basin, erosion removed most or all of the shale. This erosion left a highly dissected landscape so that the remaining Lower Rietmond shale, where present, is highly variable in thickness, even between closely spaced boreholes. Where the erosion removed the Lower Rietmond shale completely, the Upper Rietmond sandstones rest directly on the Auob Member sandstones.

(iii) Upper Rietmond Member

This rests unconformably on the underlying rocks. It crops out on the farms Neu Lore 97, Helpmekaar 588 and Doornboompan 542 west of Leonardville, in the Nossob River valley at Leonardville and north and south of the town and in road cuttings at Stampriet. It is not know to crop out anywhere else. Although reaching 180 m in thickness, the thickness of the Upper Rietmond Member is highly variable due to pre-Kalahari erosion which cut deeply into the Karoo succession, and at its deepest, cut right through both Rietmond and Auob Members into the underlying Mukorob shales.

The Upper Reitmond Member is highly variable in character. Athough consisting mainly of sandstones, it contains layers of interbedded shale in places which vary in number from one to six (e.g. six in WW 10869, Elbow 392, 2318CB). It is rare for shale to exceed sandstone in amount but in a few places shale makes up 70% of the Upper Rietmond succession (e.g. WW 820, Schurfpenz 120, 2418 AB; WW 696, Helgoland 117, 2418 CB).

Characteristically, the Upper Rietmond sandstones have a reddish brown colour which is relatively light at higher stratigraphic levels but usually deepens in intensity with increasing depth. However, white, brown, orange, purple, red, pink, green, grey and yellow sandstone layers are also commonly recorded in the borehole logs. Where exposed, bedding tends to be thin to very thin. Grain size varies continuously, often on a small scale, and coarse- to medium-grained sandstones often have a thin cover of very fine-grained, highly micaceous sandstone or siltstone. Many of the sandstone layers are highly micaceous whereas others are less micaceous. Porosity of the sandstones is highly variable and often porous layers are bounded by highly micaceous layers with low porosity.

The interbedded shales are also highly variable in colour and although often grey when fresh, red, brown, reddish brown, purple, pink, yellow, white and black coloured shales have been recorded in borehole logs. Locally thin coal lenses are interbedded with the dark grey to black shale layers.

Rather than consisting of continuous layers, the succession appears to consist of stacked lenses of shale and sandstone of differing grain size and mica content.

In the absence of the Lower Rietmond Member shale, it can be difficult distinguishing the sandstones and grey shales of the Upper Rietmond Member from the grey shales and sandstones of the Auob Member. However, characteristic for the Upper Rietmond sandstones are their reddish brown colour and the high mica content of many of the layers.

The water table in borholes drilled only into the Upper Rietmond Member is highly variable and deeper than the Auob water table in nearby boreholes that go all the way down into the Auob Member.

There appears to be minimal lateral and vertical permeability within the Upper Rietmond Member due to the lithological variability, the lensoid nature of individual layers, the high mica content and the highly variable water table levels. The Upper Rietmond Member, therefore, despite it consisting mainly of sandstone, appears to be an effective aquitard where it lies directly on the Auob sandstones. Any large-scale connectivity between the Rietmond and Auob sandstones would be reflected in the Rietmond and Auob having the same water table elevation over large areas and this is not the case. In a few boreholes that were drilled to near the base of the Upper Rietmond Member where it rests directly on the Auob Member, the Rietmond water table is the same as that in nearby boreholes than went into the Auob Member. This indicates a fracture connectivity between the basal Rietmond sandstones and Auob Member in a few isolated cases.

(6) Whitehill Member

The White Hill Member is know to occur with certainty in only one place in the area of investigation on the farms Dorndaberas 16 and Gross Daberas 17 east of Asab. The 1:1 million scale Geological Map of Namibia shows the White Hill Member here to occur in a succession of shale overlying the Auob sandstones. Part of the Lower Rietmond Member must therefore be the lateral equivalent of the White Hill Member but nothing in the rock chips or the geophysical logs of the JICA boreholes indicates exactly which part of the Lower Rietmond Member would be equivalent to the White Hill Member.

(7) Kalkrand Basalt

The distribution of the Kalkrand Basalt is shown in Fig. 2.2-1. Dated at 180 million years, the basalts are Triassic in age. There is thus a large time gap between the Rietmond Member and Kalkrand Basalts. The basalts rest unconformably on the

Rietmond Member on the farm Rietmond 116 east of Mariental and then transgress westwards across each of the underlying formations

The Kalkrand succession consists of stacked basalt flows with or without fragmented bases and tops. Scattered over much of the exposed part of the basalt succession are several thin interbeds of limited lateral extent of well bedded pan deposits consisting of basalt-derived sandstones and gritstones and white fresh-water limestones. The sandstones also contain well rounded quartz grains of aeolian origin. Casts of gypsum roseates are common.

The basalt succession is up to 370 m thick. Since many of the water boreholes struck water within the basalt succession, some of them were clearly in the interbedded pan deposits based on the descriptions of the cuttings and very few were drilled through to the underlying rocks.

(8) Karoo Dolerite Sills

Karoo Dolerite Sills intrude the top of the Karoo Sequence and in places cut out the whole of the Rietmond Member and most of the Auob Member. The dolerite may consist of more than one intrusion since Karoo sediments are often interbedded with dolerite. South of 26° S, many of the faults in the Karoo Sequence have been intruded by dolerite dykes. Many of these dykes must be feeders to the dolerite sills. Faults and feeder dykes must be expected below the Kalahari cover in the main Stampriet Basin. Only the aero magnetic data is likely to show the location of such faults and dykes.

(9) Kalahari Beds

The Kalahari Beds form a continental deposit made up of unsorted fluviatile deposits, aeolian sands and local pan accumulations all variously cemented by calcrete and minor silcrete. The base of the Kalahari Beds is made up of poorly sorted, small-pebble, partly imbricated conglomeratic fan-deposits thoroughly cemented by calcrete. Where the top of these calcretes is exposed over considerable areas (e.g. on top of the Weissrand escarpment south of Mariental), a karst topography has developed. The age of this karsting is uncertain but since water strikes are often made in the calcretes at the base of the Kalahari it is likely that this karsting is extensive underneath the younger Kalahari sediments. The overlying Kalahari deposits are largely poorly sorted sands of fluvial origin and better sorted aeolian sands. Gritty zones can be either aeolian lag deposits or fluvial in origin. Calcrete cement varies in abundance in these sands. Silcretes are reported from some of the water boreholes but tend to be relatively rare in the southern Kalahari.

2.2.3 Geological Structure

Geological structures (faults) are shown in the Geological Map (Fig. 2.2-1). Dykes are also included into these categories.

A number of large-scale faults are recognized in the western part of the study area, showing mainly N-S in direction. NW-SE and N-S trending lineaments are developed in the southwestern part of the study area, where the Kalahari calcrete crops out. In other area, geological structures are recognized scarcely.

Some lineaments are almost parallel to main drainages such as the Auob, Olifants and Nossob Rivers and seem to control flow direction.

Many NE-SW faults in the northeastern part of the study area (Aminuis area) are covered the Kalahari Beds.

The identified faults are post-Karoo in age and have been identified through the borehole analysis. Some but not all, can be identified on the aeromagnetic maps of the basin. Most do not have a post-Kalahari expression. However, some of the NS faults in the western part of the basin do cut the basal Kalahari calcrete and are visible on aerial photographs.

2.3 Meteorology and Hydrology

2.3.1 Meteorology

Due to the geographical location, the climate of Namibia is classified as subtropical and, most of the Namibian territory falls under semi-arid to arid zone. The annual rainfall varies from 50mm to 700mm. The evaporation is much higher than the rainfall. There are two distinct seasons; the rainy season starts in October and continue until end of April. Most of the rainfall occurs between end of December and middle of April. The average temperature is 25 °C, the highest may rise up to 40 °C in the dry season and the lowest could be below freezing point over most of the country during the winter.

°C In the study area, the highest annual rainfall was 774 mm (1977-78) in Owingi located in the upstream of the Black Nossob River. Rainfall is high in the north and gradually decreases towards the south. The isohyetals of annual average rainfall are presented in Fig.2.3-1. The study area approximately falls within the area of annual average rainfall 150 – 300 mm.

Most of the study area has a maximum average temperature of 30 °C and minimum average temperature of 2 °C.

Annual potential evaporation is between 3,200 mm and 3,800 mm (Refer to Fig.2.3-2). Using the data measured at Hardap dam site (70% of actual value), daily evaporation rate for the study area is between 9.7 mm/day (December) and 4.2 mm/day (July).

The longest and shortest sunshine hours measured at Mariental are the longest, 11.4 hours/day in December and 9.3 hours/day in March respectively.

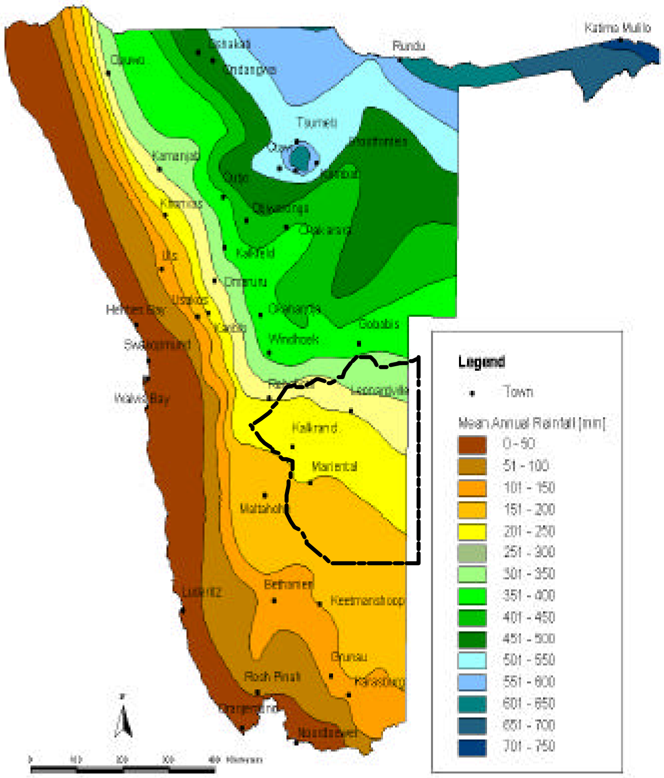


Fig.2.3-1 Mean Annual Rainfall in Namibia

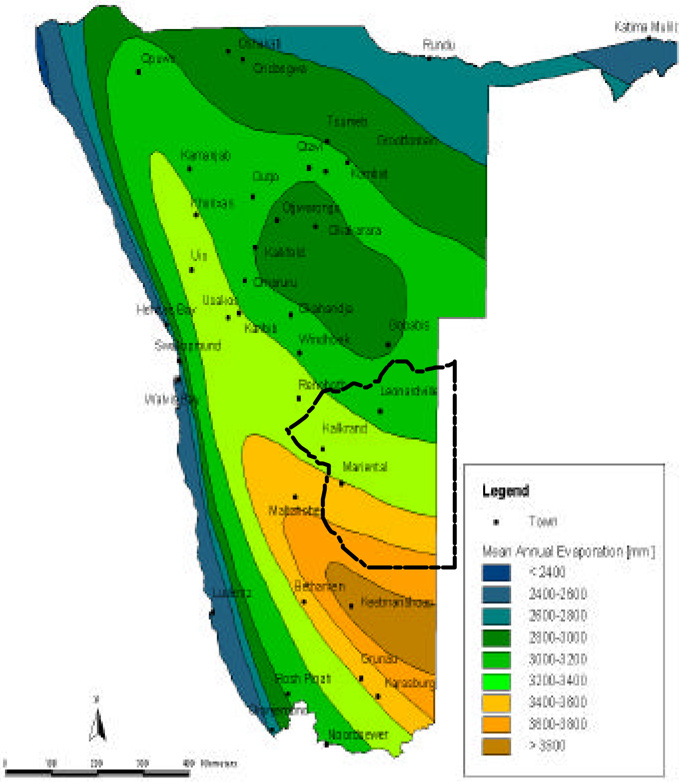


Fig.2.3- 2 Mean Annual Evaporation in Namibia

2.3.2 Hydrology

Except the international rivers such as the Kunene, the Okavango and the Zambezi in the northern border, and the Orange in the southern border, Namibia does not have any perennial river within its territory. The rivers within the Namibian territory are intermittent, however, during the rainy season all become active according to the amount of rainfall in the catchments.

The study area is situated within the catchments of the Nossob-Auob Rivers. The rivers are ephemeral and only flow for short periods during the rainy season. Both of the rivers originate near Windhoek.

The upper part of the Nossob River has two tributaries namely, the Black Nossob and the White Nossob. They merge at a point approximately 20 km north of Leonardville in Gobabis District of the Omaheke Region. Another tributary, the Klein Nossob, joins the Nossob at a point about 20 to 30 km before the Nossob crosses the Namibian border with Botswana. The catchment area of the Nossob within Namibia is 50,050 km^2.

The Auob River originates from northwest of Stampriet at an elevation of about 1,200 mASL. The Olifants River originates in the northeast of Windhoek and meets the Auob at Tweerivier in the southeastern corner of the Mariental District. The Auob Catchment Area including the Olifants River within Namibia is 74,081 km^2.

Five runoff stations are available in the study area. The observed runoff data was reviewed and an annual average was calculated. The results are tabulated in Table 2.3-1.

Table 2.3-1 Annual Runoff Calculated in the Study Area

Name of Station	Name of River	Catchment Area (km^2)	Annual Average Runoff (m^3)	Runoff Depth/ Unit Runoff (mm)
Henopsrus (10 years data)	Black Nossob	4,530	2,459,000	0.54
Mentz (15 years data)	Black Nossob	8,160	1,689,000	0.21
Amasib (11 years data)	White Nossob	9,250	2,165,000	0.23
Stampriet (11 years data)	Auob	19,200	4,646,000	0.24
Gochas (15 years data)	Auob	19,600	9,249,000	0.47

According to the "Unit Runoff Map of Namibia" by DWA, the value of the unit runoff is very small. This is due to the fact that the observed runoff value is very small.

Using the proper data set of rainfall and runoff, runoff coefficient was calculated on the Nossob and the Auob Rivers. Characteristics and calculated runoff coefficient are shown in Table 2.3-2, 2.3-3, respectively.

Table 2.3-2 Characteristics of Gauging Stations

	Black Nossob	Auob
Runoff gauging station	Henopsrus	Stampriet
Catchment area	4,530 km^2	19,200 km^2
Type of section	weir	open section
Rainfall stations used for calculation	Owingi and Otjisororindi	Hofmeyr, Kous, Krumhuk and Stampriet

For the calculation of runoff coefficient, only two hydrological years with a sufficient rainfall and runoff sets have been selected: the 1985-86 and 1988-89 years.

Table 2.3-3 Runoff Coefficients Calculated in the Study Area

River	Year	Month/ Date	Total Observed Runoff (x $10^3 m^3$)	Average Rainfall (mm)	Runoff Coefficient
Black Nossob	1985-86	3 - 9 Feb	122.6	36.8	0.00073
Black Nossob	1988-89	28 Jan - 14 Feb	178.4	177.2	0.00022
Auob	1983-84	2 - 12 Dec	141.8	20.0	0.0004
Auob	1983-84	25 Dec - 4 Jan	43,950.0	47.0	0.0487
Auob	1983-84	20 Mar - 21 Apr	4,021.0	65.0	0.0032
Auob	1990-91	1 - 11 Dec	553.7	36.0	0.0008
Auob	1990-91	15 Mar **	944.8	49.0	0.0010

Runoff coefficient is given by following formula:
Runoff Coefficient = (Total observe runoff)/(Runoff without loss)
= (Total observe runoff)/(Average rainfall x Catchment area)

In the hydrological year, 1999-2000, the study area received an intensive rainfall. This rainfall caused huge amount of runoff to the Auob and the Nossob Rivers, and they reached the border with South Africa. The monthly rainfall data of some selected stations in and around the study area are presented below.

Table 2.3-4 Monthly Rainfall observed in the year 2000

Station	Monthly Rainfall (mm)		Total (mm)	Annual Average (mm)
	February	March		
Stampriet	156.0	58.0	214.0	205
Leonardville	173.4	61.0	234.4	255
Gobabis	130.6	31.0	161.6	365
Aranos	224.5	41.0	265.5	230
Gochas	198.6	67.1	265.7	195
Mariental	349.6	106.3	445.9	198
Kalkrand	105.0	90.8	195.8	210
Otjisorindi	203.0	150.0	353.0	410
Windhoek	202.7	154.2	356.9	355

Note: Annual average has been estimated with Fig.2.3-1.

The intensity of rainfall (consecutive 3 days rainfall) during this rainy season at eight selected stations surrounding the study area is presented below.

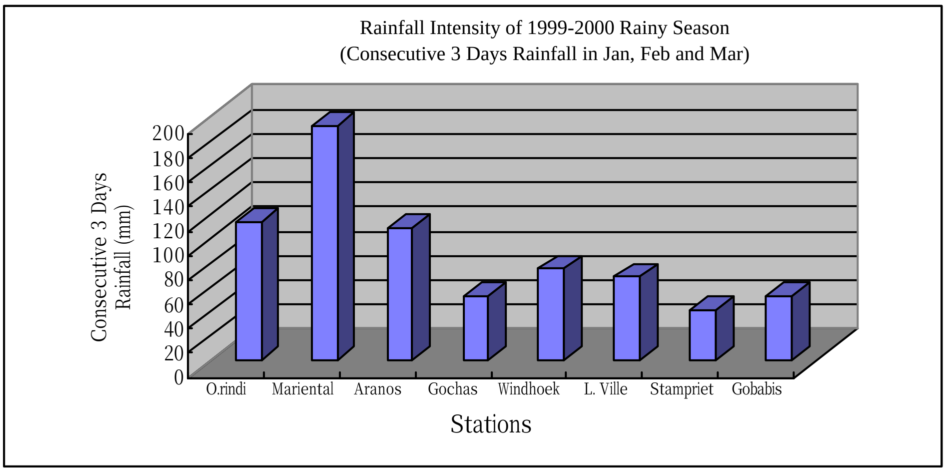


Fig. 2.3-3 Rainfall Intensity in 1999/2000 Rainy Season

At Gochas, there was no any runoff during October-November. In December, Gochas had about 18,880 m^3 of runoff, whereas Stampriet had 430,300 m^3.

The probable maximum annual rainfall was evaluated for few selected stations as shown in Table 2.3-5

Total rainfall at Stampriet in 1999/2000 is recorded 358mm, which is near to 1/50 in Table 2.3-5. A probability of annual rainfall in the study area could not be calculated accurately because of luck of rainfall data. In this study, the probability is regarded as 1/50 considering monthly rainfall at other locations in Feb. and Mar. 2000, news and so on.

Table 2.3-5 Probable Maximum Annual Rainfall (unit: mm)

Return Period (Year)	**Station Name**				
	Mariental	**Stampriet**	**Leonardville**	**Aranos**	**Gochas**
2	172	142	224	192	166
5	249	218	315	302	238
10	295	272	379	371	283
20	337	325	443	435	326
50	389	396	430	517	381
100	426	452	598	577	421

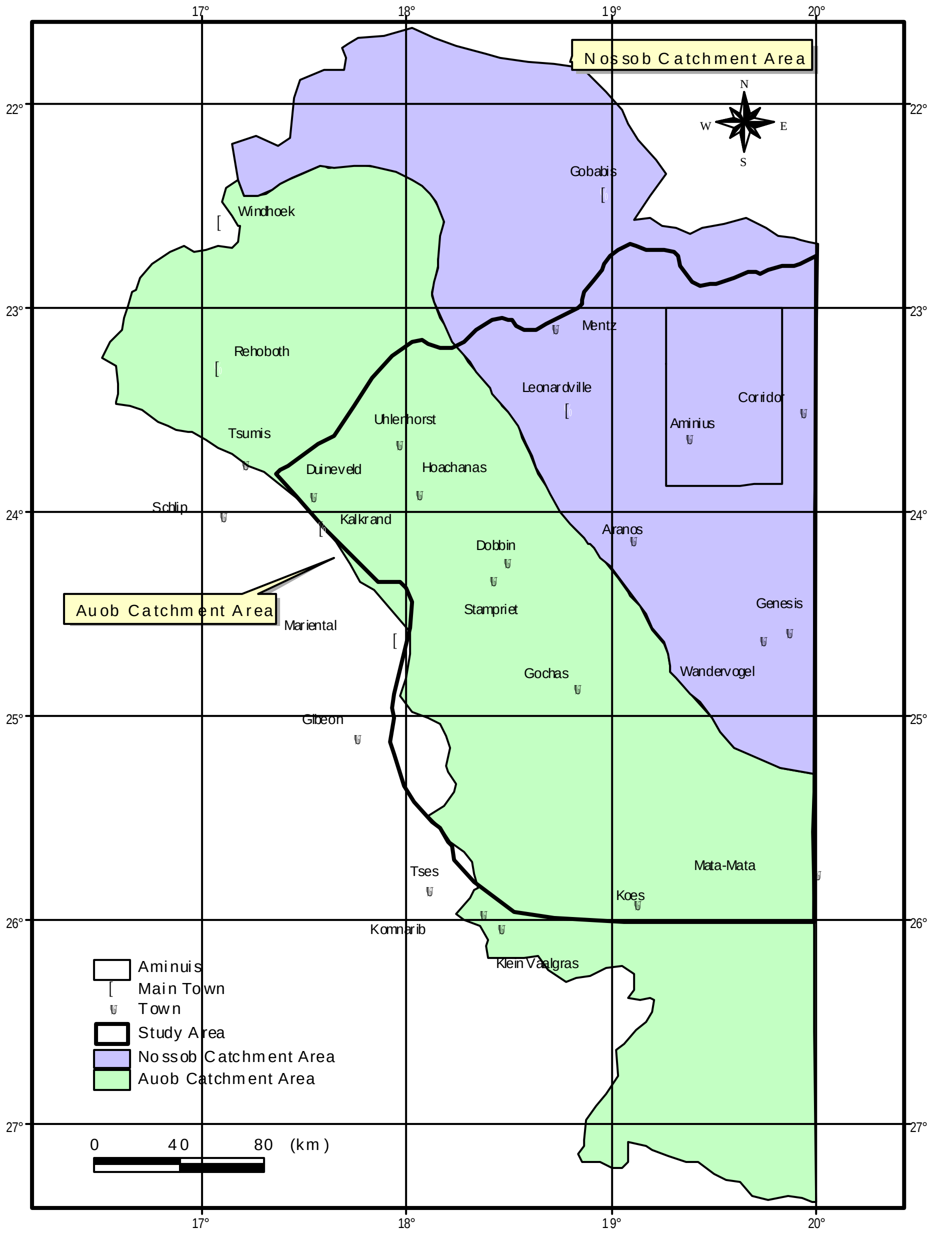


Fig.2.3-4 Catchment Area

2.4 Socio-economic Aspects

2.4.1 Socio-economy

1) Administration

The study Area is administratively composed of four regions, five districts and five villages and it includes communal lands in the three districts:

Regions	Districts	Villages	Communal Land
Khomas	Windhoek	-	-
Hardap	Mariental, Rehoboth	Aranos, Gochas, Stampriet, Kalkrand	Namaland & Hoachanas
Omaheke	Gobabis	Leonardville	Aminuis & Corridor
Karas	Keetmanshoop	-	Namaland

Each village has a village council to work for various social services. Mariental district office is located at Mariental municipality.

2) Population

The population in the Study Area is divided into three groups; village center, commercial farms and communal land. It will be estimated based on the result of the Hydro-census commenced in November 1999 by sub-contract basis. On the 1991 census basis, population in the Study Area was estimated at 28,815 and that of present taking into account annual growth rates since1991 would be 35,096.

Districts	Village Centers	Commercial Farms	Communal Land	Total
Mariental	3,865	7,944	1,906	13,715
Gobabis	797	3,451	7,830	12,078
Rehoboth	-	600	-	600
Windhoek	-	880	-	880
Keetmanshoop	-	474	438	912
Total	4,662	13,349	10,174	28,815

Note. Figures on 1991 census basis.

3) Ethnic Groups

Ethnic groups in the Study Area are composed of Tsuwana, Herero, Nama, San and Whites. In the communal land of Aminuis and Corridor, Tswana, Herero San groups depend mainly on raising livestock. Nama groups in the Hoachanas and Namaland live also on raising livestock. Most of "Whites" who own commercial farms are predominantly Afrikaaner and Germans.

4) Culture and Custom

Ethnic groups living in the Study Area have their own customs and way of life styles. "Whites" maintain their European lifestyle living on commercialised livestock raising or agricultural production with irrigation systems. Contrary native people like Herero, Nama, and San etc. live on subsistence livestock raising. The husband is the decision maker in their families as shown below;

	Money to Spend	Animals to be Sold	Food to be Bought	Children To be Sent To School	Cloths To be Bought
Head	72%	63%	50%	54%	49%
Spouse	3%	4%	15%	6%	9%
Both	17%	21%	26%	28%	33%
Others	8%	12%	9%	12%	9%

Source. Socio-economic survey eastern communal areas 1994

5) Livelihood of the People

"Whites" who manage commercial farms enjoy their lives with higher living standards in the Study Area compared to farm workers and people in the communal areas. On an average six workers are employed in a commercial farm. Farm workers live on the salary of N$200 to N$400 per month per capita and with some supplementary commodities and housing spaces. Owners of commercial farms live by selling livestock or agricultural crops on commercial basis. Most of agricultural products are marketed through cooperatives. Commercial farming is mechanized with tractors, irrigation systems, cold storage etc. While people in the communal land are living on subsistence livestock raising, pensions and wages. They sometimes sell livestock at auctions being held regularly. Catholic settlement areas also exist in the Study Area in which clinic, school, workshop, processing plant etc. are provided. They live on raising livestock and growing crops with irrigation systems. There are several farms which are distributed to landless families under the resettlement program of the government.

6) Income and Expenditures

Socio-Economic Survey in the Eastern Communal Areas 1994, SSD reports that 42% of households have access to between N$ 109 and N$ 250 per month and 38% of survey households spend more than N$250 whereas 20% of all households spend less than N$ 109 per month.

"The Value of Water-A Study of the Stampriet Aquifer in Namibia" written by Ms. Anna Lindgren, has tried to analyse the household income of the commercial farms in the Study Area, which is the only data available for the commercial farms at this moment. In this report, monthly income is estimated at about N$ 48,000 per commercial farm. This implies that there exists considerable disparity between commercial farms and communal farms in the Study Area.

7) Trend of Livestock and Agriculture

Livestock in the Study Area are composed of sheep, goats and cattle, of which sheep accounts for 65% while 15% for cattle and 14% for goats. Dependency on sheep farming is considered due to low rainfall and grazing capacity of the Study Area. Annual rainfall from 1949/50 to 1996/97 is averaged at 185 mm and since 1980s there were droughts continuously excluding 1990/91(385mm/year).

Number of Livestock

Cattle	120,941 head
Sheep	525,979 head
Goats	110,245 head
Horses	5,123 head
Pigs	713 head
Donkey	2,823 head
Ostriches	18,842 birds
Poultry	19,668 birds

Note. Estimated on 1998 livestock census

As a whole, the number of livestock in the Study Area shows a declining tendency over the past 10 years, particularly with regards to sheep and goats.

Natural grazing is prevailingly done on both commercial farms and communal lands for cattle and sheep/goats. Carrying capacity in the Study Area is considerably varied from 3 ha/SSU to 25 ha/SSU depending on wild grass production which is affected by rainfall. Grazing conditions from January to March is very good with rainfall and grass, but grass starts yellowing even in March and drying in May. From June to July livestock loses weight due to low temperature. In commercial farms supplementary feeding is usually done by feeding wheat, hay, Lucerne, etc.

Lucerne, Grapes, Water Melons, Sweet Melon and other vegetables are planted in the Study Area. However, those crops cannot be grown without irrigation because of the arid climate. Since irrigation needs higher investment only commercial farmers, therefore, can invest in irrigation systems although small-scale irrigation is done even in the Catholic settlements and other settlements under the Ministry of Lands, Resettlement and Rehabilitation. Irrigable and irrigated areas in the commercial farms are averaged at 10.7 ha and 7.2 ha per farm, respectively.

8) Industries and Its Products

Since economic activities in the Study Area are concentrated on livestock and agricultural production industrial products are also related to those. Sheep, goats and cattle are the major products in the Area. Sheep is processed into carcasses at the slaughterhouse in Mariental. Mariental district is known for Karakul and Dorper sheep as well as Ostriches. Karakul pelts are processed on small scale at the commercial farms. The first commercial Ostrich farm originated in Mariental.

Vegetables, sweet melons/watermelons, Lucerne and grapes are also main agricultural products, which are mainly grown along the Auob River with irrigation systems. Most crops are marketed to Windhoek as well as for export purposes. Lucerne (alfalfa) hay is processed into pellets by the plant of Hardap cooperative. Mariental is famous for producing good quality raisins for exporting.

9) Tourism

Tourism is also another industry in the Study Area. There are eight hotels and 11 lodges which have 10 to 15 rooms on average.

2.4.2 Infrastructure and Public Services

1) Water Supply

Local authorities are responsible for village water supply on contract basis with Nam Water. While DRWS is responsible for rural water supply for small communities. In the commercial farming areas it is the responsibility of the individual farmers themselves. In communal areas, a water-point is created for domestic consumption by DWA. However, currently there are no formal agreements on water supply between rural communities and DWA. Some farms in communal areas have windmills constructed by the government and beneficiaries pay a water fee of N$ 5 per household per month.

2) Electricity

Electricity network links most village centers in the Study Area but the unpopulated areas such as communal land are not reasonably developed for electrification.

3) Roads and Railway

The Study Area is traversed by the main trunk road traversed at the western part which provides direct link between Windhoek and South Africa. Well–maintained gravel roads as well as paved roads also link between the major village centers.

Main railway along main trunk also traverses in the Study Area and links between

Windhoek and South Africa.

4) Telecommunication

Telecommunication in the village centers is well developed in the Study Area, however poor in the communal lands.

5) Education

Primary and secondary schools are distributed in the Study Area. Currently Teacher/Pupil ratio is 1:21 to 1:24. One agricultural college is in Hardap region.

6) Solid Waste Treatment

Village councils manage dumping sites on the outskirts of the villages in which solid wastes are burned or buried into the ground.

7) Waste Water Treatment

Village councils are responsible for wastewater treatment in village centers by collecting wastewater regularly by tank lorries from household's conservancy tanks and dumping it into oxidation ponds which is placed at the outskirts of the villages.

8) Health

There are five hospitals in Hardap region, four in Karas, one in Omaheke, respectively. Ratio of bed/1,000 population is 5.5 in Hardap, 5 in Karas, 3.5 in Omaheke.

2.4.3 Employment Condition of Farm Workers

Farm workers on commercial farms usually live on the farm. They work caring for livestock, crops and repairing agricultural machinery and cars etc. Their salary ranges from N$ 200 to N$400 per month and in addition to the salary they are offered meal, tobacco, sugar and sometime meats etc. In the harvesting season, commercial farms planting vegetables and grapes hire many labourers from outside. The Labour Act (Namibian Labour Code) came into operation in 1992, which regulates the basic condition of employment.

2.4.4 Disposition of Waste Water and Solid Waste

Conservancy tanks or septic tanks combined with French drains are usually used in households in the village centers. Oxidation ponds are managed by the Local

Authorities to dump sewerage water collected from households. On the individual commercial farms, septic tanks combined with French drains are usually used, by which sewerage water is disposed by seepage into the ground. In the communal land there are considerable households and populations that use the bush as toilets. Solid wastes are treated at dumping sites outside the villages and burned or buried into the soil. Livestock manure is not treated because livestock usually grazes in broad areas.

2.4.5 Commodity Prices

Statistics on consumer price index is not available for the Study Area. However it can be said through survey in the Area that there is not a big difference in commodity prices between Windhoek and the Area.

CHAPTER 3 HYDROGEOLOGY

3.1 General

Groundwater aquifers in the Southeast Kalahari Artesian Basin have been said to appear in the following geological units;

- The Kalahari Beds
- The Auob Member
- The Nossob Member

These three aquifers are generally separated by impermeable shale, however, the Kalahari Beds and the Auob Member are interconnected in some places due to the lack of the impermeable shale. Although basalt and dolerite also yield groundwater mostly in the western side of the study area such as Kalkrand, most of attentions were, however, paid to the sedimentary aquifers mentioned above.

Through the study each aquifer was given new definition and evaluated in this report.

3.2 Existing Data Sources

A number of studies were carried out in the study area prior to this study. Among them, following data were mostly used for interpretation of hydrogeology in the study area:

- Core borehole logs for exploration of mineral resources: Agip Carbone (1984), CDM Minerals (1982,83), etc.
- CSIR Water Quality Data
- Aeromagnetic data obtained by Geological Survey of Namibia
- Database of Farms and Boreholes constructed by DWA

In addition to these, an IAEA project, "Framework for IAEA Regional Model Project Raf/8/029: Applying Environmental Isotopes to a Hydrogeological Model of the South East Kalahari Artesian Basin, Namibia", is currently going on in the study area aiming quantitative analysis of groundwater recharge. In this study, a number of test boreholes were drilled in many places in the Study area where groundwater recharge was taken place. Groundwater samples were taken from those boreholes for water quality analyses as well as isotope analyses. Such analysed data were supplied to the Study.

DWA has a Rural Water Supply scheme in the study area. New borehole logs obtained by this scheme were also supplied to the Study.

3.3 Supplementary Surveys and Analyses

Although a lot of studies and surveys were carried out in the study area, the Study is the first comprehensive study from the hydrogeological point of view. A couple of survey and analyses were included into the Study to supplement the hydrogeological information. They are Hydrocensus, Geophysical Survey, Test Borehole Drilling, Borehole Elevation Survey, and Water Quality and Isotope Analyses.

In this Clause, only survey and analyses results are presented. These results are interpreted and discussed in subsequent Clauses.

3.3.1 Hydrocensus

It is said that there are an estimated 1500 farms with a total of 5,000 to 6,000 boreholes in the study area. A pioneering hydrocensus was conducted in a limited area by DWA from 1986 to 1988. No further survey was conducted in the study area. In order to grasp precise information on farms and boreholes existing in the study area, the Hydrocensus was carried out in the Study covering the entire study area.

Two kinds of questionnaire sheets were prepared: one was for borehole information and another for farm information (For sheets, refer to Data Book).

The survey was implemented visiting all the farms and interviewing the farmers. Such survey results were presented in the spreadsheets (For sheets, refer to Data Book).

The Hydrocensus revealed that there were 1,269 farms in the study area and 1,167 farmers possessed these. However, most of communal farms like Aminuis and the Corridor Farms were not listed. A total of 6,284 boreholes including spring and wells were listed. Itemized table for boreholes is shown below.

Table 3.3-1 Itemized Borehole Number and Status in the Study Area

Item	Total	Use	Not use	Destroyed	Unknown
Borehole	6,012	4,735	889	370	18
Well	99	46	40	13	0
Spring	169	137	24	7	1
Water point	1	0	1	0	0
Oil exploratory well	1	0	1	0	0
Undifferentiated	2	1		1	0
Total	6,284	4,919	955	391	19

4,915 boreholes including springs out of 6,284 boreholes are currently in use. Their water uses are for Domestic, Stock Watering and Irrigation. Data obtained by this Hydrocensus were used in hydrogeological analyses.

3.3.2 Geophysical Survey

A geophysical survey was executed applying the TDEM method to define the geoelectrical structure of the Southeast Kalahari Artesian Basin and relate to this structure to lithology and geological structures. In addition to this, an existing aeromagnetic data set was interpreted in order to identify the geological structures, and the distribution of basalts and dolerites.

1) The TDEM Survey

The TDEM soundings were made at a total of 200 points along the eight survey lines as shown in Fig. 3.3-1. Details of the TDEM survey are presented in Chapter 5 in the Supporting Report.

Three first order effects were interpreted as the vertical resistivity features.

(1) Surficial Zone (R3): a overburden layer with high resistivity more than 100 Ohm-m.

(2) Surficial Zone (C1): a saturated zone by groundwater

(3) Basement Zones (R5): the Damaran Basement Rocks.

The second order resistivity effects were also interpreted as summarized in Table 3.3-2.

Table 3.3-2 Interpretation Results of the TDEM Survey

	Description	Estimated Lithology
Porous Zone (R1)	A low resistivity area occurred in the northern, western and central part of the study area, and underlain by the Basement Rocks (R5).	Rietmond Member Auob Member Mukorob Member Nossob Member Dwyka Member
Basalt/Dolerite Zone (C3)	A high resistivity, which shows low porosity, occurred in mainly the western part of the study area.	Kalkrand Basalt Karoo Dolerite
Contact or Barrier Zone (R4)	A higher resistivity zone existing between C3 and C2.	-
Saline Zone (C2)	A low resistivity zone, corresponds to the so-called "Salt Block" distributed in the south from Gochas.	-

In the Contact or Barrier Zone (R4), following geological features appear.

(1) The Auob Member becomes much thinner. This may be due to erosion of the Karahari into the Auob Member or due to sedimentological reasons.

(2) The Rietmond Member that usually overlies the Auob Member is in the main missing.

(3) There appears to be more structural deformation in the area. At least one fault can be postulated as well possible folding.

A typical resistivity profile is shown in Fig. 3.3-2.

2) Interpretation of Existing Aeromagnetic Survey Data

A set of existing aeromagnetic survey data available at GSN was interpreted. As shown in Fig. 3.3-3, the distribution of basalts and dolerites were clearly interpreted and geological structures such as faults including structures in the deep were also detected.

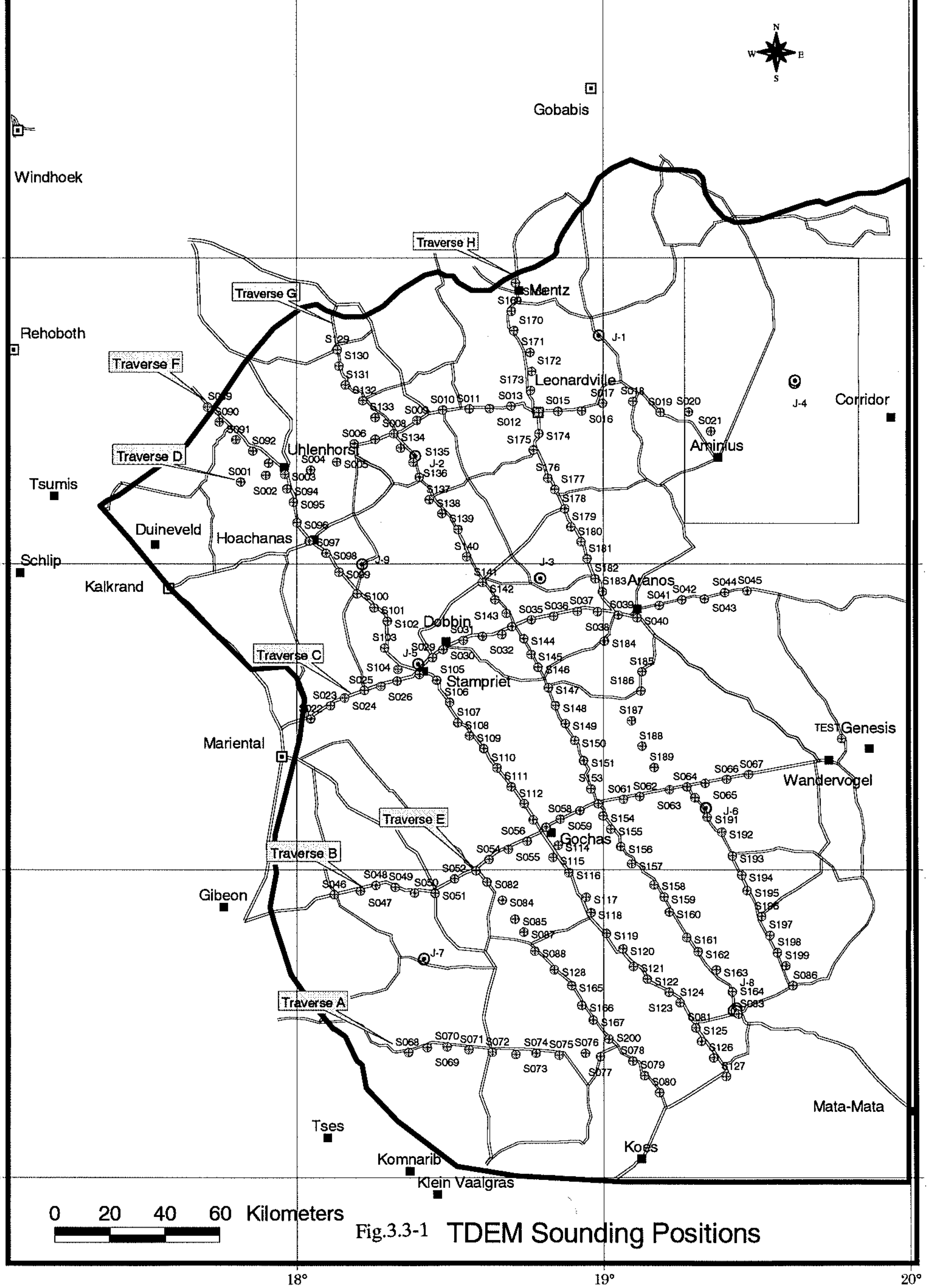
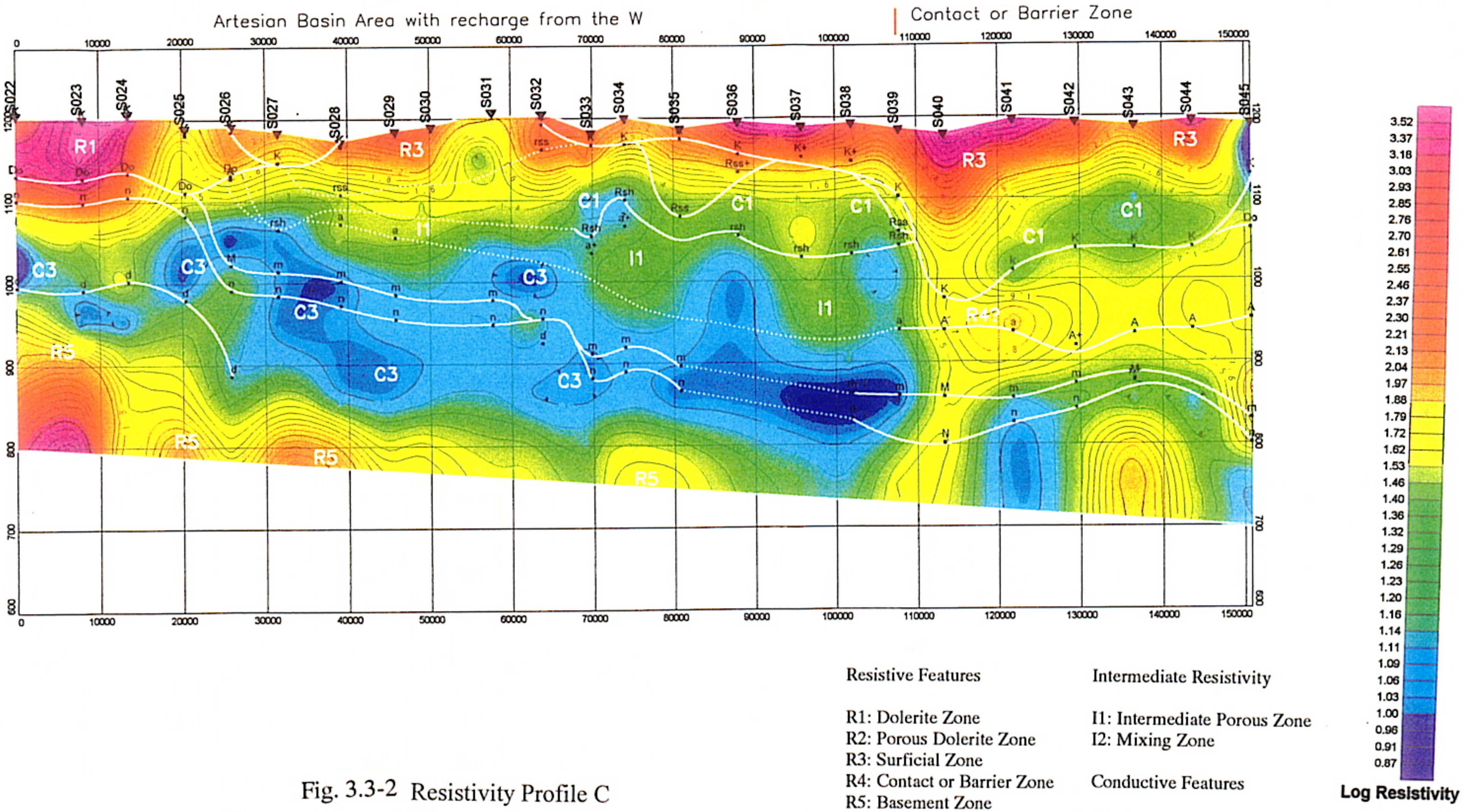


Fig.3.3-1 TDEM Sounding Positions



Resistive Features

R1: Dolerite Zone
R2: Porous Dolerite Zone
R3: Surficial Zone
R4: Contact or Barrier Zone
R5: Basement Zone

Intermediate Resistivity

I1: Intermediate Porous Zone
I2: Mixing Zone

Conductive Features

C1: Surficial Zone
C2: Saline Zone
C3: Porous Zone

Fig. 3.3-2 Resistivity Profile C

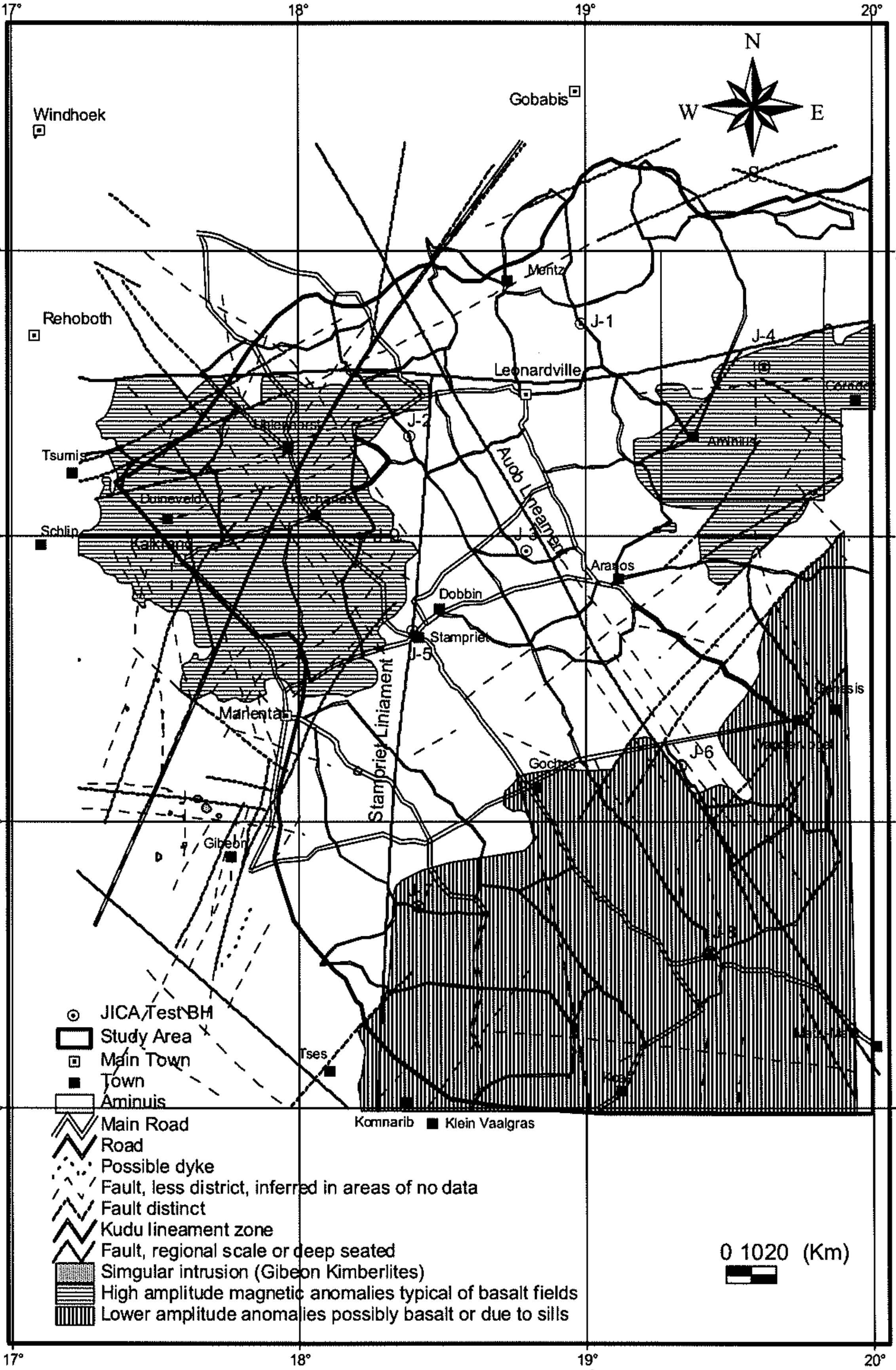


Fig. 3.3-3 Aeromagnetic Interpretation Map

3.3.3 Test Borehole Drilling

1) Purpose of Test Borehole Drilling

There are number of existing surveys results and borehole database. However, hydrogeological information is not so much accumulated because existing surveys have not paid much attention from the hydrogeological point of view. Although more than 6,000 boreholes were drilled in the Study, purpose of such boreholes is to abstract groundwater. Most of them have no proper casing in the boreholes. Even, it has, casing was corroded in many cases. It causes leaking of groundwater between the aquifers and groundwater is mixed in the boreholes. It suggests that there are some errors in the water level data and water analyses data.

Considering these circumstances, a test borehole drilling programme was planned in order to get precise hydrogeological information of aquifers locating 19 boreholes at nine sites. The programme includes borehole logging, pumping test, and collection of water samples from different aquifers for water quality and isotope analyses. An automatic water level recorder was installed in each borehole after the completion of borehole. In addition, eight automatic water level recorders were installed in the existing boreholes to supplement the groundwater monitoring.

2) Outline of the Programme

Location of test boreholes and existing boreholes installed with water level recorders are shown in Fig. 3.3-4. Each borehole was planned to target exactly one aquifer. If plural aquifers were appeared in the borehole, non-targeted aquifer(s) was sealed to avoid leaking or mixing of groundwater as shown in Fig. 3.3-5. Therefore, two or three boreholes were allocated in one site if it is necessary.

Contents of the Programme are summarized in Table 3.3-3. Details of the contents and specification of the programme is presented in Chapter 6 of Supporting Report.

