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

EXECUTIVE SUMMARY

MARCH 2002

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

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02-19

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,

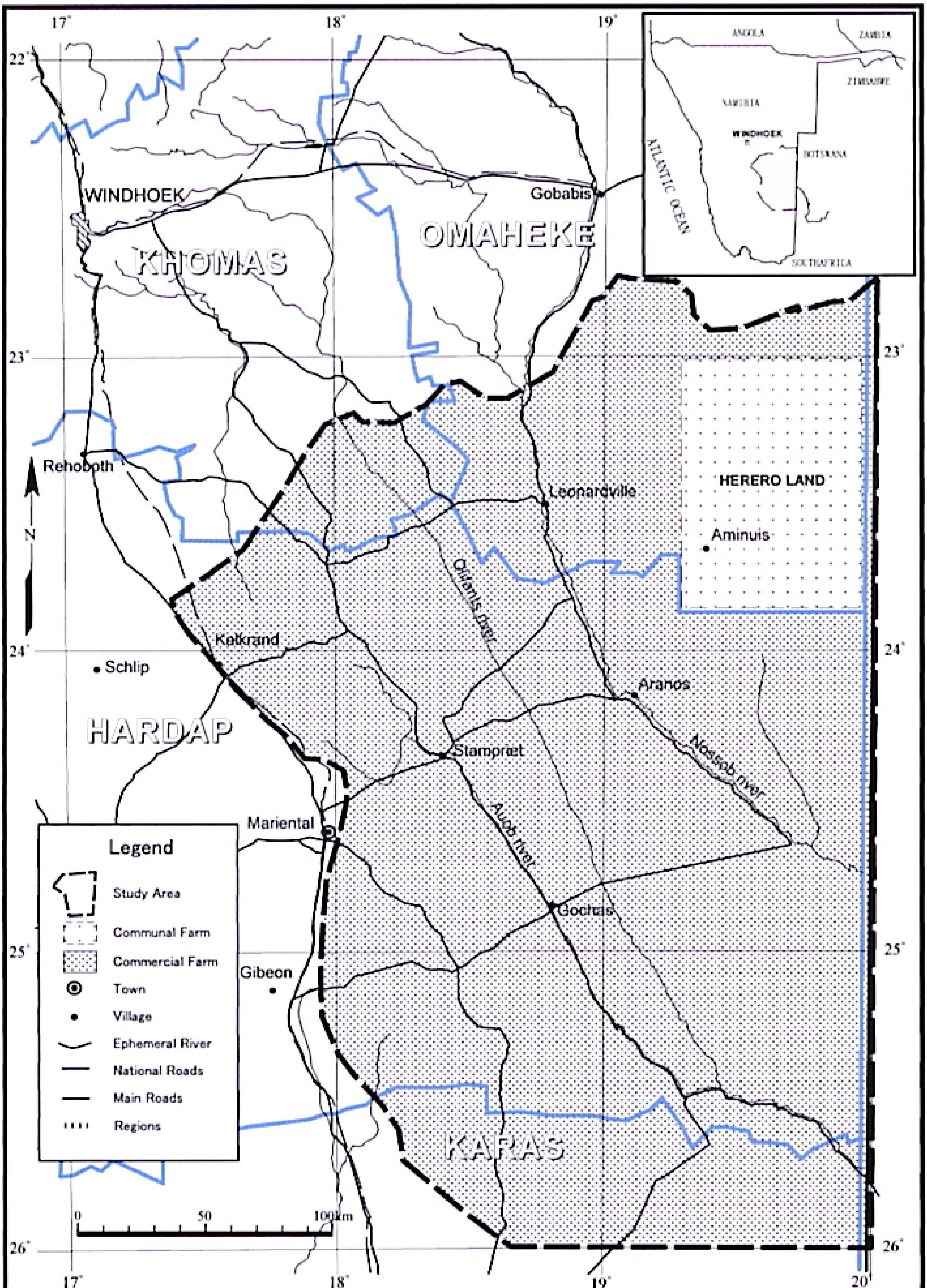
We are pleased to submit the final report entitled "THE STUDY ON THE GROUNDWATER POTENTIAL EVALUATION AND MANAGEMENT PLAN IN THE SOUTHEAST KALAHARI (STAMPRIET) ARTESIAN BASIN IN THE REPUBLIC OF NAMIBIA". The Study Team has prepared this report in accordance with the contract between Japan International 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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Leonardville
HERERO LAND
Aminuis
Olifants river
Kalkrand
Schlip
Aranos
HARDAP
Nossob river
Stampriet
Mariental
Auob river
Gochas
Gibeon
KARAS
Legend
Study Area
Communal Farm
Commercial Farm
Town
Village
Ephemeral River
National Roads
Main Roads
Regions
0
50
100km

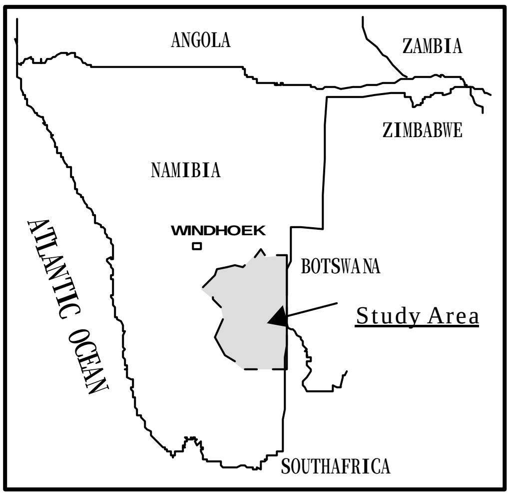
Study Area

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



<Location Map of the Study Area >

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.

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.3-1)

(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.5-1)

(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.3-6)

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 Figs.4-1, 4-2 and Table4-1)

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)

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 5-2,3 and Fig.5-2) 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.

(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.7-1 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.7-1) 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.

SUMMARY

1. INTRODUCTION

1-1 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 extraction within the basin is maintained by the regulations prescribed in the Water Act. Extensive groundwater extraction by commercial farmers occurs in the central area of the western side of the basin. According to some monitoring wells installed during 1978, groundwater levels have been declining continuously since 1980

<Fig.1-1 Location Map of the Study Area >

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 extraction of the groundwater. Since then, no further study has been done, although, groundwater use has steadily increased to nearly twofold of 1988.

DWA (Department of Water Affairs) needs to understand the nature of the entire aquifer system in order to manage the excessive extraction. 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, and furthermore, to formulate a groundwater management plan for sustainable groundwater development. This study was carried out from June 1999 to January 2002.

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.

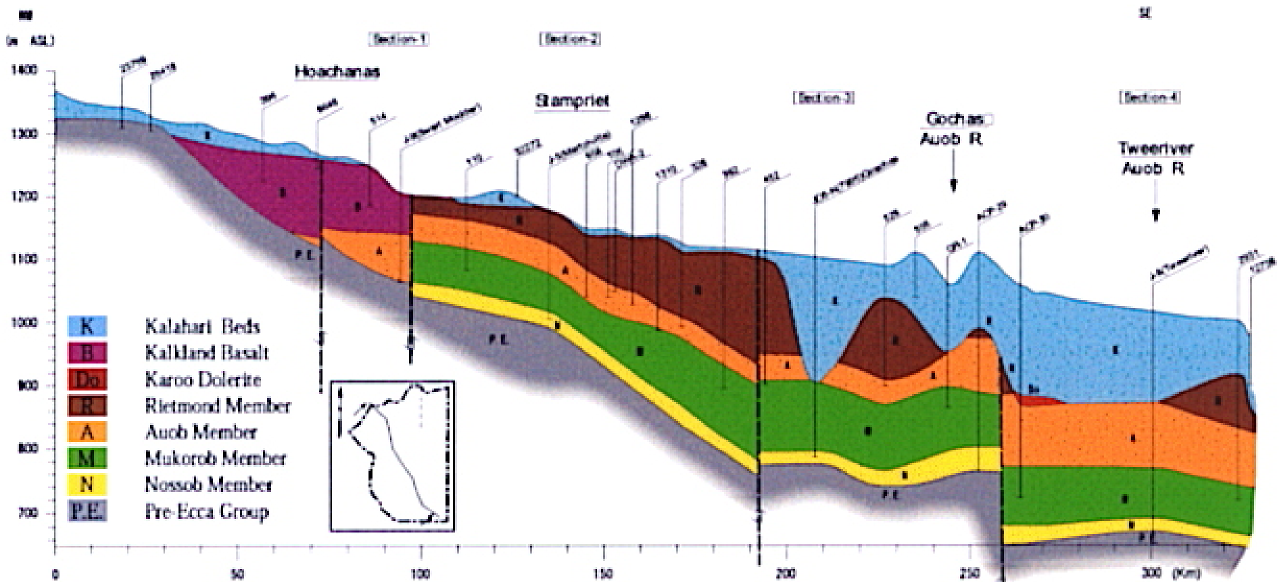
2. GENERAL DESCRIPTION OF STUDY AREA

2-1 Geomorphology

In general, the topography of the study area is flat, and the gradient is 2/1000 in average. The elevation of the study area decreases towards the southeast from 1,500m to 950m. Most of the areas where Kalahari calcretes crop out are significantly flat. Sand dunes developed in the northern and central part of the study area are typically in a NW-SE direction (as shapes by the prevailing winds) and are of varying sizes. Two types of drainage are imminent, one being an external drainage of surface streams and the other of an internal drainage of “Pans” developed from sinkholes in the distribution area of the Kalahari Beds. They show almost circular or ellipse shapes with varing sizes.

2-2 Geology

The Pre-Ecca Group; Damara Sequence, the Nama Group and the Dwyka Group, can be regarded as the hydrogeological basement rocks of the study area. The Nossob and the Auob Members are the major aquifers in the study area, and are included in the Prince Albert Formation that consists mainly of non-marine sediments deposited in the early Permian Period (280 million years ago). Faults and dolerite dykes or sills occurre in the Prince Albert Formation. The Kalkrand Basalt was formed in an extensive area to the north of Mariental. The Kalahari Beds, which age is of late Cretaceous to Recent, were deposited on an erosional landscape known as the “African Surface” or “Pre-Kalahari Valley”.



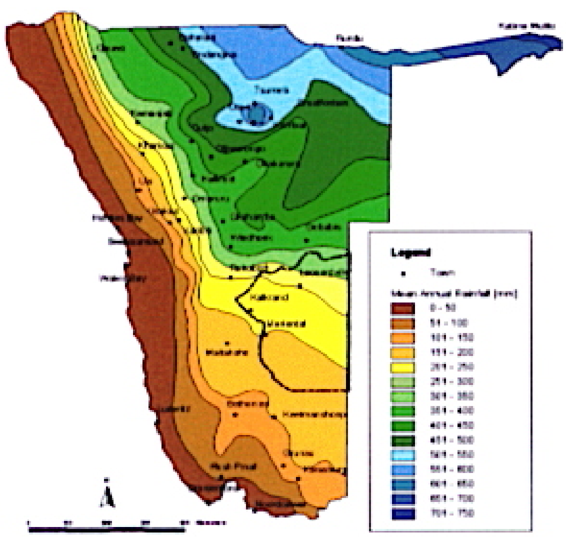
< Fig.2-1 Geological Cross Section of Study Area >

2-3 Meteorology and Hydrology

(1) Meteorology

Namibia is classified as a subtropical country with an arid to semi-arid climate. The annual rainfall varies from 50mm to 700mm. Most of the rainfall occurs from the end of December to the middle of April. The average temperature is 25 °C, the maximum may rise up to 40 °C in the summer months and the lowest could be below freezing point during the winter.

