that the water in the aquifer hardly receives direct recharge from precipitation.

4-6 Aquifer properties

4-6-1 Transmissibility and storativity

The major aquifer hydraulic characteristics that affect groundwater movement and groundwater development potential are the ability to transmit water and the ability to yield water from storage. These characteristics are called transmissibility and storativity, respectively, and are established by pumping tests. Results of pumping tests and other hydrogeologic data of boreholes tapping aquifers in the study area are given in Tab. 4-10.

a) Basement complex area
Six pumping tests were conducted during this study in boreholes located in the basement complex area. The computed transmissibility was generally poor, ranging from a low of 1.58 m^2/day at Ruwan Bore to a high of 38.59 m^2/day at Dauran. These results indicate transmissibilities about 10 to 100 times lower than those of aquifers in the sedimentary area.

b) Gundumi formation
Pumping tests conducted at six sites in boreholes tapping the aquifer in the Gundumi formation indicate a wide range in transmissibility. This ranged from a low of 3.7 m^2/day at Isa to a high of 814.7 m^2/day at Gusau-Sokoto Road mile 99+4000. Tests in a number of boreholes tapping the aquifer indicated lower yields and higher drawdowns as basement rock was approached, principally because the water-bearing beds become thinner and contain more clay near the basement rock contact.

c) Illo formation
Little pumping test data is available on the aquifer in the Illo formation. The pumping test conducted at Kuka-Kogo indicated a transmissibility of 44.5 m^2/day. This is moderately low compared with that found in the Gundumi formation.

d) Rima group
The transmissibility computed from the data of pumping tests conducted at eight sites in boreholes tapping the aquifer in the Rima group ranged from a low of 34.8 m^2/day at Wurno to a high of 3279 m^2/day at Dogwandaji. According to Anderson and Oglibee (1973), the computed transmissibility at Dogwandaji may be somewhat high and possibly

Table 4-10 results of Aquifer Tests

Location	Borehole	Date of test	Duration of test (hour)	Average yield (m³/day)	Drawdown (m)	Distance (m)	Transmissivity (m²/day)	Storage coefficient	Aquifer (m below land surface)	Screen (m below land surface)
Basement Area										
Tunga Ardo	JICA	Jan.1989	24	18.7	12.00 PB	0				36- 43 48- 55
Kuwan Bore	JICA	Jan.1989	48	100.8	38.85 PB	0	1.58			52- 62 73- 75 80- 84
Ruwan Bore	JICA	Jan.1989	48	100.8	3.25 OB	140				36- 40 56- 64 70- 74
Dauran	JICA	Jan.1989	24	185.8	6.33 PB	0	38.59			36- 40 52- 56 73- 80
Yambuki	JICA	Jan.1989	48	99.4	8.10 PB	0	7.65			49- 55 66- 73 89- 91
Yambuki	JICA	Jan.1989	48	99.4	0.02 OB	220				36- 41 52- 57 68- 73
Maga	JICA	Jan.1989	48	144.0	57.83 PB	0	2.10			42- 45 123-129
Maga	JICA	Jan.1989	48	144.0	2.68 OB	45				
Zugu	JICA	Jul.1989	48	40.3	31.71 PB	0	1.12			
Zugu	JICA	Jul.1989	48	201.6	5.42 PB	0	23.60			
Gundumi - Illo Formation										
Dange---------GSN	3512	Oct.1965	0	142.6	1.92 OB	15	283.2	---------	177-192	185-190
Sabon---------	3513	1966	21	370.7	13.10 OB	11	32.3	3.7×10^{-4}	119-125	119-154
Isa-----------	3514	June1966	24	163.5	21.21 OB	12	3.7	4.0×10^{-3}	123-126	121-126
Gusau-Sokoto rond mile 99 + 4,000	3521	July	30	588.7	0.73 OB	9	814.7	4.0×10^{-3}		82- 87
Bakura	3701	Apr.1956	9	499.7	5.10 OB	15	60.9	1.9×10^{-4}	76- 82	78- 83
Girawsi-------	3704	Apr.1966	3	218.0	0.07 OB	0	720.3	---------	269-281	276-280
Kuka Kogo	JICA	Feb.1989	48	455.0	10.16 PB	0	44.5		- 70	51- 60
Rima Group										
Sokoto--------GSN	2859	Mar.1966	25	545.1	0.42 OB	139	546.4	2.5×10^{-4}		51- 55
Do--------	3504	May 1966	22	272.5	0.10 OB	853	511.7	1.2×10^{-4}	101-119	110-114
Do--------	3505	July1966	6	254.4	0.11 OB	324	645.8	---------	61-110	104-110
Wurno---------	3506	Apr.1966	24	367.9	16.76 PB	0	34.8	---------	148-154	148-152
Dogwandaji----	3507	June1966	24	545.0	0.67 OB	7	3278.7	---------	67- 0	76- 81
Bodinga-------	3508	July1965	24	467.0	0.94 OB	10	807.2	1.8×10^{-5}	30-105	94- 99
Shuni (now Shiunni)-	3511	Aug.1965	12	480.6	2.67 OB	11	288.1	1.0×10^{-4}	76-107	86- 90
Horo Birni	JICA	Nov.1988	48	432.0	8.26 PB	0	77.76		33- 95	72- 81
Horo Birni	JICA	Nov.1988	48	432.0	0.55 OB	6			30- 94	51- 60
Gwandu Formation										
Birnin Kebbi--GSN	2482	Sep.1963	72	381.6	1.55 OB	356	290.6	6.0×10^{-5}	52- 74	52- 58
Rafin Kubu----	2499	Oct.1964	24	261.6	0.17 PB	0	653.3	---------	110-138	133-137
Bacaka--------	2674	June1965	21	745.0	6.40 PB	0	8.7	---------	298-303	298-303
Balle---------	3054	Feb.1966		808.5	0.21 PB	0	2111.3	---------	123-184	157-158
Do--------	3055		15	781.3	2.13 PB	0	113.0	---------	107-116	112-113
Kurdula-------	3056	Nov.1964	40	726.8	2.30 OB	23	119.2	1.1×10^{-4}	245-259	250-255
Tangaza-------	3059	Feb.1965	42	681.4	0.55 OB	61	1031.1	2.7×10^{-5}	46- 89	52- 60
Yeldu---------	3063	May 1964	48	381.6	1.37 OB	30	181.3	1.2×10^{-4}	145-163	155-159
Karfin Sarki--	3069	June1965	21	1090.2	0.66 OB	23	1348.7	8.2×10^{-5}	177-200	180-185
Safla---------	3501	Apr.1965	46	681.4	0.41 OB	16	1589.7	2.8×10^{-5}	30- 47	41- 44
Soro	JICA	Dec.1988	24	455.0	4.22 PB	0	140.0		35- 88	65- 76

PB : Producing Borehole
OB : Observation Borehole

reflects a recharge source such as a river or spring intercepted during the testing.

e) Gwandu formation

Pumping tests conducted at eleven sites in boreholes tapping the confined Gwandu aquifer indicate a wide range in transmissibility. This ranges from a low of 8.7 m^2/day at Bacaka to a high of 2111.3 m^2/day at Balle. Except for the transmissibility at Bacaka, boreholes in the aquifer indicate that the Gwandu aquifer has the highest transmissibility of all aquifers in the study area.

4-6-2 Specific capacity

A hydraulic characteristic indexing the ability of an aquifer to yield water from a well is "specific capacity". Specific capacity is the amount of yield divided by drawdown, and it closely relates to transmissibility.

Empirically, transmissibility is given by:

$$T = a * Q / s = a * Sc \quad \text{.........................} \quad (4\text{-}2)$$

where:

T	=	Transmissibility (m^2/day)
Sc	=	Specific capacity (m^3/day/m)
s	=	Drawdown in the well (m)
Q	=	Yield of the well (m^3/day)
a	=	Dimensionless constant. Based on field experience, Logan (1964) suggested a = 1.22

Specific capacity is the most available aquifer characteristic because yield and drawdown records have been recorded in most boreholes, while borehole drillings accompanied by pumping tests are scant. Therefore, it is valuable to collect records of specific capacity as much as possible to evaluate the hydraulic characteristics of the aquifers.

A specific capacity map based on borehole records and constructed by SARDA is given in Fig. 4-3. From the figure, it is seen that specific capacity varies regionally. Frequency distributions of specific capacity in respective aquifers are given in Fig. 4-12. From these figures, it is seen that:

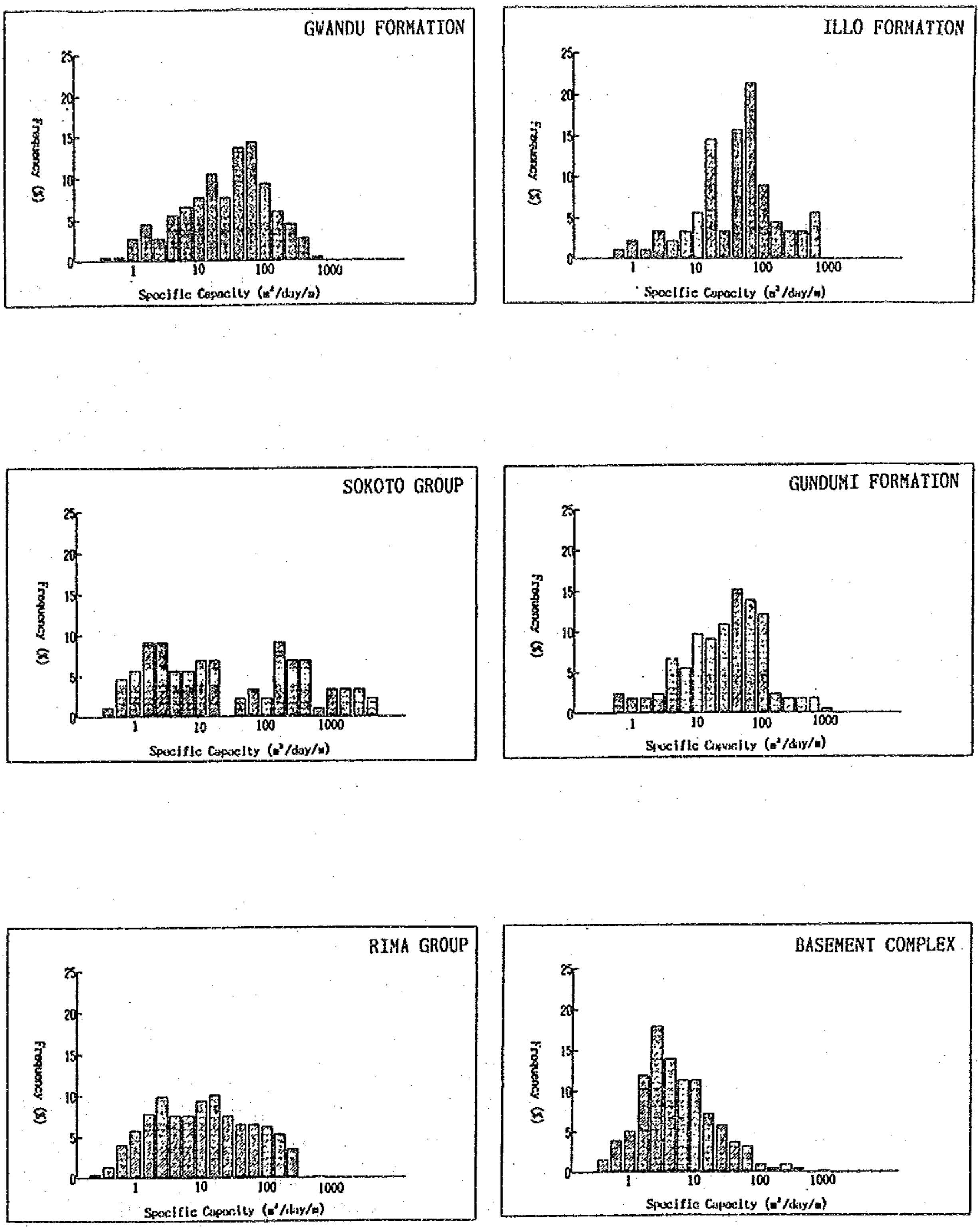


Fig. 4-12 Distribution of Specific Capacity

- the magnitude of specific capacity is generally related directly to the transmissibility; specific capacities computed in the basement complex area are generally low, whereas those computed in the Gwandu aquifer are high.

- the Gundumi aquifer and the Gwandu aquifer resemble each other in frequency distribution.

- the Sokoto Group aquifer has two peaks around the specific capacities of 2 m^3/day/m and 150 m^3/day/m. This may reflect the fact that the Kalambaina formation, which is the main aquifer of the Sokoto group, is composed of limestone. The hydraulic characteristics of a limestone aquifer vary regionally because they are dominated by un-uniformly formed fractures and caves in limestone.

- the Rima aquifers and the basement complex gave relatively flat configurations of distribution.

- frequency distribution for the Sokoto aquifer and Illo aquifer varies widely.

4-7 Groundwater Use

Three methods of abstracting groundwater are used in the study area:

- Dug-wells
- Boreholes equipped with a hand pump
- Boreholes equipped with a mechanized pump

4-7-1 Dug-wells

Dug-wells are abundant throughout the area. They have been the principal water source in rural areas. Even in semi-urban to urban areas, dug-wells are often used especially where a systematic water supply does not exist or does not work satisfactorily. However, dug-wells suffer from a number of problems. Since the depth of water in a dug-well is usually shallow and it taps an unconfined aquifer, whose water fluctuation is generally large, many dug-wells are likely to dry up during the dry season. Dug-wells also commonly collapse when they are not lined. When a dug-well is shallow and sanitary conditions around the well are poor, the water is likely to be polluted. Determining the number of dug-wells and their abstraction is practically impossible. However, in terms of groundwater development, abstraction from dug-wells is considered to be negligible in considering the potential of groundwater because the yield of a dug-well is generally too s mall to effect the water level in an unconfined aquifer.

4-7-2 Boreholes

(1) Boreholes equipped with a hand pump

A project aiming to provide hand pump-equipped boreholes in rural areas has been undertaken by SARDA It is reported that more than 1,500 boreholes have been completed in the area. The boreholes were usually drilled deep into confined aquifers. Abstraction from these boreholes in estimated 10-40 ℓ/min.

(2) Boreholes equipped with a mechanized pump

In terms of groundwater development, abstraction from boreholes equipped with a mechanized pump is most important because abstraction is much greater than with other methods of abstraction, sometimes causing a large drawdown of water levels. When some boreholes are constructed close to each other, interference between wells often occurs. A large number of boreholes of this type have been drilled in Sokoto City. Most of them are probably used for drinking water, for both public and private purposes. The depression of water levels in the Kalambaina aquifer is probably caused by the overpumping that have been expanding around Sokoto City. Groundwater balance, which is the difference between groundwater recharge and discharge, has been negative in the area.

4-7-3 State of groundwater abstraction

Information on boreholes equipped with a mechanized pump was studied by FDWR in 1982. During the study, most of the boreholes in Sokoto state ware visited and individual information on the boreholes were collected.

Based on the study, we determined state of groundwater abstraction by boreholes equipped with a mechanized pump, under assumption that the study covered all of the boreholes in Sokoto state.

(1) Number of boreholes

459 boreholes existed in 1981. Number of boreholes in each local government and history of borehole construction are shown in Tab. 4-11. It is evident from

TABLE 4 - 11 CHANGES IN NUMBER OF BOREHOLE CONSTRUCTION DURING 1970 TO 1981

LOCAL GOVERNMENT	UNKNOWN	BEFORE 1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	TOTAL
			YEARS WHEN A BOREHOLE WAS CONSTRUCTED											
DANGE	1	2	0	0	0	0	0	0	1	0	0	3	3	10
TALATA MAFARA	1	1	0	5	0	0	0	0	1	0	1	6	0	15
BODINGA	2	2	0	0	0	0	1	0	0	0	0	2	0	7
GWADABAWA	12	0	1	0	0	0	0	2	0	0	0	2	0	17
TAMBUWAL	10	0	0	1	0	0	0	0	0	0	0	1	3	15
JEGA	11	0	0	1	0	0	0	0	0	0	0	1	1	14
TANGAZA	19	5	0	0	2	0	0	0	0	0	0	4	3	33
KWARE	10	1	0	0	0	0	0	0	2	0	0	4	3	20
WURNO	13	0	0	0	0	0	0	0	0	0	0	4	0	17
AREWA	24	0	0	0	0	0	0	2	0	0	0	5	1	32
SABON BIRNI	33	0	0	0	0	0	0	0	0	0	0	2	1	36
SOKOTO	6	16	0	2	1	5	2	2	0	0	1	4	5	44
RABAH	0	8	0	0	0	0	0	0	0	0	0	4	4	16
SILAME	6	0	0	0	0	0	0	0	0	0	0	4	4	14
ZURU	0	0	0	1	0	0	0	0	0	0	0	6	1	8
YABO	2	1	0	0	0	0	0	0	0	0	0	3	4	10
ARGUNGU	5	2	1	0	0	0	0	0	0	0	0	2	5	15
BUNZA	12	0	0	0	0	0	0	0	0	0	0	2	0	14
GADA	16	0	0	0	0	0	0	0	0	0	1	1	0	18
SAKABA WASAGY	4	0	0	0	0	0	0	0	0	0	0	6	0	10
BIRNIN KEBBI	23	5	1	0	0	0	0	0	0	0	0	6	1	36
BAGUDO	1	0	0	0	0	0	0	0	0	0	0	3	0	4
ZURMI	1	0	0	0	0	0	0	0	0	0	0	4	2	7
GUMMI	5	0	0	0	0	0	0	0	0	0	0	2	1	8
GUSAU	0	0	0	4	0	1	0	3	2	2	0	2	5	19
MARDUN	3	0	0	0	0	0	0	0	0	0	0	1	1	5
ISA	1	0	0	0	0	0	0	0	0	0	0	2	4	7
KAURA NAMODO	0	0	0	0	0	0	0	0	0	0	0	1	1	2
TSAFE	0	0	0	0	0	0	0	0	0	0	0	2	0	2
KOKO	0	0	0	0	3	1	0	0	0	0	0	0	0	4
TOTAL NUMBER	221	43	3	14	6	7	3	9	6	2	3	89	53	459

the table that most of boreholes were constructed in 1980 and 1981. The most concentrated area in borehole number was Sokoto L. G. which had 36 boreholes respectively.

Among the 459 boreholes, 269 boreholes had been functioning and 190 boreholes had been abandoned as shown in Tab. 4-12 Among abandoned boreholes, 110 boreholes had been abandoned due to poor yield or being back-filled, the rest of 80 boreholes had been abandoned due to a faulty pump or generator.

(2) Groundwater abstraction

Records on the functioning boreholes averaged by each local government are shown in Tab. 4-13. Groundwater abstraction in each local government was estimated under assumptions as follows:

a. Capacity of a pump is same as an average test-yield in respective local government.

b. Average duration of pumping is eight hours a day.

According to the result, the total groundwater abstraction in Sokoto state in 1981 was estimated to be about 36,500m^3/day. Concentrated groundwater abstraction of 5,000m^3/day was estimated in Sokoto L. G. followed by Arewa L. G. of 4400m^3/day and Birnin-Kebbi L. G. of 3100m^3/day.

Records on the functioning boreholes averaged by each aquifer are shown in Tab. 4-14. As is evident from the table, average records on boreholes in the Kalambaina aquifer had highest yield with shallowest depth to water.

Groundwater abstraction from each aquifer was estimated by the same procedure applied above. The groundwater abstraction from the Gwandu aquifer wad estimated to be 12,600m^3/day, which is about one-third of the total abstraction in Sokoto state. Contrary to the good characteristics of the Kalambaina aquifer in pumping groundwater, the groundwater abstraction from the aquifer was estimated smaller than that from the Gundumi aquifer and the Rima aquifer. It is explained by the fact that the extent of the Kalambaina aquifer is limited only from Sokoto city to the north of the city in contrast to wide extents of the Gundumi and the Rima aquifer.

TABLE 4 - 12 NUMBER OF ABONDONED AND FUNCTIONING BOREHOLES

LOCAL GOVERNMENT	ABONDONED BOREHOLES			FUNCTIONING BOREHOLES	TOTAL
	A	B	TOTAL		
DANGE	5	1	6	4	10
TALATA MAFARA	3	2	5	10	15
BODINGA	4	0	4	3	7
GWADABAWA	8	1	9	8	17
TAMBUWAL	7	3	10	5	15
JEGA	1	8	9	5	14
TANGAZA	10	12	22	11	33
KWARE	7	1	8	12	20
WURNO	5	4	9	8	17
AREWA	3	3	6	26	32
SABON BIRNI	7	13	20	16	36
SOKOTO	15	2	17	27	44
RABAH	2	2	4	12	16
SILAME	1	5	6	8	14
ZURU	0	3	3	5	8
YABO	0	0	0	10	10
ARGUNGU	1	2	3	12	15
BUNZA	2	4	6	8	14
GADA	4	0	4	14	18
SAKABA WASAGY	2	3	5	5	10
BIRNIN KEBBI	7	5	12	24	36
BAGUDO	0	1	1	3	4
ZURMI	1	0	1	6	7
GUMMI	1	4	5	3	8
GUSAU	8	1	9	10	19
MARDUN	2	0	2	3	5
ISA	0	0	0	7	7
KAURA NAMODO	0	0	0	2	2
TSAFE	0	0	0	2	2
KOKO	4	0	4	0	4
TOTAL NUMBER	110	80	190	269	459

A:ABONDONED DUE TO POOR YIELD OR BOREHOLE BACK FILLED
B:ABONDONED DUE TO FAULTY PUMP OR GENERATOR

TABLE 4 - 13 AVERAGE RECORDS ON FUNCTIONING BOREHOLES
- BY LOCAL GOVERNMENT -

LOCAL GOVERNMENT	DRILLED (m)	DEPTH TO WATER (m)	TEST YIELD (l/sec.)	BOREHOLE NUMBER	ESTIMATED ABSTRACTION (m3/day)
DANGE	153.	50.6	3.26	4	376.
TALATA MAFARA	63.	25.7	2.81	10	810.
BODINGA	114.	35.8	4.04	3	349.
GWADABAWA	155.	39.8	3.19	8	734.
TAMBUWAL	148.	52.7	5.84	5	841.
JEGA	105.	48.4	4.39	5	632.
TANGAZA	168.	10.2	7.97	11	2526.
KWARE	166.	41.1	4.09	12	1412.
WURNO	179.	30.6	4.79	8	1103.
AREWA	179.	38.7	5.91	26	4423.
SABON BIRNI	120.	53.5	4.52	16	2081.
SOKOTO	73.	25.3	6.54	27	5086.
RABAH	210.	51.0	3.86	12	1333.
SILAME	111.	16.2	5.97	8	1376.
ZURU	57.	8.2	1.78	5	256.
YABO	119.	20.4	9.16	10	2637.
ARGUNGU	114.	25.7	5.22	12	1803.
BUNZA	95.	34.4	3.61	8	832.
GADA	119.	71.3	1.89	14	763.
SAKABA WASAGY	60.	18.0	3.40	5	490.
BIRNIN KEBBI	104.	24.1	4.43	24	3065.
BAGUDO	137.	15.0	9.00	3	778.
ZURMI	37.	2.7	2.08	6	359.
GUMMI	127.	56.7	1.87	3	161.
GUSAU	35.	3.5	4.94	10	1423.
MARDUN	99.	17.5	3.10	3	268.
ISA	131.	40.2	3.53	7	712.
KAURA NAMODO	36.	7.8	1.55	2	89.
TSAFE	52.	10.3	2.25	2	130.
KOKO	0.	0.0	0.00	0	0.
AVERAGE / TOTAL	118.	29.6	4.84	269	37511.

NOTE : ESTIMATED ABSTRACTION (Q) WAS OBTAINED AS
Q = TEST-YIELD * 3.6 * 8 (hours) * BOREHOLE-NUMBER

TABLE 4 - 14 AVERAGE RECORDS ON FUNCTIONING BOREHOLES - BY AQUIFER -

AQUIFER	DRILLED (m)	DEPTH TO WATER (m)	TEST YIELD (l/sec.)	BOREHOLE NUMBER	ESTIMATED ABSTRACTION (m3/day)
BASEMENT COMPLEX	57.	13.3	3.06	38	3350.
GUNDUMI FORMATION	156.	45.2	3.65	60	6310.
ILLO FORMATION	107.	26.3	5.66	12	1956.
RIMA GROUP	137.	39.5	4.84	62	8636.
KALAMBAINA FORMATIO	36.	14.3	8.22	18	4261.
GWANDU FORMATION	133.	25.4	5.55	79	12626.
AVERAGE/TOTAL	118.	29.6	4.84	269	37511.

NOTE : ESTIMATED ABSTRACTION (Q) WAS OBTAINED AS
Q = TEST-YIELD * 3.6 * 8 (hours) * BOREHOLE-NUMBER

4-8 Groundwater Flow

The eight main regional aquifer systems in the study area correspond with the following formations :

1) Basement Complex		Precretaceous
2) Gundumi Formation		
3) Illo Formation		Cretaceous
4) Taloka Formation	(Rima Group)	
5) Wurno Formation	(Rima Group)	
6) Kalambania Formation	(Sokoto Group)	
7) Gwandu Formation		Tertiary
8) Alluvium		Quaternary

4-8-1 Basement complex

The characteristics of the aquifers in the basement complex area are predominantly controlled by the nature of the rocks composing the area. Since the controlling factors, which are the degree of weathering and density of fractures or joints in the rocks, are strongly ununiform both laterally and vertically, aquifers formed in the area are generally local. In many cases, the extension of an aquifer is small and aquifers are isolated from each other. Consequently, it is practically impossible to determine the general movement of groundwater in the aquifers.
As results from chemical quality tests and tritium concentration tests indicate, the resident time of the water in the aquifers is generally short compared with the water in the aquifers in the sedimentary area.

4-8-2 The Gundumi and Illo Formations

The two formations may link together at the outcrop area of the Illo formation. Hence, the groundwater between the two is probably continuous.

(1) Groundwater flow pattern

Figure 4-13 (1) is a map of the water table configuration in the Gundumi-Illo Formations observed in June, 1988. Since the observed boreholes in the Gundumi formation were limited to the northeastern parts of the sedimentary area, and boreholes in the Illo formation are found only in the southern part of the area, it is hard to determine the water level in the Gundumi aquifers in the western and northwestern parts of the area. Records of static water levels of the existing boreholes tapping the Gundumi aquifer and drilled in the vacant area were collected and interpolated to complete the water table map.

The groundwater flows from the northeastern end of the sedimentary area in Sokoto State. Initially, the water flows westward, then it changes direction of flow gradually towards the southwest in the south of Sokoto City. The water probably flows into the Illo formation aquifers, and its level is continuous. The water apparently discharges into the River Niger. A steep water level gradient of 0.8m/km is observed along the discharging area, compared to an average water level gradient of 0.4m/km to 0.5m/km.

(2) Change in water level

Weekly water level observations were carried out at the Kunawa borehole. Figure 4-14 (1) shows water level fluctuation in the borehole from July, 1988 to September, 1989. The lowest water level was recorded in July 1988, when the observation commenced.

The water level rose gently from that time until February, 1989, after which there was a gentle decline to June 1989. The water level rose again after that time. Although there is about half a year of time lag between the peak of the rainy season and the peak of the water level, this cyclic fluctuation of the water level possibly corresponds to the climatic cycle of the area, because the predominant factor controlling the movement of groundwater in the aquifers is apparently the recharge from precipitation. A noticeable movement of the water level is that, although it indicates seasonal fluctuation, it shows long-term tendency to increase its level. This movement is commonly observed in the water level in every weekly-observation borehole (Figure 4-14(1) through (6)). Since no possible cause except that of groundwater recharge by rain is presumed to exist for the rise in water level, the steady rising of the water level is attributed to the record-breaking amount of rain the area received in the rainy season in 1988 which extended from July to September. In terms of water balance, the movement clearly represents the fact that the recharge to groundwater body surpasses groundwater discharge.

