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

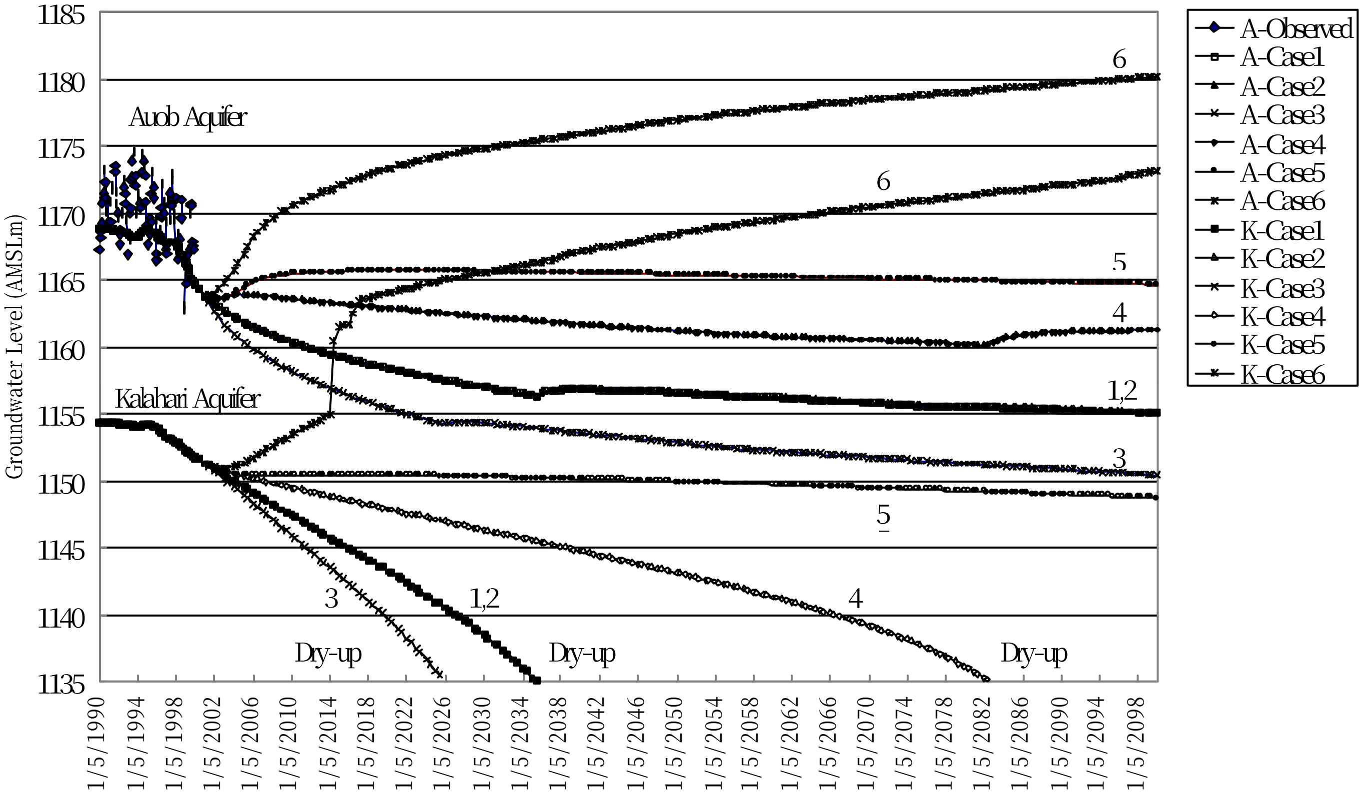
The simulation results are summarized in Table 5-3. The Stampriet area (Area II in Fig.4-2) is currently over-pumped at the present groundwater usage. More than 50% reduction in irrigation use is necessary for the Stampriet area, otherwise, the Kalahari Aquifer in the area will dry up in near future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

