CHAPTER 3 HYDROGEOLOGY

3.1 General

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

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

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

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

3.2 Existing Data Sources

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

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

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

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

3.3 Supplementary Surveys and Analyses

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

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

3.3.1 Hydrocensus

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

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

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

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

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

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

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

3.3.2 Geophysical Survey

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

1) The TDEM Survey

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

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

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

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

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

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

Table 3.3-2 Interpretation Results of the TDEM Survey

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

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

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

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

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

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

2) Interpretation of Existing Aeromagnetic Survey Data

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

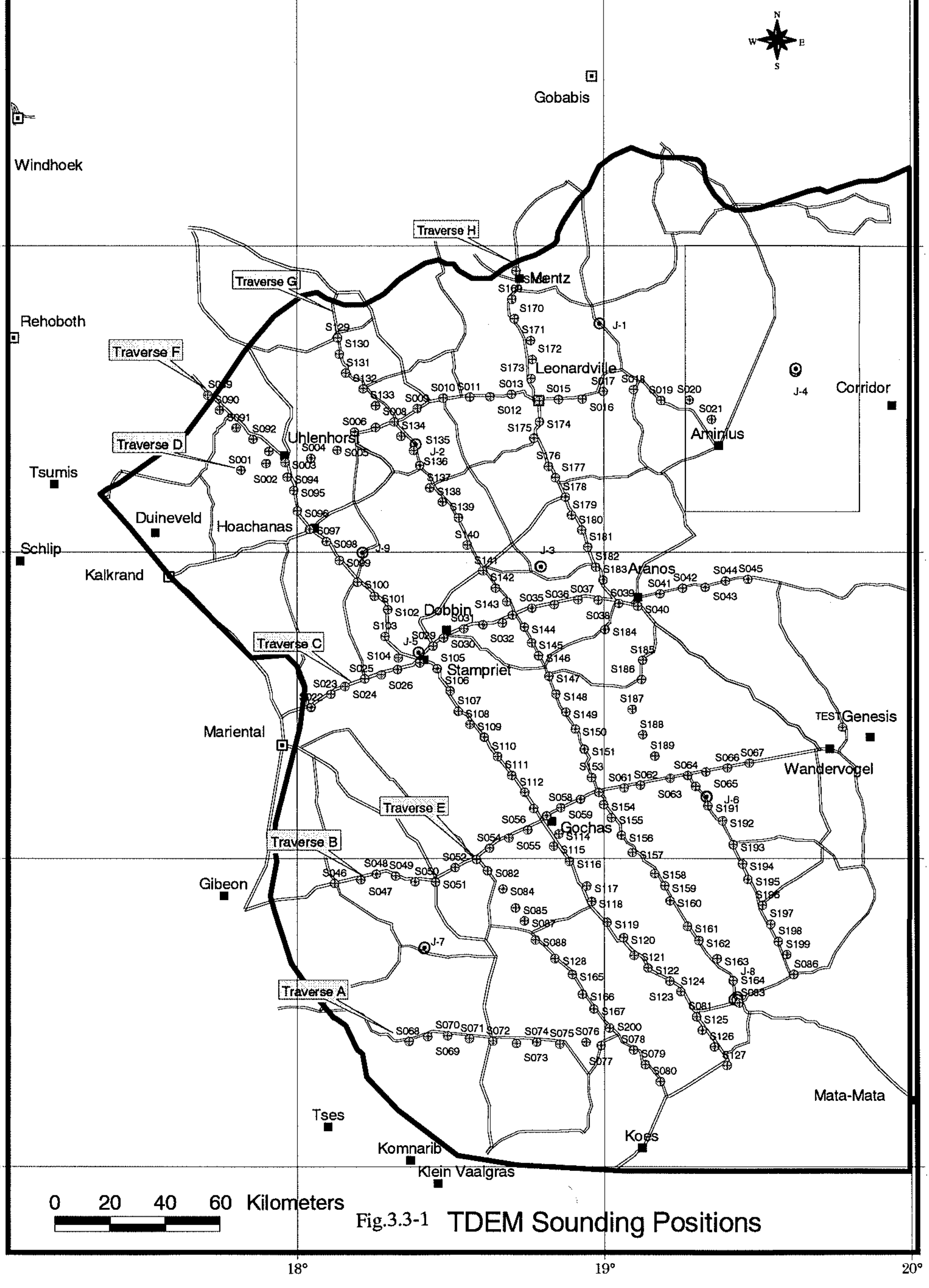


Fig.3.3-1 TDEM Sounding Positions

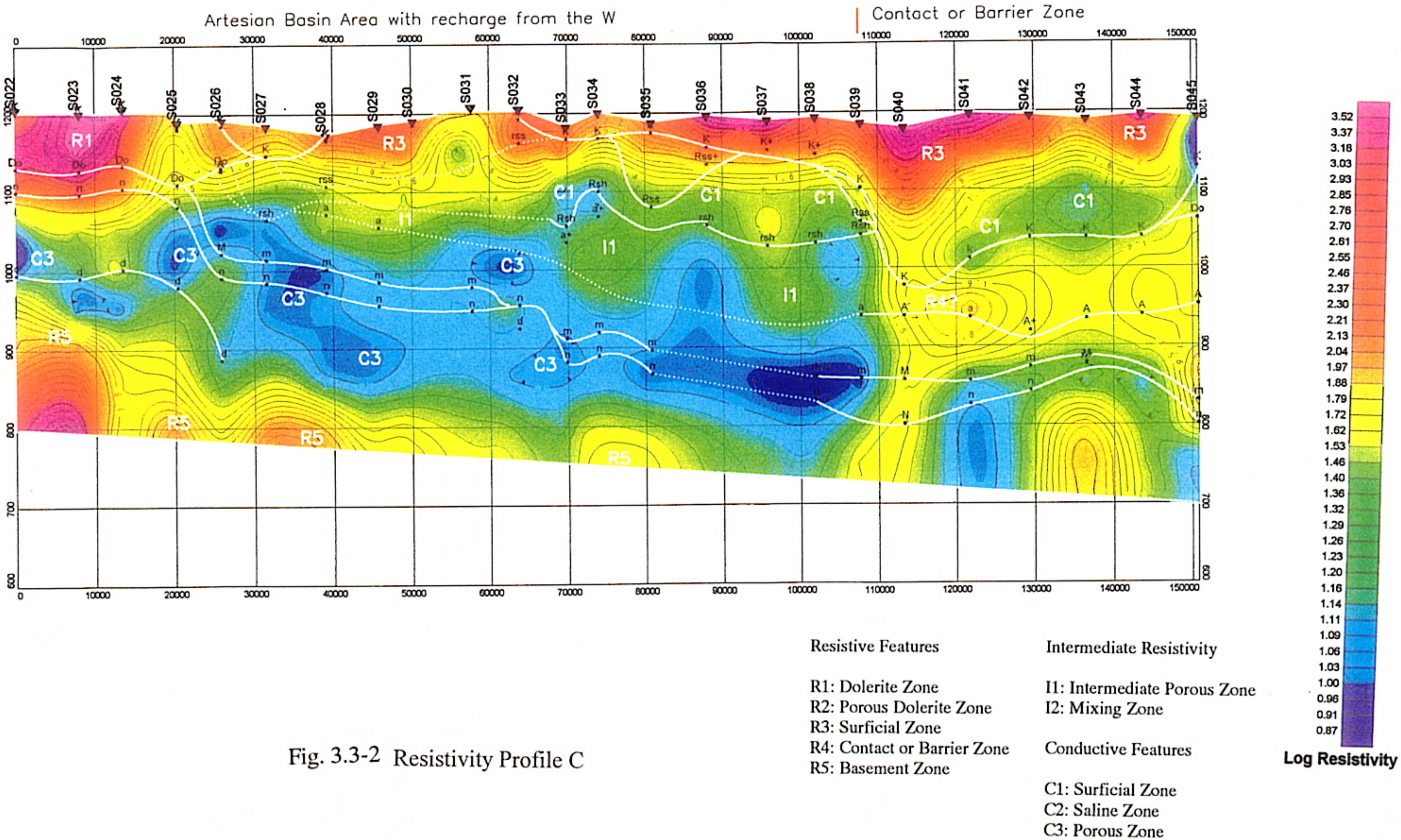


Fig. 3.3-2 Resistivity Profile C

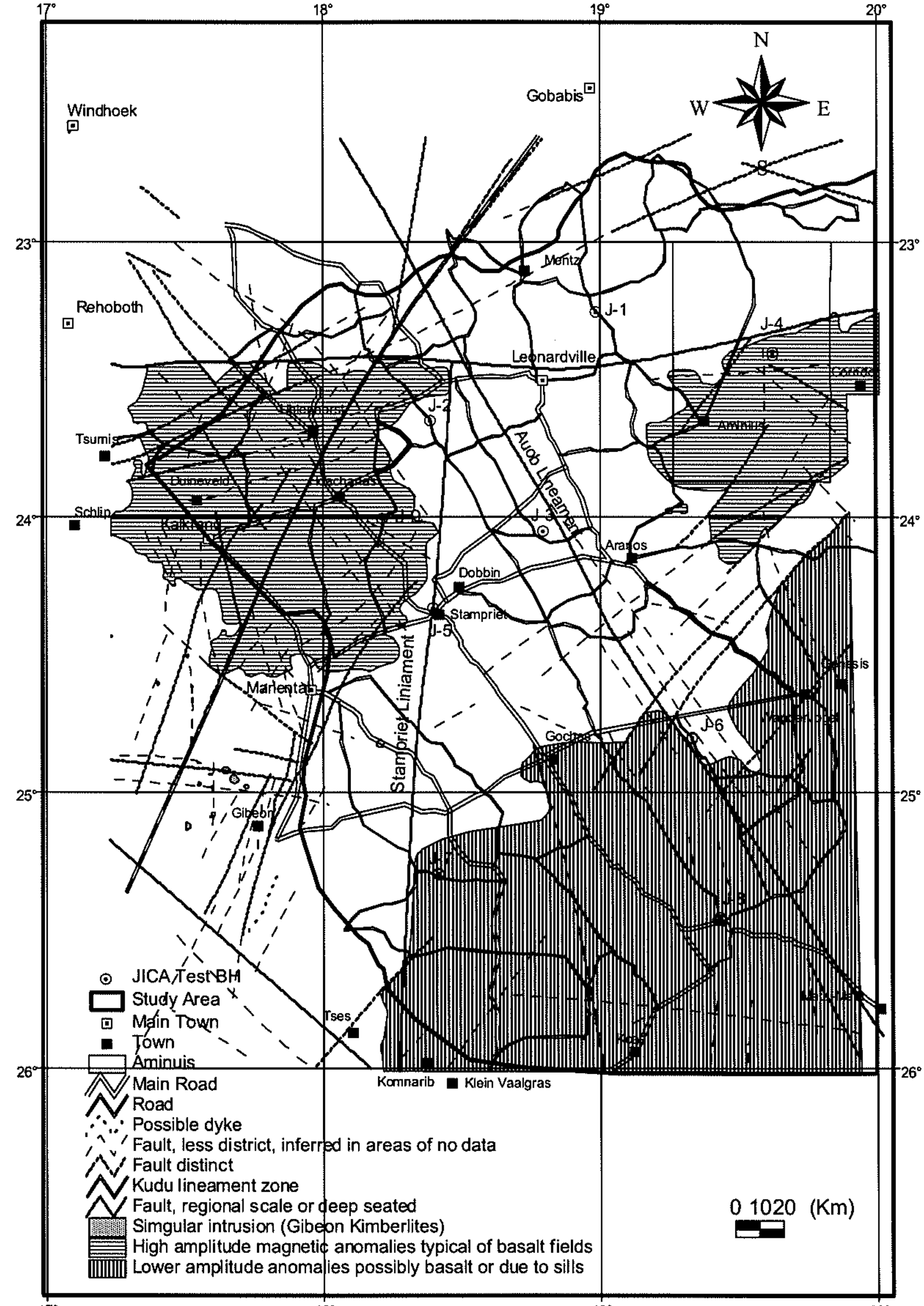


Fig. 3.3-3 Aeromagnetic Interpretation Map

3.3.3 Test Borehole Drilling

1) Purpose of Test Borehole Drilling