Table 3.3-3 Contents of the Test Drilling Programme

Item	Description	
Test borehole drilling	19 boreholes at 9 sites	5 boreholes for the Kalahari 7 boreholes for the Auob 7 boreholes for the Nossob
Borehole logging	Resistivity, SP, T, Natural Gamma, Calliper and Neutron	
Pumping test	Step draw down test Constant discharge test Time recovery test	Basically 5 steps as round steps. Basically 72 hours. Basically a minimum of 24 hours.
Groundwater sampling	For water quality and isotope analyses	During and/or after pumping test. During drilling operation, if possible

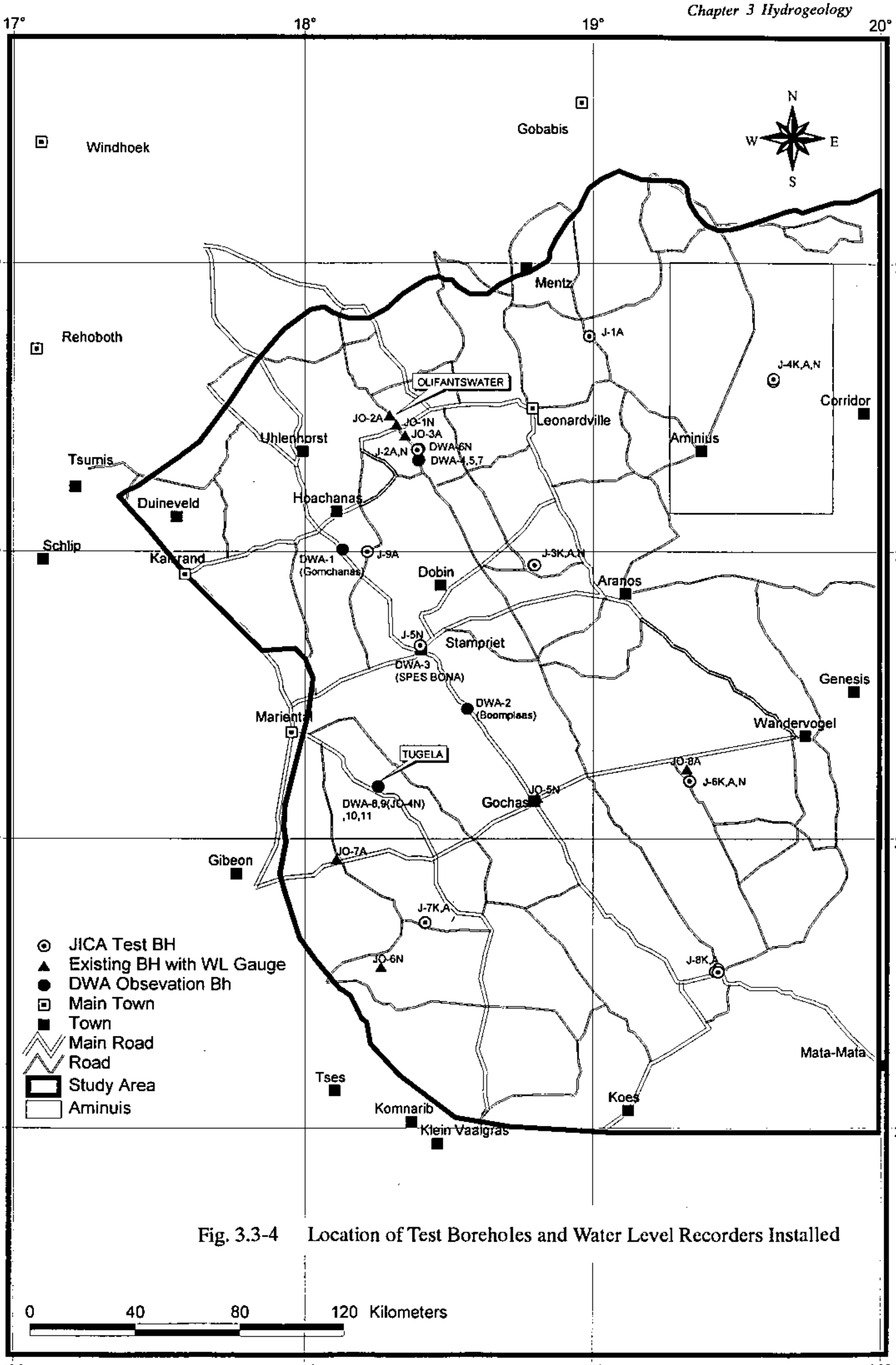


Fig. 3.3-4 Location of Test Boreholes and Water Level Recorders Installed

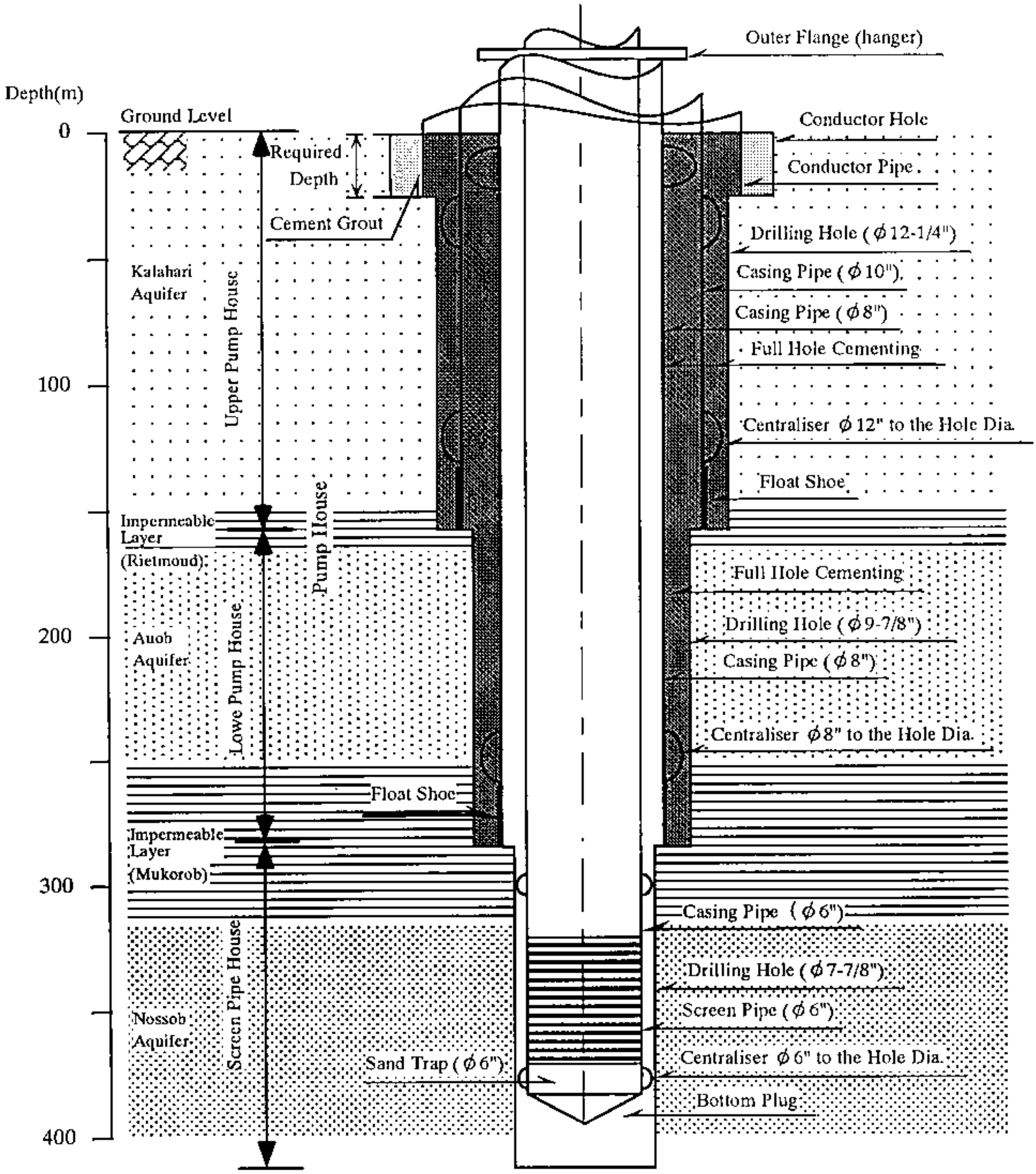


Fig. 3.3-5 Typical Specification of Test Boreholes (For the Nossob Aquifer)

3) Results of Test Borehole Drilling

(1) Test Borehole Data

Test borehole data such as location, borehole No. (WW Nos.), coordinates, depth drilled, borehole structure, water level and results of tests are summarized in Table 3.3-4.

Table 3.3-4 Test Borehole Data

Locality Information									Borehole Structure				Pumping Data									
Location		Borehole Number		Coordination						Screen Pipe			Static water level									
No.	Farm Name	JICA Ref. No.	WW No.	Latitude (d:m:s)	Latitude (decimal)	Longitude (d:m:s)	Longitude (decimal)	Elevation (masl)	Depth drilled (m)	from (mbgl)	to (mbgl)	Thick-ness (m)	(mbgl)	(masl)	Date	Yield (m^3/h)	Dynamic water level (mbgl)	Specific yield (m^3/h/m)	EC (mS/m)	TDS (mg/lit.)	pH	Temp. ℃
J1	Christiana	J1A	39839	23°15'14.9"	23.25415	18°59'12.0"	18.98668	1331.71	256.00	84.00	180.55	30.55	57.49	1274.22	5/6/2000	8.00	68.29	0.741	85	553	7.62	25.0
J2	Olifantswater West	J2A	39840	23°38'50.9"	23.64747	18°23'19.4"	18.38873	1275.26	130.51	95.05	127.51	26.41	16.94	1258.32	3/7/2000	3.40	54.94	0.089	90	585	7.78	25.8
		J2N	39841	23°38'53.1"	23.64808	18°23'19.4"	18.38871	1275.60	209.00	181.07	204.47	23.40	39.72	1235.88	2/7/2000	2.90	73.93	0.085	91	592	8.34	30.0
J3	Steynsrus	J3K	39842	24°02'45.3"	24.04592	18°47'36.2"	18.7934	1208.05	102.00	44.23	76.90	17.52	19.35	1188.7	10/7/2000	1.50	29.84	0.143	330	2,145	7.17	21.9
		J3A	39843	24°02'52.5"	24.04792	18°47'35.2"	18.79312	1205	253.00	121.34	247.74	32.15	15.77	1189.23	4/7/2000	19.88	20.26	4.428	115	771	(7.5)	29.3
		J3N	39844	24°02'54.9"	24.04858	18°47'46.1"	18.79614	1205	409.00	336.80	363.40	14.60	-24	1229	7/9/2000	0.15	-	-	461	3,089	8.41	14.4
J4	Okanyama (Aminuis)	J4K	39845	23°24'03.5"	23.40098	19°37'29.6"	19.62489	1258.05	53.20	30.00	50.30	20.30	45.1	1212.95	2/10/2000	0.10	50.71	0.018	227	1,476	8.58	29.3
		J4A	39846	23°24'01.8"	23.40049	19°37'32.8"	19.62577	1256.39	204.00	59.60	175.97	56.05	59.13	1197.26	8/9/2000	19.70	79.54	0.965	646	2,119	7.47	23.8
		J4N	39847	23°24'03.8"	23.40105	19°37'34.4"	19.62621	1256.38	356.00	328.00	351.35	23.35	10	1246.38	10/7/2000	11.80	65.31	0.213	100	650	8.89	30.3
J5	Maritzville	J5N	39848	24°19'41.7"	24.32824	18°23'52.6"	18.39794	1168.33	187.00	158.00	179.23	20.46	-20	1188.33	21/8/2000	0.80	26.46	0.017	139.5	904	8.27	31.1
J6	Cobra	J6K	39849	24°48'00.3"	24.80009	19°20'05.4"	19.33483	1102.67	168.50	108.50	165.00	17.50	101.98	1000.69	5/8/2000	3.00	122.7	0.145	2,310	15,015	9.09	29.8
		J6A	39850	24°48'02.1"	24.80059	19°20'06.7"	19.3352	1102.47	273.00	237.90	264.00	26.10	104.41	998.06	31/7/2000	3.96	128.29	0.166	188	1,216	8.54	26.9
		J6N	39851	24°47'58.7"	24.79963	19°20'04.5"	19.33457	1103.18	385.00	350.18	373.58	23.40	-16	1119.18	Oct-00	-	-	-		0		27.8
J7	Jackalsdraai	J7K	39852	25°17'29.9"	25.29163	18°25'00.4"	18.41678	1144	55.00	27.60	51.00	23.40	10.04	1133.96	21/8/2000	7.15	19.44	0.761	103	670	7.44	27.0
		J7N	39853	25°17'28.2"	25.29117	18°24'59.4"	18.4165	1144	250.00	226.83	241.33	14.50	22.45	1121.55	5/8/2000	0.30	88.33	0.005	431	2,743	9.08	29.1
J8	Tweerivier	J8K	39854	25°27'40.4"	25.46122	19°25'57.6"	19.43266	1021.25	129.00	84.60	114.00	23.40	60.31	960.94	21/7/2000	0.24	75.2	0.016	351	2,282	8.74	27.0
		J8A	39855	25°27'42.3"	25.46174	19°26'01.4"	19.43373	1021.13	250.00	234.10	242.80	8.70	172.32	848.81	Oct-00	-	-	-	1,039	6,754	12.19	28.0
		J8N	39856	25°27'41.3"	25.46148	19°25'59.7"	19.43324	1021.26	346.00	320.15	337.55	17.40	20.77	1000.49	Oct-00	-	-	-	>5,000	33,500	8.64	21.8
J9	Klein Swart Modder	J9A	39857	24°00'06.5"	24.00182	18°12'55.0"	18.21529	1210.16	141.50	65.43	135.33	69.90	2.23	-2.23	30/8/2000	45.00	5.05	15.957	101	656	7.69	28.6

(2) Geological Interpretation

In the course of drilling, drill cutting samples were collected every 1 metre to describe the lithological facies and the penetration rates were recorded. Based on the interpretation of record and geophysical logging, detailed lithological column of each borehole was established. The Auob Member was subdivided into five units from A1 to A5 in ascending order: Among them A1, A3 and A5 are sandy permeable layer, while A2 and A5 are impermeable shaley facies. Thickness of each aquifer is summarized in Table 3.3-5.

Table 3.3-5 Thicknesses of Geological Units

Geological Units		**Thickness**								
		J1	J2	J3	J4	J5	J6	J7	J8	J9
Kalahari		4	12	50	16	-	158	49	141	-
Kalkrand Basalt		-	-	-	-	-	-	-	-	Bas.
Karoo Dolerite		-	-	-	Dol.	-	-	-	-	-
Rietmond	Upper	17		68	-	43	10	19	-	-
	Lower	62	47	-	-	10	9	-	-	-
Auob	A5	33		25	35		32	20	42	
	A4	6		6	3		13	38	26	
	A3	21	27	27	34	43	10	27	12	74
	A2	26		50	24		4	0.5	12	
	A1	27		20	28		28	11	8	
Mukorob	Upper	-	25	28	87	9	21	9	25	-
	Lower	38	39	61	59	53	67	53	53	-
Nossob		-	Int.	Int.	22	Int.	28	Int.	Int.	-
Dwyka		17	3	43	5+	4+	5+	5+	9+	-

(Remarks)

-	: Missing/not exist
62	: Impermeable layer (shale, mudstone) and it's thickness (m)
33	: Permeable layer (sand stone) and it's thickness (m)
Dol.	: Dolerite
Bas.	: Basalt
Int.	: Intercalation of permeable and impermeable layer

(3) Aquifer Constants

Aquifer constants were obtained by the analyses of a series of pumping test results. They are summarized in Table 3.3-6.

Specific capacity is the highest in the Auob Aquifer ranging from 0.089 m^3/h/m (J2A) to 15.94 (J9A). At J9A (Klein Swart Modder), the Auob Aquifer shows a uniform facies of loose quartz sand. In contrary with this, the Nossob Aquifer shows the smallest specific capacity generally less than 0.1 m^3/h/m, except J4N (Steynsrus), which means the difficulty of groundwater abstraction from the Nossob Aquifer.

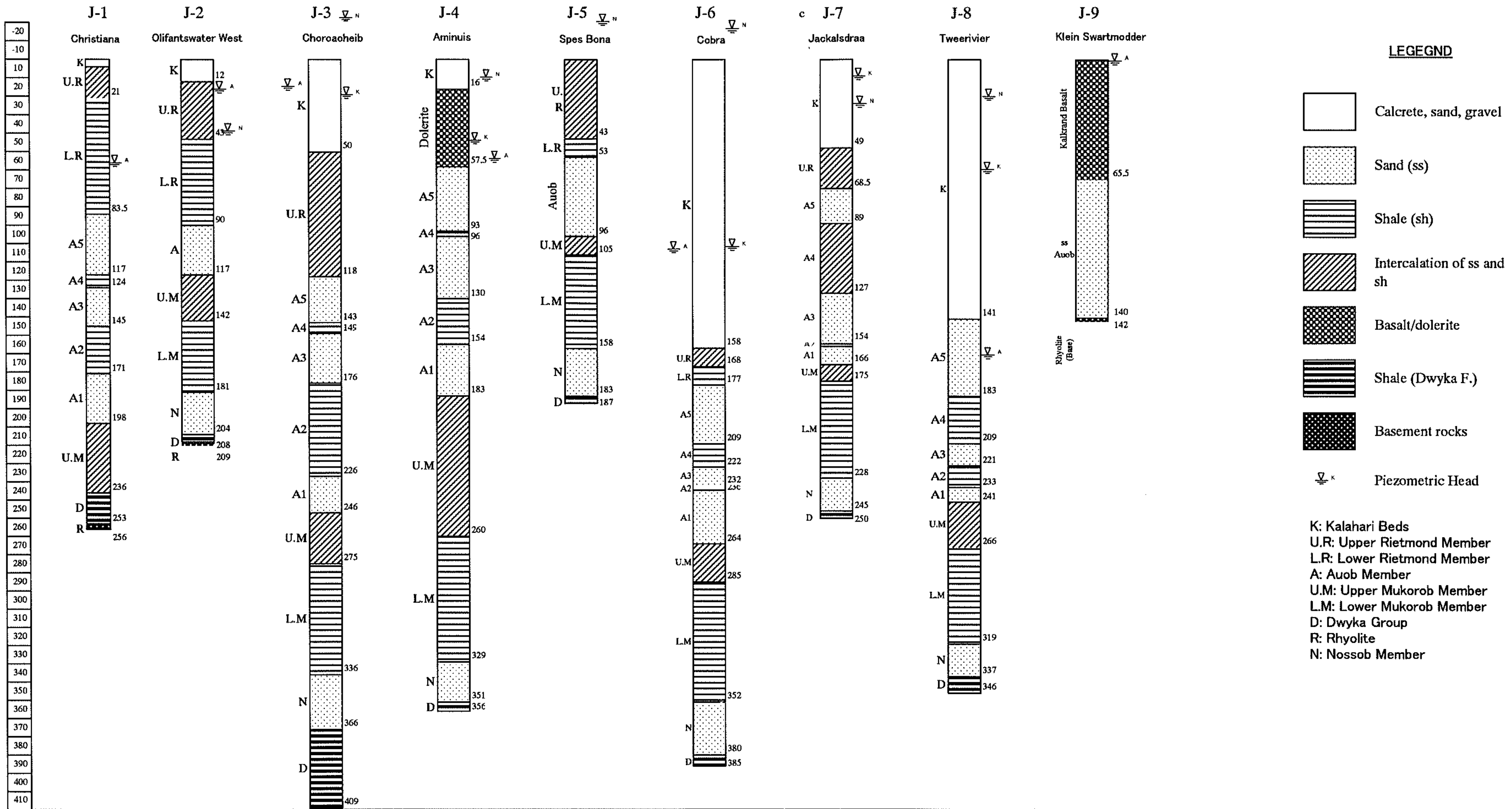
Table 3.3-6 Aquifer Constants

Aquifer	Borehole No.	Specific Capacity (m^3/h/m)	Transmissibity (m^3/day/m)	Permeability (cm/sec)	Storage Coefficient
Kalahari	J3K	0.143	6.42	1.50E-04	1.00E-06
	J4K	0.018	0.135	7.74E-06	-
	J6K	0.145	6.23	1.40E-04	1.00E-05
	J7K	0.763	30	1.20E-03	2.00E-04
	J8K	0.016	0.132	5.10E-06	5.00E-03
Auob	J1A	0.74	25.2	3.90E-04	1.00E-05
	J2A	0.089	3.42	1.60E-04	1.00E-05
	J3A	4.409	194	6.60E-03	1.00E-05
	J4A	0.923	87.6	2.00E-03	1.00E-05
	J6A	0.165	8.44	3.30E-04	3.00E-09
	J8A	-	0.006	2.30E-07	1.00E-10
	J9A	15.94	1,240	1.90E-02	3.00E-03
Nossob	J2N	0.085	2.94	1.40E-04	5.00E-06
	J3N	0.00082	1.3	1.03E-04	2.00E-05
	J4N	0.21	7.01	1.60E-04	5.00E-05
	J5N	0.016	1.2	5.50E-05	3.00E-05
	J6N	-	1.487	6.10E-05	1.00E-05
	J5N	0.0043	0.01	2.10E-06	1.00E-10
	J7N	-	0.02	8.80E-07	1.80E-06

(4) Water Quality and Isotope Analyses of Test Boreholes

Groundwater samples were collected from each aquifer which is completely independent from other aquifers. Water quality and isotope analyses results of test boreholes are presented in Table 3.3-7.

The summary of JICA test boreholes is shown in Fig. 3.3-6



J-1			J-2			J-3		
Kalahari	WL	-	Kalahari	WL	-	Kalahari	WL	19.08 ml
	WL	-		WL	-		WL	1188.97 mAS
	T	-		T	-		T	6.4 m^2/day
	EC	-		EC	-		EC	330 mS/m
	TDS	-		TDS	-		TDS	2157 mg/L
	pH	-		pH	-		pH	7.2
	Temp	-		Temp	-		Temp	21.9°C
Auob	WL	57.72 mBGL	Auob	WL	15.01 mBGL	Auob	WL	13.62 mBGL
	WL	1274.00 mAS		WL	1260.25 mAS		WL	1194.44 mAS
	T	25.2 m^2/day		T	3.4 m^2/day		T	194.0 m^2/day
	EC	85 mS/m		EC	90 mS/m		EC	116 mS/m
	TDS	564 mg/L		TDS	605 mg/L		TDS	775 mg/L
	pH	7.6		pH	7.8		pH	7.5
	Temp	25.0°C		Temp	25.8°C		Temp	29.8°C
Nossob	WL	-	Nossob	WL	39.45 mBGL	Nossob	WL	-30.91.0 mBC
	WL	-		WL	1236.15 mAS		WL	1238.96 mAS
	T	-		T	2.9 m^2/day		T	1.3 m^2/day
	EC	-		EC	91 mS/m		EC	460 mS/m
	TDS	-		TDS	616 mg/L		TDS	3303 mg/L
	pH	-		pH	8.3		pH	8.2
	Temp	-		Temp	30.0°C		Temp	24.9°C

J-4			J-5			J-6		
Kalahari	WL	49.40mBGL	Kalahari	WL	-	Kalahari	WL	102.14 mBGI
	WL	1208.66 mAS		WL	-		WL	1000.53 mAS
	T	0.1 m^2/day		T	-		T	6.2 m^2/day
	EC	227 mS/m		EC	-		EC	2,310 mS/m
	TDS	1481 mg/L		TDS	-		TDS	14874 mg/L
	pH	8.5		pH	-		pH	8.6
	Temp	29.3°C		Temp	-		Temp	26.9 ℃
Auob	WL	59.15 mBGL	Auob	WL	-	Auob	WL	102.8 mBGL
	WL	1197.25 mAS		WL	-		WL	999.66 mASI
	T	87.6 m^2/day		T	-		T	8.4 m^2/da
	EC	326 mS/m		EC	-		EC	187 mS/m
	TDS	2084 mg/L		TDS	-		TDS	1248 mg/L
	pH	7.1		pH	-		pH	8.6
	Temp	27.0°C		Temp	-		Temp	26.9 ℃
Nossob	WL	6.23 mBGL	Nossob	WL	-29.57 mBGI	Nossob	WL	-19.64 mBGI
	WL	1250.15 mAS		WL	1197.90 mAS		WL	1001.19 mAS
	T	7.01 m^2/day		T	1.2 m^2/day		T	1.49 m^2/day
	EC	100 mS/m		EC	136 mS/m		EC	1038 mS/m
	TDS	665 mg/L		TDS	909 mg/L		TDS	6955 mg/L
	pH	8.9		pH	8.5		pH	9.5
	Temp	30.3°C		Temp	28.5°C		Temp	27.8°C

J-7			J-8			J-9		
Kalahari	WL	9.72 mBGL	Kalahari	WL	59.75 mBGL	Basalt	WL	-
	WL	1138.47 mAS		WL	961.5 mASL		WL	-
	T	30.0 m^2/day		T	0.13 m2/day		T	-
	EC	103 mS/m		EC	351 mS/m		EC	-
	TDS	670 mg/L		TDS	2282 mg/L		TDS	-
	pH	7.40		pH	8.70		pH	-
	Temp	27.0 ℃		Temp	27.0 ℃		Temp	-
Auob	WL	-	Auob	WL	183.8 mBGL	Auob	WL	2.3 mBGL
	WL	-		WL	831.18 mASI		WL	1207.9 mASL
	T	-		T	0.3 m^2/day		T	1240 m^2/day
	EC	-		EC	1,039 mS/m		EC	101 mS/m
	TDS	-		TDS	6754 mg/L		TDS	656 mg/L
	pH	-		pH	9.66		pH	7.70
	Temp	-		Temp	28.0 ℃		Temp	28.6 ℃
Nossob	WL	21.65 mBGL	Nossob	WL	20.46 mBGL	Nossob	WL	-
	WL	1126.50 mAS		WL	1000.8 mASI		WL	-
	T	0.01 m^2/day		T	0.02 m^2/day		Q	-
	EC	431 mS/m		EC	5,030 mS/m		EC	-
	TDS	2743 mg/L		TDS	33,500 mg/L		TDS	-
	pH	9.10		pH	8.64		pH	-
	Temp	29.1°C		Temp	21.8°C		T	-

Note: *EC,pH,Temp* : Field measurement
mBGL : m below ground level
mASL : m above sea level
T : Transmissivity

Fig. 3.3-6 Geological Columnar Sections and Hydrogeological Characteristics

Table 3.3-7 Water Quality of Test Boreholes

Locality Information				Isotope Analysis						Samples			Chemical Contents															
Location		Borehole Number																										
No.	Farm Name	JICA Ref. No.	WW No.	Laboratory Number	^{18}O (o/oo)	^{2}H (o/oo)	^{3}H (TU)	^{14}C (pMC)	^{15}N	Sample Number	Date Sample taken	Date Sample analysed	pH	Conductivity mS/m	Total Dissolved Solids	Sodium as Na	Potassium as K	Sulphate as SO4	Nitrate as N	Nitrite as N	Silicate as SiO2	Fluoride as F	Chloride as Cl	Total Alkalinity as CaCO3	Phenolphthalein Alkalinity as CaCO3	Total Hardness as CaCO3	Calcium as CaCO3	Magnesium as CaCO3
J1	Christiana	J1A	39839	G4972	-7.03	-51	0.0 ± 0.2	14.6 ± 0.3	9.5	DS6838	14-Jun-00	2-Oct-00	8.2	84.1	563	92	11	12	9.8	<0.1	27	0.2	30	356		256	110	146
J2	Olifantswater We	J2A	39840	G4977	-6.65	-50	0.0 ± 0.2	3.0 ± 0.2	13.8	DS6836	20-Jun-00	2-Oct-00	8.1	90.3	605	140	11	35	13.8	0.1	23	0.6	63	300		155	55	100
		J2N	39841	G4976	-6.72	-50	0.0 ± 0.2	4.0 ± 0.2	-	DS6835	11-Jun-00	2-Oct-00	8.3	92.0	616	190	5	97	2.8	0.1	15	1.1	66	274		39	23	17
J3	Steynsrus	J3K	39842	G4992	-6.27	-47	0.0 ± 0.2	55.2 ± 0.6	10.6	DS6832	29-Jun-00	2-Oct-00	7.7	322.0	2,157	300	19	65	176.0	0.1	59	0.6	465	288		912	345	567
		J3A	39843	G4993	-6.99	-50	0.0 ± 0.2	25.5 ± 0.3	-	DS6833	8-Jul-00	2-Oct-00	8.1	115.6	775	145	9	43	23.1	0.5	39	1.2	47	426		269	140	129
		J3N	39844	G5044	-7.41	-52	-	1.4	-	DS7503	9-Oct-00	25-Oct-00	9.1	493.0	3,303	1,020	4	460	<0.5	<0.1	12	3.2	900	460	26.0	53	33	21
J4	Okanyama (Aminuis)	J4K	39845	G4975	-7.21	-50	0.0 ± 0.2	44.1 ± 0.4	-	DS6837	4-Jun-00	2-Oct-00	7.8	221.0	1,481	545	7	210	1.3	3.3	38	0.7	184	748		115	28	88
		J4A	39846	G4973	-7.19	-52	0.0 ± 0.2	60.1 ± 0.5	9.3	DS6834	23-May-00	2-Oct-00	8.0	311.0	2,084	465	18	290	17.5	<0.1	54	0.3	600	482		589	273	317
		J4N	39847	G4974	-7.85	-54	0.0 ± 0.2	0.25 ± 0.2	-	DS6839	31-May-00	2-Oct-00	8.5	99.2	665	230	4	31	<0.5	<0.1	15	0.7	29	448	10.0	7	3	4
J5	Maritzville	J5N	39848	G5037	-6.96	-52	-	1.7	-	DS7176	24-Aug-00	5-Oct-00	8.3	135.7	909	365	4	105	<0.5		15	2.4	45	592		9	5	4
J6	Cobra	J6K	39849	G4994	-5.03	-42	0.0 ± 0.2	6.2 ± 0.2	14.7	DS7177	27-Aug-00	5-Oct-00	9.2	2220.0	14,874	7,400	39	1,850	60.0		30	19.0	4,100	6,520	1,084	7	3	4
		J6A	39850	G4995	-7.07	-52	0.0 ± 0.2	0.9 ± 0.2	-	DS7174	4-Aug-00	5-Oct-00	8.4	186.3	1,248	495	5	125	<0.5		15	1.2	220	592		7	3	4
		J6N	39851																									
J7	Jackalsdraai	J7K	39852	G5038	-6.47	-48	0.0 ± 0.2	50.7	9.5	DS7171	25-Aug-00	5-Oct-00	7.7	97.8	655	121	5	82	14.0		73	0.7	63	316		268	118	150
		J7N	39853	G5039	-6.81	-50	-	10.8	-	DS7173	1-Sep-00	5-Oct-00	8.7	395.0	2,647	1,020	5	840	< 0.5		13	4.5	590	460	16.0	28	20	8
J8	Tweerivier	J8K	39854	G4996	-5.86	-47	0.0 ± 0.2	54.9 ± 0.2	13.0	D7175	15-Aug-00	5-Oct-00	8.7	328.0	2,198	880	12	320	15.0		34	3.7	295	1,068	52.0	13	5	8
		J8A	39855	G5041	-3.56	-36	-	99.3	8.9	DS7501	16-Sep-00	25-Oct-00	11.8	1,026.0	6,874	1,800	20	880	8.4	0.7	22	2.0	1,120	1,630	1,360	17	13	4
		J8N	39856	G5042	-4.52	-41	-	26.5	-	DS7502	16-Sep-00	25-Oct-00	9.0	5,890.0	39,463	17,000	32	8,500	<0.5	<0.1	1	0.8	20,500	118	24.0	406	160	246
J9	Klein Swart Modder	J9A	39857	G5040	-6.76	-51	-	47.5	7.5	DS7172	2-Sep-00	5-Oct-00	7.8	97.3	652	152	5	105	13.3		57	0.9	64	286		184	105	79

3.3.4 Borehole Elevation Survey

Topography of the study area is generally flat although most of the area is covered by stabilized sand dunes. In order to determine the precise groundwater level/piezometric head precise elevation of boreholes is indispensable. Therefore, an elevation survey was executed covering more than 300 boreholes by the Differential GPS.

The result was used for determination of groundwater level. Details of the survey are presented in Appendix E of the Data Book.

3.4 Classifications and Definition of Aquifer

It has been generally said that there are three main aquifers in the Southeast Kalahari Artesian Basin, the Kalahari, the Auob and the Nossob Aquifers from the top, and they are hydrogeologically separated by impermeable layers, the Rietmond Member, the Mukorob Member and the Dwyka Member. The Kalahari Aquifer is an unconfined aquifer and other two aquifers are confined. The Kalahari and the Auob are seemed to have an interaction in places, however, details have not been known.

The Study revealed that:

- The Rietmond and the Mukorob Members have a sandy facies unit at the upper part. Those are considered to be permeable although permeability is low.
- The Auob Aquifer is subdivided into five units A1 to A5 in ascending order.
- A large scale of erosion surface was confirmed under the bottom of the Kalahari Beds mainly in the southern part of the study area. The erosion surface is called as "the African Surface" and reaches the Auob Member.

Considering the above, three aquifers are hydrogeologically classified as shown in Fig. 3.4-1.

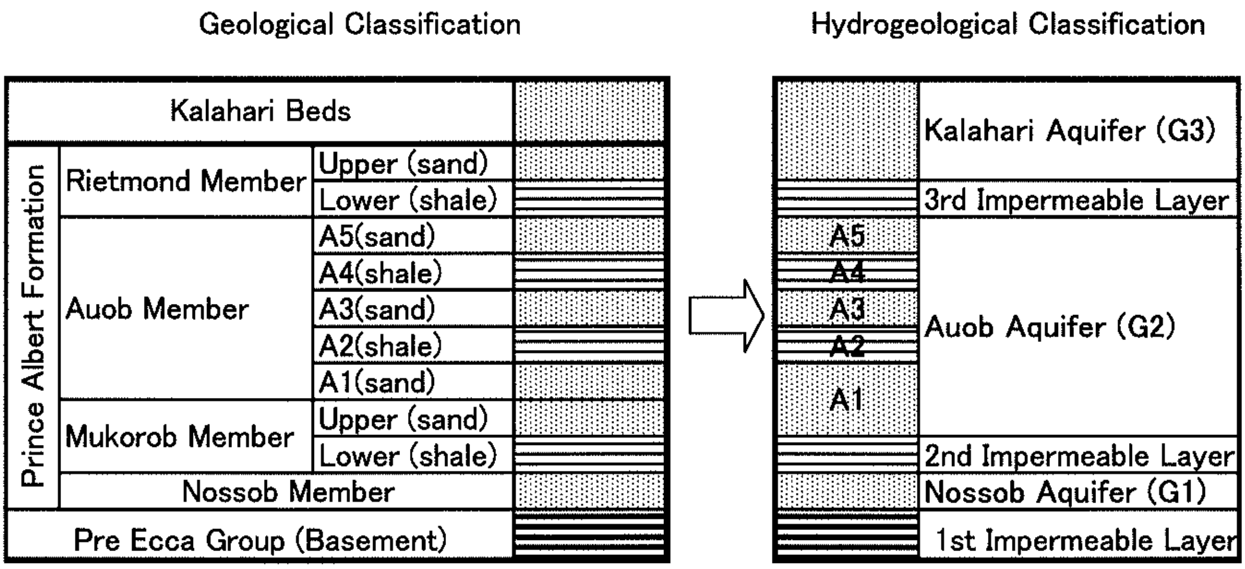


Fig. 3.4-1 Reclassification of Aquifers

In the Study, new definitions were given to the Kalahari and the Auob Aquifers based on the classification above.

- Kalahari Aquifer

  The Kalahari Aquifer is the top of the aquifers and is composed of the Kalahari Beds and the upper sandy part of the Rietmond Member. The bottom of the aquifer is limited by the impermeable lower part of the Rietmond Member. The Rietmond Member is sometimes absent due to the erosion; therefore, the aquifer has hydrogeological connection with the Auob Aquifer in such places.

- Auob Aquifer

  The Auob Aquifer is the middle of aquifers, and includes the Auob Member and the underlying upper sandy part of the Mukorob Member. The aquifer is subdivided into five units from A1 to A5. Among these, A1, A2 and A3 show sandy facies and form the aquifer. The aquifer is hydrogeologically limited by the lower part of the Rietmond Member at the top and by the lower part of the Mukorob Member at the bottom. Due to the absence of the Rietmond Member, the aquifer is sometimes connected with the Kalahari Aquifer.

- Nossob Aquifer

  No new definition was given to this aquifer. The aquifer consists only of the Nossob Member and is independent from other aquifers.

3.5 General Features of Aquifer

3.5.1 Kalahari Aquifer

The most of the study area is covered by the Kalahari Beds except the area near Hoachanas, northwest from Stampriet, where the Kalkrand Basalt distributes. Calcrete, consolidated sediments by salt and calcium, occupies the top of the aquifer. Except for the southwestern part of the study area, the Kalahari Aquifer is overlain by the stabilized sand dunes. In the area overlain by the sand dunes, scarce streams are developed, while the Auob, the Olifants and the Nossob Rivers flow in the area. In the southwestern part of the study area, the Kalahari Aquifer crops out on the plateau. Two kinds of depressions are observed on the surface of the Kalahari Aquifer; one is so-called “Pan” and the other is “Sinkhole”. The surface of Pans is mostly covered with thick salt crust and sometimes water is standing. On the one hand, no salt crust is observed in the sinkhole, only muddy sediments sometimes accumulated. Functions of those depressions are discussed later on in this Chapter.

The Kalahari Aquifer is most intensively used in the study area. Approximately 4500 boreholes, more than 80% of total boreholes, were sunken into the Kalahari Aquifer. A total of 9.8 x 10^6 m^3/year of groundwater is abstracted from the Kalahari Aquifer, which is 65 % of the total abstraction in the study area.

3.5.2 Auob Aquifer

The Auob Aquifer is underlain by the Mukorob Member and is overlain by the Rietmond Member. Since this is a confined aquifer and contains good quality water, local people used to utilize it for along time. Total production volume is 4.97 x 10^6 m^3/year, which is about 33 % of the total abstraction in the study area. . The withdrawal has being done especially in the western part of the basin; around Stampriet and Aranos where the depth of the aquifer is relatively shallower than eastern. The total number of the Auob borehole is estimated approximately 700. It implies that a withdrawal intensity of the aquifer on average is more than three times as much as the Kalahari Aquifer.

3.5.3 Nossob Aquifer

The Nossob Aquifer is a confined aquifer, which is intercalated between two impermeable layers; the Mukorob Member and the Pre-Ecca Group. Less than 30 boreholes were drilled into the Nossob Aquifer. Although the Nossob Aquifer has the highest piezometric head among the aquifers, reaching more than 20 m above the ground surface however total groundwater extraction form this aquifer is only 0.2 million m^3/year which is about 1.3 % of the total abstraction in the study area because this aquifer has thin thickness, deep existence and inferior aquifer contents.

3.6 Configuration of Aquifer

3.6.1 Kalahari Aquifer

A bottom surface of the Kalahari Aquifer is shown in Fig.3.6 -2. This map indicates an erosion surface before sedimentation of the Kalahari Beds in the other words, “African Surface”. It also shows that the Pre-Kalahari Valley was deeply eroded and the cross sections also present that its erosion reached the Auob Aquifer as shown in Fig.3.6-9 to 12. Fig.3.6-2 presents the thickness of the lower Rietmond Member. It shows the considerably extensive area of its non-distribution in the centre and south of the basin.

Since this means that the Kalahari Aquifer covers the Auob Aquifer directly without impermeable layer, there is a possibility that groundwater of the Auob Aquifer is leaking upward into the Rietmond Member. However, no matter what this circumstance is recognized locally, both aquifers should be treated as an independent aquifer each other because of the poor connectivity in the upper Rietmond Member.

On the other hands, the distribution of thickness of the Kalahari Beds in Fig.3.6-1 well coincides with the Pre-Kalahari Valley. Its maximum thickness is 250 meters more.

3.6.2 Auob Aquifer

The Auob Member is locally cropped out at the east of Mariental and along the scarp that is extending to the south of Mariental. This member can be classified into five units; A1 to A5 from geological viewpoint. However, they are dealt with one hydrogeological unit in this study because of their horizontally changeable lithofacies.

The Mukorob Member underlain the Auob Member consists of the upper part, which is regarded as a permeable layer and the lower part, which is an impermeable layer. Therefore the Auob Aquifer was defined as the combination of the upper Mukorob Member and the whole of the Auob Member.

A top surface of the Auob Aquifer is shown in Fig.3.6-4. As a whole, the surface declines from northwest to southeast. Its elevations at the north-western margin of the basin and the south-eastern corner of it are 1350m ASL and 800m ASL respectively.

Isopach map of the Auob Aquifer is illustrated in Fig.3.6-5. It implies that the major distribution extends from the south of Aminius to the east of Aranos. In this distribution area, the thickness of the aquifer ranges from 100 meters to 150 meters and 150 meters more in places. On the other hands, it becomes thinner immediately near the marginal area of the basin. It is remarkable that the area ranges from 0 to 50 meters thick extends N-S direction in the centre of the basin.

3.6.3 Nossob Aquifer

The outcrops of this aquifer are locally recognised along the scarp extended in the west of N-S faults, which lie to the west of the basin.

The isopach map of the lower Mukorob Member, which plays as an impermeable layer, is shown in Fig.3.6-6. Increase of thickness takes place from the west to the east of the basin and the maximum value comes up to 125 metres.

According to the top surface of the Nossob Aquifer shown in Fig.3.6-7, it is inclined from the northwest to the southeast likewise the Auob Aquifer. Its elevation is approximately 1000m ASL at the northeastern margin of the basin and 650m ASL at the southeastern corner.

The distribution of the Nossob Aquifer's thickness is presented in the isopach map in Fig.3.6-8. The figure indicates that the thickness of aquifer intends to increase toward the centre of the basin, although there is no distribution on the margin of the basin. An average thickness of the aquifer is estimated approximately 25 meters. However, there are thick parts of the aquifer in places. The maximum thickness of it is reported 94 meters in the petroleum core holes, drilled in the farm Vreda during 1963 and 1994.

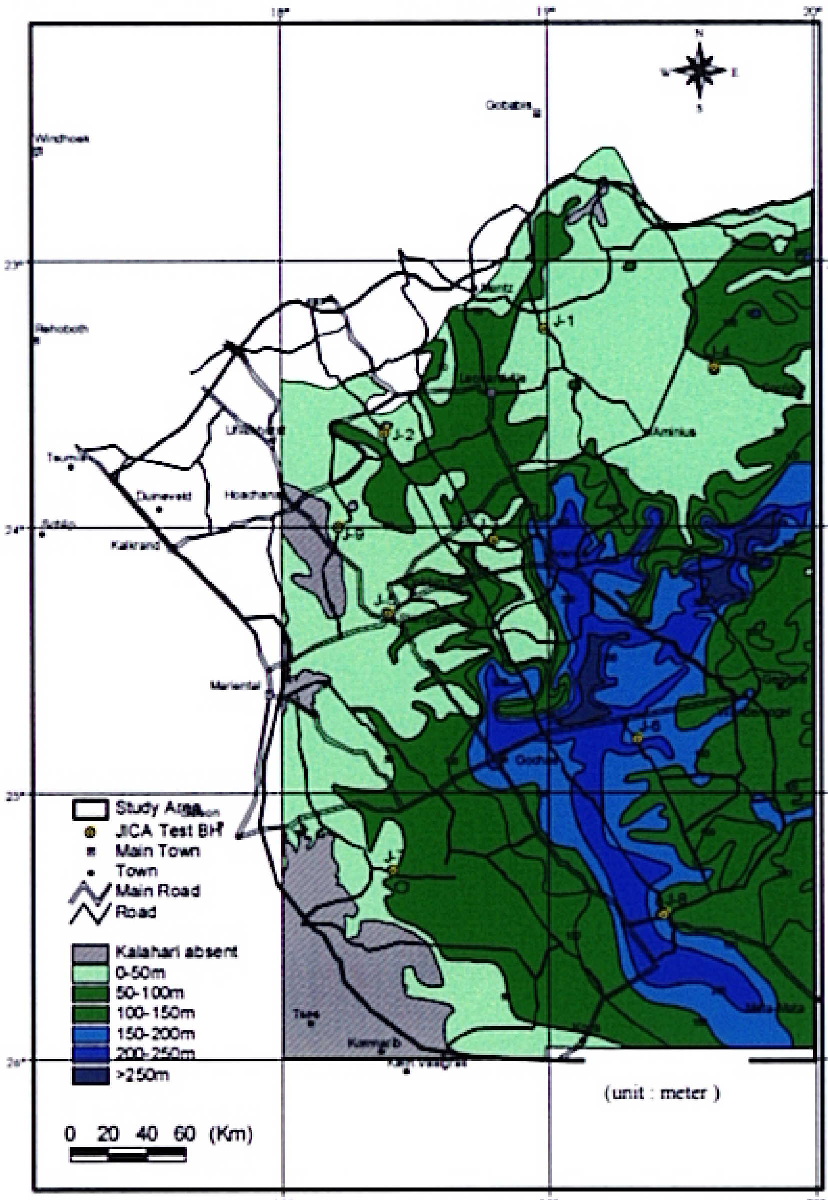


Fig. 3. 6-1 Isopachs of Kalahari Beds

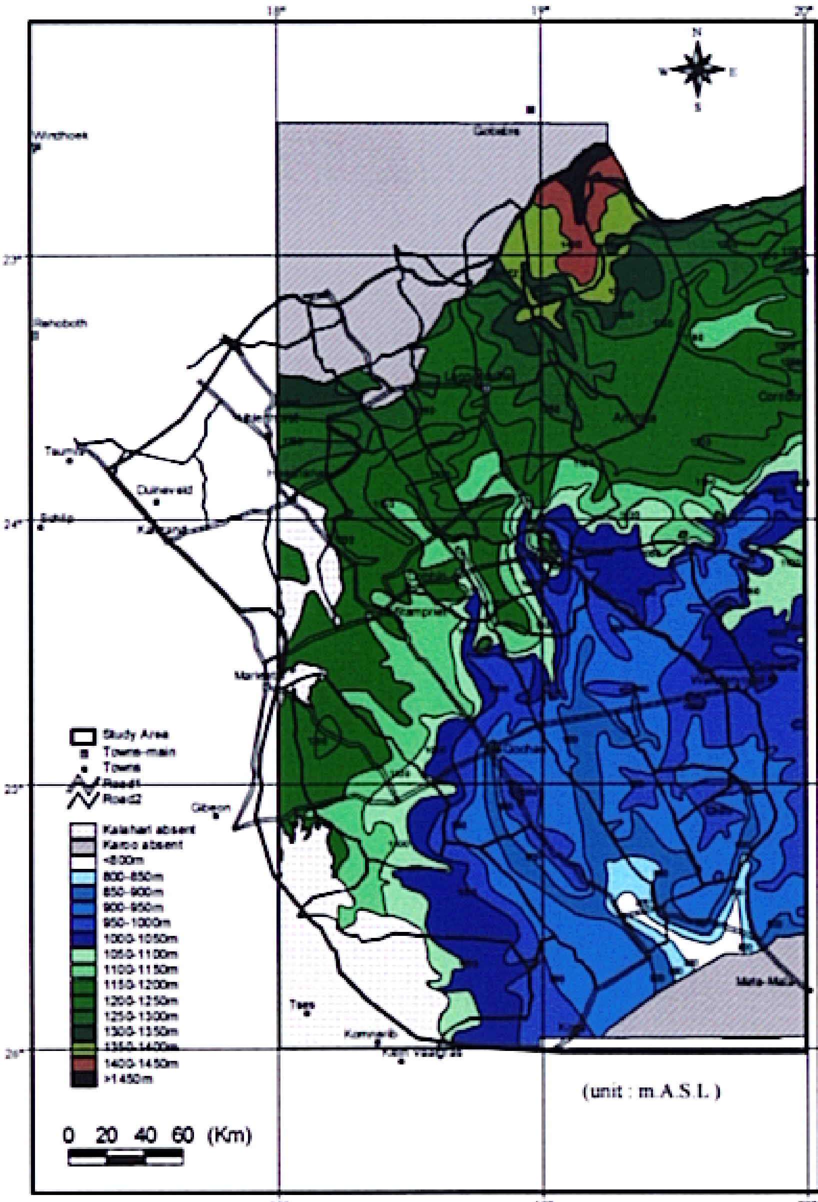


Fig. 3. 6-2 Bottom of Kalahari Beds

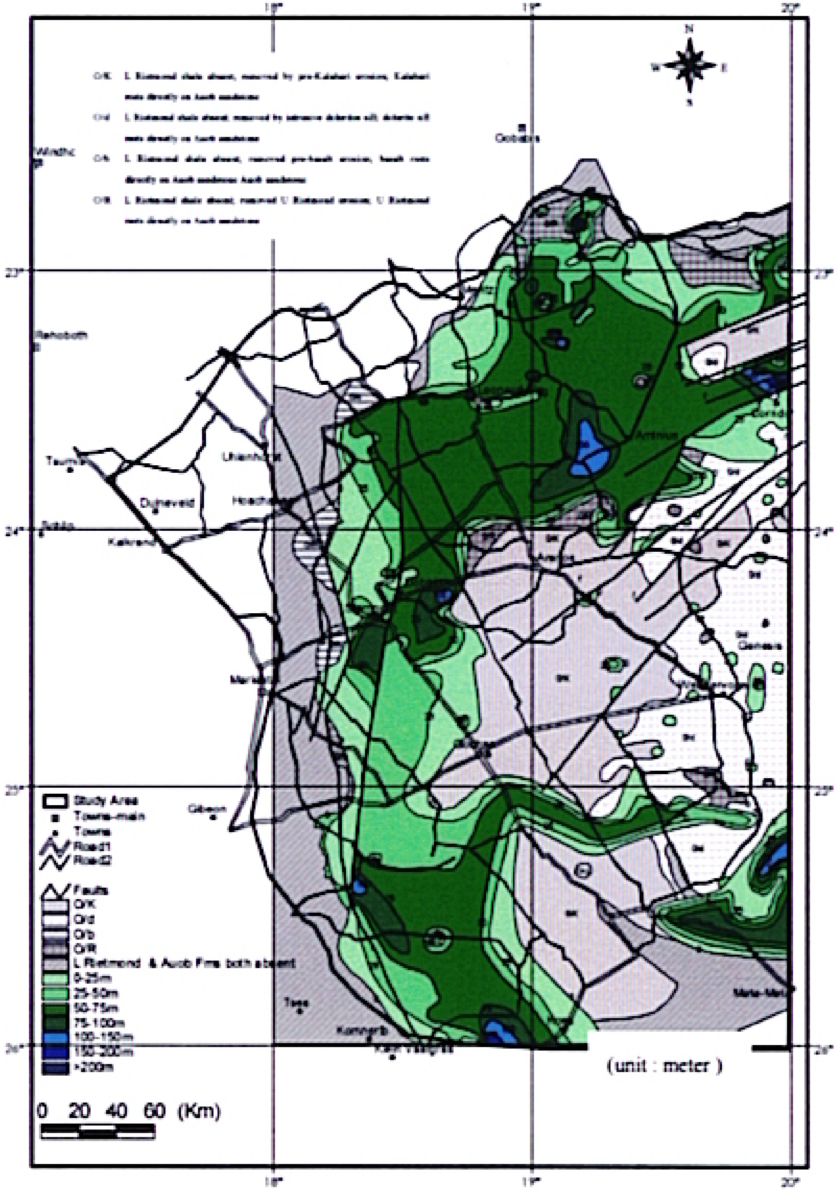


Fig. 3.6-3 Isopachs of Lower Rietmond Member

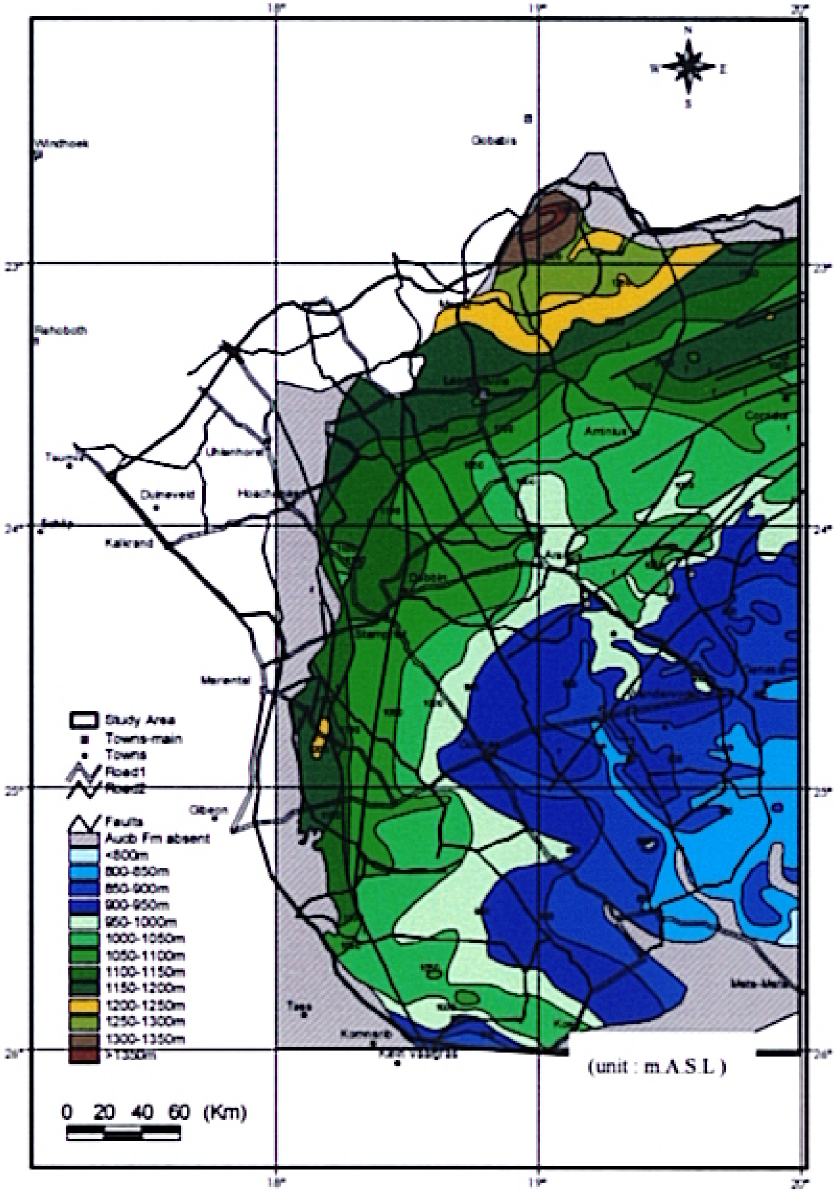


Fig. 3.6-4 Top of Auob Aquifer

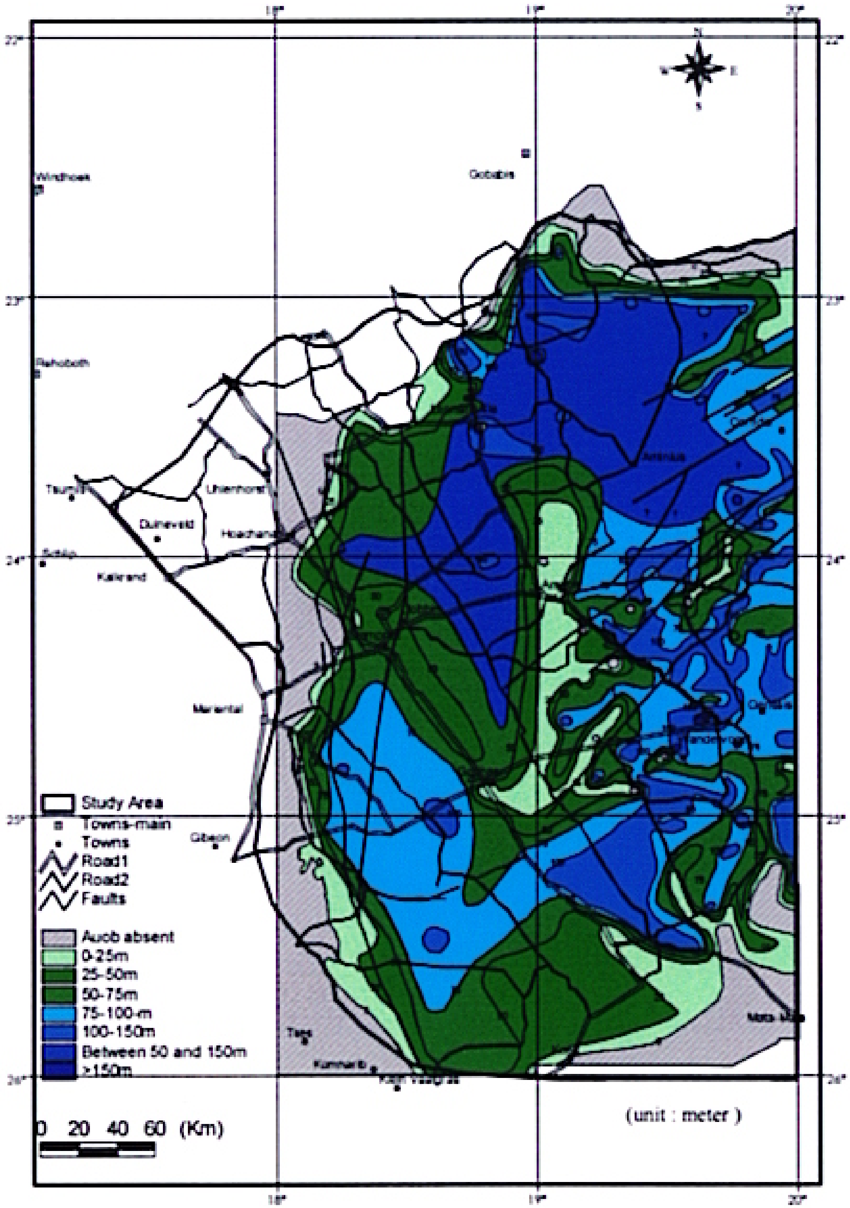


Fig. 3.6-5 Isopachs of Auob Aquifer

(Auob Member + Upper Mukorob Member)