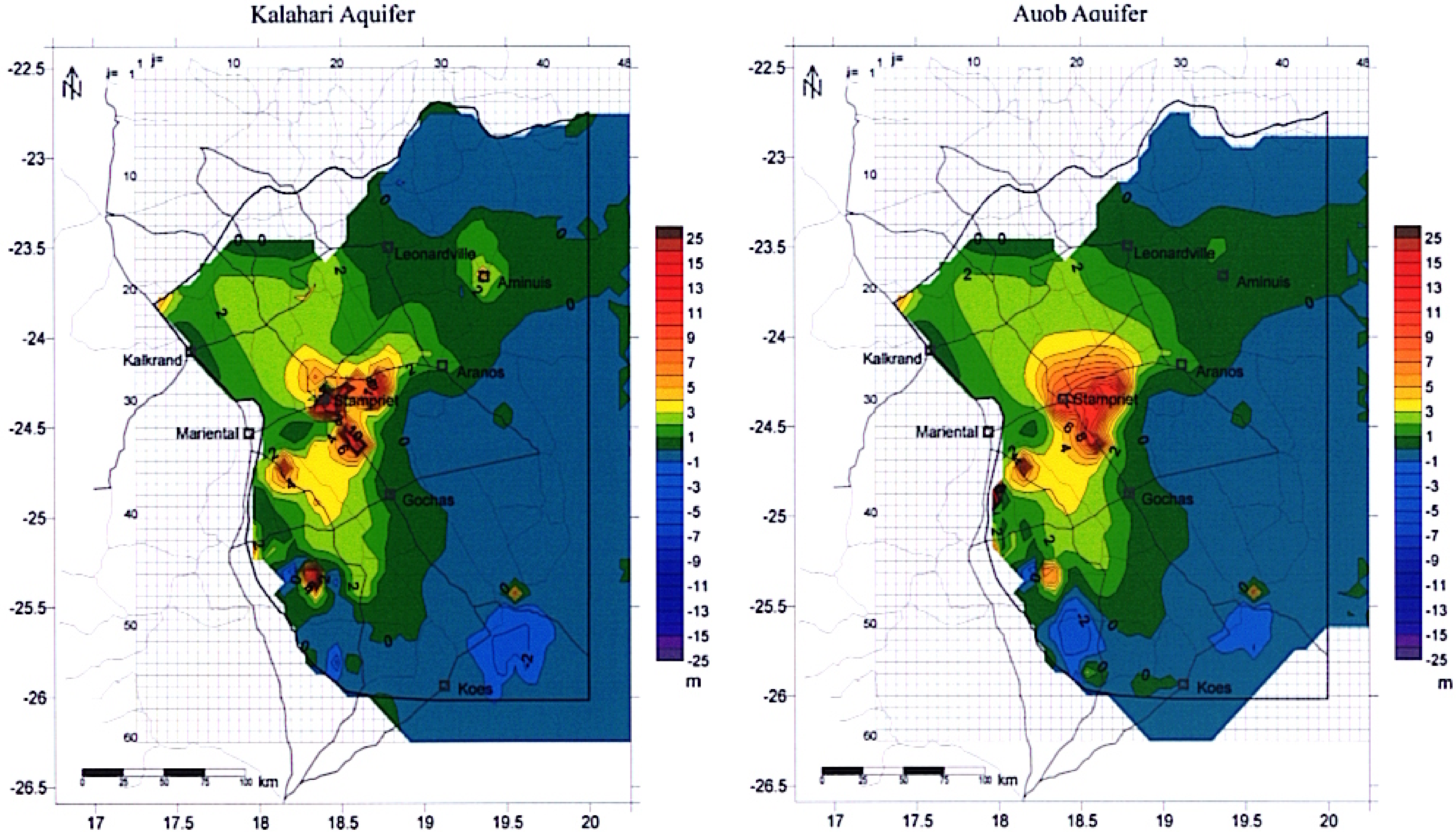
< Table 5-3 Results of Groundwater Simulation >