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

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

2) Outline of the Programme

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

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

Table 3.3-3 Contents of the Test Drilling Programme

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

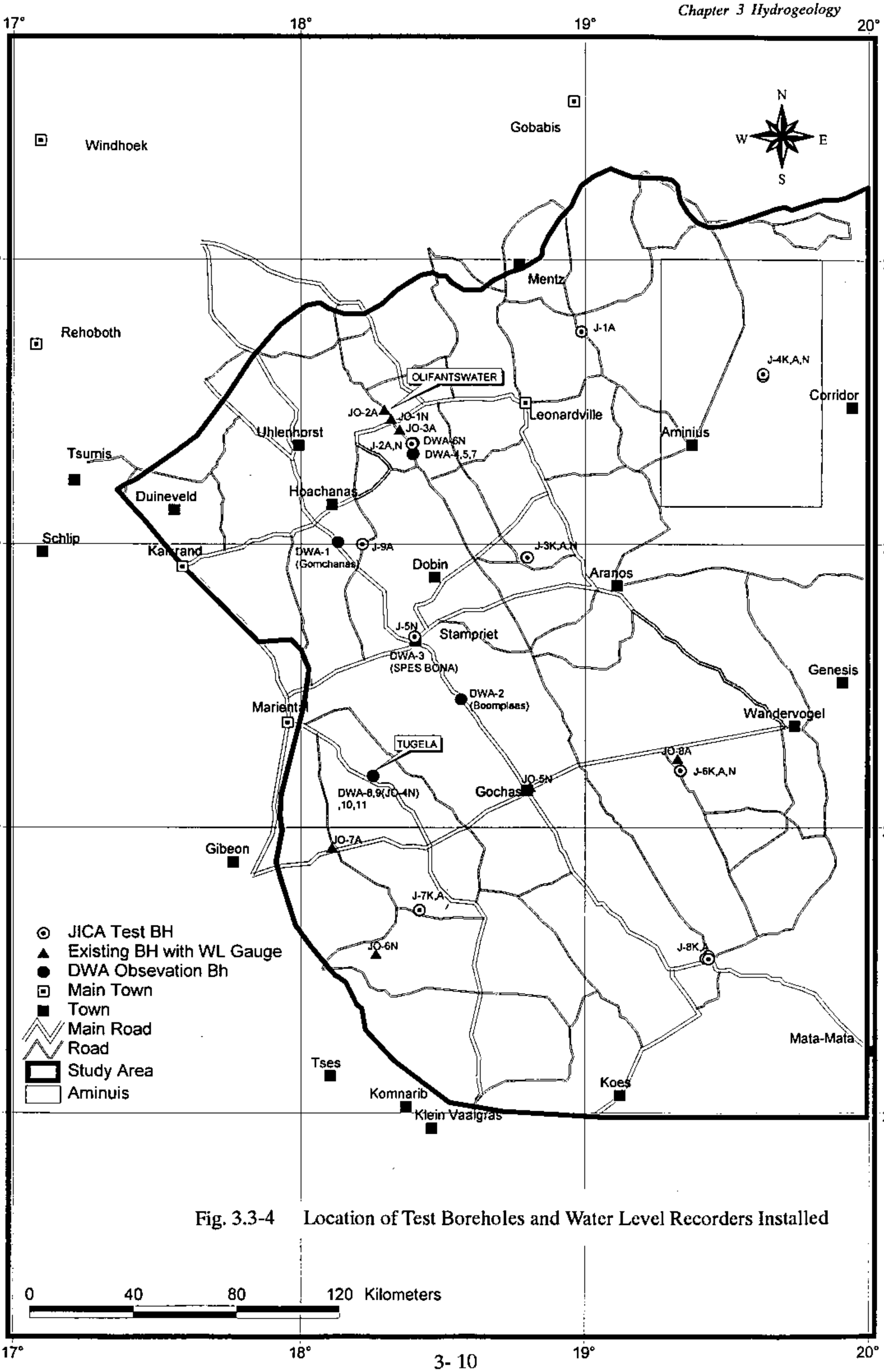


Fig. 3.3-4 Location of Test Boreholes and Water Level Recorders Installed

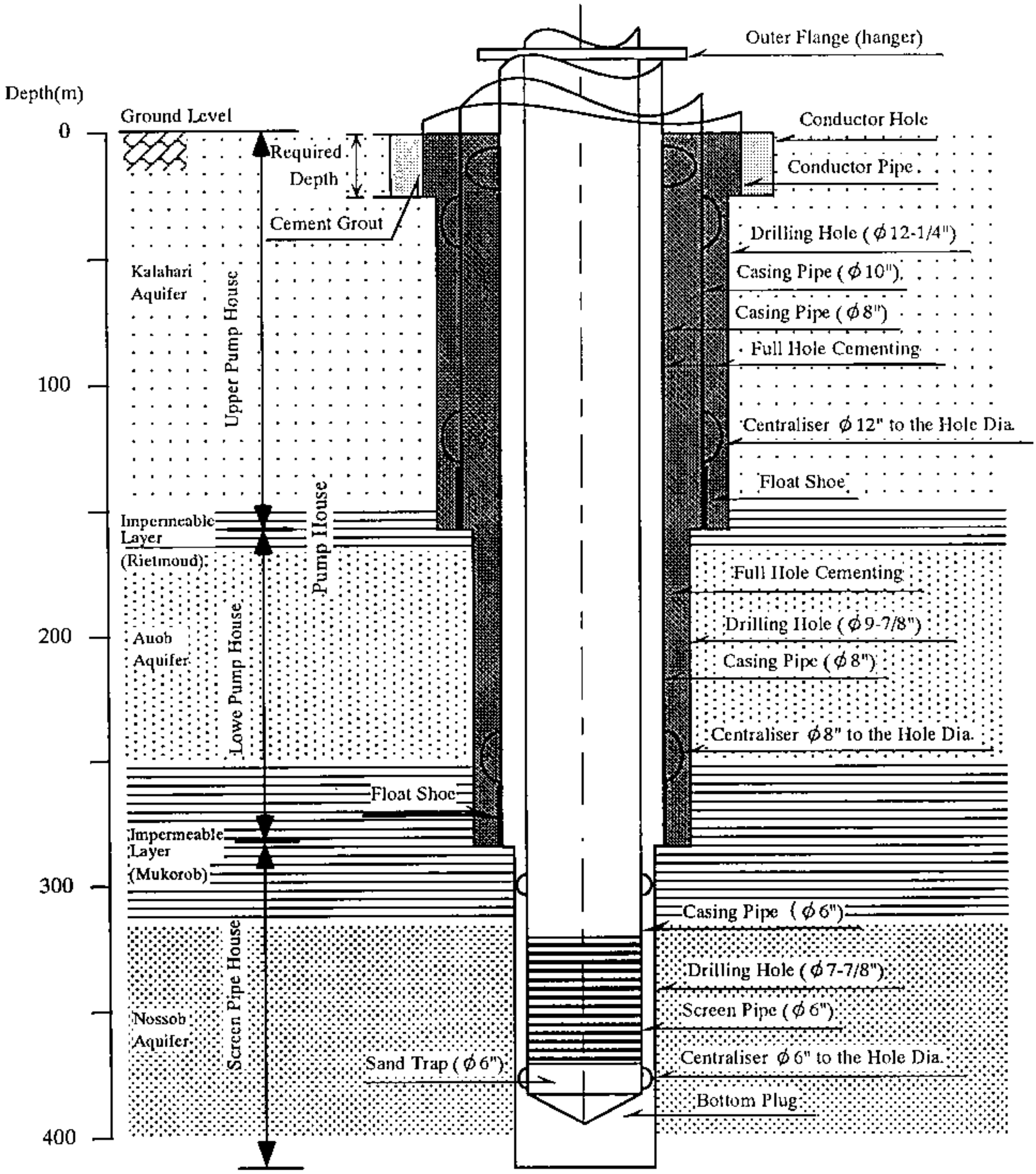


Fig. 3.3-5 Typical Specification of Test Boreholes (For the Nossob Aquifer)