The isohyets of annual average rainfall in the study area are presented in the Fig.2-2. The approximate range is within 150 – 300 mm.



< Fig.2-2 Mean Annual Rainfall in Namibia >

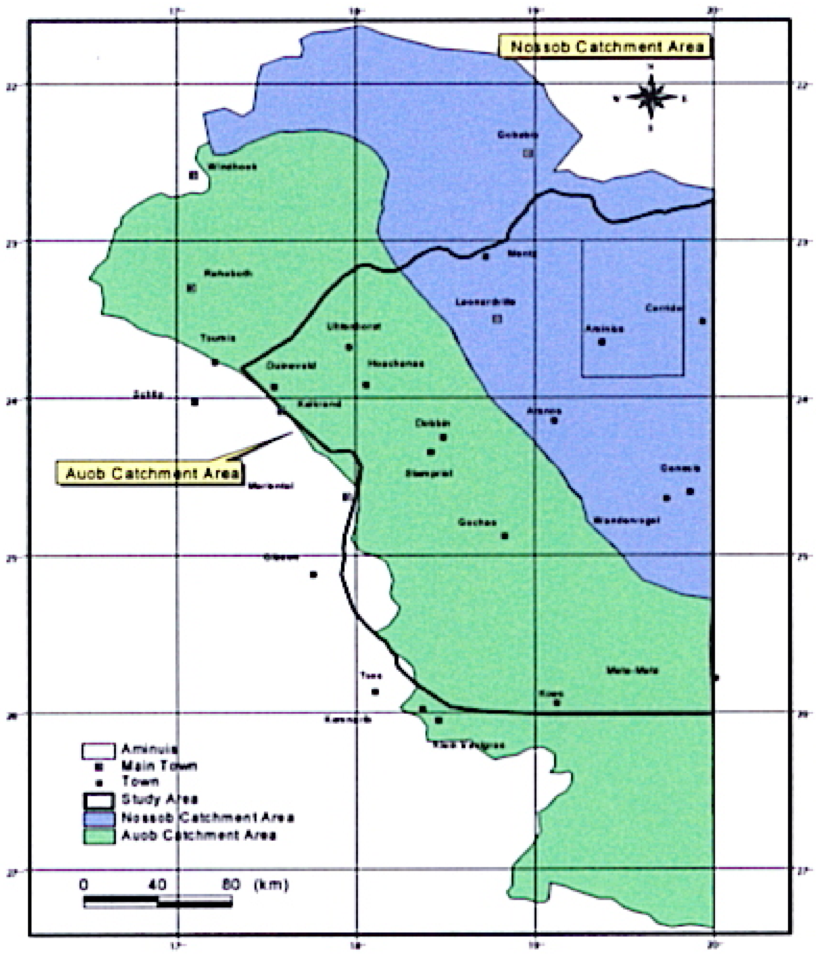
(2) Hydrology

The study area is situated within the catchments of the Nossob and Auob River with catchment area of 50,050km^2 and 74,081km^2 respectively. They are ephemeral and flow only for short periods during the rainy season. The runoff coefficient was calculated for the Nossob and the Auob Rivers as shown in the table below. The coefficients are very low.

< Table 2-1 Runoff Coefficients Calculated in the Study Area >

River	Rainy Season	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 - 25	944.8	49.0	0.0010

During the1999-2000 rainy season, the study area received an intensive rainfall, which caused a huge amount of runoff in the Auob and the Nossob Rivers, and river waters reached the border of South Africa. At Gochas station, 43 million m^3 of discharge was recorded which was approximately 5 times more than the ordinary value.

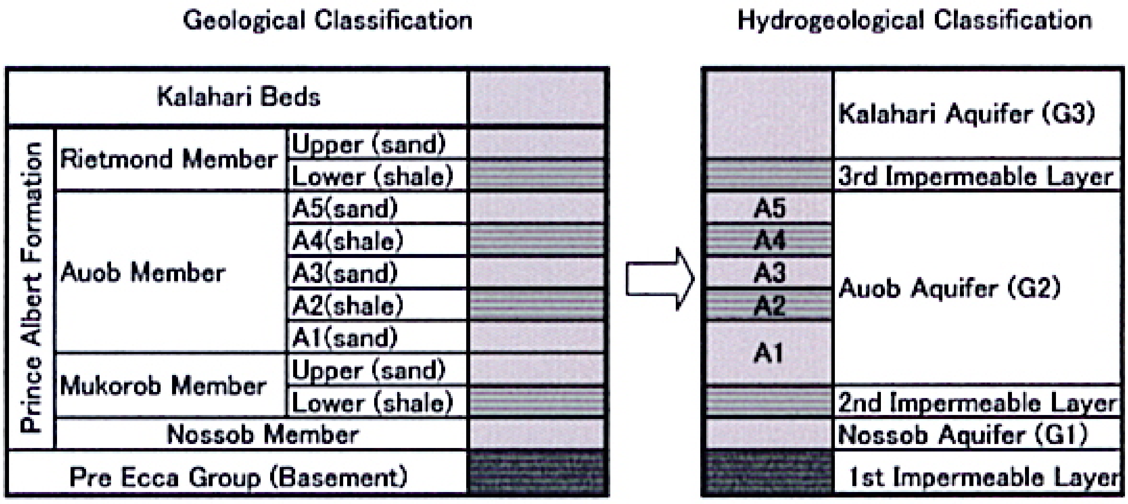


< Fig.2-2 Catchment Area and Study Area >

3. HYDROGEOLOGY

3.1 Definition of Aquifer

In this study, new definitions were given to the Kalahari Aquifer and Auob Aquifer based on the classification below.



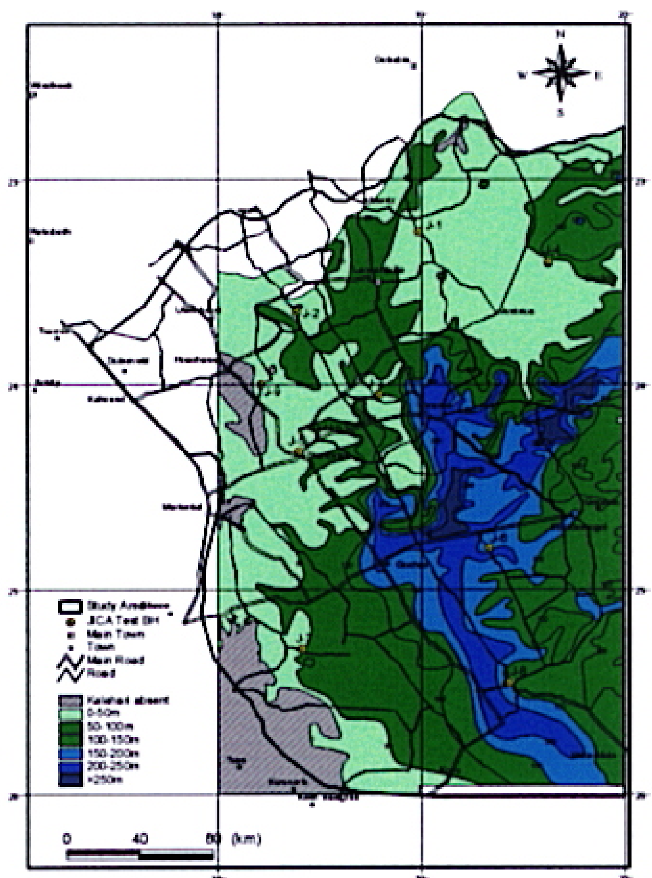
< Fig. 3-1 Reclassification of Aquifers >

3-2 General Feature of Aquifer

(1) Kalahari Aquifer

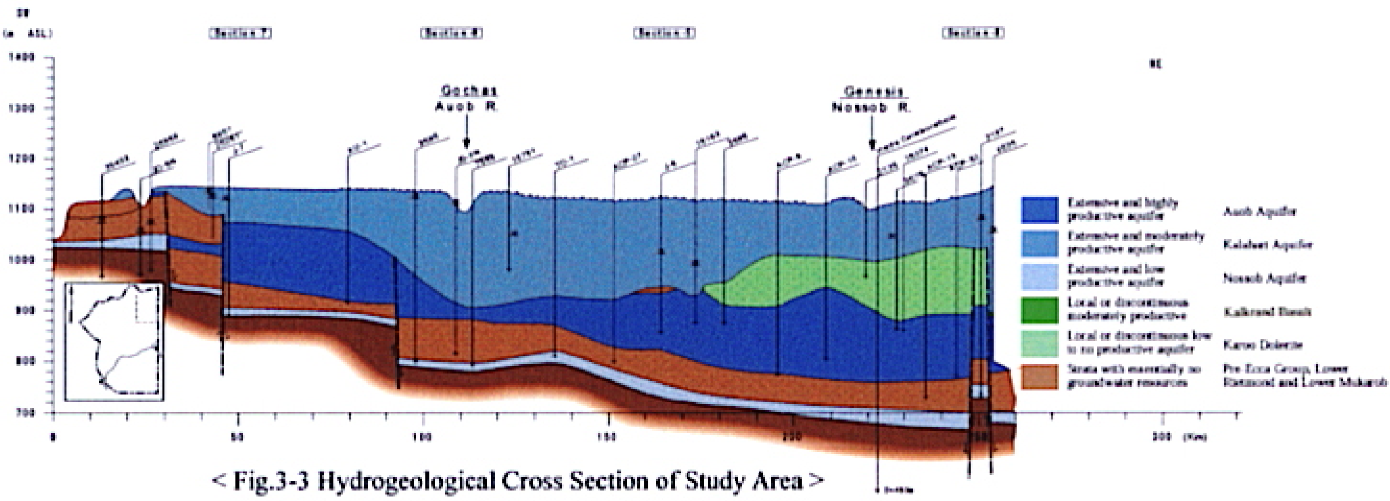
Although most of the study area is covered by the Kalahari Beds, the area around Hoachanas, northwest from Stampriet, consists predominantly of the Kalkrand Basalt. Pans and sinkholes are the two kinds of depressions observed on the surface of the Kalahari Aquifer.

The Kalahari Aquifer is the most intensively used aquifer in the study area. Approximately 4,500 boreholes, (more than 80% of total boreholes), were drilled into the Kalahari Aquifer and 9.8 x 10^6 m^3/year of groundwater is abstracted from it annually, which reperesents 65 % of the total extraction within the study area.



< Fig.3-2 Isopachs of Kalahari Aquifer >

A pre-Kalahari surface of the Kalahari Aquifer is shown in Fig.3-2, which indicates an erosional surface before sedimentation of the Kalahari Beds occurred known as the "African Surface". It shows that the Pre-Kalahari Valley was deeply eroded and the cross section (Fig.3-3) indicates that the erosion reached the Auob Aquifer as shown in Fig.3-3.

