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Estimating the availability of recharge for long-term support of forestry shelterbelts to protect against desert encroachment along the Nile. FINAL REPORT, MARCH 1990

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BRITISH GEOLOGICAL SURVEY

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EXECUTIVE SUMMARY

Groundwater contouring and geochemical analysis of groundwaters in the Affad basin show the Nile is the major source of groundwater feeding the shallow aquifer. There is therefore no real restriction on the availability of water for shelterbelt development in terms of quantity. Increased abstraction for agricultural purposes or shelterbelt development in the Affad basin will result in a drop in groundwater levels. It is expected this will be small but it is recommended that groundwater levels should be monitored at two or three points on a monthly basis. If a significant fall does occur, a full hydrogeological study should be mounted to quantify the safe yield and best means of development of the groundwater resources of the area.

1. INTRODUCTION

This project began in March 1989 and was part of the ODA sponsored, BGS R & D programme for the financial year 1989-90. The original project document is attached as Appendix A.

SOS Sahel, along with many other agencies, are promoting shelterbelt development at various locations along the Nile with the intention of protecting long-established agricultural communities from dune encroachment. The figure in Appendix A shows the location of the SOS Sahel forestry project. All the work described in this document is related to the Affad basin, shown on the same figure.

The long term success of shelterbelt development depends, amongst other things, on the availability of a permanent supply of groundwater for irrigation water for the trees. Also, the abstraction of this irrigation water should not significantly reduce the availability of water required by the existing riverside agricultural practices.

2. PROJECT DESIGN

BGS agreed to assist SOS Sahel in assessing whether the groundwater supply to the shelterbelt in Assad basin could be maintained over several years and whether use of this extra water would affect existing supplies. The project was to be as economical as possible so as to be appropriate to the low cost of the development project proper. So, whilst it would be necessary to mount an extremely expensive and long-term drilling programme to give reasonably accurate quantitative answers to the questions, in the first instance a qualitative approach was adopted. The need and quality of future work would depend on the results of this qualitative approach.

BGS had previously carried out a study of the aquifer system near Shendi to the south (Edmunds et al., 1987), also, global studies of the regional aquifer system are available (Brinkmann and Heinl, 1985). This previous work suggested that recharge from rainfall was negligible and that the Nile may be the sole source of all groundwater in the project area. The approach adopted in this study was to test this hypothesis and then draw conclusions as to the effects of increased development of the groundwater for shelterbelt use.

3. GROUNDWATER PIEZOMETRIC STUDY

BGS provided SOS Sahel with two graduated barometers suitable for determining approximate ground levels rapidly. Fig. 1 is a sketch map of the pilot area studies, the Affad basin. The barometers were calibrated against each other over the course of a morning by moving both barometers simultaneously around the extremes of the topography of the location. Table 1 summarises the results and indicates that barometer 1 reads consistently 19 ± 3 m, greater than barometer 2.

Table 1 Barometer Correlation (metres).

No. 1	No. 2	Difference
291	275	+16
300	285	+15
298	281	+17
289	267	+22
302	282	+20
310	289	+21
315	295	+20
301	280	+21
		Avg = 19 ± 3

Barometer 2 was then kept at the fixed point shown on the sketch map and barometer 1 was used to take ground level readings at all the points shown on the map. At each point the wells were dipped and so an estimate of the groundwater level relative to that of the fixed point shown could be gained. Table 2 lists the readings made. Fig. 2 shows the apparent difference in groundwater level recorded (± 3 m) and the deduced approximate contours of groundwater level.

3.1 Interpretation of Data

The contours of groundwater level, although only approximate, confirm that the water table dips away from the Nile to the north. This suggests strongly that the Nile is the main source of water for the aquifer system on the northern bank. These results confirm that the Nile is the main source of water for the aquifers in the right-hand bank. This situation is exactly that found at Shendi/Kaboutir in an earlier BGS study (Edmunds et al., 1987). It is also known that the Nile acts as a source of recharge on a regional scale to the Nubian Sandstone aquifers of the south-western bank (Brinkmann and Heinl, 1986).

4. GEOCHEMICAL STUDY

4.1 Background

Recent studies in the Shendi area (Wadi Hawad-Abu Delaig) have shown that it is possible to distinguish River Nile recharge water on the basis of its chemical and/or stable isotope contents from palaeowaters. This is important evidence for deciding whether further abstraction for various purposes, including shelterbelt planting is derived from renewable water resources (the Nile) or from palaeowaters which effectively would need to be mined. The situation is summarised on the cation trilinear diagrams (Fig. 3) where the baseflow of the River Nile at Shendi is represented by water with a significantly enriched Mg/Ca ratio when compared with Nile flood water derived mainly from the Blue Nile. Boreholes drilled in Wadi Hawad give a water composition close to that of the Nile baseflow and the few shallow wells in the Nile Valley of the Shendi area are slightly enriched in Mg/Ca above that of the Nile. The high flow compositions are generally unimportant in influencing the groundwater chemistry. Any palaeowater has a composition lower in Mg/Ca ratio.

Table 2. Barometer Water Level Difference Survey

Well No.	Distance from river (m)	Depth (m)	Time	Moving Barometer (No. 1)	Stationery Barometer (No. 2)
1	500	5.70	7.35	305	285
2	760	6.44	7.45	305	285
3	960	5.53	7.50	301	285
4	800	5.85	7.55	301	285
5	830	5.72	8.00	300	280
6	1400	5.00	8.05	301	280
7	1220	5.53	8.10	300	280
8	1150	5.88	8.15	300	280
9	1040	5.38	8.20	299	280
10	1580	5.60	8.25	299	279
11	1620	6.22	8.25	299	279
12	1310	6.28	8.30	299	279
13	1210	5.56	8.30	295	279
29	3000	6.78	8.35	292	279
27	2850	6.40	8.40	291	279
28	2900	8.14	8.45	295	279
26	2800	7.35	8.50	292	275
25	2700	9.63	8.50	291	275
24	2980	5.50	8.55	291	275
22	2840	8.45	9.00	291	275
23	2900	8.10	9.05	293	275
21	2720	8.00	9.05	291	275
19	2800	7.10	9.10	291	275
20	2800	7.20	9.15	289	275
18	2300	6.60	9.20	289	275
15	1080	5.48	9.25	288	275
16	800	7.40	9.25	290	275
17	1000	6.90	9.30	290	272
14	1150	7.00	9.35	290	272

This simple chemical picture has been confirmed by the use of stable isotope ratios of oxygen and hydrogen in the groundwater (Fig. 4). The palaeowater can be confirmed by the very light (negative) values of $\delta^{18}O$ and $\delta^{2}H$, In the present study it was decided only to investigate the chemical parameters in view of the confidence provided by the previous studies of the Nile surface-groundwater system.

4.2 Sampling, Analysis and Results

Samples of the River Nile were collected from mid-stream by SOS Sahel staff over the period October 1988-June 1989. No local data were available on the flow of the river over this period but this coincided with the extreme rainfall and flooding of the Nile Valley between July-September 1988 (Sutcliffe et al., 1989). The flood peak at Dongola was reached on September 3rd some 16 days after Khartoum (Fig. 5). It is assumed that flooding of the Ed Debba region occurred at this time affecting shallow wells but the effect or extent is not known for the basis of this report.

Shallow wells were sampled on 6th August 1989 in the villages near to Ed Debba, shown in the map in the Appendix, nearly one year after the flood. Samples received at Wallingford were analysed by ICP-OES for most major and some minor elements and by automated colorimetry for chloride and nitrate. All results are presented in Table 3 in mg l^{-1} and in Table 4 as meq l^{-1}. In Table 5 the ionic balances are given where it is seen that with two exceptions, the balances are below 6% indicating reasonable analysis, bearing in mind that bicarbonate was measured in the laboratory rather than in the field.

The River Nile has a distinctive chemistry which varies with flow throughout the year. The flood water can be recognised most easily by the low chloride (2 mg l^{-1}) rising to 16 mg l^{-1} during the period of baseflow. By comparison the groundwaters have a higher chloride indicating some concentration by evaporation or mixing with more saline water. The main chemical characteristics of the river water are shown in Fig. 6. The trend is from a relatively Ca-rich composition at high flow to a water enriched in Na and Mg relative to calcium at low flow.