3) Results of Test Borehole Drilling

(1) Test Borehole Data

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

Table 3.3-4 Test Borehole Data

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

(2) Geological Interpretation

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

Table 3.3-5 Thicknesses of Geological Units

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

(Remarks)

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

(3) Aquifer Constants

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

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

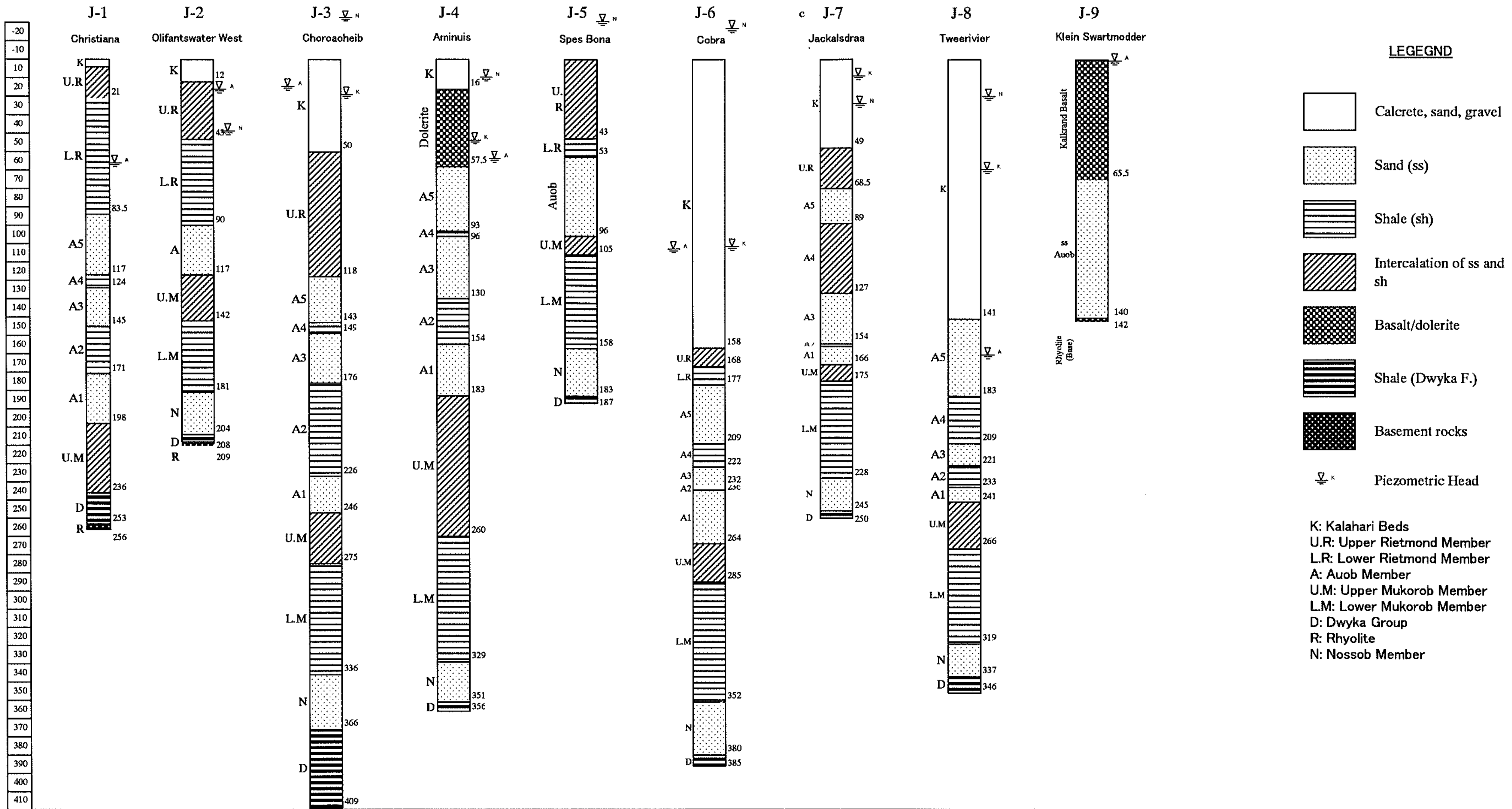
Table 3.3-6 Aquifer Constants

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

(4) Water Quality and Isotope Analyses of Test Boreholes

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

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



J-1			J-2			J-3			J-4			J-5		
Kalahari	WL	-	Kalahari	WL	-	Kalahari	WL	19.08 ml	Kalahari	WL	49.40mBGL	Kalahari	WL	-
	WL	-		WL	-		WL	1188.97 mAS		WL	1208.66 mAS		WL	-
	T	-		T	-		T	6.4 m^2/day		T	0.1 m^2/day		T	-
	EC	-		EC	-		EC	330 mS/m		EC	227 mS/m		EC	-
	TDS	-		TDS	-		TDS	2157 mg/L		TDS	1481 mg/L		TDS	-
	pH	-		pH	-		pH	7.2		pH	8.5		pH	-
	Temp	-		Temp	-		Temp	21.9°C		Temp	29.3°C		Temp	-
Auob	WL	57.72 mBGL	Auob	WL	15.01 mBGL	Auob	WL	13.62 mBGL	Auob	WL	59.15 mBGL	Auob	WL	-
	WL	1274.00 mAS		WL	1260.25 mAS		WL	1194.44 mAS		WL	1197.25 mAS		WL	-
	T	25.2 m^2/day		T	3.4 m^2/day		T	194.0 m^2/day		T	87.6 m^2/day		T	-
	EC	85 mS/m		EC	90 mS/m		EC	116 mS/m		EC	326 mS/m		EC	-
	TDS	564 mg/L		TDS	605 mg/L		TDS	775 mg/L		TDS	2084 mg/L		TDS	-