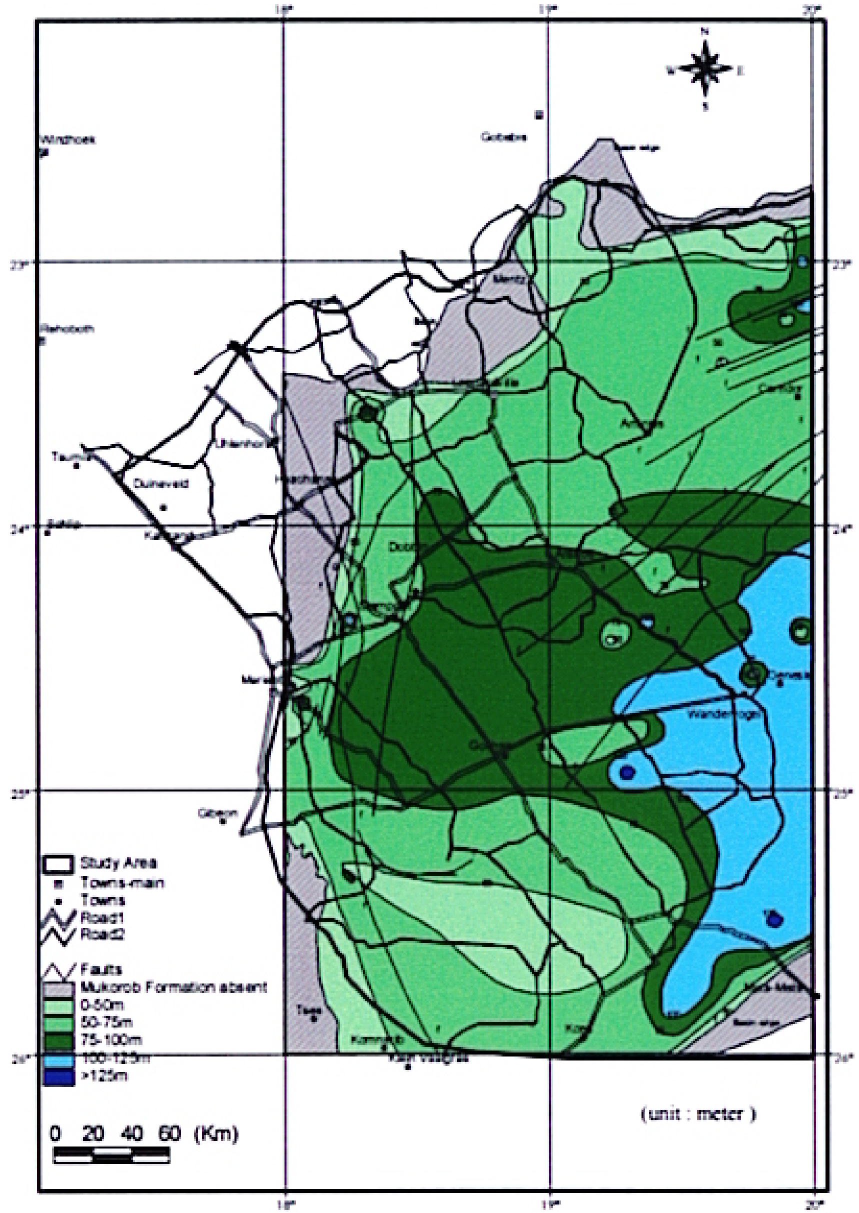


Fig. 3.6-6 Isopachs of Lower Mukorob Member

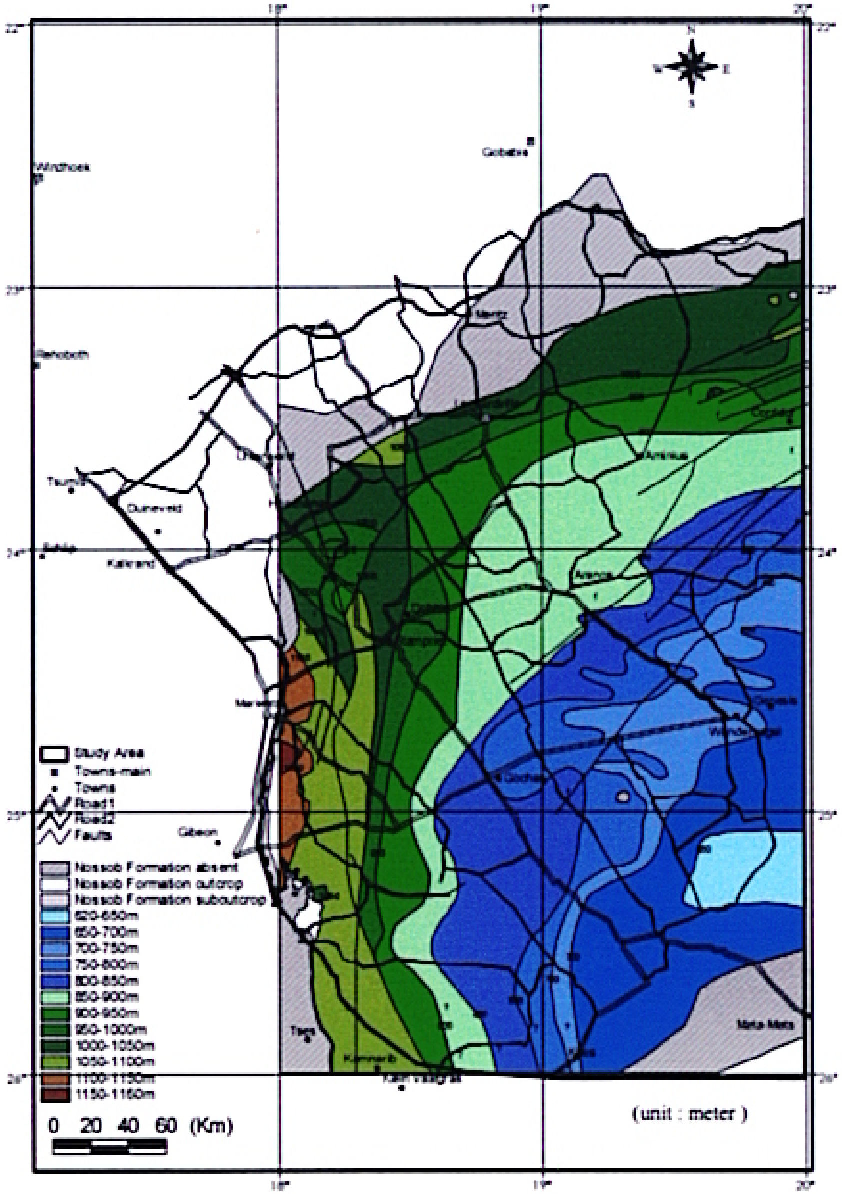


Fig. 3.6-7 Top of Nossob Aquifer

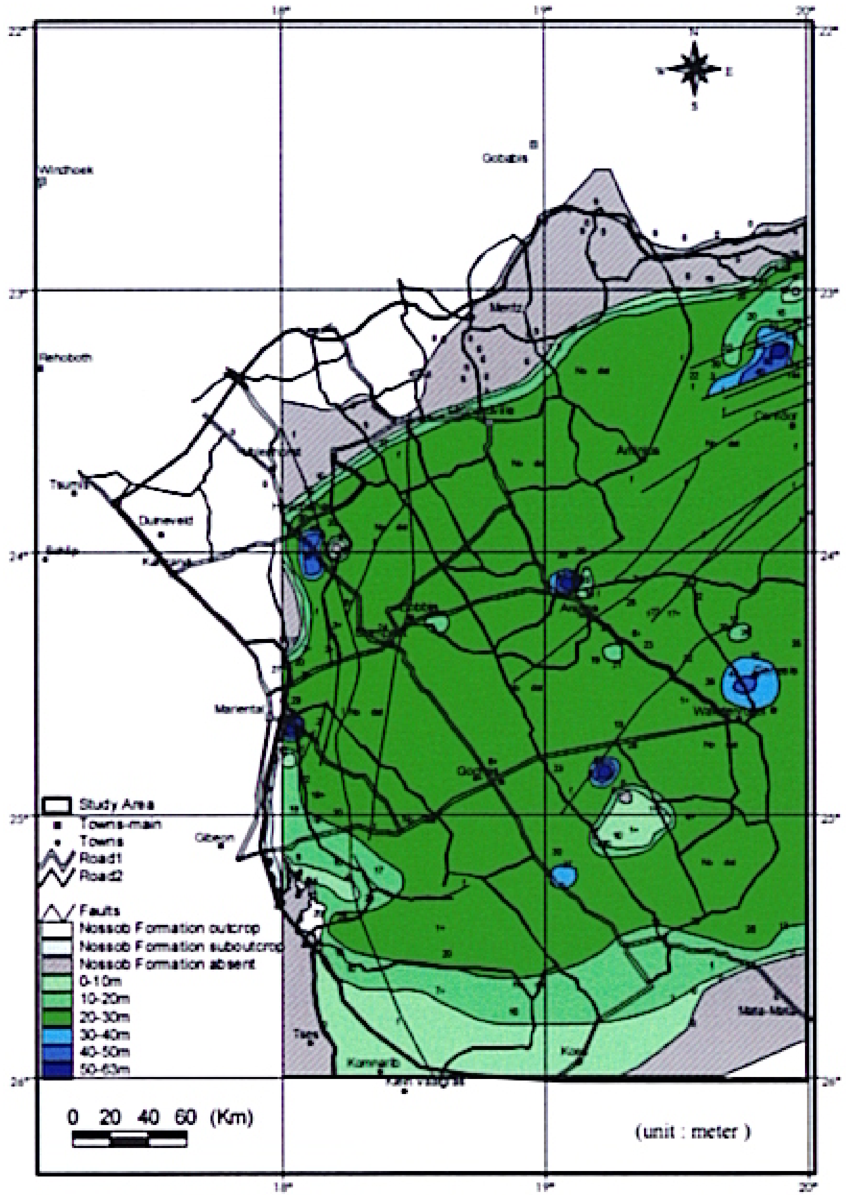


Fig. 3.6-8 Isopachs of Nossob Aquifer

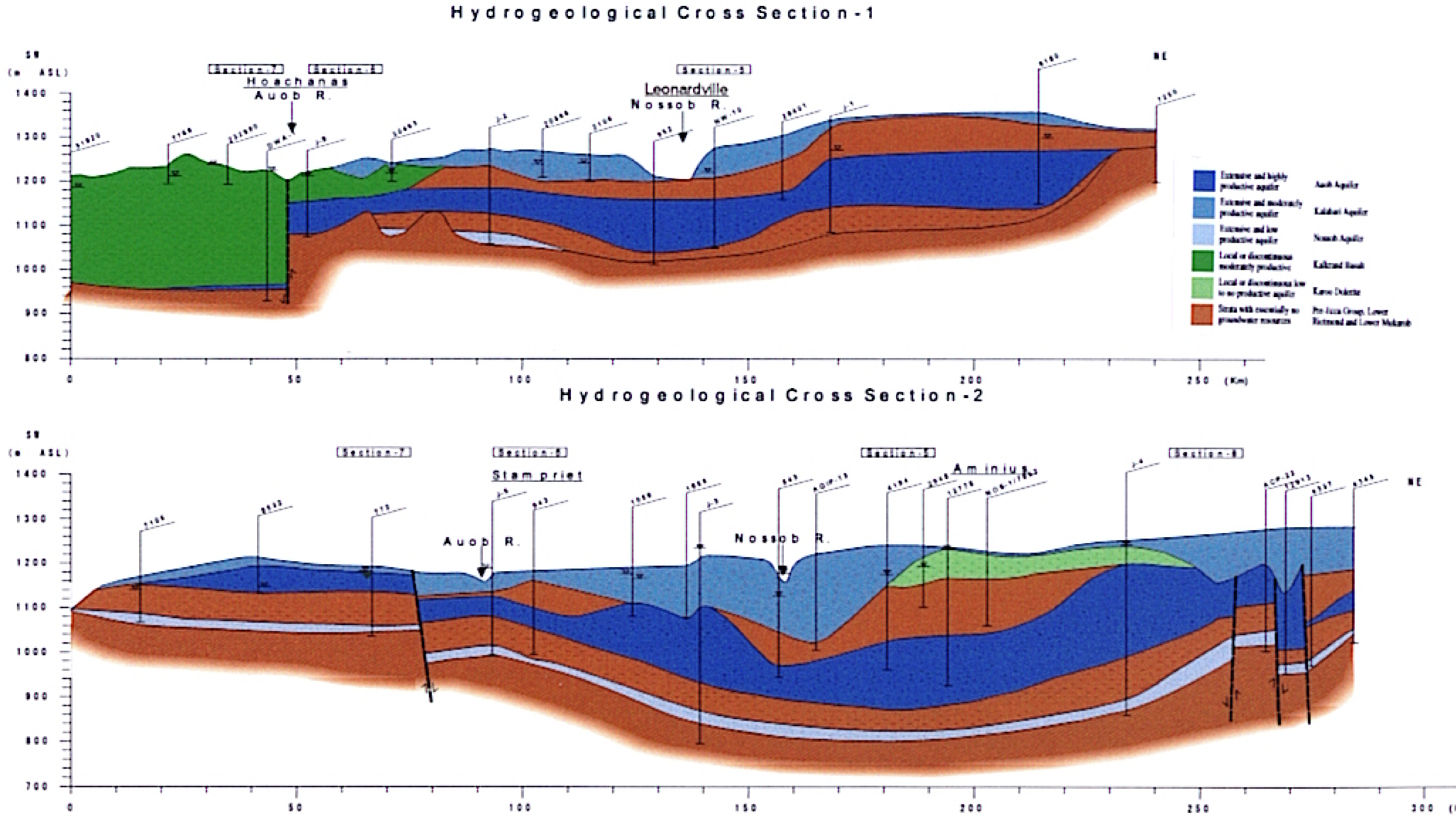
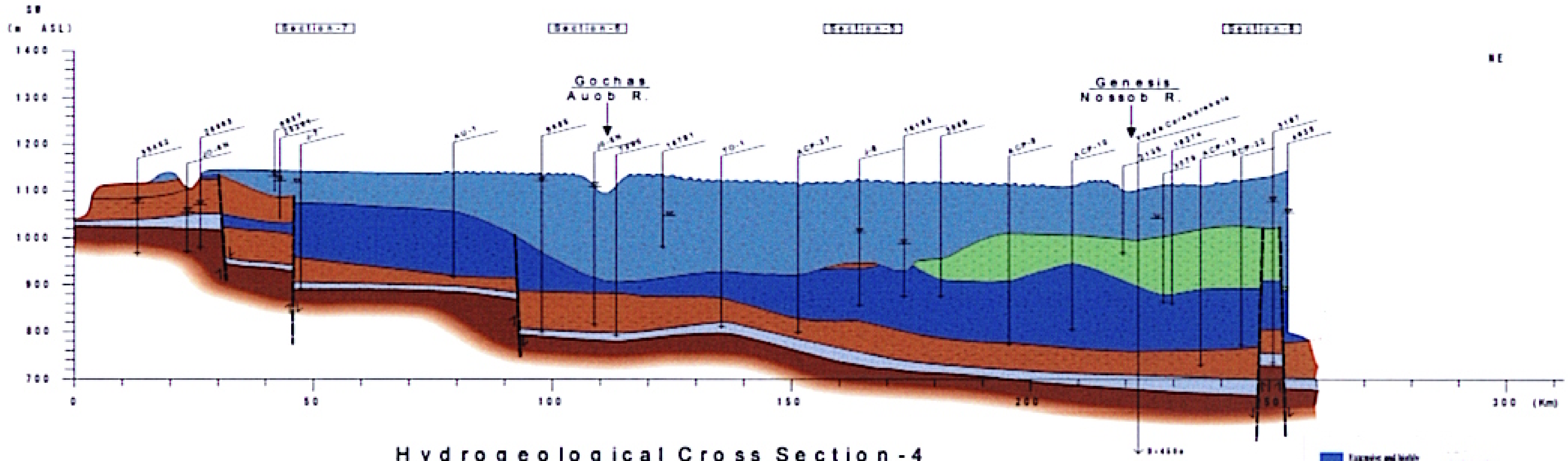


Fig. 3.6-9 (1) Hydrogeological Cross Section

Hydrogeological Cross Section-3



Hydrogeological Cross Section-4

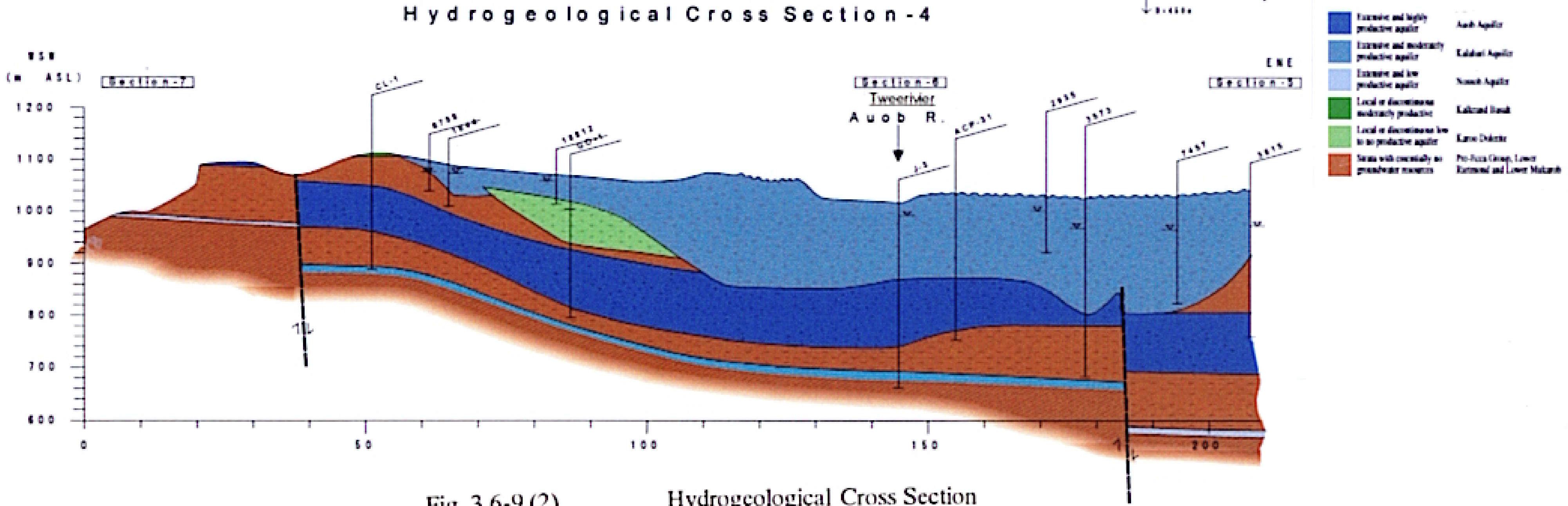


Fig. 3.6-9 (2) Hydrogeological Cross Section

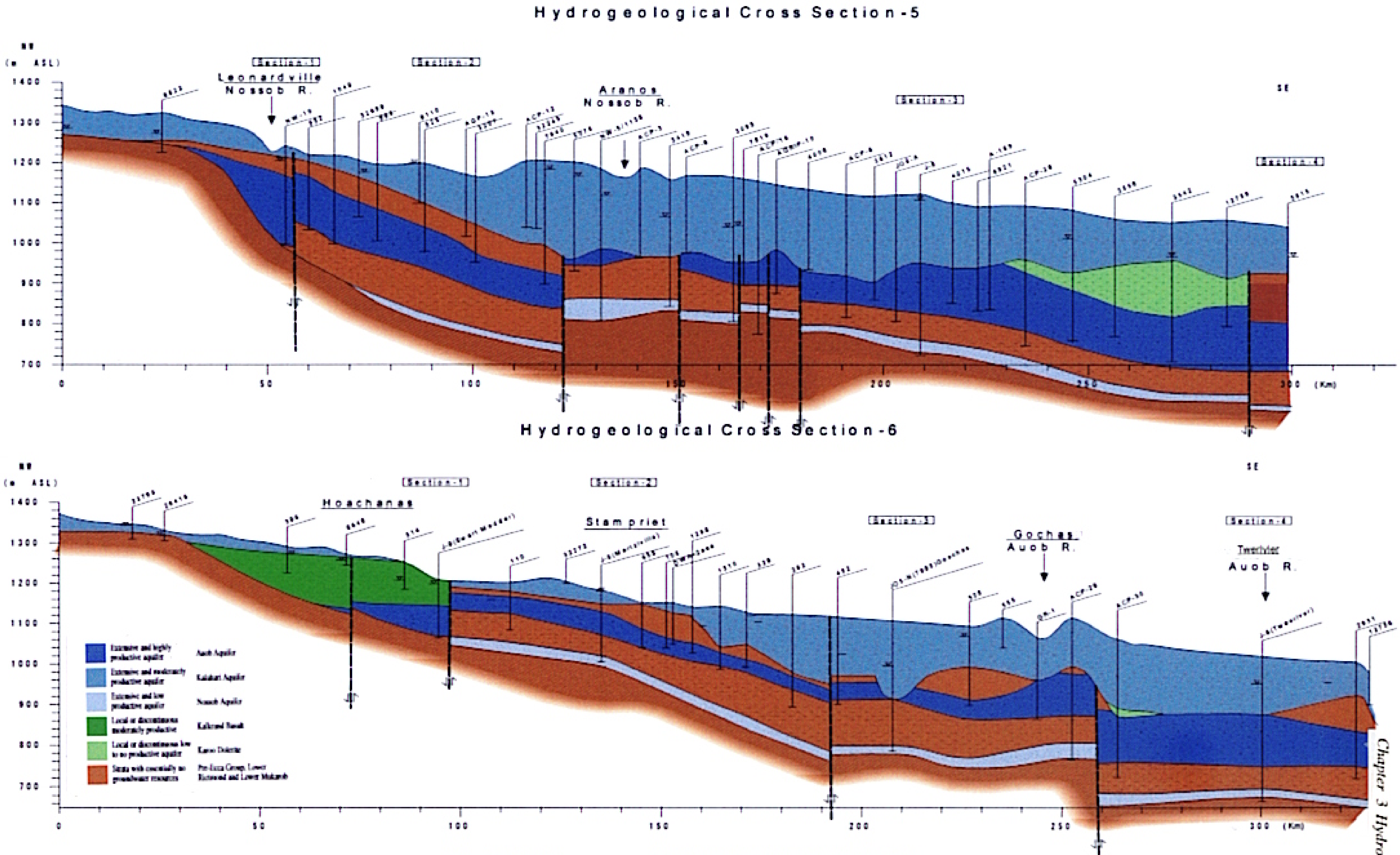


Fig. 3.6-9 (3) Hydrogeological Cross Section

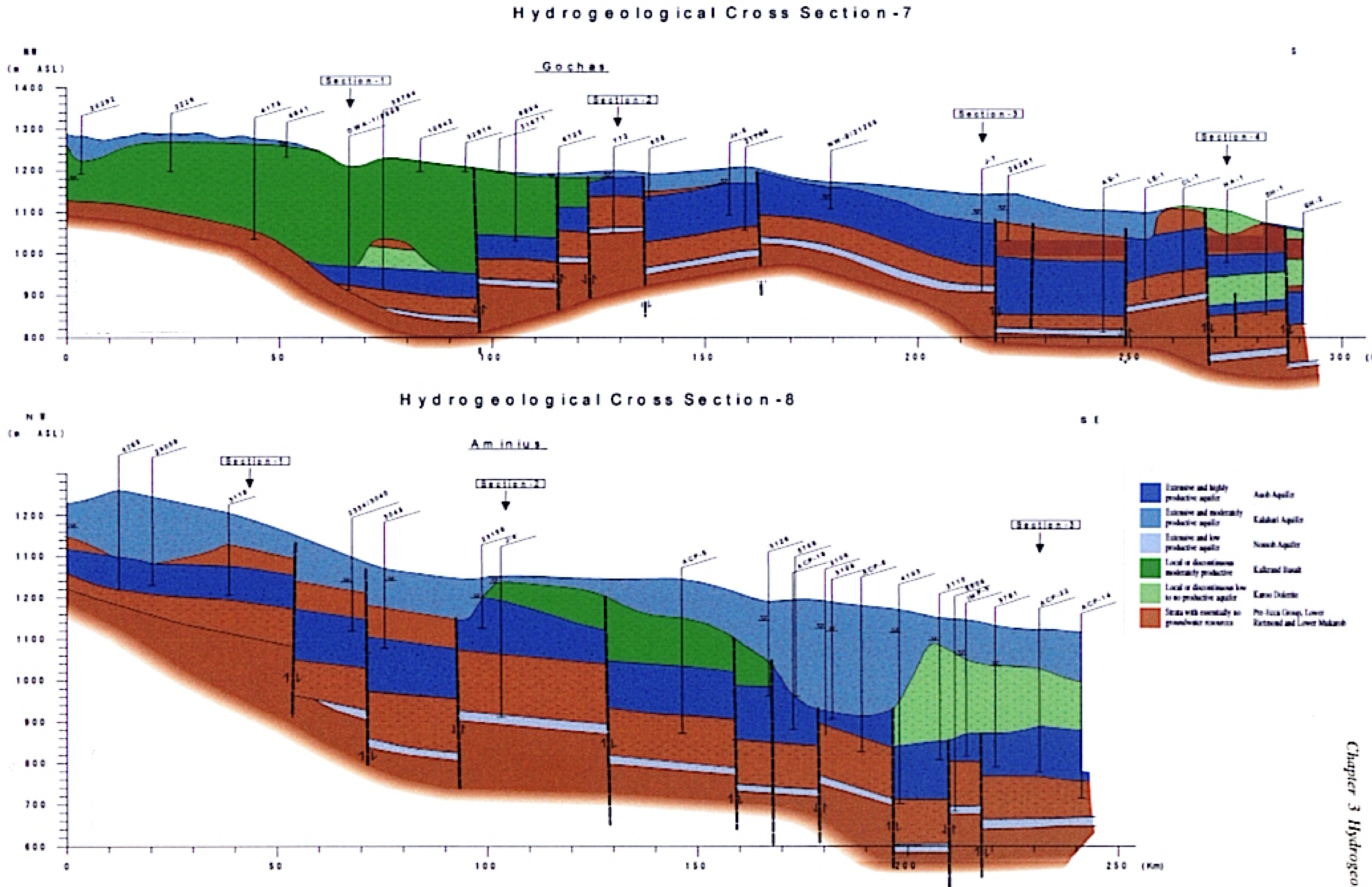


Fig. 3.6-9 (4) Hydrogeological Cross Section

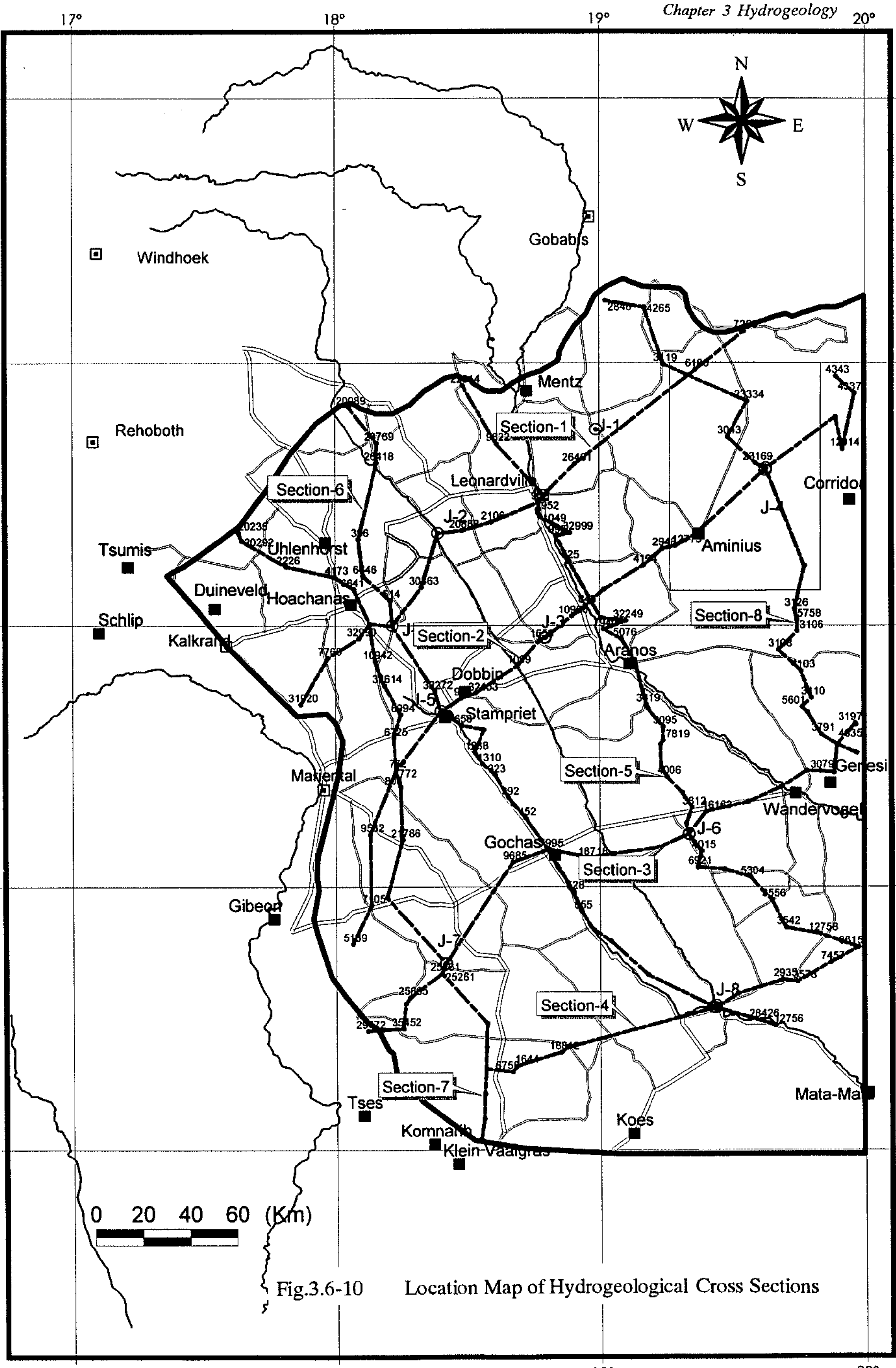


Fig.3.6-10 Location Map of Hydrogeological Cross Sections

3.7 Piezometric Head

3.7.1 Kalahari Aquifer

1) Present Rest Water Level

Rest water level in the Kalahari Aquifer is shown in Fig. 3.7-1. The figure shows the elevation of rest groundwater level above sea level. Groundwater of the Kalahari Aquifer is flowing from the northwest to the southeast harmonizing with geological conditions. A gradient of groundwater table becomes steeper in Aranos or Gochas area but it is inclined gently toward the Salt Block.

2) Long-term Variation of Rest Water Level

The variation of groundwater level in the Kalahari Aquifer at Olifantswater West and Tugela is shown in Fig.3.7-4 to Fig.3.7-6. It is clear that the water levels have been decreasing constantly while showing periodic fluctuation by 5.8 cm/year in Olifantswater West or 4.2 cm/year in Tugela on average since 1986 as shown in Table 3.7-1.

On the other hand, they were suddenly changed after the heavy rain in the rainy season from 1999 to 2000. (hereinafter referred to as 99-00 rainy season)

Table 3.7-1 Results of Water Level Monitoring in Kalahari Aquifer

Area	Well No.	WW No.	*Decreasing Rate (cm/yr)	Increasing Value in 99-00 Rainy Season (cm)	Note
Olifantswater West	DWA-7K(1)	21814	5.5	38	Weak Withdrawal Pattern
	DWA-7K(2)	21815	6.6	46	Withdrawal Pattern
	DWA-5K(1)	22545	5.5	69	Withdrawal Pattern
	DWA-5K(2)	22545	5.5	62	Withdrawal Pattern
	DWA-4K(1)	22546	5.5	46	Weak Withdrawal Pattern
	DWA-4K(2)	22546	6.1	46	Weak Withdrawal Pattern
	Average	-	**5.8**	**51**	-
Tugela	DWA-8K	21814	4.0	192	Weak Withdrawal Pattern
	DWA-10K	21815	4.4	215	Weak Withdrawal Pattern
	DWA-12K	22545	4.3	354	Weak Withdrawal Pattern
	Average	-	**4.2**	**254**	-

*During 1986 to 1999

3.7.2 Auob Aquifer

1) Present Piezometric Head

Groundwater flow of the Auob Aquifer as a whole is similar to the Kalahari Aquifer. A concentric circle at J-8 seems to be attributed to its peculiar circumstance that the observation borehole for Auob Aquifer at J-8 targeted merely the A1 bed situated in the lowest of the Auob Member so that this borehole doesn't represent the whole Auob Aquifer. (Refer to Fig.3.7-2)

2) Long-term Variation of Piezometric Head

Piezometric head of the Auob Aquifer has been recorded at DWA-4A, 5A, 6A and 7A in Olifantswater West, Boomplaas (DWA-2A) and Spes Bona (DWA-3A) although they are strongly affected by withdrawal for irrigation. The monitoring results of piezometric head of the Auob Aquifer are shown in Table 3.7-2.

DWA-6A typically reveals that the piezometric head of the Auob Aquifer had been declining by 5.4cm/year same as the Kalahari Aquifer and slightly risen after heavy rain in 1999 to 2000 rainy season.

Table 3.7-2 Monitoring Results of Piezometric Head in Auob Aquifer

Well No.	WW No.	Area	*Decreasing Rate (cm/yr)	Increasing Value in 99-00 Rainy	Riedmond Member	Note
DWA-2A	10120	Boomplaas	Recognition of tendency	Recognition of tendency	Exist	Strongly effected by irrigation withdrawal
DWA-7A	21784	Olifantswater West	3.6	0	Exist	-
DWA-6A	22544	Olifantswater West	6.2	Slightly	Exist	-
DWA-5A	22545	Olifantswater West	5.9	200	None	-
DWA-4A	22546	Olifantswater West	6.5	Slightly	Exist	Almost same as DWA-7A
DWA-3A	32457	Spes Bona (Stampriet)	Recognition of tendency	Recognition of tendency	Exist	Strongly effected by irrigation withdrawal
DWA-8A	22838	Tugela	5.8	172	?	Same as DWA-8K
DWA-10A	22839	Tugela	5.8	200	?	Same as DWA-10K
DWA-11A	22556	Tugela	4.5	118	?	Same as DWA-8A,10A

*During 1986 to 1999

3.7.3 Nossob Aquifer

1) Present Rest Water Level

General direction of groundwater flow is also from the northwest to the southeast. The gradient of groundwater piezometric head becomes steep locally near the west of Aranos. The average of piezometric head in the Nossob Aquifer is gentle as 1/1000.

This value does not largely change among three aquifers. Although the Nossob Aquifer is located at the lowest altitude, its piezometric head is the highest in the southeastern part of the basin. (Refer to Fig.3.7-3)

2) Long-term Variation of Piezometric Head

There are four observation boreholes for monitoring piezometric head of the Nossob Aquifer by DWA at Gomchanas (DWA-1N) and Tugela (DWA-8N, 9N and 10N) as shown in Fig.3.7-10, 11. Fluctuations of piezometric head of the Nossob Aquifer at DWA-8N and 10N except for DWA-1N or 9N, which are recorded extraordinary data, are very similar to the Kalahari Aquifer. It seems that these boreholes are affected by leakage. Groundwater of the Nossob Aquifer probably can be regarded as fossil water. Whether it is true or not, the analysis of monitoring data from JICA test boreholes is indispensable