Figures 4-15(1), (2) show the variations of water levels in boreholes tapping the Gundumi aquifers and the Illo aquifers. The levels were measured during simultaneous observations. In all boreholes except the Isa dug-well, water levels measured in January, 1989 were the highest among the four observations, June, 1988, July, 1988, January, 1989, and May, 1989. In all boreholes, water levels observed in July, 1988 were the lowest. This variation of water level is common to the other three aquifers : the Rima aquifer, Sokoto aquifer, and the Gwandu aquifer (Figures 4-15(3) through (5)).

(3) Recharge and Discharge

The main recharging areas for the aquifers are the outcrop areas of the two formations (Figure 4-13). The bulk of the rain in the areas receives is believed to be lost to evapotranspiration and surface runoff. The remainder infiltrates into the ground to recharge the groundwater body. The outcrop areas of the Gundumi formation and the Illo formation are 20,800 sq. km and 8,400 sq. km, respectively.

Groundwater in the Gundumi aquifer predominantly discharges into the Illo formation as is evident from the figure. Groundwater in the Illo formation is believed to discharge into the River Niger. Artificial discharge, which is a borehole abstraction from the aquifers, is presumed to be small, because few major cities are located on the outcrop areas of the formations. Figure 4-16 schematically illustrates the groundwater flow system in the sedimentary area.

4-8-3 The Rima Group

The Rima Group aquifers consist of the aquifers of the Taloka and Wurno formations. They are divided by the shaley Dukamaje formation in the north of Sokoto City, thus they should be treated as individual hydrological units in that area. However, as the Dukamaje formation thins out, they become a hydrogeologically single unit in the south of Sokoto City.

Since little borehole data has been collected on the Wurno aquifers, comments made regarding the Rima group aquifers in this report refer only to the Taloka formation.

(1) Groundwater flow pattern

Figure 4-13(2) shows a map of the water table configuration in the Taloka aquifers in the Rima group. Water initially flows from the northeastern recharge area westwards. It turns southwest in the area west of Sokoto City and flows down into the outcrop area of the Illo formation. The water level is then probably continuous with that of the Illo and Gundumi aquifers in that area. The water then probably discharges into the River Niger.

The movement of the Rima group groundwater is basically similar to that of the Gundumi formation groundwater. However, some distinctive features have been found in the configuration of the Rima group aquifers. According to the map of the water table configuration, a groundwater mound has been formed northeast of Sokoto City. Since the location of the groundwater mound is coincident with the location of Goronyo Dam, and geologically, the area is an outcrop area of the Rima group, the mound is possibly caused by seepage from the reservoir of the Goronyo Dam. A gentle groundwater depression has probably been formed around Sokoto City. It probably reflects heavy and concentrated abstraction of the groundwater in the city. The gradients of the water table in the Rima aquifers vary widely. A-steep gradients are found from east of Illela to Sokoto City and from Gummi to Birnin Kebbi, whereas the gradient in the northwest area is gentle. Regional differences in aquifer characteristics and configuration may cause the variation in the water table gradients.

(2) Changes in water level

Weekly water level observations have been carried out in the boreholes at Rabah and Yauri-Road-BH3, and in the dug wells at Rijiyar-Hido and Dan-Tasako. An automatic water level recorder was installed in the borehole at Yauri-Road-BH3, and recording commenced in February, 1989. Figures 4-14(2) through (5) show water level fluctuations in the boreholes and dug wells, based on the weekly observation, from July, 1988 to September, 1989. Figure 4-17(1) shows the water level fluctuation in the Yauri-Road-BH3 borehole recorded by the automatic water level recorder.

Water level fluctuations vary with the location. However, these fluctuations, except that of Rijiyar-Hido dugwell, are basically similar to that recorded in the Kunawa borehole in the Gundumi aquifers. The water level fluctuation in the dug-well at Rijiyar-Hido appeared as distinctly different from that of the other three wells. The water level reached a peak just after the rainy season. There was no time lag between the peak in the water level and the rainy season, which is usually about half a year at other points. After that, the water level declined until the beginning of the next rainy season. With the beginning of the next rainy season, it rose again and reached its peak in August. This movement is considered to be typical of shallow wells. Unconfined shallow aquifers, which shallow wells tap, are directly recharged from precipitation during the rainy season. Since the land surface and water table are close to each other and the transit time of water to the groundwater body is short, response of the groundwater level to rain infiltration is generally quick compared to that of confined aquifers.

Throughout the following dry season, the water level declines until the beginning of the next rainy season. Despite the fact that the water level at Dan-Tasako was measured in a dug-well, it did not show the typical movement of a shallow well possibly because the well may tap a confined aquifer below a shallow unconfined aquifer.

(3) Recharge and Discharge

The mechanism of recharge and discharge of the aquifers resembles that of the Gundumi aquifers. The main recharging area for the aquifers is the outcrop area of the Rima group which is the strip from Goronyo to the east of Jega (Fig. 4-13). It covers an area of about 13,600 sq. km. The configuration map of the water table in the aquifers indicates the possibility of recharge from the Goronyo Dam reservoir. Further investigation is necessary to verify this. Groundwater in the Rima aquifers predominantly discharges into the Illo Formation in the same manner as in the Gundumi aquifers (Figure 4-16).

The groundwater in the Rima aquifers is considered to be utilized mainly on and near the outcrop area. The abstraction from the aquifers in Sokoto City, where the Kalambaina aquifer overlies, is presumably increasing, because of the exhaustion of water in the Kalambaina aquifer. Locally observed water table depression around Sokoto City is possibly associated with the increasing abstraction.

4-8-4 The Sokoto group

The Sokoto group aquifer refers the aquifer in the Kalambaina Formation. The aquifer is constituted by weathered and fractured limestone in the formation. Since fractures in the limestone where the upper Gwandu formation overlies are generally poor, the permeability of this limestone is low. Consequently, only the limestone in the outcrop area seems to form the aquifer. Boreheles tapping the Kalambaina aquifer are limited to along the Sokoto-Illela Road and within Sokoto City.

(1) Groundwater flow pattern

Since the water levels of only four boreholes tapping the Kalambaina aquifer were measured during the Study, the map of the configuration of the water table shown in Figure 4-13(3) could not be drawn in detail. However, it would be possible to say, from the result of the simultaneous observation, that the water flows from the east of Sokoto City towards the west. This direction of the groundwater flow in the Kalambaina aquifer conforms nearly to the dip of the Kalambaina formation and to the initial directions of groundwater flow in the Gundumi aquifers and in the Rima aquifers.

(2) Changes in water level

Weekly water level observation was carried out at Yauri-Road-BH1. An automatic water level recorder was installed at the same borehole, and recording commenced in February, 1989. Water level fluctuations recorded by weekly observation and the automatic recorder are shown in Figures 4-14(6) and 4-17(3) respectively.

Seasonal fluctuation and long-term increase of groundwater level in the aquifer is basically similar to those in other aquifer systems. However, the water level fluctuation in the aquifer is characterized by its wide range of variation. The difference between the highest level and lowest level of the groundwater in the borehole was nearly two meters in contrast to water level fluctuations in other weekly-observation boreholes which were less than one meter. The other characteristic of the water level fluctuation is its short-term variations. The variations are possibly attributed to the artificial discharge of water by pumping.

(3) Recharge and Discharge

The aquifer is recharged from precipitation in the same manner as other aquifer systems. The recharge area of the aquifer is its outcrop area, which extends between Illela to Dange.

Most perennial lakes located along the strip between Illela and Boinga, such as Lakes Kalmalo, Kainuwa, and Bodinga, are fed by effluence from the aquifer. The effluence appears to occupy the majority of the discharge from the aquifer. According to the discharge measurement carried out at Lake Kainuwa during the Study, the dry season discharge of the lake, which is almost equivalent to the effluence from the aquifer to the lake, is more than $0.1 m^3/sec$. ($8640 m^3/day$). This indicate that the effluence to the lake is larger than the daily groundwater abstraction in Sokoto L.G. in 1981, which was estimated to be $5,100 m^3/day$ pumped by use of 27 boreholes.

In spite of inferiority in terms of the discharge component of the aquifer, the present state of groundwater abstraction from the aquifer is remarkably noticeable in terms of groundwater conservation. Because of its ability to yield a large quantity of water, and because of the relatively shallow depth to the water bearing bed compared with the deeper Rima formation, the aquifer has been an important source of water for Sokoto City. With the urban development of the area and the increase in demand for water, many boreholes have been drilled by both public and private users. However, since no restrictions or regulations have been issued regarding the conservation of groundwater resources, little data exists with which to evaluate the situation of groundwater resources in the Kalambaina aquifer. Water levels in several boreholes were measured monthly in 1984 by FDWR. Some of these boreholes were also used for simultaneous water level observation in this study. Therefore, the change in water level between January, 1984 and January, 1989 can possibly be obtained by comparing the water levels measured in those two periods. Figure 4-18 shows a comparison of water levels below ground level during the two periods. Most water levels observed in 1989 were approximately the same as or higher than those measured in 1984. Only three boreholes recorded lower water levels than in 1984.

They were :

Sokoto, in the Kalambaina aquifer	: 5.72m decline
Wurno, in the Rima aquifers	: 2.72m decline
Gada, in the Rima aquifers	: 2.24m decline

If these results are reliable, it appears that the water level in the Kalambaina aquifer has been declining for at least these five years.

High-density weekly water level observations and continuous observations by automatic water level recorders should be carried out in Sokoto City to strengthen the monitoring system of the water level in the area.

4-8-5 The Gwandu formation

Detailed studies have been done on the hydrogeology in the Gwandu formation because the formation forms prolific aquifers.
The formation contains four main sand zones. According to Oteze (1971), the sand zones in the formation were designated as Upper Zone 1, Upper Zone 2, Middle Zone, and Lower Zone, respectively. Upper Zone 1 forms an unconfined aquifer. The other three zones form confined aquifers except in the outcrop areas.

(1) Groundwater flow pattern

Figure 4-13(4) shows a map of the water table configuration in the Gwandu confined aquifer. The highest water levels are in the northeastern parts of the outcrop areas of the Gwandu formation. The water levels are about 250m. The water flows from the northeast to the southwest as a regional flow. The flow of the water is similar to that of the Gundumi and Rima aquifers. The similarity would be accounted for by their common drainage system, namely in that the water flows into the Illo formation aquifer and then is discharged into the River Niger.

(2) Changes in water level

Since there is a lack of continuous observation in the borehole in the aquifers, it is hard to discuss in detail the fluctuation of water level in the aquifers. However, since the variations of water levels in boreholes tapping the aquifer, based on the results of simultaneous water level observations, are similar to those in the Gundumi aquifers and the Rima aquifers, it would be possible to say that the fluctuation of the aquifers is basically similar to that of the Gundumi aquifers and the Rima aquifers (See Figure 4-15).

(3) Recharge and Discharge

The unconfined aquifer in the Gwandu formation, which is the Upper Zone 1, is exposed to recharge over almost all of its surface area. The other aquifers in the formation, which are all confined aquifers, are recharged from precipitation in their outcrop areas. Leakage of groundwater may take place between aquifers in the formation where a clayey layer which isolates an aquifer to the others thins out.

The majority of the groundwater apparently is discharged into the Illo aquifers in the same manner as the groundwater in the Gundumi aquifers and the Rima aquifers. However, as river discharge records indicate, some water in the unconfined aquifer is also discharged into the River Rima, the River Zamfara and small rivers along the course of their flow to the southwest of the state. The discharge maintains the perennial flow of the rivers.

Groundwater in the aquifers is widely utilized for both domestic and urban water supply. Most of boreholes tap probably the Middle or the Lower aquifer, because the yield from the Upper aquifer, which is unconfined, is generally small.

4-8-6 Alluvium

Alluvium has been deposited in the main rivers to form a so-called "fadama".

An alluvium deposit plays an important role in determining the discharge of a stream. As is discussed in section 3-4, the Rima River loses some water to the alluvium deposits, which compose the riverbed, in the course of downflow between Sabon-Birni and Wamako. In the dry season, the perennial flow of the Rima River and its tributaries are supported partly by effluence from the alluvium deposits.

Where an alluvium deposit consists of coarse sand and gravel, it forms prolific aquifer. Successful shallow boreholes have been drilled into the alluvium at Sokoto, Maru, Koko, etc.

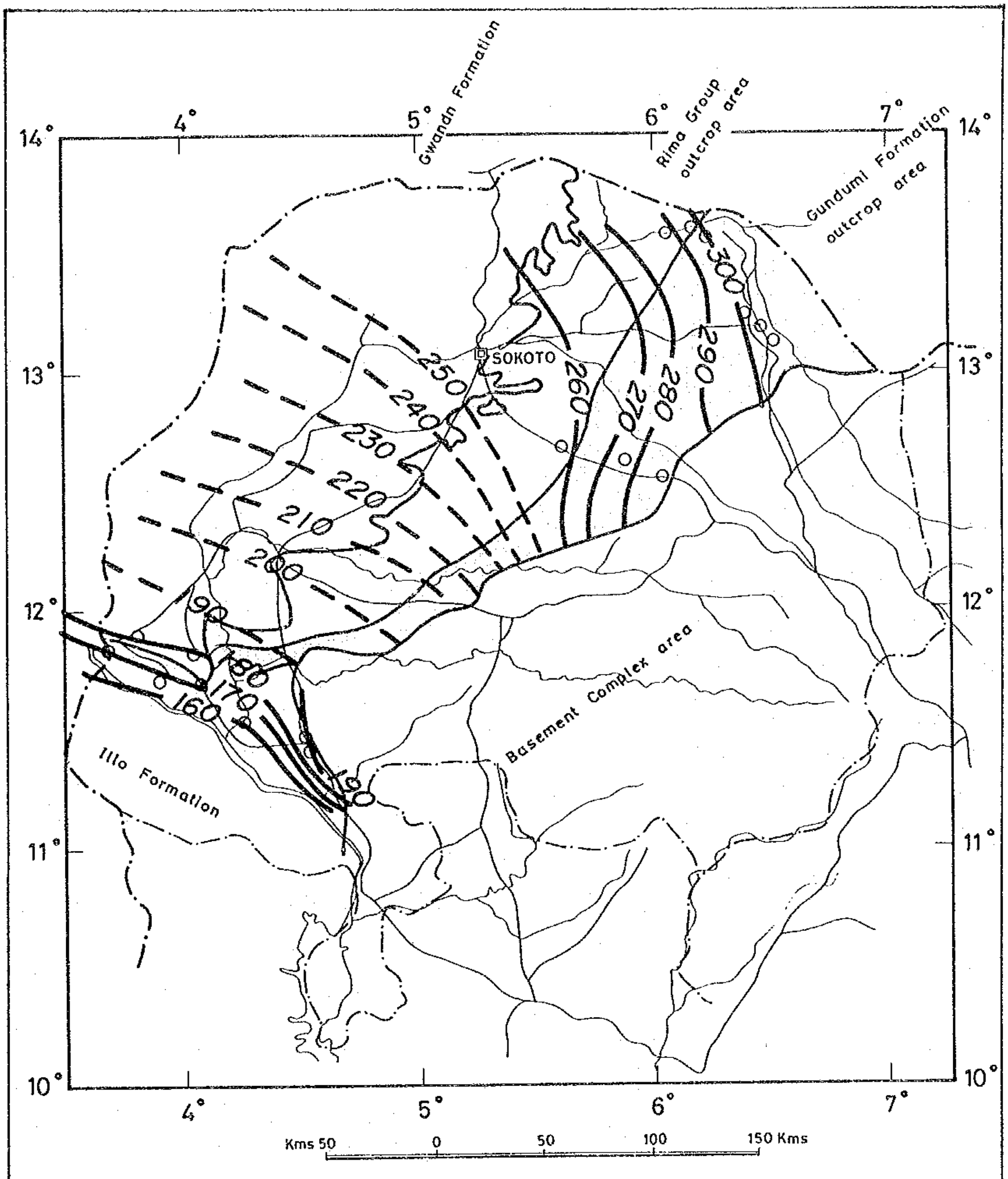


Fig.4-13(1) Map of the Water Table Configuration
- Gundumi Formation - observed 31/5/88 to 15/7/88

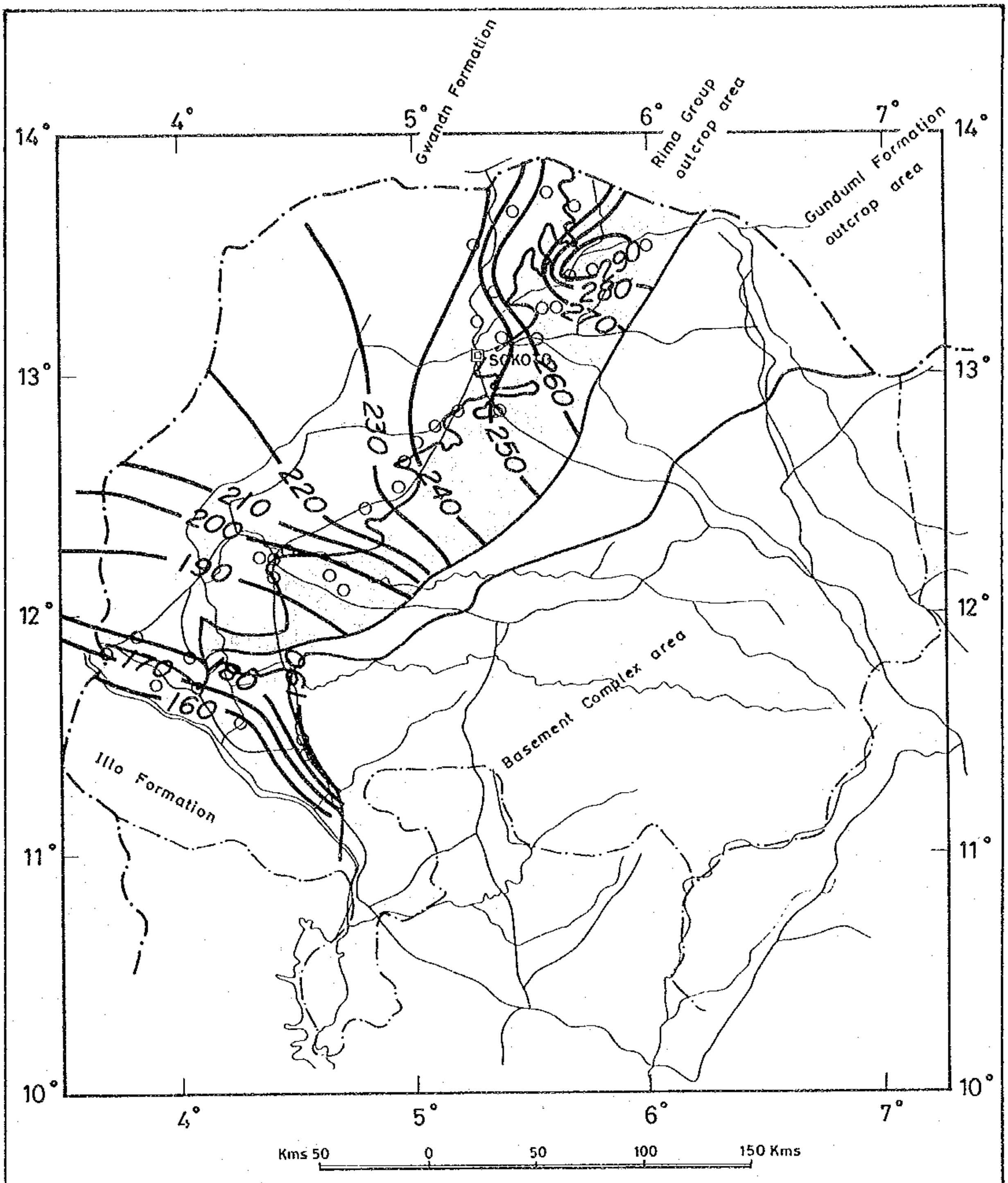


Fig.4-13(2) Map of the Water Table Configuration
- Rima Group - observed 31/5/88 to 15/7/88

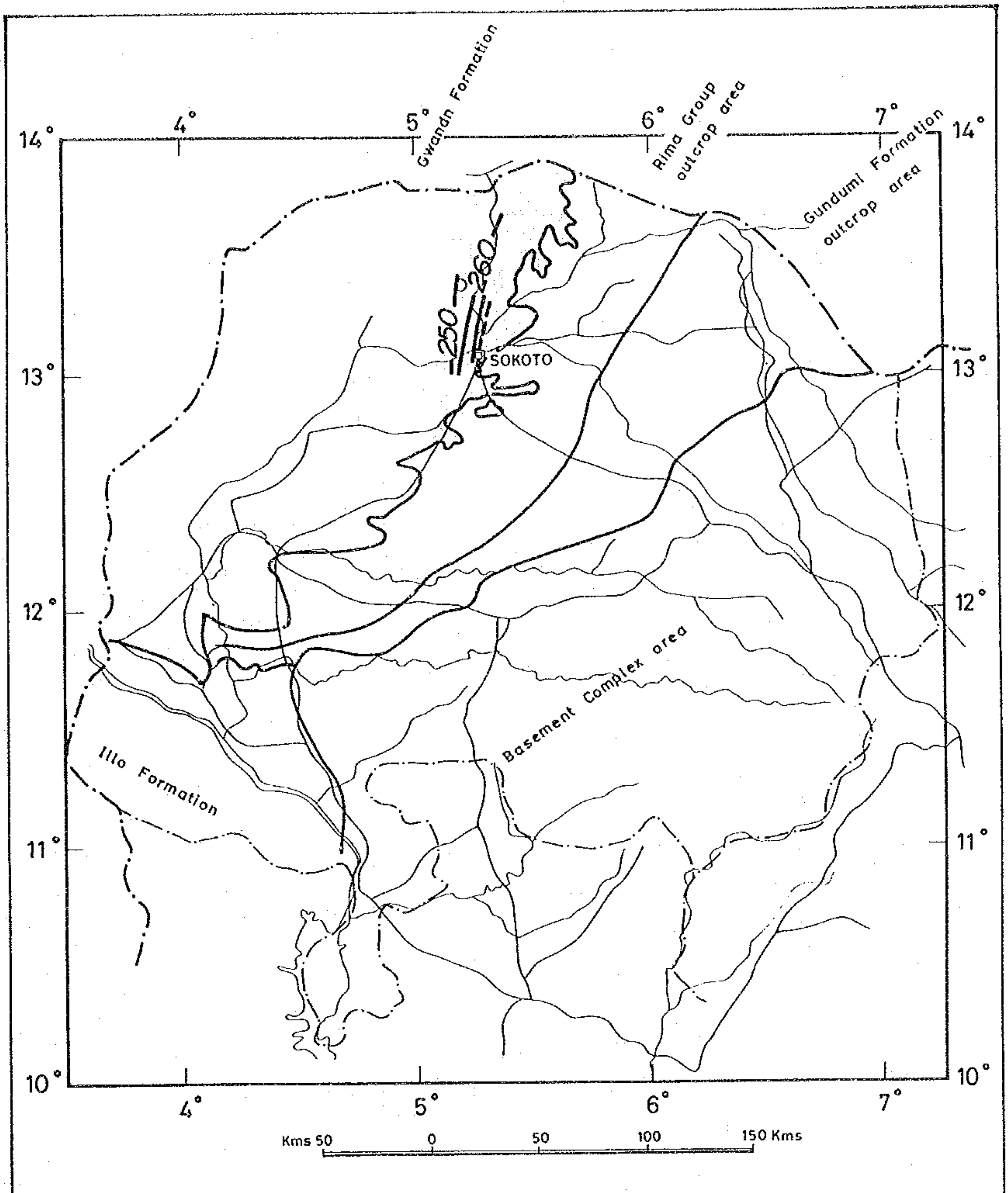


Fig.4-13(3) Map of the Water Table Configuration
- Kalambaina Formation - observed 31/5/88 to 15/7/88

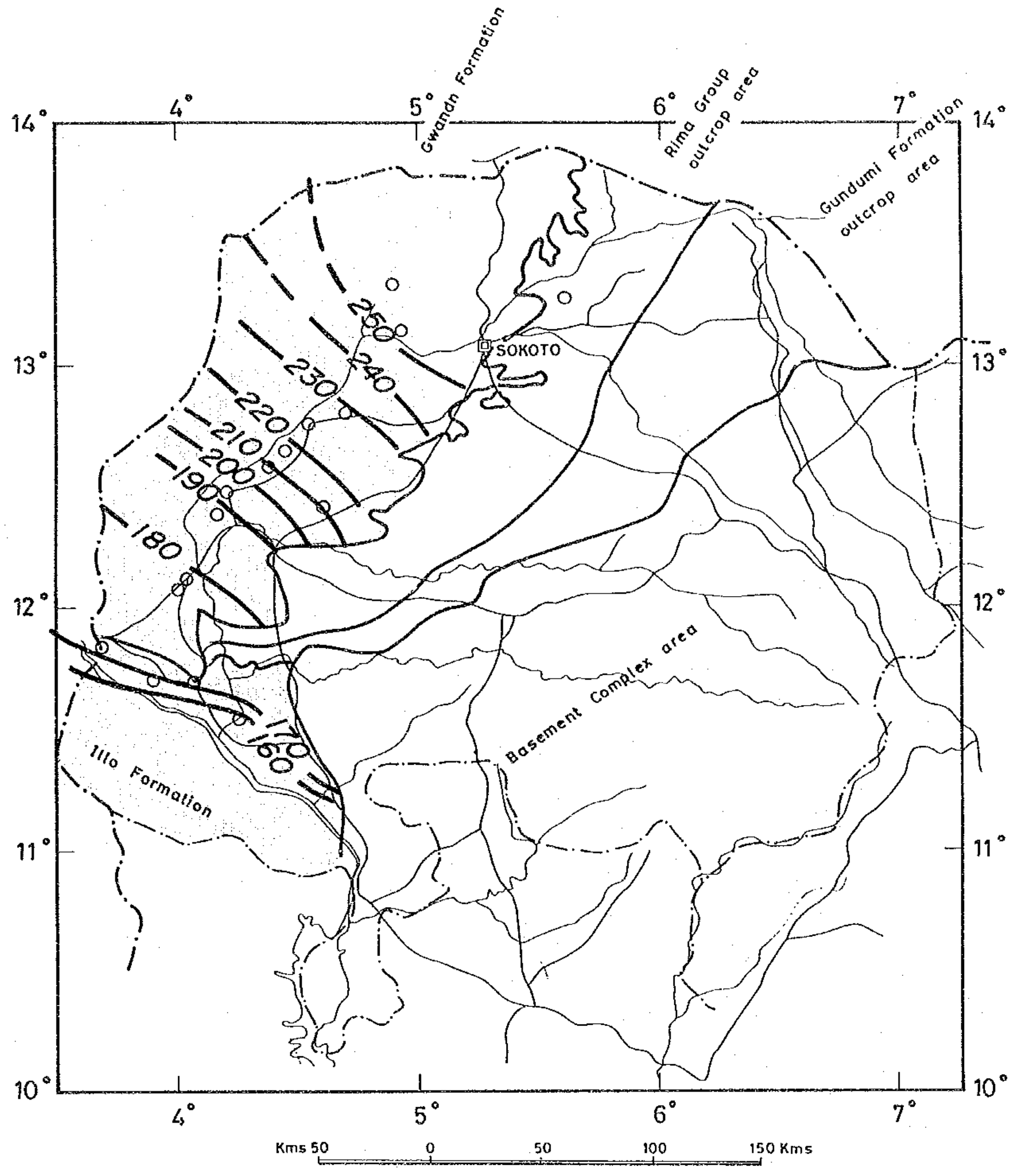


Fig.4-13(4) Map of the Water Table Configuration
- Gwandu Formation - observed 31/5/88 to 15/7/88

Fig. 4-14 (1) Result of Weekly Water Level Observation
- Kunawa borehole in the Gundumi Formation -