	pH	7.6		pH	7.8		pH	7.5		pH	7.1		pH	-
	Temp	25.0°C		Temp	25.8°C		Temp	29.8°C		Temp	27.0°C		Temp	-
Nossob	WL	-	Nossob	WL	39.45 mBGL	Nossob	WL	-30.91.0 mB(	Nossob	WL	6.23 mBGL	Nossob	WL	-29.57 mBGl
	WL	-		WL	1236.15 mAS		WL	1238.96 mAS		WL	1250.15 mAS		WL	1197.90 mAS
	T	-		T	2.9 m^2/day		T	1.3 m^2/day		T	7.01 m^2/day		T	1.2 m^2/day
	EC	-		EC	91 mS/m		EC	460 mS/m		EC	100 mS/m		EC	136 mS/m
	TDS	-		TDS	616 mg/L		TDS	3303 mg/L		TDS	665 mg/L		TDS	909 mg/L
	pH	-		pH	8.3		pH	8.2		pH	8.9		pH	8.5
	Temp	-		Temp	30.0°C		Temp	24.9°C		Temp	30.3°C		Temp	28.5°C

J-6			J-7			J-8			J-9		
Kalahari	WL	102.14 mBGl	Kalahari	WL	9.72 mBGL	Kalahari	WL	59.75 mBGL	Basalt	WL	-
	WL	1000.53 mAS		WL	1138.47 mAS		WL	961.5 mASL		WL	-
	T	6.2 m^2/day		T	30.0 m^2/day		T	0.13 m2/day		T	-
	EC	2,310 mS/m		EC	103 mS/m		EC	351 mS/m		EC	-
	TDS	14874 mg/L		TDS	670 mg/L		TDS	2282 mg/L		TDS	-
	pH	8.6		pH	7.40		pH	8.70		pH	-
	Temp	26.9 ℃		Temp	27.0 ℃		Temp	27.0 ℃		Temp	-
Auob	WL	102.8 mBGL	Auob	WL	-	Auob	WL	183.8 mBGL	Auob	WL	2.3 mBGL
	WL	999.66 mASl		WL	-		WL	831.18 mASl		WL	1207.9 mASL
	T	8.4 m^2/da		T	-		T	0.3 m^2/day		T	1240 m^2/day
	EC	187 mS/m		EC	-		EC	1,039 mS/m		EC	101 mS/m
	TDS	1248 mg/L		TDS	-		TDS	6754 mg/L		TDS	656 mg/L
	pH	8.6		pH	-		pH	9.66		pH	7.70
	Temp	26.9 ℃		Temp	-		Temp	28.0 ℃		Temp	28.6 ℃
Nossob	WL	-19.64 mBGl	Nossob	WL	21.65 mBGL	Nossob	WL	20.46 mBGL	Nossob	WL	-
	WL	1001.19 mAS		WL	1126.50 mAS		WL	1000.8 mASl		WL	-
	T	1.49 m^2/day		T	0.01 m^2/day		T	0.02 m^2/day		Q	-
	EC	1038 mS/m		EC	431 mS/m		EC	5,030 mS/m		EC	-
	TDS	6955 mg/L		TDS	2743 mg/L		TDS	33,500 mg/L		TDS	-
	pH	9.5		pH	9.10		pH	8.64		pH	-
	Temp	27.8°C		Temp	29.1°C		Temp	21.8°C		T	-