4.3 Surface and Groundwater Chemistry

4.3.1 The Chemistry of the River Nile.

The distinctive chemistry of the River Nile is illustrated in Fig. 3 for data from Shendi where the effect of the Blue Nile Flood is seen in a high calcium composition. The White Nile baseflow, occurring in spring and early summer has a chemistry much more enriched in magnesium (Mg/Ca ratio of around 1). In between these two periods a mixed composition is found. The data from the present study also lie along the same compositional trend (Fig. 6) one exception being the flood water of 10/88 which from its unique composition carries for one month the influence of runoff from catchments other than two main Nile sources.

The flood water can also be recognised (Table 3) by the very low chloride as well as the total amount of dissolved constituents (Table 5). In previous work, it was concluded that the River Nile acts as a perennial recharge source to adjacent aquifers which can be recognised by the chemical characteristics of the river at baseflow. The flood water is unimportant as a recharge source in normal years but if actual flooding occurs as in 1988, then it is almost certain that some direct vertical recharge will also occur.

ID	Locality	Date	pH	Na	K	Ca	Mg	HCO3	SO4	Cl	NO3-N	Si	Sr	Ba	B	Fe	Mn
				mg/l									ug/l				
900271	ABU SAID 1	060889	8.63*	360.0	1.9	2.8	2.7	793*	64.7	38.5	2.6	16.0	56	5	86	<15	<3.0
900272	ABU SAID 2	060889	8.43*	278.0	7.7	21.3	21.7	602*	72.5	146.0	3.8	18.5	270	34	61	<15	<3.0
900273	ABU SAID 3	060889	8.23*	89.6	7.1	28.9	20.1	296*	49.8	34.0	3.7	24.4	226	25	34	<15	<3.0
900274	ABU SAID 4	060889	7.89*	177.0	11.8	15.1	41.2	285*	169.0	126.0	8.4	17.0	334	33	37	<15	<3.0
900275	ABU SAID 5	060889	8.25*	89.6	10.2	39.5	90.4	251*	273.0	115.0	4.9	28.9	703	35	32	<15	<3.0
900276	GHALA'A 6	060889	7.61*	48.8	4.5	13.4	17.1	195*	34.4	13.0	1.6	33.5	246	19	35	<15	<3.0
900277	GHALA'A 7	060889	8.48*	190.0	6.6	24.9	7.7	461*	57.6	26.0	5.7	33.9	173	22	65	<15	<3.0
900278	GHALA'A 8	060889	8.61*	240.0	6.4	18.1	10.2	463*	106.0	70.0	13.4	37.9	165	19	69	<15	<3.0
900279	GHALA'A 9	060889	7.74*	106.0	10.1	14.2	16.5	192*	124.0	35.0	3.1	29.6	304	35	73	<15	<3.0
900280	GHALA'A 10	060889	7.68*	58.6	9.8	18.7	26.9	178*	66.1	48.0	11.0	23.9	424	46	72	<15	<3.0
900281	GHALA'A 11	060889	8.10*	28.9	8.2	65.8	14.6	231*	42.3	30.5	11.0	22.1	451	45	52	<15	<3.0
900282	GHALA'A 12	060889	8.38*	177.0	8.0	29.1	18.2	409*	140.0	40.0	5.4	26.9	248	26	33	<15	<3.0
900283	GHALA'A 13	060889	8.17*	1040.0	14.0	18.1	20.9	363*	1690.0	210.0	30.7	35.2	478	33	32	<15	<3.0
900284	HIZENAB 14	060889	7.62*	68.5	6.6	13.9	11.7	160*	75.9	15.5	2.7	28.8	197	19	22	18	<3.0
900285	HIZENAB 15	060889	8.56*	162.0	8.1	30.5	23.5	419*	137.0	36.0	2.6	36.5	262	37	19	<15	<3.0
900286	HIZENAB 16	060889	8.41*	128.0	6.2	6.5	13.8	409*	66.9	23.0	6.2	22.8	158	13	28	<15	<3.0
900287	HIZENAB 17	060889	7.89*	81.2	5.1	7.6	11.3	225*	33.0	12.5	2.7	26.3	128	10	24	<15	<3.0
900288	JIMAB 18	060889	8.23*	95.2	6.7	35.7	31.2	338*	72.7	55.5	1.6	31.3	200	16	24	<15	<3.0
900289	JIMAB 19	060889	8.01*	138.0	5.4	10.7	6.7	324*	52.8	20.5	1.6	33.6	97	9	22	<15	<3.0
900290	JIMAB 20	060889	7.95*	94.1	5.6	18.6	7.8	282*	34.8	16.5	1.5	23.7	135	16	22	<15	<3.0
900291	JIMAB 21	060889	8.32*	129.0	5.1	11.3	17.7	303*	94.4	36.0	<0.3	32.8	167	14	28	<15	<3.0
900292	JIMAB 22	060889	8.18*	81.0	5.7	25.7	15.4	239*	75.3	27.5	<0.3	25.3	190	20	33	<15	<3.0
900293	JIMAB 23	060889	7.63*	77.5	5.6	21.1	19.2	211*	82.6	27.5	1.6	30.7	244	20	20	<15	<3.0
900294	JIMAB 24	060889	8.15*	42.8	5.4	46.2	54.7	142*	183.0	93.0		48.2	397	26	44	<15	<3.0
900295	NUGDALAB 25	060889	8.07*	416.0	5.5	54.1	49.2	277*	707.0	216.0	17.3	23.4	684	55	27	<15	<3.0
900296	NUGDALAB 26	060889	7.95*	99.8	3.5	23.3	12.5	214*	97.5	29.5	2.7	26.0	188	15	22	<15	<3.0
900297	NUGDALAB 27	060889	8.00*	22.0	2.4	35.6	21.6	216*	44.5	19.5	0.7	36.1	192	23	28	<15	<3.0
900298	NUGDALAB 28	060889	8.56*	524.0	4.4	16.6	10.9	552*	492.0	198.0	2.3	24.4	234	21	17	<15	<3.0
900299	NUGDALAB 29	060889	7.98*	125.0	6.1	10.1	8.4	285*	61.2	42.5	2.4	22.6	119	12	27	<15	<3.0
900300	R.NILE	231088	6.97*	11.6	2.8	8.5	1.9	56*	6.0	6.0	<0.3	5.5	85	8	<10	<15	<3.0
900301	R.NILE	231188	7.07*	11.8	3.4	8.9	4.1	77*	6.6	2.0	<0.3	3.0	35	10	20	31	<3.0
900302	R.NILE	231288	7.37*	14.6	4.9	10.2	5.5	89*	4.7	3.8	<0.3	7.4	99	11	19	<15	<3.0
900303	R.NILE	230189	7.44*	23.8	8.4	10.0	7.0	178*	4.6	7.2		4.6	103	19	39	25	5.0
900304	R.NILE	020389	7.98*	18.7	6.0	17.6	6.8	156*	3.7	4.0	<0.3	0.4	139	19	16	<15	<3.0
900305	R.NILE	260389	7.51*	20.6	6.1	19.1	7.4	142*	5.0	6.0	<0.3	8.1	156	23	20	<15	<3.0
900306	R.NILE	250689	7.57*	25.8	9.3	21.2	9.2	160*	11.2	10.2	<0.3	5.3	188	32	18	<15	<3.0
900307	R.NILE	230789	7.52*	20.7	6.3	31.6	9.6	160*	11.1	16.5	2.3	7.5	209	32	19	<15	<3.0
900308	R.NILE	060889	7.44*	16.8	4.3	31.8	7.6	125*	13.3	10.2	4.4	6.3	175	25	14	<15	<3.0

Table 3. Chemical analyses of shallow groundwaters from the Shelterbelt area and flood plain villages together with the River Nile (mg l^{-1}).

Table 4. Analyses expressed as milliequivalents per litre.