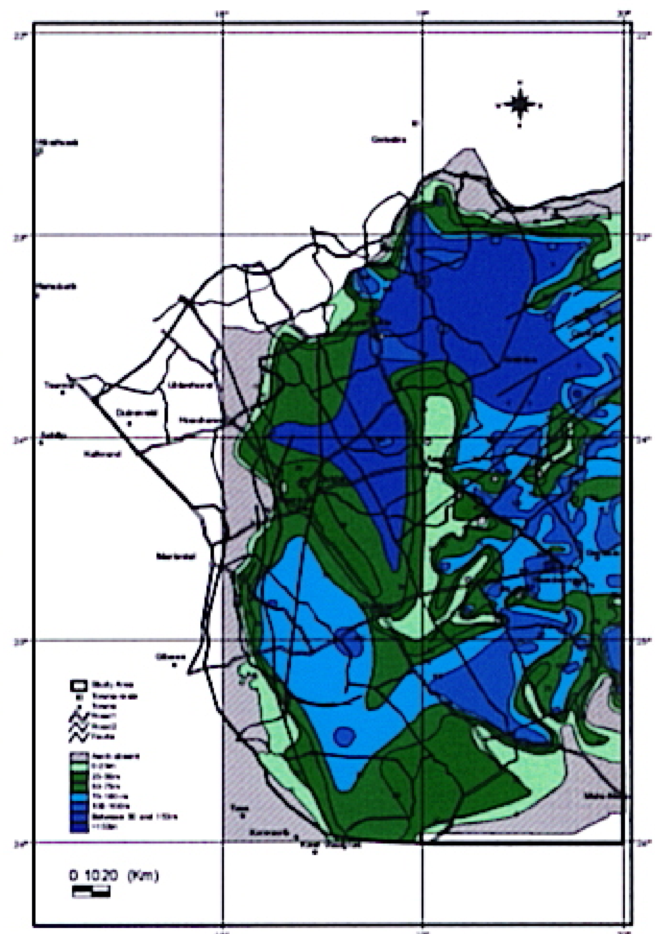


< Fig.3-3 Hydrogeological Cross Section of Study Area >

(2) Auob Aquifer

Since the Auob Aquifer is a confined aquifer and contains good water, local people used to utilize it for along time. Total production volume; which is round 4.97 x 10^6 m^3/year, is about 33 % of the total extraction in the study area. The withdrawal is higher in the western part of the basin; around Stampriet and Aranos where the depth of the aquifer is relatively shallower than in the east.

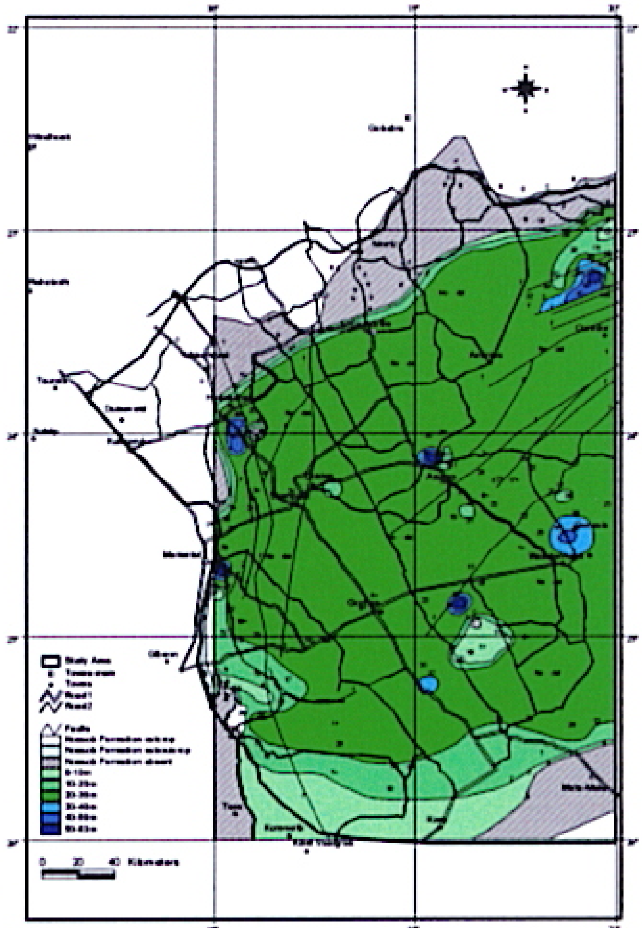
An isopach map of the Auob Aquifer is illustrated in Fig.3-4. It implies that the major distribution extends from south of Aminius to the east of Aranos. In this part, the thickness of the aquifer ranges from 100 meters to 150 meters and exceeds 150 meters in several places. On the other hand, it becomes thinner immediately close to the marginal area of the basin.



< Fig. 3-4 Isopach of Auob Aquifer >

(3) Nossob Aquifer

Although the Nossob aquifer has the highest piezometric head of all the aquifers, reaching more than 20 m above the ground surface, the total groundwater abstruction from this aquifer is only 0.2 million m^3/year which is about 1.3 % of the total extraction in the study area. This is mainly due to the thin nature excess depth and the frequent inferior water quality of the aquifer.



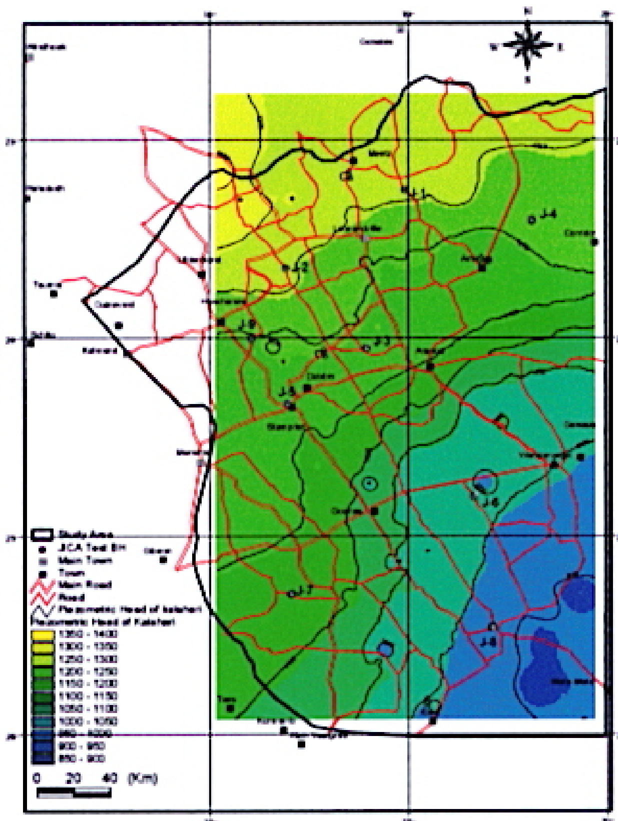
< Fig. 3-5 Isopach of Nossob Aquifer >

The thickness of the Nossob Aquifer is presented in the isopach map in Fig.3-5. It indicates that the thickness of aquifer tends to increase toward the center of the basin, although there is no distribution on the margin of the basin. An average thickness of the aquifer is estimated at approximately 25 meters. However, there are thicker parts of the aquifer in some places. The maximum thickness is reported to be 94 meters in the petroleum core holes, drilled in the farm Vreda during 1963 and 1994.

3-3 Piezometric Head

(1) Present Piezometric Head

The rest water level of the Kalahari Aquifer is shown in Fig.3-6. Groundwater is flowing from the northwest to the southeast harmonizing with hydrogeological conditions. The gradient of the groundwater table becomes steeper in Aranos / Gochas area but then flattens toward the Salt Block. (Refer to



< Fig.3-6 Water Level of Kalahari Aquifer >

flattens toward the Salt Block. (Refer to Fig.3.8)

Groundwater flow of the Auob Aquifer as a whole is similar to the Kalahari Aquifer. The general direction of groundwater flow in the Nossob Aquifer is also from the NW to the SE. However, the average of piezometric head is gentle as being around 1/1000.

(2) Long-term Variation of Piezometric Head

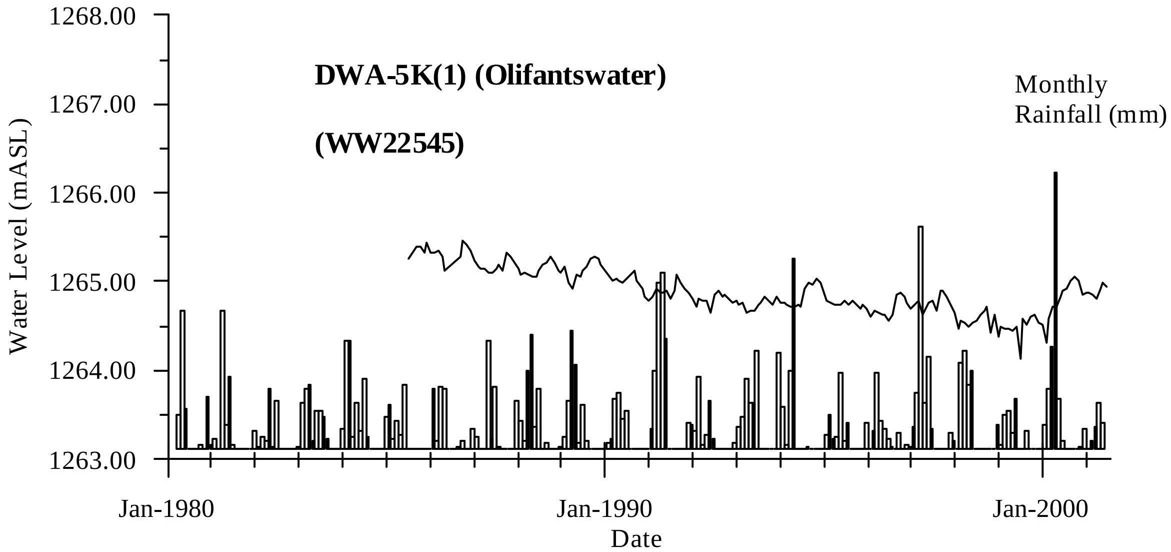
The variation of the groundwater level in the Kalahari Aquifer at Olifantswater West is shown in Fig.3-7. It is clear that the water levels have been decreasing constantly with a periodic fluctuation of approximately 5 cm/year on average since 1986. This pattern was however altered after the heavy rains from 1999 to 2000. (hereinafter referred to as '99-'00 rainy season) As for the Auob and Nossob Aquifer, reliable data from JICA test boreholes should be monitored over the long term.

3-4 Groundwater Quality (TDS)

A distribution of TDS concentration in each aquifer is shown in Fig.3-8.

(1) Kalahari Aquifer

It is obvious that the high concentration area of TDS is located in the southeastern part of the study area, especially around J-6. This area mostly coincides with the Pre-Kalahari Valley or



< Fig.3-7 Water Level Variation of Kalahari Aquifer >

"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.

(2) Auob Aquifer

A high concentration area of TDS is recognized around J-8. The existence of the Salt Block is poorly appeared. The maximum value of the Auob Aquifer is 6,754 mg/l at J-8. Water quality in the northeastern half of the study area is better than the standard, and is likewise for the Kalahari Aquifer.

(3) Nossob Aquifer

A high concentration area of TDS is also distributed around J-8 (33,500mg/l). The water quality of the Nossob Aquifer is the worst of the three aquifers.

3-5 Isotope Analysis

(1) Age of Groundwater by ^{14}C

The ^{14}C ages in the unconfined aquifer system are overall 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 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 J8K, confirming the importance of floodwater recharge in the basin.On the other hand, the groundwater in the Auob Aquifer and the Nossob Aquifer is generally old or very old even close to the northern and western edge of the basin. (refer to Fig. 3-9)

Considering the high ^{14}C ages, very low tritium values can be expected in both of them. Nevertheless, it is an important confirmation that natural recharge is a very slow process. The trace amounts of tritium in a few boreholes within 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.

(3) Nitrogen Isotope Ratio

According to the results of the nitrogen isotope ratio ($^{15}N/^{14}N$), most of the ratios are low but some of them are high enough to indicate a potential pollution source by livestocks. Fortunately, there is no indication of pollution by chemical fertilizer.