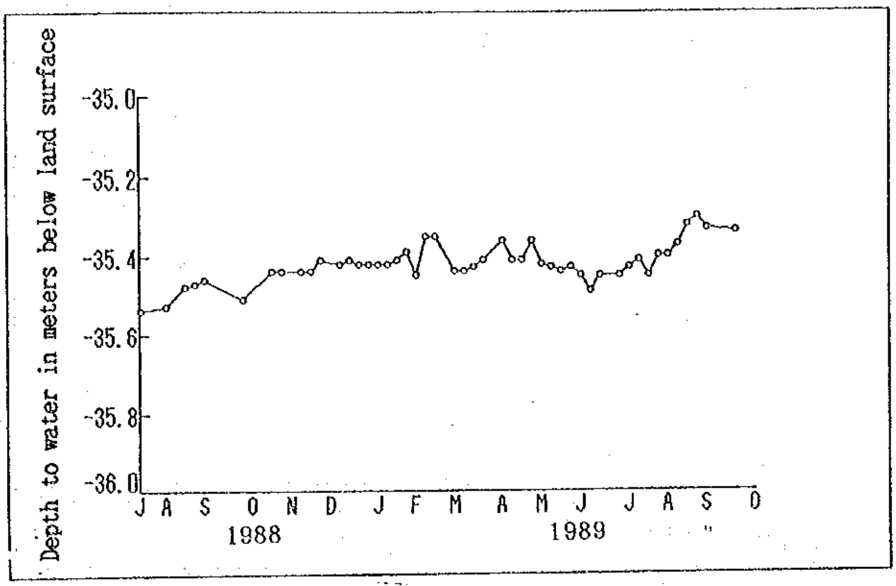


Fig. 4-14 (2) Result of Weekly Water Level Observation
- Rabah borehole in the Rima Group -

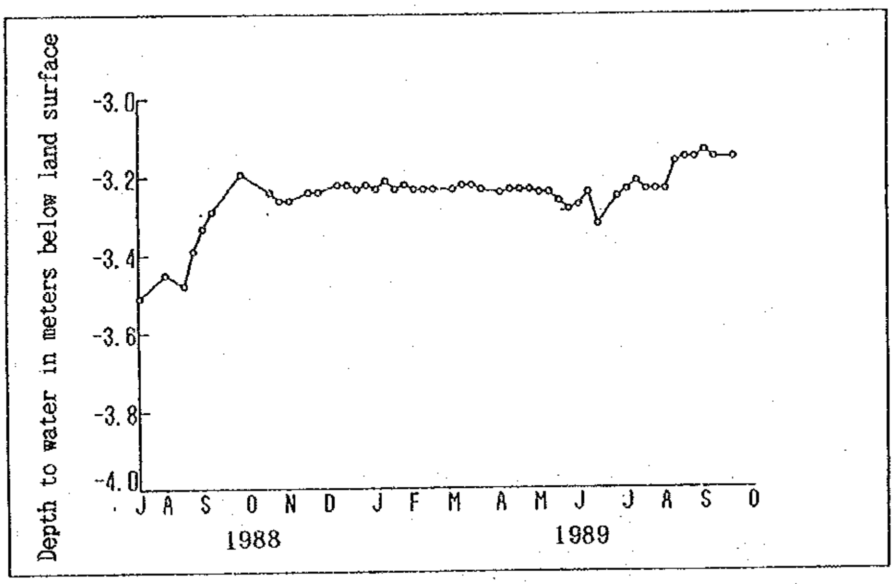


Fig. 4-14 (3) Result of Weekly Water Level Observation
- Yauri Road No.3 borehole in the Rima Group -

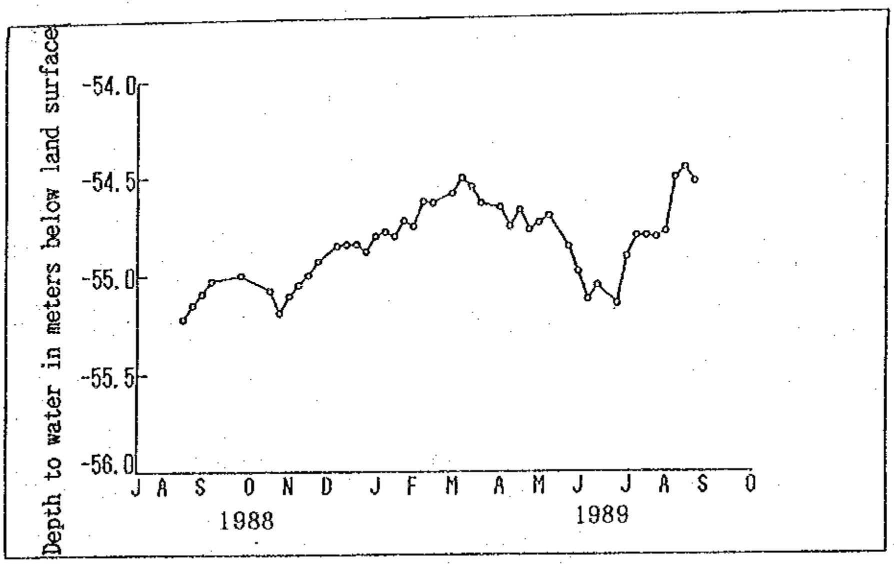


Fig. 4-14 (4) Result of Weekly Water Level Observation
- Rijiyar-Hido dug-well in the Rima Group -

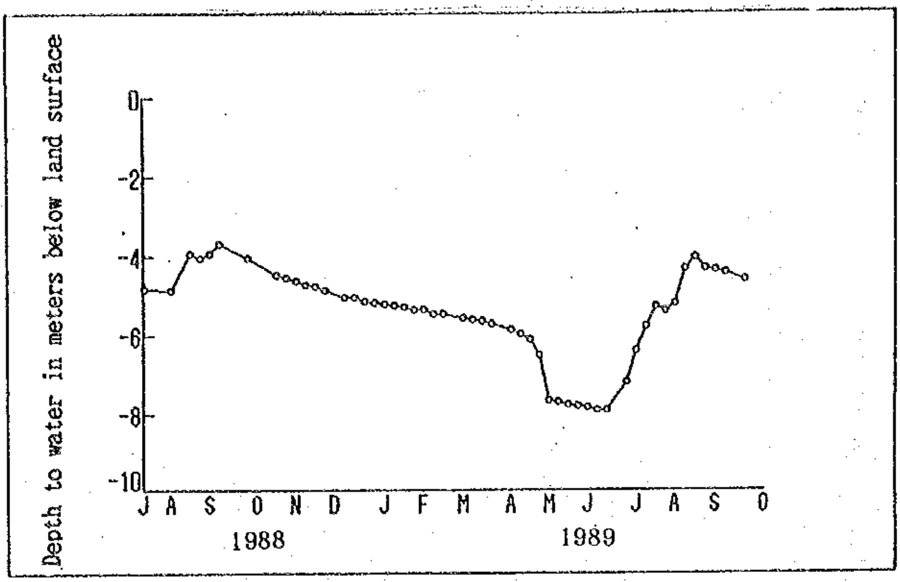


Fig. 4-14 (5) Result of Weekly Water Level Observation
- Dan-Tasako dug-well in the Rima Group -

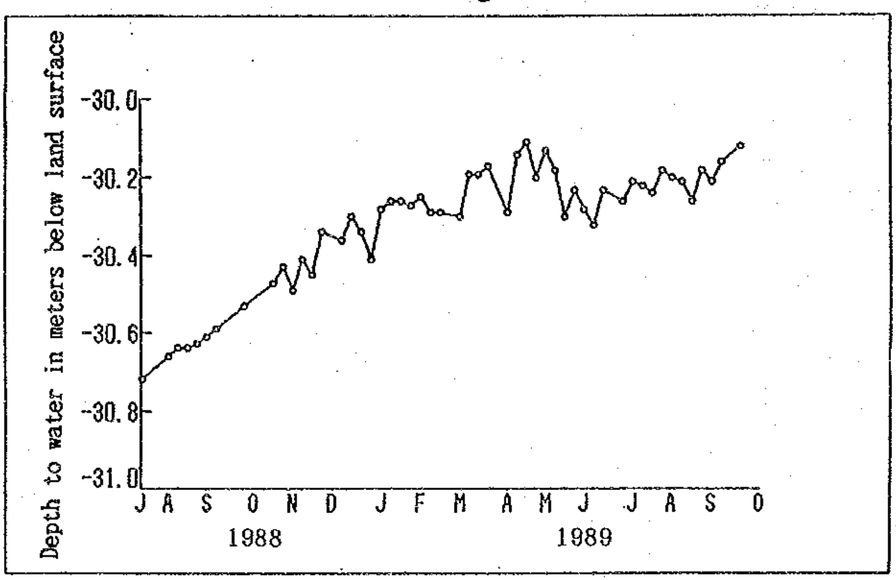
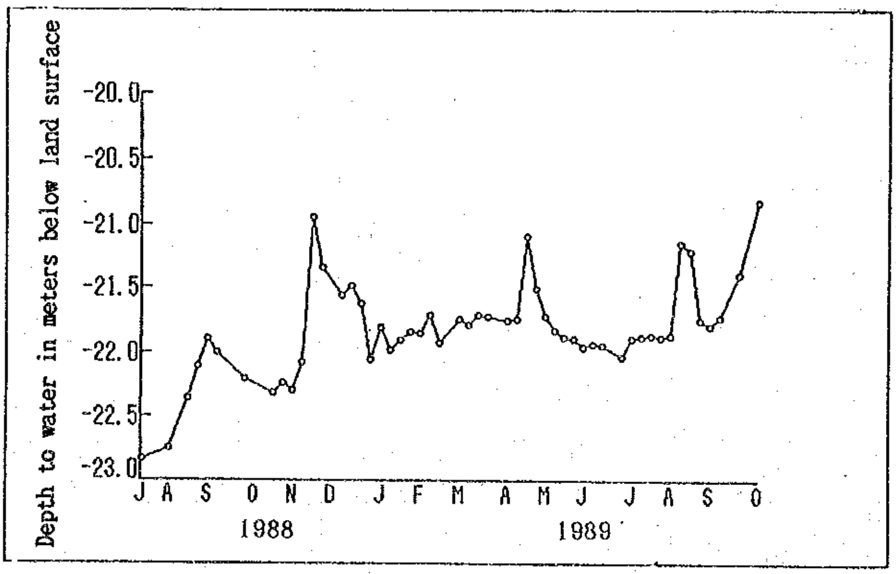


Fig. 4-14 (6) Result of Weekly Water Level Observation
- Yauri Road No.1 borehole in the Kalambaina Formation -



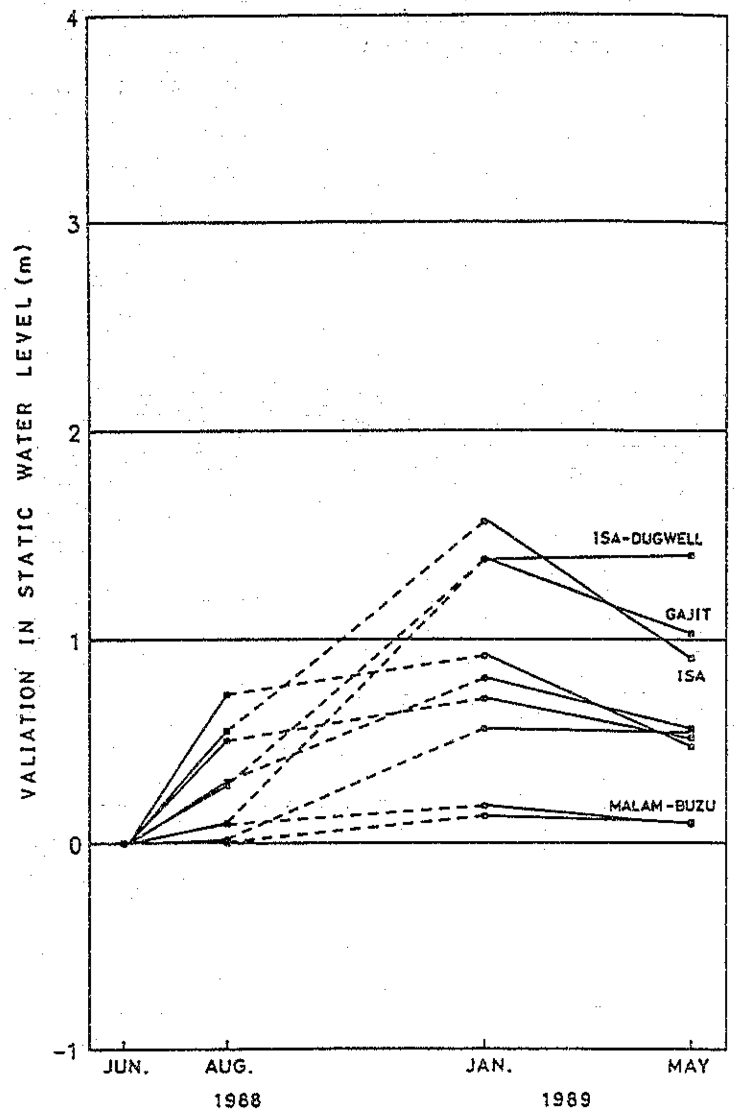


Fig. 4-15 (1)
Variation in Static Water Levels in Boreholes in the Gundumi Formation

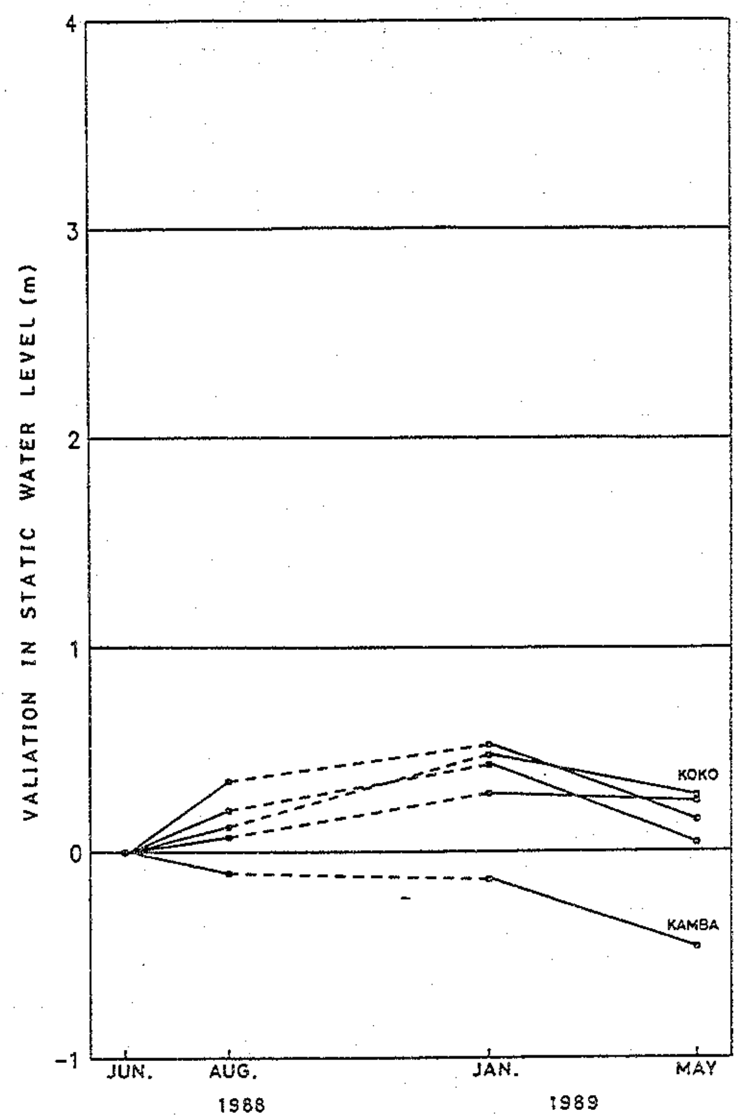


Fig. 4-15 (2)
Variation in Static Water Levels in Boreholes in the Illo Formation

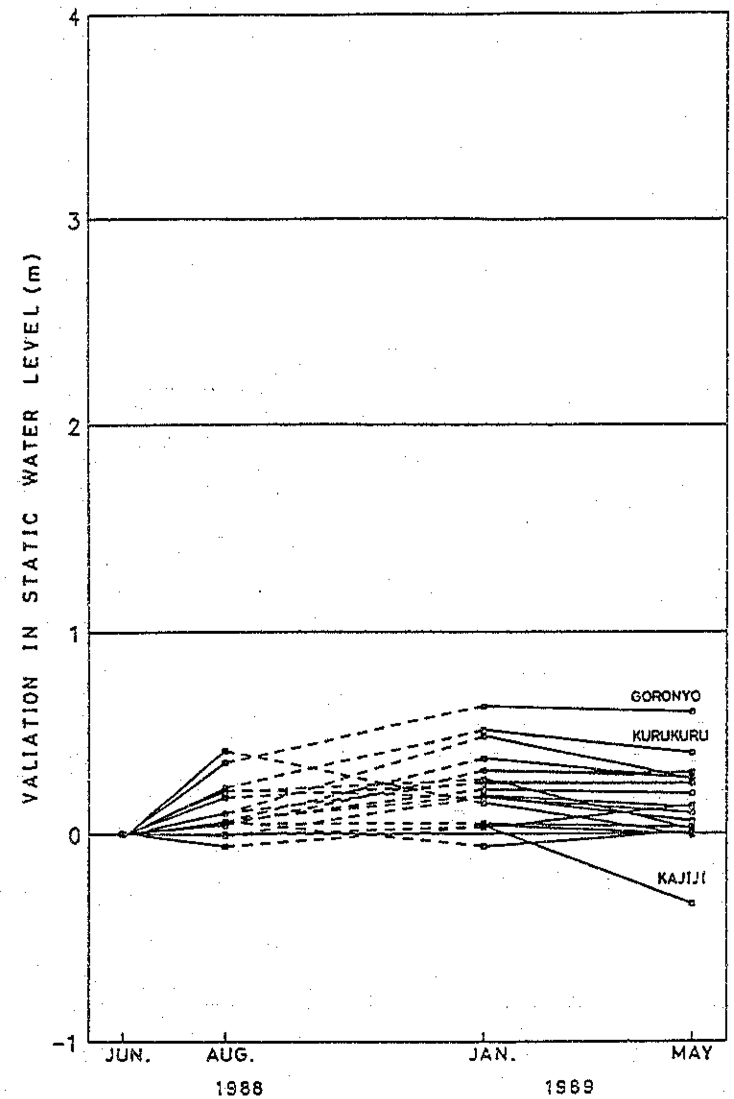


Fig. 4-15 (3)
Variation in Static Water Levels in Boreholes in the Rima Group

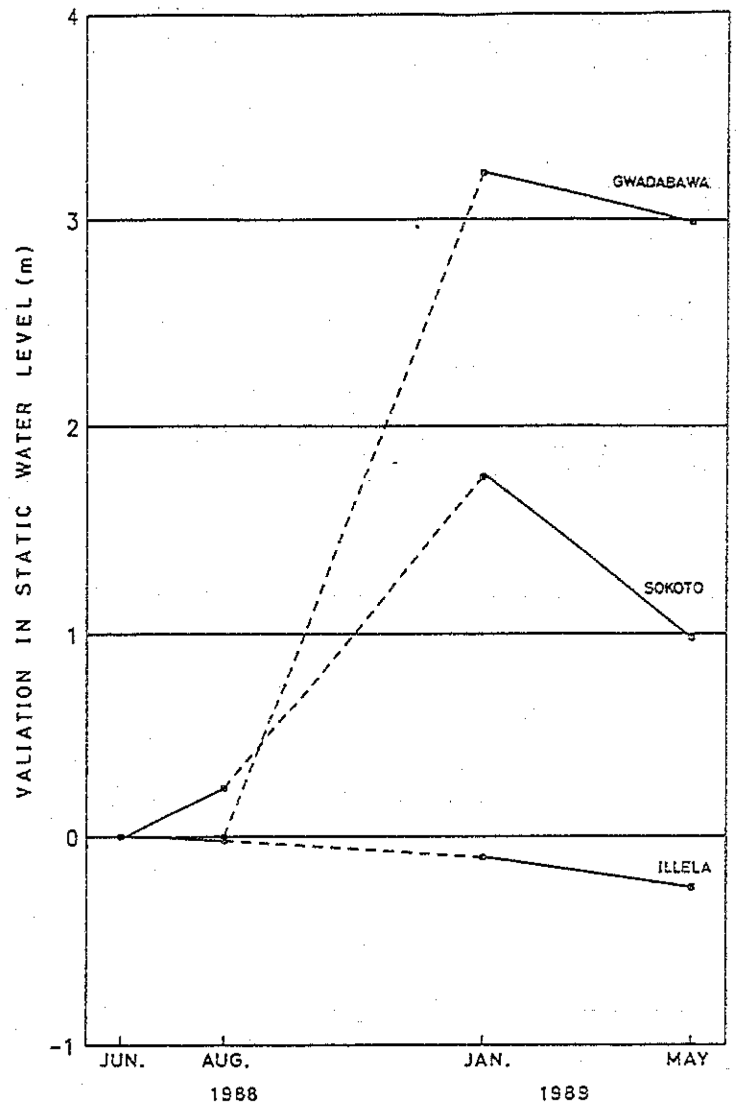


Fig. 4-15 (4)
Variation in Static Water Levels in Boreholes in the Kalambaina Formation

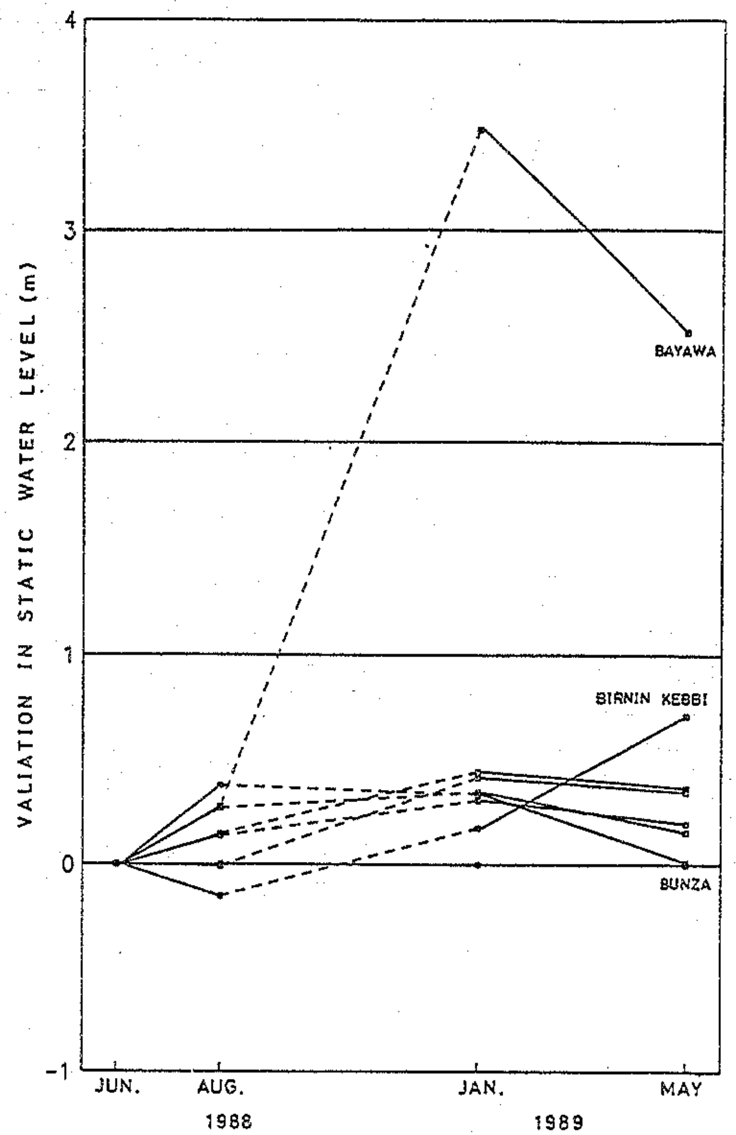


Fig. 4-15 (5)
Variation in Static Water Levels in Boreholes in the Gwandu Formation

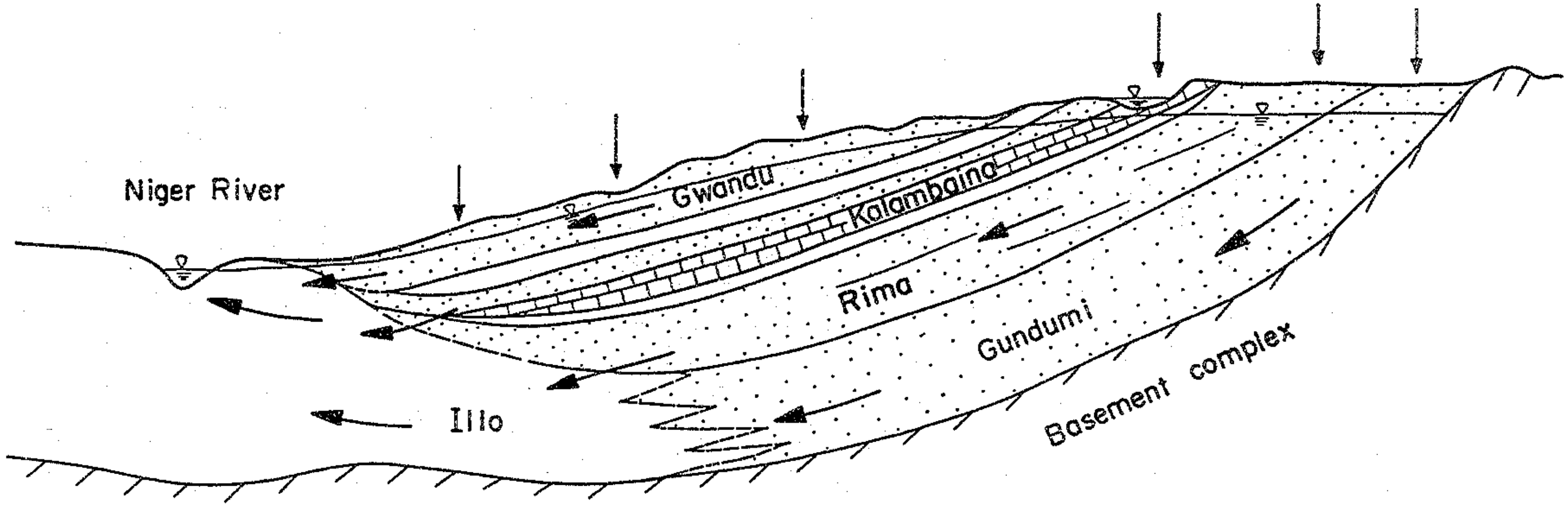


Fig. 4-16 Schematic Diagram of the Groundwater Flow System

Fig. 4-17 (1) Water Level Fluctuation at Yauri Road No.3 borehole in the Rima Formation