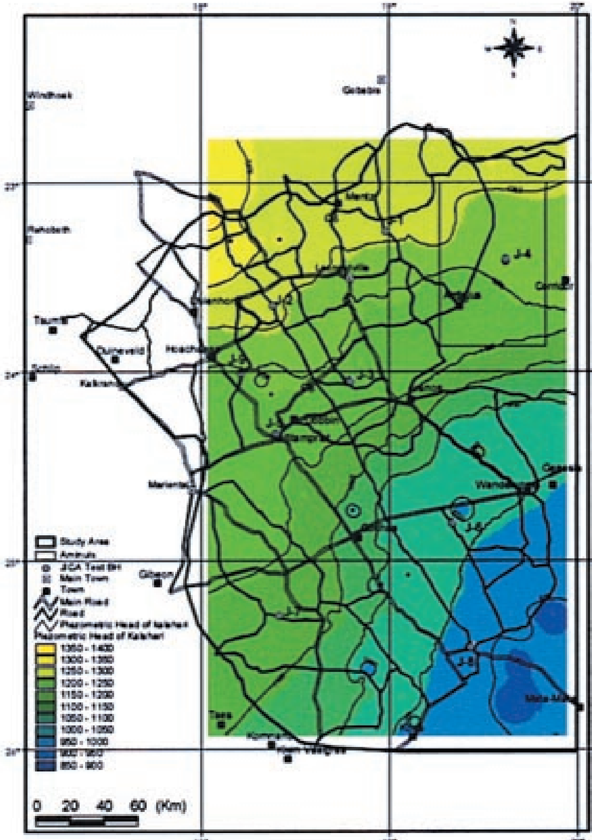


Fig. 3.7-1 Piezometric Head of Kalahari Aquifer

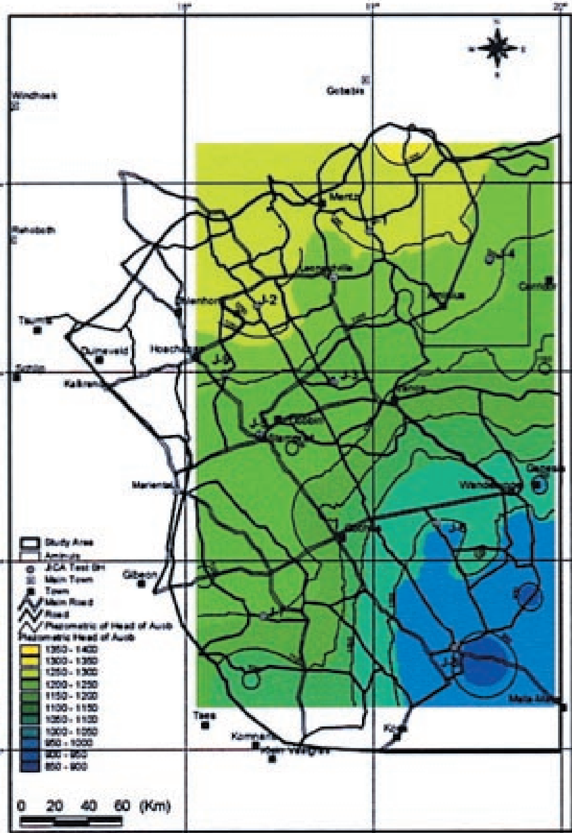


Fig. 3.7-2 Piezometric Head of Auob Aquifer

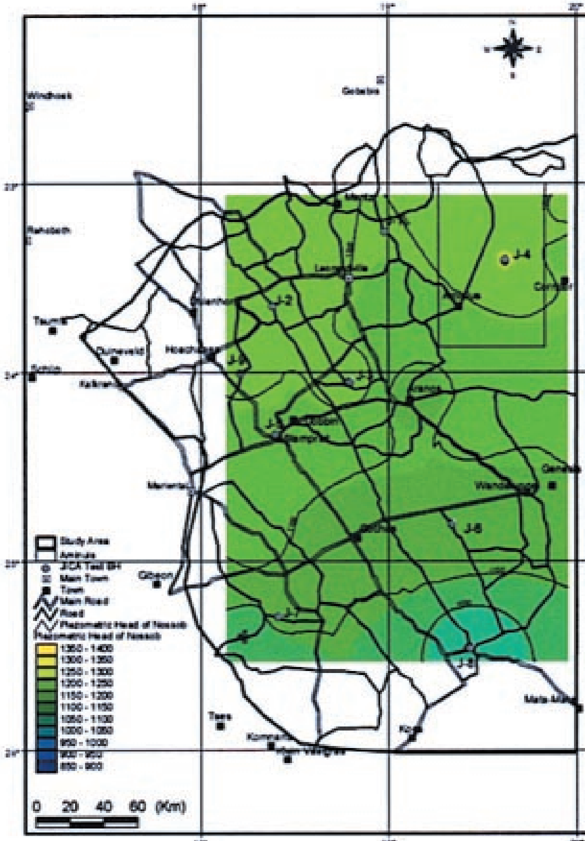


Fig. 3.7-3 Piezometric Head of Nossob Aquifer

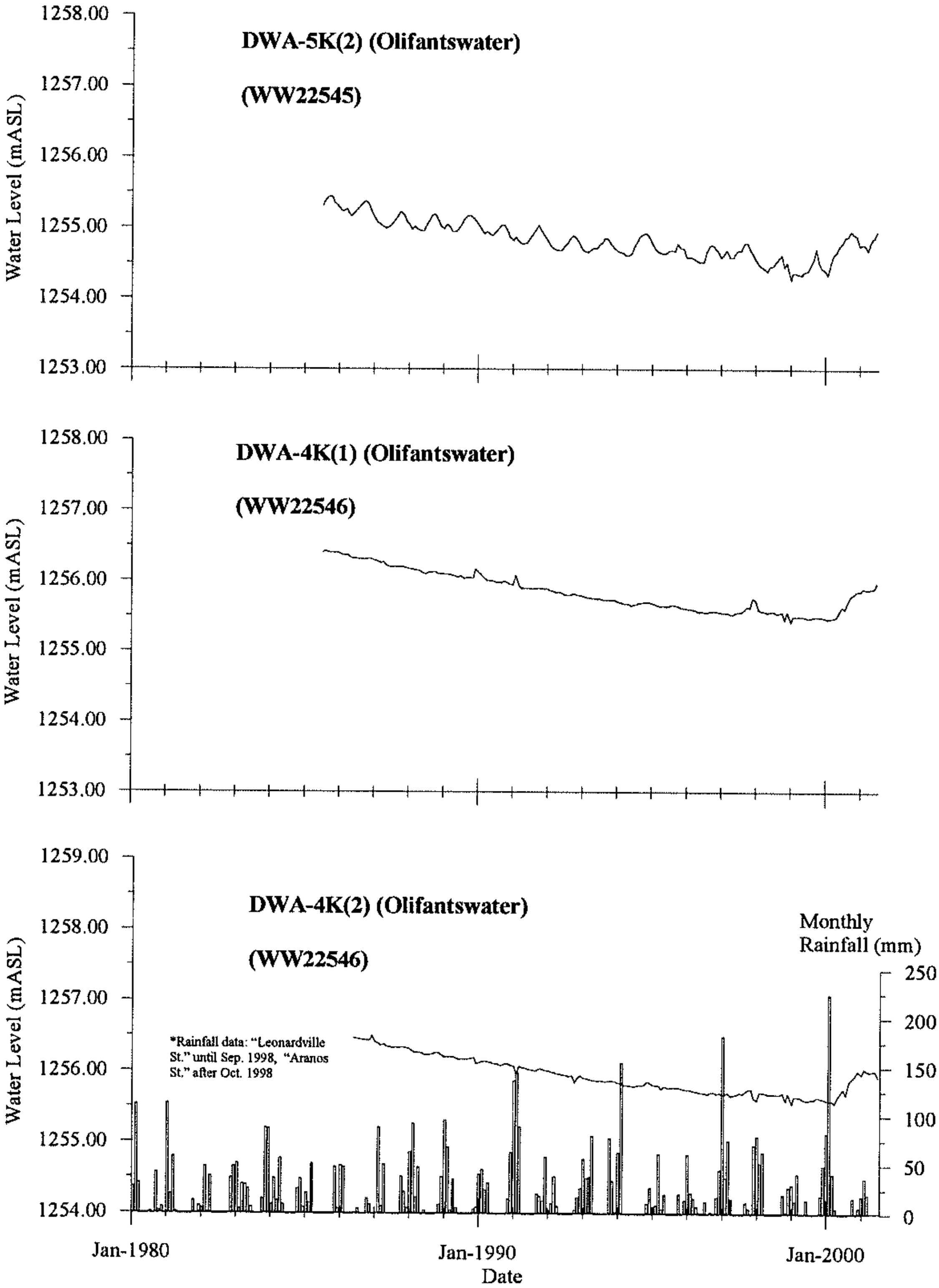


Fig.3.7-4 (1) Variation of Piezometric Head in Kalahari Aquifer

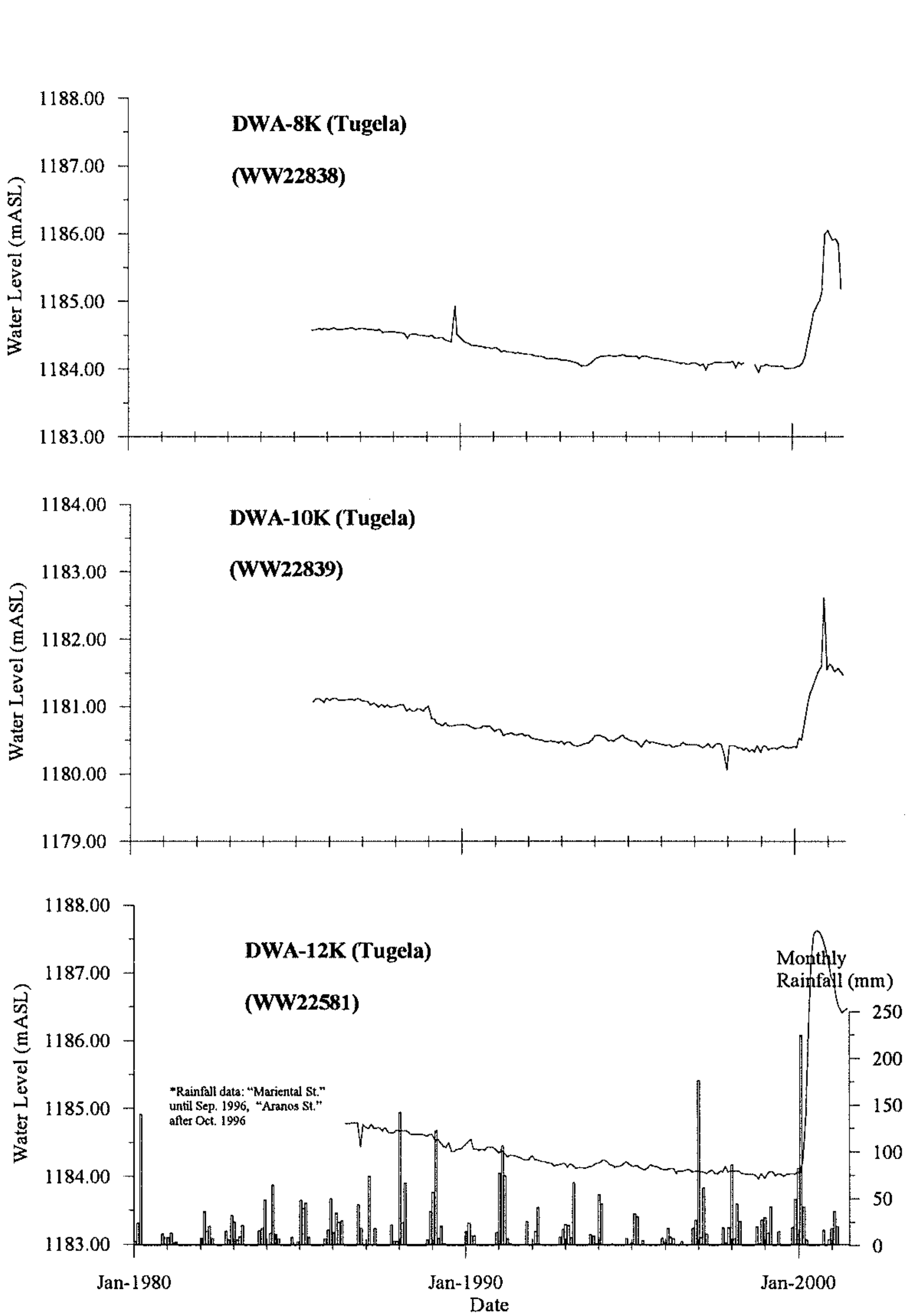


Fig.3.7-4 (2) Variation of Piezometric Head in Kalahari Aquifer

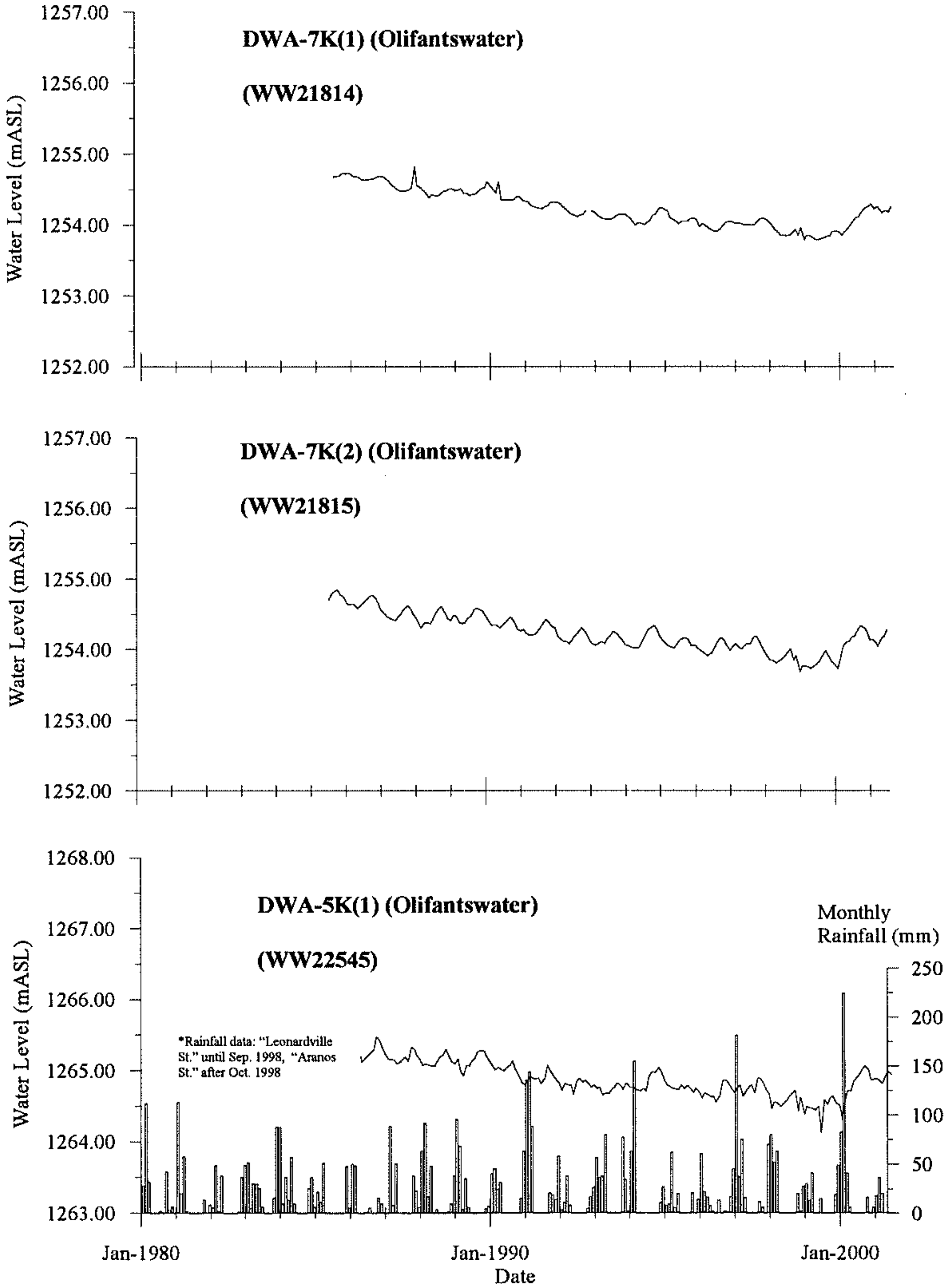


Fig.3.7-4 (3) Variation of Piezometric Head in Kalahari Aquifer

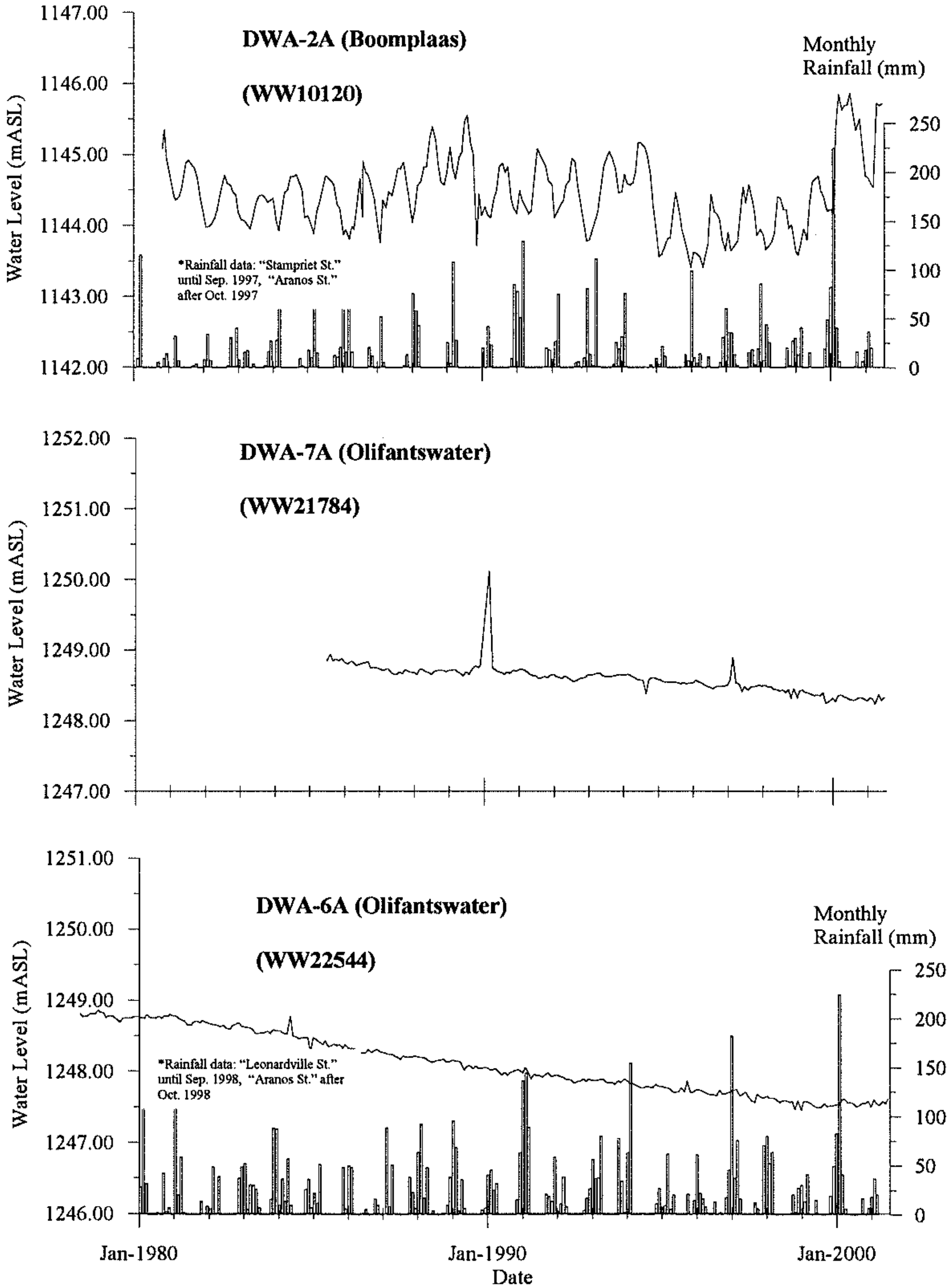


Fig.3.7-5 (1) Variation of Piezometric Head in Auob Aquifer

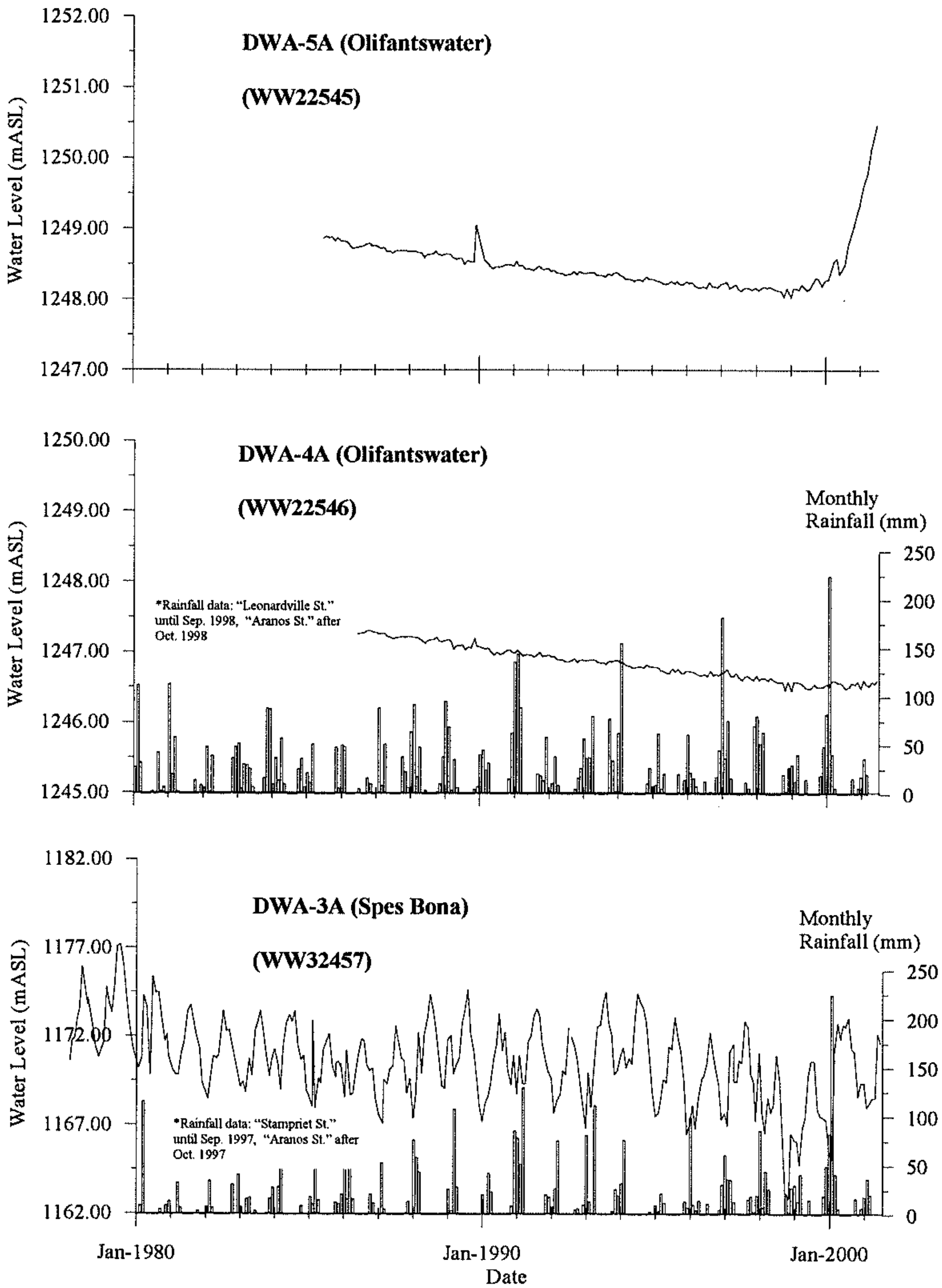


Fig.3.7-5 (2) Variation of Piezometric Head in Auob Aquifer

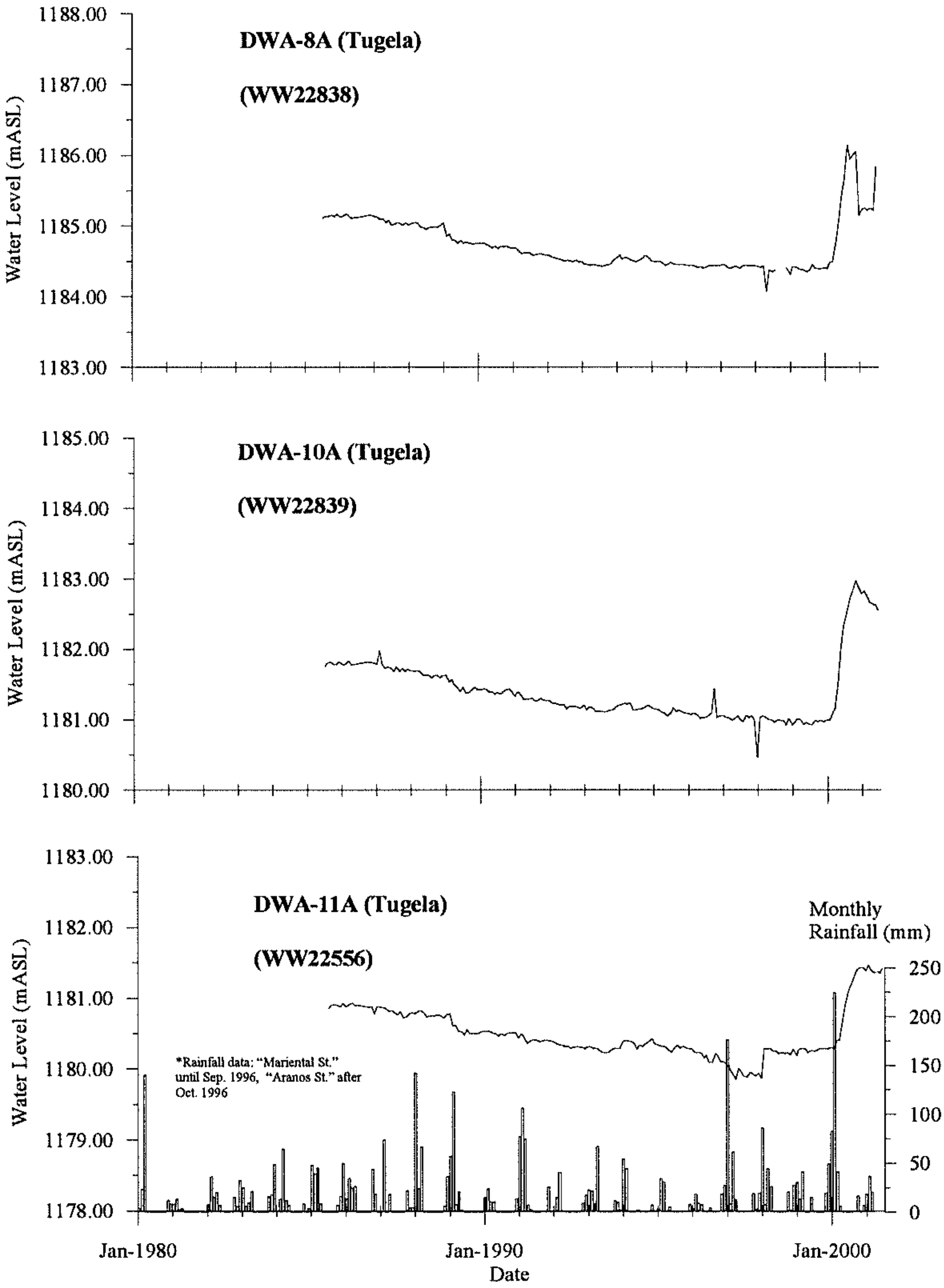


Fig.3.7-5 (3) Variation of Piezometric Head in Auob Aquifer

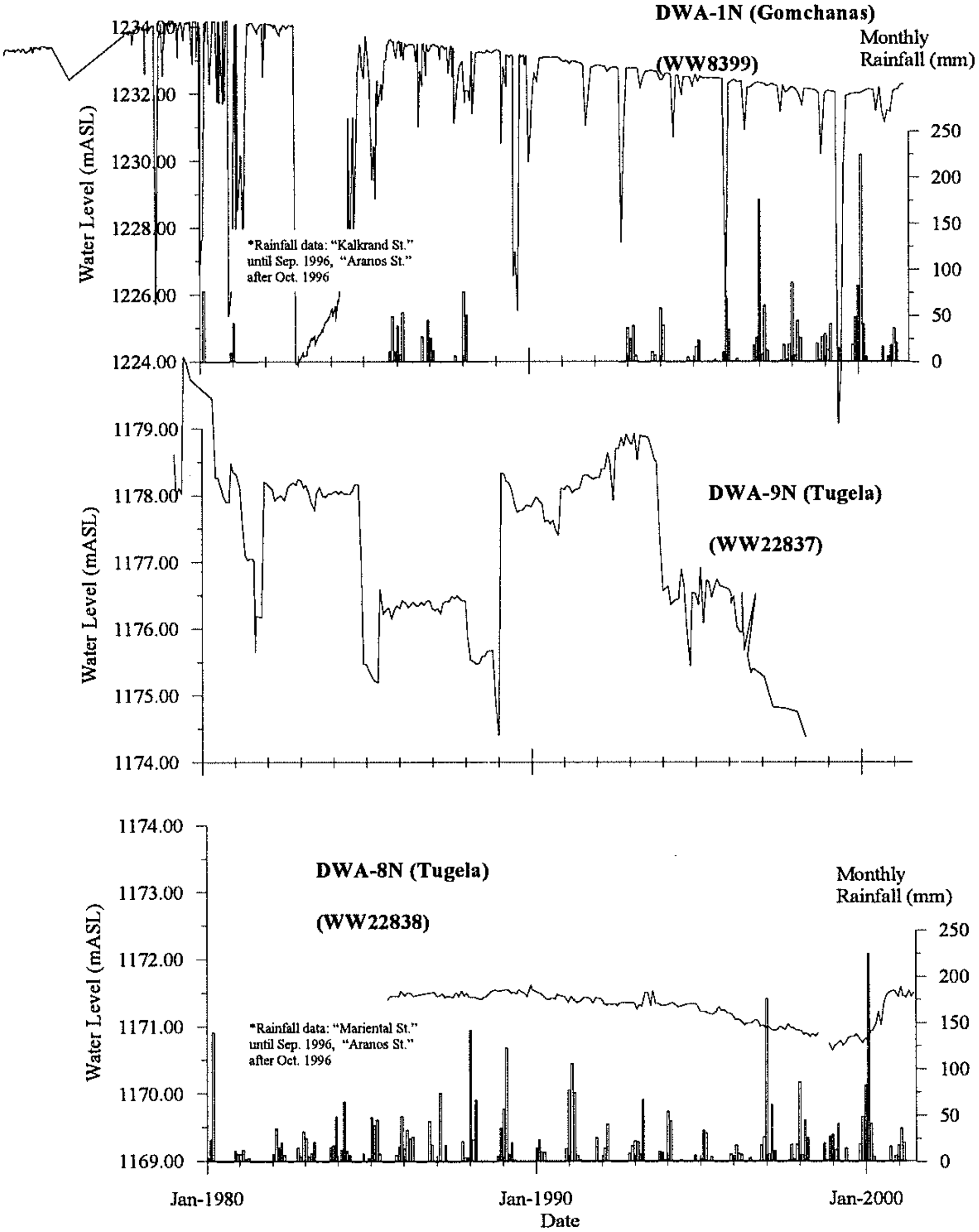


Fig.3.7-6 (1) Variation of Piezometric Head in Nossob Aquifer

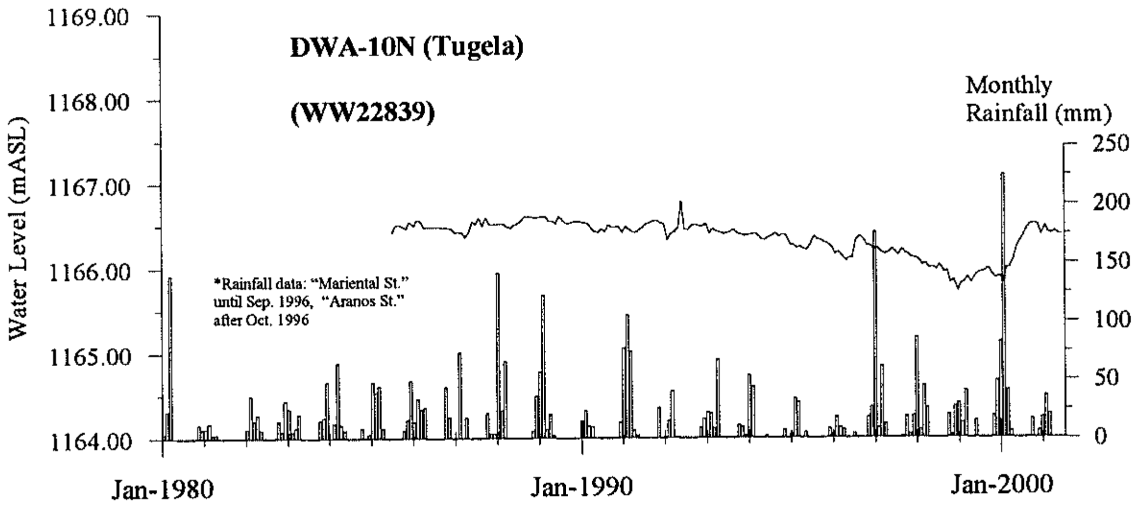


Fig.3.7-6 (2) Variation of Piezometric Head in Nossob Aquifer

3.8 Groundwater Quality

TDS data was obained during this study from JICA test boreholes and selected existing boreholes representing each aquifer. A distribution of TDS concentration of each aquifer is shown in Fig.3.8-1 to Fig.3.8-3.

1) Kalahari Aquifer

It is obvious that the high concentration areas are located in the southeastern part of the study area, especially around J-6. This area mostly coincides with the Pre-Kalahari Valley or “Salt Block”. The maximum concentration of TDS 14,874 mg/l was recorded at J-6.

According to WHO’s Standards for Drinking Water, TDS should be less than 1,000 mg/l. However, its value in the southeastern area from Aranos exceeds the standard.

2) Auob Aquifer

High concentrations of TDS are observed around J-8. The existence of the Salt Block is not so much conspicuous as vague. The maximum value of it is 6,754 mg/l at J-8. Water quality in the northeastern half of the study area is better than the standard as well as that of the Kalahari Aquifer.

3) Nossob Aquifer

High concentration area of TDS in the Nossob Aquifer is also distributed around J-8. Due to a lack of sufficient data and the deep existence of the aquifer, quality evaluation of the data is no possible. A available data seems to indicate that water quality of Nossob Aquifer is the worst among the three aquifers. TDS in most of distribution area of the Nossob aquifer do not satisfied the standard.

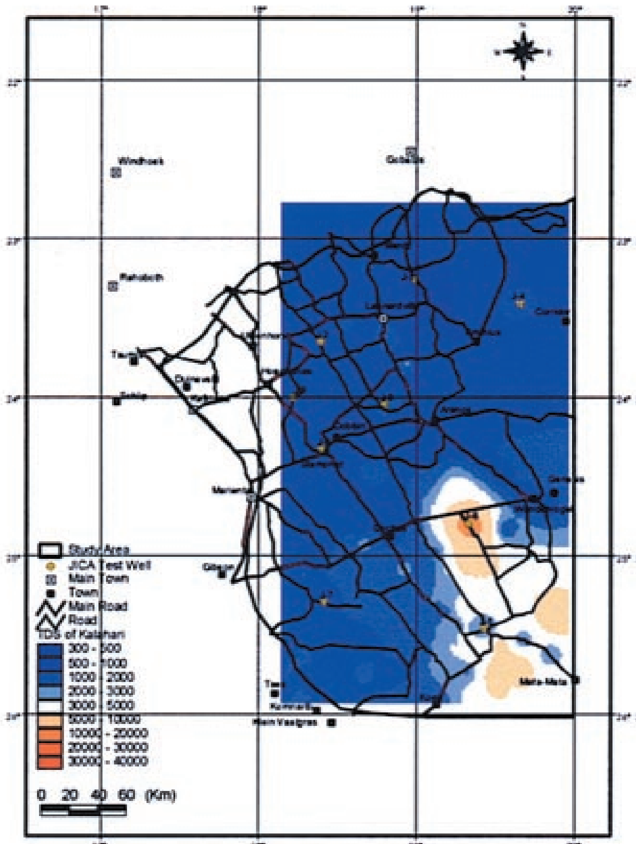


Fig. 3.8-1 TDS of Groundwater in Kalahari Aquifer

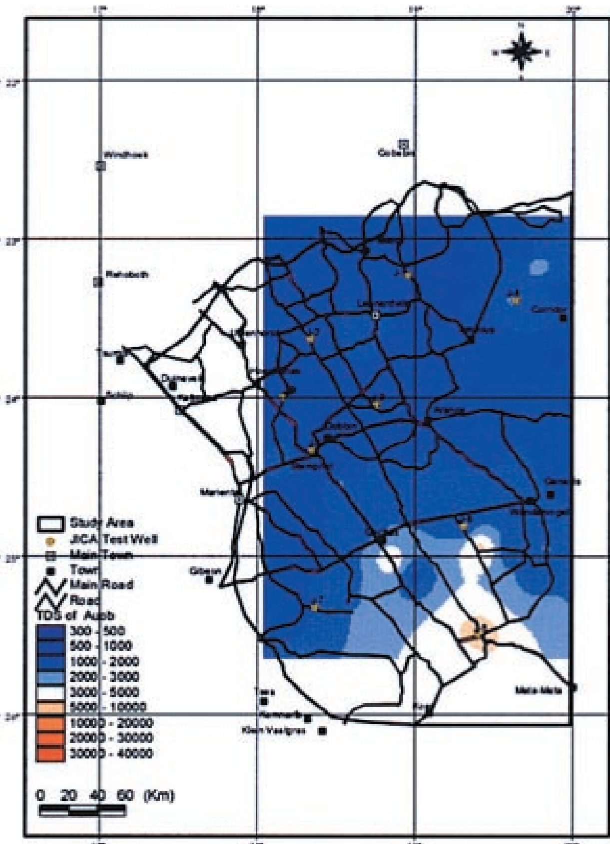


Fig. 3.8-2 TDS of Groundwater in Auob Aquifer

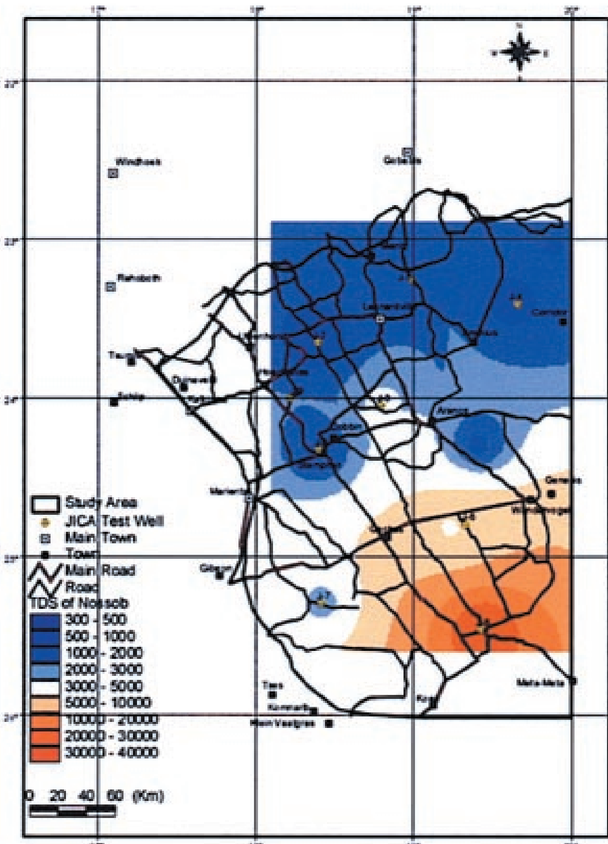


Fig. 3.8-3 TDS of Groundwater in Nossob Aquifer

3.9 Isotope

3.9.1 Environmental Radioisotope Determination and the "Age "of the Groundwater

As explained above, it is essential at any particular point to know how long it took the groundwater to reach that point, calculated from the time it was recharged. The ^{14}C ages in the unconfined aquifer system are shown in Fig. 3.9-1a. Overall, the ages are high, despite the fact that the aquifer system can be recharged virtually everywhere in the basin. Nevertheless, it is important to note that younger water occurs in the northwestern part of the basin in or near the Kalkrand basalt. Younger water (< 2000 a) also occurs along the lower reaches of the Nossob River, which confirms recharge from the riverbed during periods of flood. Younger water (< 5000 a) of good quality also occurs along the lower reaches of the Auob River at borehole WW39854 (J8K), confirming the importance of floodwater recharge in the basin.

On the other hand, groundwater in the Auob Aquifer is generally old, even close to the northern and western edge of the basin (see Fig.3.9-1b). The pattern is relatively consistent but in the centre of the area (mainly in an elongated zone along the Nossob River, and extending towards borehole WW39850 (J6A)) the ages are very high. These high ages are inconsistent as far as the relative distance to any potential recharge area is concerned. Also in the Nossob Aquifer the ages are very high, already in the northeastern part of the basin (see Fig.3.9-1c). The younger age at borehole WW39856 (J8N) is considered to be incorrect as it is a very low yielding borehole and the sample may have become contaminated during the extended sampling process.

Considering the high ^{14}C ages, very low tritium values can be expected both in the unconfined aquifer (see Fig.3.9-2a) and in the confined Auob Aquifer (see Fig.3.9-2b). Nevertheless, it is important confirmation that natural recharge is a very slow process. The trace of tritium in a few boreholes in the unconfined aquifer and also in one borehole in the Auob Aquifer could indicate that younger water may be blended into the aquifer and that a mixture of very old and younger water is abstracted in places. It may possibly also confirm that the ^{14}C ages could be overestimated due to chemical reactions.

3.9.2 Stable Environmental Isotope Results

Both the deuterium and ^{18}O stable isotope results (in ‰) are negative numbers as these waters are depleted in these isotopes. However, the programme that was used for plotting the values could not handle negative data and the results were multiplied by –1 before plotting. When multiplied by –1, the deuterium values in the unconfined aquifer system decrease from the northwest to the southeast (see Fig.3.9-3a). This agrees with the direction of the topographic gradient. However, the difference in elevation is only 350 to 400 m, which will allow a maximum increase of 10 ‰ due to the altitude effect. The difference is somewhat greater and, therefore, the water was possibly also subjected to evaporation. The low values along the lower Nossob are conspicuous as they are lower than expected for that area and must be related to the recharge processes, which will be discussed further below. The large number of data points is due to the parallel IAEA project under which two-thirds of the stable isotope analyses (^{2}H and ^{18}O) were carried out.

Except for the extreme south, deuterium values in the Auob Aquifer do not vary significantly over the basin (see Fig.3.9-3b). This would indicate that once the groundwater has reached the aquifer, no evaporation or other process can significantly affect the stable isotope concentrations. Only mixing with water from another source can change the stable isotope composition. The higher values in the far south agree with the values in the unconfined aquifer system, indicating that the two aquifers are in hydraulic contact. Fig.3.9-3c shows a similar consistent pattern for the Nossob Aquifer. The extremely high value (-20 ‰) at borehole WW36986 on the Weissrand contrasts with the nearby borehole WW39853 (J7N) with a more realistic value of –50 ‰.

Initially it would seem that the ^{18}O distribution in the unconfined aquifer system differs from that of deuterium, but it seems to be largely related to the choice of contour intervals (see Fig.3.9-4a). Also in this case the values increase in a southeasterly direction along with the topographic gradient and the groundwater flow direction. In the unconfined aquifer system evaporation or evapotranspiration is possible over most of the basin. In this case the low values (up to –9.0 ‰) along the lower reaches of the Nossob River are also clearly evident. In the Auob Aquifer the values in the southwestern half of the basin are consistently above –7.0 ‰ while they are smaller than –7.0 ‰ in the northeastern half of the basin (see Fig.3.9-4b). In the extreme south, the values are comparable with those of the unconfined aquifer system.

In the Nossob Aquifer (see Fig.3.9-4c) the same two boreholes, WW36986 and WW39853 (J7N), with high deuterium values, also have anomalously high $d^{18}O$ values.

In Fig. 3.9-5a all the available stable isotope data points are plotted together. The graph also shows the meteoric water line and a linear regression line for the Kalahari groundwater. The main feature is that most of the points plot along a linear regression line with a slope of approximately 5, which agrees with a typical evaporation line. Thus virtually all the groundwater in the basin has been subjected to evaporation. The isotope data for the unconfined aquifer system of the Kalahari, basalt (Kalkrand Formation) and the Rietmond Formation are plotted separately in Fig.3.9-5b. This clearly shows the distribution of the points along the evaporation line. Two of the boreholes along the lower reaches of the Nossob River with low values for both variables can clearly be seen in the lower left-hand corner of the graph. These waters are close to the meteoric water line and have, therefore, not been subjected to evaporation or evapotranspiration. This is of significance, as it would indicate that the floodwater soaked away quickly before the water had a chance to evaporate at the surface. The outliers at the higher end of the scale have already been identified on the maps.

The graph for the Auob Aquifer (Fig.3.9-5c) shows that the deviation from the meteoric water line is generally less for the Auob groundwater, except for a few outliers, which have already been identified on the maps. Most of the Nossob groundwater also plots in this part of the graph (see Fig.3.9-5d).

The nitrogen isotope ratio ($^{15}N/^{14}N$), expressed as d^{15}N ‰, has been determined for fifty samples in the unconfined aquifer system and the Auob Aquifer in areas where nitrate occurs. The results were plotted on maps for providing an overview of the situation (see Fig.3.9-6a and 3.9-6b). Generally, a d^{15}N value of +5 to +8 ‰ indicates that the nitrate is from a natural soil/plant origin, while a d^{15}N value higher than +10 ‰ may indicate nitrogen from an animal source or on-site sanitation. Although most of the isotopic ratios are low, some of them are high enough to indicate a potential pollution source. These values confirm observations in the field where boreholes, particularly shallow ones, are often inadequately protected against pollution from the surface at stock-watering points. In other cases on-site sanitation has not been properly designed and septic tanks and their french drains are too close to the boreholes. In the case of the unconfined aquifer system, a total of eight boreholes sampled for ^{15}N showed potential signs of pollution, while at four of these it could be more likely. Two, or potentially three of the boreholes sampled in the Auob Aquifer may be affected. The identified boreholes should be inspected for further follow-up actions.

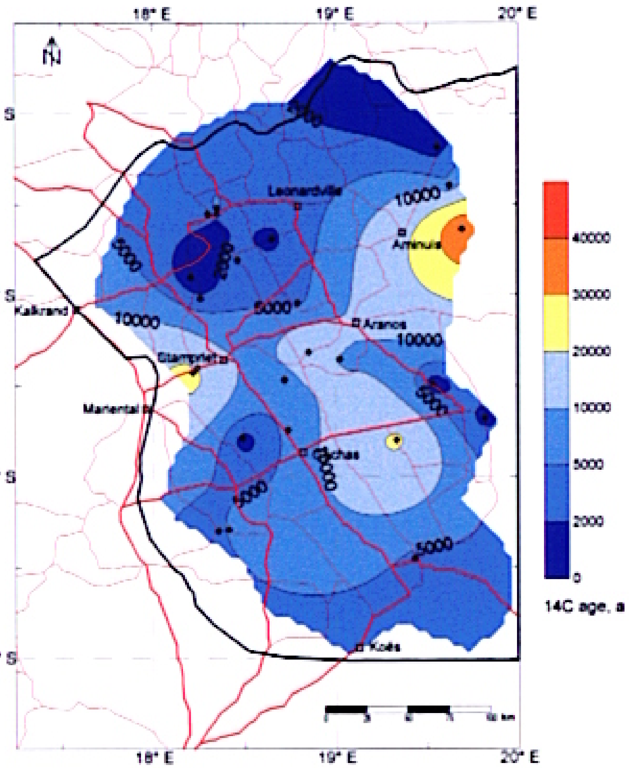


Fig.3.9-1a Carbon-14 groundwater age in the unconfined aquifer system (Kalahari, basalt & Rietmond)

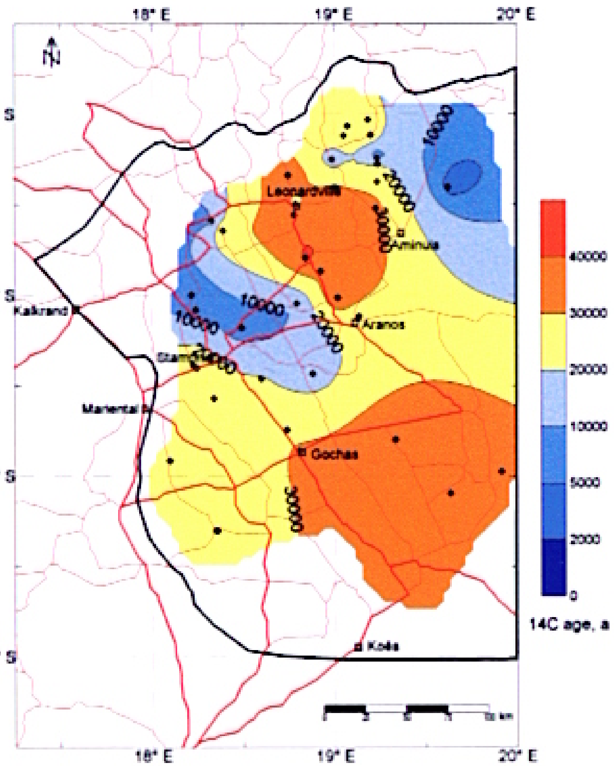


Fig.3.9-1b Carbon -14 groundwater age in the Auob aquifer

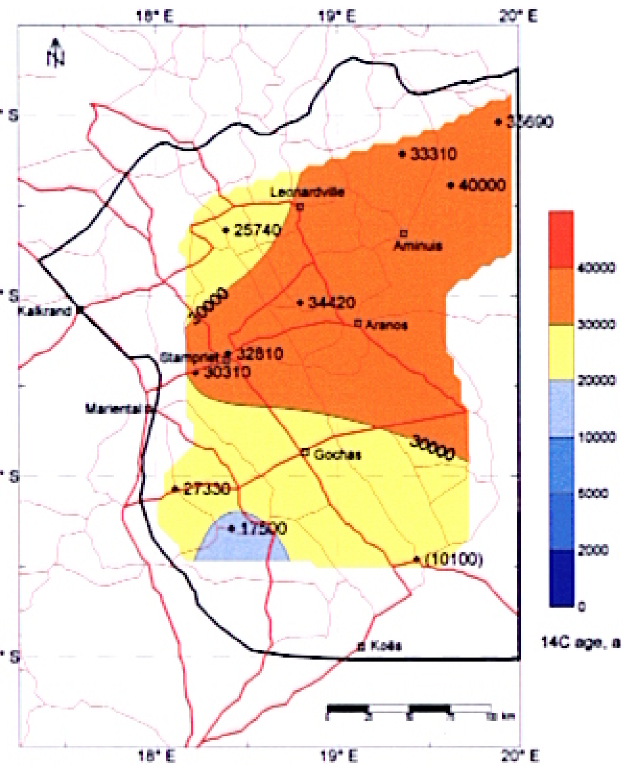


Fig.3.9-1c Carbon-14 groundwater age in the Nossob aquifer

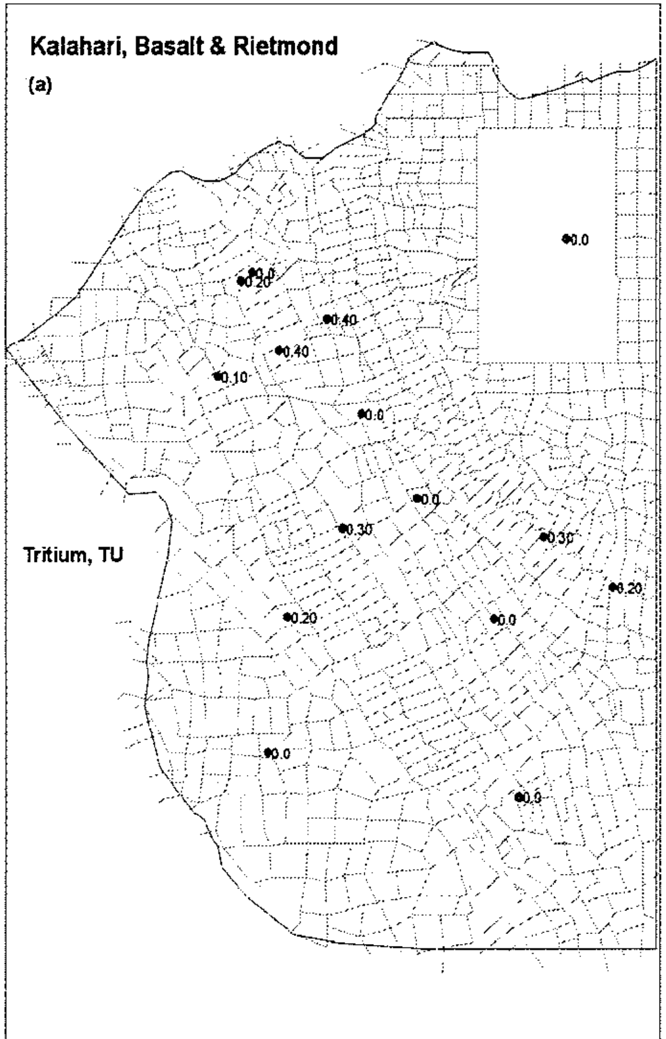


Fig.3.9-2a Tritium concentrations in the unconfined aquifer system (Kalahari, basalt & Rietmond)

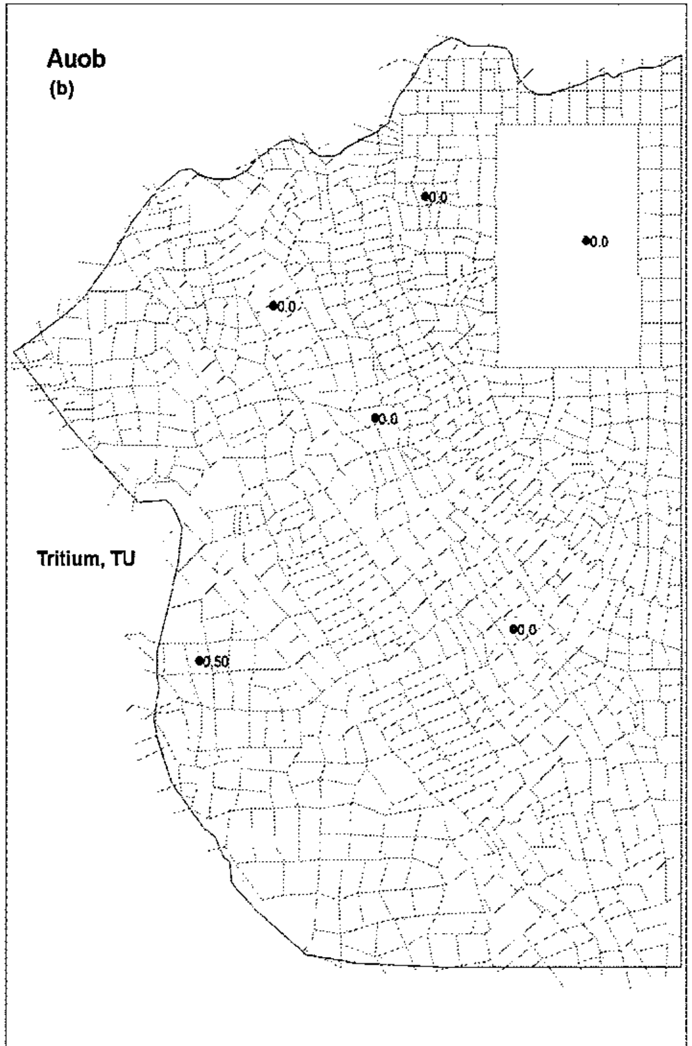


Fig.3.9-2b Tritium concentrations in the Auob aquifer

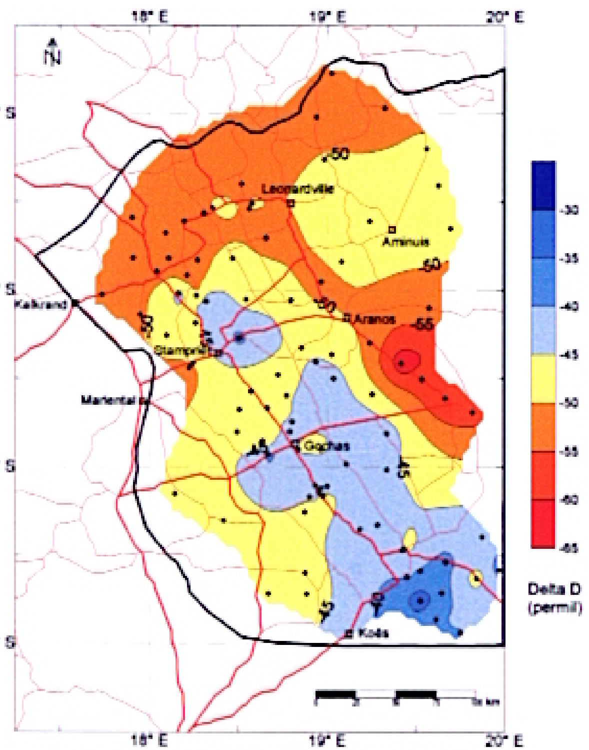


Fig.3.9-3a Deuterium ratios (delta D) in the unconfined aquifer system (Kalahari, basalt & Rietmond)

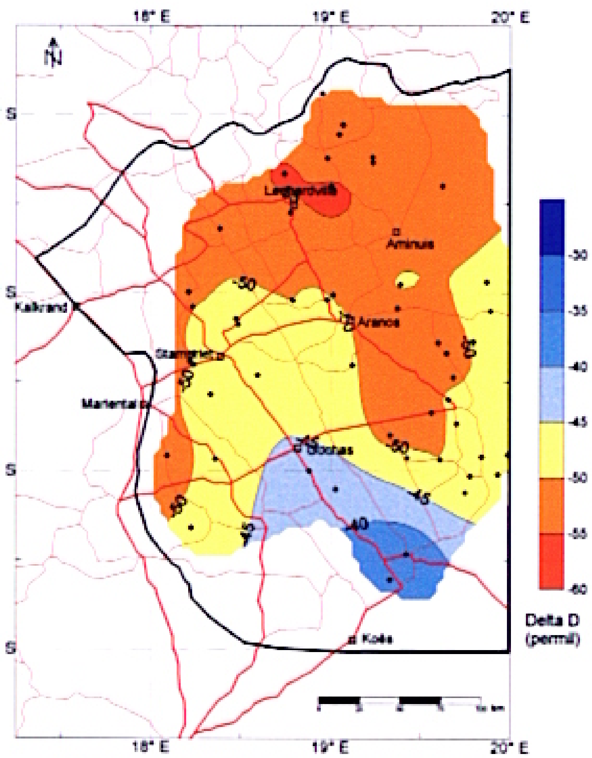


Fig.3.9-3b Deuterium ratios (delta D) in the Auob aquifer

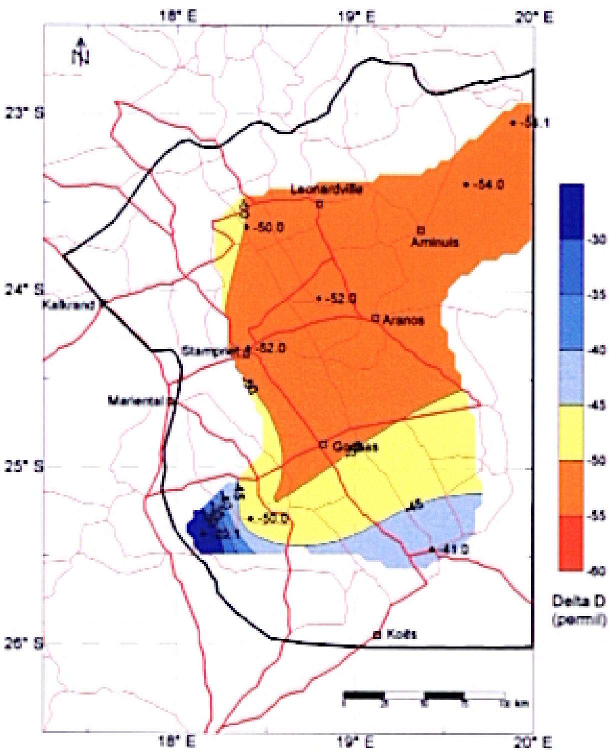


Fig.3.9-3c Deuterium ratios (delta D) in the Nossob aquifer

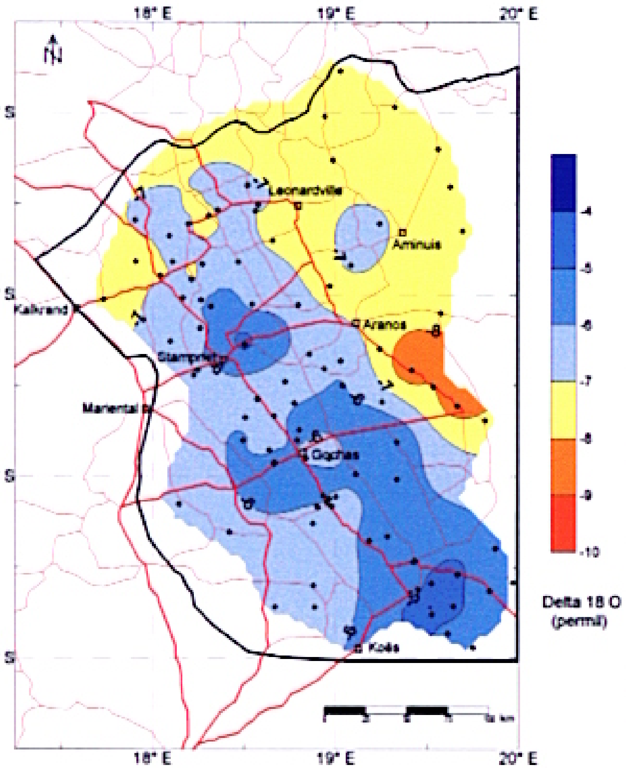


Fig.3.9-4a Oxygen-18 ratios (delta 18 O) in the unconfined aquifer system (Kalahari, basalt & Rietmond)