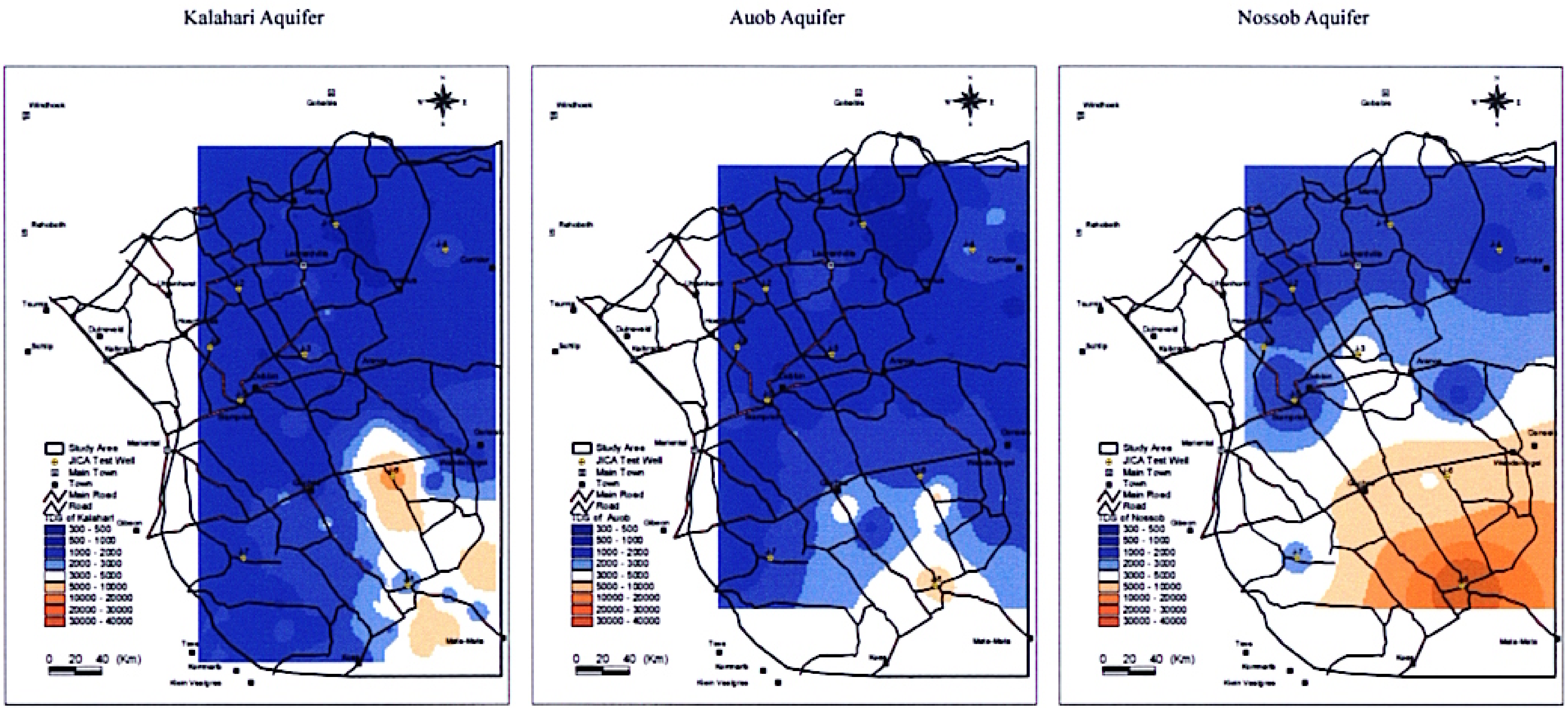
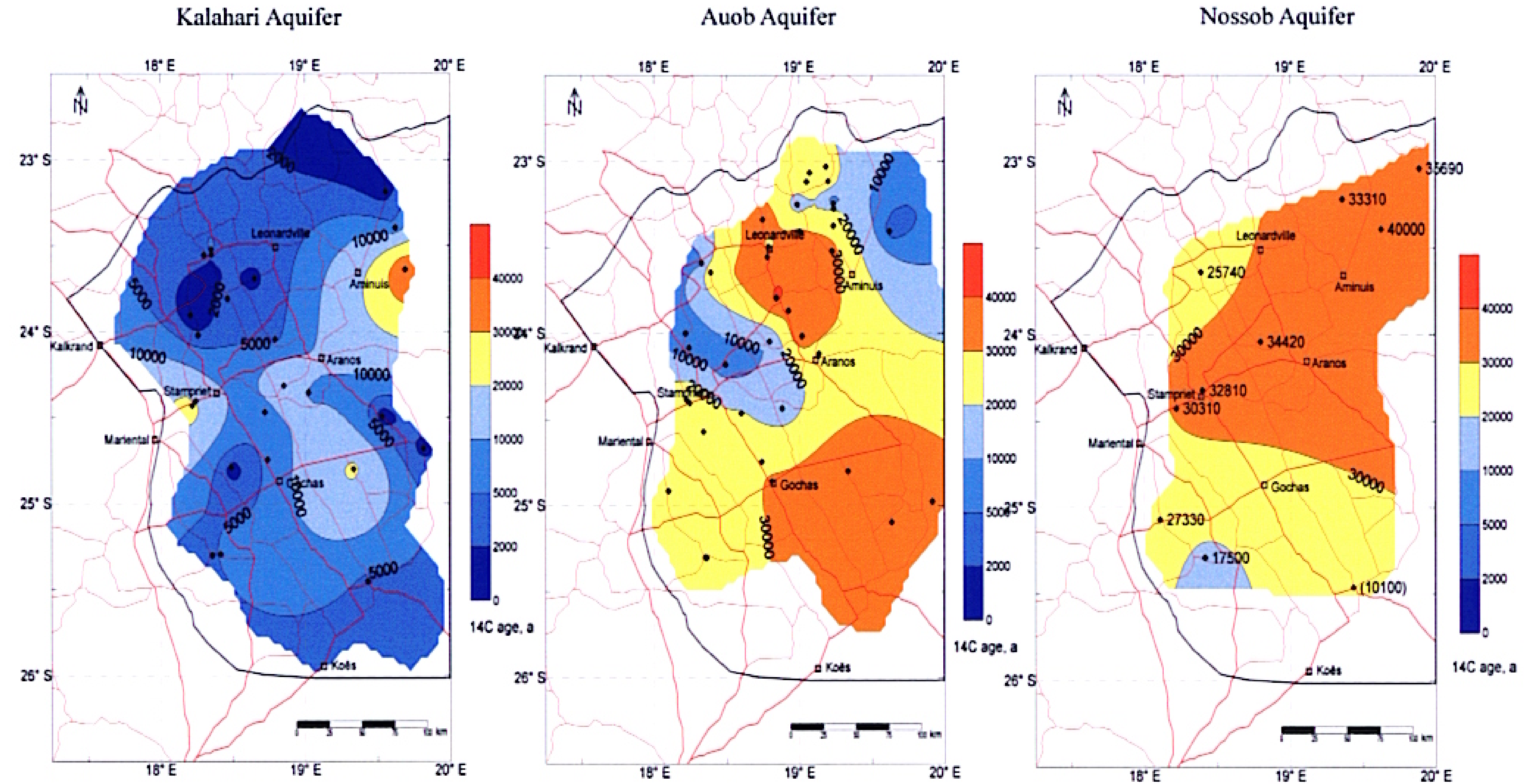


Fig. 3-8 TDS of Groundwater in Each Aquifer



< Fig. 3-9 Carbon-14 Groundwater Age in Each Aquifer >

3-6 Groundwater R the '99-'00 rainy season echarge

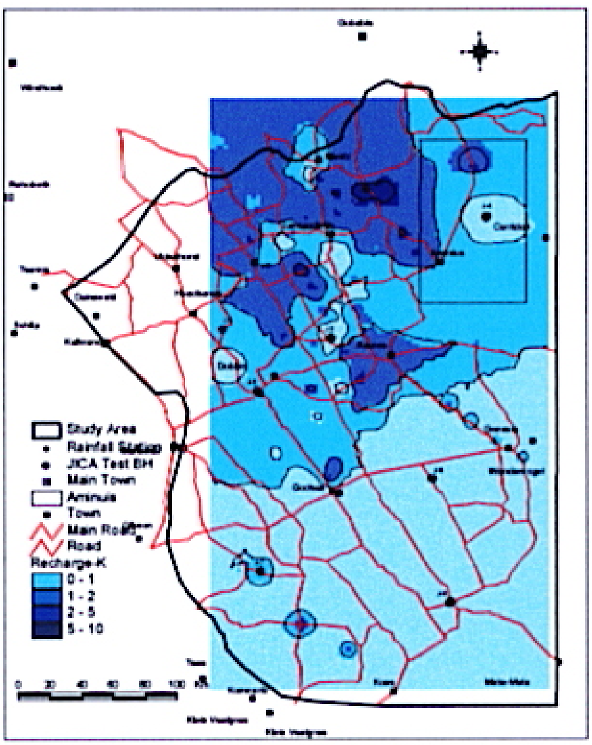
In this study, it was regarded that groundwater recharge was attributed to rainfall into Kalahari Aquifer directly and the Auob Aquifer was recharged indirectly through the Kalahari Aquifer. The water of the Nossob Aquifer seems to be regarded almost entirely as fossil water.

(1) Recharge Volume in Ordinary Year

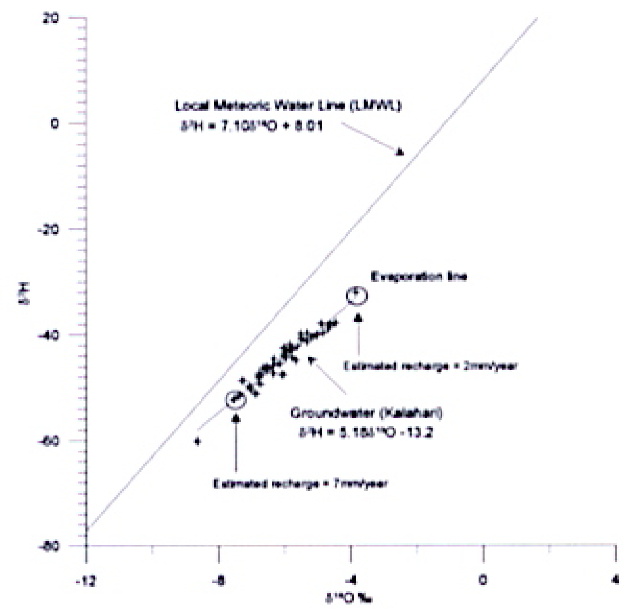
Recharge volume into the Kalahari Aquifer was estimated by Chloride Mass Balance Method as shown in Fig.3-10. The distribution of recharge into the northwestern half and southeastern half of the basin is subdivided by the 1 mm/year contour line of recharge. The total recharge volume is 0.105 billion m^3 /year. It is also equivalent to approximately 0.4% of the total rainfall within the catchment area. Fig.3-11, which presents the estimated recharge by stable isotopes, supports the above-mentioned recharge.

(2) Recharge Volume in '99-'00 Rainy Season

Recharge during the '99-'00 rainy season, which has a probability of one in 50 years was considerably higher. Suppose an average recovery of water level within the whole study area is 50cm, the recharge volume can be calculated as 1.3 billion m^3/year during the '99-'00 rainy season. This is approximately 15 times as much as an ordinary year.



< Fig.3-10 Estimated Recharge into Kalahari Aquifer by CMBM >



< Fig. 3-11 Estimated Recharge by Stable Isotopes >

3-7 Macro Water Balance

The macro water balance in the study area is illustrated in Fig. 3-12 and Fig. 3-13. The macro water balance is analyzed on two cases, namely, an ordinary year and the ’99 – ’00 rainy season, moreover each case is subdivided into underground and ground for the sake of convenience.

(1) Ordinary Year

- Underground
  Recharge is only 0.4% (0.105 billion m^3/year) of the total precipitation (22.1 billion m^3/year). 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 results in a deficit of 0.13 billion m^3/year. Therefore, the deficit results in an annual lowering of the water level year by year.