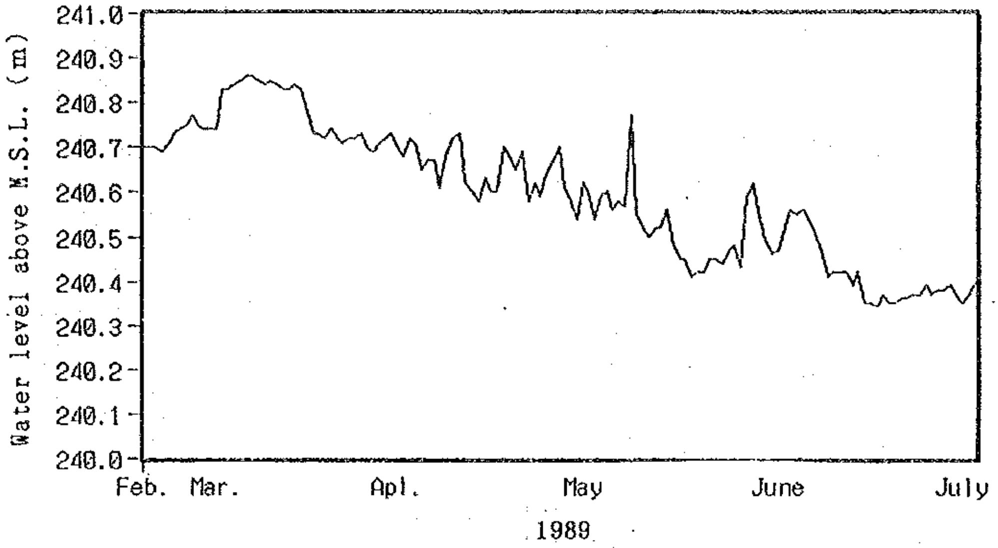


Fig. 4-17 (2) Water Level Fluctuation at Horo-Birni in the Rima Formation

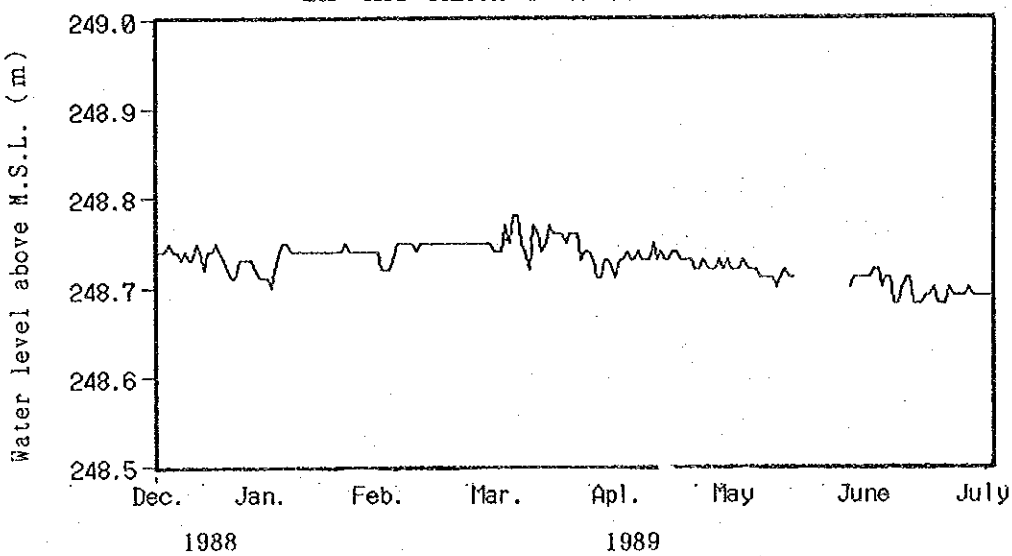
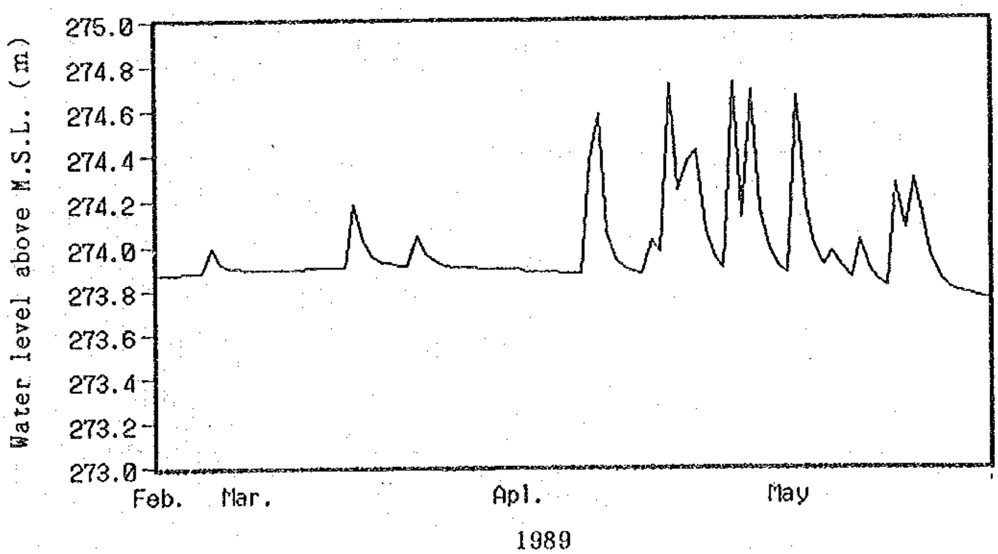


Fig. 4-17 (3) Water Level Fluctuation at Yauri Road No.1 borehole in the Kalambaina Formation



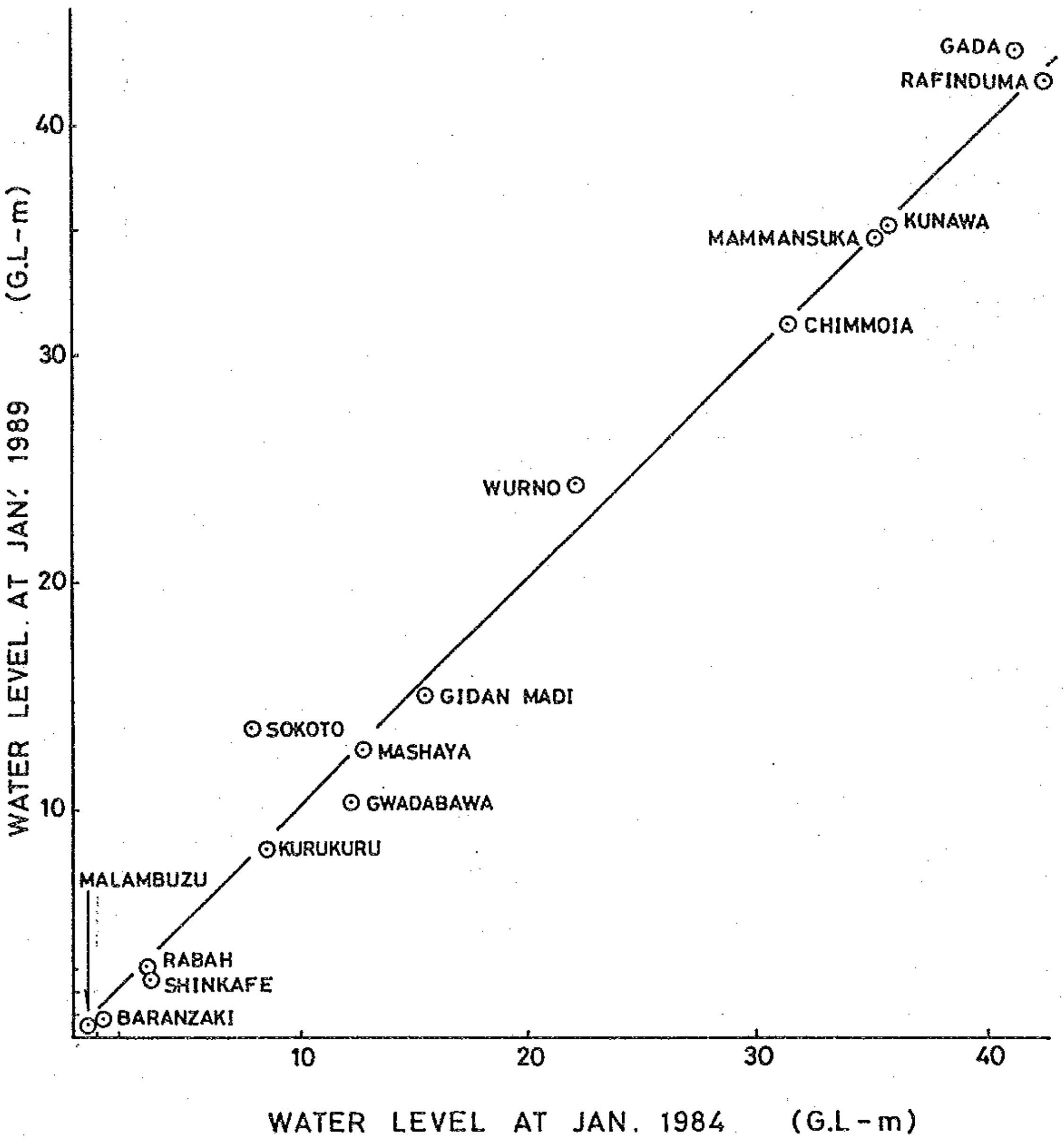


Fig. 4-18 Comparison of water levels between January, 1984 and January, 1989

5. DATABASE FOR GROUNDWATER UTILIZATION AND MANAGEMENT

In the study area, a great deal of borehole drilling and studies and observation related to groundwater development have been undertaken.
However, because of the poor condition of data preservation and management, some data are missing or have become useless.

The purpose of database construction is to construct a system to preserve and manage hydrological and hydrogeological data in Sokoto State. The system will effectively provide data to users and support groundwater development in the area. Since a considerable amount of data will be managed by the data base, and since real-time response is necessary, a computer-aided system is absolutely required.

5-1 Existing Data Base

The data base section of the National Water Resources Institute (NWRI) has been constructing a hydrological data base over the past few years. The study team visited the NWRI and discussed this data base with its staff.
The present state of the data base is as follows:

① Computer Type and Name:
I.B.M. UPC with 20 MB hard disk

② Language:
Advance BASIC (BASICA)

③ Progress in data base construction:
The data entry routine is already functional.

a) Hydrological data (gauge height record, discharge records):
Raw data have been transcribed on to a standard information sheet.
Data entry work has not been completed.

b) Meteorological Data:
Raw data has been collected.
It has not been transcribed yet.

c) Hydrogeological Data (borehole record):
   Data collection has not been completed.

Through discussion with the NWRI staff and through study of the condition of its database, it was strongly felt that the study team and the NWRI should cooperate in the use of the data base for the development of water resources in Nigeria.

5-2 Data Base Construction

(1) Data to be managed by the data base

The data managed by the data base is divided into the following four classifications:

1. Meteorological data

2. Hydrological data

3. Hydrogeological data

4. Literature records

Meteorological data is composed of precipitation, temperature, evaporation data and records of humidity, wind, and sunshine, which is the basic data needed to analyze water balance.

Hydrological data is composed of records of discharge and the water levels of observation boreholes. These are also basic data needed to analyze water balance, and to develop both surface water and groundwater.

Hydrogeological data is composed of borehole drilling records, pumping test results, and water quality data, basic information needed for groundwater development.

Literature records are composed of a list and brief comments or summaries of topographical maps, geological maps, reports of geological/hydrological/ hydrogeological studies, publications, and other data related to the development of the study area. This information will help users to find literature necessary or helpful in their work.

A schematic diagram of the structure of the database system is given in Figure 5-1.

(2) Functions of the data base

In order to satisfy the purpose of data base, the data base has the following sub-programs

1. Data entry sub-program
2. Data file management sub-program
3. Data modification sub-program
4. Hardcopy output sub-program

Data is entered into the data base using the data entry sub-program.
In creating the program, it was remarked that:

- Design must effectively balance efficiency of operation (size, access speed, etc.) with accommodation of the data's nature.
- Operation must be easy for the unskilled engineer.
  Entered data will be stored into and retrieved from data files using the data file management sub-program.
- Data files must have sufficient area to accommodate large amounts of data.
- Data exchange between the operator and the data base must be rapid.

Stored data can be modified, if necessary, using the data modification sub-program.
Text and graphics can be output using the hardcopy output sub-program.

(3) Hardware

In order to satisfy the functions above and manage a large amount and variety of data, hardware having sufficient capacity and rapid access is required.

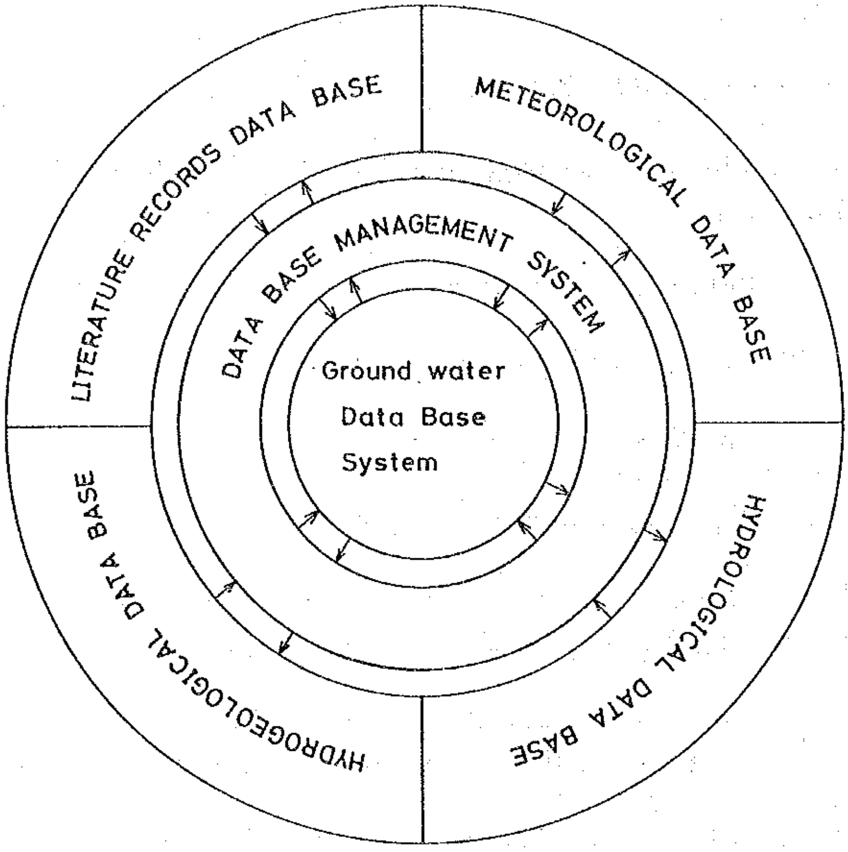


Fig.5-1 Schematic Diagram of the Data Base System

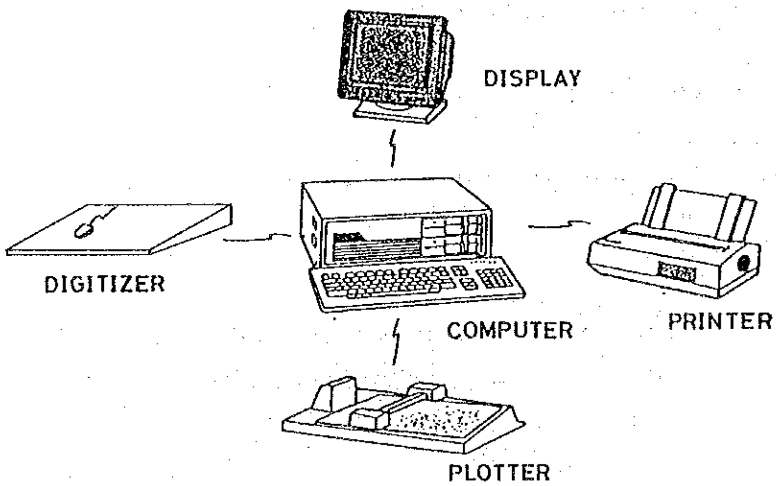


Fig.5-2 Schematic Diagram of the Hardware Components

Furthermore, the conditions of the working environment must be taken into account.

Hardware was chosen to satisfy the following conditions:

- The hardware must be compact and not require specially made construction for installation.

- Operation and maintenance must not require a computer electrical engineer.

- A built-in hard disk is required for rapid data processing.

- Floppy disks must be used to store data files.

- Equipment for printing, drawing and digitizing is required to process data.

The hardware components are :

a) Computer:
NEC Personal Computer model PC-9801 VX41 with 20MB hard disk drive and two 1MB floppy disk drives.
ROM : 24K ×2 R AM : 640K CPU : 80286 (10MHz)
Operating systems : MS-DOS (Ver.3.1), N88 BASIC (Ver.4.1)

b) Display:
NEC 14" Color Display PC-KD854

c) Printer:
NEC PC-PR201TH

d) Plotter:
GRAPHTEC MP3100

e) Digitizer:
GRAPHTEC KD 4600

A schematic diagram of the hardware components is given in Figure 5-2. The hardware has been installed in the Joint Study Team Office in the Federal Secretariat in Sokoto City.

(4) Software

Since various types of data will be stored in the data base, software design of the database considered that:

- The structure of the data base must be simple, so as to make programming and operation easy.
- The size of the program and database should not become too large, so as to secure rapid data access.

In order to satisfy the functions and to help effective programming, the application software d-Base Ⅲ was chosen as the data base management system.

5-3 Data Base Utilization and Management

In the course of the data collection work for the study we found that much of the data has been lost or damaged. In most cases, the situation probably resulted from poor management of data preservation.

The data base will help us improve the situation. Data stored in the system will be kept in good condition and will be retrievable when needed. However, we must note that a data base is only a part of a data management system, which also involves data collection, data checking, data preservation, and data processing. Without correct understanding and proper employment of the system, the data base can not be fully utilized. Thus, besides the importance of data base management, we need to understand the importance of collecting reliable data, checking the data properly, preserving the data in good condition, and fully understanding how the data will be processed and used.

5-3-1 Data collection and preservation

Matters to be taken into consideration in collecting and preserving data are:

(1) Data collection

1. We need to understand correctly the method and required accuracy in collecting data. We need to fully instruct those handling data for the first time on operations involving the collection of data, to avoid any possible accidents.

2. Collected data must be recorded on a specified data sheet designed for the specific purpose.

3. Some data must be collected regularly. Some stations such those consisting of an automatic water level recorder require regular maintenance. A schedule to cover all data collection and maintenance should be established.

4. Data must be checked upon collection to avoid missing items or errors.

(2) Data preservation

1. A check list to manage data preservation should be prepared. Items in the list will be the data name, station name, station specifications, when and by whom the data was collected, when and by whom the data was checked, when and by whom the data was entered into the data base, where the raw data was stored, etc.

2. Some raw data such as records on discharge measurement or automatic water level recorder need to be processed to determine the required value. Results of data processing should be compared with each other or with former results in order to check whether the processing has been done correctly.

3. Raw data should be stored in order in a regular place. Even though records of the data have been entered in the data base, the raw data should be preserved for future reference.

5-3-2 Data base operation and management

The operation manual for the data base is found in the Supplemental Report (Vol. 4). Refer the manual for details in data base operation.

There are various ways to use the data base, such as the printing out of a table of discharge at a specified station, the locating of boreholes tapping the Rima aquifer, or the referring to a report on hydrology in the Sokoto-Rima basin, etc., but without practice in operating the data base, familiarity with the data base is not achieved, thus the data base can not be utilized and fully for the work.

In order to secure the data stored in the data base, backups, at least monthly, are recommended. Instruction on making a backup is found in the manual. Users are also recommended to print out data upon entry to check the data entry.

6. HYDROGEOLOGICAL SURVEY OF CANDIDATE VILLAGES

6-1 Preliminary Survey

6-1-1 Survey procedure

The field surveys for the hydrological study and related water supply study were conducted by separate groups. While the hydrological study group did not always locate its observations with respect to the candidate villages, the group for hydrogeological and other related water supply studies visited the candidate villages one by one.

Forty-seven villages were visited from bases located at Sokoto, Argungu, Gusau, Zuru, Yauri and Koko.

The study group, after arriving in each candidate village, was divided into small parties for more effective engagement in the following activities:

a) Interview with the village head or village representative on the social conditions of the village, especially on water supply circumstances as reflected in the prepared questionnaire.

b) Observation of the existing water supply system and water sources, including measurement of water level in wells, checking of water quality (color, taste, temperature, electric conductivity, etc.), and sampling water for quality tests in the laboratory.

c) Topographic and geological mapping of the village and its surrounding area by pacing distances and using a clinometer to determine azimuth. Most of the villages have been mapped on a scale of 1/5,000 to represent the following items :

- clustered areas
- location of existing water sources for domestic use
- peculiar topographic features such as alluvial flats, terraces, ditches , or water channels, hills, cliffs, etc.
- type and facies of the rock where outcrops are found
- location of geophysical survey points
- direction

d) Resistivity prospecting in a method of vertical sounding using an McOHM type resistivity meter and four equally spaced electrodes. This survey was usually conducted by two parties with the cooperation of 5 to 8 local, casual laborers in each village.
The number of points measured was 2 to 4 in each village.

e) Resistivity mapping or resitivity sounding through the magnetotelluric method (MT method) by use of ELF-MT or PL-MT equipment. Two to five points were surveyed in each village with the cooperation of 2 to 4 local, casual laborers. For a comparison of the result with the above ERS, the survey points were located mostly to correspond with those of the ERS.

6-1-2 Classification of the Candidate Villages

The 47 villages , among which 18 are situated in the basement rock area and 29 in the sedimentary area, were visited and surveyed during the study period.
One of the purposes of village classification is to narrow down the target sites for further detailed survey.
A summary of the findings are tabulated in Supplementary Report 1, and the points are discussed in the following paragraphs.

(1) Population

It was believed that the 47 villages chosen in Sokoto State as candidate sites for a water supply project were "middle-, to large-scale villages" with populations ranging from 3,000 to 20,000.
However, small-scale villages with populations less than 1,000 are included among the 47 villages (e.g. Bambaram, 1,000; Kimbar Bawa, 300; Tabki, 200; and Bakyasuwa, 1,000). Very large villages with populations of more than 20,000 are also included (e.g. Tunga Ardo, 30,000; Dauran, 23,500; Yambuki, 25,000; Birnin Yauri, 22,000; Jambako, 22,000; and Kalmalo, 50,000).
Some of the population figures given by the village heads or representatives do not seem to be reliable, since many of the villages have no census records, and the estimated population is, in some cases, limited to the central community area of the village.
However, on the assumption that the reported population is not far different from the actual population, a trial population classification was made to compare the patterns of population distribution of the sedimentary and

basement rock areas.

In Table 6-1, villages in each area are ranked according to population, and the number of villages within each rank is given. The difference between the two geological areas is clear : comparatively large population villages were chosen from the basement rock area. The percentage of large-scale villages with populations of more than 10,000 is 50 % in the basement rock area, and 7 % in the sedimentary area.

Table 6-1 Number of Villages classified by population grade

Population	Number (percentage) of Villages		
	Basement Rock area	Sedimentary area	Total
less than 1,000	1 (5 %)	2 (7%)	3 (6%)
1,000~ 3,000	2 (11 %)	9 (31%)	11 (23%)
3,000~ 5,000	3 (17%)	8 (28%)	11 (23%)
5,000~ 10,000	3 (17%)	8 (28%)	11 (23%)
10,000~ 15,000	3 (17%)	1 (3%)	4 (9%)
15,000~ 20,000	1 (5%)	0 (0%)	1 (2%)
20,000~ 25,000	4 (22%)	0 (0%)	4 (9%)
more than 25,000	1 (5%)	1 (3%)	2 (4%)
Total	18 (100%)	29 (100%)	47 (100%)

(2) Type and scale of villages

There are two types of villages among the 47 villages visited. One is the "concentrated" type in which a single settlement is clustered. The other is the scattered type village which has many small settlements in one village area several hundred meters apart from each other.
About 74 percent (35 villages) of the 47 villages are of the concentrated type, and about 26 percent (12 villages) are of the scattered type.

The scattered type villages are found mostly in the basement rock area (9 out of 12), with only 3 in the sedimentary area. This fact may indicate a limited amount of water being available from any one source in the basement rock area, as people are more likely to live near a source of water.

Since the area of the settlement measured during the field survey was limited, due to limited time to the major settlement in the scattered type villages, scale classification of villages has been done only with the concentrated type villages.

As reflected in Table 6-2, the number of small scale villages with areas of less than 10ha out of 35 concentrated type villages is 18 (about 51%), middle-scale villages with areas between 10 and 30ha, 12 (34%), and large-scale villages with more than 30ha, 5 (about 15%)

The average population density in the concentrated type villages is about 569 person/ha.

Table 6-2 List of concentrated type villages classified by scale (area)

Scale Classification	Serial Number	Name of Village	Approx. Area (ha)	Population	Sedimentary/ Basement Rock
Villages with comparatively small areas less than 10 ha	5	Dokau	5	10,000	B
	11	Bajida		4,000	B
	15	Zugu	10	4,000	B
	19	Gumbai	8	6,000	S
	20	Maruda	10	3,000	S
	22	Kimbar Bawa	1.5	300	S
	24	Tabki	2	200	S
	25	Gudale	10	11,000	S
	28	Danjiro	2	2,000	S
	32	Gendene	4	3,100	S
	33	Kalgo	9	3,000	S
	34	Soro	3	4,500	S
	35	Sabiyel	6	3,000	S
	39	Zamache	5	1,500	S
	44	Kuka Kago	5	3,500	S
	45	Giro	10	7,300	S
	46	Mallamawa	5	10,000	S
	47	Samalu	5	4,500	S
Middle-scale villages with areas between 10 and 30 ha	7	Dauran	20	23,500	B
	13	Illelar Auwal	14.4	10,000	S
	16	Raha	20	2,200	S
	17	Birnin Yauri	20	22,000	B
	18	Takware	25	10,000	S
	23	Horo Birni	25	8,000	S
	27	Kwakwazo	15	4,000	S
	31	Rahayel	14	1,500	S
	36	Tozai	28	5,000	S
	41	Araba	20	3,200	S
	42	Sambawa	14	8,000	S
	43	Kimba	13	6,200	S
Large villages with areas of more than 30 ha	8	Yambuki	40	25,000	B
	14	Daki Takwas	35	20,000	B
	30	Jambako	50	22,000	B
	37	Mayasa	56	10,000	B
	40	Kalmalo	40	50,000	S

(3) Existing water sources

The type and number of existing water sources in the villages studied are shown in Table 6-3.

In the three villages of Kalmalo, Araba and Tsamaye, semi-urban type water supply systems with power-pumped boreholes have been installed, but most of the systems are not functionning due to poor maintenance.
In the village of Giro, construction of a new water supply system was under way when the village was visited, probably under the management of the SRRBDA.
The seven villages of Bullakke, Dauran, Maga, Tsafanade, Danjiro, Bakyasuwa, and Mallamawa have been equipped with 1 to 3 borehole wells with manual pumps, but some of these wells are not used or have been abandoned due to a shortage of pump parts or because the wells have dried up.
In the two villages of Gumbai and Maruda, a borehole with manual pump is under construction.
The other 30 villages have no borehole wells. Among them, 14 villages depend mainly on free groundwater from open dug-wells, and 11 villages utilize half dug wells and half surface water. The five villages of Bambaram, Bamamu, Tungwa Kofa, Bajida, and Kuka Kago depend on surface water alone.

With regards to the quantity of water for domestic use taken from the above sources, most of the villages seem to achieve short supply especially in the basement rock area, as shown in Table 6-3. According to answers to the questionnaire, a satisfactory amount of water throughout the year is obtained only in the two villages of Gumbai and Maruda.

Table 6-3 Type and number of existing water sources

Type of water source	Number of Villages		
	Basement rock area	Sedimentary area	Total
Power-pumped Borehole	0	3 ※1	3
Hand Pump	4	6 ※2	10
Mainly Dug-well	4	14	18
Dug-well and River / Pond	6	5	11
River / Pond	4	1	5
Total	18	29	47

※ 1 Including Giro where construction of a power-pumped borehole is under preparation.

※ 2 Including Gumbai and Maruda where hand-pumped wells are under construction.

Table 6-4 Village classification with quantity of water from existing sources

Quantity of water	Number of Villages		
	Basement rock area	Sedimentary area	Total
Satisfactory amount throughout the year	0	2	2
Not so unsatisfactory but more desired	0	7	7
Shortage only in dry season	5	12	17
Shortage throughout the year	13	8	21
Total	18	29	47

(4) Health environment

It is very clear that water born diseases occur frequently in the places where sources of domestic water are dependent mostly on non-flowing surface water like ponds, lakes, or dam reservoirs. Slow flowing water channels or shallow dug-wells without sanitary protection are also not free from the contamination of colon bacilli and other bacteria.