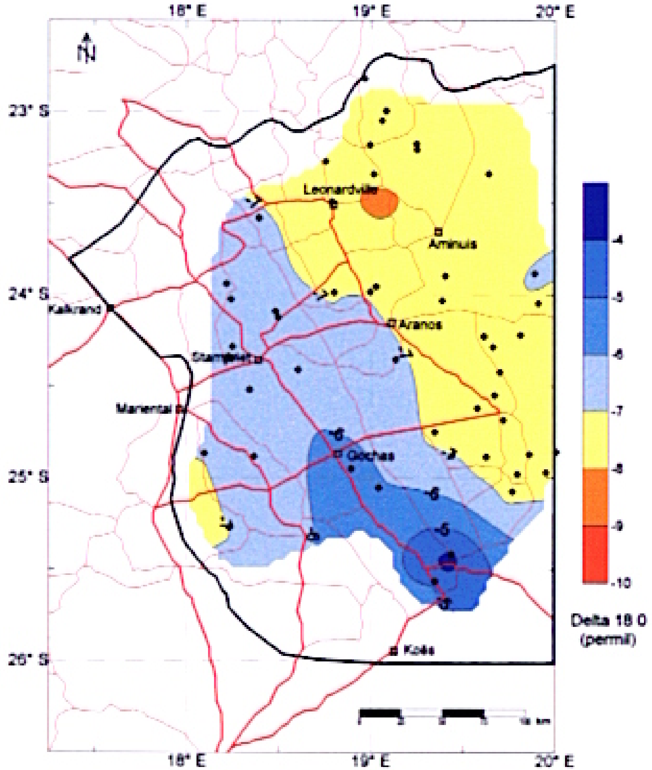


Fig.3.9-4b Oxygen-18 ratios (delta 18 O) in the Auob aquifer

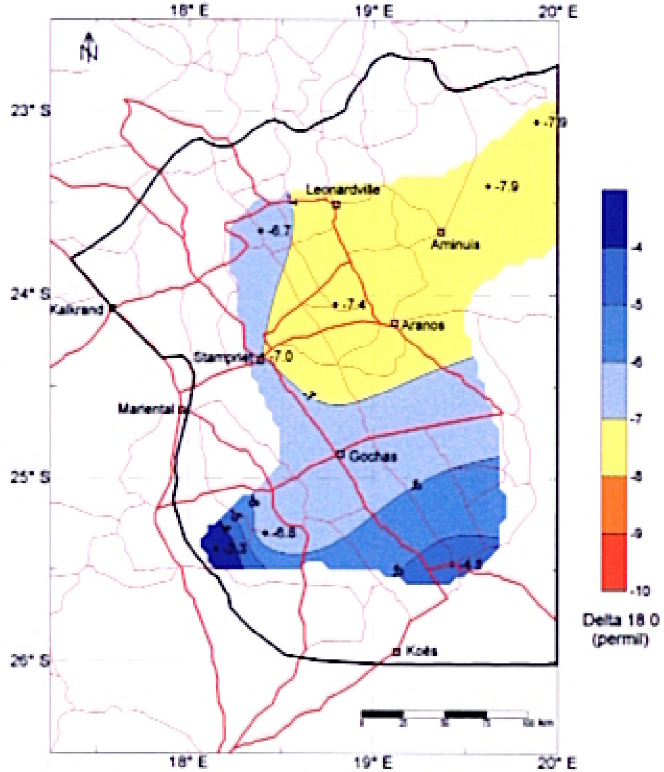


Fig.3.9-4c Oxygen-18 ratios (delta 18 O) in the Nossob aquifer

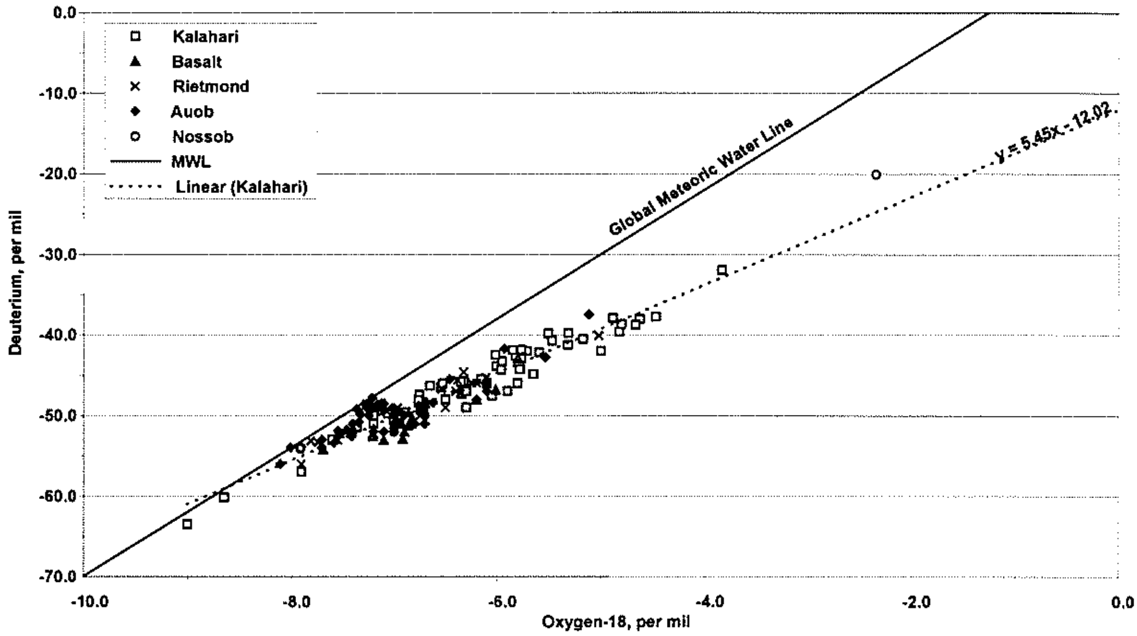


Fig.3.9-5a **Stable isotope relationships in all aquifers**

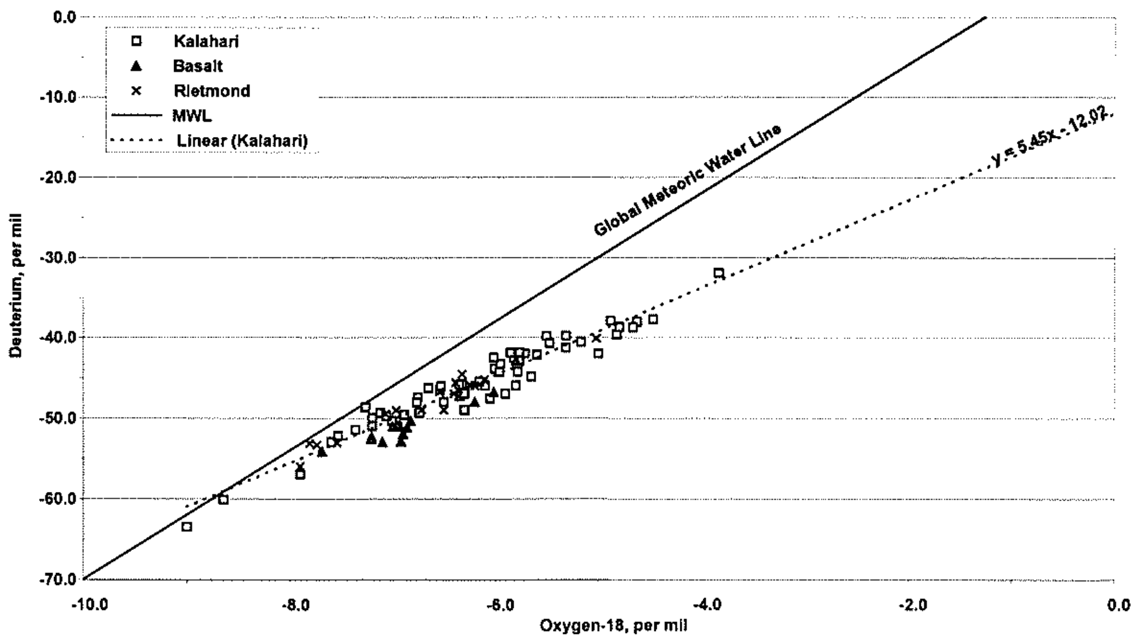


Fig.3.9-5b **Stable isotope relationships in the unconfined aquifer system: Kalahari, basalt & Rietmond**

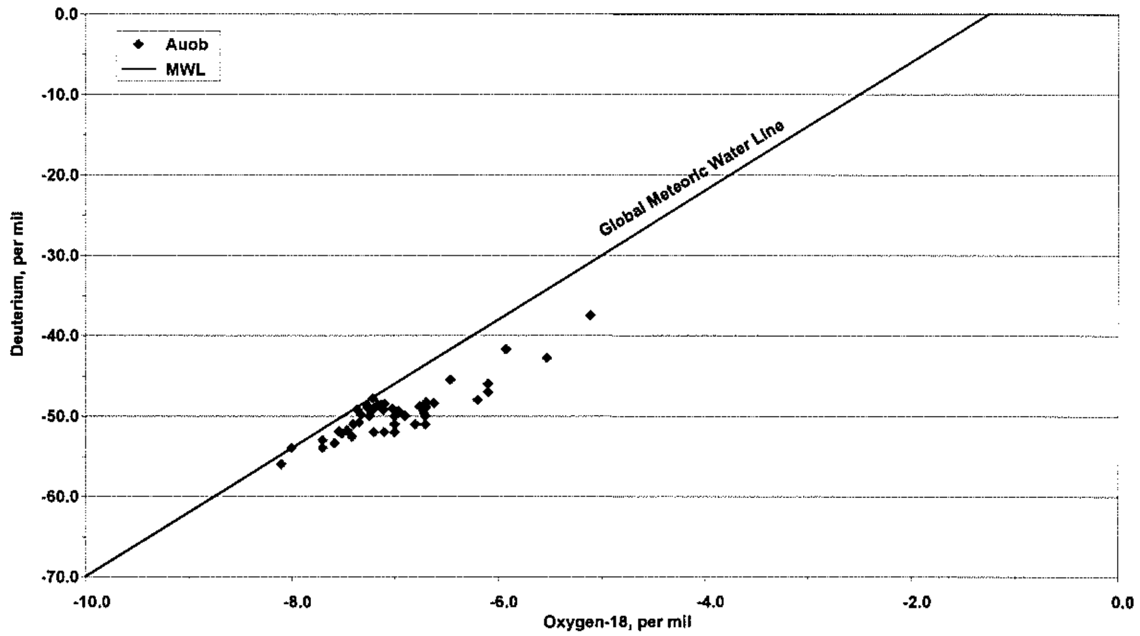


Fig.3.9-5c **The stable isotope relationship in the confined Auob aquifer**

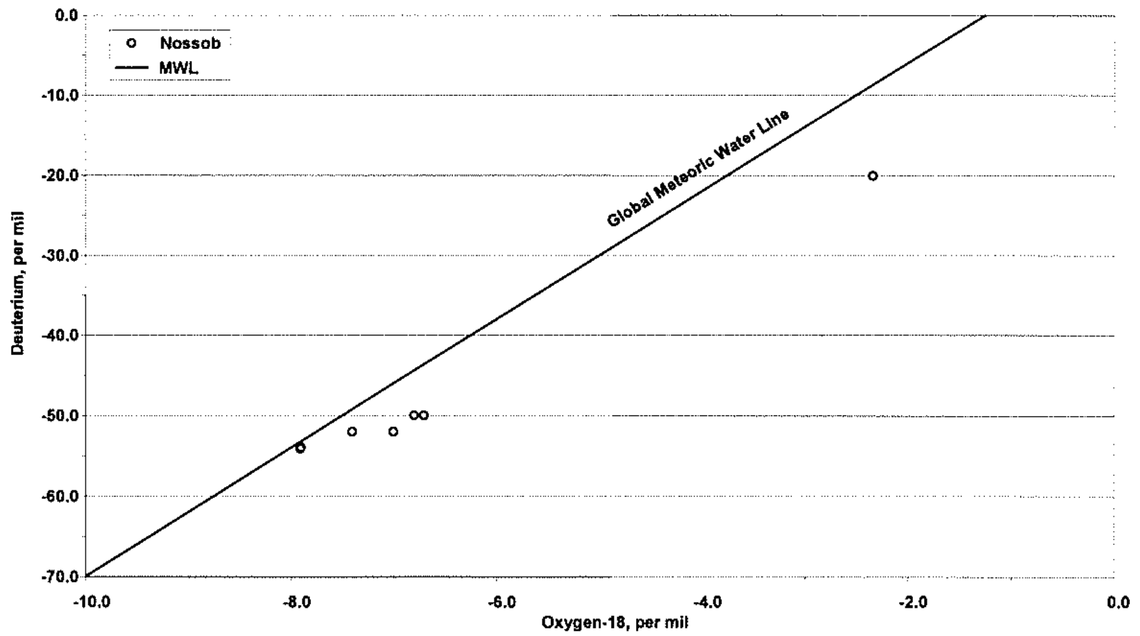


Fig.3.9-5d **The stable isotope relationship in the confined Nossob aquifer**

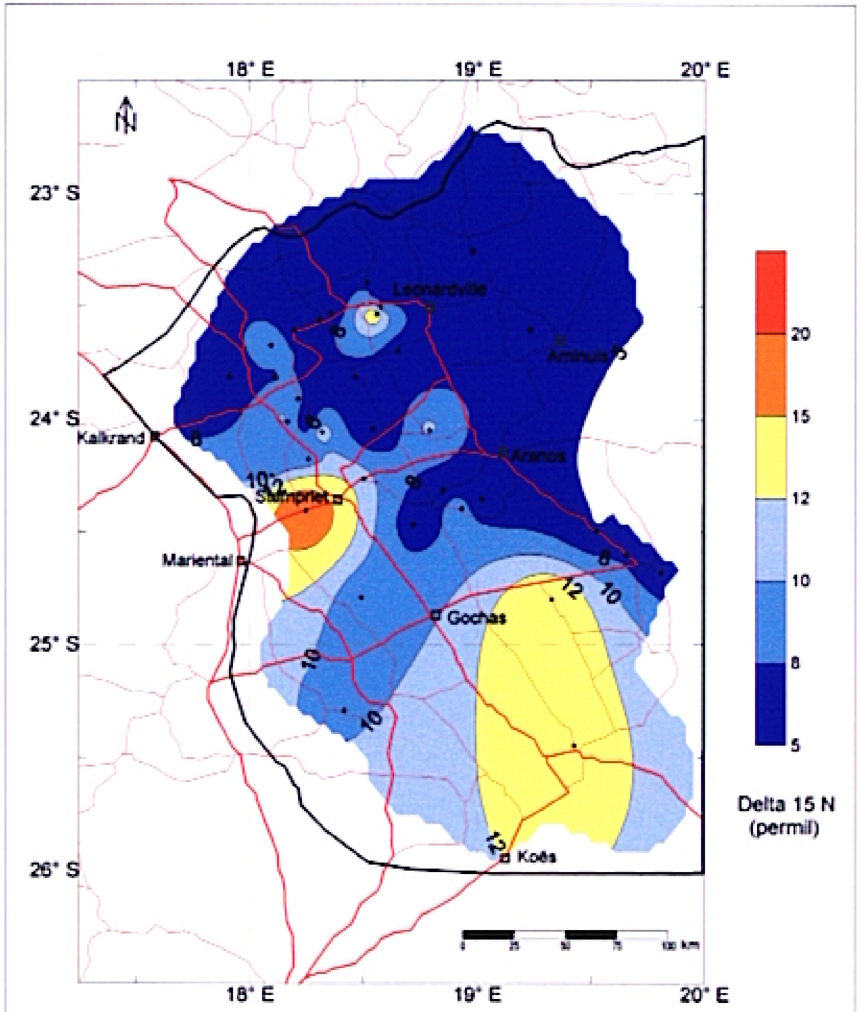


Fig.3.9-6a Nitrogen-15 ratios (delta 15 N) in the unconfined aquifer system (Kalahari, basalt & Rietmond)

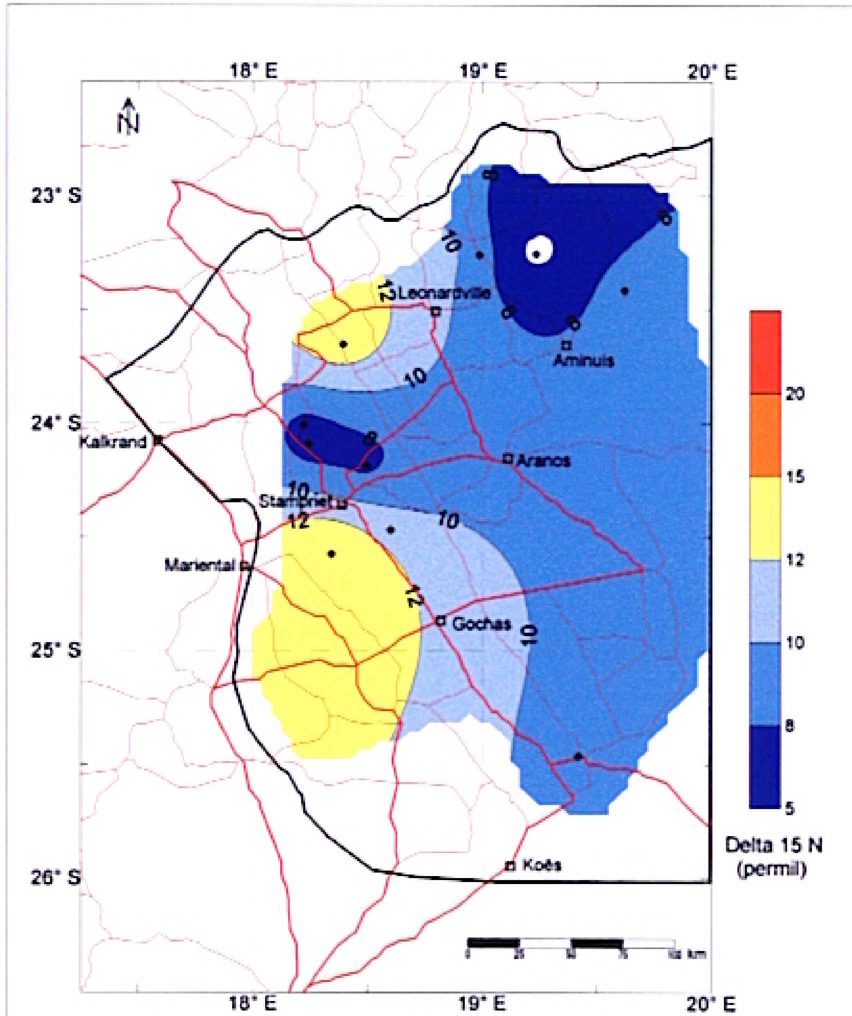


Fig.3.9-6b Nitrogen-15 ratios (delta 15 N) in the Auob aquifer

3.10 Groundwater Recharge and Macro Water Balance

Water balance of the basin is generally presented as the following formula.

$$\Pr - Qs - R - Er = \Delta Sgr + \Delta Ssr$$

Pr: Precipitation in recharge area, Qs: Discharge of Surface flow,

R: Recharge, Er: Evapo-transpiration, △Sgr: Groundwater storage change

△ Ssr: Surface water storage change

3.10.1 Precipitation

The study area is situated in the downstream of both catchment areas, the Auob and the Nossob River. The areas of them are listed in the Table 3.10-1. The study area occupies approximately 70% of the whole catchment area.

Table 3.10-1 Catchment Areas

Unit: km^2

Catchment	Study	Upstream	Total
Auob	40,002	15,414	55,416
Nossob	29,576	17,410	46,986
Total	69,578	32,824	102,402

The precipitation in an ordinary year was estimated from annual average rainfall of past ten years at nine observation stations before 99-00 rainy season as shown in the Supporting Report Chapter 2. Fig.3.10-1 and Table 3.10-2 show the distribution of annual precipitation of the basin in an ordinary year. On the other hand, the precipitation volume in 99-00 rainy season, which was an extraordinary year in terms of rainfall volume and intensity in short period, is also calculated.

Table 3.10-2 Precipitation Volume in Ordinary Year and 99-00 Rainy Season

Unit: $10^9 m^3$/year

Catchment Area	Ordinary Year		99-'00 Rainy Season	
Upstream Area	7.8	(100%)	17.5	(224%)
Study Area	14.3	(100%)	33.8	(236%)
Total	22.1	(100%)	51.3	(232%)

The precipitation of the study area in an ordinary year is shown in Fig.3.10-2, whereas Fig.3.10-3 shows the heavy rain during Feb. and Mar. in 99-00 rainy season. Table3.10-2 summarize the two cases of precipitation volume in the study area and the upstream area. The table indicates that the precipitation volume in 99-00 rainy season was more than two times of an ordinary year.

3.10.2 Groundwater Recharge

1) Water Level Analysis

(1) Kalahari Aquifer

The average upturn of water level in 99-00 rainy season is recorded at 51cm in Olifantswater West and 254cm in Tugela. It is remarkable that the upturn of water table in Tugela is five times as large as Olifantswater. It can be assumed that J-3K and J-7K are regarded as the representation of the Kalahari Aquifer in Olifantswater West and Tugela respectively. The aquifer contents in Tugela are much better than Olifantswater West as shown in Table 8.6-2.

Table 3.10-3 Aquifer Constants of Kalahari Aquifer

Aquifer	Borehole No.	Specific Capacity (m^3/h/m)	Transmissibility (m^3/day/m)	Permeability (cm/sec)	Storage Coefficient
Kalahari	J3K (Olifantswater)	0.143	6.42	1.50E-04	1.00E-06
	J4K	0.018	0.135	7.74E-06	-
	J6K	0.145	6.23	1.40E-04	1.00E-05
	J7K (Tugela)	0.763	30	1.20E-03	2.00E-04
	J8K	0.016	0.132	5.10E-06	5.00E-03

This may be the main reason for the big difference between their upturns of the water table. It is also reflected the vegetation and geomorphology of the study area as shown in Fig. 3.10-3 and Fig. 2.1-1. These two figures are well related to one another. Tugela is located in “Dwarf Shrub Savanna” area that has scanty vegetation and outcropped bedrocks. The bedrocks have high potential of infiltration but poor ability of containing water within the unsaturated zone because of many cracks and sinkholes in it.

However, recharge in the sand dune area that has a vegetation comprising of Mixed Trees and Shrub Savanna or Camelthorn Savanna, is considerably low because water in the sand dune is easily released by transpiration before reaching the groundwater level.

The average drawdown rate of 5cm/year in the basin means that recharge in an ordinary year cannot even cover the water demand and hence reduce groundwater storage. Groundwater storage change volume (△Sgr) can be estimated as follows.

$\triangle$Sgr = Distribution Area of Kalahari Aquifer$\times$Effective Porosity (5%)$\times$Drawdown (5cm)

= 5.26×10^{10} $m^2\times0.05\times0.05m=0.13\times10^9$ m^3/year =<u>360,000m^3/day</u>

On the contrary, recharge (R) might be more than the recovery of water level in an extraordinary year in terms of rainfall for example '99-'00 rainy season whose probability is one in 50 years. Suppose an average recovery of water level in whole study area is 50cm, water volume that is equivalent to the recovery can be calculated by the above-mentioned equation.

Recharge > Distribution Area of Kalahari Aquifer $\times$ Effective Porosity (5%)$\times$Recovery (50cm)

= 5.26×10^{10} $m^2\times0.05\times0.5m=1.3\times10^9$ m^3/year =<u>3,600,000m^3/day</u>

(2) Auob Aquifer

According to the hydrogeological structure of the Auob Aquifer as shown in Fig. 3.6-9, recharge is not possible by rainfall directly. However, recharge to the Auob Aquifer seems to be indirectly through the Kalahari Aquifer in the central area of the basin where the Kalahari Aquifer covers the Auob Aquifer directly without the Rietmond Member as impermeable layer. (Refer to Fig. 3.6-3, Fig. 3.6-9 to Fig. 3.6-12)

The quantitative analysis of the recharge for the Auob Aquifer based on water level observation is not clear and it is compelled to entrust the further study including analysis of monitoring data from JICA test boreholes. Regarding the recharge of the Auob Aquifer, it is considered as follows in this study.

- No direct recharge to the Auob Aquifer from precipitation. Recharge from the boundary of the basin is negligible.
- The central part of the Auob Aquifer, which is covered directly by the Kalahari Aquifer, is recharged through it indirectly. Response of water level by precipitation is considerably sensitive similar to the Kalahari Aquifer.
- In the place where the Rietmond Member separates the Kalahari and Auob Aquifer from each other, the response is slow and recharge is very low into the Auob Aquifer.

(3) Nossob Aquifer

According to the hydrogeological condition of the Nossob Aquifer as illustrated in Fig.3.6-9, there is no direct recharge from precipitation, thus the water can be regarded as fossil water.

2) Chloride Mass Balance Method

The basin can be recharged by precipitation. At first, the Kalahari Aquifer receives rainwater and it contributes to the Auob Aquifer indirectly. Then, "Chloride Mass Balance Method" (hereinafter referred as CMBM) was applied to estimate recharge volume.

The general equation of this method is as follows

.

$$R = \frac{(PCl_p + D)}{Cl_{gw}}$$

R: Recharge (mm/year)

P: Mean Annual Precipitation (mm/year)
Cl_p: Chloride concentration (mg/L) in rain
D: Dry chloride deposition (mg/m^2/year)
Cl_{gw}: Chloride concentration (mg/L) in groundwater.

The theoretical background of CMBM is that the total input of chloride by wet and dry atmospheric deposition would equal to the chloride output by transport through the unsaturated zone for a chloride mass balance under steady state conditions if the Kalahari Beds themselves do not produce any chloride.

Formulas, which are used for the inland of the Republic of South Africa; $Cl_p = 0.000002P^2 + 0.0003P + 0.2207$, $D = 0.1Cl_p$, are adopted in this study. Where, P is the mean annual precipitation (mm/year).

As to Cl_{gw}, the data of water quality, which approximately 300 samples were analysed during the study, are applied for this calculation. The calculations were taken place at every three-kilometre grids and the distribution of recharge intensity is drawn as Fig.3.10-4 and Fig.3.10-5.

(1) Recharge in Ordinary Year

The distribution of recharge in the ordinary year is subdivided northwestern half and southeastern half of the basin by 1 mm/year contour line of recharge. There are some spots that is more than 5mm/year in the former. Total recharge volume is 0.105 billion m^3 /year (288,000m^3/day) calculated by summing up recharge volume at every each grid. It is also equivalent to approximately 1.5 mm/year on average in the whole basin and 0.4% to the total rainfall in catchment area or 0.7% in the basin.

(2) Recharge in 99-00 Rainy Season

It is noticeable thing that recharge in the salt block area where is located southeastern area of the basin was less than 1 mm/year even if it was record-breaking heavy rainfall. In contradiction to this, the northwestern part of the basin received much water as the area recharged more than 5 or 10mm/year extended widely. The total recharge volume is calculated in this rainy season as 0.341 billion m^3/year (934,000m^3/day) which is more than three times as much as ordinary year. It is equivalent to 4.8mm/year or one percentage of the total rainfall.

3) Isotope Method

In this section, the rates of recharge per year in Kalahari Aquifer are estimated by characteristic of displacement of groundwater from metric water line.

According to Harmon Craig's founding (Craig H., 1961 Isotopic variation in meteoric waters,. *Science*,133:1720-1703), the relationship with $\delta^{18}O$ and $\delta^{2}H$ in fresh water correlates on a global scale, which is indicated by a profile in Fig.3.10-1. The Local Metric Water Line (LMWL) is based on the evaporation of local surface water in a certain local place. The groundwater samples in Kalahari show the correlation between the ^{18}O and ^{2}H composition, which plot in Fig. 3.10-1 and not parallel to the LMWL. The lower slope of the $\delta^{18}O$ and $\delta^{2}H$ relationship implies degree of the dry. This indicates groundwater in Kalahari exists in dry condition than LMWL do. Consequently, the groundwater in Kalahari is displaced further from the local meteoric water line. It is considered that during extensive evaporation from the unsaturated zone, kinetic effects by vapour diffusion are greater than those associated with evaporation from open surface. Evaporation from an open surface in a local place causes a non equilibrium enrichment in the residual water. This is due to the difference in gaseous diffusion rates for ^{18}O and ^{2}H through the thin boundary layer of 100% humidity above the water surface. Comparing to LMWL, the layer in Kalahari would be as much thicker and can dramatically increase kinetic evaporation effects. Therefore, the slope of the $\delta^{18}O$ and $\delta^{2}H$ relationship is lower than the range for evaporation from open water surface.

This characteristic can be explained by the concept of displace of groundwater from

LMWL which Allison et al. (1984) developed.

It showed that groundwater recharged under conditions of direct infiltration often possibly indicate the result like the samples in Kalahari. This is due to the mixing that occurred between the evaporated soil moisture and a subsequent rain that infiltrates and displaces the residual soil water downward. Ultimately, this mixed parcel of water will reach the water table. If the recharge conditions remain relatively uniform over time, groundwater should follow a line parcel to but displaced from local meteoric water line. Therefore, the displacement of groundwater from the meteoric water line offers a crude estimate of recharge. In other words, for high rates of recharge, evaporate enrichment is minimal, whereas for low recharge rates, a large displacement for groundwater will be seen.

Allison et al. (1983) give the empirical relationships:

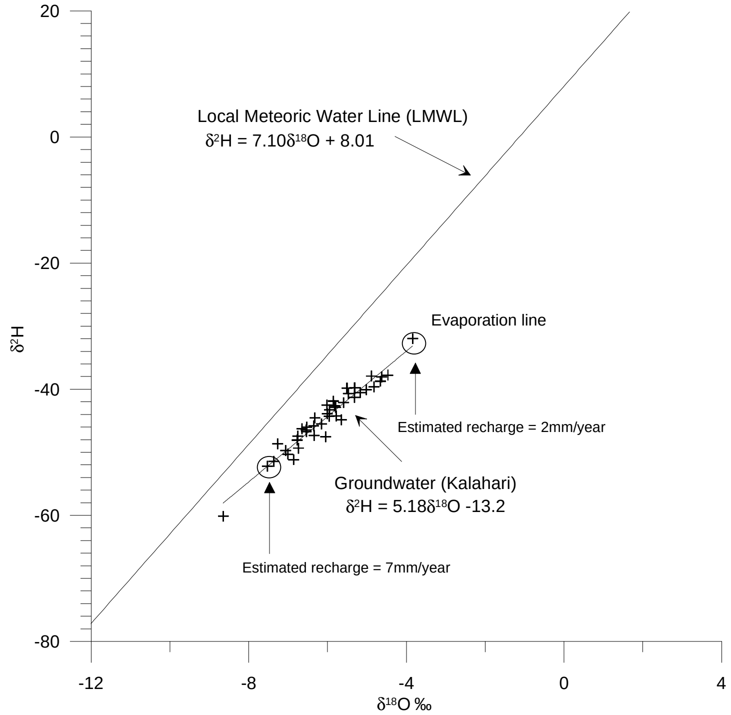


Fig.3.10-1 Evaporation Line of Groundwater in Kalahari Aquifer

$$\delta\ {}_2Hshif = 22/\sqrt{recharge(mm/yr)}$$

By using the above equation, the rates of recharge in Kalahari Aquifer tried to be calculated (see Fig 3.10-1). Accordingly, the result shows the recharge rates in Kalahari range approximately between 2 and 7 mm/year. These values support the estimation of recharge by CMBM in the ordinary year.

3.10. 3 Withdrawal of Groundwater

Intensity of withdrawal from each aquifer in 1999 is presented in Fig.3.10-7. According to the total withdrawal intensity form all aquifers, it concentrates in and around Stampriet where goes in to approximately 60km squared area.

3.10.4 River Discharge

River discharge out of the basin or catchment area is also difficult to estimate because of lacking actual observation data. Since it is inevitable item for the water balance, the data in page 14 in Chapter 2 was applied to estimate it. Based on the data, specific discharge of the Auob River and the Nossob River is estimated to be $328m^3/km^2$ and $472m^3/km^2$ respectively. Therefore, the river discharge in the ordinary year is estimated as follows.

$$Qs=55,416km^2 \times 472m^3/km^2 + 46,986km^2 \times 328m3/km^2 = 4.16 \times 107m^3$$

As to ‘99 -’00 rainy season, the river discharge at Gochas station was recorded 43 million m3 as following table that is approximately 4.6 times compared with the ordinary year. On the assumption that this value is applicable to other catchment area, the river discharge in this season is regarded as $19.14 \times 107m^3$.

Table 3.10-4 Observation Results of Auob River Discharge in 99-00 Rainy Season

Unit: million m^3

Station	Dec. '99	Jan.'00	Feb.'00	Mar.'00	Apr.'00	Total
Gochas	0.12	1.35	8.13	26.49	6.72	42.81
Stampriet	0.43	7.9	10.88	-	-	19.21

Source: DWA

3.10.5 Groundwater Discharge

Directions of groundwater flow in three aquifers are generally northeast to southeast. Outflow volume of groundwater toward outside of the basin is calculated as follows.

$Qd = KiA$ Qd : Groundwater discharge (m^3/day)

K : Permeability (cm/sec)

i : Gradient of piezometric head

A: Cross section area (km^2)

The total outflow of groundwater is estimated as approximately $7,000m^3$/day as shown Table 3.10-5.

Table 3.10-5 Outflow of Groundwater

Aquifer Type	Permeability K (cm/sec)	Gradient of Piezometric Head I	Area of Aquifer Cross Section S (km^2)	Outflow of Groundwater Q (m^3/day)
Kalahari Aq.	1.00E-07	1.31E-03	17.07	**193**
Auob Aq.	3.30E-06	1.42E-03	16.77	**6,790**
Nossob Aq.	8.80E-09	8.50E-04	2.74	**2**
Total	-	-	-	**6,985**

3.10.6 Evapo-transpiration

Since the potential of evaporation in the study area is more than 3,000mm/year as illustrated in Fig.2.3-2, it seems that almost of annual precipitation, which is 200mm/year to 300mm/year, is consumed by evaporation. According to the potential of evaporation, it is no wonder that an entire precipitation in the basin is disappeared under the most appropriate conditions for evaporation.

Though actual pouring rain generally occurs within a few days and some amount of rainfall reaches to the groundwater table under the cool and humid conditions, almost all of recharged water is lost again to the air by transpiration. Then the real chance of recharge seems to be so much limited. As evaporation and transpiration are almost impossible to calculate, the remains in water balance analysis are regarded as them in this study.

3.10.7 Macro Water Balance in the Basin

On the basis of above-mentioned analysis, macro water balance in the study area is illustrated in Fig. 3.10-8 to Fig. 3.10-10. The whole river catchment area, which consists of the Auob river catchment and the Nossob river catchment, is dealt with this macro water balance because it is necessary to consider the river discharge in the balance.

The macro water balance is analysed on two cases, namely, ordinary year and ’99 – ’00 rainy season, moreover each case is subdivided into underground and ground for the sake of convenience.

1) Ordinary Year

(1) Underground

Recharge is only 0.4% (0.105 billion m^3/year) of the total precipitation (22.1 billion m^3/year) or 0.7% of the precipitation in the study area. Withdrawal is only 0.1% (0.015 billion m^3/y) of the precipitation in the study area or 14.3% of the total recharge.

On the other hand, transpiration is almost two times of recharge and a shortage of water balance, which equals to recharge (0.13 billion m^3/year) is covered by the reduction of groundwater storage. Therefore, water level draws down year by year.

(2) Ground

On the ground, river discharge is 114,000m^3/day (0.042 billion m^3/year) or 0.2% of rainfall and 0.4% of rainfall percolates into underground. Yet more than 99% of it disappears by evaporation. According to the evaporation of Namibia as shown in Fig.2.1-2, the potential of evaporation 3,000mm/year suggests that it sounds quite possible.

2) 1/50 Heavy Rain Year ('99-'00 rainy season)

The possibility of the heavy rain which happened during '99-'00 rainy season is one in fifty years. The heavy rain changed the groundwater balance of the basin dramatically. The recharge by the rain stopped not only drawdown of groundwater table but also raised it.

Two cases of the macro balance for the year is studied as follows.

i) Case-1

Recharge in '99-'00 rainy season, which is estimated by CMBM, is adopted in this case.

(i) Underground

The recharge, 0.341 billion m^3/year into the basin is equivalent to 0.7% of the total precipitation, 51.3 billon m^3/year in the whole catchment area or 1.0% of the precipitation, 33.8 billion m^3/year in the basin. The recharge became approximately 3.2 times as much as the ordinary year caused by 2.3 times of precipitation volume.

Assuming that transpiration and groundwater outflow are same as the ordinary year, approximately 31% of recharge contributes to the groundwater storage in the basin.

As a result of the recharge, the water table of the Kalahari Aquifer comes up 4cm in average as shown in Fig. 3.10-9.

(ii) Ground

The heavy rain in '99-'00 rainy season brought about river discharge at Gochas 4.7 times as much as the ordinary year and recharged into underground 3.2 times as much as the year. Then, the remains 99.2% of precipitation came back to the air by evaporation.

ii) Case-2

The water table of the Kalahari Aquifer rose up approximately 50cm on average in the basin based on the results of DWA's observation boreholes.

Supposing the transpiration, withdrawal and groundwater flow are likewise the ordinary year, the recharge is equivalent to 4.5 times of Case-1 and approximately 15 times of the ordinary year.

Though the recharge of Case-1 is harmonized with the result by the isotope method, 4cm water table rise is too small than observation results. On the other hand, the recharge in Case-2 supports groundwater simulation model. It seems that the result of isotope method don't cover extraordinary year as '99-'00 rainy season but mainly ordinary or average year's condition. After all, it can be concluded that Case-2 is better for water balance in '99-'00 rainy season so far.

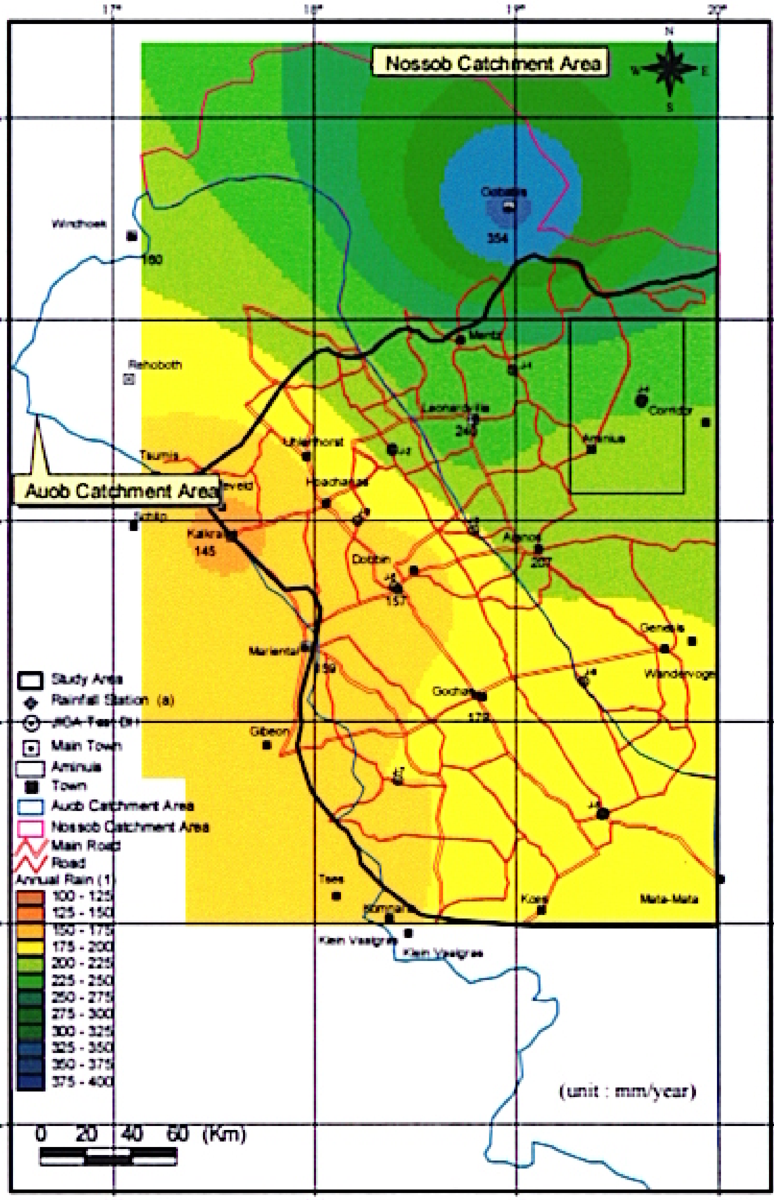


Fig. 3. 10-2 Precipitation of Study Area in Ordinary Year

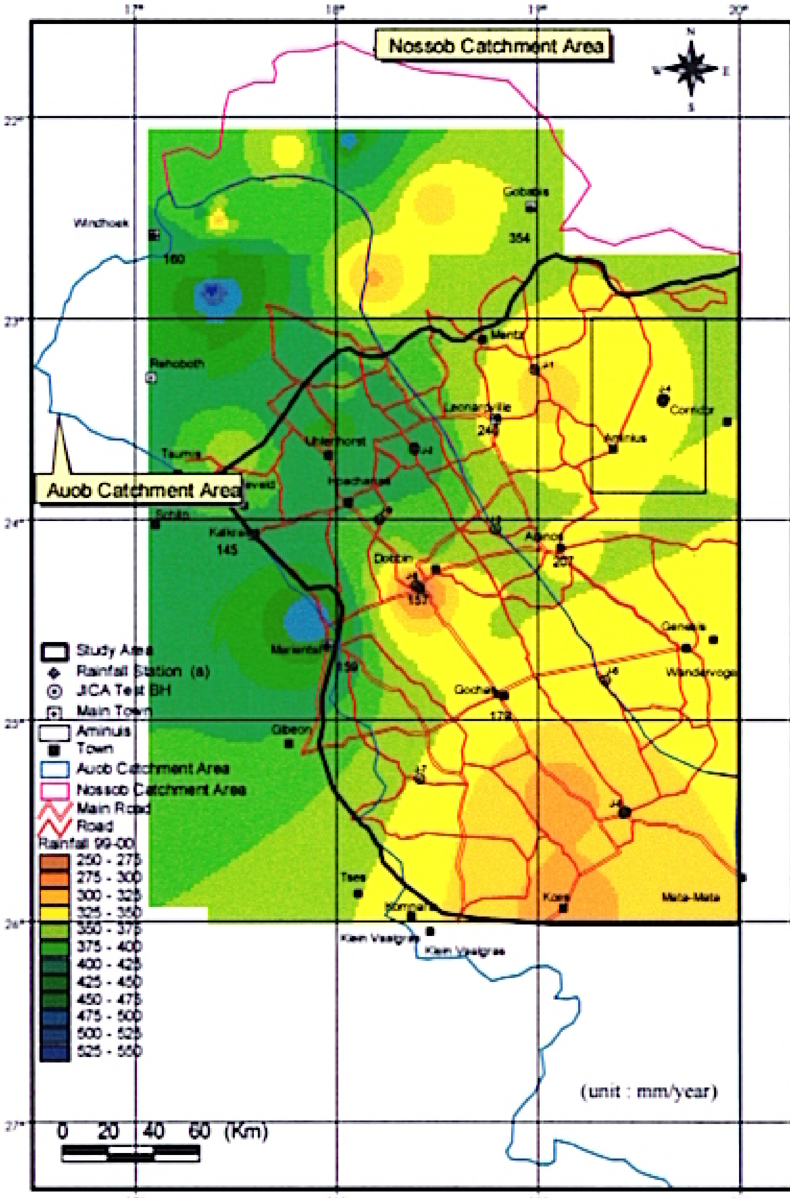


Fig. 3. 10-3 Precipitation of Study Area during Feb. and Mar. in '99-00' Rainy Season