- Ground
  River discharge is 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 due to the high evaporation potential of 3,000mm/year in the study area suggests that it sounds quite possible.

(2) 1/50 Heavy Rainy Year (’99-’00 rainy season)

The possibility of the heavy rain that happened during ’99-’00 rainy season is one in fifty years. The heavy rain altered the groundwater balance of the basin dramatically. The recharge resulted in a rise of the rest water level. On the assumption that transpiration, withdrawal and groundwater flow are the same as an ordinary year, calculations resulted in the following for the macro water balance.

- Underground
  Recharge is 3% (1.55 billion m^3/year) of the total precipitation (51.3 billion m^3/year).

- Ground
  The heavy rain brought about river discharge at Gochas 4.7 times as much as the ordinary year and recharged into underground approximately 15 times as much as the ordinary year. Nevertheless 96.6% of precipitation or 2.3 times as much as the ordinary year was evaporated.

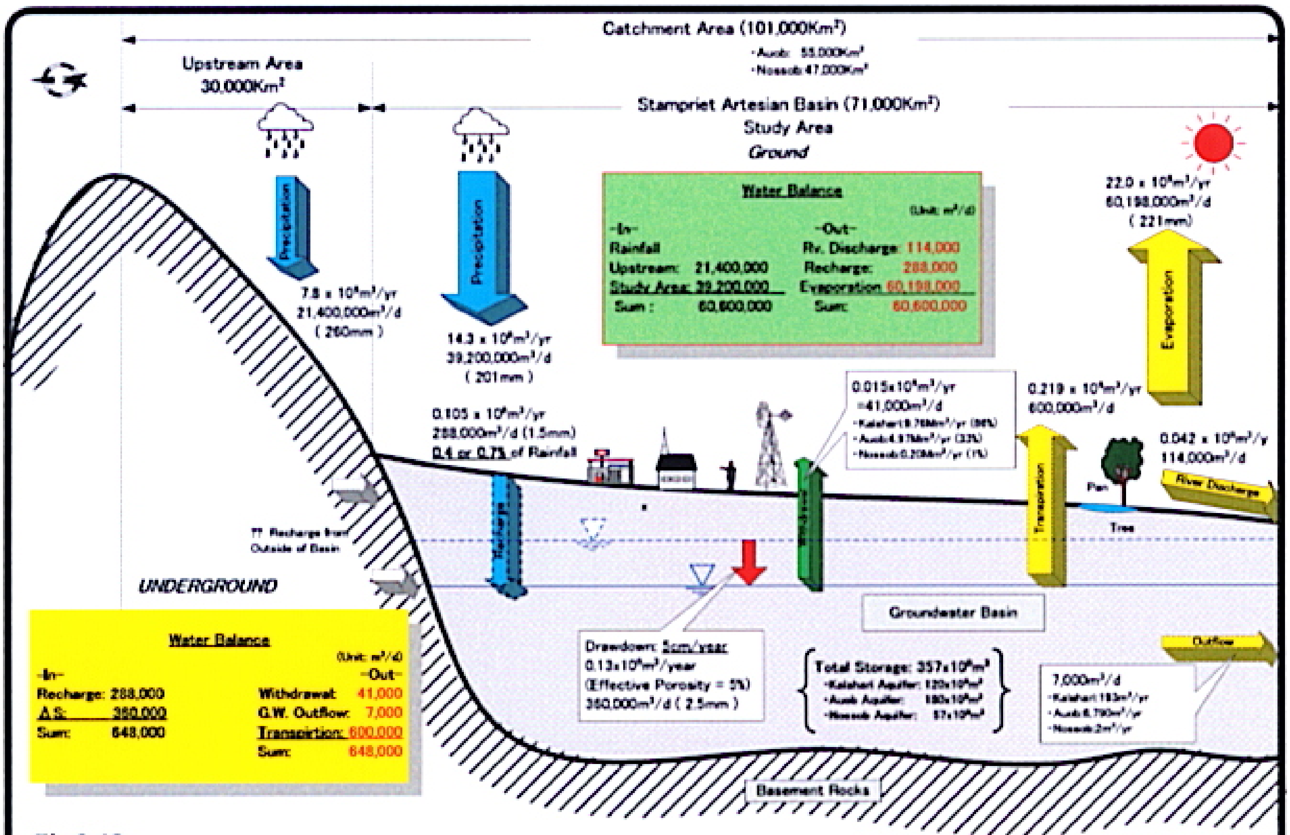


Fig.3-12 Macro Water Balance of Southeast Kalahari (Stampriet) Artesian Basin in Ordinary Year

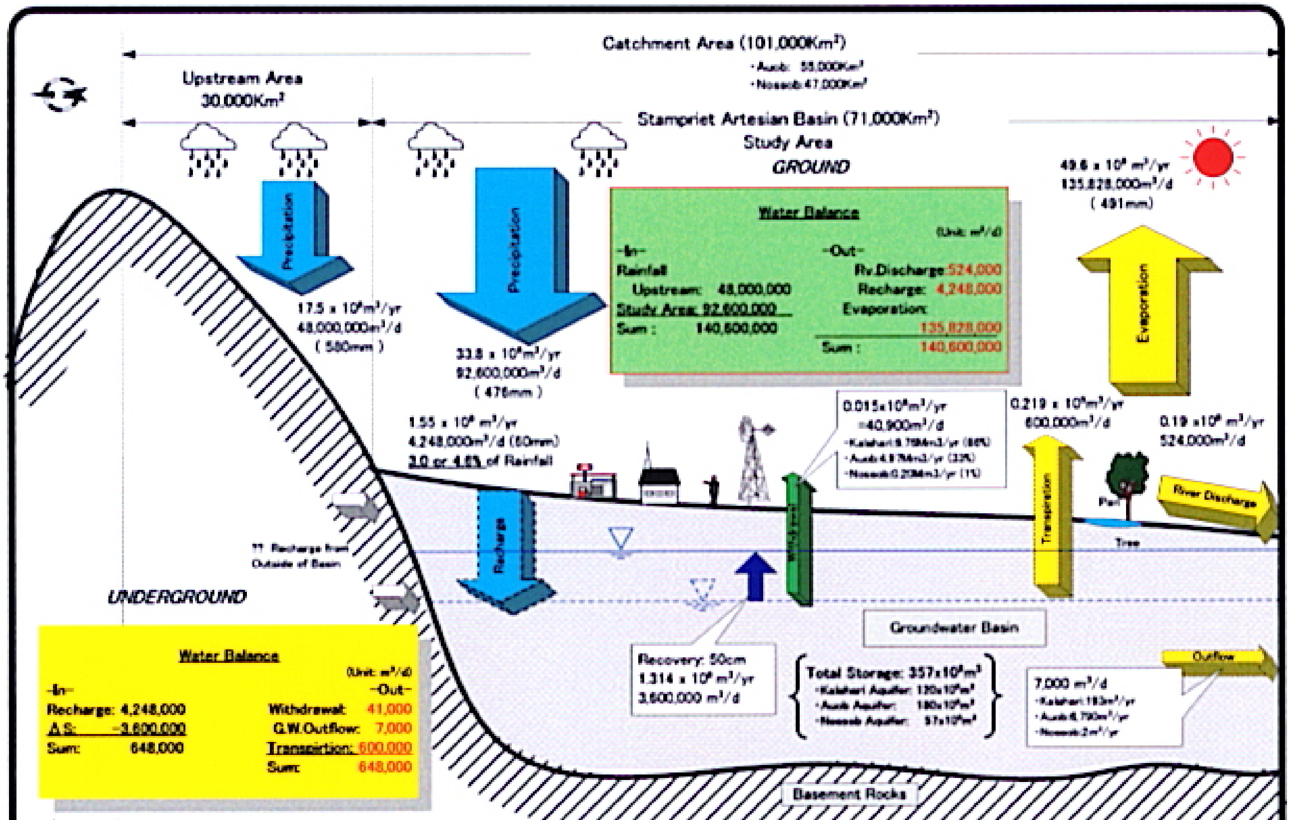


Fig.3-13

Macro Water Balance of Southeast Kalahari (Stampriet) Artesian Basin in '99–'00 Rainy Season

4. EXISTING WATER USAGE

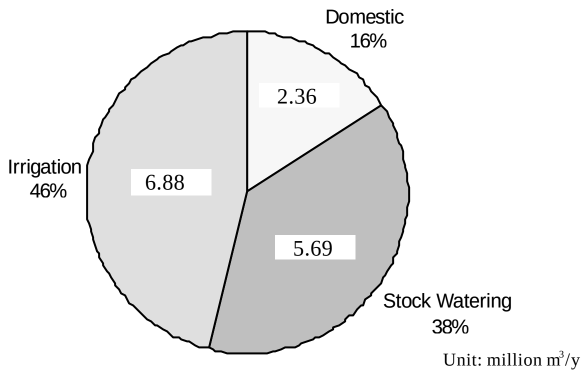
4-1 Water Usage in Study Area

On the basis of existing statistical information and the hydrocensus, which was conducted in this study, water usage amounts to 14.97 million m^3/y in total and its sectoral breakdown is shown in the pie diagram. It is remarkable that irrigation makes up almost a half of the diagram.

4.2 Irrigation

(1) Irrigation Area and Water use

Commercial farms practicing irrigation are mainly located along the Auob River. In the Stampriet area (Area II), 23% of the total number of irrigation farmers consumes 78% of the total irrigation water. (refer to Table4-1 and Fig.4-1)



< Fig.4-1 Water Usage in Study Area >

The permitted irrigation area is 399 ha of 2000 ha based on DWA's data. The difference between this and 546 ha in Table 4-1 is attributed to small irrigation area less than one hectare that need no permission, or to illegal irrigation. The main crops in the irrigation area are Lucerne, vegetable and maize.

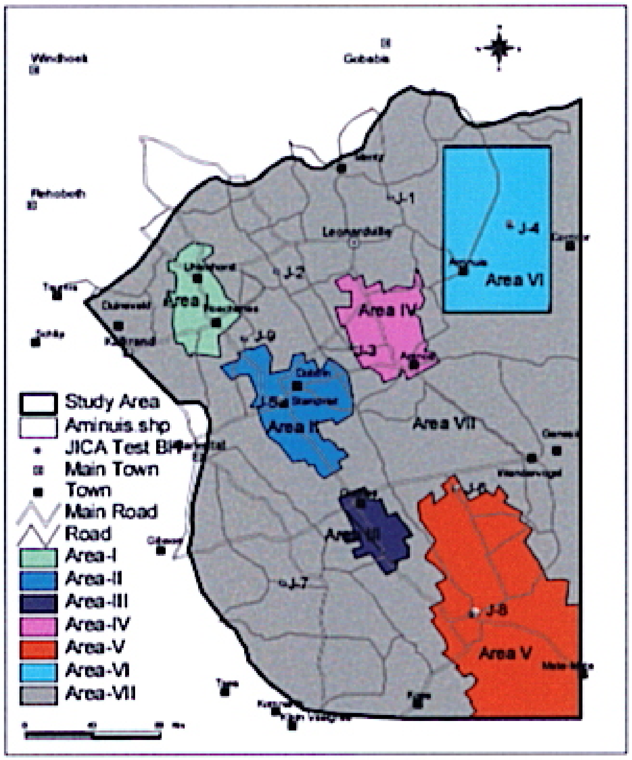
< Table 4-1 Irrigation Area and Irrigation Water Use >