Locality	Calcium	Magnesium	Sodium	Potassium	Bicarb	Sulphate	Chloride	Nitrate
ABU SAID 1	0.14	0.22	15.6	0.04	12.9	1.3	1.08	0.18
ABU SAID 2	1.06	1.78	12.0	0.19	9.8	1.5	4.11	0.27
ABU SAID 3	1.44	1.65	3.8	0.18	4.8	1.0	0.95	0.26
ABU SAID 4	0.75	3.38	7.6	0.30	4.6	3.5	3.55	0.59
ABU SAID 5	1.97	7.43	3.8	0.26	4.1	5.6	3.24	0.34
GHALA'A 6	0.66	1.40	2.1	0.11	3.1	0.7	0.36	0.11
GHALA'A 7	1.24	0.63	8.2	0.16	7.5	1.1	0.73	0.40
GHALA'A 8	0.90	0.83	10.4	0.16	7.5	2.2	1.97	0.95
GHALA'A 9	0.70	1.35	4.6	0.25	3.1	2.5	0.98	0.22
GHALA'A 10	0.93	2.21	2.5	0.25	2.9	1.3	1.35	0.78
GHALA'A 11	3.28	1.20	1.2	0.20	3.7	0.8	0.86	0.78
GHALA'A 12	1.45	1.49	7.6	0.20	6.7	2.9	1.12	0.38
GHALA'A 13	0.90	1.71	45.2	0.35	5.9	35.1	5.92	2.19
HIZENAB 14	0.69	0.96	2.9	0.16	2.6	1.5	0.43	0.19
HIZENAB 15	1.52	1.93	7.0	0.20	6.8	2.8	1.01	0.18
HIZENAB 16	0.32	1.13	5.5	0.15	6.7	1.3	0.64	0.44
HIZENAB 17	0.38	0.92	3.5	0.13	3.6	0.6	0.35	0.19
JIMAB 18	1.78	2.56	4.1	0.17	5.5	1.5	1.56	0.11
JIMAB 19	0.53	0.55	6.0	0.13	5.3	1.0	0.57	0.11
JIMAB 20	0.92	0.63	4.0	0.14	4.6	0.7	0.46	0.10
JIMAB 21	0.56	1.45	5.6	0.13	4.9	1.9	1.01	-0.02
JIMAB 22	1.28	1.26	3.5	0.14	3.9	1.5	0.77	-0.02
JIMAB 23	1.05	1.57	3.3	0.14	3.4	1.7	0.77	0.11
JIMAB 24	2.30	4.49	1.8	0.13	2.3	3.8	2.62	0.00
NUGDALAB 25	2.69	4.04	18.0	0.14	4.5	14.7	6.09	1.23
NUGDALAB 26	1.16	1.02	4.3	0.08	3.5	2.0	0.83	0.19
NUGDALAB 27	1.77	1.77	0.9	0.06	3.5	0.9	0.54	0.05
NUGDALAB 28	0.82	0.89	22.7	0.11	9.0	10.2	5.58	0.16
NUGDALAB 29	0.50	0.69	5.4	0.15	4.6	1.2	1.19	0.17
R. NILE	0.42	0.15	0.5	0.07	0.9	0.1	0.16	-0.02
R. NILE	0.44	0.33	0.5	0.08	1.2	0.1	0.05	-0.02
R. NILE	0.50	0.45	0.6	0.12	1.4	0.0	0.10	-0.02
R. NILE	0.49	0.57	1.0	0.21	2.9	0.0	0.20	0.00
R. NILE	0.87	0.56	0.8	0.15	2.5	0.0	0.11	-0.02
R. NILE	0.95	0.60	0.8	0.15	2.3	0.1	0.16	-0.02
R. NILE	1.05	0.75	1.1	0.23	2.6	0.2	0.28	-0.02
R. NILE	1.57	0.78	0.9	0.16	2.6	0.2	0.46	0.16
R. NILE	1.58	0.62	0.7	0.11	2.0	0.2	0.28	0.31

Table 5. Ionic balances, total determined constituents and sodium adsorption ratios for analyses given in Table 3.

Locality	Cations (meq/l)	Anions (meq/l)	Balance (%)	Total Determined Ions (mg/l)	SAR
ABU SAID 1	16.0	15.6	1.44	1266	36.7
ABU SAID 2	15.1	15.7	- 2.03	1153	10.1
ABU SAID 3	7.1	7.1	0.44	529	3.1
ABU SAID 4	12.1	12.3	- 0.81	833	5.3
ABU SAID 5	13.5	13.3	0.64	873	1.8
GHALA'A 6	4.3	4.3	- 0.92	327	2.0
GHALA'A 7	10.3	9.8	2.06	779	8.5
GHALA'A 8	12.3	12.7	- 1.52	927	11.1
GHALA'A 9	6.9	6.9	- 0.01	500	4.5
GHALA'A 10	5.9	6.4	- 3.94	417	2.0
GHALA'A 11	5.9	6.3	- 2.94	432	0.8
GHALA'A 12	10.8	11.1	- 1.27	826	6.3
GHALA'A 13	48.2	49.2	- 1.06	3386	39.5
HIZENAB 14	4.8	4.8	- 0.29	354	3.2
HIZENAB 15	10.7	10.9	- 0.98	818	5.3
HIZENAB 16	7.1	9.1	-12.24	659	6.5
HIZENAB 17	4.9	4.9	0.53	378	4.3
JIMAB 18	8.6	8.7	- 0.42	636	2.8
JIMAB 19	7.2	7.1	0.89	559	8.1
JIMAB 20	5.8	5.9	- 0.98	460	4.6
JIMAB 21	7.7	7.9	- 1.04	596	5.5
JIMAB 22	6.2	6.2	- 0.17	469	3.1
JIMAB 23	6.1	6.0	0.64	446	2.9
JIMAB 24	8.8	8.7	0.25	567	1.1
NUGDALAB 25	24.9	26.5	- 3.11	1742	9.8
NUGDALAB 26	6.6	6.5	0.45	482	4.1
NUGDALAB 27	4.5	5.0	- 5.14	362	0.7
NUGDALAB 28	24.6	25.0	- 0.82	1800	24.5
NUGDALAB 29	6.7	7.3	- 3.74	540	7.0
R. NILE	1.1	1.1	- 1.40	92	0.9
R. NILE	1.3	1.4	- 1.94	113	0.8
R. NILE	1.7	1.6	2.46	132	0.9
R. NILE	2.3	3.2	-16.04	239	1.4
R. NILE	2.4	2.7	- 6.22	212	0.9
R. NILE	2.6	2.5	0.59	205	1.0
R. NILE	3.1	3.1	0.88	246	1.1
R. NILE	3.4	3.4	- 0.81	258	0.8
R. NILE	3.0	2.9	2.09	213	0.6

4.3.2 The Chemistry of Shallow Groundwaters.

The results of all shallow waters are plotted in the trilinear diagram (Fig. 6). Without exception they are more saline than the river water indicating that if recharge has occurred there has been significant reaction between the water and the rock and/or concentration by evaporation. There is a wide range of compositions in the groundwater and there are no distinct characteristics of the groups of waters at any specific village or part of the flood plain. This is a typical characteristic of shallow groundwater which may have been influenced not only by the geology but in this case by a degree of recycling from irrigation and other practices (it is not possible to quantify these in the present investigation). It is also assumed that all of these wells are similar in character and that none of the data are from deep boreholes. It is not possible therefore to assess any extent of mixing with the deep aquifer which may contain a component of water derived from the regional aquifer, as demonstrated at Shendi.

The main characteristics of these groundwaters is their variable sodium content relative to this rather constant Mg/Ca ratio, their trend towards higher sulphate content (note that the SO_4/Cl ratio is significantly above 1), and the existence of many waters with Na and HCO_3 as the main constituents (i.e. soft water).