It is believed that "Guinea Worm" disease is prevalent in the five villages of Tunga Ardo, Dokau, Bamamu, Yambuki and Kalmalo, where mostly the above-mentioned water is used. In particular, Yambuki, where reservoir water is used, is in such a miserable condition that more than half of the inhabitants are attacked by the Guinea worm.

Four of the above five villages are situated in the basement rock area. Kalmalo is in the sedimentary area, and this village has a water distribution system with a power-pumped borehole, but many people take their water from Kalmalo Lake because the system does not function.

In the village Kuka Kago, where the domestic water source is limited to the river, many people suffer from gastroenteritis and dysentery.
The other 11 villages where the water source is chiefly surface water generally have problems with water-related diseases.

(5) Accessibility

Access to the candidate villages falls into five classes. The evaluation criteria of classification are as follows, and the number of classified villages are listed in Table 6-5.

a. Excellent : The village is served by an asphalt-paved road.

b. Fairly good : The surface of the access road is not asphalted, but is smooth and passable for normal vehicles in all seasons.

c. Good : The road is passable for normal vehicles except in heavy rains, even though the road surface may be somewhat bumpy, or be covered with loose sand and becomes muddy during rainy season.

d. Poor : It is very difficult for ordinary vehicles to pass because of such obstacle as ruts and potholes, river crossings, mud during the rainy season, or very loose sand during the dry season.

e. Very poor : Almost impossible for ordinary cars or trucks to pass even in dry season. Even four-wheel drive vehicles are able to pass only with great difficulty.

Table 6-5 Number of villages classified by accessibility

Classification	Number of Villages		
	Basement rock area	Sedimentary area	Total
Excellent	6	1	7
Fairly good	2	4	6
Good	5	13	18
Poor	4	10	14
Very poor	1	1	2
Total	18	29	47

6-1-3 Topographic and geological survey

Prior to the field reconnaissance of the individual sites, the LANDSAT pictures and the aerial photographs were carefully observed which pertained to the areas concerned. In addition, the reference materials covering the target areas were reviewed to obtain preliminary knowledge of the site and its surrounding areas.

On the way to the sites from the base camp town, the topographic features closely related with geologic composition were observed to confirm the preliminary knowledge. When outcrop was found, the geologic composition was confirmed in order to renew the preliminary knowledge, and to confirm or revise the boundary of strata and rock facies.

Upon arriving in the day's scheduled site, the work began with the outline mapping by pacing and using a clinometer in an approximate scale of 1/5,000, since none of the sites had been covered on a large-scale map. During the mapping work, geological information was also mapped, such as :

- Peculiar topographic features of rivers, terrace, hills, cliffs, ponds, swamps, etc.
- Housing cluster areas and locations of their existing water sources
- Locations of geophysical survey points

The distinguished topographical and geological features in and around the individual sites are noted in the summary tables of the Supplementary Report 1. All of the information obtained throughout the field work is incorporated in the preliminary hydrogeological map.

6-1-4 Geophysical prospecting

(1) Purpose of work and outline of methodology

Two types of electrical survey were carried out in this study for depth sounding to aquifers and/or resistivity mapping for area classification of groundwater potential.
One type is an electrical resistivity survey by the Gish-Rooney Method by use of Wenner's Electrode Configuration (4 equally spaced electrodes), hereinafter referred to simply as "resistivity sounding", and the other is a magnetotelluric method (MT method) including different types of PL-MT and ELF-MT methods.

Resistivity sounding is a method in which electrode spacing is increased from 1m to an extent in accordance with the depth of interest to obtain information from successively greater depths at a given surface location. A commutated direct current is introduced to the ground through outer two electrodes, and voltage between the inner two electrodes is measured to calculate the apparent resistivity from the ground surface to a depth corresponding to the electrode spacing.
The apparent resistivity curve, which is usually called "ρ-a curve" (apparent resistivity vs. electrode spacing) is analyzed through a standard curve matching method to calculate actual resistivity value along with the depth of each subsurface layer of different resistivity. Thus, the resistivity columnar is drawn for the survey points.

The survey points, which are the center of 4 electrodes on a single line, are usually arranged on the field every 100 to 300m apart from each other, either in a line or in checkerboard pattern. The resistivity columnars are placed on graphing paper side by side to prepare the resistivity profiles or resistivity block diagram. In the sedimentary area, this resistivity profile is used for differentiation of the coarse-grained material like sand or gravel (permeable layer indicated by higher resistivity) and fine-grained material like silt or clay (aquiclude indicated by very low resistivity). In the basement rock area, the profiles differentiate decomposed rock (probable water-bearing zone indicated by comparatively low resistivity) from fresh bedrock (aquiclude indicated by very high resistivity).

The magnetotelluric (MT) method is a method in which orthogonal components of the horizontal electric and magnetic field induced by various electric or magnetic phenomena are measured simultaneously as a function of the frequency.

The measured ratio between the induced electric and magnetic field, i.e., electromagnetic impedance, is the basis of apparent resistivity, ρ_a, of the point in the following equation;

$$\rho_a = 1/\omega \cdot \mu \times |E/H|^2$$

where, E is the induced electric field measured (V/m)

H is the induced magnetic field measured (A/m)

ω is the frequency (rad./sec)

μ is the magnetic permeability ($4\pi \cdot 10^{-7}$ henries/m)

By changing the frequency of the induced magnetic field, or by use of different frequencies which naturally exist, the average resistivities from ground surface to certain depths corresponding to frequency (shallow portion by high frequency and deep by lower frequency) will be measured. By plotting these resistivity values on log-log section paper, trial-and-error type curve matching is made by computer, thus resistivity depth sounding is attained. If the frequency range is limited, just apparent resistivity is plotted on a map for resistivity mapping.

The PL-MT (power line magnetotelluric) Method is the measurement of the induced electric/magnetic field originating from a power line. The PL-MT meter has the functions of measurement and output of the elements in the service frequency (50Hz) and its peak frequencies of resonance periods (100, 150, 200, 250, 300, 350, 400, 450, 500, and 550 Hz). The depth of concern depends on the range of frequency (shallow by higher frequency and deep by lower one). An apparent resistivity from ground surface to a depth of about 700m is taken within the range of 50Hz, provided subsurface material is homogeneous with resistivity of 100Ω-m, and of about 200m within the range of 550Hz., under the same assumption.

By arrangement of the apparent resistivity with different frequency, the resistivity classification with depth is roughly done in the same manner as in the "resistivity sounding", with regards to the portion deeper than 200m.

The ELF-MT (extremely low frequency magnetotelluric) Method utilizes the induced electric/magnetic field derived from resonance of atmospheric discharge (Schumamn Resonance) with frequency of about 8, 14, 20, 26, 32···Hz).

Since frequency is much lower, the depth of concern is bigger than that of the

PL-MT Method. However, depth sounding (resistivity classification with depth) by this method is very difficult, because the signal is usually unstable, the number of frequencies is very limited. Therefore, this method is used generally for "resistivity mapping".

(2) Results of resistivity sounding

It is necessary for resistivity soundings to be taken at as many survey points as possible in the area concerned for the survey results to be properly evaluated. However, in the preliminary field surveys done for the 47 candidate villages, only one to four points were measured because of the number of sites that had to be covered in a limited period. The results obtained are therefore not very satisfactory, and had to be corrected in the detailed survey. Nevertheless, preliminary surveys did produce the following useful findings.

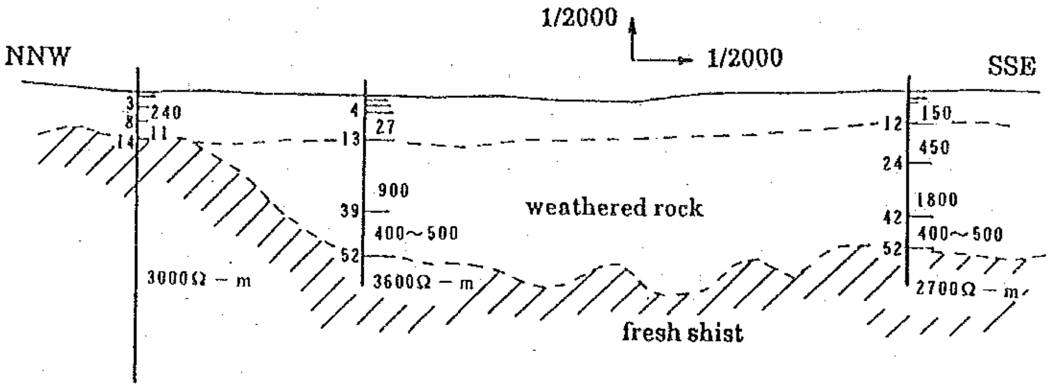
① In the basement rock area, irregularity or depth to the surface of the fresh base rock differs greatly from place to place. The possibility of groundwater development, even in the so-called difficult areas can therefore be maximized, provided proper surveys are conducted prior to well construction. A checkerboard-survey-point pattern with a spacing of 80 to 150m is strongly recommended for the detailed survey.

② In the sedimentary area, variation of resistivity with depth is mostly conformable with the stratigraphy. In some sites, however, different variation patterns are found in neighboring survey points, even though both ground surface and bedding of the layers are nearly flat. This may be reflected by irregular distribution of lenticle beds, or other heterogeneous structures caused by an irregular sedimentary environment.
In order to clarify these conditions, several survey lines arranged in a rectangle with strike become neccessary in some places.
The outcome of resistivity sounding, which is a series of resistivity profiles, is found in the Supplementary Report 1, while a summary of those results is tabulated in Table 6-6.

In the resistivity profiles, a simplified resistivity columnar with depth (left side) and resistivity value (right side) is represented as shown in Figure 6-1.

In the basement rock area, high resistivity, usually higher than 3000Ω-m, is taken to indicate fresh bedrock (aquiclude), while in the sedimentary area, comparatively higher resistivity indicates a higher permeable layer, which is a probable aquifer.

Example from besement rock area (1) Tunga Ardo NNW-SSE



Example from Sedimentary area (25) Gudale SSW-NNE

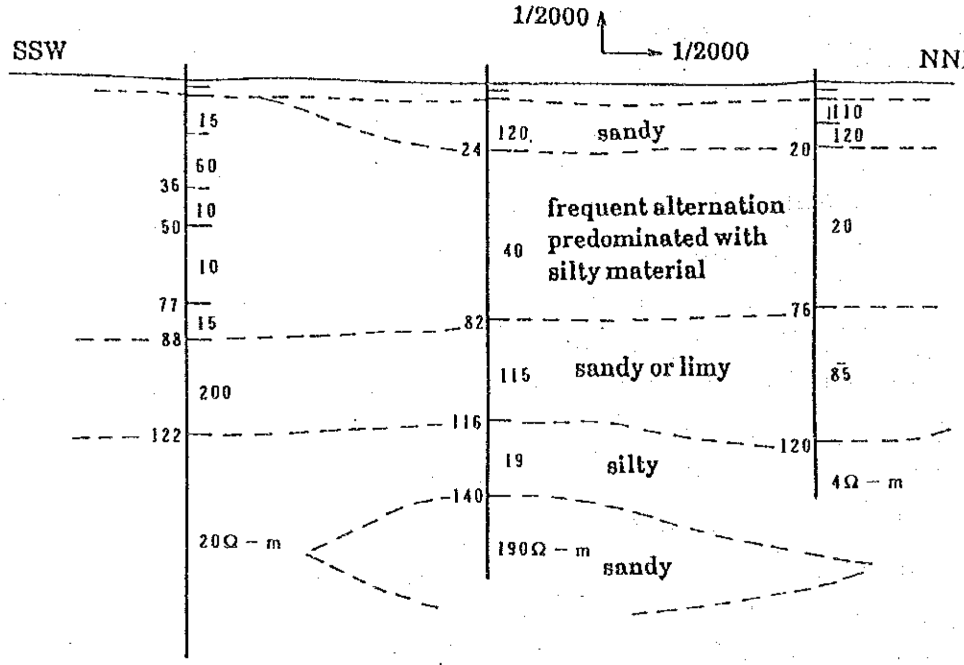


Figure 6-1 Examples of resistivity profile

Table 6-6 Summary results of resistivity sounding
(1) Basement rock area

	I.D. Number, Name of village		Description
Basement rock area	1	Tunga Ardo	Geologic boundary probably exists (Pegmatite/schist). Weathered rock is thick (50m) in the south.
	2	Bullakke	Generally, fresh rock is shallow, extending to about 20m, becoming deeper in the north (50m).
	4	Ruwan Bore	Partial deep weathering (more than 100m) in the east of settlement.
	5	Dokau	Very deep weatheing down to more than 200m, or probable wide, fractured zone along tectonic line. High g/water potential is assumed.
	6	Bamamu	Irregular surface weathering from 30 to 70m deep.
	7	Dauran	Comparatively monotonous surface weathering, with depth varying from 30 to 70m deep.
	8	Yambuki	Highly decomposed rock portion becomes thicker in the south (further from settlement is better for gw. dev.)
	9	Tungwa Kofa	Southern part is more promising for basin gw., with deeper weathered rock. Boundary of different rock facies is presumed in the village, so fissure water is also promising.
	10	Maga	Irregular deep weathering from 60 to 100m or more. Much of gw. may be obtained.
	12	Sanchi	Irregular surface weathering extending 40 to 50m deep.
	14	Daki Takwas	Neither basin gw. nor fissure water are likely promising in most of the area, except of the lower resistivity portion found at point No.3.
	15	Zugu	Irregular surface weathering, and deep weathering. High gw. potential is presumed
	17	Birnin Yauri	Shallow surface weathering (less than *15m BGS), with little groundwater potential.
	29	Bakyasuwa	Highly decomposed rock or sedimentary material extends in uniform thickness of 30 to 40m. Fissure water may exist north and south of the settlement.
	30	Jambako	Gw. basin with depth of about 40m is presumed beneath the clustering area.

* BGS - Below ground surface.

Table 6-6 Summary results of resistivity sounding

(2) Sokoto sedimentary basin

	I.D. Number, Name of village		Description
Sedimentary area	13	Illelar Auwal	Confined aquifer is expected below 40m BGS. From 20 to 40m depth may be silty material with resistivity of less than 100Ωm.
	16	Raha	
	19	Gumbai	Mostly clay or silt predominate to 70 m BGS. Confined gw. is expected in deeper portion. Simple and flat bedding.
	20	Maruda	Flat and simple sedimentation. Water may be hit between 30 and 100m BGS. Deeper than 100m is most promising for gw.
	21	Tsafanade	Confined aquifer expected below 40m BGS in clustering area.
	22	Kimbar Bawa	Good aquifer is not expected in shallower than 50m. Confined water is expected below that.
	23	Horo Birni	Confined aquifer is expected below 30m BGS because of thick (10~30m) and wide confining bed of silty material with low resistivity (less than 6 Ωm)
	24	Tabki	Very thick permeable beds are extensive. Much water is expected, but not confined.
	25	Gudale	Flat but complicated sedimentary condition with lenticle beds. Confined aquifer between 80 and 120m BGS in the north, and between 100 and 120m BGS expected in the south.
	26	Chibike	Flat and wide extention of probable limestone bed, 20~30m thick, between 30 and 60m BGS may be aquifer.
	27	Kwakwazo	Below 50m BGS (down to at least 80m) is probably sand dominated material (Data not reliable).
	28	Danjiro	
	31	Rehayel	Aquifer of coarse sand material is expected below 15m BGS which probably underlies silty material with a thickness of 10m and a low resistivity (20Ωm).
	32	Gendene	Complicated sedimentary condition with many lenticle beds, gw. potential looks high with an abundance of alternated permeable beds with silty material.
	33	Kalgo	No good aquifer likely below 60 m BGS down to at least 150 m.
	34	Soro	
	35	Sabiyel	Confined aquifer is expected below 20m BGS. Aquifer is probably sandy material that is overlain by silty material.

Tabe 6-6 Summary results of resistivity sounding
(2) Sokoto sedimentary basin (cont.)

	I.D. Number, Name of village		Description
Sedimentary area	38	Tsamaye	From 20 to more than 50m BGS may be sand dominated material with resistivity of 100~200 Ωm. (Data not reliable)
	39	Zamache	
	40	Kalmalo	Alternation of silty and sandy materials. If no good water-bearing bed by 65m BGS, deeper drilling is advised to (more than 90m in west and 130m in east)
	41	Araba	Confined gw. below 40 m BGS is suggested by thick (20m or more) clayey layer.
	42	Sambawa	Frequent alternation of silty-and sandy-dominant materials. Sedimentation is not simple with many lenses.
	43	Kimba	May be same condition in all places if borehole is drilled down to 20~150 m BGS.
	44	Kuka Kago	Two aquifers likely exist. Between 50 and 60m BGS, and between 80 and 100m BGS. Almost flat.
	46	Mallamawa	Shallower than 200m consists mostly of silt-dominated material, with highest R of 40 Ωm.
	47	Samalu	Inclined limestone bed is presumed. High R of more than 7500 Ωm (deeper than 30 m in south and 70 m in north) may be compact limestone.

(3) Results of MT sounding and mapping

Resistivity values obtained through ELF-MT (frequency below of 8, 14 and 20 Hz) and PL-MT (50, 100 and 150 Hz) are tabulated.

In the sedimentary area, most of the apparent resistivity, i.e., the average resistivity from ground surface down to several hundred meters, was within 100 Ω-m, while in the basement rock area, apparent resistivity was very high, exceeding 5,000 Ω-m. The resistivity difference between the sedimentary area and the basement rock area was very obvious.

Since the signal (resonance of magnetic field) was so unstable in higher frequency range during the survey period, important information for shallower than 200m was hardly obtained by the MT Method. Therefore, the outcome of this survey was confined to just knowing the clear difference between the sedimentary area and the basement rock area. The number of survey points in each site was limited to only 2 to 5 due to the limited time. Neither area classification within a village nor detection of a structural line could be attained by the MT Method.

At the villages where resistivity was measured in different frequency ranges, the resistivity with depth was analyzed by inversion using a computer.

A table of resistivity value, an apparent resistivity distribution map and an example of resistivity analysis are attached in the appendix of the Supplementary Report 1.

6-1-5 Selection of the sites for detailed survey

In order to narrow down the target sites for the detailed survey, the following selection criteria (elimination) were established.

a. Population and area:
Since the "Project Target" is water supply for large scale villages, the villages with population larger than 3,000 or settlement area larger than 10ha were chosen.

b. Accessibility and health environment:
In order to carry out the survey effectively in a limited period, and also with the consideration of water supply system construction, the villages with "poor" or "very poor" accessibility were eliminated, except where water related health problems are serious.

c. Existing water supply system:
The villages which have installed water supply systems with power-pumped boreholes, and the villages where another water supply project was on going or under preparation were eliminated.

d. Groundwater potential:
Some of the villages where groundwater development have been revealed to be almost impossible or very difficult by the preliminary study were eliminated, but, mostly kept in view for further investigation.

Based on the above selection or elimination criteria, the sites for detailed survey were narrowed down to 21 villages, among which 10 villages were chosen from the basement rock area and another 11 from the sedimentary area, as shown in Table 6-7.
The elimination/selection procedure is shown in Figure 6-2.

Table 6-7 The Selected Villages for the Sites of Detailed Survey

Area	Serial No.	Village Name	Local Goverment	
Basement rock area	1	Tunga Ardo	Anka	10 Vill.
	2	Bullakke	Anka	
	4	Ruwan Bore	Gusau	
	5	Dokau	Gusau	
	6	Bamamu	Gusau	
	7	Dauran	Kaura Namoda	
	8	Yambuki	Kaura Namoda	
	10	Maga	Zuru	
	14	Daki Takwas	Gummi	
	15	Zugu	Gummi	
Sedimentary area	18	Takware	Yauri	11 Vill.
	23	Horo Birni	Yabo	
	25	Gudale	Argungu	
	26	Chibike	Argungu	
	32	Gendene	Bagudo	
	34	Soro	Silame	
	42	Sambawa	Jega	
	43	Kimba	Jega	
	44	Kuka Kago	Jega	
	46	Mallamawa	Sokoto	
	47	Samalu	Sokoto	

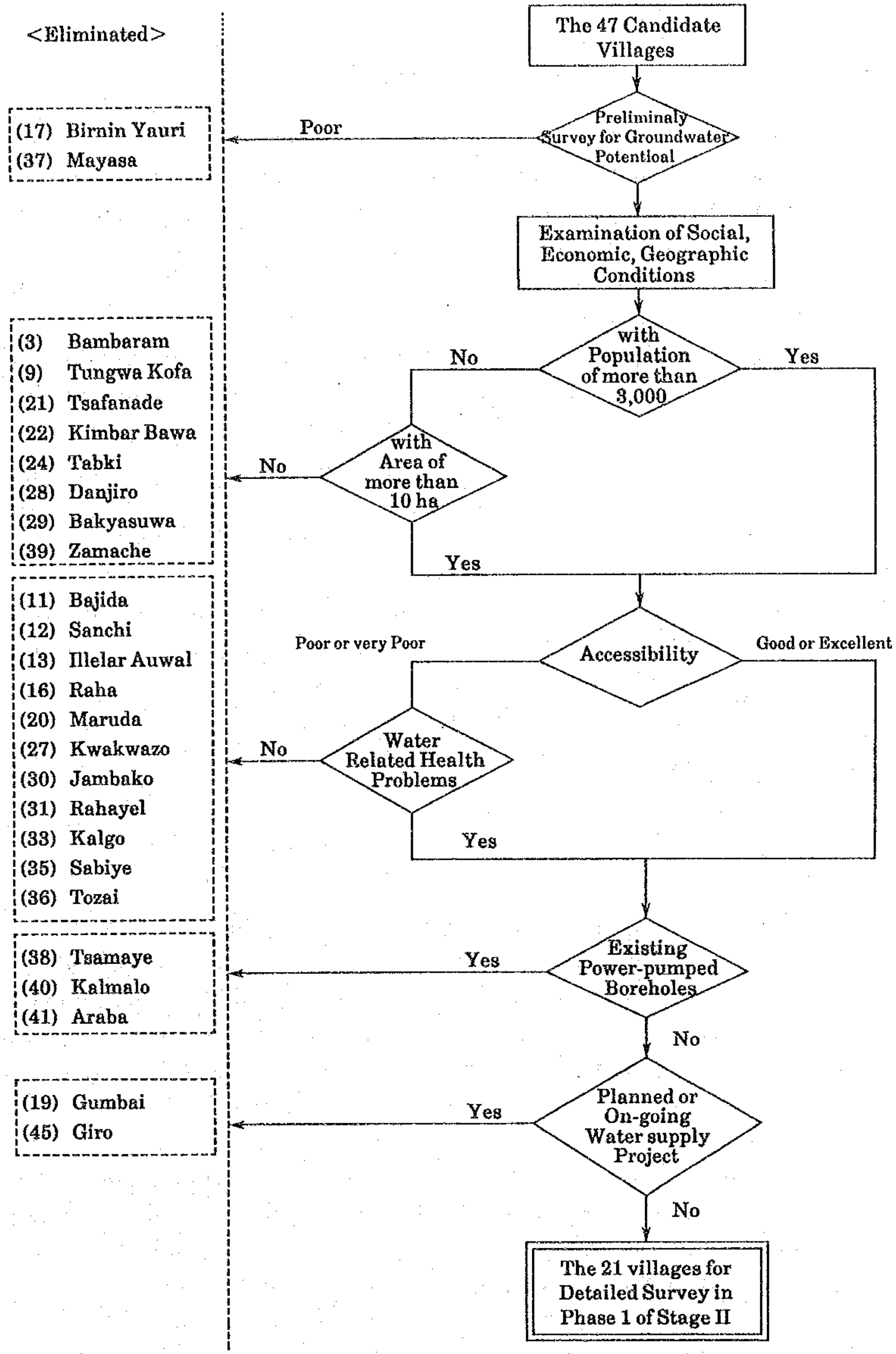


Figure 6-2 Flow Chart of Site Selection for Detailed Survey

6-2 Detailed Survey

6-2-1 Detailed hydrogeological reconnaissance

A field survey for hydrogeological study was conducted in detail in the 21 selected candidate villages and their surroundings (Table 6-7), based on the results of preliminary hydrogeological investigation and additional aerial photography interpretation. A detailed site survey was simultaneously conducted in order to properly locate test drilling sites.

This hydrogeological reconnaissance was carried out parallel to geophysical prospecting in each candidate village . Based on the results of reconnaissance and the geophysical prospecting, a comprehensive hydrogeological analysis was simultaneously conducted in order to evaluate the groundwater potential to determine test drilling points and to prepare for the planning of a water supply system.

The results of this work are summarized in Table 6-8 and are presented in detail in the outline maps of the detailed hydrogeological survey in the Supplementary Report 1. Major useful findings are described in 6-2-2, "Geophysical prospecting".

6-2-2 Geophysical Prospecting

Detailed electrical resistivity sounding, employing the Gish-Rooney Method with Wenner's Electrode Configuration and an Mc-OHM-type resistivity meter, was carried out in the 21 selected candidate villages. The resistivity sounding was conducted parallel with detailed hydrogeological reconnaissance to estimate hydrogeological composition and to evaluate the groundwater potential in the candidate villages and their surroundings.