Area No.	No. of Irrigation Farmers	Total Farm Area (ha)	Total Irrigation Area (ha)	Average Irrigation Area	Irrigation Water Use		
					(m^3/y)	%	(m^3/ha/y)
I	22	173,929	22	1	224,840	3	10,220
II	38	285,716	412	10.84	5,334,341	78	12,947
III	6	112,403	11	1.83	112,420	2	10,220
IV	10	200,833	24	2.4	394,119	6	16,422
VII	83	4,719,973	77	0.92	810,712	12	10,598
Total	163	6,306,250	546	3.35	6,876,432	100	60,407
Average	-	-	-	2.8	-	-	10,068

(2) Irrigation Permission

Farmers who intend to operate irrigation farming over one hectare or more have to get permission for water allocation from DWA. Once permission is given it is valid for five years on average. At present, 54 irrigation permits are approved for the commercial farms in the Stampriet Artesian Basin amounting 8.27 million m^3/y. New permit applications are currently given various allocations in terms of irrigation permit areas as follows. (refer to Fig.4-3)

- Permit Area 1: 19,000 m^3/y
- Permit Area 2: 54,000 m^3/y
- Permit Area 3: 45,000 m^3/y



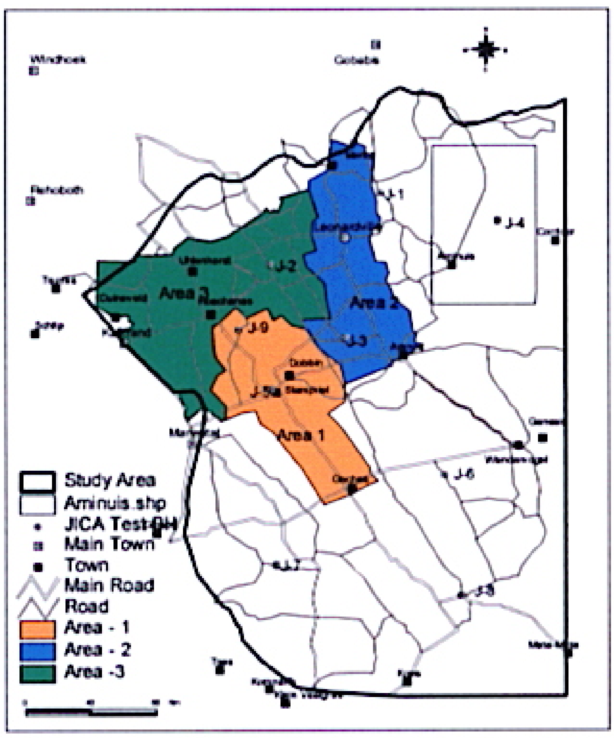
< Fig.4-2 Division for Socioeconomic Analysis >

(3) Water use efficiency

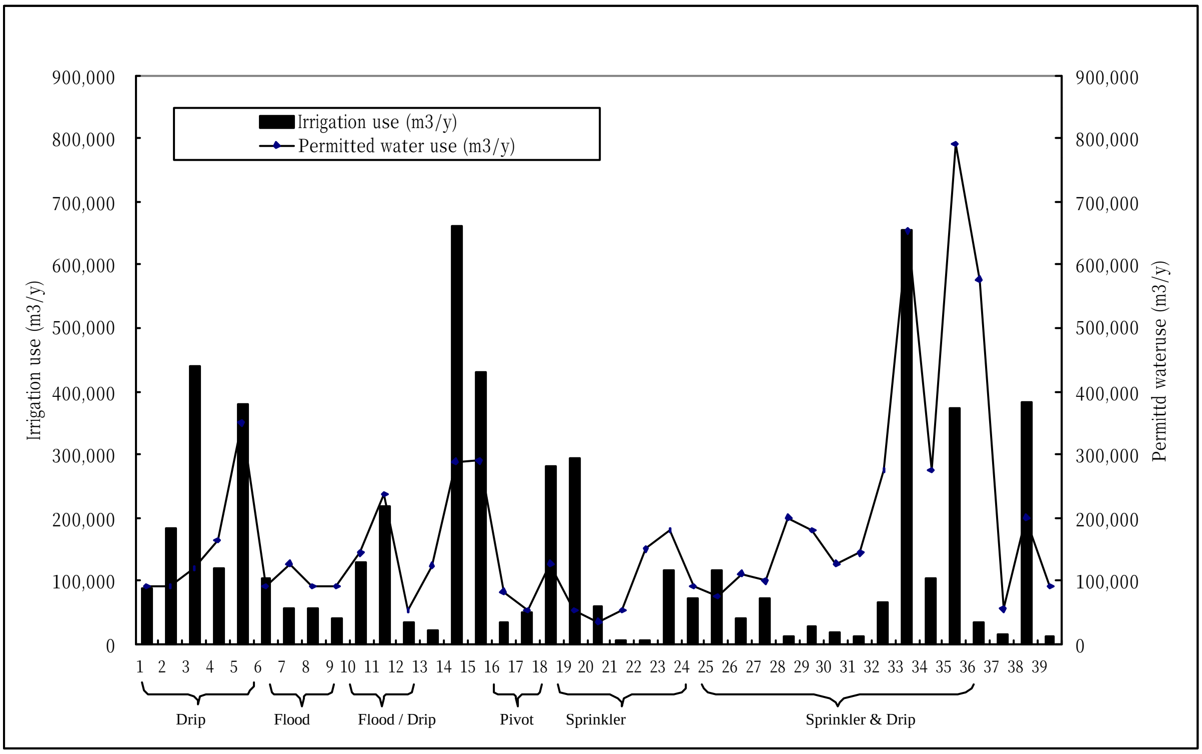
Although the total irrigation water use is 6.87 million m^3/y under the current total permitted amount, an excessive water use is practiced illegally at nine farms in Area II. (refer to Fig.4-2 and 4-4)

(4) Irrigation method

Drip irrigation is widely applied in the study area and its area amounts to 104.6 ha which is 23% of total irrigation area. The other methods in used, in the area are sprinkler and mixed applications (sprinkler, drip and others) respectively. When considering mixed applications together with drip irrigation, 58.9% of the farm areas can be considered to apply efficient irrigation methods. Farm areas, which apply only flood irrigation, are relatively few, and the total area amounts to about 30.5 ha (6.8%). Therefore, bearing this in mind, an alteration of irrigation methods is not to result in a drastic saving in water.



< Fig. 4-3 Monitoring Area for Irrigation Permission Holder >



< Fig.4-4 Comparison between Irrigation Water Use and Permitted Water Allocate >

5. GROUNDWATER POTENTIAL EVALUATION

5-1 Storage of Groundwater

Storage of groundwater in each aquifer was estimated as shown in Table 5-1. Although these groundwater storages are huge in volume, it should be considered that a very little of the groundwater within the aquifers is virtually available for extraction because of technical and economical reasons. Therefore, it is necessary to consider other indices instead of aquifer storage in order to evaluate the groundwater potential of the aquifers.

< Table 5-1 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**

5-2 Groundwater Potential Evaluation

Four indices; water depth, water quality, depth of aquifer and specific yield have been selected for this purpose as shown in following table and total evaluation for each aquifer was marked out of 400 points. The results of the evaluation are illustrated in Fig.5-1

(1) Kalahari Aquifer

The southeastern part of the basin that it is called the "Pre-Kalahari Valley" or "Salt Block" is evaluated as poor. The area which comprises more than 275 points and evaluated as considerably good extends widely in the western part of the basin.

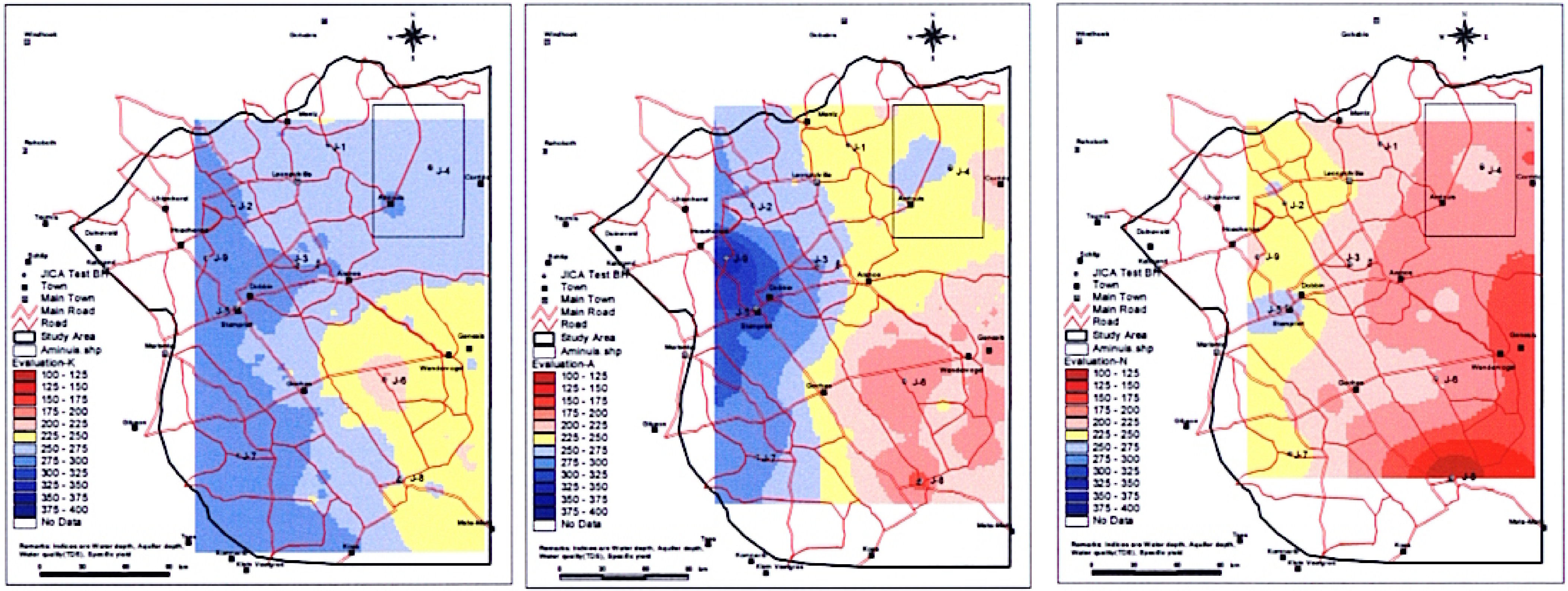
(2) Auob Aquifer

The central area of the western part of the basin including Stampriet obtains a good score of more than 300 points and it coincides with the present area of high intensive withdrawal from this aquifer. However, the area which obtains less than 225 points is extensively distributed in the southeastern part of the basin. It is remarkable that there is a considerable extent of the land that has more than 250 points in the north in Aminius.

(3) Nossob Aquifer

Most of the area analyzed is covered by the reddish color that implies less than 225 points and has a low or very low evaluation except for the small area around Stampriet.

Kalahari Aquifer　　　　Auob Aquifer　　　　Nossob Aquifer



< Fig. 5-1 Groundwater Potential Evaluation of Each Aquifer in Stampriet Artesian Basin >

5-3 Groundwater Simulation

(1) Simulation Model

Based on the hydrogeological investigation, the three aquifers in the basin were modeled by the finite difference three-dimensional manner.

(2) Input Data

The aquifer constants, pumpage, and the recharge rates were inputted for each cell, and manipulated from previous 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) Prediction

To predict the groundwater level change caused by the change in the pumping rates, 6 cases were studied. Cases 1 and 2 were assumed to keep the 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. Case-2 on the Kalahari and Auob aquifer is presented in Fig.5-3.