The high Mg/Ca ratio of groundwater is strong evidence that they are genetically related to and therefore derived from the River Nile. Palaeowaters from the adjacent aquifers are likely to have compositions with a much lower Mg/Ca ratio (Fig. 3). The even higher Mg/Ca ratio in the groundwaters than in the river may result from reaction of Mg-rich clays which are common in arid environments or alternatively from the reactions of carbonates. Most groundwaters are saturated with calcite, but continued reaction of carbonates (possibly derived from drying out of soil water and irrigation water), will tend to add Mg to the solution at the expense of Ca. The trend towards higher sulphate is mainly an expression of concentration by evaporation or evapotranspiration of the River Nile water, since the SO_4/Cl ratio remains the same as in the River Nile baseflow (Fig. 6) - in other words any increase in sulphate is also reflected in an increase in chloride. There is some gain in sodium above that in the River Nile (after comparing the Na/Cl ratio in both sources and assuming chloride as a stable reference element). This can also be explained by exchange of Ca^{2+} for $2Na^{+}$ with clay minerals allowing the build-up of bicarbonate yet maintaining saturation with calcite or other carbonate minerals.

All of the chemical indicators therefore are consistent with the modification of River Nile recharge water. There is little or no evidence for recharge from the 1988 floods having influenced the chemistry directly. Some recharge may have occurred but is undetectable either because the mass of water is still infiltrating or because the dilution is too small to be detectable. The net effect could be a decrease in salinity if wells are monitored over the next couple of years.

Other aspects of the water chemistry are of interest and help to confirm the Nile as the origin of the groundwater. The boron concentrations remain low even at high chloride and this was also found to be a feature of shallow groundwaters in the Nile Valley near Shendi. Nitrate concentrations are generally absent in the river due to high biological uptake. Most of the flood plain groundwaters are also relatively low in nitrate and pollution from irrigation waters is not significant. The recommended limit for potable waters is 10 mg l^{-1} NO_3-N, which is exceeded in only five groundwaters. The quality of the waters for agricultural use is also excellent as indicated (Table 5) by samples with SAR (sodium adsorption ratio) below 10 and low salinities (below 500 mg l^{-1}).

5. THE GROUNDWATER SYSTEM

Fig. 7 shows the likely cross-section of flow through the aquifer system. There is a regional flow from the Nile towards the south-west where heads in the Nubian sandstone are generally lower. This regional flow determines what happens in the north-eastern or right-hand bank. Initially, flow occurs from the Nile towards the north-east but it eventually reverses direction at depth to flow towards the south-west.

It is very likely the amount of water being pumped for irrigation purposes in Affad is a small percentage of the regional flow. There is a large volume of palaeowater in store in the Nubian to the north of the Nile although this is at a lower static level and is fed only locally by the recharge mound of the Nile Valley. It is likely that increased pumping in Affad for shelterbelt purposes will have only a small local effect on the groundwater levels . Indeed the effect of abstraction at the present day from the many domestic and irrigation wells cannot be detected against the overall, smooth regional gradient away from the Nile.

For completeness it should be mentioned that all development along the Nile and in the Nubian sandstone aquifer is interconnected and that, ideally, there should be a regional plan for development of the whole aquifer. Such a study would need to be international and would take many years. Meanwhile, development for shelterbelt purposes is on such a small scale that it can be pursued with confidence in that it cannot seriously affect even nearby users. A very long term threat to Affad from regional users is real, however, and eventually should be addressed by the region as a whole.

6. RECOMMENDATIONS FOR FURTHER WORK

- Increased use of the groundwater resources for shelterbelt development can continue with confidence.

- Existing groundwater levels should be monitored at two or three points on a monthly basis.

- If groundwater levels are seen to be falling dangerously low so as to jeopardise existing users, a full hydrogeological study should be pursued.

REFERENCES

Edmunds et al. (1987) Estimation of aquifer recharge using geochemical techniques. British Geological Survey Report No. WD/OS/87/1.

Brinkmann, P J and Heinl, M (1986) Numerical Groundwater Model. Berliner Geowissenschaftliche Abhandlungen, Reihe A/Band 72, Ed. Ulf Thorweihe, Berlin, pp 135-155.

Sutcliffe, J V, Dugdale, G and Milford, J R (1989) The Sudan floods of 1988. Hydrol. Sci. J., 34, 355-364.