In detailed investigation, different survey point arrangements were adopted for the sedimentary and basement complex areas. In the sedimentary area, survey lines mostly cut straight across the strikes of geological formations, with 4 to 6 survey points spaced 100 to 200m

Table 6-8 Result of Detailed Survey (1/3)

No.	Village Name Population (Local Gov.)	Groundwater Potential: Hydrogeological Features	Groundwater Potential: Result of Geophysical Prospecting	Groundwater Potential: Expected W/Quality	Social and Health Environment	Willingness and Payability for Operation and Maintenance	Access-ibility	Result of Test Drilling and Well Discharge	Recommendable Water Supply System
1	Tunga Ardo 30,000 (Anka)	·Weathered and fractured schist with granite dykes ·S/C : 9m^3/d/m (from existing boreholes)	·Partial deep weathering (more than 60m) in the southeast of settlement ·Higher G/water potential is expected along granite dyke	·Good ·E/C 280 (μυ/ cm)	·Scattered village with 12 settlements ·Guinea worm disease ·Urgent necessity for borehole water	Strong (100% of Fami. N1~5/M/F)	Good	T/D (80m) 17ℓ/min by air lift	Numbers of hand-pump wells with 40 to 50 m depths
2	Bullake 10,500 (Anka)	·Thin Alluvial deposits and weathered granite with pegmatite veins ·S/C : 3m^3/d/m	·Basin shaped deep weathering (45~90m) in N-S direction controled by structural lineament	·Good ·E/C 660	·Scattered village ·Shortage of water in dry season	Normal (100% of Fami. N1~3/M/F)	Good	—	6 to 8 hand-pump wells with depth of 40 to 60 m at the places of basin wide deep weathering
4	Ruwan Bore 11,500 (Gusau)	·Weathered and fractured schist with quartzite veins ·S/C : 0.7~32m^3/d/m	·N-S basin shaped deep weathering (70~170m) controled by structural lineament ·Higher G/water potential along quartzite veins	·Good ·E/C 700	·Guinea worm disease ·Urgent necessity for borehole water	Normal (More than 50% of Fami. N2~3/M/F)	Fairly good	T/D(84m) 49ℓ/min T/W(90m) 84~166ℓ/min by air lift	Small capacity power pump elevated tank and gravity destribution system with 4 to 5 communal fauset
5	Dokau 10,000 (Gusau)	·Weathered and fractured schist ·Situated in wide fractured zone with evident N-S lineament ·S/C : 0.2~6m^3/d/m (Outside of fractured zone)	·Very deep weathering in whole area with fracturing and fault clay ·G/water potential may generally be high, but w/level might be different by place to place due to irregular fracturing facies	·Salty ·E/C 1,200	·Concentrated and semi-urban style village ·Urgent requirement for borehole water ·Guinea worm disease	Strong (100% of Fami. N1~5/M/F)	Poor	—	Borehole with power pump, elevated tank near the center of village with gravity distribution system
6	Bamamu 10,000 (Gusau)	·Weathered and fractured granite covered with thin Alluvial deposits. ·S/C : 1~14m^3/d/m	·Valley shaped partial deep weathering (45~60m) in N-S direction controled by structural lineament	—	·Scattered village with 7 settlements ·Guinea worm disease ·Urgent necessity for borehole water	Strong (100% of Fami. N1~5/M/F)	Poor	—	6 to 7 hand pump wells with depth of 40 to 50 m at the places of basin wide deep weathring
7	Dauran 23,500 (Kaura Namoda)	·Weathered schist with fractured zone ·S/C : 1~200m^3/d/m	·Valley shaped partial deep weathering (45~90m) in directions of NW and NE	·Good ·E/C 890	·Semi-urban style village ·Serious shortage of water through the year	Normal (More than 70% of Fami. N1~3/M/F)	Excell-ent	T/W(84m) 120~210ℓ/min by air lift	2 wells with motor pump with semi-urban type water supply system (Gravity)
8	Yambuki 25,000 (Kaura Namoda)	·Weathered gneiss and granite with fractured zone ·S/C : 2~200m^3/d/m	·Partial deep weathering (45~160m) in NS, NW and NE directions controled by structural lineament	·A little salty ·E/C 1,200±	·Semi-urban style village ·Seriously sufferd by Guinea worm disease ·Shortage domestic water has begun due to collapse of the dam by 1988'2 flood.	Strong (100% of Fami. N1~5/M/F)	Fairly good	T/D(30m) 69ℓ/min T/W(102m) 80ℓ/min by air lift	2 wells with small capacity motor pump with semi-urban type water supply system (Gravity)

S/C : Range of specific capacity of existing wells nearby or surroundings of concerned area
N : Naira

E/C : Electric Conductivity in μυ/cm
/M/F : Per Month Per Family

Table 6-8 Result of Detailed Survey (2/3)

Village Name Population (Local Gov.)		Groundwater Potential			Social and Health Environment	Willingness and Payability for Operation and Maintenance	Access-ibility	Result of Test Drilling and Well Discharge	Recommendable Water Supply System
		Hydrogeological Features	Result of Geophysical Prospecting	Expected W/Quality					
10	Maga 4,000 (Zuru)	·Weathered and fractured schist and meta-sediments with quartzite veins ·S/C : $0.8m^3/d/m$	·Basin shaped deep weathering (70~170m) in a direction of NE-SW controled by structural lineament	·Good ·E/C 95~300	·Serious shortage of domestic water during dry season	Normal (100% of Fami. N 1/M/F)	Excel-lent	T/D(84m) 5ℓ~20ℓ/min T/W(138m) 120~200ℓ/min by air lift	Gravity distribu-tion system, with a water source of drilled Test Well.
14	Daki Takwas 20,000 (Gummi)	·Weathered schist and meta-sediments ·S/C : unknown due to no nearby borehole	·Generally monotonous and shallow surface weathering with a depth ranging from 20 to 30m. ·Comparatively poor G/water potential	·Good ·E/C 52~300	·Concentrated and semi-urban style village ·Serious shortage of domestic water part-icularly in dry season	Normal (100% of Fami. N 2/M/F)	Excel-lent	—	Numbers of hand pump boreholes with more or less 30m deep.
15	Zugu 4,000 (Gummi)	·Weathered meta-sediments with quartzite vein ·N-S wide fractured zone is apparent along the river	·Deep weathering (more than 100m) along the river in accordance with lineament of fractured zone ·Probable high G/water potential along quarzite vein	·Good ·E/C 380~470	·Serious shortage of water for domestic use during dry season	Normal (100% of Fami. N 1/M/F)	Excel-lent	T/W 1 (130m) T/W 2 (120m) 400ℓ/min by air lift	One deep well with motor pump, and gravity distribution system. Well depth 100~150m.
18	Takware 10,000 (Yauri)	·Illo Formation ·Consists mostly of semiconsolidated fine to medium sand ·S/C : $70m^3/d/m$	·Aquifer of medium to coarse grained sand probably lie in a depth of between 10 and 40m, and deeper than 70m.	·Good ·E/C 930	·Shortage of water for domestic use during dry season	Less than Normal (100%of Fami. N 0.5/M/F)	Good ~ poor	—	80 to 100m deep well with motor pump, and gravity distribution system.
23	Horo Birni 8,000	·Taloka Formation ·Consists mainly of semiconsolidated fine to medium sand ·S/C : $7\sim180m^3/d/m$	·Numbers of minor aquifer are presumed between 30 and 200m depth, with frequently alternated by beds of clayey material	·Good ·E/C 300	·Particularly strong desire for deep well construction, because numbers of shallow dug wells dry up during dry season	Strong (100 of Fami. N 5/M/F)	Fairly good	T/D(150m) 209ℓ/min T/W(120m) 380ℓ/min by air lift	Gravity distribu-tion system, with a water source of drilled test well. (small capacity motor pump)
25	Gudale 11,000 (Argungu)	·Gwandu and Kalambaina Formations ·S/C : $0.3\sim216m^3/d/m$	·Major aquifer consisting of sand presumably lies between 80 and 120m depth.	·Good ·E/C 160~710	·Shortage of water for domestic use especially during dry season	Normal (100% of Fami. N /M/F)	Poor	—	2 boreholes with depth of more or less 120m. Gravity distribu-tion system.
26	Chibike 5,000 (Argungu)	·Upper members of Gwandu Formation ·S/C : $0.5\sim24m^3/d/m$	·Major aquifer composed of coarse sand lies between 30 and 60m depth.	·Good ·E/C 46	·Scatterd village with 3 settlements ·Shortage of water for domestic use especially in dry season	Normal (100% of Fami. N /M/F)	Poor	—	60m deep borehole with small capacity power pump, and Gravity distribu-tion system for major settlement

S/C : Range of specific capacity of existing wells nearby or surroundings of concerned area　E/C : Electric Conductivity in μυ/cm
N　: Naira　/M/F :Per Month Per Family

Table 6-8 Result of Detailed Survey (3 / 3)

No.	Village Name Population (Local Gov.)	Groundwater Potential: Hydrogeological Features	Groundwater Potential: Result of Geophysical Prospecting	Groundwater Potential: Expected W/Quality	Social and Health Environment	Willingness and Payability for Operation and Maintenance	Accessibility	Result of Test Drilling and Well Discharge	Recommendable Water Supply System
32	Gendene 3,100 (~11,000) (Bagudo)	·Illo Formation composed mostly of semi-consolidated fine to coarse sand ·S/C : $1.8 \sim 53 m^3/d/m$	·Major aquifer being composed of coarse sand is expected in deeper than 60m.	·A little poor ·E/C 1300	·Scattered village with a major settlement near to the River Niger. ·Bridge and new road are under construction as of 1989 ·Shortage of water in dry season	Normal (100% of Fami. N 1/M/F)	Good	—	One borehole with gravity distrubution system for major settlement
34	Soro 4,500 (Silame)	·Lower members of Gwandu Formation and Kalambaina Forma-tion ·S/C : $1.4 \sim 59 m^3/d/m$	·High G/water potential is expected from frequently alternated beds. Major aquifer is sand or limestome which lies in deeper portion than 40m.	·Good ·E/C 300 (Guwandu Formation)	·Shortage of domestic water in dry season	Strong (100% of Fami. N 3/M/F)	Good	T/W (150m) 900ℓ/min by air lift	Gravity distribution with a sourse of drilled test well
42	Sambawa 8,000 (Jega)	·Gwandu Formation composed mostly of sandy and clayee material ·S/C : $1.3 \sim 93 m^3/d/m$	·Frequently alternated sand and silty material. Major aquifer probabiy lies deeper than 110m BGS.	·Good ·E/C 295~440	·Shortage of domestic water in dry season	Normal (100% of Fami. N 1/M/F)	Good ~ poor	—	One borehole with a depth of more than 110m. and gravity distribution system
43	Kimba 6,200 (Jega)	·Taloka Formation ·S/C : $1.5 \sim 42 m^3/d/m$	·Very high G/water potential is expected by abundance of gravelly material overlain/alternated with other beds.	·Good ·E/C 140~680	·Shortage of domestic water in dry season	Normal (100% of Fami. N 1/M/F)	Good ~ poor	—	One borehole of 120 to 150m deep, and gravity distribution system
44	Kuka Kogo 3,500 (Jega)	·Illo Formation ·S/C : $7 \sim 160 m^3/d/m$	·High G/water potential is expected owing to alternation of fine sand, gravelly sand and silty material. Major aquifer may exist between 30 and 100m deep.	—	·Diseases caused by river water drinking	Normal (100% of Fami. N 2/M/F)	Good	T/W (113m) 800ℓ/min by air lift	Gravity distribution system using drilled test well as a source.
46	Mallamawa 10,000 (Sokoto)	·Kalambaina and Wurno Formations ·S/C : $0.7 \sim 5.6 m^3/d/m$	·Poor G/water potential due to the formations composed mostly of silty or clayey materials down to 200m deep.	—	·Shortage of domestic water	Normal (100% of Fami. N 1/M/F)	Good ~ poor	—	Numbers of shallow/deep hand pump wells as point sources
47	Samalu 4,500 (Sokoto)	·Gwandu and Kalambaina Formations ·S/C : $1.7 \sim 79 m^3/d/m$	·Good aquifer of limestome or marly limestome is underlain between 20 and 40m deep. Lower portion than that is also supposed to be full of aquifers.	·Good ·E/C 59~81 (But only in Gwandu Formation)	·Shortage of domestic water	Normal (100% of Fami. N 1~2/M/F)	Good	—	One borehole of 100~150m deep, and gravity distribution system

S/C : Range of specific capacity of existing wells nearby or surroundings of concerned area
N : Naira

E/C : Electric Conductivity in μυ/cm
/M/F : Per Month Per Family

along the lines. The target depth of sounding was 150 to 200m. In the basement complex area, the survey points were arranged in a checkerboard pattern, with a spacing of 100m and covering an area of 0.25 to 0.5 km^2. The number of survey points at each site was 10 to 25, and the sounding depth was 50 to 200m.
As mentioned in 6-2-1, the results of the resistivity soundings were analyzed hydrogeologically and summarized in Table 6-8, and the outcome of the resistivity sounding, which is a series of resistivity profiles and mappings, is found in the Supplementary Report 1.
The resistivity soundings, along with detailed hydrogeological reconnaissance and analysis, produced the following findings.

(Basement complex area)

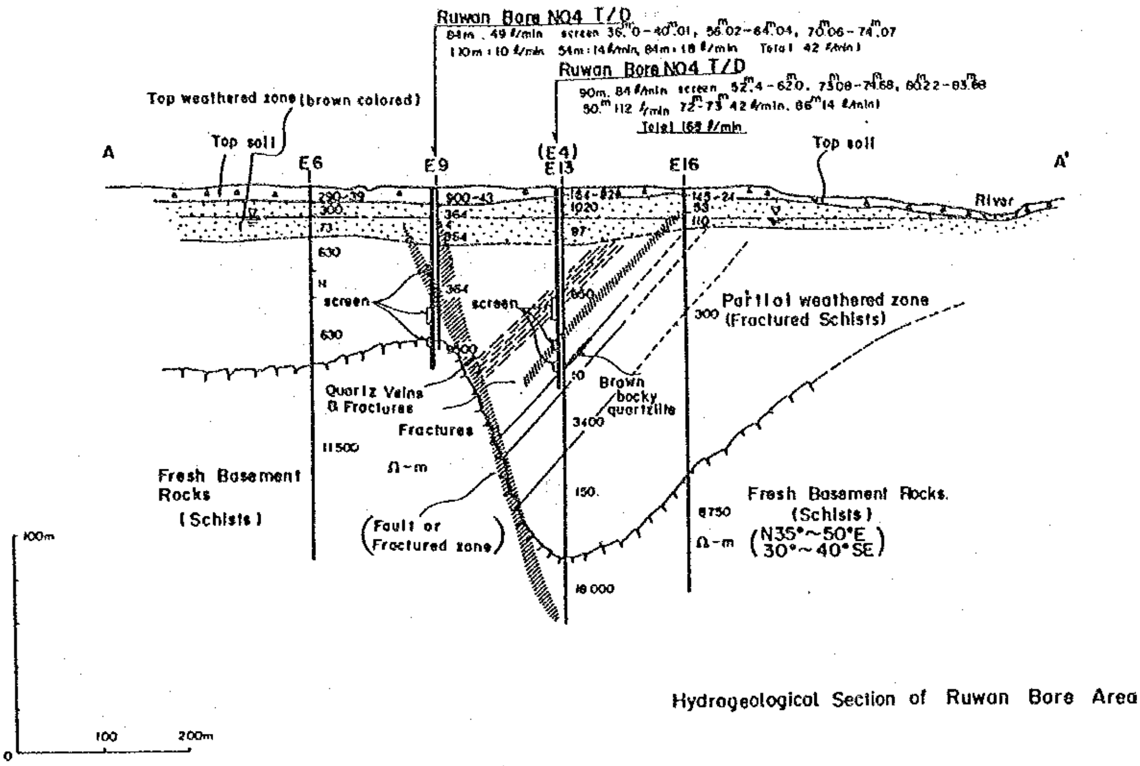
① In the basement complex area, high resistivity, usually higher than 2000Ω-m, was found and taken to indicate fresh bedrock (aquiclude or aquifuge).

② Irregularity and depth to the surface of the fresh bedrock differs greatly from place to place. The shape of deep weathering found in this study is roughly divided into 5 types:

1) Basin-shaped deep weathering controlled by geological structures such as faults, fractured zones and contact zones with pegmatite or quartzite veins and dykes of igneous rock (No. 4 Ruwan Bore, No.7 Dauran No.8 Yambuki and No.10 Maga. Maps are shown in Figures 6-3~6-6).

2) Valley-shaped deep weathering controlled by such geological structures as exampled above. (No.1 Tunga Ardo, No.2 Bullake and No.6 Bamamu. Maps are shown in Figures 6-7~6-9).

3) Deep weathering along rivers, probably in accordance with the lineament of fractured zones (No.15 Zugu, see Figure 6-10).



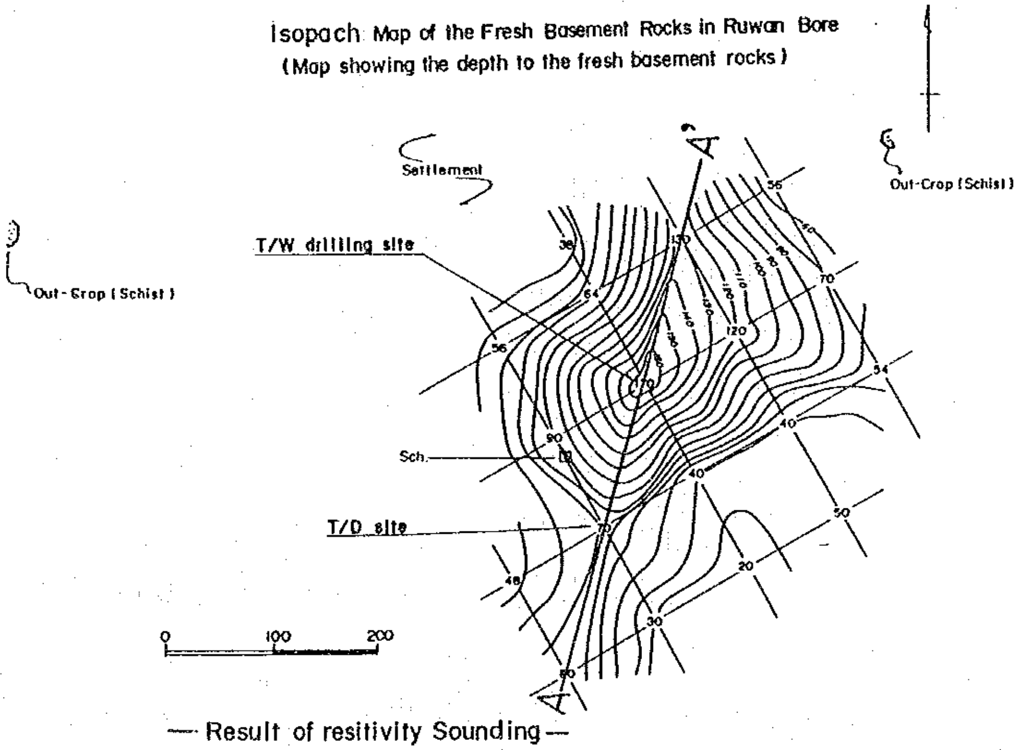


Fig. 6-3 Hydrogeological Profile of Ruwan Bore Area

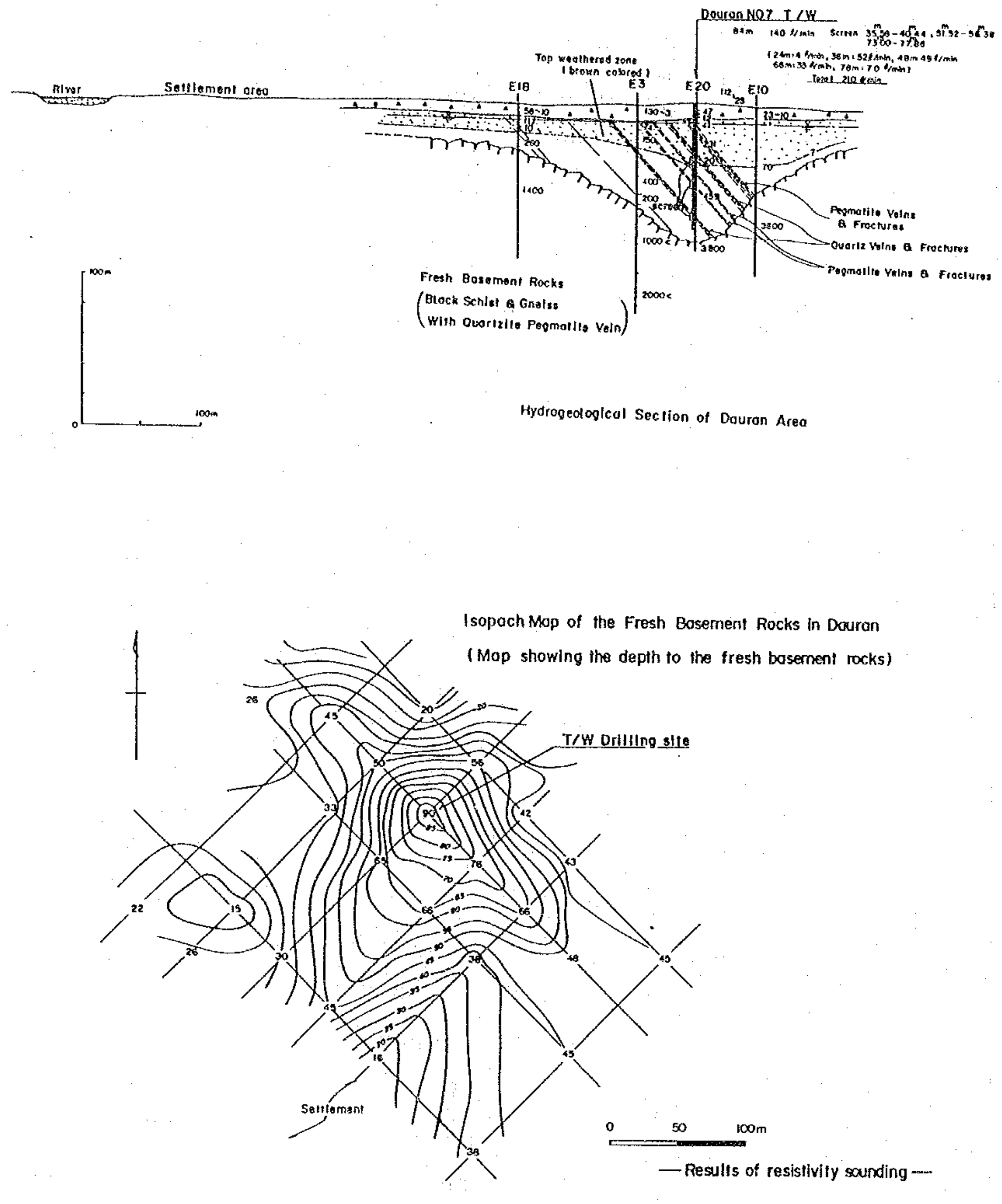
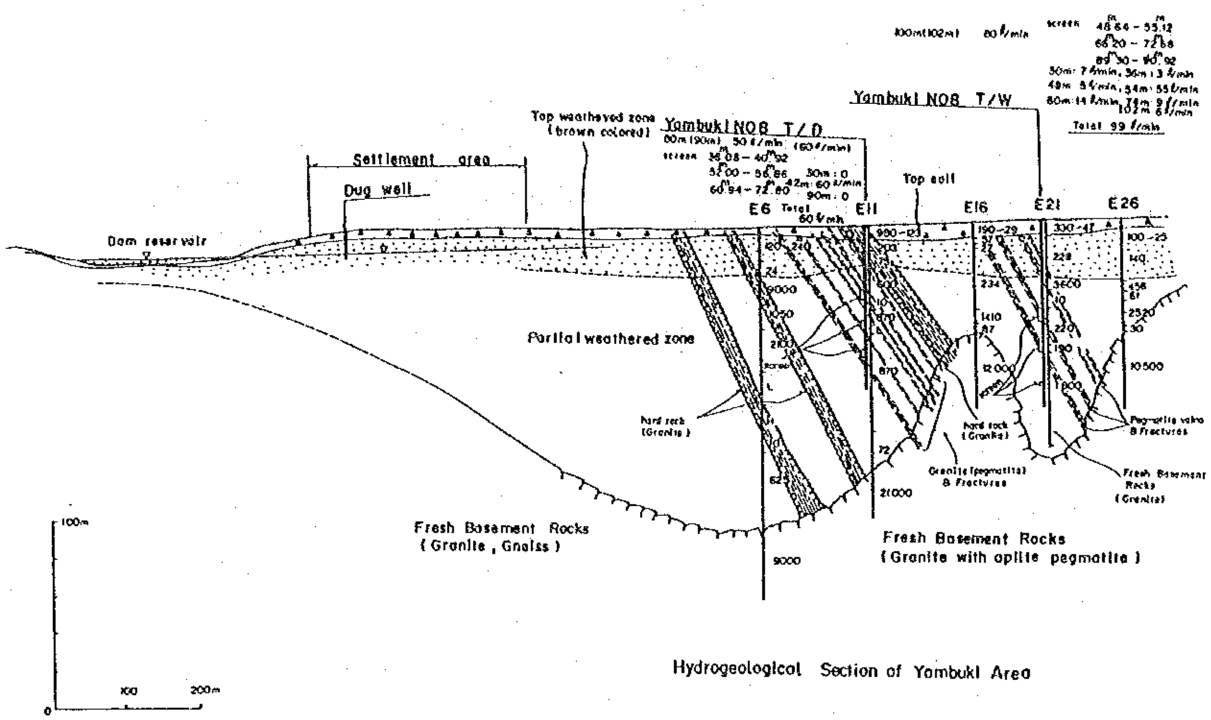


Fig. 6-4 Hydrogeological Profile of Dauran Area



Hydrogeological Section of Yambuki Area

Isopach Map of the Fresh Basement Rocks in Yambuki
(Map Showing the depth to the fresh basement rocks)