< Table 5-2 Conditions of Groundwater Simulation Cases >

Case	Pumping Rate (million m^3/year)				Recharge Rate (million m^3/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

(4) Prediction Results and Permissible Yield

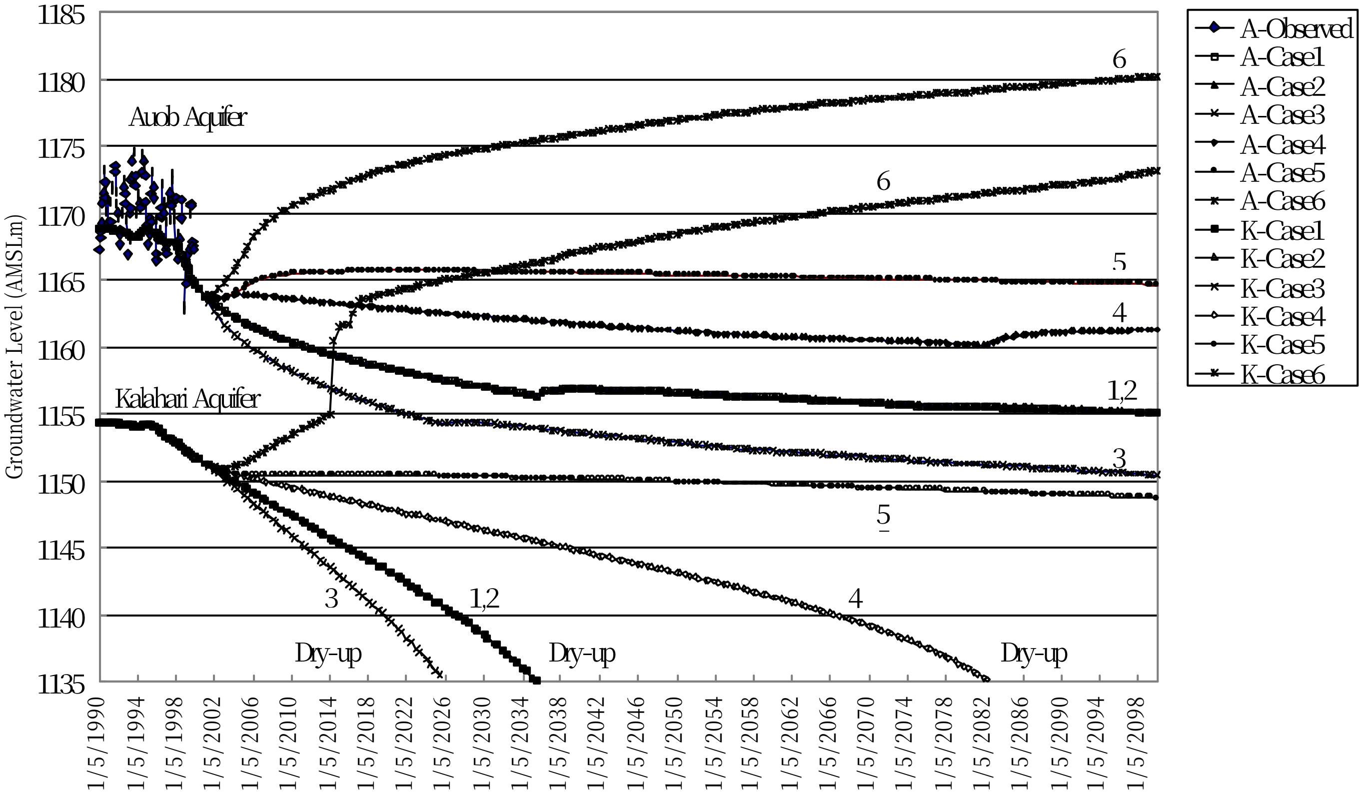
The simulation results are summarized in Table 5-3. The Stampriet area (Area II in Fig.4-2) is currently over-pumped at the present groundwater usage. More than 50% reduction in irrigation use is necessary for the Stampriet area, otherwise, the Kalahari Aquifer in the area will dry up in near future after 25 years after in Case 3, if the present groundwater extraction rate is continued. (Refer to Fig.5-2)

On the other hand, in other areas, a problem does not arise in any of the simulation cases, since its groundwater use is mainly for stock watering or domestic purpose, and besides, it never seems to increase remarkably. In Stampriet area, Case 5 (reducing irrigation use to 50%) and Case 6 (reducing irrigation use to 0%) are acceptable. Case 4 (reducing irrigation use to 70%) is not allowable since the Kalahari Aquifer will dry up within 80 years. To prevent the dry-up of the aquifer, groundwater pumping for irrigation use must at least be reduced to 50% of that in 1999, which is almost the same as the irrigation use in 1992.

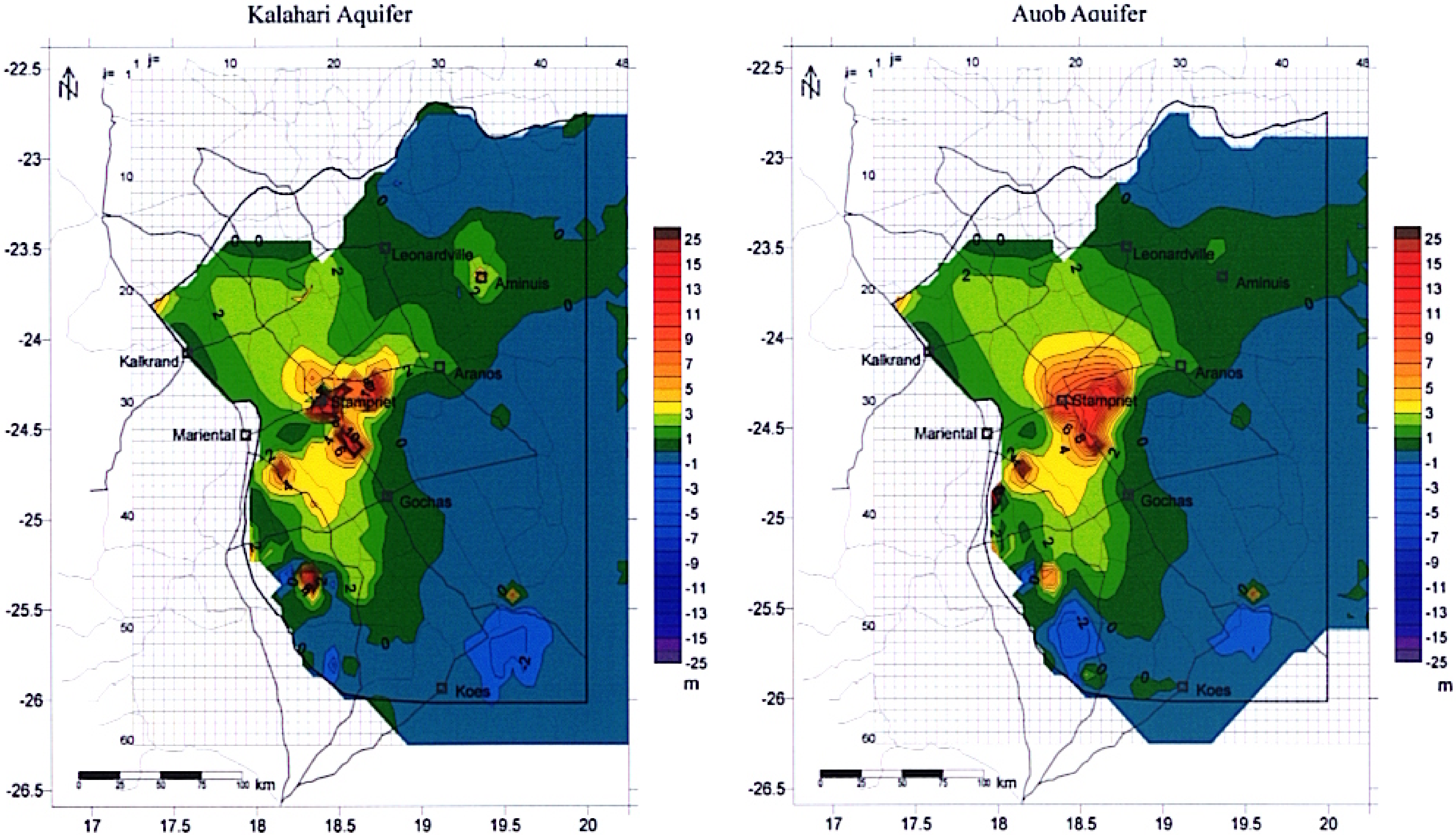
< Table 5-3 Results of Groundwater Simulation >

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

Remarks: Water Balance, G=Good (0-0.03m/y), A=Allowable (0.03-0.10m/y), UD=Undesirable (>0.11m/y), NA=Not Allowable (Dry up)
(Drawdown) Economic: G=Good (0-10m), A=Allowable (10-20m), UD=Undesirable (>20m), NA=Not Allowable (Dry up)



< Fig.5-2 Variation of Groundwater Level of the Kalahari and Auob Aquifer at Stampriet (Spes Bona) >



< Fig.5-3 Simulated Drawdown of the Kalahari and Auob Aquifer, Case 2 (100 years after) >

6. ENVIROMENT

Initial Environmental Examination (IEE) was carried out in order to identify the environmental impact on areas, which will be affected by the groundwater management plan for the sustainable use of the resource. The identification and screening were conducted in line with the "Environmental Management Act of Namibia (1988)" and the Guidelines prepared by JICA (1992).

None of the 23 environmental items, listed in the tables of the JICA Guidelines, were evaluated as having a potentially serious impact ("A"-rating), as the proposed project does not involve infrastructure development. The ratings given should be considered as evaluating the existing or potential future situation due to anthropogenic and other activities. All environmental items with a "B" rating will be considered for further evaluation.

6-1 Economic Activities

The sustainable groundwater management may involve the reduction of water use for the irrigation, and it may lead to the deceleration in the economic activities in the Area. The detailed study on the optimal water use to maximize both economic and environmental potential is required, and mitigation measures should be applied.

6.2 Water Rights and Rights of Common

Water rights may be affected by legislative regulation of water. The governmental control of water use by itself does not have any legal conflict, but in practice, it may cause a considerable social impact for the water users. To mitigate the impact, a zoning and step-wise introduction of regulation are proposed, along with the information dissemination to the local councils and the public

6.3 Groundwater

The proposed groundwater management plan is expected to cause only positive impacts on the groundwater potential in the Stampriet Artesian Basin.

6.4 Fauna and Flora

The alien vegetation invasion is considered to increase water losses from the subsurface and to reduce the natural recharge. It also imperils the natural vegetation. Overgrazing and desertification may similarly reduce the sustainability of the area. A further investigation is required in this regard.

In view of the uncertainties regarding the exact impacts on three other environmental items, these were given a "C"-rating, i.e. public health, waste and water pollution. It is recommended that these items should be reviewed as the project progresses.

7. GROUNDWATER MANAGEMENT PLAN

7-1 Reduction Target of Groundwater Extraction

According to the groundwater simulation results, a 50% reduction of the current irrigation water use is required to sustain the groundwater level. However, an immediate reduction by half the current water use is not practical. Therefore, as the first step, a 30% reduction should be a reasonable target for the control of groundwater extraction.

7.2 Action Plans for Groundwater Extraction Control

As shown in Table7-4, eight concrete countermeasures for groundwater extraction control and their priorities are established. Four items from them, "conversion of cultivation crops", "application of efficient irrigation method", "reduction of irrigation area", and "pricing on groundwater" are descried as follows.

(1) Crop Conversion

The effects of crop conversion on water use reduction were examined for the cases of conversion from lucerne to grape and from lucerne to maize. The results are summarized in the following table.

< Table 7-1 Crop Conversion and Reduction of Irrigation Water >

Case 1 Lucerne → Grape

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

Case 2 Lucerne → Maize

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

According to the above result, a 34% reduction of irrigation water use is achieved by only applying Scenario 2 in the Case 1.