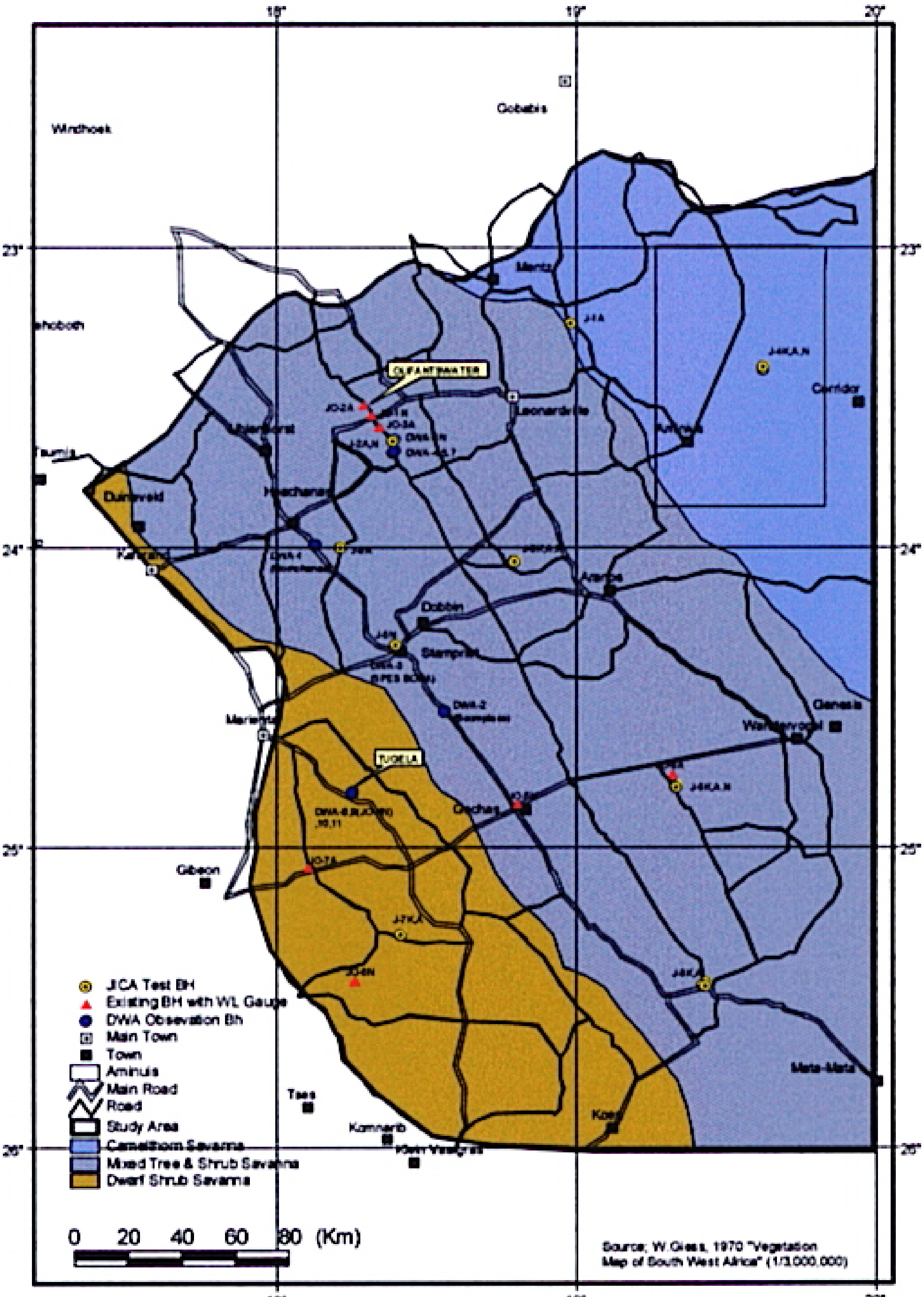


Fig.3.10-4 Vegetation Map of Study Area in 1999

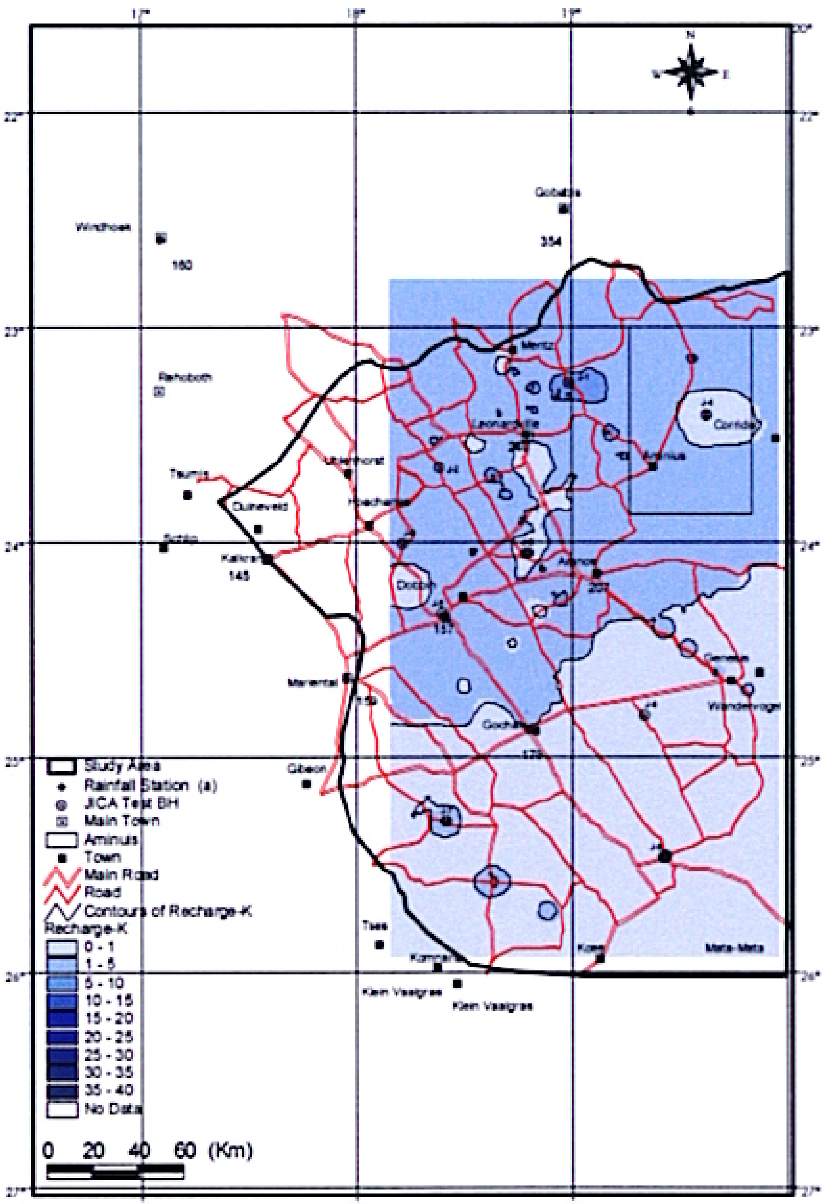


Fig. 3.10-5 Recharge of Kalahari Aquifer in Ordinary Year by CDBM

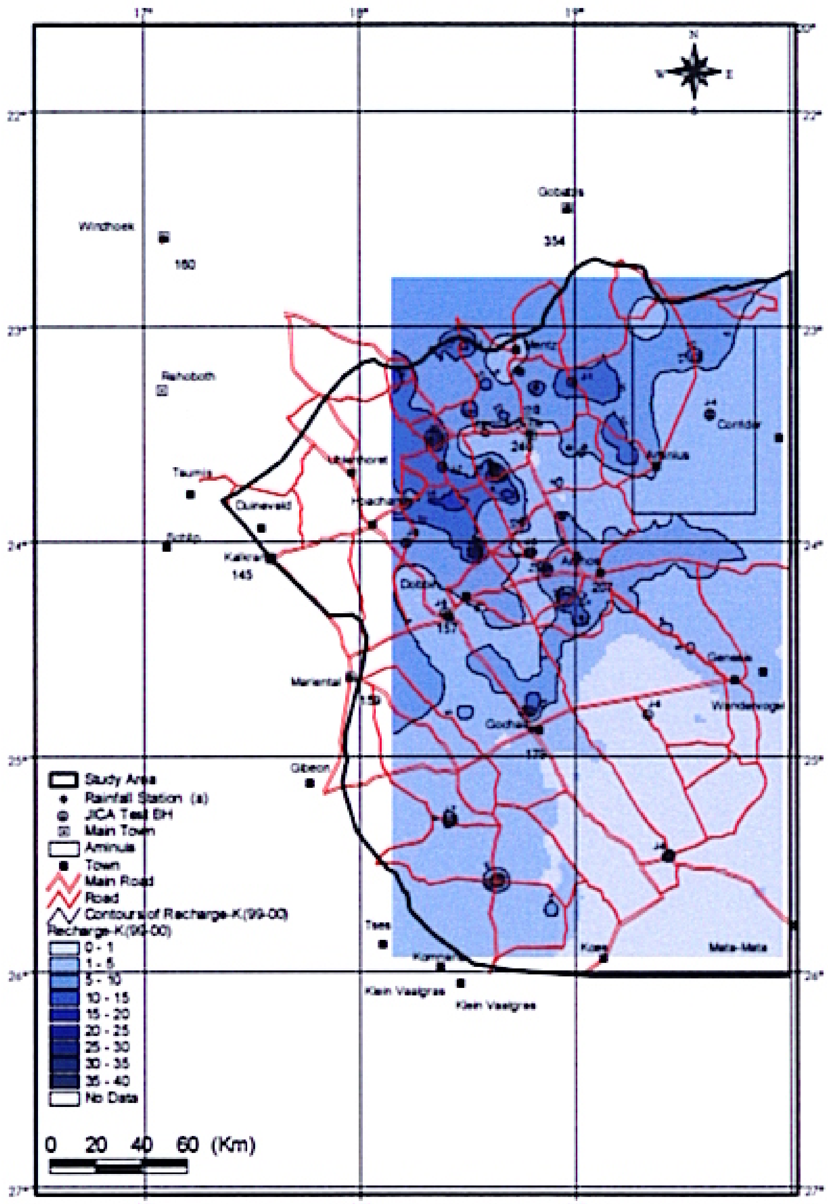


Fig. 3.10-6 Recharge of Kalahari Aquifer in '99-00 Rainy Season Year by CDBM

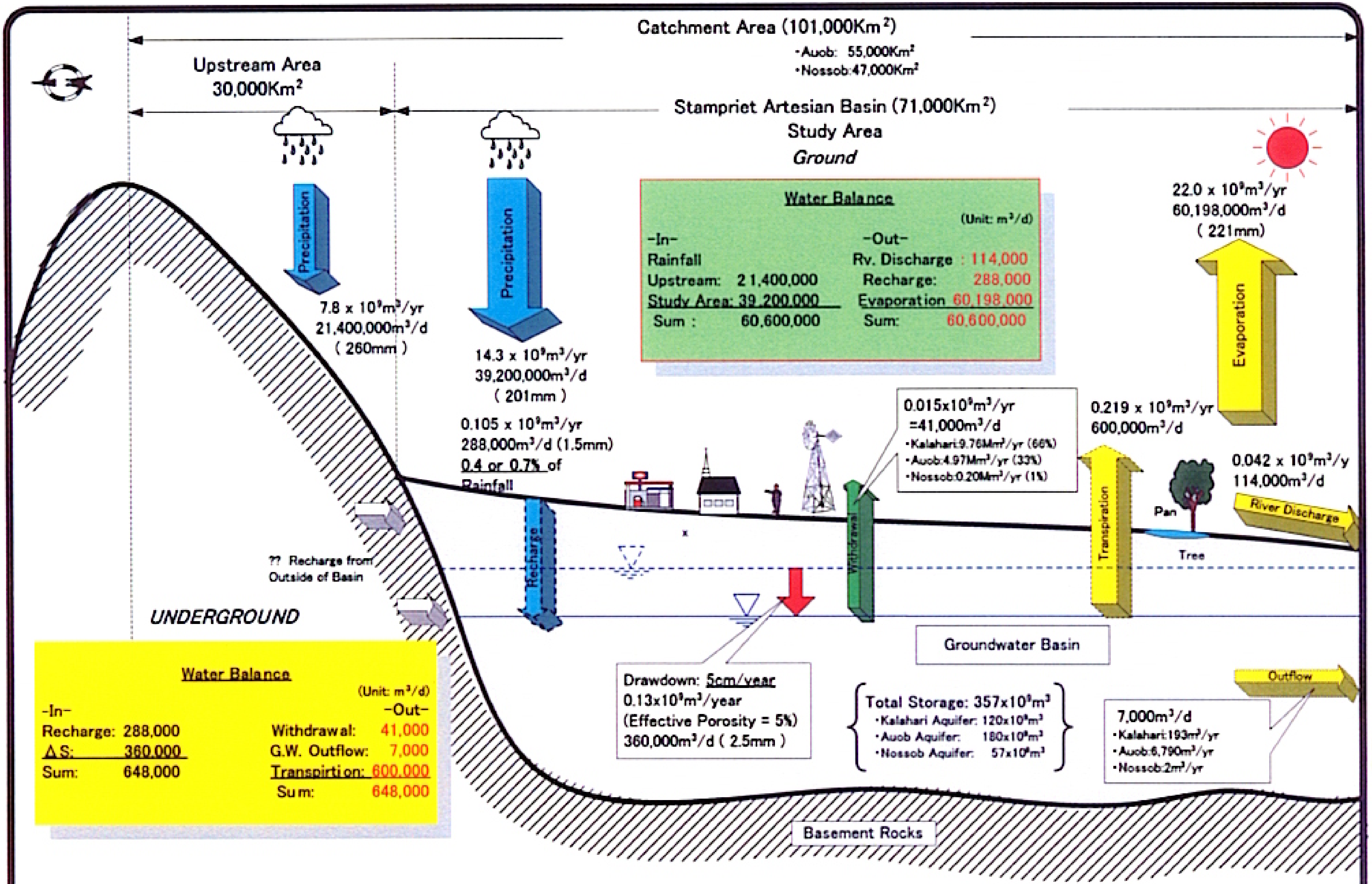


Fig.3.10-8 Macro Water Balance in Ordinary Year

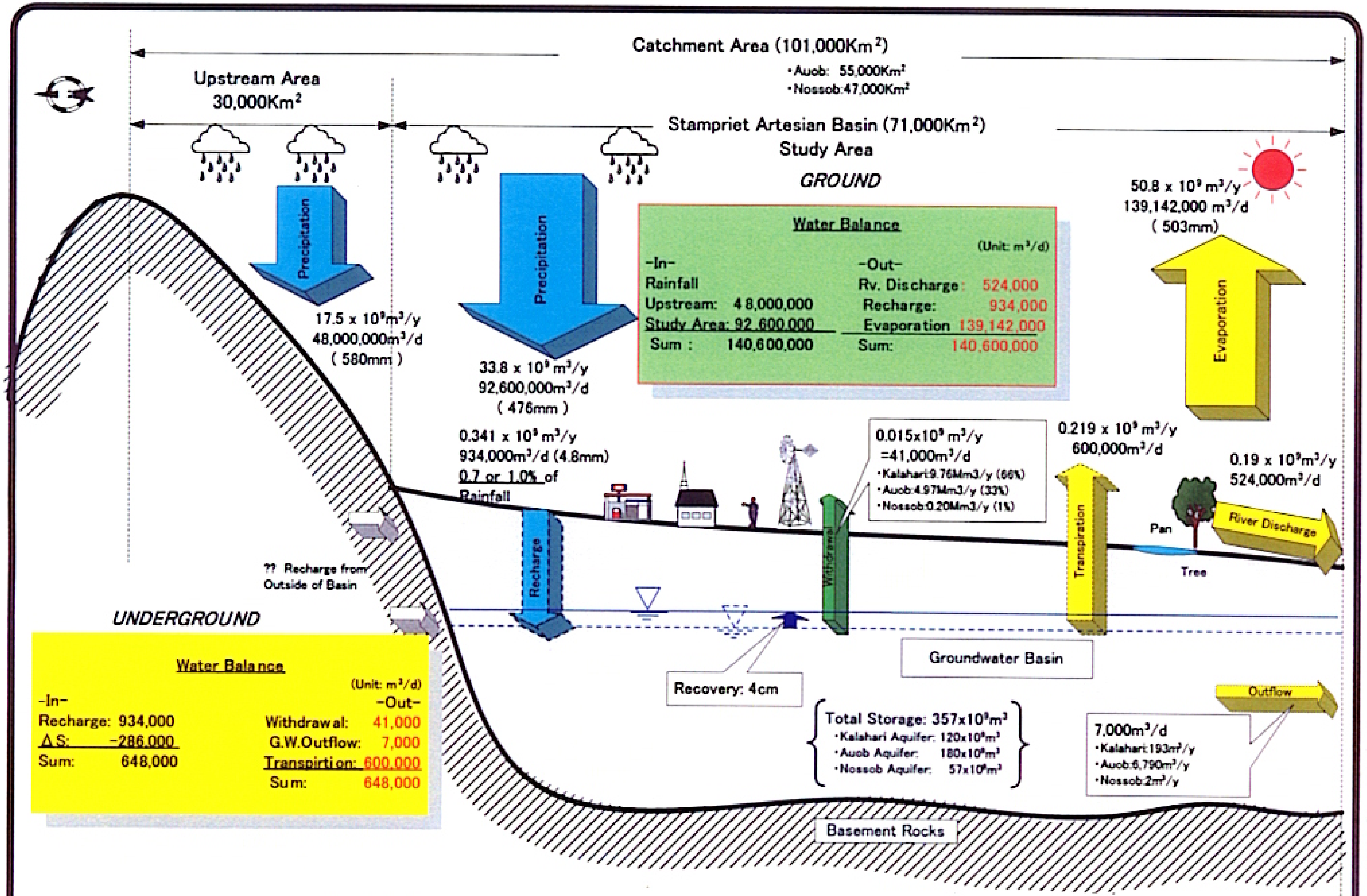


Fig.3.10-9 Macro Water Balance in '99-'00 Rainy Season (Case-1 CMBM for Recharge)

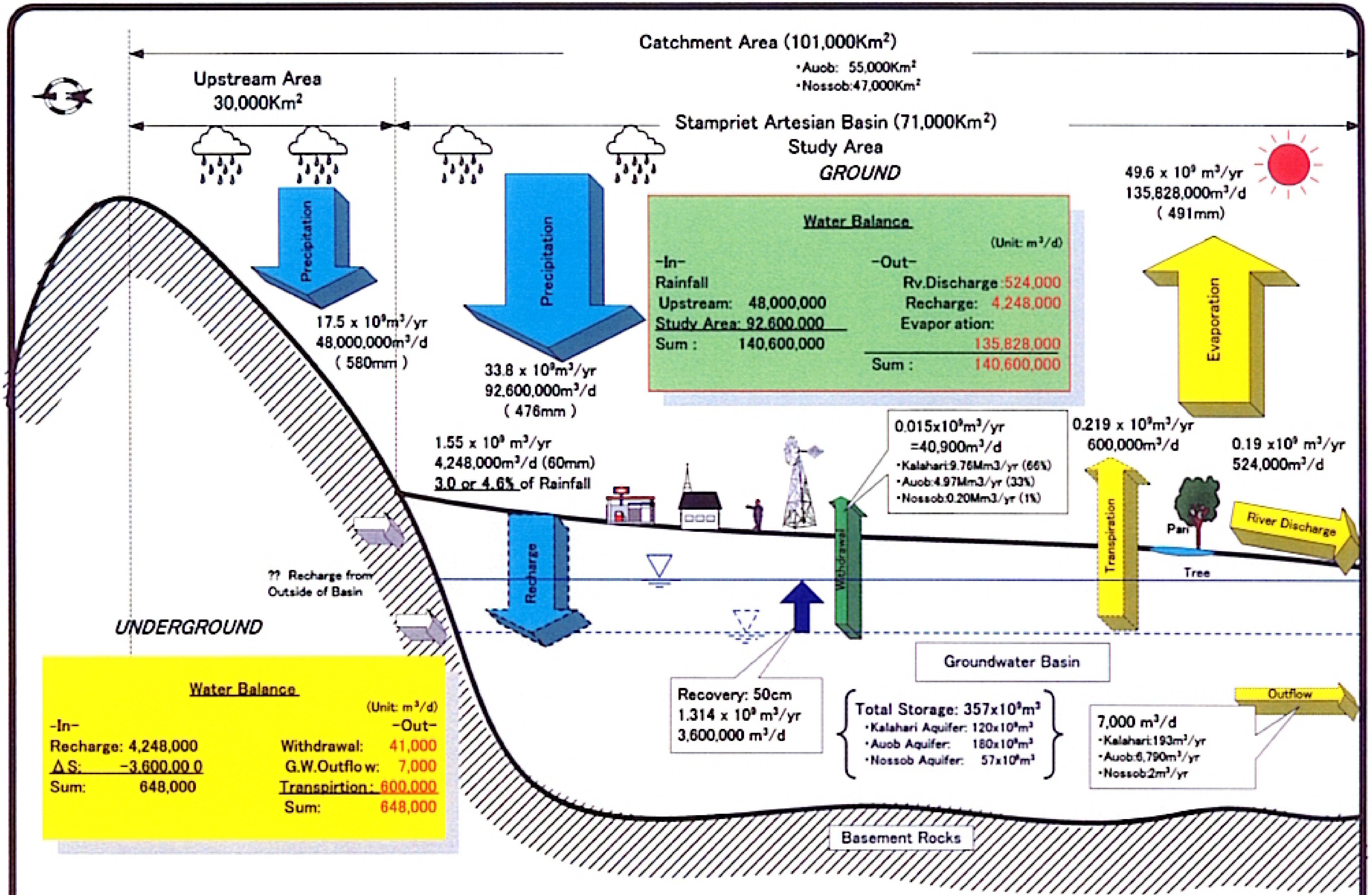


Fig.3.10-10 Macro Water Balance in '99-'00 Rainy Season (Case-2 Recovery of Water Level for Recharge)

CHAPTER 4 EXISTING WATER USE

4.1 Current Water Use and Supply Systems

4.1.1 Villages

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. To maintain the facilities water fees from N\$2.35 to N\$2.96 /m^3 are charged to beneficiaries which are composed of village centers, commercial farms and communal land which operate irrigation, livestock and tourism activities (refer to Table 4.1-1). However, it is reported that the fee collection ratio is not 100 %. Using the latest monthly abstraction data in the eight village centres, the total water use volume of about 562,000 m^3/year is estimated in Table 4.1-2.

Table 4.1-1 Population and Areas Served

	1991	1999
Village centers	4,662	6,186
Commercial farms	13,349	16,780
Communal land	10,174	12,130
Total	28,185	35,096

Note. Estimated as of March 2000

Table 4.1-2 Water Supply Scheme by Nam Water

Village	Scheme's Capacity (m^3/year)	Agreement (m^3/year)	Amount Used (m^3/year) 2001
Stampriet	111,600	61,200	64,479
Aranos	554,400	349,200	276,293
Gochas	108,000	91,800	68,724
Leonardville	108,000	122,400	81,234
Aminuis	24,120	16,920	39,125
Onderombapa	61,300	19,080	21,115
Kriess	31,320	18,720	11,126
Total	998,740	679,320	562,095

Source: Nam Water

4.1.2 Domestic Water in the Commercial Farms

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

Domestic water for human consumption on commercial farms was calculated based on the hydro-census data. The average unit water consumption is about 400m^3/capita/year. Using this data, the total domestic water consumption in this study area is estimated at 1,716,000 m^3/year.

Table 4.1-3 Domestic Water Uses on the Commercial Farms

Area*	Farm Area (ha)	No. of Farm**	Domestic Usage (m^3/y)	%	Averaged Domestic Use/Farm (m^3/y)
Area I	173,929	36 (30)	87,162	5	2,905
Area II	285,716	69 (62)	141,182	8	2,277
Area III	112,403	23 (19)	26,426	2	1,391
Area IV	200,833	50 (41)	58,254	3	1,421
Area V	813,397	110 (85)	109,646	6	1,290
Area VII	4,719,973	929 (905)	1,292,991	75	1,429
Total	6,306,250	1,212 (1142)	1,715,661	100	1,502

Note: Analysis of JICA Study Team based upon Hydro-census data
*refer to Fig.4.1-1
**( ) real figures of respondents

4.1.3 Domestic Water in the Communal Lands

The Hydro-census survey did not cover most of the farm information (including number of residence, stock, and water consumption, etc.) in the communal land. The detailed data in those areas could not be obtained. Accordingly using population census obtained from the National Statistic Office, the total population in the communal lands of Aminuis, Corridor, Hoachanas and Namaland was estimated at 11,588 as of 1999. Unit water demand of 30 litre/capita/day results in 126,889m^3/year (30 litre/capita/day x 365 day x 11,588/1,000 litre).

4.1.4 Industries

Though there is one abattoir (slaughterhouse) in the Study Area, which disposes 850 to 1,100 heads of sheep per day and consumes 150 m^3/day, this plant is supplied with water from the Hardap scheme.

4.1.5 Tourism

There are 11 lodges in the Study Area. Assuming that 29,700 tourists stay in a lodge a year (the tourism season is from March to November), the total water use in the tourism sector in the Study Area was estimated at 4,445 m^3 /year (29,700 x 0.15 m^3).

4.1.6 Stock Watering

As a result of analysis using the hydro-census data, the total stock watering volume was estimated at 5.678 million m^3 /year. In addition, stock watering volume per farmer ranged from 5,000 to 7,000m^3 /year.

Table 4.1-4 Stock Watering

Area*	No. of Farm	Grazing Area	Large Stock	Small Stock	Stock Watering (m^3/y)	Stock Watering /farm (m^3/y)
Area I	26	142,243	1,190	39,396	131,107	5,043
Area II	48	209,391	2,588	63,255	219,656	4,576
Area III	16	88,248	1,678	31,100	113,473	7,092
Area IV	33	177,199	2,851	610	222,705	6,749
Area V	100	718,099	9,610	135,585	525,691	5,257
Area VII	730	3,918,411	96,894	1,081,149	4,465,509	6,117
Total	953	5,253,591	114,811	1,351,095	5,678,141	5,958

Note: Analysis of JICA Study Team based upon Hydro-census data
*refer to Fig.4.1-1

4.1.7 Irrigation

(1) Irrigation Area

Commercial farms that operate irrigation farming are mainly located along the Auob River. The Stampriet area is particularly concentrated with 76% of irrigation farms in that area (refer to Fig 4.1-1 and Table 4.1-5).

According to DWA data the permitted irrigated area is 399.5 ha (as of 2000). There is a big difference between the permitted area and the actual irrigation area (refer to Table 4.1-5) calculated using hydro-census data. This is because the figure includes the farmers who illegally over irrigate more than the permitted area and irrigation farmers whose farm areas are less than one hectare.

As shown in Table 4.1-6 crops cultivated in the study area are very diverse. The main crops are Lucerne, Maize and vegetables. In particular, Lucerne is a dominant crop and the cultivated area amounts to the half of the total irrigation area.

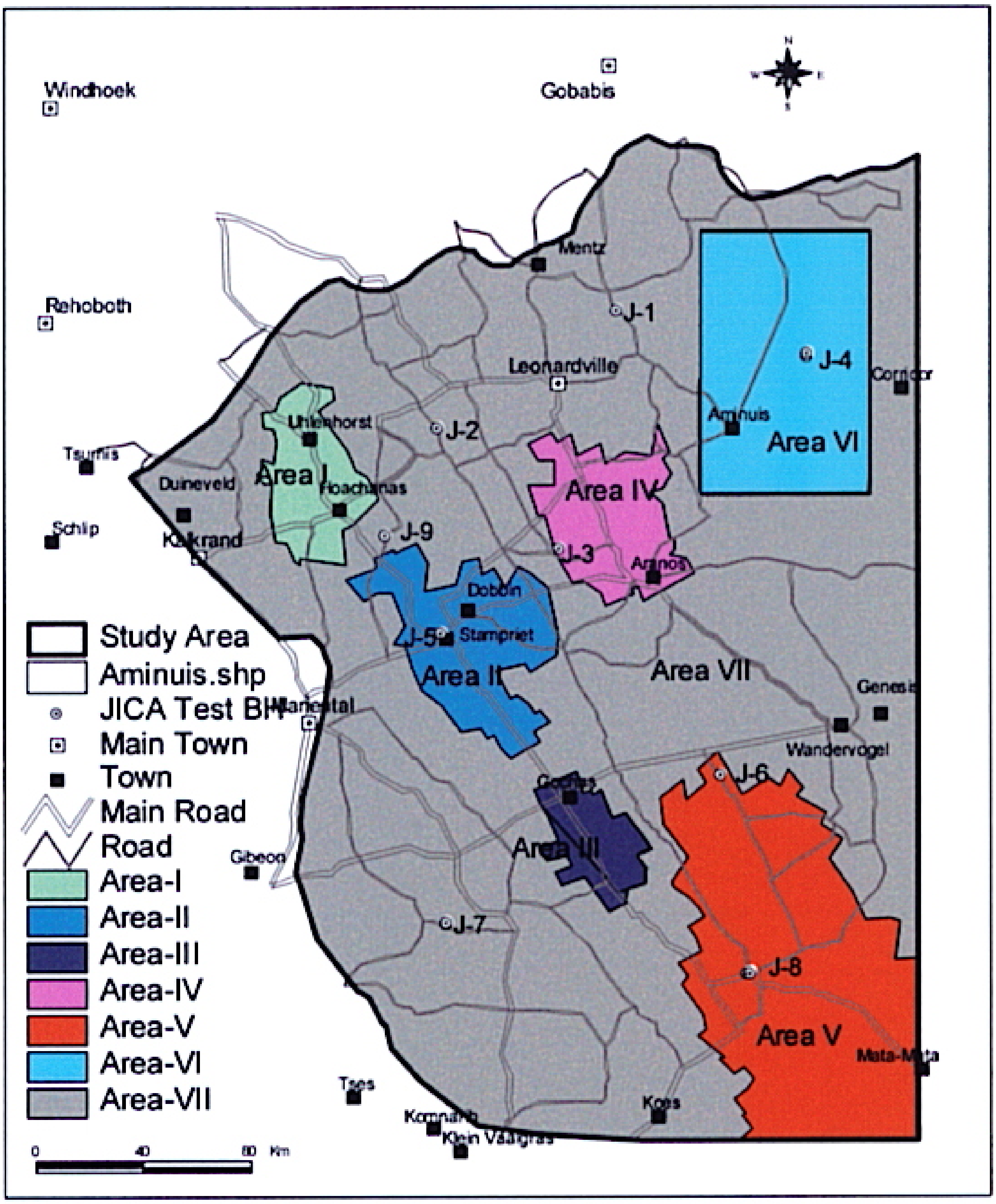


Fig.4.1-Division for Socio-economic Analysis

Table 4.1-3 Irrigation Area and Irrigation Water Use

Area	Farm area (ha)	No. of irrigation farm	Irrigation area (ha)	Irrigation use (m^3/y)	%	Irrigation use (m^3/ha/yr)	Irrigation use ratio (%)	Irrigation area /irrigation farm (ha)
Area I	173,929	22	22	224,840	3	10,220	51	1.00
Area II	285,716	38	412	5,334,341	78	12,947	94	10.84
Area III	112,403	6	11	112,420	2	10,220	45	1.83
Area IV	200,833	10	24	394,119	6	16,422	58	2.40
Area VII	4,719,973	83	77	810,712	12	10,598	12	0.92
Total	6,306,250	163	546	6,876,432	100	60,407	48	3.35

Note: Analysis of JICA Study Team based upon Hydro-census data

Table 4.1-6 Irrigation Area by Crop Types

unit:ha

Crop types \ Area	Area I	Area II	Area III	Area IV	Area VII	Total	%
Lucerne	8.6	167.8	4.3	42.0	10.1	232.8	**48.0**
Vegetable	2.9	82.0			2.6	87.5	**18.0**
Maize		61.0		2.0	21.5	84.5	**17.4**
Grapes		15.0				15.0	**3.1**
Citrus	6.5	4.2			4.2	14.9	**3.1**
Sorghum		13.5				13.5	**2.8**
Oranges		4.0			1.1	5.1	**1.1**
Water melon		5.0				5.0	**1.0**
Cabbage		4.5				4.5	**0.9**
Fruit	0.4			0.5	3.0	3.9	**0.8**
Oats	0.2			3.0		3.2	**0.7**
Sweet melon		3.0				3.0	**0.6**
Mealies		1.0	0.3		1.3	2.5	**0.5**
Pumpkin		2.0				2.0	**0.4**
Sweet potatoes		2.0				2.0	**0.4**
Tomatoes		1.5				1.5	**0.3**
Barley		1.0				1.0	**0.2**
Carrot		1.0				1.0	**0.2**
Prickly pears					1.0	1.0	**0.2**
Collen					1.0	1.0	**0.2**
Garden					0.5	0.5	**0.1**
Guavas					0.1	0.1	**0.0**
Total	18.6	368.5	4.5	47.5	46.3	485.4	**100.0**

Note: Analysis of JICA Study Team based upon Hydro-census data

(2) Irrigation Permission

According to Water Act, farmers who intend to operate irrigation farming over areas greater than one hectare have to get permission for water allocation from DWA. At present 54 irrigation permissions are approved for the commercial farms in the Stampriet Artesian Basin amounting for 8,266,560 m^3/year. They are given various water allocations according to the designated areas (refer to Table 4.1-7 and Fig. 4.1-2). Permission is valid for five years.

Table 4.1-7 Permitted Water Use

Area*	Allocated water volume (m^3 /ha/ year)
Area 1	19,000
Area 2	54,000
Area 3	45,000

Source: DWA *Refer to Fig.4.1-2

(3) Irrigation Water Use

Total irrigation water used in the Study area is 6.88 million m^3/ year (refer to Table 4.1-5). Table 4.1-10 indicates that the total water extraction volume is under the permitted volume, however there are many farmers who illegally drafted and use groundwater in the Study Area. The numbers are nine in Area II and three in Area VII. Totally twelve farmers extracted much more groundwater than the allocated volume (refer to Table 4.1-8 and Table 4.1-9).

Table 4.1-8 and 4.1-9 also indicates the following things:

- A farmer in Area VII used about five times of allocated water quantity by sprinkler irrigation.
- Most of illegal farmers are operating irrigation farming using drip or sprinkler etc. that enables more efficient water use than flood irrigation.

Table 4.1-8 Illegal Farms in Area II

Farms	Actual water use (m^3/y)	Permitted water use (m^3/y)	Irrigation use (m^3/ha/y)	Irrigation method	Times※
1	659,980	288,000	N/A	N/A	2.3
2	442,015	120,000	17,681	Drip	3.7
3	384,000	200,000	N/A	N/A	1.9
4	282,109	126,000	17,632	Pivot	2.2
5	431,011	290,000	N/A	N/A	1.5
6	182,500	90,000	18,250	Drip	2.0
7	116,800	75,000	23,360	Sprinkler, Drip	1.6
8	379,600	350,000	21,089	Drip	1.1
9	103,660	90,000	17,277	Drip	1.2

※ Times＝Irrigation use (m^3/ha/y)/ Permitted water use (m^3/ha/y)

Table 4.1-9 Illegal Farms in Area VII

Farms	Actual water use (m^3/y)	Permitted water use (m^3/y)	Irrigation use (m^3/ha/y)	Irrigation method	Times※
1	292,000	54,000	97,333	Sprinkler	5.4
2	659,980	288,000	N/A	N/A	2.3
3	59,819	36,000	29,910	Sprinkler	1.7

※ Times＝Irrigation use (m^3/ha/y)/ Permitted water use (m^3/ha/y)

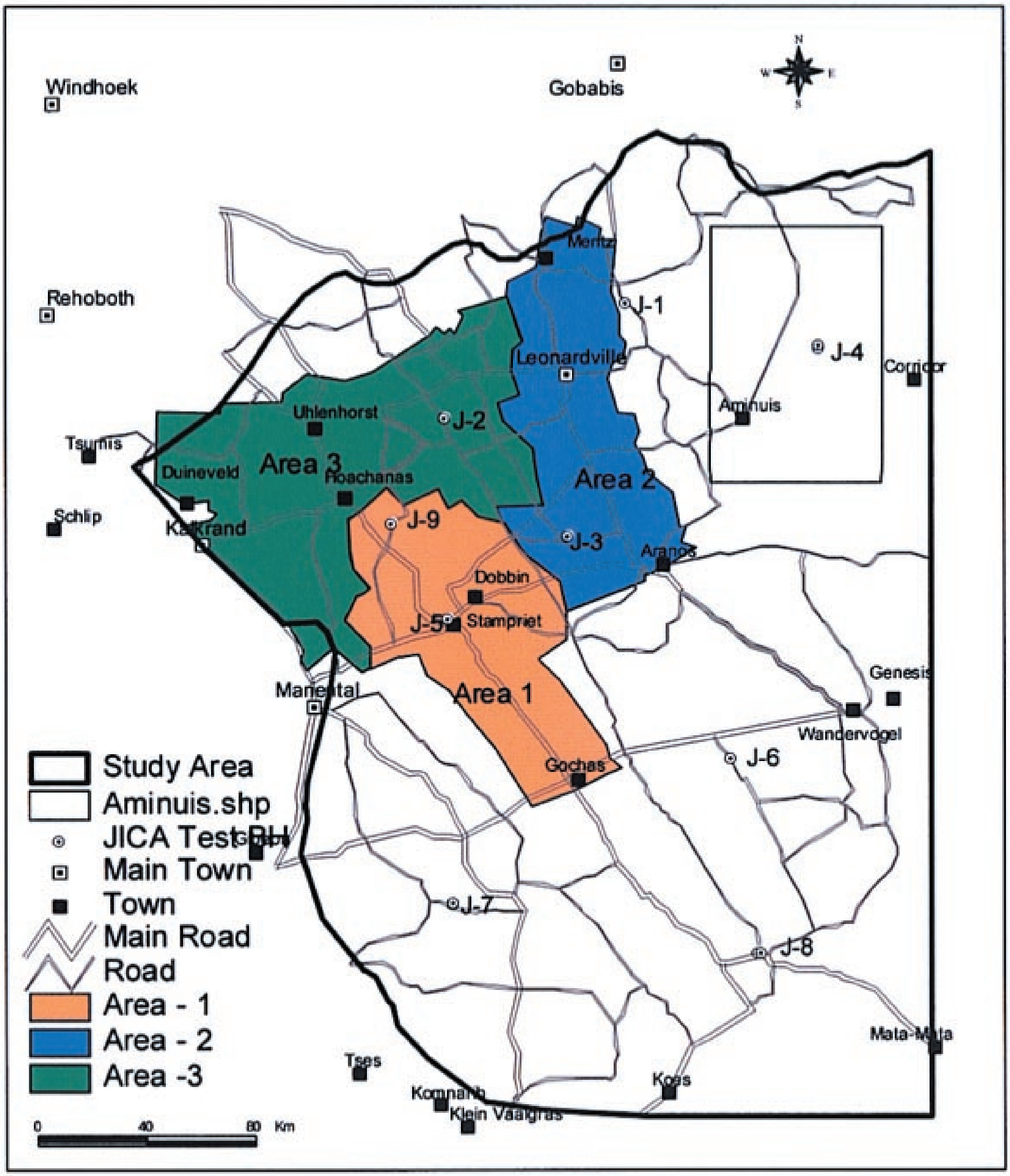


Fig. 4.1-2 Monitoring Area for Permission Holder

Table 4.1-10 Comparison Between Actual Water Use and Permitted Water Use

No.	Actual Water use (m^3/y)	Permitted water use (m^3/y)	Actual water use (m^3/ha/y)	Methods	Irrigation area (ha)
1	89,060	90,000	4,453	Drip	20.0
2	182,500	90,000	18,250	Drip	10.0
3	442,015	120,000	17,681	Drip	25.0
4	119,720	165,000	7,981	Drip	15.0
5	379,600	350,000	21,089	Drip	18.0
6	103,660	90,000	17,277	Drip	6.0
7	55,298	126,000	9,216	Flood	6.0
8	55,298	90,000	9,216	Flood	6.0
9	38,873	90,000	15,549	Flood	2.5
10	129,575	145,000	43,192	Flood, Drip	3.0
11	219,000	237,000	16,846	Flood, Drip	13.0
12	32,906	54,000	N/A	N/A	N/A
13	21,900	124,000	2,738	N/A	8.0
14	659,980	288,000	N/A	N/A	N/A
15	431,011	290,000	N/A	N/A	N/A
16	36,230	81,000	N/A	N/A	N/A
17	49,242	54,000	3,517	Pivot	14.0
18	282,109	126,000	17,632	Pivot	16.0
19	292,000	54,000	97,333	Sprinkler	3.0
20	59,819	36,000	29,910	Sprinkler	2.0
21	4,380	54,000	1,460	Sprinkler	3.0
22	4,380	150,000	548	Sprinkler	8.0
23	117,165	180,000	11,717	Sprinkler	10.0
24	71,905	90,000	23,968	Sprinkler	3.0
25	116,800	75,000	23,360	Sprinkler, Drip	5.0
26	40,880	110,000	3,407	Sprinkler, Drip	12.0
27	73,000	100,000	6,083	Sprinkler, Drip	12.0
28	10,585	200,000	1,059	Sprinkler, Drip	10.0
29	27,375	180,000	913	Sprinkler, Drip	30.0
30	18,250	126,000	2,607	Sprinkler, Drip	7.0
31	13,140	144,000	1,195	Sprinkler, Drip	11.0
32	65,335	275,000	5,940	Sprinkler, Drip	11.0
33	655,000	655,000	10,917	Sprinkler, Drip, Flood	60.0
34	103,660	275,000	5,183	Sprinkler, Drip, Flood	20.0
35	371,935	792,000	37,194	Sprinkler, Flood	10.0
36	35,040	576,000	1,752	Sprinkler, Flood, Drip	20.0
37	15,108	55,000	N/A	N/A	N/A
38	384,000	200,000	N/A	N/A	N/A
39	12,188	90,000	N/A	N/A	N/A
Total	5,819,922	7,027,000	-	-	399.5

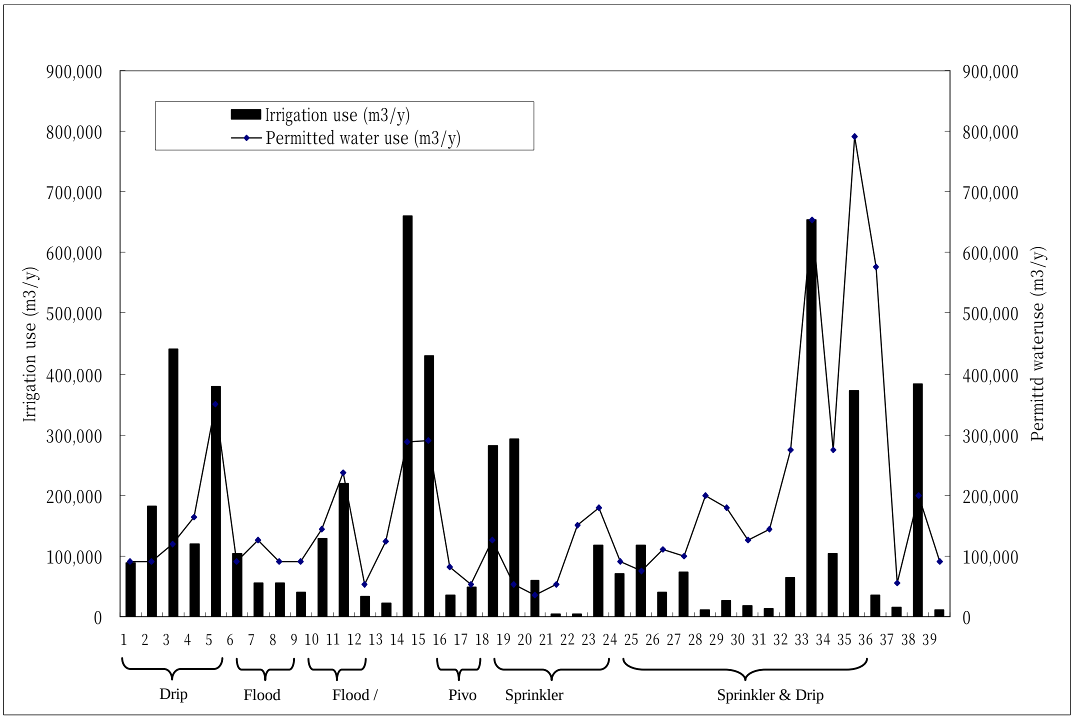


Fig.4. 1-3 Comparison Between Actual Water Use and Permitted Water Use

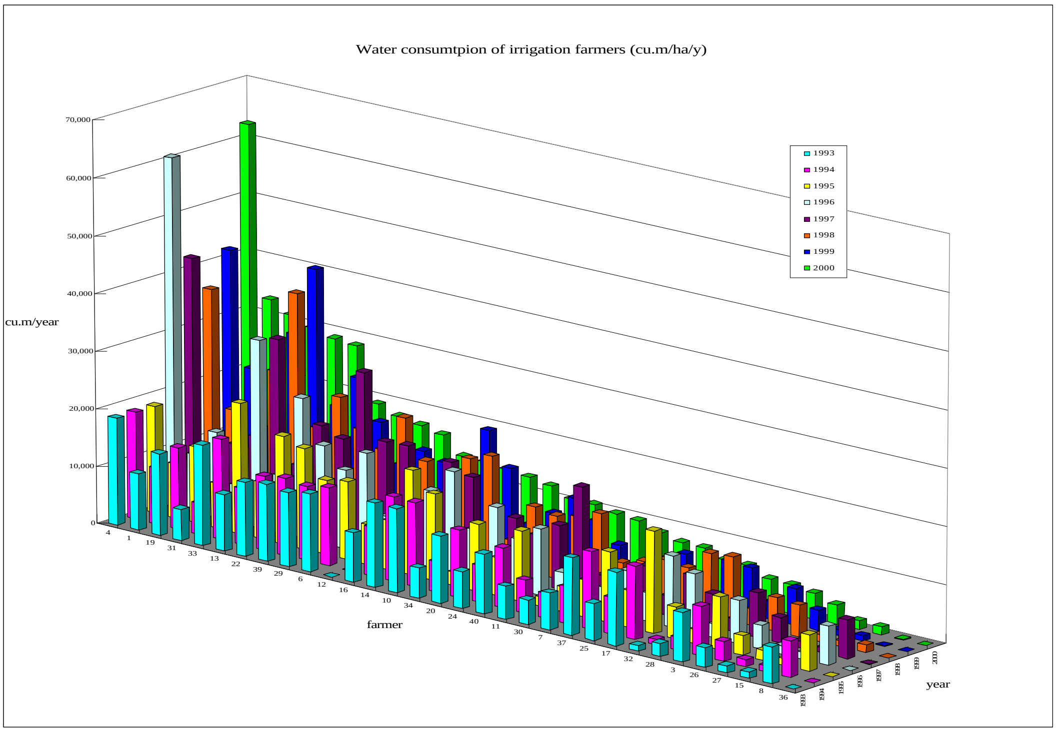


Fig. 4.1-4 Irrigation Water Use by Permitted Farms (1994-1999)

(4) Irrigation method

As Table 4.1-11 indicates, drip irrigation is widely applied in the study area and it is the area under this method amounts to 104.6 ha, which is 23% of the total irrigated area. Sprinkler and mixed application with sprinkler, drip and other methods comes after this in term of coverage.

Including mixed application with drip and sprinkler, 58.9% of farm areas are applied efficient irrigation methods. The areas that apply only the flood method are quite few, and the total area amounts to about 30.5 ha (6.8%). As the result of this, conversion of irrigation method cannot expect a drastic water saving.

Table 4.1-11 Irrigation Area by Applied Methods in the Study Area

Unit: ha

Irrigation method \ Area	I	II	III	IV	VII	Total	%
Drip		98.5		2.0	4.1	104.6	23.8
Sprinkler		56.0	1.0	20.0	6.0	83.0	18.9
Sprinkler, Flood, Drip		77.0				77.0	17.5
Sprinkler, Drip	2.0	62.5				64.5	14.7
Flood	3.0	17.5	4.0		6.0	30.5	6.9
Flood, Drip					21.0	21.0	4.8
Pivot		15.0				15.0	3.4
Micro sprayer	1.0	12.0			1.0	14.0	3.2
Sprinkler, Flood	1.0	10.0			2.0	13.0	3.0
Sprinkler, Drip, Micro sprayer	12.5					12.5	2.8
Flood, Micro sprayer	2.0					2.0	0.5
Micro sprayer, Drip					2.0	2.0	0.5
Hose				0.5		0.5	0.1
Total	21.5	348.5	5.0	22.5	42.1	439.6	100.0

Source: Analysis of JICA Study Team based upon Hydro-census

4.1.8 Estimated Present Water Consumption in the Study Area

The following table shows estimations of water usage by sector in the Study Area as of March 2000.

Sectors	Water Usage (million m^3/year)	Proportion (%)
1. Domestic water		
1.1 Village centres	0.635	4.26
1.2 Commercial farms	1.594	10.69
1.3 Communal land	0.127	0.85
Sub-total	2.356	15.80
2. Industries	0	0.00
3. Tourism	0.004	0.03
4. Stock watering	5.678	38.07
5. Irrigation	6.876	46.10
Total	14.914	100.00

CHAPTER 5 GROUNDWATER POTENTIAL EVALUATION

5.1 Introduction

The groundwater potential of three aquifers, namely the Kalahari, Auob and Nossob Aquifer is evaluated in this chapter using hydrogeological indices.

5.2 Storage of Groundwater

The storage of groundwater in each aquifer can be estimated from their volumes and effective porosity as shown in Table 5.2-1. An effective porosity is necessary to estimate the amount of groundwater, which means available void space of each aquifer for water use. This value was assumed on the basis of the results of neutron logging at the JICA test boreholes.

Table 5.2-1 Groundwater Storage of Each Aquifer

Aquifer	Thickness (m)	Area (m^2)	Volume (m^3)	Effective Porosity (%)	Groundwater Storage (m^3)
Kalahari (Saturated)	0-250	52.6E+9	2.36E+12	5	**120E+9**
Auob Aquifer	0-150	50.7E+9	3.60E+12	5	**180E+9**
Nossob Aquifer	0-60	9.98E+9	1.24E+12	5	**57E+9**

The table indicates that the Auob Aquifer contains more groundwater than the Kalahari and the Nossob Aquifer. The amount of groundwater within the Auob Aquifer is more than three times of that of the Nossob Aquifer. It is concluded that the Auob Aquifer is a better aquifer than the other aquifers in the study area in terms of groundwater storage. These groundwater storages are huge volumes, however, it should be considered that a very little of groundwater within the aquifers is virtually available for the extraction because of technical and economical reasons. Consequently, it is necessary to consider other indices instead of aquifer storage to evaluate the groundwater potential of the aquifers.

5.3 Groundwater Potential Evaluation

Four indices, water depth, water quality, depth of aquifer and specific yield were selected for this purpose as shown in Table 5.3-1.

The evaluation point is given to the maximum as 100 points and minimum as 0 point in each index and it distributes equally between them. For example, water depth of the Nossob Aquifer varies G.L-172.3m to G.L. +23.9m (artesian). The former is given 0 point as the minimum evaluation and the latter is given 100 points as the maximum evaluation. Total evaluation point (TP) is summed them up. Therefore the maximum total evaluation is given 400 points. The point in each index is calculated with a simple linear function as follows.

Table 5.3-1 Index for Evaluation of Aquifers

Index \ Items		Maximum Evaluation		Minimum Evaluation		Related Factors
		Maximum Value (100 Point)	Aquifer	Minimum value (0 Point)	Aquifer	
I	Water Depth (B.G.L m)	-23.9	Nossob	172.37	Kalahari	Withdrawal cost, Operation cost
II	Water Quality (TDS mg/l)	354.6	Auob	39,428	Nossob	Human health, Productivity or quality of crops and
III	Depth of Aquifer (B.G.L. m)	0	Kalahari	440	Nossob	Initial cost (Drilling cost)
IV	Specific Yield (m^3/hr/m)	15.92	Auob	0.0008	Nossob	Capacity of aquifer

I, II, III: $y = \dfrac{(x - Mm) \times 100}{Mx - Mm}$

IV: $y = \dfrac{100}{Mx - Mm} \times (x - Mm)$

$$TP = \sum_{n=I}^{VI} y_n$$

Mx : Maximum Value
Mm : Minimum Value
y : Evaluation Value
x : Data Value
TP : Total Evaluation Point
n : Index No.

Since the statistical weight among indices is changeable for any purposes, they were treated evenhandedly in this study.

5.3.1 Groundwater Depth

The required capacity of the pump for withdrawal depends on the depth of the groundwater table from the ground surface in case of the same withdrawal volume. The depth of groundwater is also closely related to withdrawal cost, namely, operation cost of production wells. The groundwater depth of each aquifer is illustrated in Fig. 5.3-1 to 5.3-3.

1) Kalahari Aquifer

Groundwater depth becomes deeper to the east side of the study area. In particular, the southeastern area around J-6 which is located in the Pre-Kalahari Valley is the deepest place and its depth reaches to 100m more. (Fig. 5.3-1)

2) Auob Aquifer

A distribution of water depth is generally similar to that of the Kalahari Aquifer. The area whose water depth is more than 100m extends around J-6 and J-8 in the southeastern area of the basin. On the other hand, it becomes shallower in the western area of the basin around Stampriet and the artesian wells are located in the area. Though many artesian wells or springs are found along the Auob and Nossob River, they are not presented in Fig. 5.3-2 except for the center of Stampriet because no data of piezometric head is available. Therefore, Stampriet is presented as a small red colored area in the figure.

3) Nossob Aquifer

Sufficient data is not available on this aquifer because of its characteristics. Therefore, it restricts the accuracy of the analysis. The Nossob Aquifer has a high piezometric head in the other words, high pressure. Four areas in red around J-3, J-5, J-6 and Gochas respectively are noticed in Fig.5.3-3. If the data on this aquifer is increased, they will put together and show a large area in the center of the basin.

5.3.2 Groundwater Quality

The total dissolved solid (TDS) as a representative of water quality is an important factor for water quality standard, treatment cost for drinking water and productivity of live stocks and agricultural crops. A discussion of water quality is omitted in this section because it has been done in Chapter 3.8.

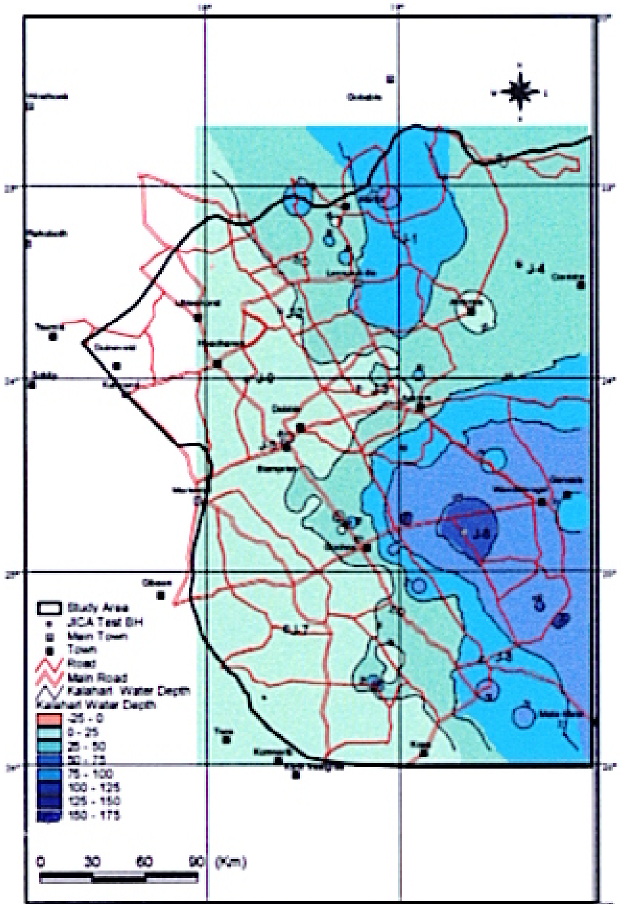


Fig. 5.3-1 Water Depth of Kalahari Aquifer

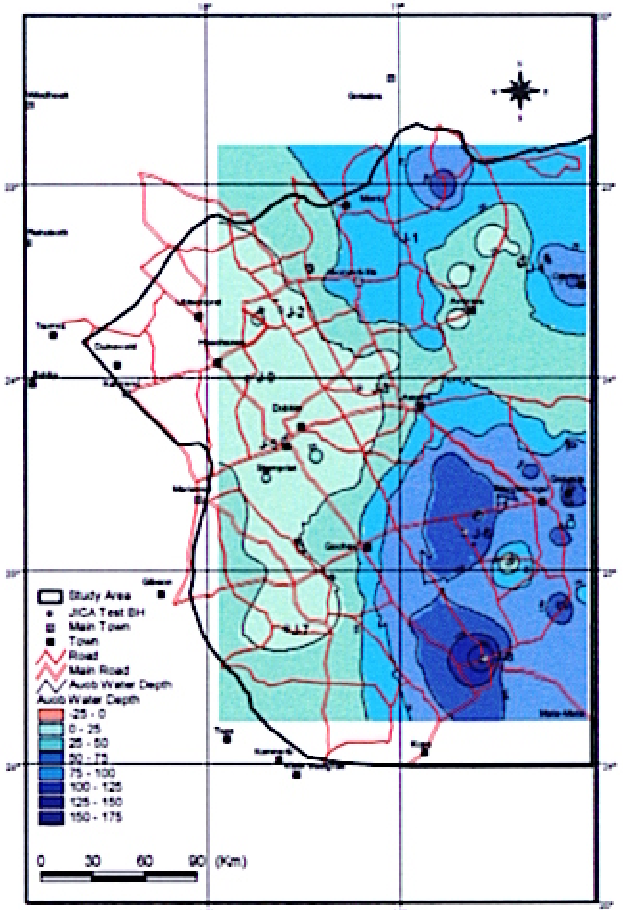


Fig. 5.3-2 Water Depth of Auob Aquifer

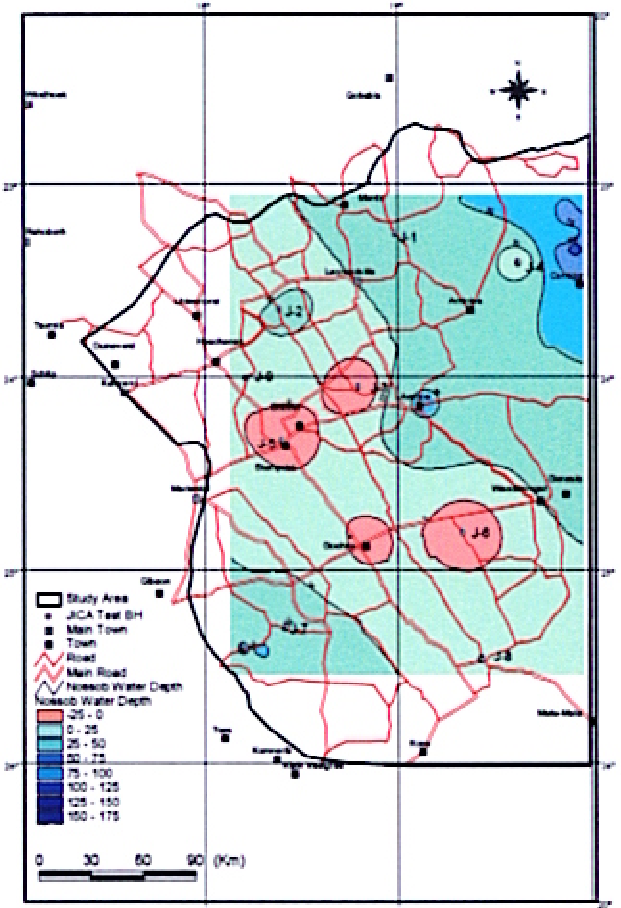


Fig. 5.3-3 Water Depth of Nossob Aquifer

5.3.3 Depth of Aquifer

A depth of an aquifer itself is a main factor of drilling cost as an initial cost for a production well. Therefore the depth of each aquifer from the ground surface was selected as one of the indices for the evaluation of aquifers. Fig. 5.3-4 and 5 show the distribution of the depth of the Auob and Nossob Aquifer. The Kalahari Aquifer is regarded as 0m although the aquifer is covered by thin surface soil or sand dune.

The depth of both aquifers becomes deeper to the eastern part of the basin. The bluish colored area showing the depth of more than 300m is spreading widely in the case of the Nossob Aquifer. (Fig.5.3-5)

5.3.4 Specific Yield

The specific yield (or capacity) of the aquifer evaluated from pumping tests was chosen as an index of aquifer productivity. As shown in Fig. 5.3-6 to 8, the range of specific yield of each aquifer is considerably broad. Although appropriate data from pumping tests is limited to the results of JICA test boreholes, it is possible to grasp the general tendency from them.

It is clear that the most superior aquifer in terms of the specific yield is the Auob Aquifer and the most inferior aquifer is the Nossob Aquifer.