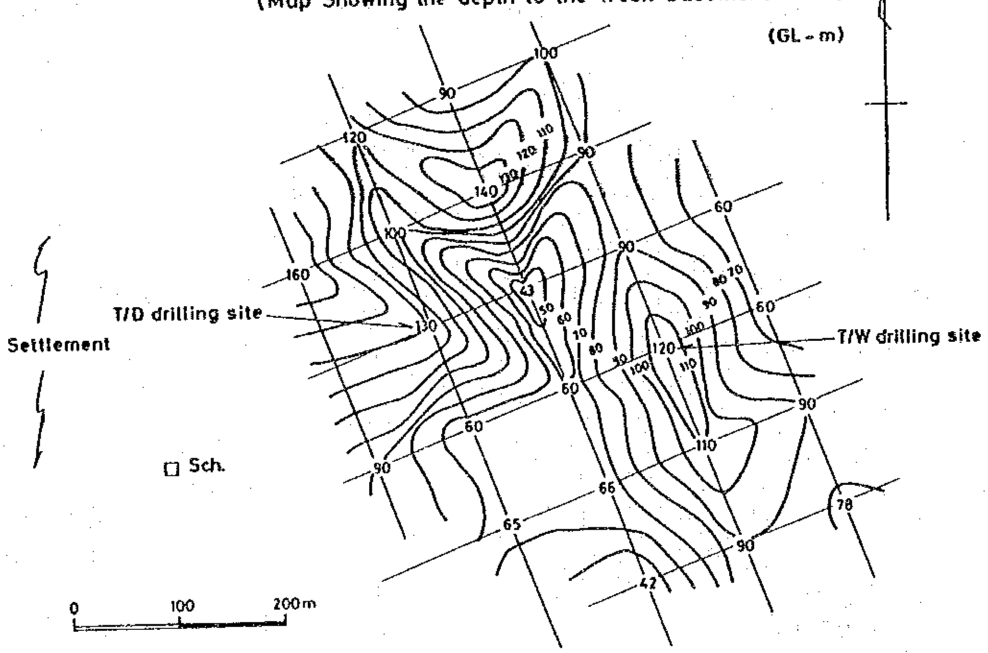


Fig. 6-5 Hydrogeological Profile of Yambuki Area

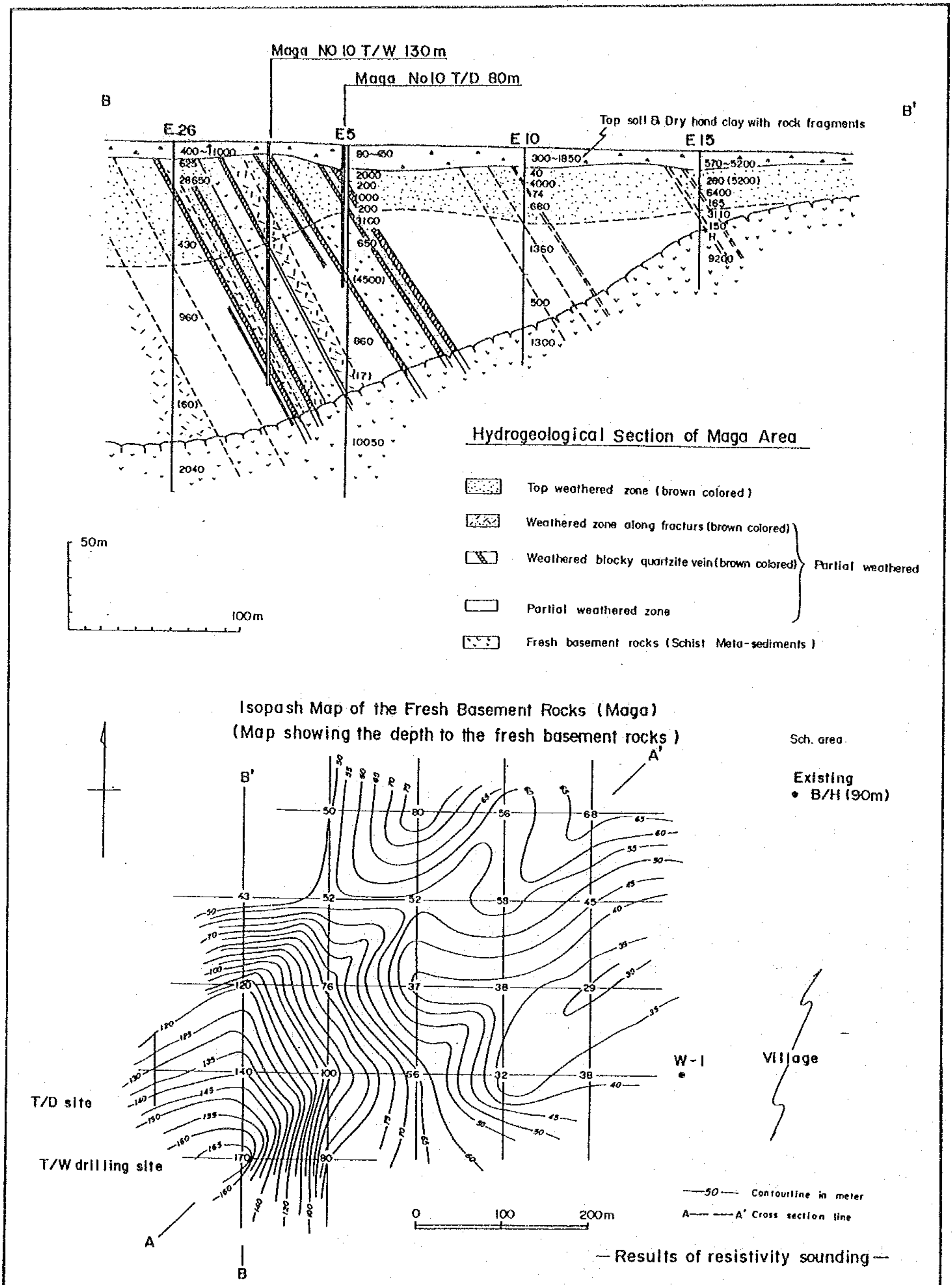
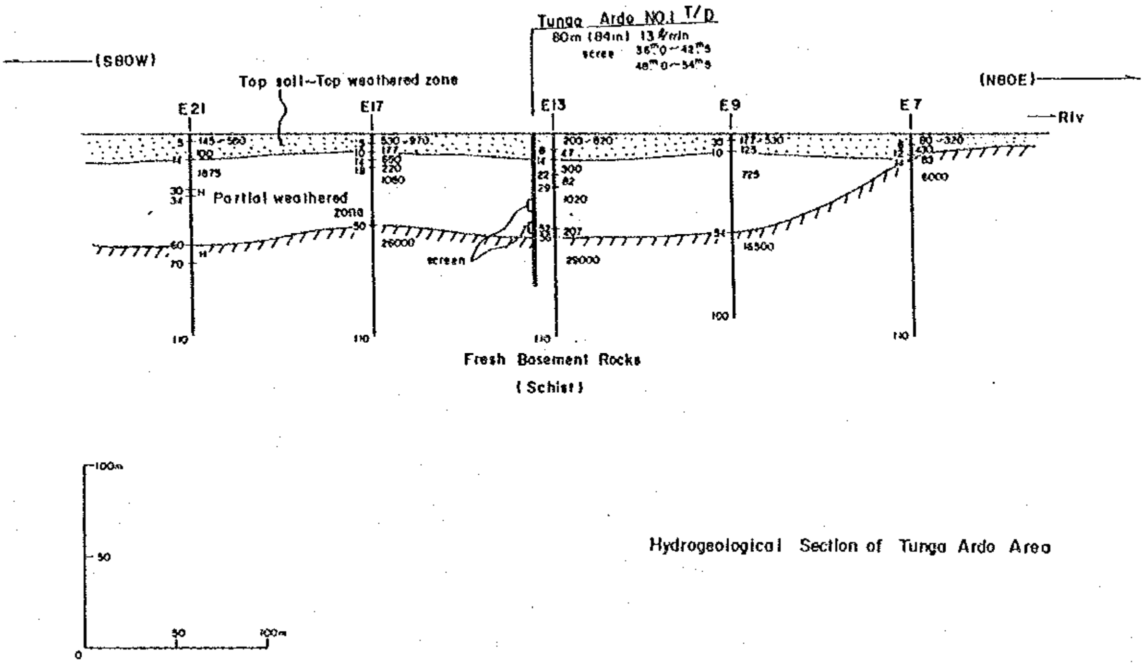
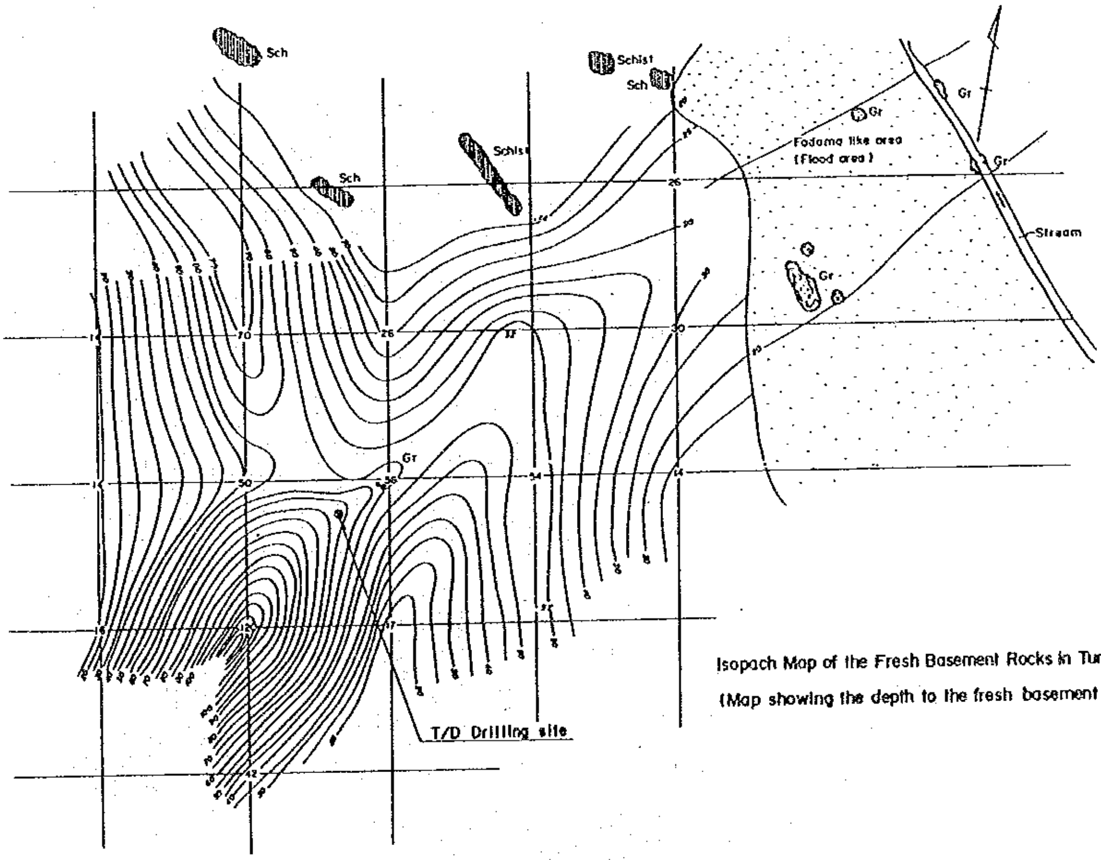


Fig. 6-6 Hydrogeological Profile of Maga Area

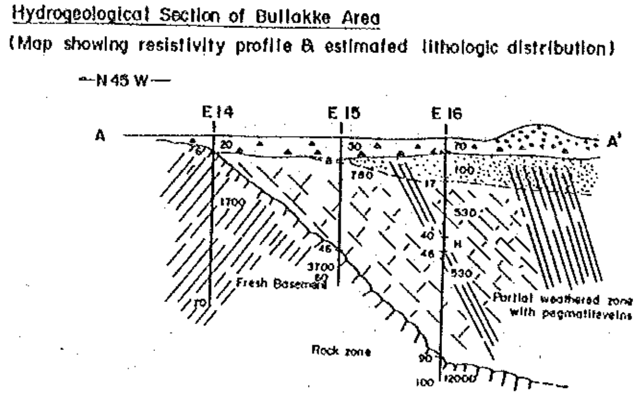


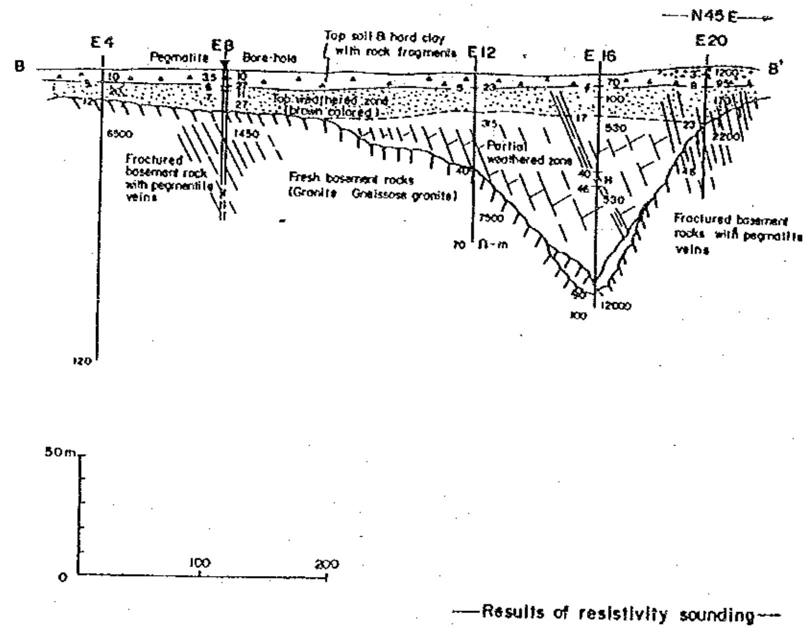
Hydrogeological Section of Tunga Ardo Area



Isopach Map of the Fresh Basement Rocks in Tunga Ardo
(Map showing the depth to the fresh basement rocks)

Fig. 6-7 Hydrogeological Profile of Tunga Ardo Area





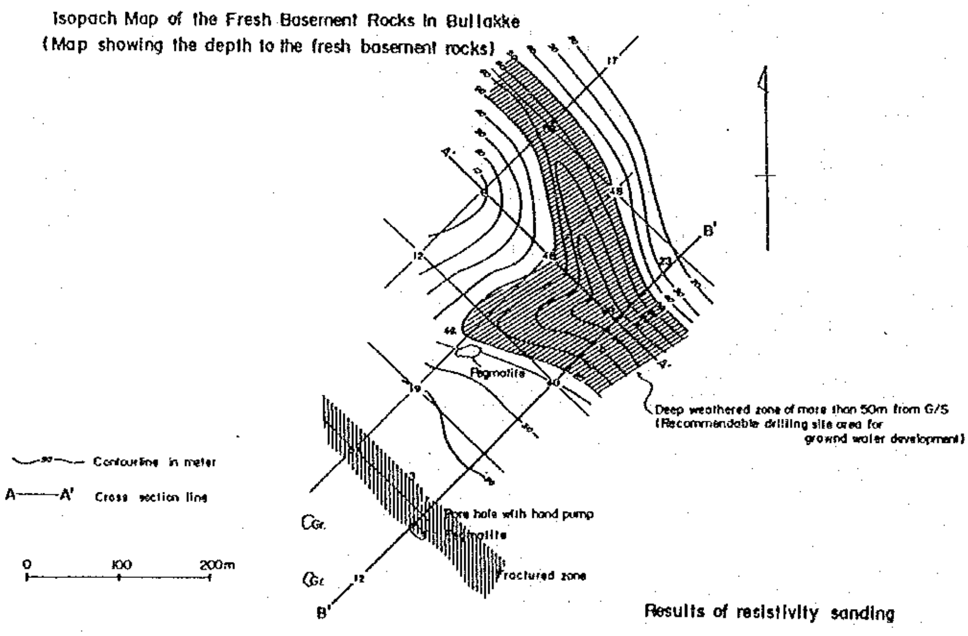


Fig. 6-8 Hydrogeological Profile of Bullake Area

Isopach Map of the Fresh Basement Rocks in Bamamu (No.6)

(Map showing the depth to the fresh basement rocks)

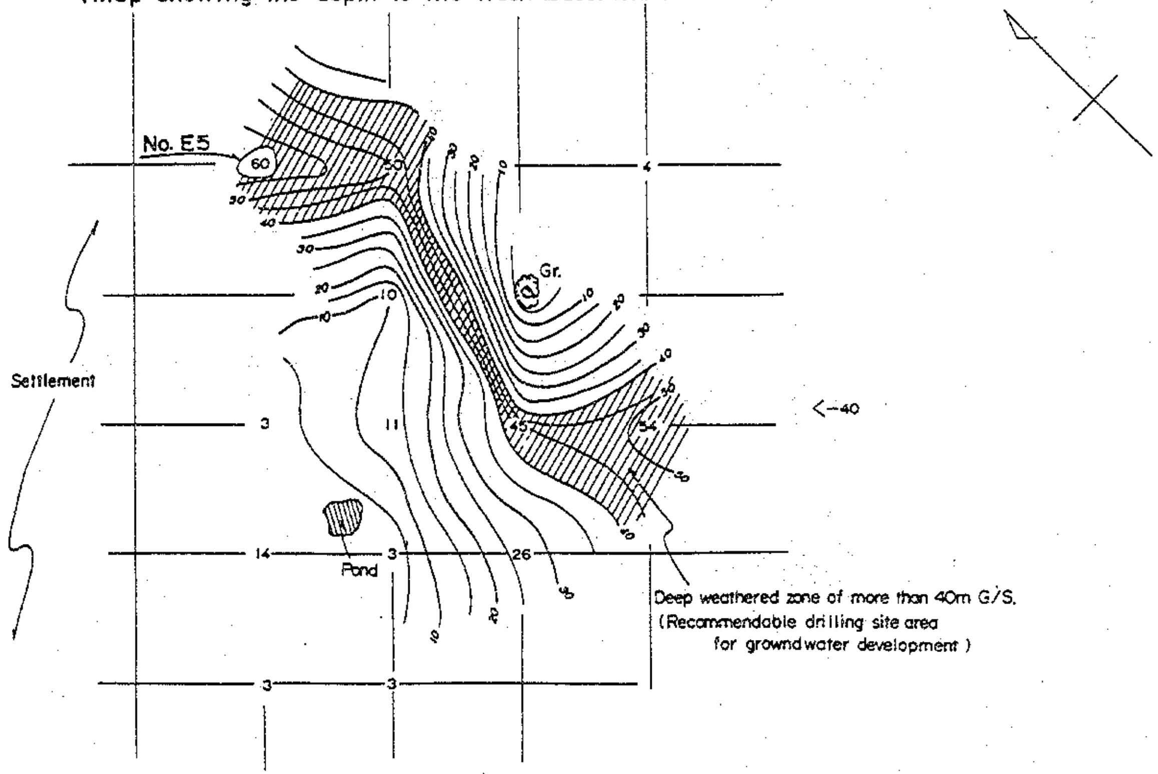
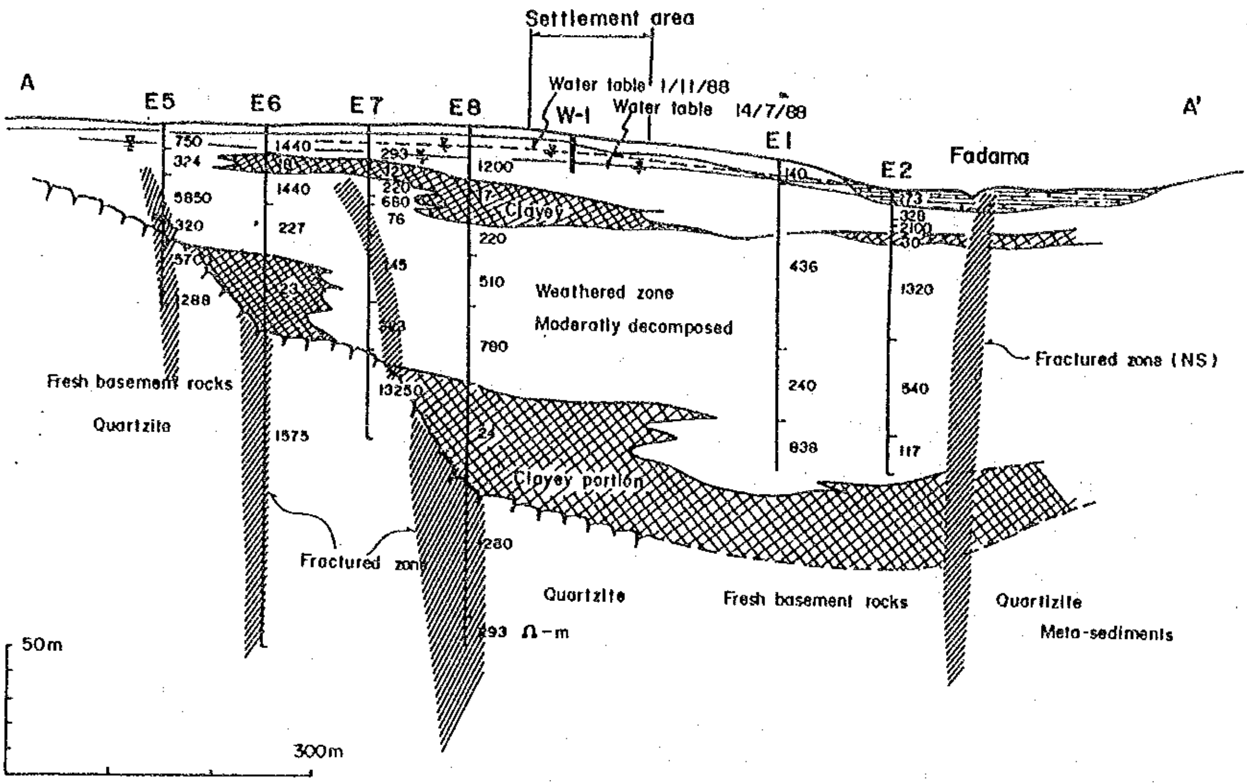


Fig. 6-9 Isopach Map of the Fresh Basement Rocks in Bamamu Area

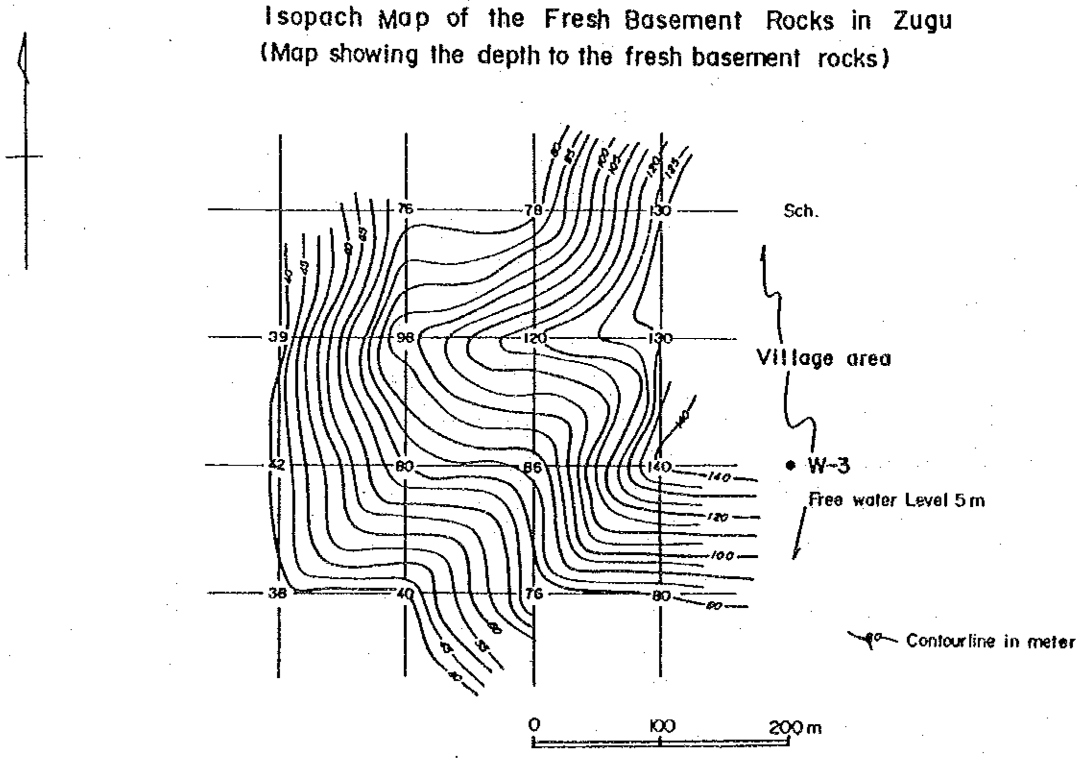


Hydrogeological Section of Zugu Area

(Map showing resistivity profile & estimated lithologic distribution)

Isopach Map of the Fresh Basement Rocks in Zugu

(Map showing the depth to the fresh basement rocks)



—Results of resistivity sounding—

Fig. 6-10 Hydrogeological Profile of Zugu Area

4) Generally monotonous and shallow surface weathering with a depth ranging from 20 to 30m (No.14 Daki Takwas. Map is shown in Figure6-11).

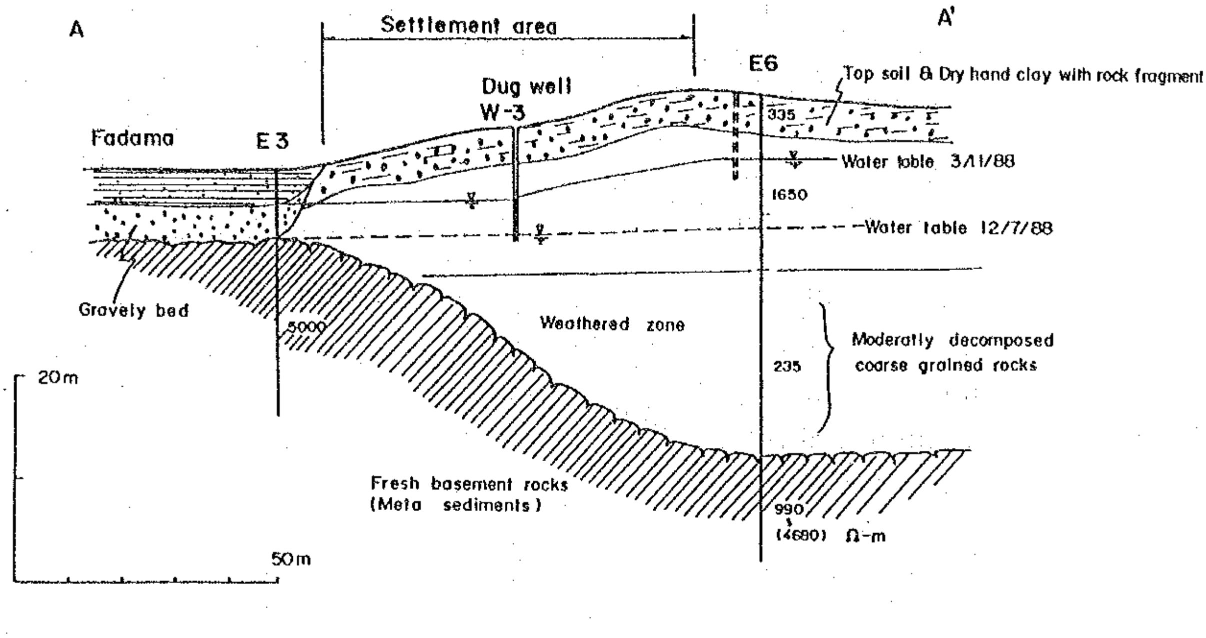
5) Very deep weathering for the entire area, with fracturing and fault clay (No.5 Dokau. Map is shown in Figure 6-12).

③ The possibility of groundwater development, even in the so-called difficult areas, can therefore be optimized, provided proper surveys are conducted prior to well construction. A checkerboard-survey-point pattern with a spacing of 50 to 100m and isopach mapping to the surface of the fresh bedrock area has been recognized to be a very effective means of comprehensive hydrogeological analysis and siting of test drilling points.

④ As mentioned above, many useful findings for groundwater exploration have been found through comprehensive hydrogeological analysis of the results of detailed surveys. In particular, the findings for groundwater exploration in the basement complex area are considered to be very important survey results because one of the major objectives of the Study is to establish an effective method of hydrogeological investigation in the so-called difficult areas where the basement complex is exposed.
The histogram of the average yield of existing boreholes in the basement complex area is given in Figure 6-13. While most of the existing boreholes yielded only 10 to 15ℓ/min., most of the newly constructed boreholes, of which the drilling points were determined basically by the above-mentioned detailed hydrogeological survey, yielded more than 60 ℓ/min. (see Table 6-9).