(2) Application of Efficient Irrigation Method

The effects of applying effective irrigation methods on water use reduction were examined. The results are shown in Table 7-2.

In the study area, most of the irrigation farms have already introduced the water efficient irrigation methods. Therefore, the comprehensive application of this action plan is estimated to reduce 5% (215,500 m^3) of current irrigation water use.

< Table 7-2 Water saving volume applied with micro irrigation methods >

	Cases Applied with Micro Irrigation Methods	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 3	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

(3) Reduction of Irrigation Area

As for the permission of irrigation farming, the permit is issued for either the unit water use per area (Fig. 4-3) or the irrigation area per farm. In the study area, at present, a total of 399.5 ha are approved as irrigation farms, however, the actual irrigation farming is applied in 546 ha. This implies that the 37% of these areas is over irrigated. The reduction of water extraction shall be achieved by the revision of this permit system and control of the over-irrigated areas.

(4) Pricing of Groundwater

If the above mentioned action plans, which largely rely on the voluntary involvement of the local public, do not produce significant results, a pricing of groundwater may also be employed as more powerful measure to control groundwater use.
Since the proposed groundwater pricing targets the irrigation water, the water price was calculated as 0.4 to 1.5 N$/$m^3$ in consideration of Value Added as shown in Table 7-3. If this is

applied, the crop conversion shall be promoted and the resulting water saving is expected. Besides, psychological effect may also increase the effect of water saving among the irrigation farmers, if they need to pay for the water that is currently given free of charge.

In the practice of groundwater management plan, a combination of these measures shall be implemented

Table 7-3 Value Added by Crops

	Gross Income (N$/ha)	Total Cost (N$/ha)	Net Income (N$/ha)	Unit Water Consumption (m^3/ha)	Value Added per m^3 (N$/ m^3)
	(1)	(2)	(3)	(4)	(3) / (4)
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

Table 7-4 Action Plans for the Reduction of Groundwater Use

No.	Priority	Action Plan	Contents	Remarks
1	◎	Awareness 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 permit 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 current permit 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 farmers, 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.

注） ◎：Action Plans for urgent implementation
○：Action Plans for implementation in short-term examination
△：Action Plans for implementation in mid to long-term examination

7-3 Groundwater Monitoring Plan

(1) Purposes of Groundwater Monitoring

- To ascertain current conditions of groundwater in the basin
- To check the proper implementation of countermeasures
- To ascertain effectiveness of the management plan
- To revise the management plan
- To improve the groundwater modeling

(2) Target Area of Monitoring

Although the plan targets the entire area of the Southeast Kalahari Artesian Basin, the serious drawdown is observed in the limited area around Stampriet area along Auob River and its eastern region. Accordingly, the above area is tentatively called the **Special Groundwater Monitoring Area**. The groundwater monitoring should give special attention to this area, while still covering the entire area of the basin.

(3) Monitoring Item and Method

The monitoring items are divided into either technical or administrative aspects as shown in Table 7-5.

< Table7-5 Monitoring 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
Administrative Item	4	◎	Extraction rate	Flow meter, inspection	Well owners (DWA)
	5	○	Irrigation improvement	Reporting, inspection	Farmers (DWA)
	6	○	Crop conversion	Reporting, inspection	Farmers (DWA)

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

(4) Technical Monitoring Items

i) Groundwater Level

The monitoring wells targeting Kalahari Aquifer exist at 14 sites, but null in the special monitoring area. For this reason, three new observation wells should be installed in the area as shown in Fig.7-1. The existing wells owned by DWA and those newly drilled in the JICA study should cover the other area.

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

The monitoring shall be conducted in the intervals as shown in Table 7-6. The result of monitoring should be organized as the groundwater graphs as Fig.3-7 to describe the fluctuation of Piezometric head.

Table 7-6 Interval of Measurement and Data Collection of Groundwater Level

Measurement Method	Interval	Data Organized as
Automatic hydrograph (digital-SEBA)	Consecutive measurement, data collected every three months	Daily fluctuation of Piezometric Head
Automatic hydrograph (analogue)	Consecutive measurement, data collected every month	Monthly fluctuation of Piezometric Head
Manual	Monthly regular measurement	Monthly fluctuation of Piezometric Head

There are also a number of natural springs in the Auob catchment around Stampriet. Five to 10 of them should be selected for the monitoring piezometric head and spring volume.

ii) Water Quality

There is an area called the Salt Block that has an extreme salinity in the study area. The Salt-water diffusion however, is not anticipated because the water extraction is very small compared to the total groundwater storage. Therefore, it is not necessary to monitor uniformly the entire area, but in the Special Groundwater Monitoring Area, where the further groundwater drawdown and accompanying water quality deterioration is anticipated. Accordingly, for water quality, the following items shall be monitored at the designated boreholes as shown in Fig. 7-1.

Table 7-7 Intervals for Water Quality Monitoring

Area	Monitoring Interval	Monitoring Item
Special Control Area	Once a year	Major cation & anion, NO_2, NO_3, SiO_2, F, pH, TDS
Others	Once every two years	

iii) Precipitation

For the examination of groundwater recharge, the precipitation data is important as well as the data of piezometric head. The observation points are required in the groundwater recharge area and upstream of the area. At present, the Meteorological Agency is conducting the observations at and around the study area; however, the data is often missing, providing insufficient data for the groundwater analysis. Therefore, it is desired 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 followings: Uhlenhorst, Hoachanas, Christiana, and Weissrand.

(2) Administrative Monitoring Items

i) Extraction Rate

Understanding of the extraction rate is essential for the groundwater balance in the study area. Therefore, the installation of flow meters and reporting should be promoted in consent with water users. The monitoring of pumping rates is an indispensable subject in the future groundwater management. The installation of flow meters and reporting should be enforced under the inspection of DWA.

ii) Improvement of Irrigation Method

As far as the irrigation water is concerned, minimum pumping for the efficient water use is desired. To achieve it, it is required to have the understanding and cooperation of the farmers through information and education. The monitoring of the improvement status is also essential to ascertain the effectiveness of the improved methods for irrigation.

iii) Conversion of Cultivation Crop

If the crop conversion is applied without proper measures, it results in reduced the income for the farmers. The 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 is required.

7.3.4 Institution and Organization

The major part of the discussed groundwater-monitoring plan can be assumed as the main input from Geohydrology Division of DWA. Table 7-8 shows the posts and tasks of monitoring engineers. The current personnel organization of the Geohydrology Division has vacant posts for almost half of the total quota. Therefore it is anticipated that the insufficient staffing may lead to insufficient conducting of monitoring activities. The following table shows the required posts and numbers of engineers only for the groundwater monitoring activities.

< Table 7-8 Monitoring Item, Contents and Required Engineers >

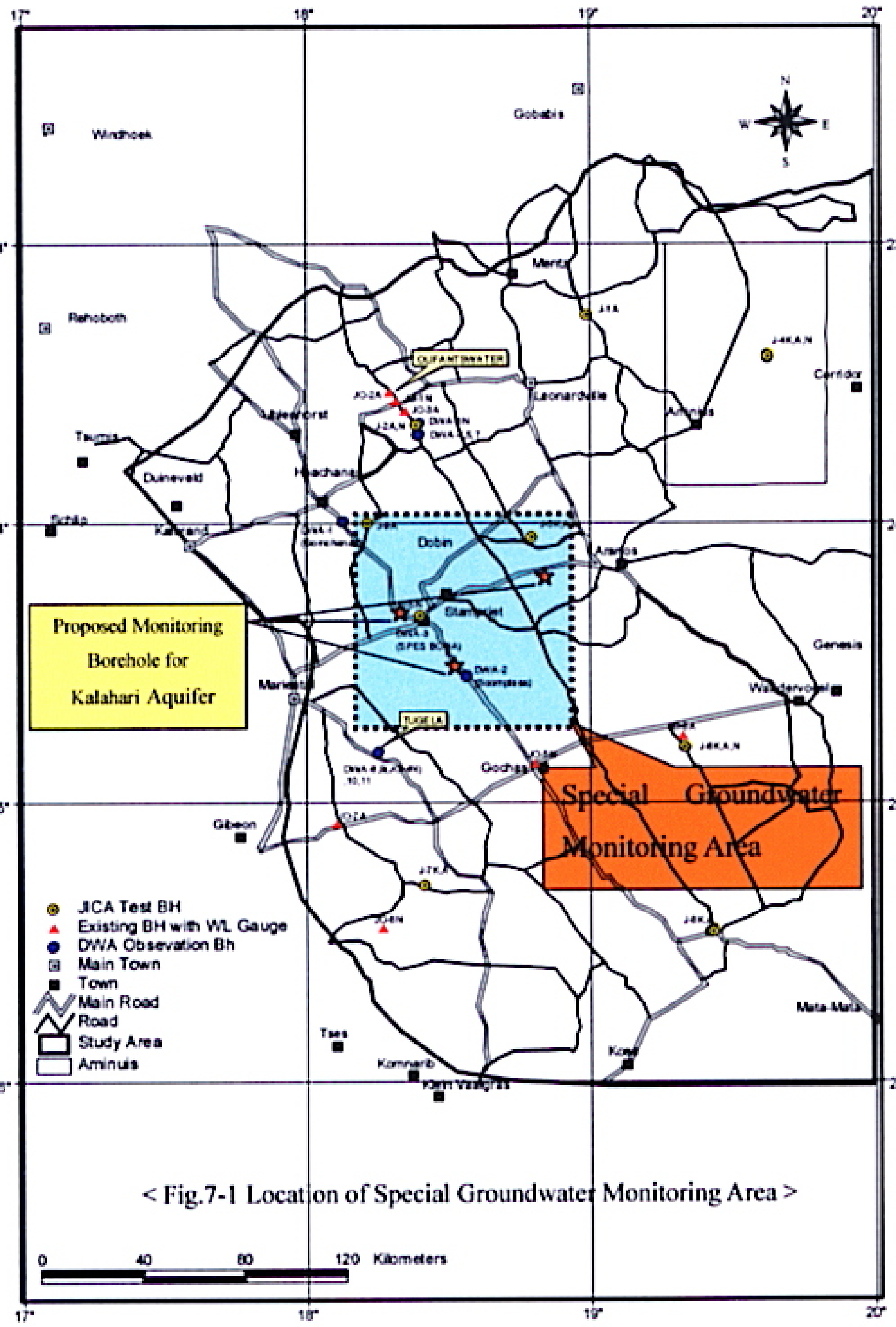
Required Engineer	Required Number	Tasks	Remarks
Senior Geohydrologist or Geohydrologist	1-2	- Management of groundwater level, analysis of observation data - Water sampling for quality analysis, analysis and interpretation of data	Urgently needed
Groundwater Simulation Expert	1	- Improvement of groundwater 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

Senior Geohydrologist and Geohydrologist are important posts to take charge of the management of groundwater monitoring. However, at present, an employment of proper personnel is assumed to be difficult. For this reason, one possibility is considered 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, for instance, accuracy of monitoring shall be assured if same technicians make graphs after reading the data in the observation of groundwater level.

Table 7-9 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.7-1 Location of 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.3-1).

(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.5-1)

(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.3-6).

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 $105 \times 10^6 m^3$/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.

<u>(5) Groundwater Demand</u>

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 Figs.4-1, 4-2 and Table4-1).

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.

<u>(6) Groundwater Simulation</u>

a) Within a 60km square area around Stampriet the drawdown of the groundwater level is remarkable. (See Fig.5-3)

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 5-2, 3 and Fig.5-2). 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.

<u>(7) Groundwater Management Plan</u>

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.7-1 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.7-1). 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.