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 >

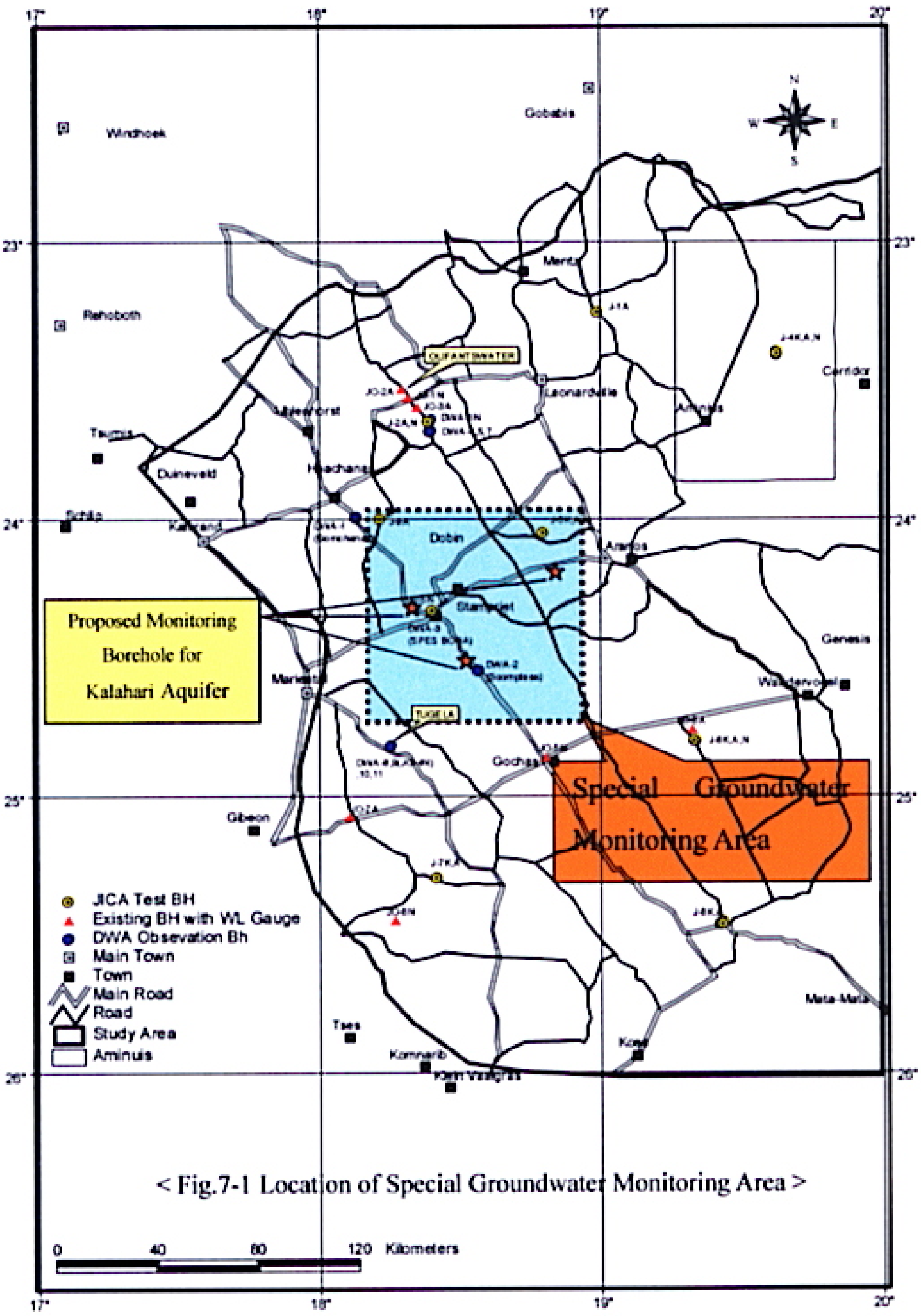
Required Engineer	Required Number	Tasks	Remarks
Senior Geohydrologist or Geohydrologist	1-2	- Management of groundwater level, analysis of observation data - Water sampling for quality analysis, analysis and interpretation of data	Urgently needed
Groundwater Simulation Expert	1	- Improvement of groundwater 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 $105\times10^6 m^3$/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.

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.