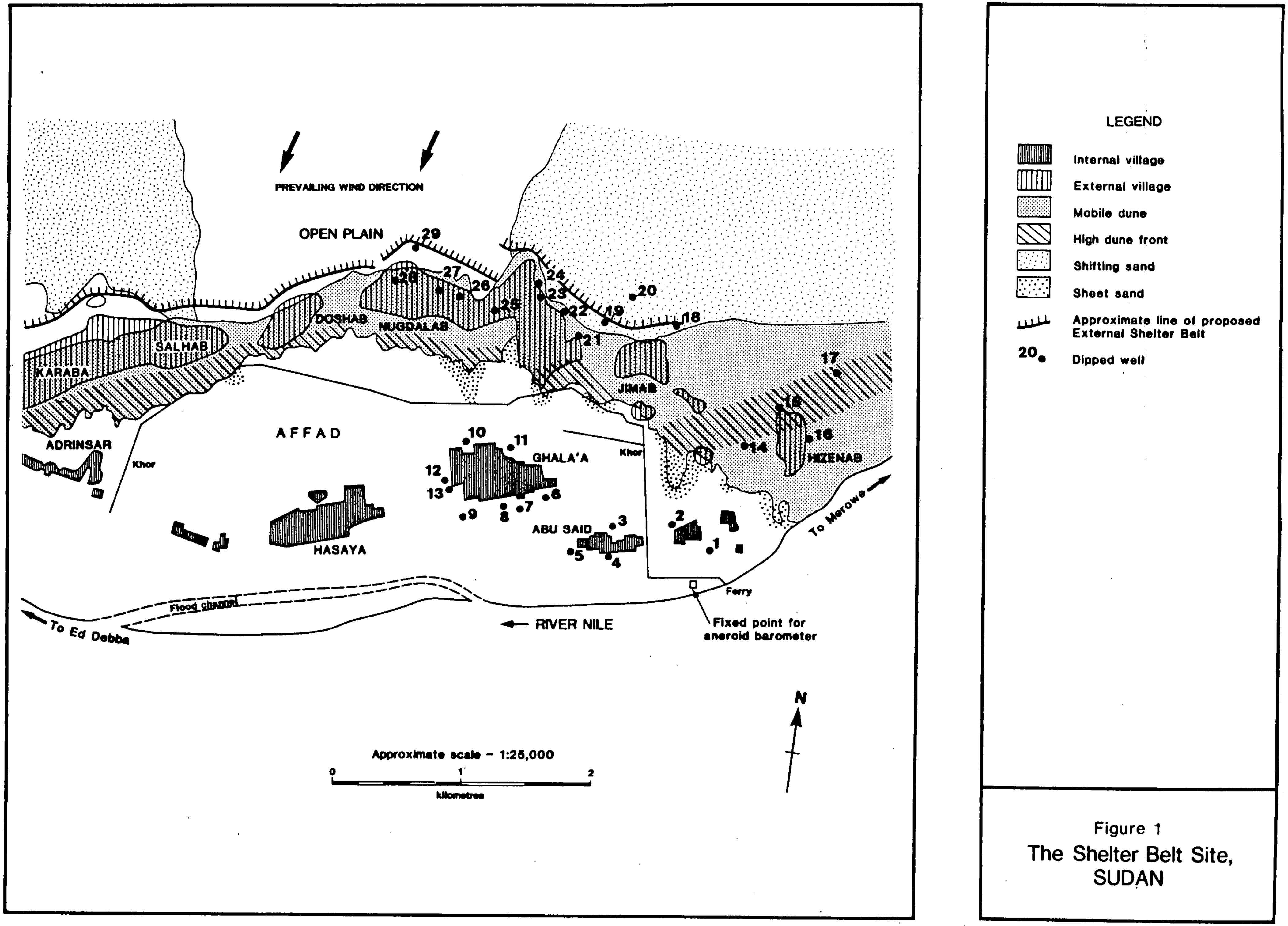


Figure 1
The Shelter Belt Site, SUDAN

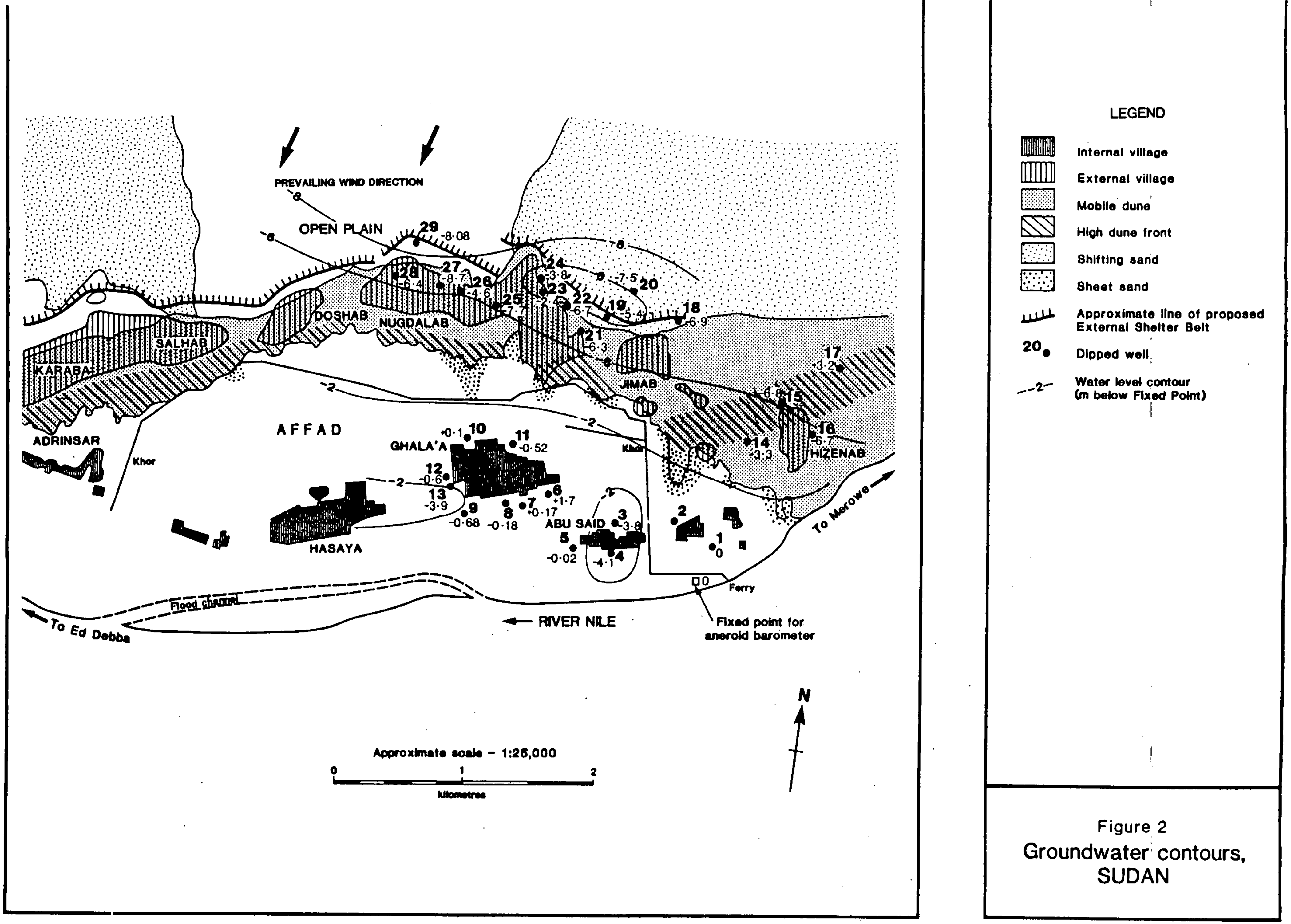


Figure 2
Groundwater contours, SUDAN

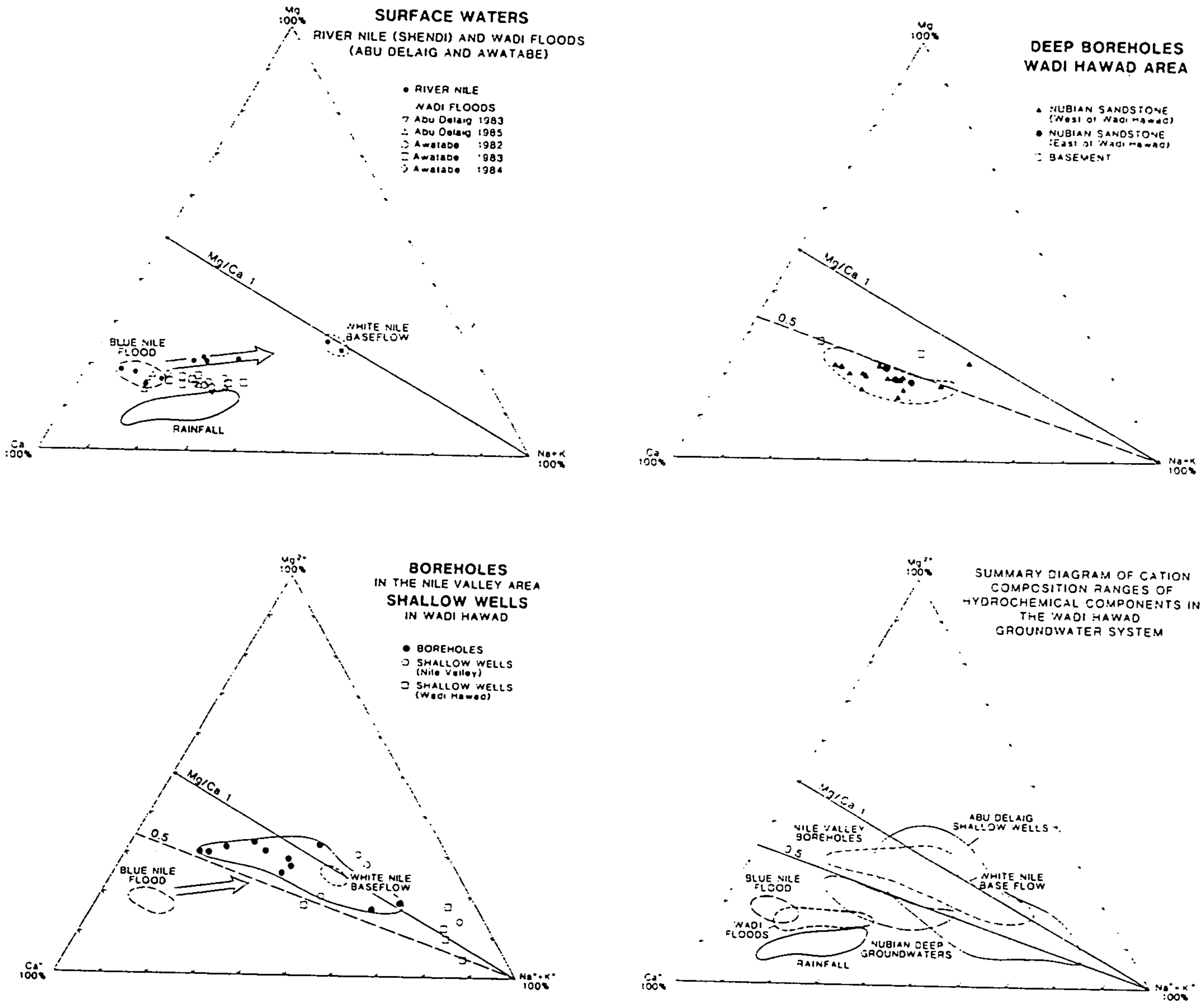


Figure 3. Chemical composition (major cations) of the River Nile in the Shendi area together with composition of deep groundwaters in the Wadi Hawad area. Deep boreholes drilled in the Nile valley are also shown which bear a direct chemical resemblance to water of the River Nile baseflow.