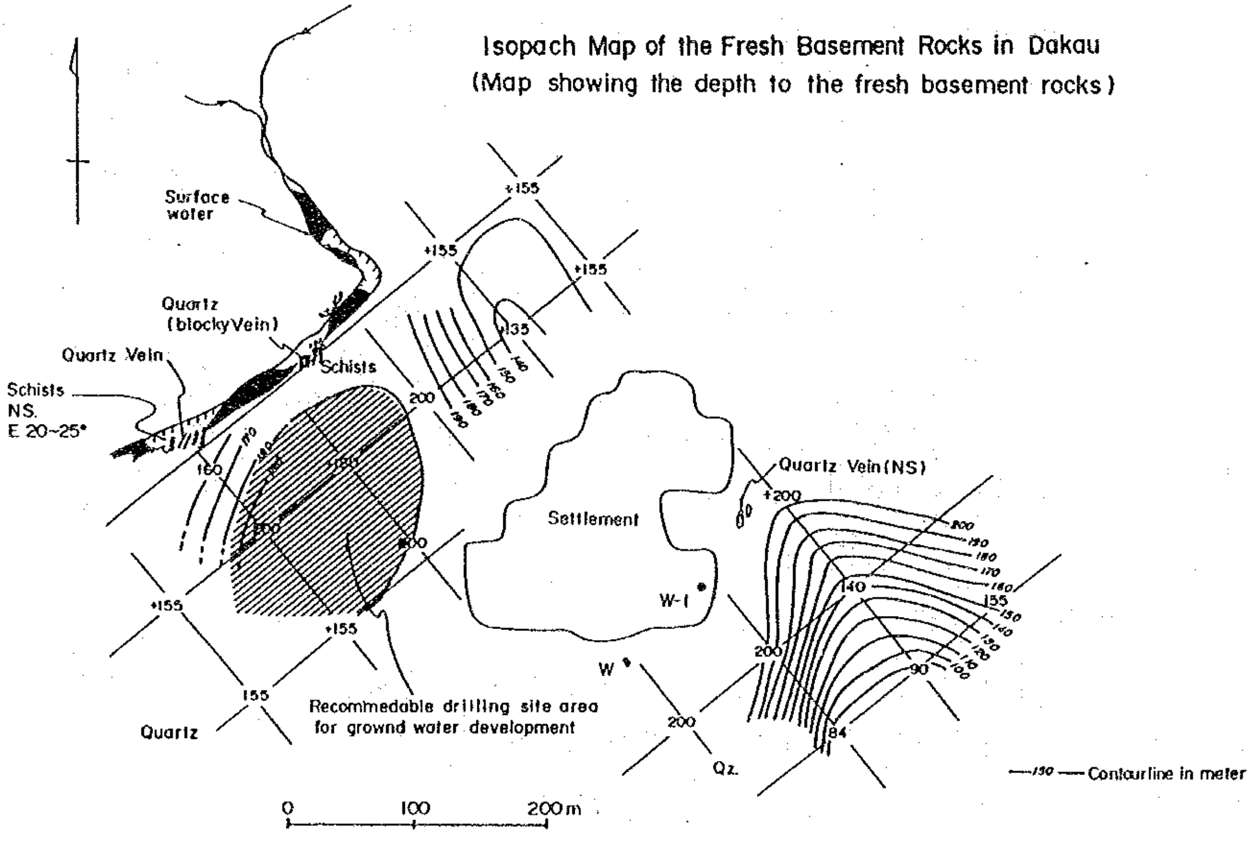
(Sedimentary area)

① In the sedimentary area, the variation of resistivity with depth generally conforms to the stratigraphy, and comparatively higher



Hydrogeological Section of Daki Takwas Area

Fig. 6-11 Hydrogeological Profile of Daki Takwas Area



Result of resitivity Sounding—

Fig. 6-12 Isopach Map of the Fresh Basement Rocks in Dakau Area

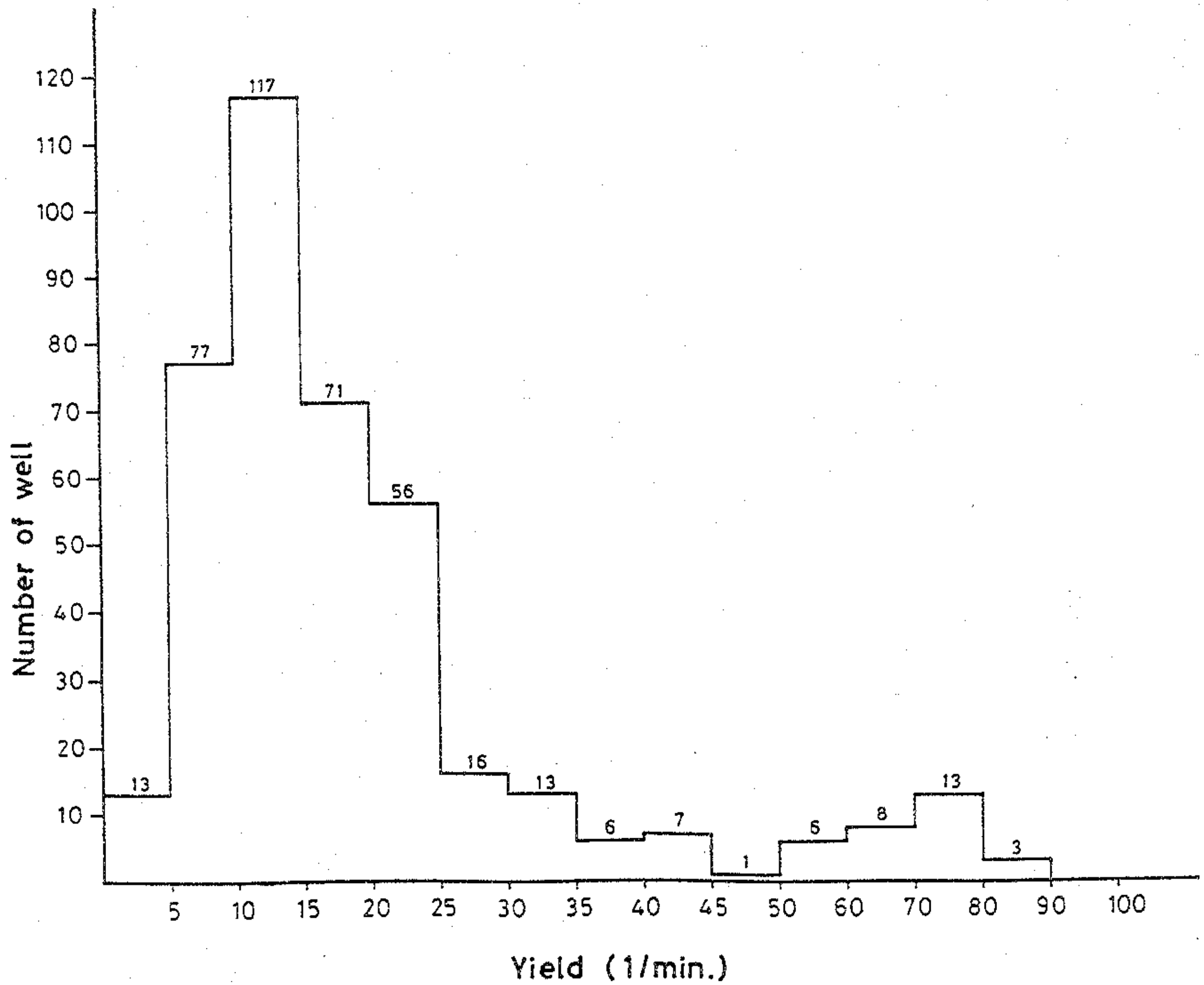


Fig. 6-13 Histogram of Yield Capacity per Single Well in the Basement Complex (407 wells)

Table 6-9 Villages selected for Test Drilling and/or Test Well Construction

Area	Serial No.	Village Name	Local Government	Drilling Depth	
				T/D	T/W
				m	m
Basement rock area	1	Tunga Ardo	Anka	80	-
	4	Ruwan Bore	Gusau	84	90
	7	Dauran	Kaura Namoda	-	84
	8	Yambuki	Kaura Namoda	80	100
	10	Maga	Zuru	84	130
Sedimentary area	23	Horo Birni	Yabo	150	110
	34	Soro	Silame	-	150
	44	Kuka Kogo	Jega	-	110

resistivity indicates a more highly permeable layer, which is a probable aquifer.

② The following correlations are generally found between resistivity and lithology in the Sokoto sedimentary basin:

Resistivity Ω-m	Lithology
From 10 to 50	Clay, Silt, Alt. clay and silt
From to 50 150	Sandy clay, Alt. sand and clay or silt
More than 150	Sand or sandstone (aquifer)
More than 1,000	Coarse sand or sandstone, gravelly sand, limestone (aquifer)

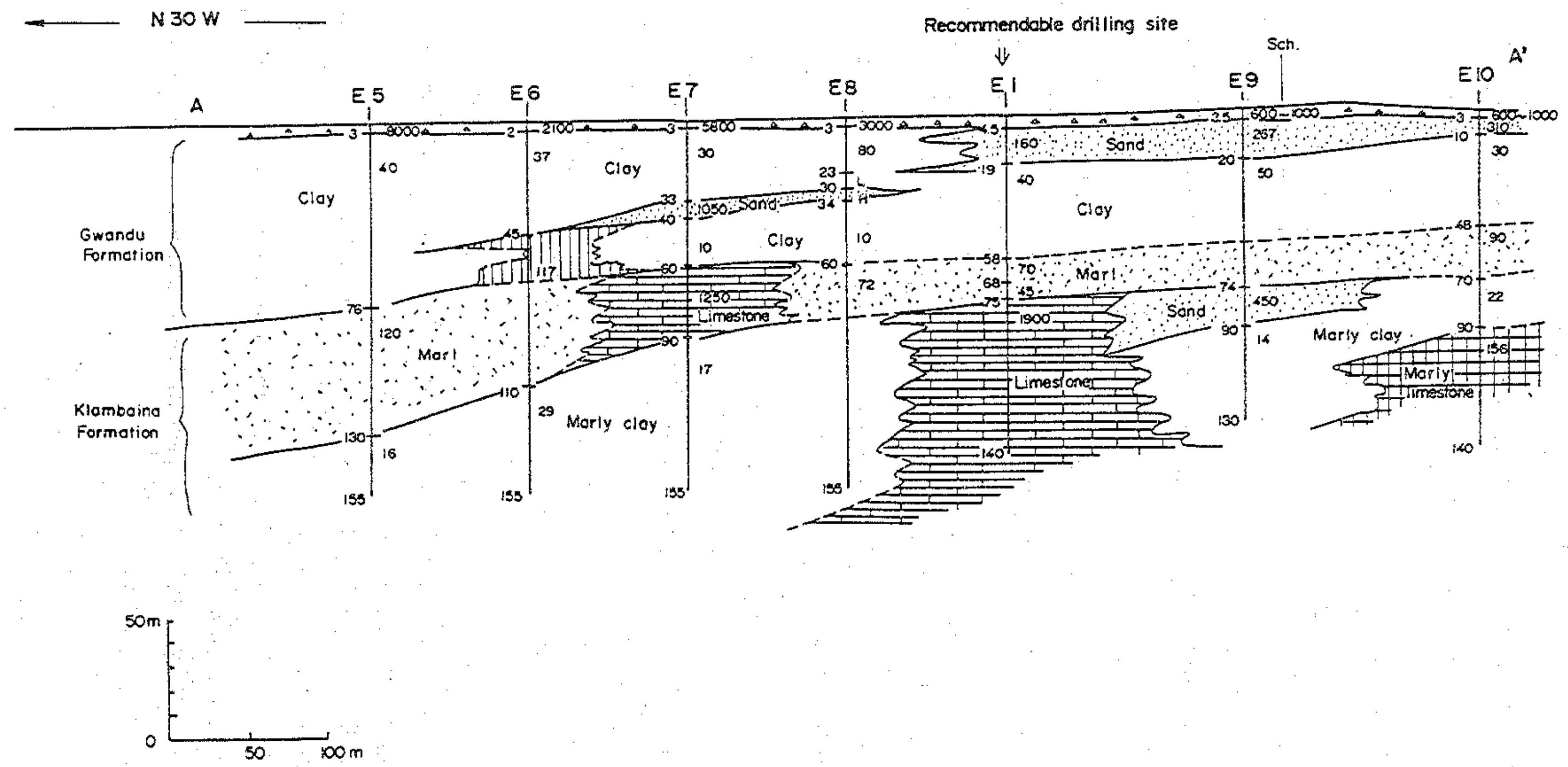
③ However, in some sites which consist mainly of the Kalambaina Formation, such as Gudale (No. 25) and Samalu (No. 47), irregular variation of resistivity is found in neighboring survey points, even though both the ground surface and bedding of the layers are nearly flat. This may be caused by irregular distribution of lenticular limestome, marly limestone, marl and marly sand or marly clay, as shown in Figures 6-14 and 6-15.

④ In some sites which mainly consist of the Illo Formation, such as Takware (No. 18) and Kuka Kogo (No. 44), irregular variation of resistivity is also found in neighboring survey points. This may be caused by irregular sedimentation of lenticular beds, or by other heterogeneous structures caused by an irregular sedimentary environment (see Figures 6-16 and 6-17).

During the detailed survey, an electromagnetic technique using a EM-37 survey kit was applied in selected sites for a comparatively macroscopic survey, focusing mostly on the basement complex area. The field works of this TEM survey, however, were carried out only in the two sites (Ruwan Bore and Tunga Ardo) in the basement complex area, due to a breakdown of the equipment (Transmitter), of which repairs took about 30 days.
Therefore, TEM was mostly used in the additional experimental survey in Zugu as described in 6-4.

Hydrogeological Section of Gudale Area

(Map showing resistivity profile & estimated lithologic distribution)



— Results of resistivity sounding —

Fig. 6-14 Hydrogeological Profile of Gudale Area

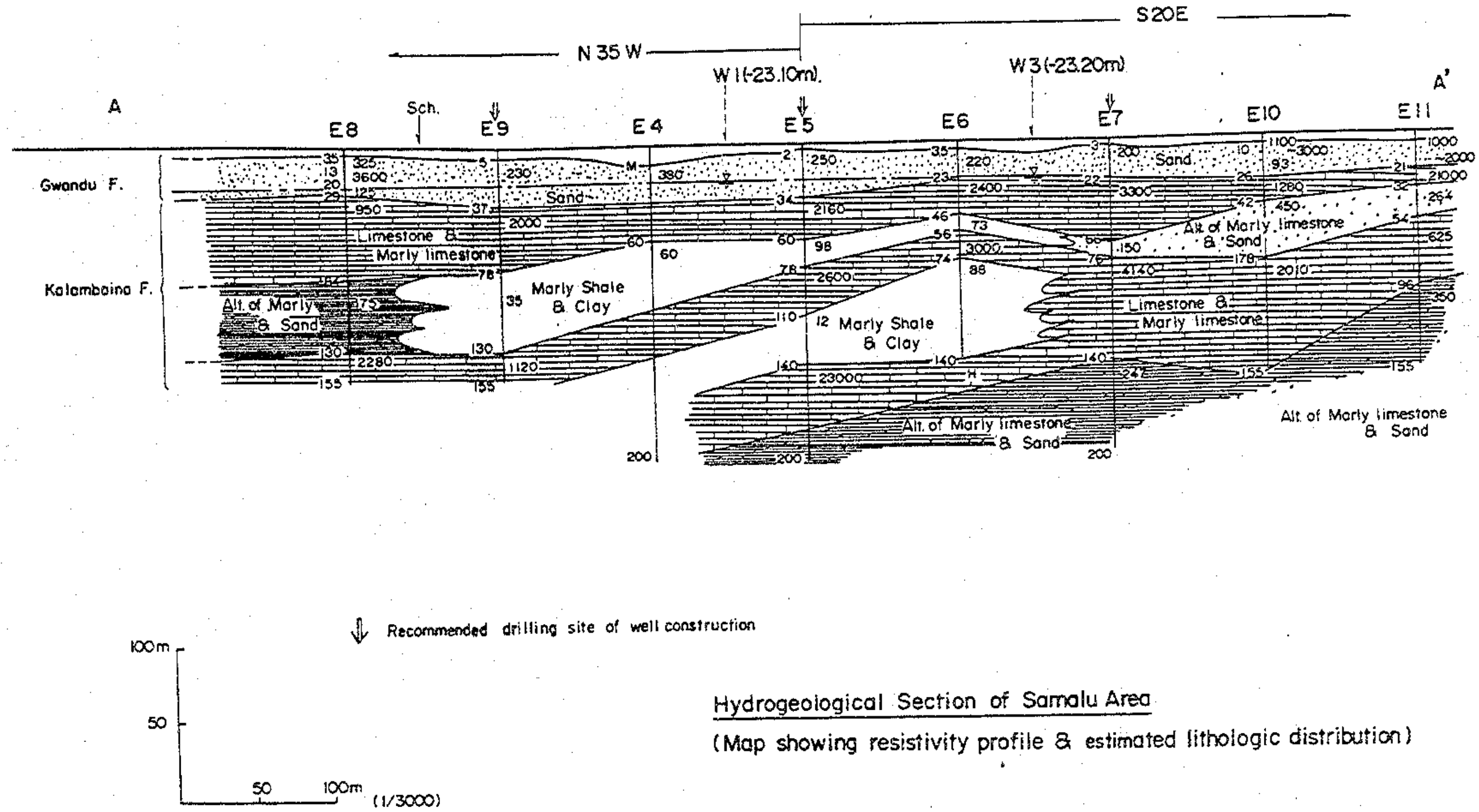


Fig. 6-15 Hydrogeological Profile of Samalu Area

Hydrogeological Section of Takware Area

(Map showing resistivity profile & estimated lithologic distribution)

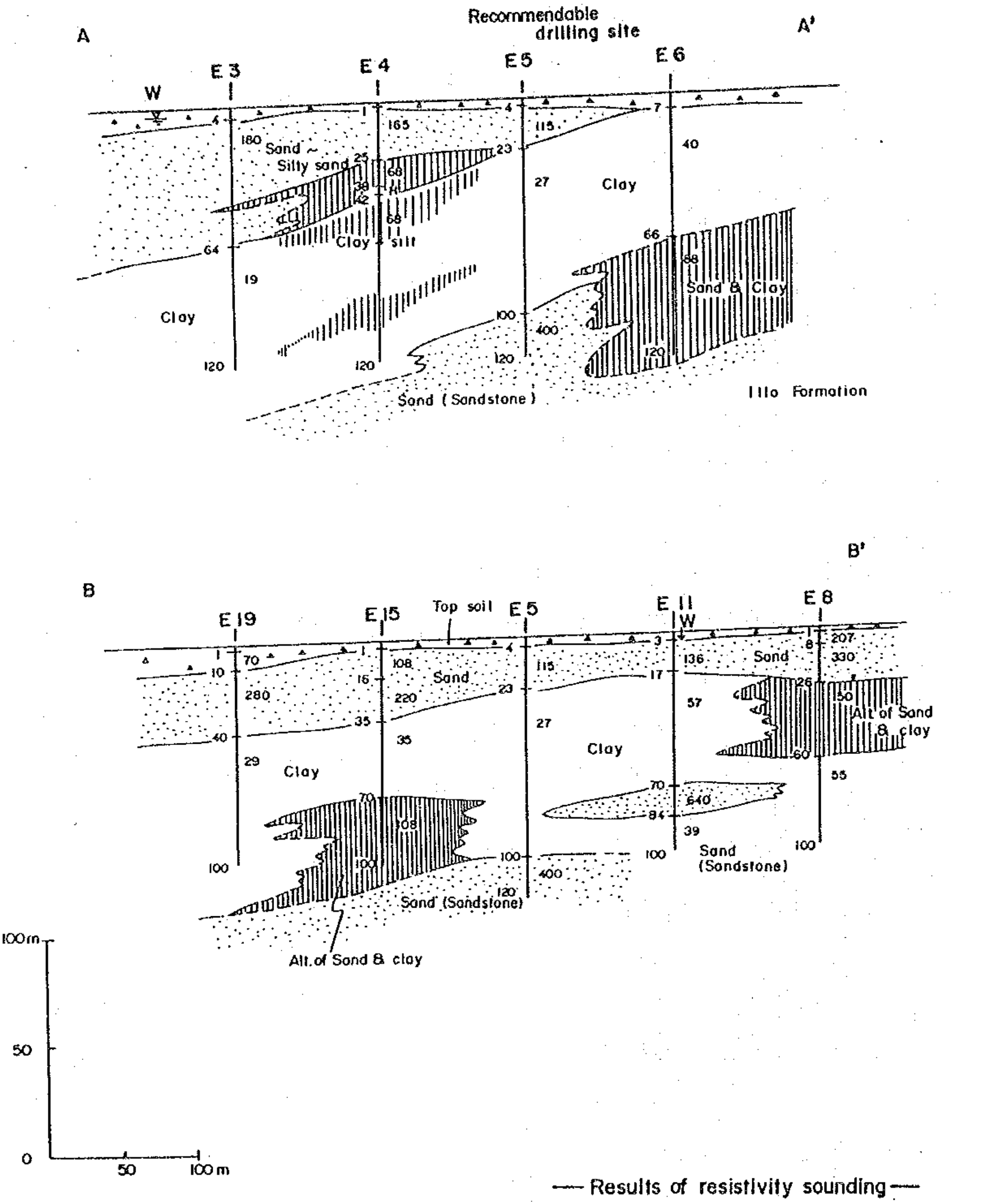


Fig. 6-16 Hydrogeological Profile of Takware Area

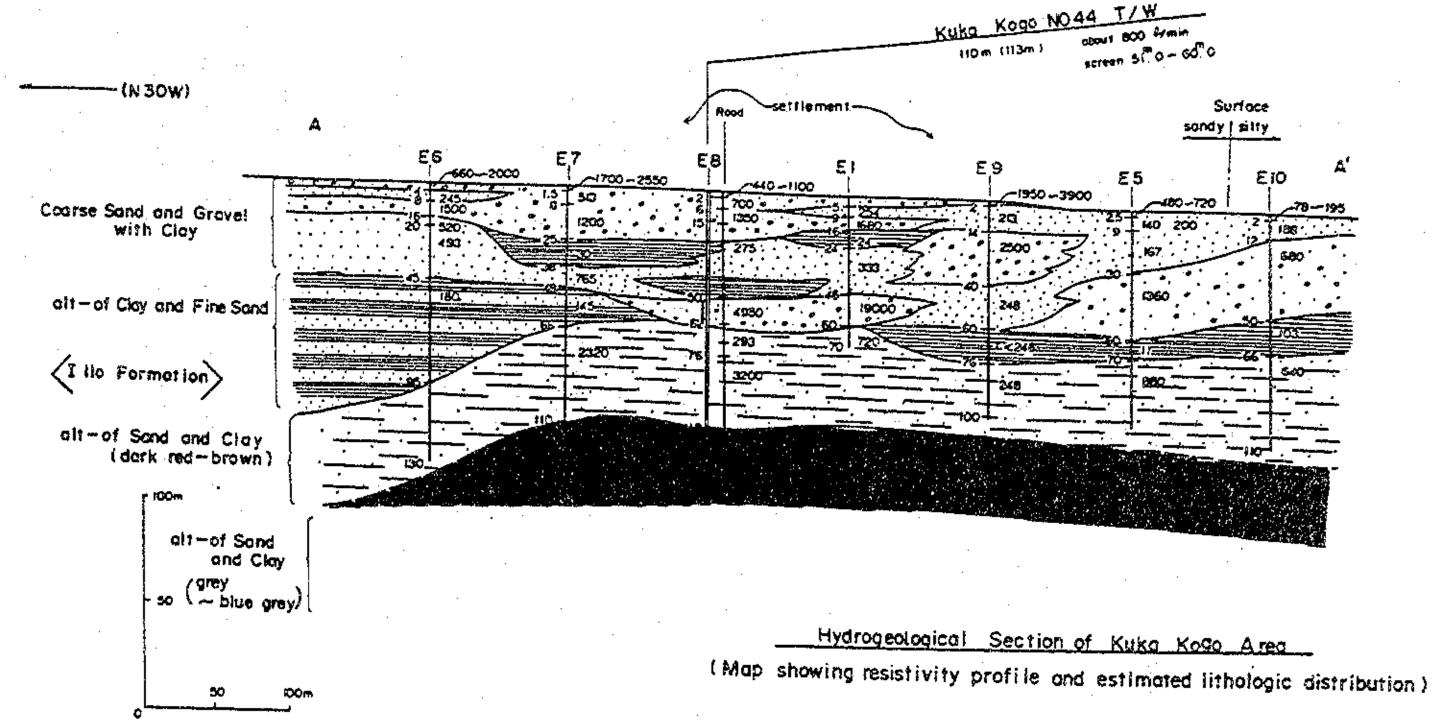


Fig. 6-17 Hydrogeological Profile of Kuka Kogo Area

The principles, measuring system and results of TEM survey are shown in the Supplementary Report 1.

6-2-3 Test drilling and test well construction

For success in groundwater development planning for domestic water supply, the three fundamental conditions shown below should be carefully considered in selecting candidate sites.

① The groundwater development in the site should be hydrogeologically promising.
Both water quality and quantity should satisfy water supply requirements.

② There should be a strong need in the candidate sites for groundwater development. Investment in development should promise a significant improvement of the general public welfare.

③ Inhabitants in the candidate site should be able to afford to share the cost of operation and maintenace of the water supply system.

At the same time, the major objectives of test drilling and well construction in the Study are :

i) To investigate groundwater level and aquifer hydraulic characteristics in order to evaluate the overall potential of groundwater resources in Sokoto State.

ii) To prepare a groundwater development plan in selected areas.

iii) To establish an effective method to explore and develop groundwater in so-called difficult areas, particularly in the basement complex area.

Based on these considerations, the following eight (8) villages were finally selected as candidate sites for test drilling and/ or test well construction (Table 6-9 and Figure 6-18)

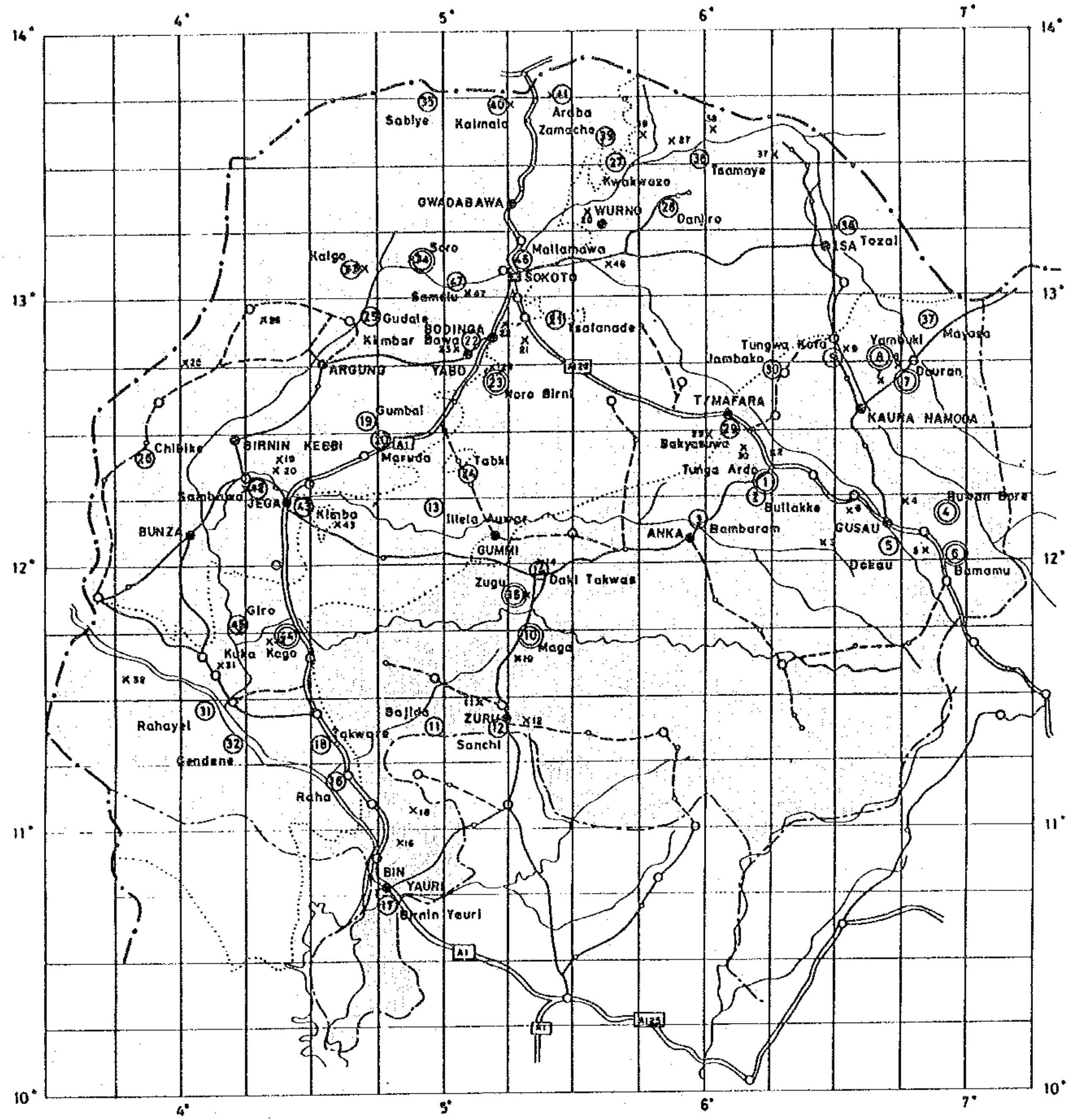


Fig. 6-18 Location map of The Candidate Villages for test drilling and test well construction

Kms 50 0 50 100 150 Kms

◯ Selected villages for the sites of test drilling and test well construction

Sedimentary rock area

Basement rock area

The major considerations for this site selection are summarized in Table 6-8. The results of the detailed hydrogeological analysis to determine drilling locations and the results of the drilling work are given in the Supplementary Report 1.
The drilling work produced the following major findings (Figure 6-19).

(Basement complex area)

Lithologic and geophysical logs of the test boreholes and wells drilled in the basement complex area are given in Figure 6-20.

① In the basement complex area, the deep weathering zone, with a depth to surface of fresh bedrock of more than 50m, can generally be divided into two (2) main weathered rock facies, i.e., the upper weathered rock facies (shallow surface weathering of a brown color) and the lower, partially weathered rock facies controlled by fractures and pegmatite and quartzite veins (see Figure 6-21).

② According to drilling results, it is quite evident that the quantity of water yield by the drilled holes is generally increased by drilling to the lower, partially weathered rock facies, but only after hitting a predominant fracture or pegmatite or quartzite vein. The water quality in the lower, partially weathered rock facies is also better than that of the upper weathered rock facies.

③ As for the selection of drilling sites, the center portion of basin-shaped deep weathering is generally recommended as the best drilling point. Drilling depth should be planned as nearly the same as the depth to surface of fresh bedrock.

④ The average depth of the existing boreholes in the basement complex area is only about 35m. This indicates that almost all existing boreholes probably have been drilled only in the upper weathered rock facies, so that the yielding capacities of the boreholes are generally very poor (Figure 6-13).

⑤ In the basement complex area, geophysical logging alone is ineffective in detecting aquifers and aquifuges (see Figure 6-20).