As for the Auob Aquifer, the specific yield in the western part of the basin around Stampriet is higher than the eastern part. Unexpectedly the specific yield of the Kalahari Aquifer is lower.

The distribution pattern of specific yield for the Nossob Aquifer is much different from them. The specific yield in the southwestern area of the basin or Stampriet area is low but it is getting better towards the Aminius area.

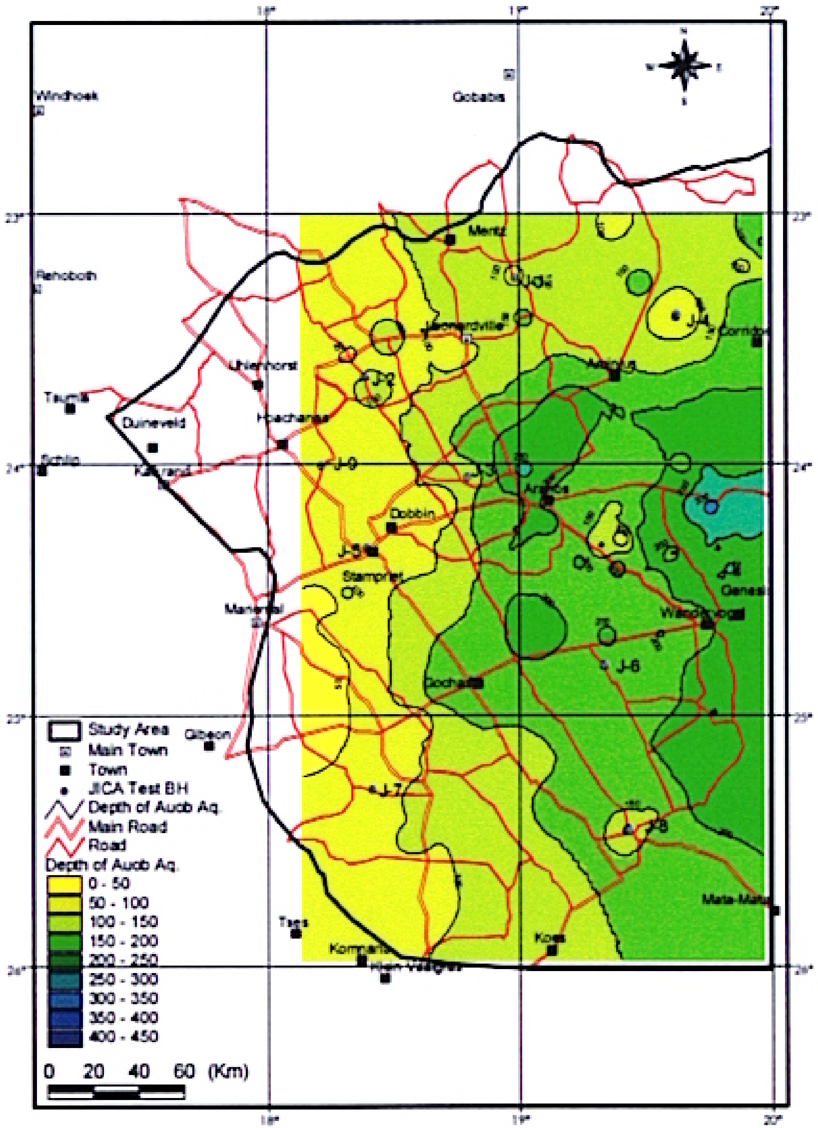


Fig. 5. 3-4 Depth of Auob Aquifer

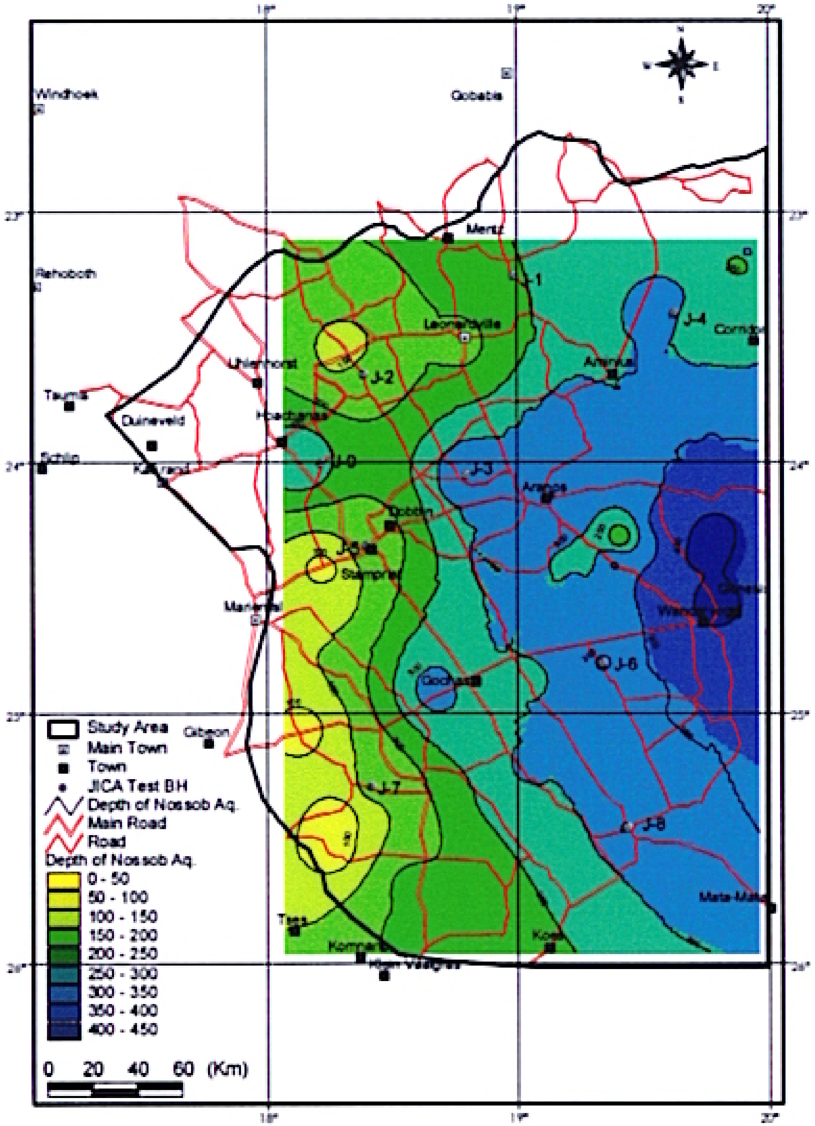


Fig. 5. 3-5 Depth of Nossob Aquifer

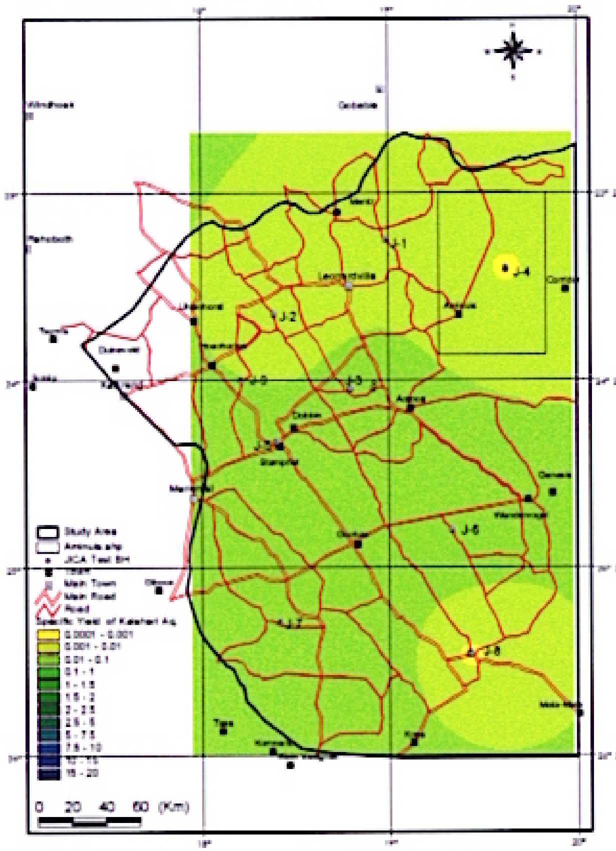


Fig. 5.3-6 Specific Yield of Kalahari Aquifer

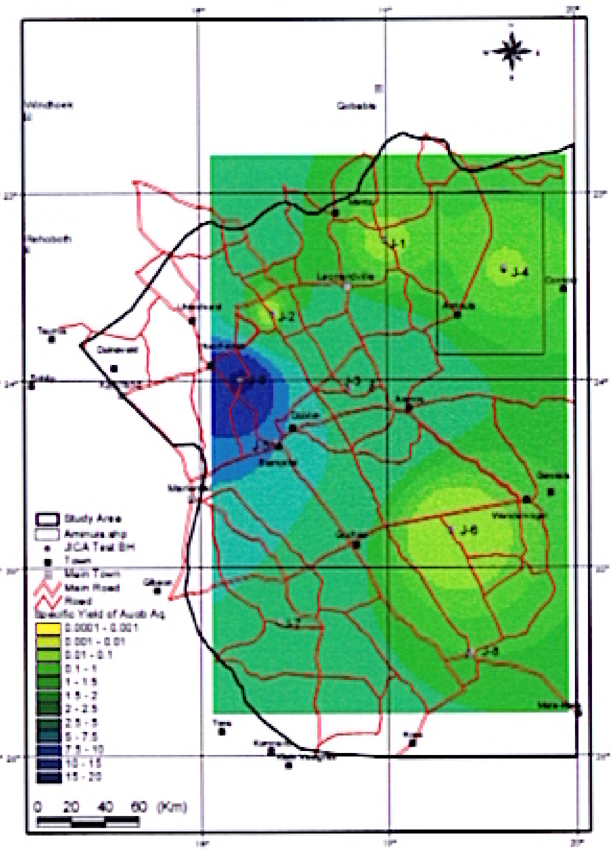


Fig. 5.3-7 Specific Yield of Auob Aquifer

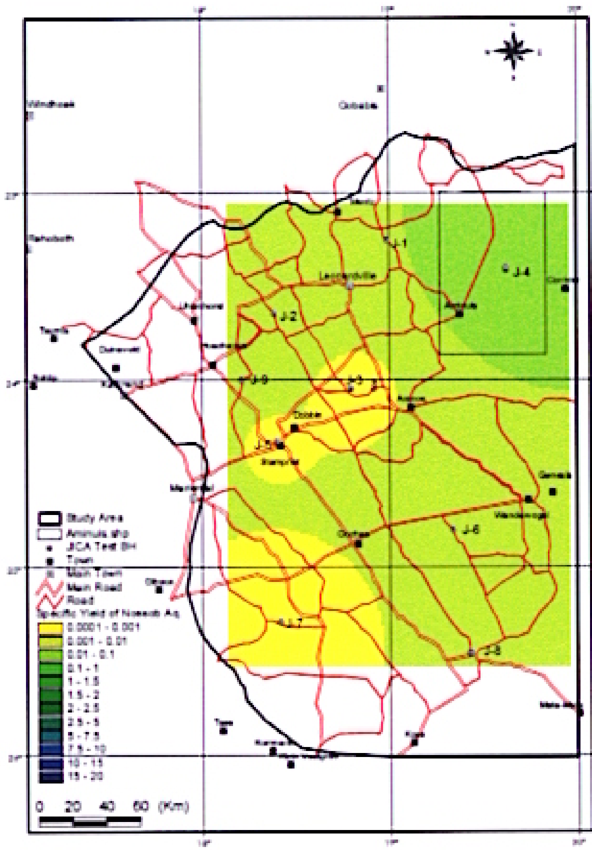


Fig. 5.3-8 Specific Yield of Nossob Aquifer

5.3.5 Hydrogeological Potential Evaluation of Aquifers

The four above-mentioned indices were summed up at every 3Km^2 calculation grid in the basin for the synthetic evaluation of aquifers. The results are illustrated in Fig. 5.3-9 to 11.

1) Kalahari Aquifer

The southeastern part of the basin, which it is called the “Pre-Kalahari Valley” or “Salt Block”, is evaluated badly. The area, which is given more than 275 points and evaluated as considerably good, extends widely in the western part of the basin. (Fig. 5.3-9)

2) Auob Aquifer

The central area of the western part of the basin including Stampriet obtains a good score of more than 300 points and as a result, it coincides with the present condition of high intensive withdrawal from this aquifer as shown in Fig.5.3-10. However, the area, which obtains less than 225 points, is distributed extensively in the southeastern part of the basin. It is remarkable that a considerable portion of the land in the north of Aminius reaches more than 250 points.

3) Nossob Aquifer

Most of the analyzed area is covered by a reddish color, which means less than 225 points and low or very low groundwater potential except for a small area around Stampriet. This aquifer is rarely utilized except for NAMWATER at Leonardville and Aranos as shown in Fig. 5.3-11.

On the basis of the evaluation results, it is possible to understand which aquifer has high potential in a certain area of the basin or which area of a certain aquifer is relatively better in terms of groundwater potential.

The synthetic evaluation for the three aquifers in the basin with four major indices is presented in this section. It is noticeable that this evaluation is not an absolute evaluation of each aquifer but a relative one. The results may vary depending on the purpose, statistic weight among indices, increase of hydrogeological data, progression of technology, and so forth.

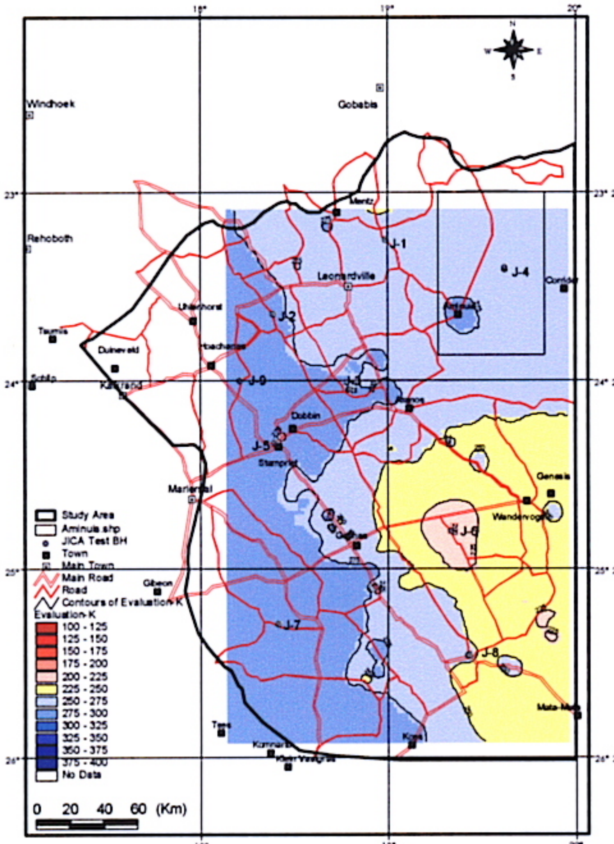


Fig. 5.3-9 Potential Evaluation of Kalahari Aquifer

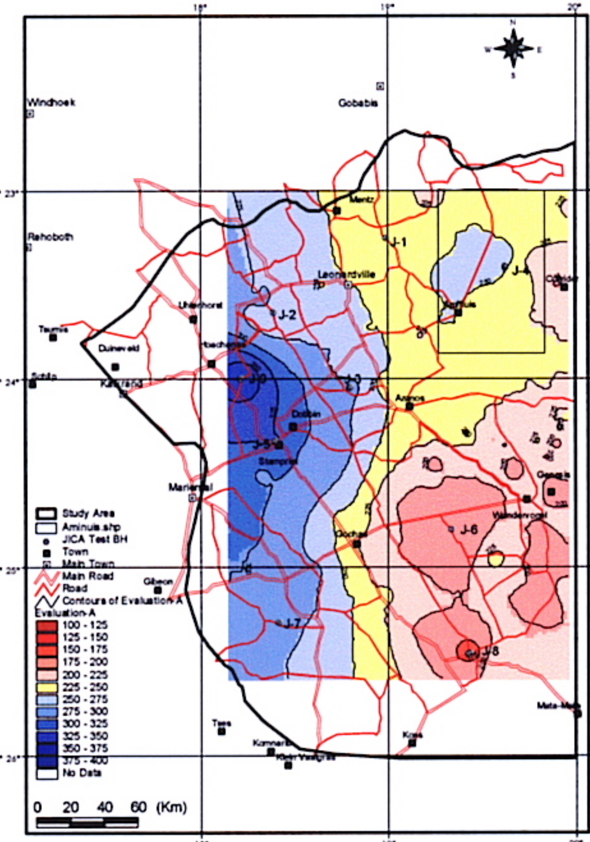


Fig. 5.3-10 Potential Evaluation of Auob Aquifer

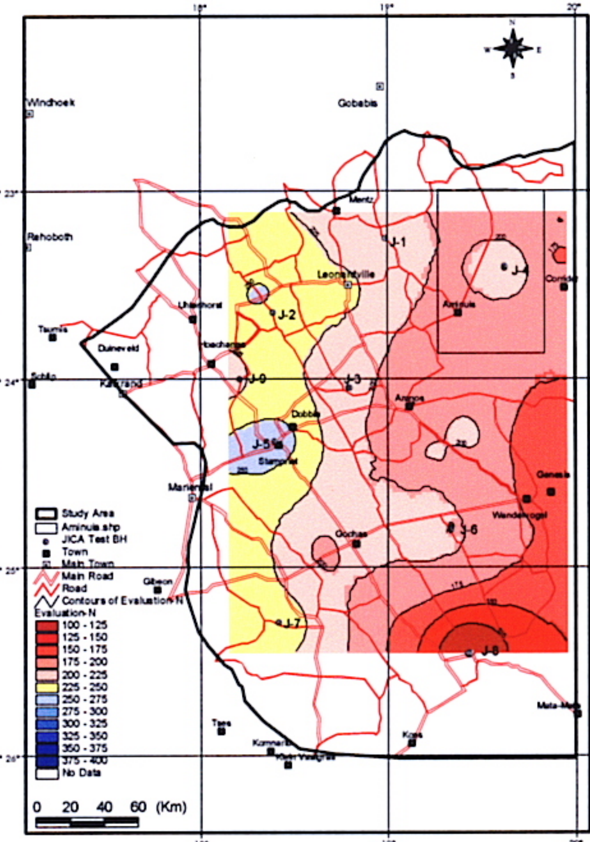


Fig. 5.3-11 Potential Evaluation of Nossob Aquifer

5.3.6 Groundwater Simulation

Additionally to the groundwater potential evaluation, a groundwater simulation was performed in order to evaluate it quantitatively.

1) Simulation Model

Based on hydro geological investigation, three aquifers (Kalahari, Auob and Nossob) in the Stampriet Artesian Basin were modelled using a finite difference three-dimensional model. The Kalahari Aquifer is unconfined, and the Auob and Nossob Aquifer are confined. The northern and southeastern boundaries are regarded as a constant head boundary to approximate groundwater inflow and outflow.

2) Input Data

The aquifer constants, groundwater abstraction, and recharge rates were inputted for each cell, manipulating from hydrological and hydrogeological studies. Present groundwater use in the basin amounts to 15 million m^3/year (domestic: 2.4 million m^3/year, stock watering: 5.7 million m^3/year, irrigation: 6.9 million m^3/year).

3) Calibration

Calculated heads were compared with results of the groundwater level survey. Then, these were calibrated with the variation of groundwater levels at observation wells. The calculated heads show a good agreement with the trend of observed groundwater levels.

4) Prediction

To predict the change of the groundwater level caused by the change of pumping rate, 6 cases were studied. Case 1 and 2 were assumed to maintain present groundwater use. In Case 3, the irrigation use was increased to 120% in comparison with the present use. In Cases 4 to 6, their irrigation uses were decreased to 70%, 50% and 0% respectively. The prediction period for each case is 100 years.

Table 5.3-2 Conditions of Groundwater Simulation Cases

Case	Pumping Rate (million m³/year)				Recharge Rate (million m³/year)	
	Domestic	Stock Watering	Irrigation (%)	Total (%)	Ordinary Year	1/50 Years Rainfall
1	2.36	5.69	6.89 (100)	14.94 (100)	4.60	-
2	2.36	5.69	6.89 (100)	14.94 (100)	4.60	79.86
3	2.36	5.69	8.27 (120)	16.32 (109)	4.60	79.86
4	2.36	5.69	4.82 (70)	12.87 (86)	4.60	79.86
5	2.36	5.69	3.44 (50)	11.49 (77)	4.60	79.86
6	2.36	5.69	0 (0)	8.05 (54)	4.60	79.86

5) Evaluation of Prediction Results

The results of the model simulation in the Stampriet Basin are summarized as Table 5.3-3 and some of the simulation results; Case 2, 4 and 5 are shown in Fig. 5.3-12 to 17.

Table 5.3-3 Results of Groundwater Simulation

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	UD	A	G	G	A	A	G	G
6	A/UD	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)

6) Permissible Yield

The present groundwater abstraction (Case1, Case 2) is acceptable in the Stampriet Basin except for the Stampriet area. In the Stampriet area, the groundwater is mainly used for stock watering and domestic purposes. It is considered that groundwater use will not increase remarkably. In the Tugela area, the declines of the groundwater level are slightly high with present groundwater pumpage. Careful monitoring is required.

In the Stampriet area, the Kalahari Aquifer will dry up in the near future, for example 25 years after in Case 3, if present groundwater abstraction is maintained. (refer to Fig. 5.3-18) From the above results, the pumping plan of Case 5 (reducing irrigation use to 50%) and Case 6 (reducing irrigation use to 0%) are acceptable in Stampriet area. Case 4 (reducing irrigation use to 70%) is not allowable since the Kalahari Aquifer will dry up within a period of 80 years. To prevent the dry-up of this aquifer, groundwater pumping for irrigation use has to be reduced to at least 50% of that in 1999, which is almost the same as the irrigation use in 1992.

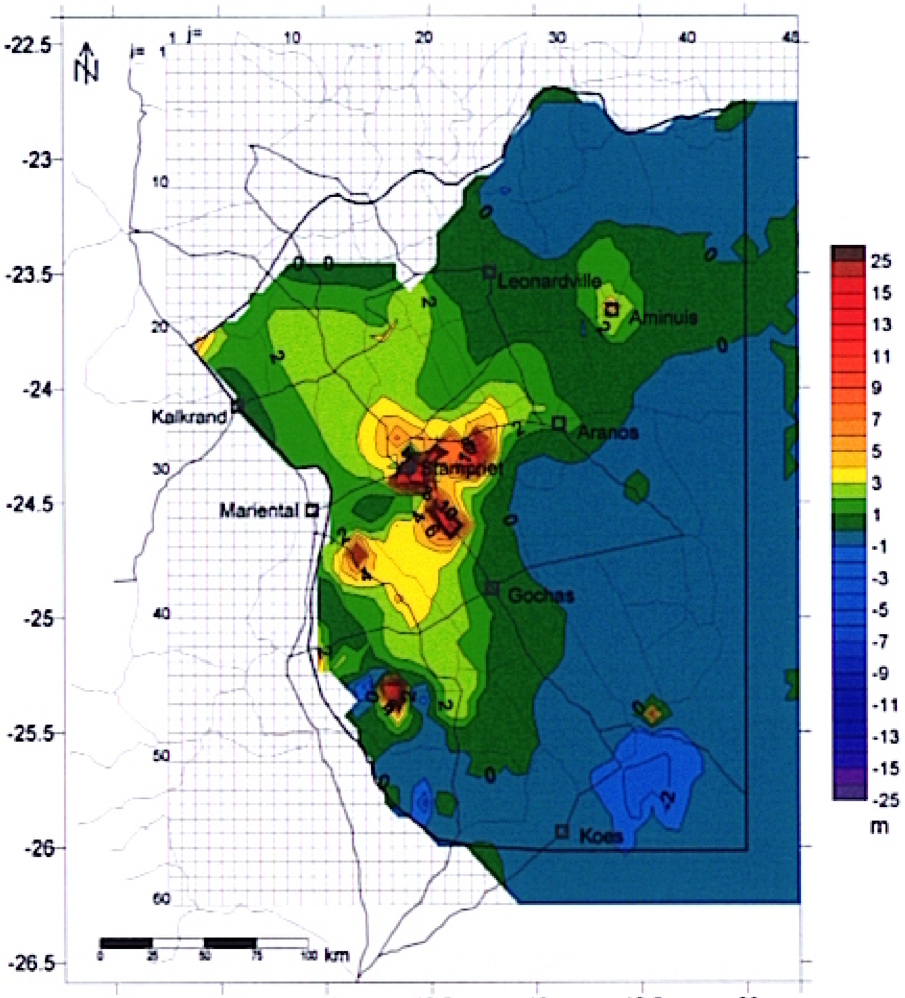


Fig.5.3-12 Calculated Drawdown of the Kalahari Aquifer, Case 2 (100 years after)

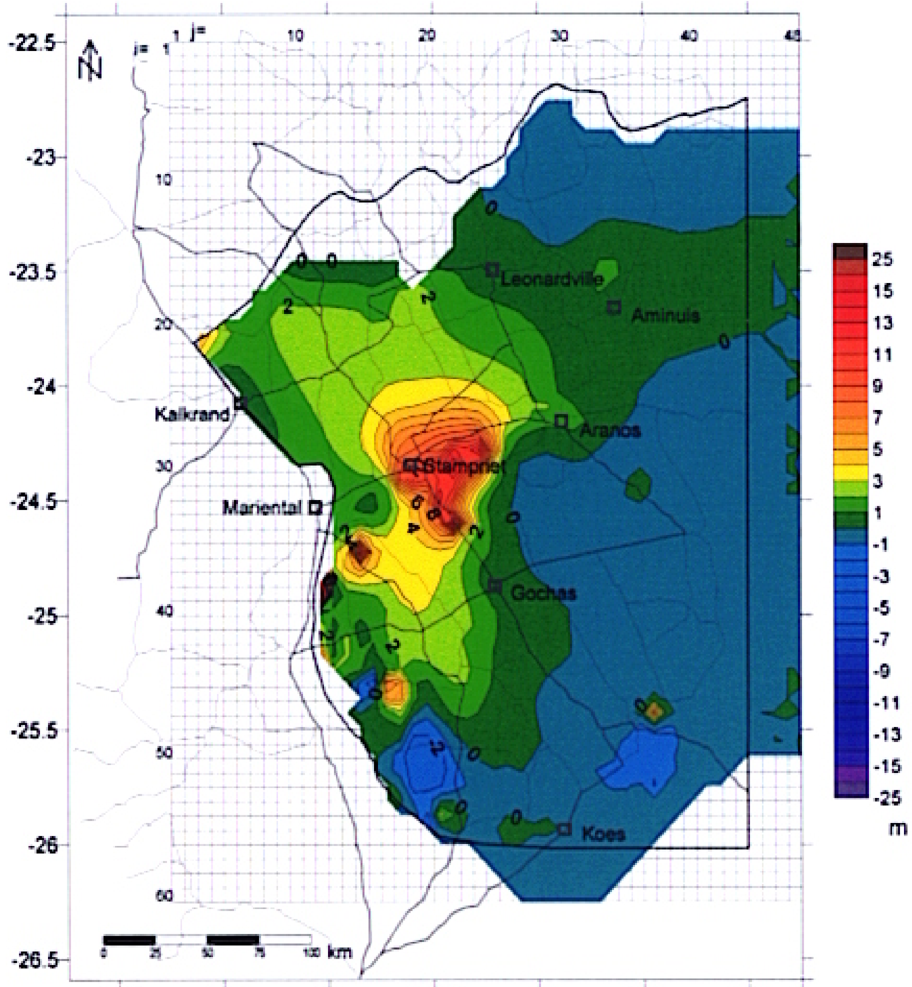


Fig.5.3-13 Calculated Drawdown of the Auob Aquifer, Case 2 (100 years after)

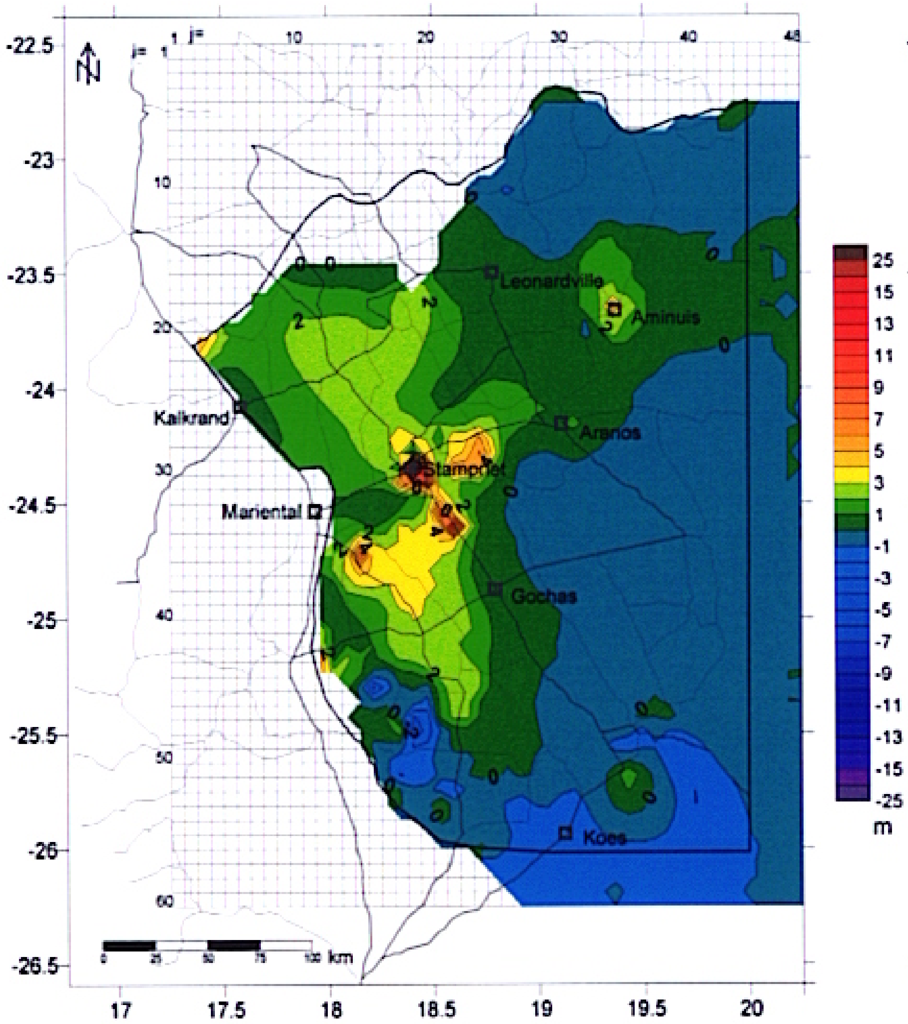


Fig.5.3-14 Calculated Drawdown of the Kalahari 1Aquifer, Case 4 (100 years after)

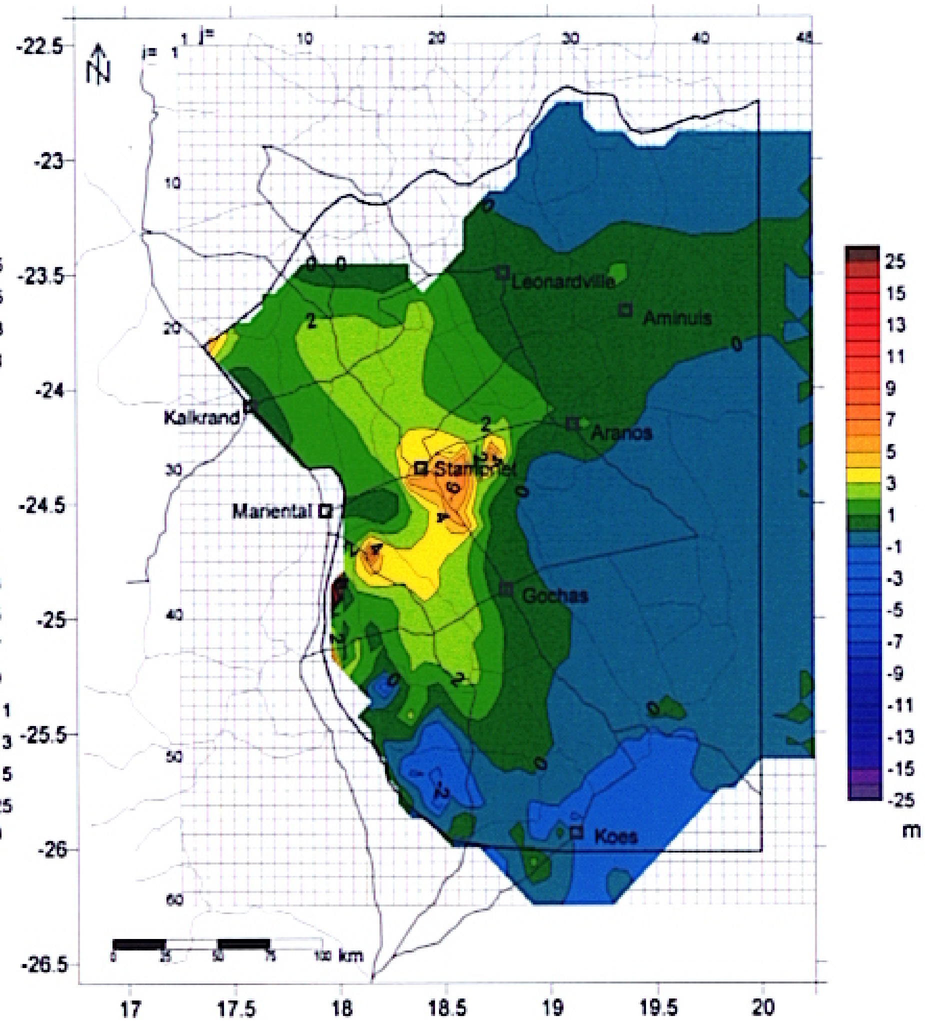


Fig.5.3-15 Calculated Drawdown of the Auob Aquifer, Case 4 (100 years after)

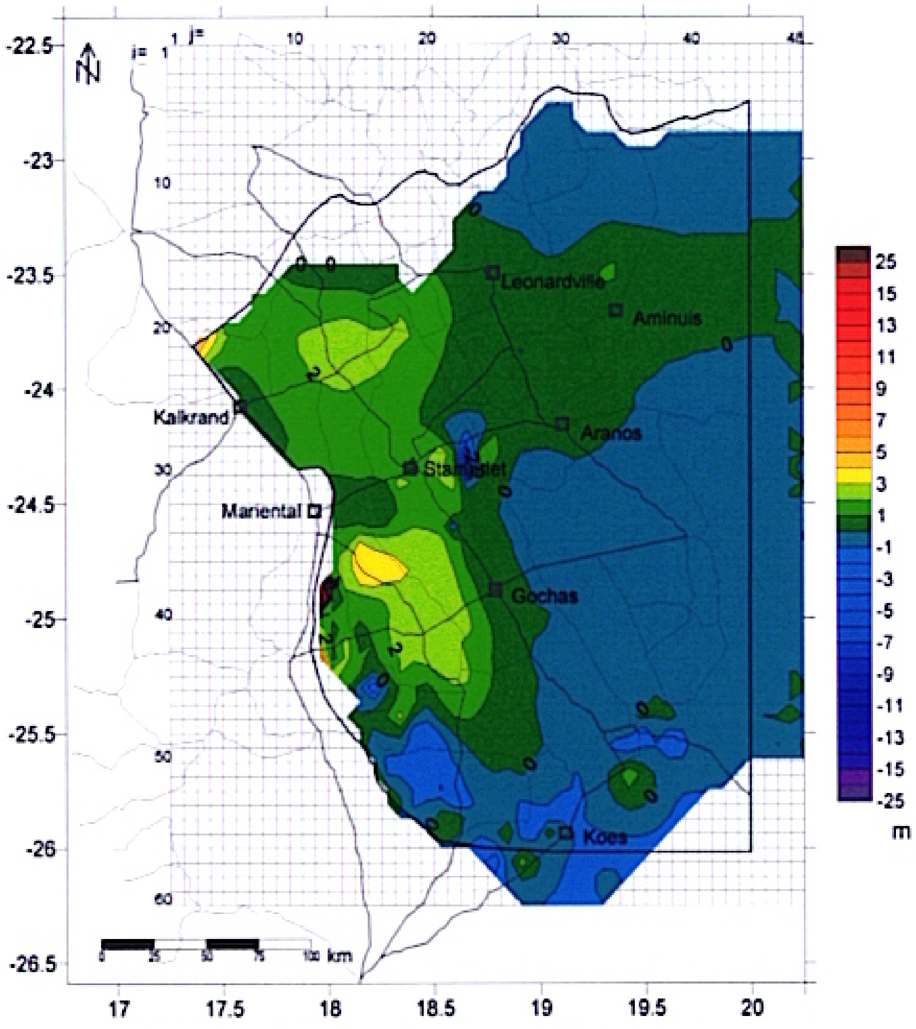


Fig.5.3-16 Calculated Drawdown of the Kalahari Aquifer, Case 5 (100 years after)

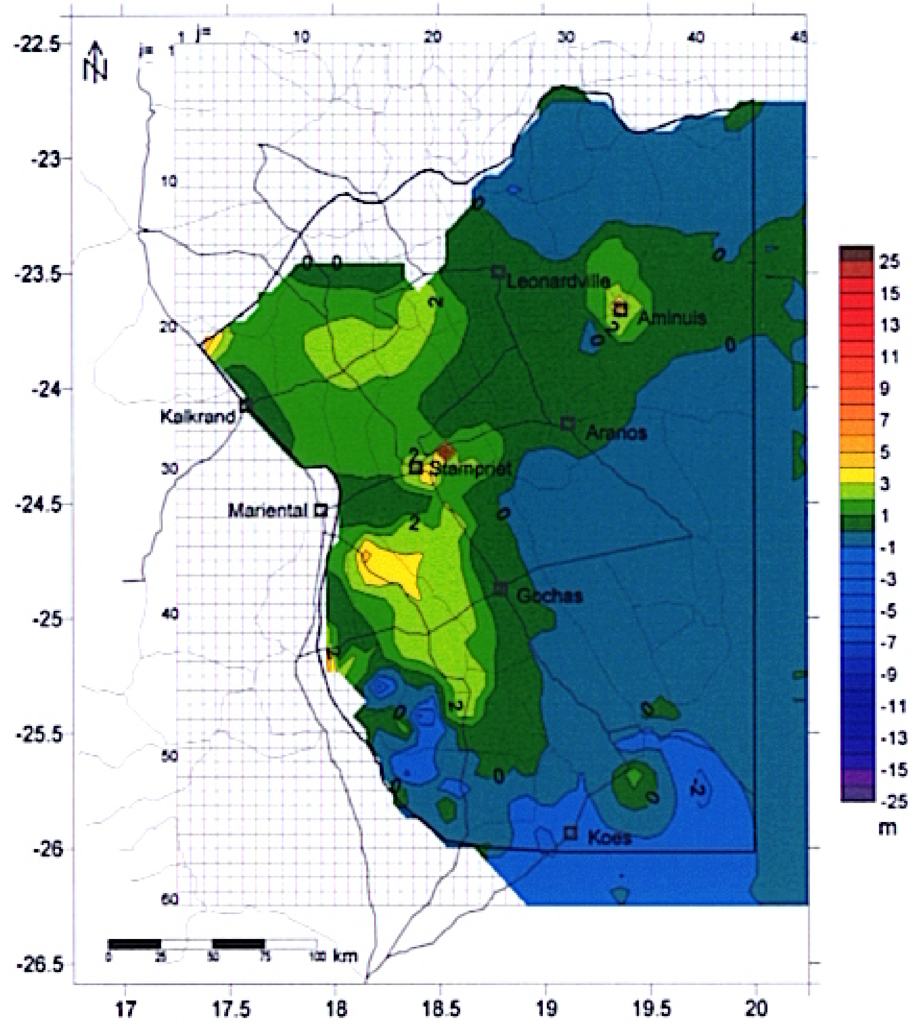


Fig.5.3-17 Calculated Drawdown of the Auob Aquifer, Case 5 (100 years after)

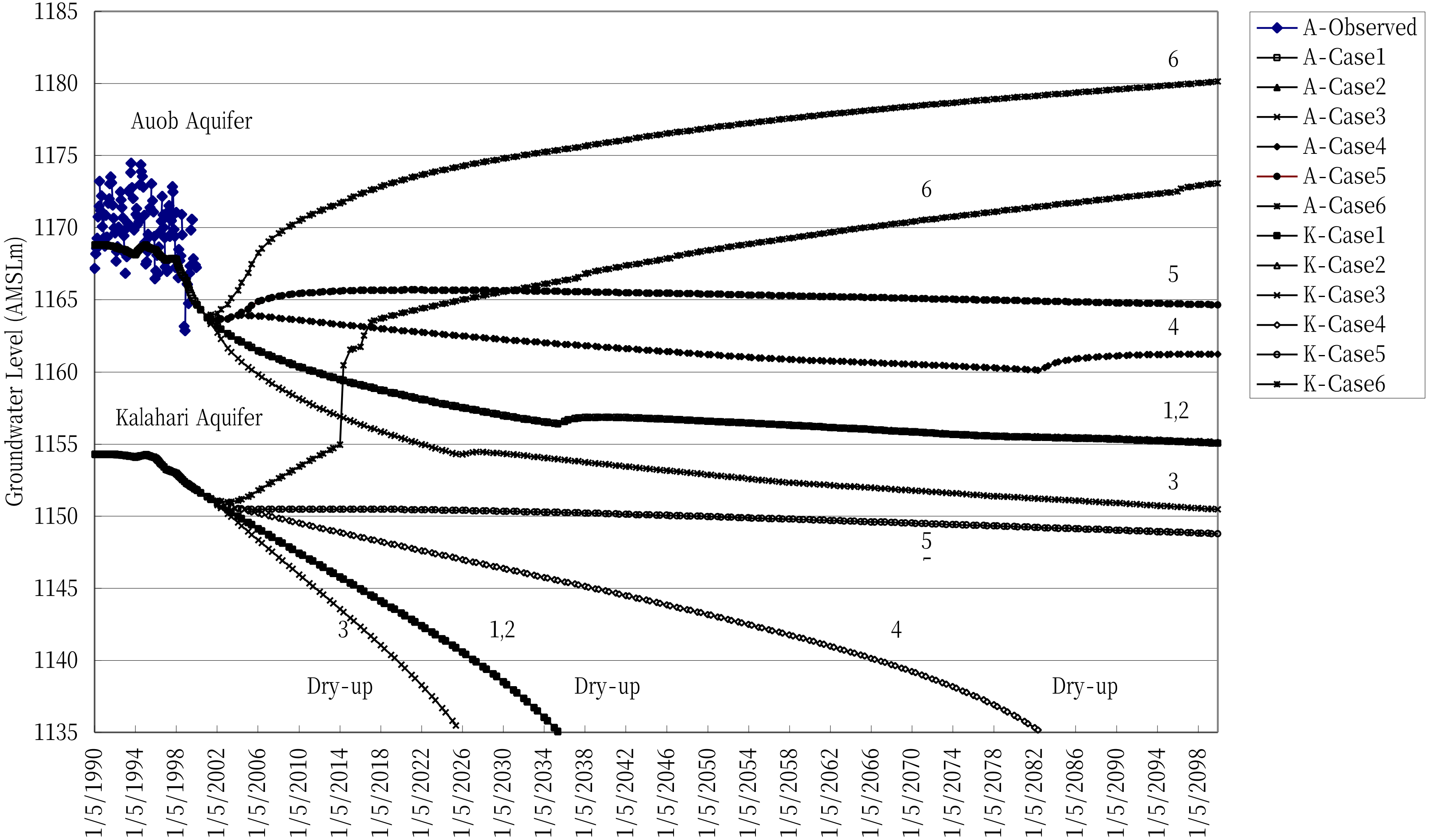


Fig.5.3-18 Variation of Groundwater Level of the Kalahari and Auob Aquifer at Stampriet (Spes Bona)

CHAPTER 6 INITIAL ENVIRONMENTAL EXAMINATION

The overall objective of this Study is to carry out the investigation of the groundwater flow and recharge mechanism in the Stampriet Artesian Basin, and to formulate a groundwater management plan for sustainable groundwater development. The Study as such is in reality an environmental assessment, which should lead to achieving and maintaining sustainable groundwater utilization in the Area. In view of the paucity of environmental base line studies in the area, this Study will essentially comprise an environmental audit.

The detailed description of natural and social environment of the Study Area shall be elaborated in Chapter 2 of this report. The project proposed through this Study is not infrastructure development project in the usual sense, but rather a resource assessment. Therefore, in this chapter, the focus is placed on the examination of interrelationship between the groundwater management and the environmental issues, which potentially have impacts on the groundwater as a natural resource, and vice versa, have potential to receive impacts from activities related to groundwater management.

6.1 Screening and Evaluation

The Initial Environmental Examination was carried out in order to identify the environmental impacts on areas, which will be affected by the groundwater management plan, and in reverse, the potential impacts on groundwater resource imposed by environmental factors. The identification and screening were conducted in line with the “Environmental Management Act of Namibia (1988)” and the Guidelines prepared by JICA (1992). The examined environmental items were adopted from the JICA Guidelines, for each of which the degree of impacts was evaluated in five (5) categories. In Tables 6-1 to 6-3 these impacts are summarised and evaluated for the Social Environment, the Natural Environment, and potential Pollution, based on the information as described above. It is evident that the main study of the sustainable potential of the Stampriet Artesian Basin will provide the necessary basis for the environmental assessment.

The following section describes the environmental items, which was concluded in this IEE to have impacts at any level regarding the groundwater use and its management.

6.1.1 Social Environment

1) Economic Activities: Loss of production base (land etc.) and change of economic structure

Economic activities in this area are mainly related to farming, tourism and trading (at towns). The farming activities involve stockbreeding and agricultural crop production by irrigation. The alternative of groundwater management plan proposes the reduction of irrigation water by 30% of the current water use of the region. If this is applied, it is estimated that the agricultural yield shall accordingly be constrained and lead to the potential deceleration in the economic growth in the Area. One possible mitigation measure on this issue is to shift the crops to those with higher market values. In this regard, natural resource accounting (Lange, 1997) could be applied to determine the domain where a reduction in water use could possibly be effected with the least impact on the economy of the study area. The specific study of the Stampriet Artesian Basin (Lindgren, 1999) may serve as a guideline in this regard. The detail of this subject is included in Chapter 8, Conclusion and Recommendation.

(1) Causes of Impacts

- Constraints on the conventional water use

(2) Possible Environmental Impacts

- Change in agricultural productivity per unit farmland

(3) Factors for Evaluation

- Economic return per cubic meter of water used for each economic activity

(4) Measures

- Measuring of actual water use by means of water meters
- Generally allow most economical use of water resource (including the change of conventional irrigation scheme)
- Restrict least economical water use
- Improve the economic productivity per unit farm land by the conversion of crop species to cash crops

(5) Related Subjects for Study

- Socioeconomic impact of restricting water use(s)
- Possible repercussions of crop conversions

2) Water Rights and Rights of Common: Obstruction of irrigation and water rights

The legal situation with regard to water in Namibia is still regulated by the Water Act of 1956 (Act No 54 of 1956). Surface water is controlled by various clauses in the Water Act and permits are required for example for the removal of any water from a catchment, or for the construction of any water controlling structures in rivers. In terms of this legislation, groundwater can also be controlled by the proclamation of subterranean water control areas. Outside such proclaimed areas, landowners have full access and rights to the groundwater underlying their property. However, this is essentially in conflict with the Constitution of Namibia and a new Water Act is being drafted for giving the Government full control over groundwater.

The Stampriet Artesian Basin, described as the Windhoek - Gobabis - Mariental - Keetmanshoop Artesian Area, was proclaimed a Subterranean Water Control Area by Government Notice No 302 of 1 October 1955. Subsequently, adjacent areas, including most of the surface catchment areas of the rivers flowing through the Stampriet Artesian Basin, were declared subterranean water control areas: the Windhoek - Gobabis Subterranean Water Control Area (Government Notice No 189 of 6 February 1970) and the Windhoek - Gobabis Subterranean Water Control Area (Extension) (Government Notice No 47 of 26 March 1976). The upper reaches of the White and Black Nossob fall outside these subterranean water control areas, which imply that, at this stage, no control can be exercised over groundwater abstraction in this area.

At present, groundwater is abstracted without any particular control measure. The legislative control of water use itself does not have any legal conflict, but in practice, it may accompany a social conflict in the subject of water right. However, since the groundwater is a natural resource with highly public significance, the sustainable water use should be carried out all through. To achieve the goal, a step-wise implementation and public education on water use and taxation may mitigate the social impact in this regard.

(1) Causes of Impacts

- Obstruction in irrigation water use by the legislative control

(2) Possible Environmental Impacts

- Reduction of agricultural production
- Public opposition on taxation and regulation of water use

(3) Factors for Evaluation

- Long-term water level trend determination at several points
- Determine sustainable groundwater potential

(4) Measures

- Step-wise implementation of water use regulation & taxation
- Establishment of intensive regulation zone
- Public education/information on the water use and regulation

(5) Related Subjects for Study

- Most economical use of water (over and above drinking water needs), possibly making use of natural resource accounting (Lange, 1997)

3) Public Health Condition: Worsening of health and sanitary condition due to generation of wastes and appearance of harmful insects

Increased population numbers and the development of towns lead to increased water use and the generation of wastewater. Though the impact of wastewater on groundwater quality has not been reported so far, the wastewater discharge and treatment should be monitored for the public health aspect. Wastewater discharges are controlled and where available, permits for wastewater treatment systems are listed in the Appendix E in the supporting report.

According to the initial examination of the result of hydro-census conducted in this Study, the use of fertilizer is assumed to be very limited both in area and quantity. Accordingly, at present, the risk of groundwater contamination from the fertilizers has not been reported. However, certain agricultural chemicals that can be harmful reach these aquifers and enter the groundwater resource. Others, such as fertilizers, may cause eutrophication of surface water supplies. Further examination and monitoring is expected for the detection of long-term impact of these factors on the groundwater resource.

(1) Causes of Impacts

- Water pollution
- Use of potentially harmful agricultural chemicals

(2) Possible Environmental Impacts

- Increase in water-related illnesses

(3) Factors for Evaluation

- Present occurrence of potentially water-related illnesses, e.g. diarrhoea, malaria
- Present usage and usage trends of agricultural chemicals

(4) Measures

- Control of wastewater discharges for protection against groundwater pollution
- Control of potentially harmful agricultural chemicals

(5) Related Subjects for Study

- Water-borne diseases, e.g. malaria, may cause a minor problem from time to time and it is considered important to obtain statistics for considering the need for further actions.
- It is potentially possible that groundwater pollution from wastewater discharges may occur which could cause water-related illnesses.

4) Waste: Generation of construction waste, surplus soils, sludge, domestic waste, etc.

No Namibian guidelines could be found for (solid) waste disposal activities. Pollution derived from waste management and disposal will not be a consequence of groundwater development and its management, but of existing anthropogenic activities. Depending on the nature of the disposal sites, they may have an effect on groundwater quality in the phreatic aquifers, and could eventually impact on the use of groundwater. Though the adverse impact has not been reported so far, a through investigation and constant monitoring and management are necessary for the prevention of contamination impacts from waste disposal.

(1) Causes of Impacts

- Waste disposal activities and sites which do not comply with minimum requirements for environmental protection needs

(2) Possible Environmental Impacts

- Groundwater pollution
- Littering

(3) Factors for Evaluation

- Quantities of waste generated
- Types of waste (apart from domestic wastes)

(4) Measures

- Informing local authorities on hazards involved
- Providing minimum guidelines (from other countries)

(5) Related Subjects for Study

- Sewage sludge disposal

6.1.2 Natural Environment

1) Groundwater: Lowering of groundwater table due to overdraft and turbid water caused by construction work

The lowering of the groundwater table is already an established trend for a large part of the study area. This may be due to a multitude of reasons, including, inter alia, a reduction in groundwater recharge, and possible overexploitation. Once the sustainable potential of the Stampriet Artesian Basin has been determined, measures will have to be implemented to ensure that overdraft is eliminated. This aspect will need detailed investigation and already forms part of the general project brief. Should the sustainable management plan is established and effectively enforced, only positive impacts are expected on the groundwater recharge of the region.