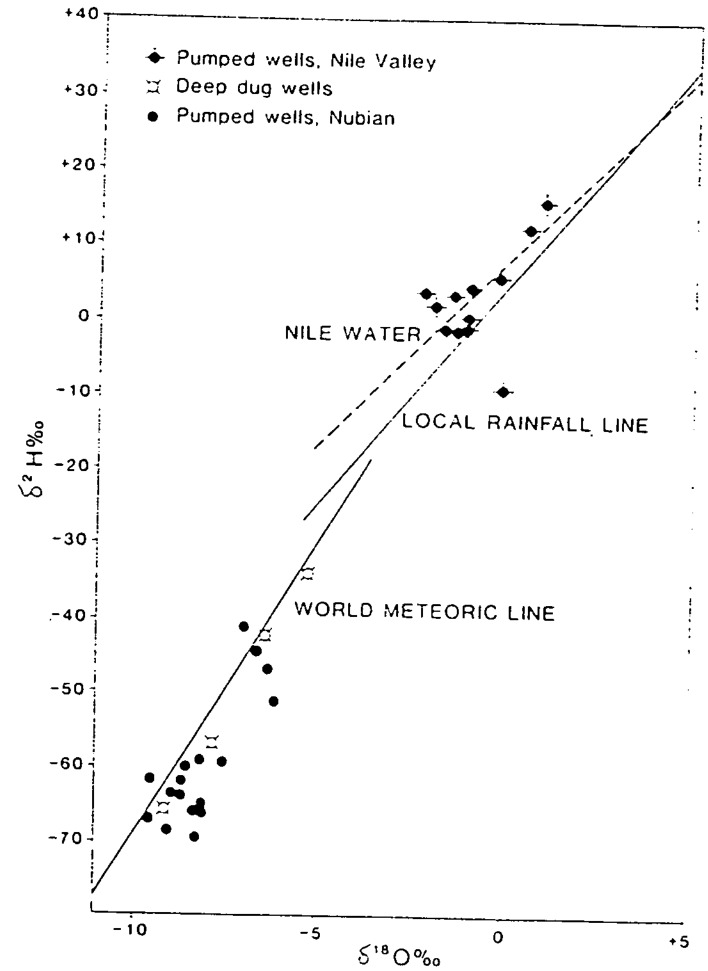


Figure 4. Isotope diagram ($\delta^{18}O$ vs. δ^2H) showing groundwater composition in the Nile valley of similar composition to the River Nile. Palaeowaters from deep wells have a much lighter (more negative) composition.

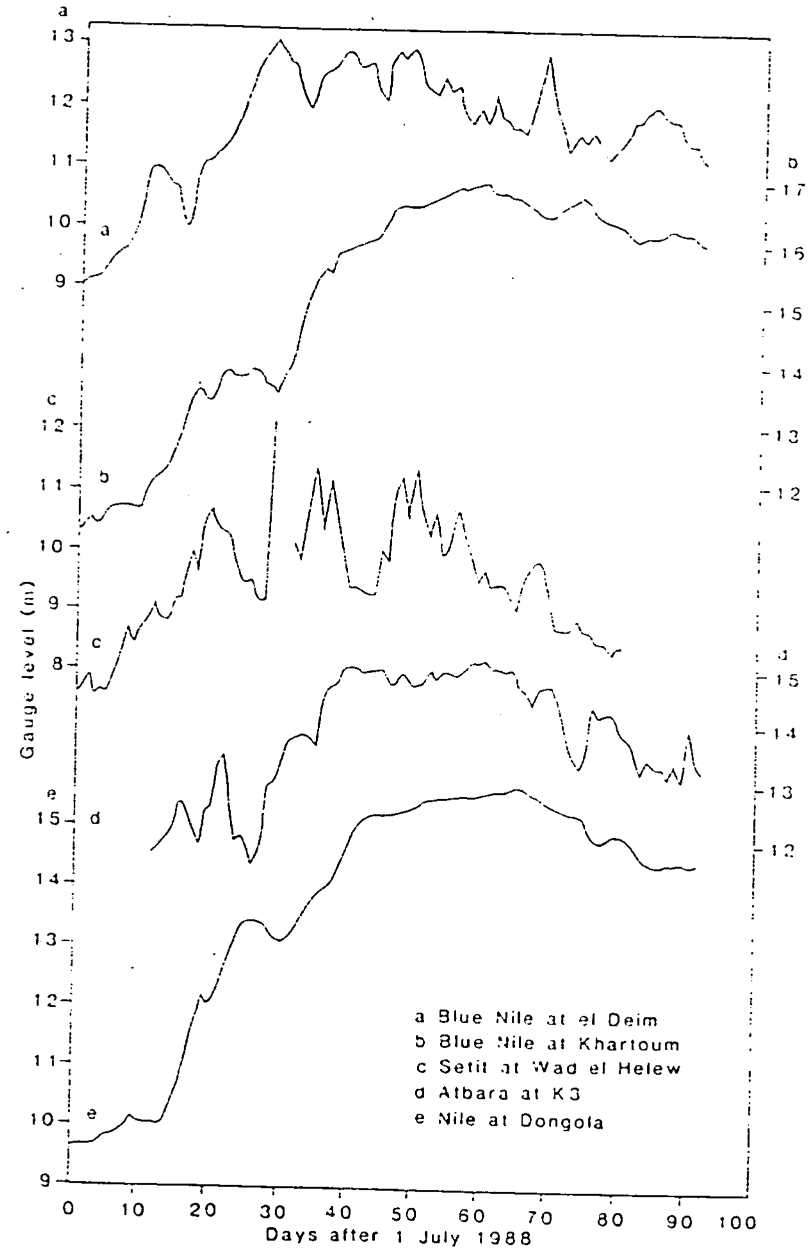


Figure 5. Flood peaks at different stations along the River Nile during the catastrophic floods of 1988 (after Sutcliffe et al., 1989).