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

Fig. 3.3-6 Geological Columnar Sections and Hydrogeological Characteristics

Table 3.3-7 Water Quality of Test Boreholes

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

3.3.4 Borehole Elevation Survey

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

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

3.4 Classifications and Definition of Aquifer

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

The Study revealed that:

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

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

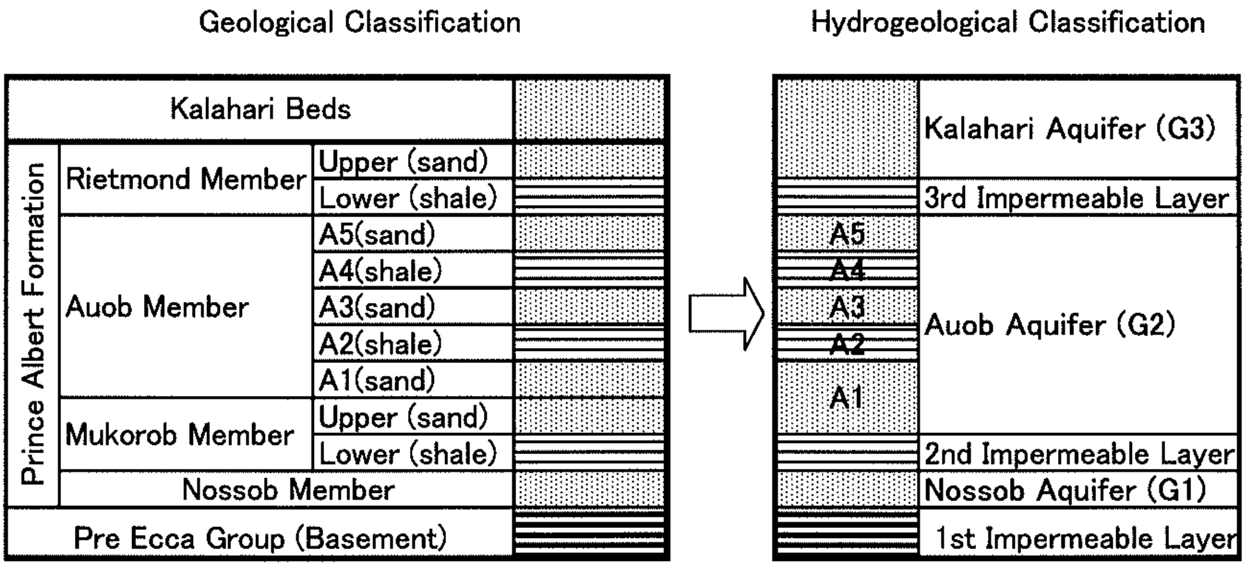


Fig. 3.4-1 Reclassification of Aquifers

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

- Kalahari Aquifer

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

- Auob Aquifer

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

- Nossob Aquifer

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

3.5 General Features of Aquifer

3.5.1 Kalahari Aquifer

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

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

3.5.2 Auob Aquifer

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

3.5.3 Nossob Aquifer

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

3.6 Configuration of Aquifer

3.6.1 Kalahari Aquifer

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

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

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

3.6.2 Auob Aquifer

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

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

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

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

3.6.3 Nossob Aquifer

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

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

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

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