(1) Causes of Impacts

- Control on overexploitation of groundwater
- Increased recharge of aquifers

(2) Possible Environmental Impacts

- Maintaining the groundwater table in phreatic and confined aquifers
- Repression of saltwater intrusion from overlying or underlying aquifers, into aquifers with good quality usable groundwater

(3) Factors for Evaluation

- Sustainable water resource potential of the whole aquifer system
- Water abstraction trends
- Water use for irrigation
- Water quality trends and saline water intrusion
- Areas of natural leakage

(4) Measures

- (Since the proposed management plan is expected to lead only positive impact on the Stempriet Artesian Basin, no further mitigation measure shall be required except a regular monitoring and management)

(5) Related Subjects for Study

- Water-use situation study (economically and population induced)
- Water quality evaluation
- Isotope studies for determining aquifer recharge and sustainable yield
- Identify leaky boreholes and find solution for providing permanent casings

2) Fauna and Flora: Interruption of reproduction or extinction of species due to change of habitat condition

According to Griffin (pers. comm., 8 November 1999) a change in the natural vegetation will eventually affect the whole ecological chain. The Kalahari ecosystem in the area around the Auob and Nossob Rivers has been described by Leser (1971). Thomas and Shaw (1991) give a general description of the Kalahari environment.

The Giess Vegetation Map of Namibia (1971) is the only countrywide survey that exists for Namibia. Presently, the National Botanical Research Institute of Namibia is carrying out a project to update the Vegetation Map of Namibia at a scale of 1:1 000 000 (Strohbach and Sheuyange, 1999). The surveying has started in the Karas and Hardap regions during the 1997 growing season, and it has covered the part of the Stampriet Artesian Basin to the east of 18 ° E and south of 24 ° S. Although no quantitative data is available, it was postulated (Strohbach, pers. comm., 10 November 1999) that the Kalahari is a relatively young desert, as only 10 to 15 plant species were found per 1000 m^2 compared the Karas Mountains where approximately 60 species per 1000 m^2 were recorded. It has to be noted that the climate in the Karas Mountains varies considerably and would lead to a greater diversity of species.

The alien Prosopis sp. is responsible for destroying the habitat of the natural vegetation. The camel thorn trees (Acacia erioloba) are very sensitive for such invasions and they would seem to be affected in many places. Strohbach (pers. comm., 1999) has the impression that the Prosopis will grow in areas, which have ample supplies of water. In the Auob River, where such invasions occur, perennial grass, Sporobolus tenulus, was found which usually occur in marshy conditions, e.g. around a spring. The extent and success of attempts to control the invasions are unknown.

With regard to the fauna in the Stampriet Artesian Basin, no specific study has been undertaken. The closest area where any study was done is the Hardap Dam National Park. Draft tables were compiled of the occurrence of amphibians, reptiles and mammals (Griffin, 1999). This type of study was carried out for all national protected areas under the control of the Ministry of Environment and Tourism. As the Hardap Dam National Park covers an area adjacent to the Stampriet Artesian Basin, the data obtained from Griffin (1999) is included in Appendix D.

(1) Causes of Impacts

- Alien vegetation invasions
- Potential overgrazing at stock watering points

(2) Possible Environmental Impacts

- Reduction in numbers of plants and species, followed by a decrease in the numbers of and species of fauna
- Desertification

(3) Factors for Evaluation

- Changes in vegetation determined by satellite imagery or aerial photography

(4) Measures

- Control of alien invasive vegetation
- Control livestock numbers

(5) Related Subjects for Study

- Occurrence of Phragmites sp in the Auob River bed on the farm Schilflage, R143, approximately 100 m south of the entrance road to the farm house (Strohbach, pers. comm., 1999)
- Over grazing near, and trampling of vegetation at watering points (DRFN, 1997).

6.1.3 Pollution

1) Water Pollution

This project in itself will not lead to any significant pollution impacts. Pollution is expected to occur through anthropogenic activities, existing and new, and that should be controlled by applying the necessary regulations and also by providing information to the local councils and the public.

The provisions of the Water Act, 1956 (Act No 54 of 1956) are intended to promote the maximum beneficial use of the country's water resources, and to safeguard public water supplies from avoidable pollution. For this reason, permit applications are required for potential polluting activities, such as wastewater treatment and waste disposal (see application form in Appendix E). See also the attached list of Towns (Appendix F) and the list of Guest Houses and other establishments (Appendix G) within the area, some of which have applied for wastewater discharge permits in terms of the Water Act.

(1) Causes of Impacts

- Potential causes are solid waste and sewage sludge disposal activities
- On-site sanitation

(2) Possible Environmental Impacts

- Deterioration of water quality in the phreatic aquifers

(3) Factors for Evaluation

- Extent of disposal activities (population related) and likely impact
- Control of permits for potential polluting activities

(4) Measures

- Inspection by Government authorities
- Information dissemination to the local councils and the public

(5) Related Subjects for Study

- Effluent standards (see Appendix H)

In Tables 6-1 to 6-3 these impacts are summarised and evaluated for the Social Environment, the Natural Environment, and potential Pollution, based on the information as described above. It is evident that the main study of the sustainable potential of the Stampriet Artesian Basin will provide the necessary basis for the environmental assessment.

Table 6-1 Screening for Groundwater Development: Social Environment

No	Environmental Item	Description	Evaluation	Remarks (Reason)
1.	Resettlement	Resettlement by land occupation (transfer of rights of residence, land ownership)	D	No resettlement is involved in the project.
2.	Economic Activities	Loss of production base (land etc.) and change of economic structure	B	Implementation of sustainable groundwater management may cause a change in the economic structure due to a potential need for reallocation of water according to basic needs and economic guidelines
3.	Traffic and Public Facilities	Impacts on existing traffic, schools, hospitals, etc. (e.g., traffic jam, accidents)	D	No permanent impacts are foreseen.
4.	Split of Communities	Separation of regional communities by hindrance of regional traffic	D	No infrastructure will be installed to this effect
5.	Cultural Property	Loss or deterioration of cultural properties, such as temples, shrines, archaeological assets, etc.	D	No infrastructure is planned that will have such an effect
6.	Water Rights and Rights of Common	Obstruction of fishing rights, irrigation and water rights	B	For sustainable groundwater development, water abstraction rights for irrigation may need to be reconsidered
7.	Public Health Condition	Worsening of health and sanitary condition due to generation of garbage and appearance of harmful insects	C	No impact negative caused by the study itself is foreseen. Groundwater quality is deteriorating in some areas due to leaky borehole casings.
8.	Waste	Generation of construction waste, surplus soils, sludge, domestic waste, etc.	C	The project will not cause any impact but existing and future anthropogenic activities can potentially cause pollution
9.	Hazards (Risk)	Increase in risk of cave-ins, ground failure and accidents	D	No impacts are foreseen. Precautions will be taken at the drilling sites to prevent any problems

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Table 6-2 Screening for Groundwater Development: Natural Environment

No	Environmental Item	Description	Evaluation	Remarks (Reason)
10.	Topography and geology	Change of valuable topography and geology due to excavation and earth fill	D	No large-scale construction is planned in the initial stage of the project.
11.	Soil erosion	Topsoil erosion by rainfall after land reclamation or deforestation	D	No large-scale construction is planned for the initial stage of the project.
12.	Groundwater	Lowering of groundwater table due to overdraft and turbid water caused by construction work	B	The lowering of groundwater levels is already an established trend, which could be related to the overdraft, reduced recharge of aquifers, and/or leaky borehole casings. The project is aimed at sustainable use
13.	Hydrological Situation	Change of discharge and water quality due to reclamation and drainage	D	Spring flow already negligible. Thus, no negative impact from this project is foreseen. However, changes in the catchments of the rivers entering the Stampriet Artesian Basin will affect the water balance in the area.
14.	Coastal Zone	Coastal erosion and sedimentation due to littoral drift and reclamation	D	The area is situated far from the coastline and the ephemeral rivers are only linked very indirectly with the coast via the Orange River system
15.	Fauna and Flora	Interruption of reproduction or extinction of species due to change of habitat condition	B	The study will not affect the fauna and flora. However, significant changes in vegetation may be taking place due to alien plant invasions. Overgrazing and desertification may also need to be evaluated.
16.	Meteorology	Change of micro-climate, such as temperature, wind, etc., due to large scale reclamation and construction	D	No impacts foreseen.
17.	Landscape	Deterioration of aesthetic harmony by structures and topographic change by reclamation	D	No large-scale construction is planned.

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Table 6-3　Screening for Groundwater Development:　Pollution

No	Environmental Item	Description	Evaluation	Remarks (Reason)
18.	Air Pollution	Pollution caused by exhaust gas or toxic gas from vehicles and factories	D	Short term limited exhaust gas generation during exploration drilling and test pumping only
19.	Water Pollution	Water pollution of river and groundwater caused by drilling mud and oil	C	Environmental pollution will be limited by employing proper drilling control and management
20.	Soil Contamination	Contamination caused by discharge or diffusion of sewage or toxic substances	D	Impact due to existing and new systems are not related to project activities
21.	Noise and Vibration	Generation of noise and vibration due to drilling and operation of pumping machines	D	Short term exploration drilling and test pumping only
22.	Land Subsidence	Deformation of the land and land subsidence due to lowering of groundwater table	D	Following completion of this project, groundwater exploration will be managed
23.	Offensive Odour	Generation of offensive odour and exhaust gases	D	Short term limited exhaust gas generation during exploration drilling and test pumping only
Overall Evaluation: Either IEE or EIA is necessary for the project implementation?			NO	However, the environmental impacts on the water quality and water balance of the Stampriet Artesian Basin may be significant

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6.2 Discussion

The ratings of the various environmental items as defined by JICA (1992) are evaluated in the following categories:

- A: Serious impact is expected
- B: Some impact is expected
- C: Extent of impact is unknown
  (Examination is needed. Impacts may become clear as study progresses.)
- D: No impact is expected. IEE/EIA is not necessary

As set out in the introduction to this report, the Study as such actually constitutes an environmental assessment for the Stampriet Artesian Basin. Accordingly, the project in itself will not lead to an environmental impact, but would rather lead to mitigation of any existing impact. For this reason, none of the 23 environmental items in the tables were evaluated as having a potentially serious impact (“A”-rating). The ratings given should be considered as the existing or potential future situation due to anthropogenic and other activities. All environmental items with a “B” rating reappear in Table 6-4 below, detailing a brief study plan and a few remarks.

The main thrust of the project is to determine the hydraulic relationships in the various aquifers as defined by means of the newly interpreted geology, and particularly the associated flow regimes in each aquifer. These findings will be supplemented with interpretations based on the water quality (chemistry and isotope) data in those areas where other information is unavailable or insufficient. Against this background, the environmental factors will have to be reviewed as the project progresses. For example, depending on the findings of the project with regard to the sustainable potential of the aquifer, it may be required that water rights have to be reallocated to conform to such potential of the aquifer. This will have to involve a detailed economic value assessment of the various water uses in the area, and the associated impacts.

The overall evaluation as set out above is summarised in Table 6-4, giving the evaluation for each item and a brief indication of the planned actions. These actions will be reviewed as the project progresses and further information becomes available.

Table 6-4 Overall Evaluation for Groundwater Development

No	Environmental Item	Evaluation	Study Plan	Remarks (Reason)
2.	Economic Activities	B	Determination of sustainable potential of artesian basin *(from main project)* Assessment of the economic value of groundwater for the different uses *(from DWA studies)* Possible reallocation scenarios *(DWA)*	Sustainable groundwater potential may be exceeded, requiring reallocation of water according to basic needs and economic guidelines
6.	Water Rights and Rights of Common	B	Water abstraction rights for basic uses, stock watering, irrigation and other purposes may need to be reconsidered *(DWA) (see item 2. above)*	If the sustainable groundwater potential is exceeded, water abstraction will have to be reduced
7.	Public Health Condition	C	Study use of potentially harmful agricultural chemicals Listing of permits issued by DWA for sewage and waste disposal Survey of sewage and waste disposal practices potentially harmful to health Establish potential impact of water quality deterioration due to leaky borehole casings	The JICA project will not create any health hazard, but existing health hazards in the study area which are identified during the study will have to be considered *(see also items 8. and 19. below)*
8.	Waste	C	Present and potential future anthropogenic activities producing waste need to be recorded *(see also items 7. and 19.)* Determine types and quantities of waste (apart from domestic waste)	The JICA project itself will not produce waste of any significance, but existing and future activities may present a hazard
12.	Groundwater	B	Evaluate abstraction trends and permanency of groundwater decline *(from main project)* Consider determining extent of impact of reduced piezometric heads on borehole leakage into/from artesian sandstones *(hydraulic modelling)* Estimate the extent of leakage due to corroded/inadequate borehole casings	Indications are that groundwater levels are receding, e.g. more and more boreholes, which were free flowing, stopped and are being pumped. Reducing/increasing water usage will affect piezometric heads and losses from the artesian aquifers
15.	Fauna and Flora	B	Estimate the role of the alien vegetation invasion with regard to groundwater losses, particularly in those areas directly affecting the natural recharge of the Karoo sandstones Consider the need for the regulation of overgrazing and desertification	Removal of alien vegetation should reduce groundwater losses and increase the recharge and sustainable potential of the artesian basin
19.	Water Pollution	C	Estimate the order of magnitude of waste generation, sewage treatment and disposal *(see items 7. and 8.)* Investigate the extent of water quality deterioration due to leaky borehole casings Develop guidelines for identifying leaky borehole casings and remedial measures, including the sealing/grouting of such boreholes	Impacts due to existing and new sewage and waste disposal systems do not related to this project but need to be recorded and managed. Leaky borehole casings may contribute significantly to water quality deterioration

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6.3 Conclusions

As such, this project should only have a beneficial impact on the environment, as the outcome should indicate what measures are required for sustainable use of the groundwater and for resource protection. Aspects, which should receive attention, are, for example:

- the presumed long term lowering of the groundwater table
- the hydrological situation in the upstream river catchments and the effect on the water balance of the Stampriet Artesian Basin
- the natural recharge situation and the need for artificial groundwater recharge, in which case further environmental assessments will be needed
- alien vegetation invasions, particularly of the river valleys
- reconsideration of the usage of water for different economic purposes
- reconsideration of water abstraction rights
- considering environmental impact assessments where irrigation water use exceeds 100 000 m^3/a as proposed in the guidelines of the Department of Water Affairs
- leaky borehole casings and the associated water quality deterioration
- control over anthropogenic activities which potentially may pollute the soil and groundwater

6.4 Recommendations

It is recommended that the outlined study plans are followed for those four environmental items having a “B”-rating (see Table 6-4), viz. economic activities, water rights & rights of common, groundwater, and fauna & flora. The definitions of these items are as given in Table 6-1 to 6-3.

It is also recommended that the three environmental items with a “C”-rating (Table 6-4), i.e. public health condition, waste, and water pollution, is reviewed as the project progresses and further information becomes available.

CHAPTER 7 GROUNDWATER MANAGEMENT PLAN

7.1 Concept of Groundwater Management

The most desired form of groundwater use is to abstract the necessary volume of water without a groundwater level reduction or land settlement.

In the study area, the aquifers of Kalahari, Auob, and Nossob are used to abstract water for domestic, stock, and irrigation purposes. The total abstraction volume (0.015x 10^9 m^3) is very small compared to the total groundwater storage (357x 10^9 m^3). However, natural recharge cannot be expected to fill the aquifers due to the limited precipitation and complex hydrogeological features of the area. Therefore, as has been made clear by the long-term monitoring carried out by DWA, the groundwater level has continuously decreased, resulting in a negative water balance. Furthermore, the groundwater withdrawal in some areas shows a marked increase, causing a severe decrease in the groundwater level.

In the study area, the largest groundwater consumers are the irrigation farms. However, inefficient water use would not appear be the cause since the irrigation method has already been converted from flood irrigation, which involves a large water loss, to more efficient sprinkler methods and/or drip irrigation. The significant increase in the abstraction volume is therefore considered to be as a result in the increase of irrigation farming and over-extraction beyond the permitted rate.

As a result of the study, as examined in Chapter 3 of this report, groundwater levels in the Kalahari aquifer could be depleted in the area around the Auob River catchment in the next 30 years. In other words, groundwater will soon be dried up in the aquifer where the community has mostly depended on it so far. In order to maintain the groundwater level of the aquifer, a 50% reduction of the current water use is required (See Chapter 3). On the other hand, changes in the groundwater level in the Auob aquifer have not been estimated to be as drastic in this time span.

Considering that the current socio-economic system of the study area is dependent on groundwater, a sudden reduction of water use by 50% is therefore not practical.

Accordingly, the study shall propose that the groundwater management plan to contain both sustainable use and practical application aspects, which are acceptable to the government and the public of the area.

7.2 Optimum Groundwater Use in the Study Area

7.2.1 Target Groundwater Extraction

According to the groundwater simulation carried out in this study, it is estimated that a depletion of the Kalahari Aquifer would take a period of 70 to 80 years if current extraction is reduced by 30%. A 50% reduction in the pumping rate is required to maintain the current groundwater level. The groundwater model applied here is based on the existing data and information, and needs further improvement for future data compilation. When the model is upgraded in the future, the depletion period may change accordingly. The ultimate purpose of the groundwater management plan is to enable the sustainable use of the aquifer. However, in practice, agricultural production provides the basis for most livelihoods in the area. In this regard, as the first step of the management plan, it is recommended that there is a reduction 30% of the current extraction rate. This will be achieved upon the implementation of several action plans as described below. This is the adaptive management plan to achieve the target reduction rate of 30%, as well as adjusting the required reduction rate based on the continuous monitoring of the effectiveness of the extraction control.

7.2.2 Environmental Consideration

Although water abstraction is inducing the gradual decrease in the water table in the study area, no other environmental impact is evident. Besides, a groundwater management plan would not involve novel developments of the groundwater resource, but rather would mitigate the decreasing tendency of the groundwater level. As a result, it would be considered to have positive impacts on the environment.

7.3 Groundwater Management Plan

7.3.1 Alternatives to Mitigation Measures

The study area is designated as Subterranean Water Control Area by Government Notice No 302 of 1st October 1955. According to this, the following three activities are required upon extracting groundwater from the study area:

(i) To obtain permission for water extraction.

(ii) To obtain permission for the operation of irrigation on farms larger than 1 ha.

(iii) To report the total extraction volume per year.

Although the above subjects are the most essential parts in the groundwater management plan, they are hardly followed in practice. The actual situation regarding items (i) and (ii) were made clear by the hydro census and DWA’s data. The information regarding illegal wells and irrigation farms in the hydro-census data was provided on condition of penalty exemption. Therefore, the handling of these illegal water users needs careful consideration upon the formulation of groundwater management

For the sustainable use of the aquifers in the study area, a reduction in the current extraction rate is required. This is especially crucial in the Subterranean Water Control Area. In this area, as stated previously, countermeasures are necessary for the control of over-extraction beyond the aquifer capacity. In this regard, action plans for the reduction of groundwater extraction are proposed in Table 7.3-1. Both items for urgent implementation and for adaptive application are described. Not all the action plans are to be implemented, but mitigation effectiveness on the groundwater receding should be monitored for the feedback adjustment of the plans.

Table 7.3-1 Action Plans for the Reduction of Groundwater Use

No.	Priority	Action Plan	Contents	Remarks
1	◎	Enlightenment of sustainable groundwater use	To hold local explanation meetings in cooperation with Farmer Union	To allow understanding for the aquifer potential and the predicted depletion of groundwater under the current water usage.
2	◎	Observation of water extraction volume	To assure the through enforcement of reporting duty of well owners.	Compulsory installation of flow meter to all wells. The pumping rate shall be regularly reported. The reporting duty and meter installation shall be inspected.
3	◎	Review of permission system	To take back the current extraction permit and reallocate them to achieve the 30% reduction target	WW No. should be issued to all existing wells including illegal ones, and the reporting of extraction rate is made mandatory.
4	○	Reduction of irrigation area	To keep the permitted irrigation area	Present irrigation area; 546ha in Stampriet area (Area II in Fig.4-2) should be reduced to 399.5ha.
5	○	Conversion of cultivation crops	To promote the conversion of crops to those with higher market values with lower water demand.	In cooperation with Department of agriculture and Farmer Union, the possibility of crop conversion shall be discussed to allow understanding and cooperation of farm. The status of crop conversion shall be monitored.
6	○	Voluntary reduction by water users	To expect the farm operators to voluntarily conserve irrigation water as a result of public education.	Closely related with the public education (item No. 1), which require the cooperation with farmers organizations as Farmer Union.
7	△	Application of efficient irrigation method	To convert the irrigation method for promoting more efficient water use.	In cooperation with farms, irrigation area and method shall be studied. The annual pumping rate shall be monitored.
8	△	Pricing on groundwater	To charge on groundwater extraction to control the excessive water use.	Setting of a valid amount of water price should be examined based on the water value calculated in the study.

◎ : Countermeasure for urgent implementation
○ : Countermeasure for short-term implementation
△ : Countermeasure for long-term implementation

7.3.2 Mitigation measures for the Reduction of Groundwater Extraction from Economic Aspects

A wide range of measures should be taken to control the water use such as raising awareness by education and information, legal measures and economic measures. However, considering the existing conditions of water use in the study area (refer to Chapter 4), this economic study focuses on the points mentioned below:

1) Conversion of cultivation crops
2) Application of efficient irrigation method
3) Reduction of irrigation area
4) Pricing of groundwater

1) Conversion of Cultivation Crops

To improve the water use efficiency from an economic perspective, reduction in the production of Lucerne and Cotton which require a lot more water than other crops and has lower added value compared to other crops is required. It is necessary to shift to high value added crops such as sweet melon, tomatoes, watermelon and other vegetables (Table 7.3-2).

Considering the farm size and the value added of crops, different scenarios of water reduction, all of which are realistic and efficient in the water use were simulated. It was examined how much water could be saved from conversion from Lucerne production into higher value added crops, while maintaining the same income of the farmers. In case farmers change their farming operation from Lucerne to Grape in Scenario 1-2 (changing ratio: 50 %) or from Lucerne to Maize in Scenario 2-1 (changing ratio: 100 %) the groundwater extraction will meet the short-term goal of a 30 % reduction in water use, which is the aim of this master plan. In Scenario 1-1 (changing ratio: 100 %) the groundwater extraction will attain the sustainable use level (68% reduction in water use).

Case 1 Lucerne → Grape

	Ratio of Changing Area	Reduced Water Volume (m^3)	Reduction Ratio
Scenario 1-1	100%	6,140,737	89 %
Scenario 1-2	50%	3,070,368	45 %
Scenario 1-3	20%	1,228,147	18 %

Case 2 Lucerne → Maize

	Ratio of Changing Area	Reduced Water Volume (m^3)	Reduction Ratio
Scenario 2-1	100%	1,917,569	28 %
Scenario 2-2	50%	958,784	14 %
Scenario 2-3	20%	383,514	6 %

Table 7.3-2 Value Added of Crops

Crops	Gross Income (N$/ha)	Total Cost (N$/ha)	Net Income (N$/ha)	Unit Water Consumption (m^3/ha)	Value Added (N$ /m^3)
Wheat	6,000	4,320	1,680	12,187	0.138
Lucerne	12,000	5,880	6,120	28,480	0.215
Maize	8,000	4,700	3,300	9,427	0.350
Cotton	11,000	5,360	5,640	16,507	0.342
Grapes	40,000	17,668	22,332	14,761	1.513
Sweet Melon	40,000	12,708	27,292	10,467	2.607

Source: MAWRD and Hardap Cooperative

2) Application of Efficient Irrigation Method

As Table 7.3-3 shows, micro irrigation methods such as Drip and Micro sprayer enable more efficient water use than with Sprinkler and Flood irrigation. Ideally irrigation water use can be saved by the application of more efficient methods.

Table7.3-3 Minimum Water Requirements for Different Crops and Irrigation Methods

Crop type	Minimum requirement (m^3/ha/year)	Irrigation methods		
		Micro (m^3/ha/year)	Sprinkler (m^3/ha/year)	Flood (m^3/ha/year)
Maize	5,656	6,284	7,070	9,427
Melon/Vegetable	6,280	6,978	7,850	10,467
Tomato	7,216	8,018	9,020	12,027
Wheat	7,312	8,124	9,140	12,187
Citrus	7,888	8,764	9,860	13,147
Grapes	8,857	9,841	11,071	14,761
Cotton	9,904	11,004	12,380	16,507
Lucerne	17,088	18,987	21,360	28,480

Source: MAWRD

Note: Sprinkler = Minimum requirement /0.8
Micro = Minimum requirement /0.9
Flood = Minimum requirement /0.6

As shown in Table 7.3-5, most of the farms have applied efficient methods such as drip, micro spray and so forth. In order to estimate exact water saving volume by alteration of irrigation methods, applicable irrigation methods should be considered based upon the information of irrigation areas and applied irrigation methods by each crop type. However, the hydro census data does not cover the detailed data of irrigation areas by crop type. Because of such data constraint, this study estimates a possible saving water volume considering the below cases which exclude the farms applying spray and flood irrigation methods mixed with other micro irrigation methods (refer to Table 7.3-4).

As Table 7.3-4 indicates, switching irrigation methods leads to a reduction of 215,500 m^3/year which amounts to about 3 % of the total irrigation water use in the study area. The figure does not meet the short-term goal as well as the sustainable water use level. However using a variety of efficient irrigation methods more reduction could be expected.

Table 7.3-4 Water Saving Volume with Application of Micro Irrigation Methods

	Cases applied with micro irrigation method	Saving volume (m^3/ year)	N.B.
Case 1	Flood → Micro (30% saving)	91,500	30.5ha x 10,000 m^3 x 30%
Case 2	Sprinkler→Micro (10% saving)	83,000	83ha x 10,000 m^3 x 10%
Case 2	Pivot → Micro (10% saving)	15,000	15ha x 10,000 m^3 x 10%
Case 4	Flood, Sprinkler →Micro (20% saving)	26,000	13ha x 10, 000 m^3 x 20%
Total		215,500	

Note: 10,000 m^3 = averaged water consumption per ha
20% is the average of Case 1 and 2

An important aspect to be noticed as Table 7.3-3 and Fig. 7.3-1 indicates is that the application of micro irrigation methods does not always contribute to water saving. Water consumptions of some farmers are far more than 28,480 m^3 per year which is almost maximum water requirement of crops, although they have applied efficient irrigation methods which require much less water than that.

The main reason for this is that water saving highly depends upon the way which the farmers use the technologies and groundwater. For instance, some farmers may not have adequate knowledge about how to use the efficient irrigation methods properly and, furthermore, may not be aware of the scarcity and the importance of ground water. To improve their knowledge and awareness, education for the farmers should be initiated in parallel with the application of more efficient irrigation methods.

Table 7.3-5 Irrigation Areas and their Employment of Various Irrigation Methods

Unit: ha

Irrigation method \ Area	I	II	III	IV	VII	Total	%
Drip		98.5		2.0	4.1	104.6	23.8
Sprinkler		56.0	1.0	20.0	6.0	83.0	18.9
Sprinkler, Flood, Drip		77.0				77.0	17.5
Sprinkler, Drip	2.0	62.5				64.5	14.7
Flood	3.0	17.5	4.0		6.0	30.5	6.9
Flood, Drip					21.0	21.0	4.8
Pivot		15.0				15.0	3.4
Micro sprayer	1.0	12.0			1.0	14.0	3.2
Sprinkler, Flood	1.0	10.0			2.0	13.0	3.0
Sprinkler, Drip, Micro sprayer	12.5					12.5	2.8
Flood, Micro sprayer	2.0					2.0	0.5
Micro sprayer, Drip					2.0	2.0	0.5
Hose				0.5		0.5	0.1

Source: JICA analysis based upon Hydro-census data

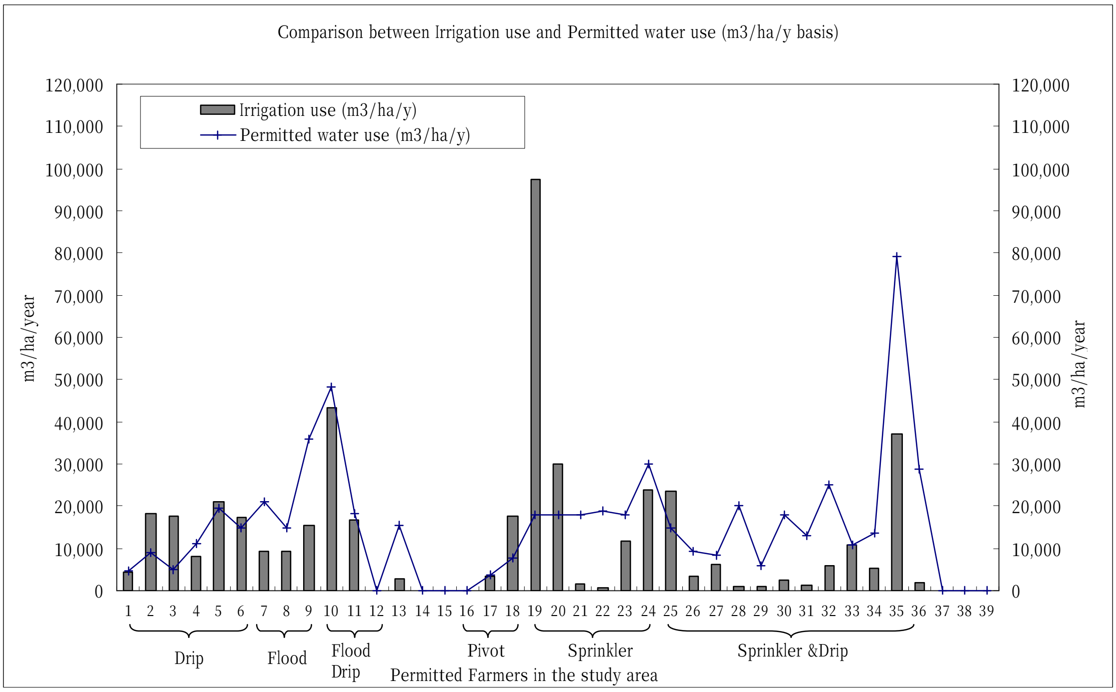

Fig 7.3-1 Water Consumption by Irrigation Methods

Source: JICA analysis based upon DWA data

3) Reduction of Irrigation Area

As mentioned in Chapter 4, farmers especially in Area II have exceeded their irrigation quotas and therefore a reduction in the irrigation area is one of the efficient ways to reduce groundwater extraction.

If the current irrigation areas (432 ha) of permitted farmers in Area II are scaled down to the permitted level by 30% reduction, then simply the same ratio of water consumption can be reduced. In this case groundwater extraction in the study area would almost meet the sustainable level.

4) Pricing of Groundwater

Enhancement and promotion of more efficient water use by education and campaign are basically conducted at the initial stage of the water reduction implementation program. However, such a policy may face some difficulty in persuading the farmers to change their behaviours. This is because currently ground water is not charged in the study area. Also it could be expected that farmers will not agree to pay for ground water. However, charging for groundwater is a useful tool for providing incentives to the farmers. As an ultimate economic measure pricing or taxing can be applied considering affordability and acceptability to farmers.

This study considers the crop conversions with pricing policies as one of recommendations (refer to 7.3.2 1)). Based upon the generalised data of costs, benefits and required water volumes for crop productions, value added per cubic meter for main crops in the study area were calculated. The figures basically indicate how efficient crop productions use groundwater.

According to Scenario1-2, changing of crop production from Lucerne to Grape enables a reduction of 34% of current water usage. However, this is quite difficult without sufficient motivation to farmers, because such a shift requires some additional costs and physical efforts on the part of the farmers.

Basically farmers change their farming activities based upon costs and benefits with the aim to get more profit with less investment. Due to the economic principle, they tend to change their activities from irrigation farming with low value added to livestock farming with high value added.

As Table 7.3-6 indicates in the case where the government charges a price between

N$ 0.4 to 1.5/m^3 for ground water, farmers who cultivate Wheat, Maize and Cotton etc which produces lower value added than N$ 0.4/m^3 will encounter a deficit with this charging. According to economic theory we would then expect to observe farmers to change their cultivating crop type from the lower value added ones to the higher value added ones like Grapes and Sweet melon. As a result of this charging policy and consequently change of crop type water consumption is expected to be reduced and should approach the sustainable level of water use.

Table 7.3-6 Value Added of Crops

Crops	Gross Income (N$/ha)	Total Cost (N$/ha)	Net Income (N$/ha)	Unit Water Consumption (m^3/ha)	Value Added (N$ /m^3)
Wheat	6,000	4,320	1,680	12,187	0.138
Lucerne	12,000	5,880	6,120	28,480	0.215
Cotton	11,000	5,360	5,640	16,507	0.342
Maize	8,000	4,700	3,300	9,427	0.350
Grapes	40,000	17,668	22,332	14,761	1.513
Sweet melon	40,000	12,708	27,292	10,467	2.607

Source: MAWRD and Hardap Cooperative

7.3.3 Groundwater Monitoring Plan

1) Purposes of Groundwater Monitoring

Monitoring is required to assure the proper implementation of the above suggested action plans, and the effectiveness of achieving the target . In case one action plan does not seem to improve the situation, other actions may need to be applied in order to reach the targets. Also, as a consequence of data compilation from the constant monitoring, the accuracy of groundwater level estimation should be also improved. Accordingly, a groundwater monitoring plan is proposed as follows.

2) Target Area of Monitoring

This study targets the entire area of Southeast Kalahari Artesian Groundwater Basin. The continuous nature of groundwater also requires a monitoring plan for the entire basin. On the other hand, however, the receding of groundwater level is not uniform in the study area. In this regard, the most significant water decrease is observed in the limited area around Stampriet along the Auob River and its eastern region. Accordingly, the above area is tentatively called as the Special Groundwater Control Area. The groundwater monitoring after the study should have special attention to the area, while the entire area of the basin has been already established as the “Groundwater Control Area” in the Water Act.

3) Monitoring Item and Method

The monitoring items are divided into either technical or administrative aspects. Table 7.3-7 shows the outline of monitoring contents.

Table7.3-7 Monitoring Item

Item	No.	Importance	Monitoring Item	Method	Responsibility
Technical Item	1	◎	Groundwater level	Automatic hydrograph, manual measurement	DWA
	2	◎	Water quality	Sampling and analysis	DWA
	3	◎	Precipitation	Automatic rain gauge	DWA
	4	◎	Flow rate	Automatic flow meter	DWA
Administrative Item	5	◎	Extraction rate	Flow meter, inspection	Well owners （DWA）
	6	○	Irrigation improvement	Reporting, inspection	Farms （DWA）
	7	○	Crop conversion	Reporting, inspection	Farms （DWA）

Remark ◎：Item for urgent implementation
○：Item that implementation is preferred

(1) Technical Monitoring Items

(i) Groundwater Level

The monitoring wells targeting the Kalahari aquifer exist at 14 sites, but there are none in the special monitoring area. For this reason three new observation wells should be installed in the area as shown in Fig.7.3-2. The existing wells owned by DWA and the newly drilled ones arising from the JICA study should cover the other area.

As for the Auob and Nossob aquifers, the monitoring shall be continued in the existing monitoring wells of both DWA and JICA.

The distribution of existing and newly planned observation wells is shown in Table 7.3-8 and Fig. 7.3-2.

Table7.3-8 List of Monitoring Wells

Category	Well No.	Location	Kalahari	Auob	Nossob
JICA Borehole	J-1	Christiana	-	◎	-
	J-2	Olifantswater West	-	◎	◎
	J-3	Steynsrus	◎	◎	◎
	J-4	Okanyama (Aminuis)	◎	◎	◎
	J-5	Maritzville (Stampriet)	-	-	◎
	J-6	Cobra	◎	◎	◎
	J-7	Jackalsdraai	◎	-	◎
	J-8	Tweerivier	◎	◎	◎
	J-9	Klein Swartmodder	-	◎	-
DWA Borehole	JO-1N	Neu Simmern	-	-	◎
	JO-2A	Gumchab Ost	-	◎	-
	JO-3A	Neumark	-	◎	-
	DWA-4,5,6,7	Olifantswater West	△	○	△
	DWA-3A	Stampriet	-	○	-
	DWA-2A	Boomplaas			
	JO-4A	Tugela	△	-	○ ?
	JO-5N	Gochas	-	-	◎
	JO-6N	Dagbreek	-	-	◎
	JO-7A	Glencoe	-	◎	-
	JO-8A	Cobra	-	◎	-
To be drilled		(Near Stampriet)	◎ or ○		
		(East to Stampriet)	◎ or ○		
		(North to Stampriet)	◎ or ○		

Remark) ◎ : automatic hydrograph (Seba) ○ : automatic hydrograph (record paper) △ : manual

The monitoring shall be conducted in the intervals as shown in Table 7.3-9. The result of monitoring should be organized as the groundwater graphs as shown in Fig. 3.7-4 of Chapter 3 to describe the fluctuation of the piezometric head.

Table 7.3-9 Interval of Measurement and Data Collection of Groundwater Level

Measurement Method	Interval	Data Organized as
Automatic hydrograph (Seba)	Consecutive measurement, data collected every three months	Daily fluctuation of Piezometric Head
Automatic hydrograph (record paper)	Consecutive measurement, data collected every months	Monthly fluctuation of Piezometric Head
Manual	Monthly regular measurement	Monthly fluctuation of Piezometric Head

Besides, there are many natural springs in the Auob catchment around Stampriet. At the time when the study was started, all the springs had stopped. After the intensive rainfall in the rainy season of 1999/2000, some of the springs resumed in places such as Hoachanas and Klein Swartmodder. Among these springs, five to ten of them should be selected for the monitoring. The owners of these springs will be entrusted for the monitoring of the flow behaviour of these springs.

(ii) Water quality

There is an area called salt block that has an extreme level of salinity in the study area. Saltwater intrusion, however, is not anticipated because the water abstraction is very small compared to the total groundwater storage. Therefore, it is not necessary to uniformly monitor the entire area, but only in the Special Groundwater Control Area, where further groundwater receding and accompanying water quality deterioration is anticipated. Accordingly, for water quality, the following items shall be monitored at the designated boreholes as shown in Table 7.3-10.

Table 7.3-10 Intervals for Water Quality Monitoring

<table>
<tr><th>Area</th><th>Monitoring Interval</th><th>Monitoring Item</th></tr>
<tr><td>Special Control Area</td><td>Once a year</td><td rowspan="2">Major cation & anion, NO_2, NO_3, SiO_2, F, pH, TDS</td></tr>
<tr><td>Others</td><td>Once every two years</td></tr>
</table>

Remark: Among the boreholes shown in Table 7.3-8, J-3N, J-6N, and J-8A are excluded from the monitoring plan because the recovery from groundwater abstraction is extremely slow at these boreholes.

(iii) Precipitation

For the examination of groundwater recharge, the precipitation data is important as well as the data of the piezometric head. The observation points are required in the groundwater recharge area and in the upstream area. At present, the Meteorological Agency is conducting the observation at and around the study area; however, the data is often missing, resulting in the provision of insufficient data for the groundwater analysis. Therefore, it would be desirable to build the DWA’s own observation system. DWA has currently installed several rain gauges in and around the study area under IAEA project. Further installation of water gauge is required in other recharge areas to augment the existing observation points. The proposed installation points are as follows: Uhlenhorst area, Hoachanas area, Christiana area, Weissrand area.

(2) Administrative Monitoring Items

(i) Extraction Rate

At present, the reporting duty prescribed by the Water Act is not completely fulfilled. Especially, item 2 in Table 7.3-1 is hardly reported due to insufficient installation of the flow meter. The grasp of extraction rate is essential for understanding the groundwater balance in the study area. Therefore, the installation of flow meter and reporting should be promoted in consent with water users.

The monitoring of the pumping rate is an indispensable subject in future groundwater management. The installation of flow meter and regular reporting should be enforced by the DWA inspections.

(ii) Improvement of Irrigation Method

In the study area, the majority of farmers have already introduced sprinkler or drip irrigation method. Therefore, the effectiveness of water conservation by the conversion of irrigation is limited. The action plan is to further promote the improvement of irrigation method to every farmer in the study area.

As far as the irrigation water is concerned, the minimum pumping for the efficient water use is desired. For this to be achieved, a thorough provision of information and education is necessary to obtain understanding and cooperation of the farmers. The monitoring of the improvement status is also essential to ascertain the application of the conversion.

(iii) Conversion of Cultivation Crop

Most of the crops cultivated in the Special Groundwater Control Area are cash crops. If crop conversion is applied without proper measures, there could be it may a decrease in the income of the farmers. Crops with higher market values with lower water demand should be introduced with the consent of farmers. The execution of this action plan is expected to make a great impact on the total extraction rate, thus a proper monitoring would be required.

7.3.4 Institution and Organization

While some part of the action plans may require cooperation with other relevant divisions, the major part of the discussed groundwater monitoring plan assumes the main input from Geohydrology Division in the DWA. Here an examination is attempted for the institutional and organizational aspects.

Table 7.3-11 shows the posts and tasks of the monitoring engineers. The Geohydrology Division has vacant posts for almost half of the total quota. Therefore it is anticipated that insufficient staffing may lead to improper conduct of monitoring activities. The major factor in the of lack of personnel is the outflow of engineers to NamWater. This tendency is not expected to change for the moment, therefore, the proposed personnel organization incorporate the rather fixed technicians and supple the other posts to strengthen the organization. The following table shows the required posts and numbers of engineers only for the groundwater monitoring activities.

Table 7.3-11 Monitoring Item, Contents and Required Engineers

Required Engineer	Required Number	Tasks	Remarks
Senior Geohydrologist or Geohydrologist	1-2	- Management of groundwater level, analysis of observation data - Water sampling for quality analysis, analysis and interpretation of data	Urgently needed
Groundwater Simulation Expert	1	- Improvement of groundwater simulation model	5 years after monitoring is started
Technician (A)•(B)	2	- Collection and processing of groundwater observation data - Collection and processing of precipitation observation data - Collection and processing of observation data of extraction rate - Water sampling for quality analysis and data processing	The task volume of the technicians may vary depending on the season. A system is required for the technicians to support each other
Technician (C)	1	- Inspection survey of irrigation method improvement and crop conversion. Organization of the survey	
	-	- Collection of river flow rate data	In cooperation with Hydrology Division

The Senior Geohydrologist and Geohydrologist post are important posts to take charge of the management of the groundwater monitoring. However, at present, the employment of proper personnel is assumed to be difficult. For this reason, one possibility would be to hire the domestic consultants or expert engineers dispatched by international donors.

As for Technicians, at present, they are in charge of data collection and reading, but not for processing. However, accuracy of monitoring could be assured if the same technician makes the graphs after the reading the groundwater level.

Table 7.3-12 Personnel Allocation in DWA as of October 2001

Post	Quota	Occupied	Vacancy
Deputy Director: Geohydrology	1	1	0
Senior Geohydrologist	3	1	2
Geohydrologist	9	1	8
Technician	10	2	8
(Drilling Section)	-	-	-
Driller	2	2	0
Foreman	3	2	1
Technical & Clerical Assistant	6	5	1
<Total>	34	14	20

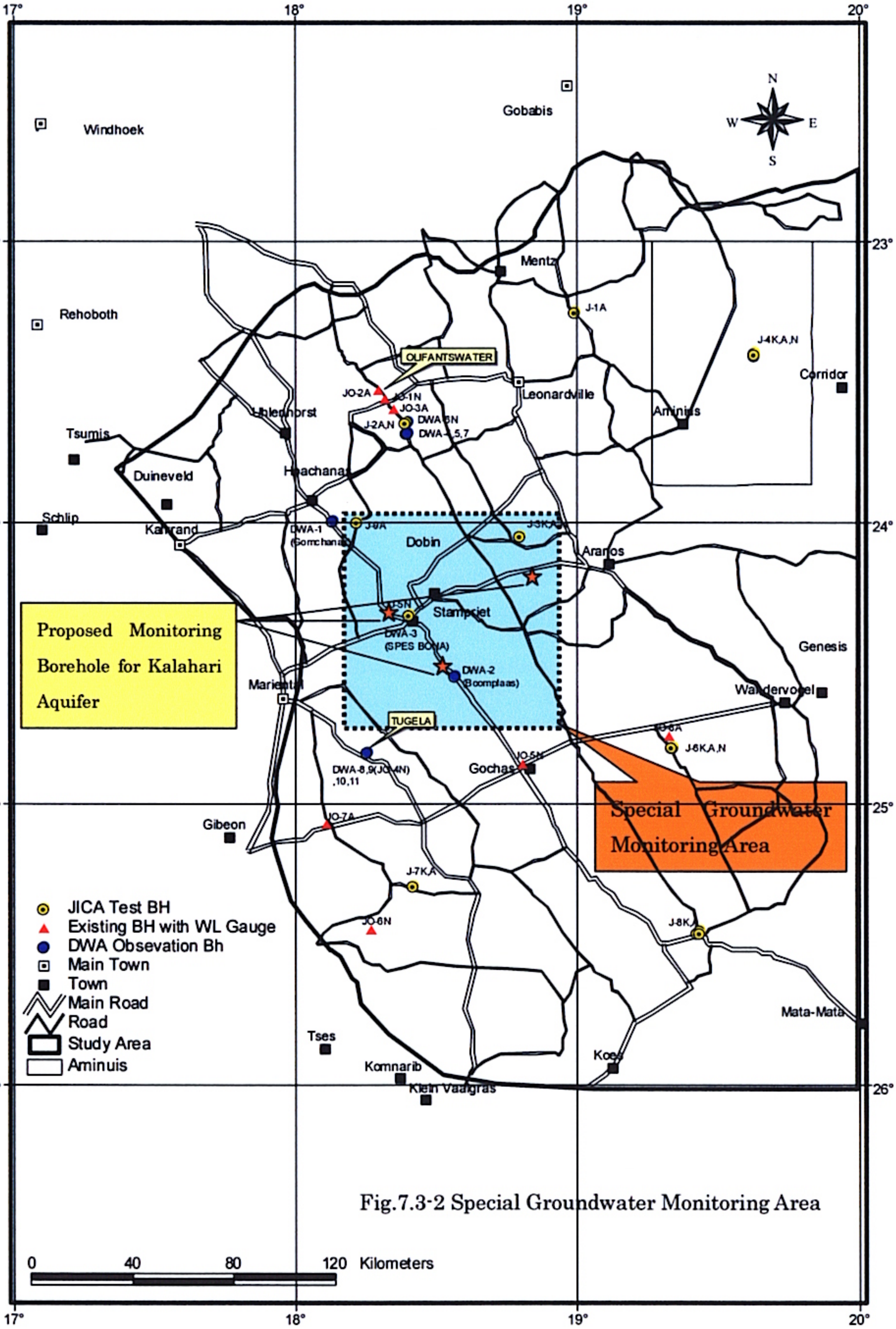

Fig.7.3-2 Special Groundwater Monitoring Area

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

1) Hydrogeological Structure

The Kalahari, Auob and Nossob Aquifer do not a simple monoclinal feature but a considerably complicated structure. Redefinition of the aquifers was also done through this study (See Fig.3.6-1).

2) Groundwater Potential Evaluation

The Auob Aquifer has the highest potential, followed by the Kalahari Aquifer, while the Nossob Aquifer shows the lowest potential. (See Fig.5.3-9 to 11)

3) Groundwater Flow and Recharge Mechanism

a) Groundwater Flow

Groundwater into each aquifer flows from NW to SE and it was estimated that it takes several thousand years to flow through the whole basin. (See Fig.3.7-1 to 3).

b) Recharge

The major recharge into the basin occurs via direct rainfall feeding the rivers and the fractures as well as the karstic sinkholes that are situated on the rim of the basin. Recharge via these features and structures feed the Kalahari Aquifer directly and this amounts to $105\times10^6 m^3$/year in an average rainfall year and 1,550 x $10^6 m^3$/year during an exceptional rainfall event (on average 1/50 years). Recharge into the Auob Aquifer via the Kalahari Aquifer and the Kalkrand Basalts does occur but this is mainly during the exceptional rainfall events. Recharge into the Nossob Aquifer is negligible and most of the resource in the Nossob Aquifer can be regarded as fossil water.

4) Water Balance

a) Under average rainfall conditions, the water level of the Kalahari Aquifer decreases by 5cm/year on average. Even though a 1/50 year heavy rainfall event does reverse the drawdown to some degree for a limited period, it does not prevent the longer term water-level decline under the present conditions.

b) Groundwater recharge volume is up to 0.5% of total rainfall during a normal rainfall event and 3% during a 1/50 year heavy rainfall event. Most of the rainwater is lost by evapotranspiration. This is exacerbated by the large amount of alien vegetation and attention should be paid to solving this problem.

5) Groundwater Demand

a) Of the total groundwater abstracted from the Basin, approximately one half of the volume of $15 \times 10^6 m^3$/year is used for irrigation ($6.88 \times 10^6 m^3$/year). Approximately 78 % of the total irrigation use is concentrated in the Stampriet area. (See P.4-12 and Table4.1-3)

b) Of the total groundwater abstraction from the Basin annually, 66% is from the Kalahari Aquifer, 33% from the Auob Aquifer and only 1% from the Nossob Aquifer respectively.

6) Groundwater Simulation

a) Within a 60km square area around Stampriet the drawdown of the groundwater level is remarkable. (See Fig.5.3-12 to 17)

b) Some wells within the Kalahari Aquifer around the Stampriet area may dry up within the next 30 years if the present condition of water use prevails. (See Table3.3-2, 3 and Fig.5.3-18) In view of the present over abstraction taking place, mitigating measures as part of a water demand management plan as described in Chapter 7 of the report should be adopted.

7) Groundwater Management Plan

a) Water Demand Management

It is proposed that the irrigation use be reduced by 30% for the short term and that the following countermeasures are suggested:

i) Start of an awareness campaign regarding the sustainable use of groundwater.

ii) Proper monitoring of water abstraction volumes.

iii) Review of permit conditions for water allocation.

iv) Reduction of over irrigated areas.

v) Switch to higher value crop cultivation.

vi) Voluntary reduction in water use by users.

vii) Application of more efficient irrigation methods.

viii) Pricing of groundwater.

b) Aquifer Management Plan

An aquifer management plan was set up as follows.

i) A regional groundwater monitoring plan was set up covering the entire basin as shown in Fig.7.3-2 and groundwater levels should be monitored on a continuous basis.

ii) A special groundwater monitoring area was also proposed in an area covering approximately 90km square around Stampriet. (See Table5.3-2, 3 and Fig.7.3-2) Here three additional observation boreholes should be drilled and installed with recorders.

c) Personal Recruitment

DWA staff should be increased to fill the approved posts in order to do the necessary follow-up work of this study and to implement the groundwater management plan.

8) Initial Environmental Evaluation

The proposed groundwater management plan is expected to have positive environmental impacts as the groundwater potential in the Stampriet Artesian Basin will be positively affected.

9) Counterpart Training

During this study, transfer of technical know-how to counter-part personnel was conducted between JICA study members in each field in the form of on-the-job training. The Director of Resource Management and the Deputy Director of Geohydrogy also took part in the counterpart-training course in Japan.

8.2 Recommendations

1) This report be accepted in principle.

2) The mean groundwater recharge into the aquifer is limited to 135 Mm^3/a, subject to future monitoring management and adjustment.

3) An appropriate aquifer management plan, as described in Section 7 of the report, be implemented.

4) The criteria for all allocation of water for irrigation should be adjusted as suggested in paragraph 7-1 to ensure that the benefits of using the available water resources are maximized.

5) In view of the present over abstraction taking place, mitigating measures as part of a water demand management plan as described in Section 7 of the report should be adopted in cooperation with all water users to reduce the water demand and the local Water Committee should play a major role in this regard.

6) Further studies must be done to improve borehole construction and reduce the leakage from the existing groundwater abstraction wells. Furthermore attention must be given to assess and rectify the suspected contamination of groundwater taking place in the Basin, to reduce the loss of artesian pressure and to enhance aquifer recharge from surface runoff in areas where this can be done. The problem of alien vegetation should be addressed.

7) The technology used and the results obtained in this study should be utilized to manage other groundwater basins in Namibia.

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