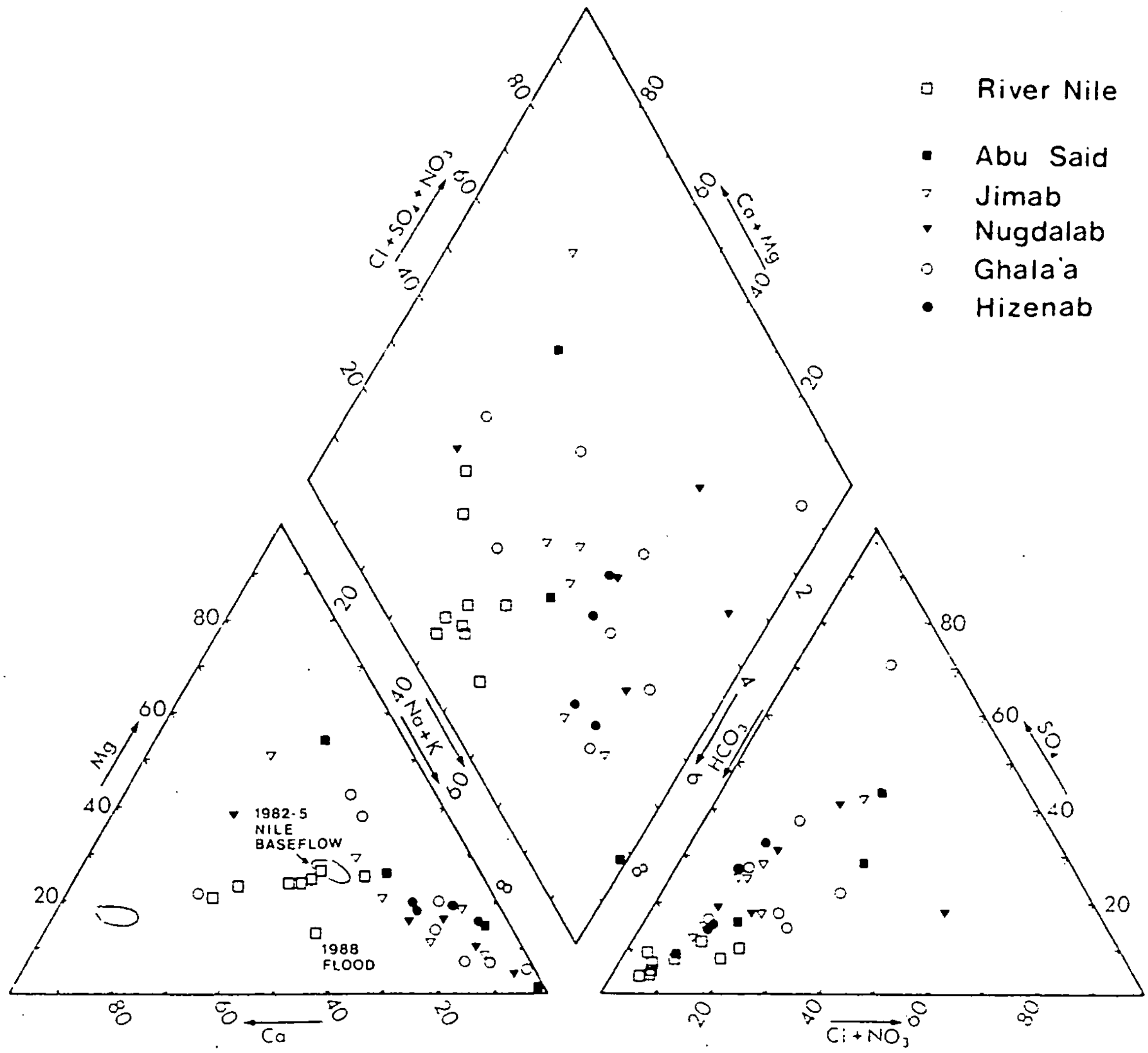


Figure 6. Chemical composition (major cations and anions) plotted as trilinear diagrams for shallow groundwaters from Nile Shelterbelt area. Also shown is the River Nile (this study) in relation to the composition at Shendi during flood and baseflow in 1982-1985.

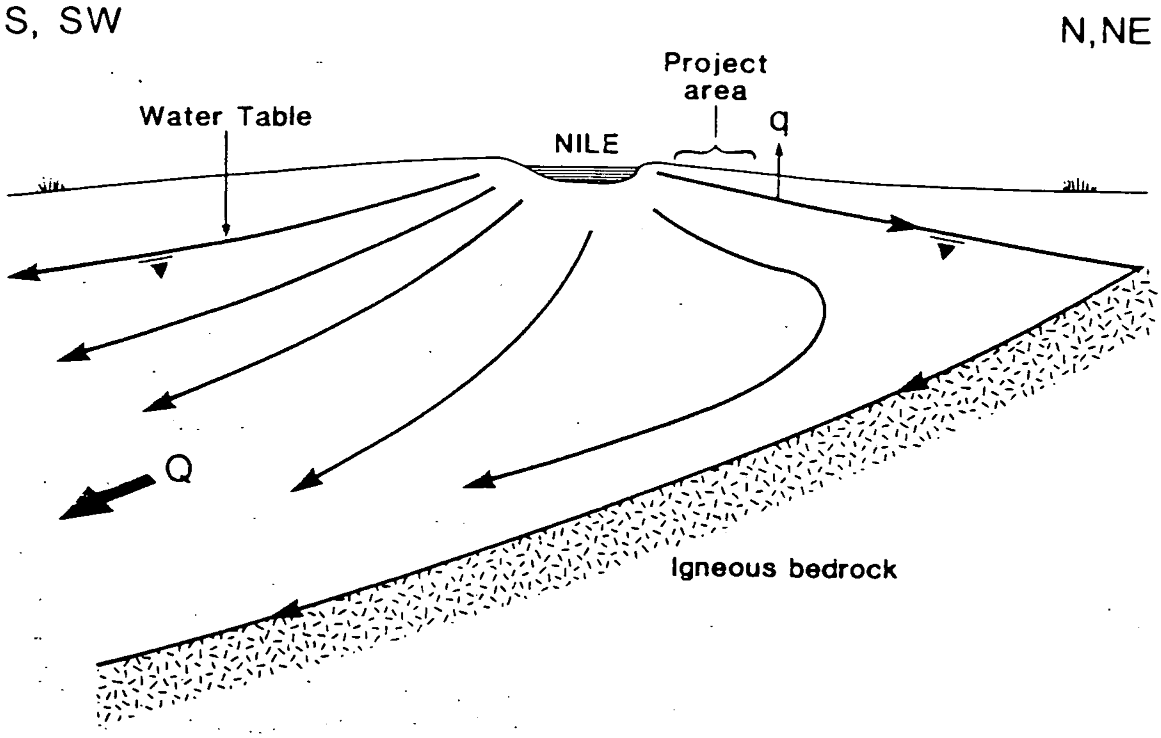


Fig 7 The Groundwater System, SUDAN

APPENDIX A

The original project proposal for financial year 1989-90.

UNIT: British Geological Survey | FORM A
PROGRESS AND PLANNING FORM: | 1989-90

ITEM NO: **89/21**

PERIOD OF FUNDING: 1989-90

LOCATION: Lab work in UK and field data collected in Affad Basin, N. Sudan

SUBJECT: **Estimating Availability of Recharge for Long-term Support of Forestry Shelterbelts to Protect against Desert Encroachment along the Nile.**

DESCRIPTION:

SOS Sahel, an NGO, are keen to assess if there are long-term groundwater supplies available to irrigate forestry shelterbelts presently being constructed and intended to protect the existing highly fertile agricultural basins bordering the Nile from encroaching desert sand. BGS have designed a data collection programme for SOS. Study of the data will ensue in the BGS laboratories using the latest geochemical techniques. The project has been designed to be as low cost as possible in keeping with the scarcity of funds for such a project.

PURPOSE:

To establish if forestry belts are viable as a long-term means of protection against dune encroachment along the Nile. The project may yield ambiguous results and lead to a requirement for a more complex and expensive study in subsequent years.

The protection is important to many irrigated basins lying along the Nile in the Sahel. Many such basins are being currently protected by shelterbelts by different aid agencies and the results may be useful to all of these.

OUTPUT:

A report of findings will be presented to SOS Sahel. It is hoped recommendations will be made as to the viability of utilising groundwater for this purpose. Alternatively, the results may indicate a more complex and costly type of investigation is necessary.

METHODS AND ACTIVITIES:

SOS Sahel will be encouraged to collect all the groundwater levels in the shelterbelt area and to collect water samples from the river, rainfall and from above the water table for chloride analysis in the UK. The data will allow definition of the groundwater flow system underneath the shelterbelt zone. Additional isotopic analysis of the samples will, it is hoped, allow an estimate of the safe groundwater yield available to be made.

SOS Sahel will gather the field data from the Affad Basin, see Figure attached. BGS will supply some sampling equipment on loan and will carry out the analysis and interpretation of results. In the first instance this project will last only one year.

PROGRESS TO DATE AND FORECAST PROGRESS:

The project will begin in April 1989 and will last one year. An insight will be gained into the groundwater flow system and if possible an estimate will be made of the safe groundwater yield. If results are ambiguous a specification will be written for further work required to achieve the above aims.

PLANNED WORK:

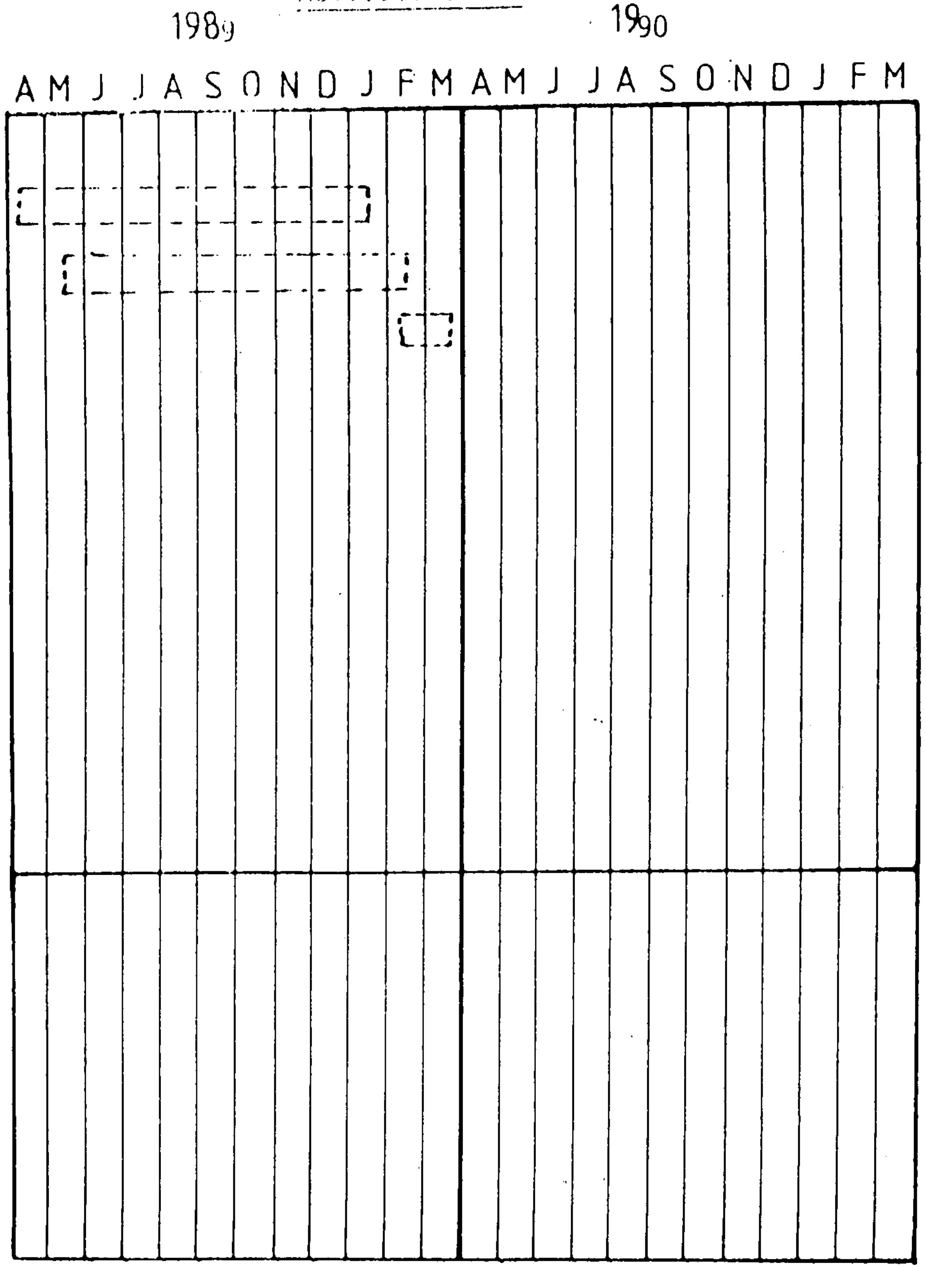
The bar charts attached show the programme of work and the required inputs.

PLANNED PROJECT OFFICERS:

Dr R Herbert (Grade 6)/Dr W M Edmunds (Grade 6), Manager
Geochemist (ASO)

RESOURCES	1988-89	1989-90	1990-91	1991-92
MAN YEARS	-	0.30	-	-
INTRAMURAL	-	19.64	-	-

ACTIVITY CHART



ACTIVITY

Collection of data.

Analysis in UK.

Reporting.

TITLE

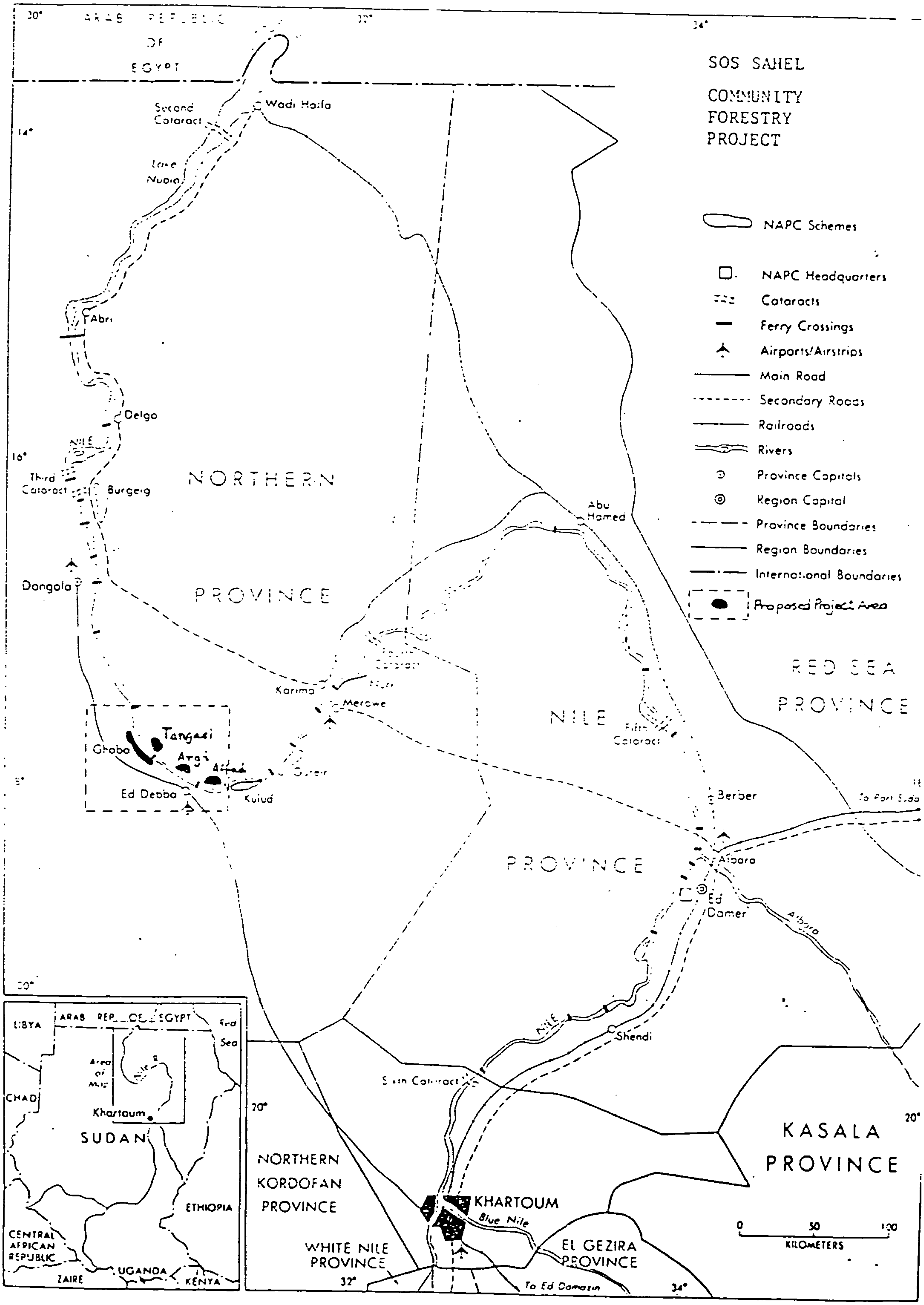
Estimating Availability of Recharge for long term support of Forestry Shelterbelts to Protect against Desert Encroachment along the Nile.

KEY

Previously planned

Actually undertaken

Currently planned


SOS SAHEL
COMMUNITY FORESTRY PROJECT
NAPC Schemes
NAPC Headquarters
Cataracts
Ferry Crossings
Airports/Airstrips
Main Road
Secondary Roads
Railroads
Rivers
Province Capitals
Region Capital
Province Boundaries
Region Boundaries
International Boundaries
Proposed Project Area
Wadi Halfa
Second Cataract
Abri
Delgo
Third Cataract
Burgeig
NORTHERN PROVINCE
Dongola
Abu Hamed
Karima
Merowe
Tangasi
Ghaba
Argi
Affad
Ed Debba
Kuiud
NILE PROVINCE
Fifth Cataract
Berber
Atbara
Ed Damer
RED SEA PROVINCE
Shendi
KASALA PROVINCE
NORTHERN KORDOFAN PROVINCE
KHARTOUM
Blue Nile
WHITE NILE PROVINCE
EL GEZIRA PROVINCE
To Ed Damazin
0 50 100 KILOMETERS
LIBYA
CHAD
SUDAN
Khartoum
ETHIOPIA
CENTRAL AFRICAN REPUBLIC
ZAIRE
UGANDA
KENYA